Tunnelling and Underground Space Technology 59 (2016) 134–145

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

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

Key techniques for the largest curved pipe jacking roof to date: A case study of Gongbei tunnel

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ARTICLE INFO

Article history:
Received 5 September 2015
Received in revised form 3 June 2016
Accepted 1 July 2016

Keywords:
Pipe jacking roof
Curved pipe jacking
Trajectory deviation
Joint seal
Reception device

ABSTRACT

The Gongbei tunnel, as a part of the Zhuhai Connection highway and Hongkong-Zhuhai-Macao Bridge project, is currently being constructed in Zhuhai, China. To guarantee the tunnel traversing under the Gongbei Port, a combination technology of curved pipe jacking roof for ground support and ground freezing for waterproof is applied. This jacked pipe roof, comprised 36 steel pipe strings of 1620 mm diameter with 355–358 mm gap between adjacent strings, has been faced with various challenges for design and construction due to the site conditions of multiple soft soil and high underground water pressure. These challenges include risks of excessive soil deformation, possibility of path deviation, excessive jacking force, leaking of pipe joint and failure of jacking machine gasketed launch and reception devices. This paper provides an overview of this project, summarizes the most challenging aspects they faced and introduces the relevant techniques applied during construction.

1. Introduction

The Gongbei tunnel, as a crucial part of China Mainland section of the Hongkong-Zhuhai-Macao Bridge project, which includes an open excavation section inland, an underground excavation section and an open excavation section on the coast, is being constructed currently in Zhuhai, China. It starts from a man-made island of the east Macau peninsula and ends in Guangdong public security border fifth detachment administrative zone. The length of left tunnel is 2741 m and right tunnel length is 2375 m. The underground excavation section tunnel of 255 m length crosses beneath the largest China Mainland port - Gongbei Port. It also has double-decker and two-way highway with a design speed of 80 km/h, three lances for each direction (Liu et al., 2014).

The tunnel is designed to construct in multiple soft soils and under high groundwater pressure (more than 0.3 MPa at the bottom of the tunnel). Furthermore, there are many buildings and infrastructures around this tunnel, such as Gongbei Port and its auxiliary buildings, Zhuhai railway station, power pipelines, water pipelines and communication pipelines. In addition, the excavation section is strictly limited on account of the existence of numerous piles of Gongbei Port and its auxiliary buildings foundation. Therefore, the previous design scheme of direct excavation under the port can not realize since there is no enough space. To reduce the soil deformation and guarantee the safety of surrounding structures, a curved pipe jacking roof is applied as a supporting structure of the tunnel (Figs. 1 and 2).

The pipe roof technology evolved from pipe umbrella method used in poor ground conditions or shallow ground cover during tunnel construction. In this method, large steel or concrete pipes are jacked to surrounding of the tunnel by pipe jacking or micro-tunneling technology. These typical pipes are mechanically linked together and form a supporting arch or ring, filled with grout or concrete before tunnel excavation. The pipe roof method was first used in an underpass crossing railway in 1971 and a total of six such projects were completed in the next decade (Coller and Abbott, 1994). The Antwerp subway station in Belgium was an early project constructed by using pipe roof in 1979 Europe (Musso, 1979; Ire, 1985). A steel pipe roof with pipe diameter of 770 mm was first applied in America in 1994 for a large shallow cover tunnel (Rhodes and Kauschinger, 1996). In terms of some examples of previous pipe roof method in China, it was used to build an underpass in Hong Kong in 1984 and Taipei Songshan airport underpass of 100 m length was constructed by using pipe roof and ESA (Endless Self-Advancing) method in 1989. The process of ESA was described detailedly in an underpass beneath Taipei international airport (Moh et al., 1999). During the construction of an underpass of Taipei in 1996, grouting process was used as reinforcement to pipe roof (Liao and Cheng, 1996). The RBJ (Roof-Box Jacking Method) was applied underpass project of Shanghai Beihong street in 2004. This pipe roof (forming a

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http://dx.doi.org/10.1016/j.tust.2016.07.001
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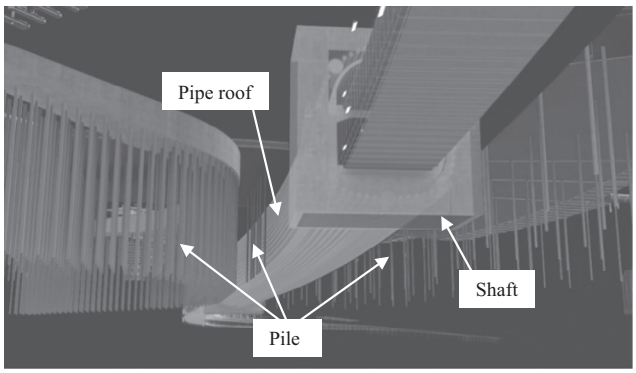


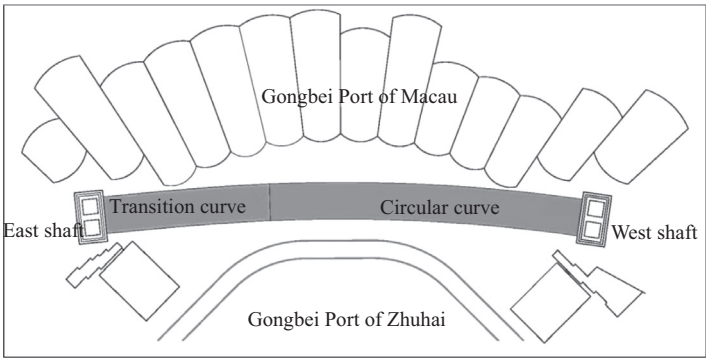
Fig. 1. The foundation piles surrounding pipe roof.

rectangular section) consisted of 80 steel pipes with diameter 970 mm and length of 125 m (Ge, 2004). Forming an arc-shaped supporting structure, Xinle ruin station of Shenyang subway line 2 was constructed by the innovative pipe-roof pre-construction method with 19 steel pipes of diameter 2000 mm and 2 pipes of diameter 2300 mm in 2011 (Li et al., 2013). In the last two or three decades, pipe roof method has been applied widely for challenging large and shallow excavation tunnels in soft soil. Generally, it is used for straight line tunnels or underpass projects in urban areas to avoid disruption of open cut and may be chosen as an alternative to large full section jacking. However, forming a pipe roof and supporting ring by curved pipe jacking of Gongbei tunnel, it is believed to be the first time to cope with large diameter and long distance of this curved pipe roof, which makes the application of this method particularly challenging.

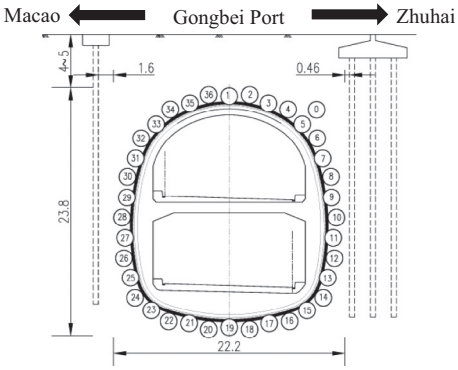
1.1. Pipe roof design

To form this supporting and waterproof structure of Gongbei excavation tunnel, pipe jacking roof is designed innovatively to combine curved pipe jacking technology and ground freezing method (Hu et al., 2014). The total length of this excavation tunnel is 255 m, including a transition curve of 88 m and a circular curve of 167 m in length (Fig. 2a). The pipe roof is made up of 36 steel pipes with a diameter of 1620 mm, and its section shape is a huge oval, which is about 22.2 m in width and 23.8 m in height. The average buried depth of pipe roof top ranges from 4 to 5 m (Fig. 2b). The maximum excavation cross-sectional area is 344.8 m^2 (Zhang et al., 2013; Li et al., 2014).

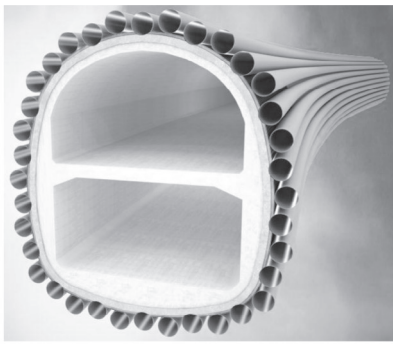
Four AVN1200TC slurry pipe jacking machines have been used to install the steel pipe strings. The upper 17 steel pipe strings, jacked from east shaft to west shaft has a wall thickness of 20 mm. And the bottom 19 steel pipe strings are 24 mm thick, jacked from the opposite direction. The minimum gap between each adjacent pipe string is ranging from 355 mm to 358 mm. A specific pipe joint quite similar with reinforced concrete pipe joint was used with adjacent jacked pipes, connected by bolts to achieve the curved steel pipe jacking project. In order to verify the key techniques, optimize construction parameters and study the soil deformation induced by pipe jacking, two test pipe strings were thrust under a buried depth of 7–8 m. The #0 test string is an additional pipe jacking, jacked from east shaft to west shaft. The #5 test string, as one of those forming the pipe roof was thrust in the opposite direction. There were four primary construction steps in this pipe roof project. Firstly, 2 testing pipe stings #0 and #5 were jacked; secondly, 4 pipe stings (#9, #10, #28 and #29) were jacked to install the shaft supporting structures subsequently; thirdly, two pipe strings groups #11–#17 and #21–#27 were jacked from



(a) The plan and location of pipe roof



(b) The section of tunnel



(c) The 3D graph of pipe roof tunnel

Fig. 2. The curved pipe jacking roof of Gongbei tunnel (unit: m).