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Study on key technology of tunnel fabricated arch and its mechanical mechanism in the mechanized construction

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ABSTRACT

There are many challenges in the construction of tunnels with large section, such as weak surrounding rock control, low efficiency of the artificial construction and poor safety. To solve these problems, a new mechanized construction technology of the fabricated arch is put forward. This technology includes fabricated confined concrete (CC) arches, intelligent arch installation equipment and corresponding matching devices. With Longding Tunnel in China as the engineering background, laboratory and numerical comparative experiments are conducted on CC arches. The results show that the strength of the CC arch is 2.05 times that of the traditional arch. At the same time, a numerical calculation is carried out on the mechanical mechanism of the fabricated CC arch during the mechanized construction. The results show that the stress on each cross-section of the arch decreases as the arch inclination angle increases and the largest stress is 101.2 MPa on the vault in the arch lifting. In order to avoid the arch damages during the installation, a reinforcement method is proposed to lift the key parts of the vault with splints. Based on the above research results, the mechanized construction of the fabricated arch is carried out at the site of Longding Tunnel. The construction efficiency is significantly improved and the deformation of the surrounding rock is effectively controlled.

1. Introduction

In recent years, with the rapid development of tunnel construction, traffic flow is increasing; and the number of the large section tunnels with corresponding bi-directional six lanes and eight lanes is increasing year by year. Because of the large cross-sectional size, the loosening and failure of the surrounding rock is serious (Wang et al., 2014), and the deformation of the tunnel surrounding rock is large (Yoshinaka et al., 1996; Meng et al., 2013; Huang et al., 2013), especially under the complex geological conditions such as high stress or weak surrounding rock. With an insufficient bearing capacity, the traditional supporting arch is prone to produce buckling failure (Zheng et al., 2015; Liu et al., 2017; Han et al., 2016), which could cause vault falling, support components broken and failed, and other accidents. Therefore, it cannot meet the requirements of the surrounding rock control. The arch installation mainly relies on labor in the tunnel construction, so the above accidents always cause casualties. The weight of the arch with large section is heavy, and therefore it is low in construction efficiency and high in labor intensity. These are the major difficulties in the construction of large section tunnels. So, to solve the above problems, it is urgent to develop a high-strength support technology and its matching mechanized construction method for the large section tunnel (Lin et al., 2006; He et al., 2018; Waris et al., 2014; Karlinski et al., 2008; Yu et al., 2007).

The CC arch is a high-strength support structure made of steel and concrete; it utilizes external constraints of the steel tube to improve the original compression characteristics of the internal concrete; and therefore, the compressive strength and ductility are increased (Deng et al., 2011; Ellobody et al., 2006; Han and An, 2014; Mirmomeni et al., 2017). Due to the "force symbiosis" produced by the steel and the core concrete, the CC arch has many advantages such as high bearing capacity, large stiffness, good plasticity and others. With its good mechanical properties and economic advantages, the arch has been widely used in ground structures such as bridges and high-rise buildings (Aghdamy et al., 2016; Hassan et al., 2016; Li et al., 2016). In recent years, the authors have applied the CC arch support to the underground engineering with complex conditions, mainly in the mine roadways with high stress, soft rocks, fault fracture zones and others; and a

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remarkable effect is achieved on the surrounding rock control (Wang et al., 2016; Wang et al., 2017). In order to solve the problems of the surrounding rock control and the artificial construction in the tunnels with large section, square steel confined concrete (SQCC) arches are applied to the tunnel engineering; fabricated CC arches, intelligent arch installation equipment and the matching devices are developed; and so, a new mechanized construction technology of the fabricated arch is put forward in the tunnel. But, due to the large cross-section size and the heavyweight, the tunnel arch is susceptible to produce greater stress in the mechanized installation, which could lead to arch deformation, thus reducing its bearing capacity and affecting its usage in late stage. Therefore, it is necessary to study the mechanical laws of the arch during the installation, then to strengthen the key parts of the arch and to guarantee the strength of the supporting arch.

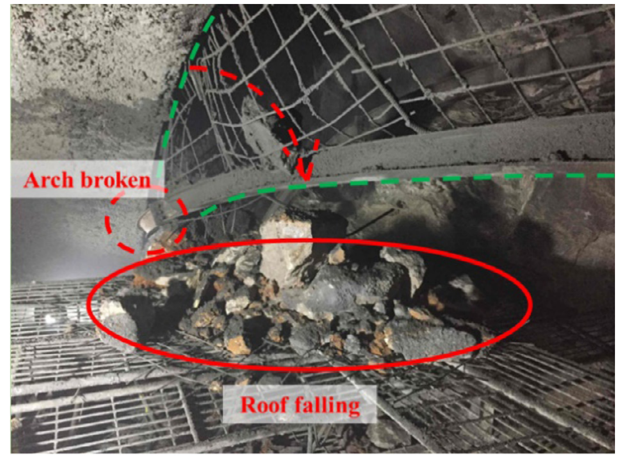
Based on the above mentioned challenges, with Longding Tunnel of China as the engineering background, the primary support system of the CC arch is put forward, comparative experiments are carried out on the traditional I-beam and the CC arches, and the mechanical properties and strength bearing characteristic of the CC arch are studies. At the same time, a key technology of the mechanized construction of the fabricated arch is developed; and an analysis is made on the mechanical laws of the fabricated arch in the mechanized construction. After all the studies, the technology is optimized and applied in the field with reinforcement made on the key parts of the CC arch.

2. Comparative experiments on the SQCC arch

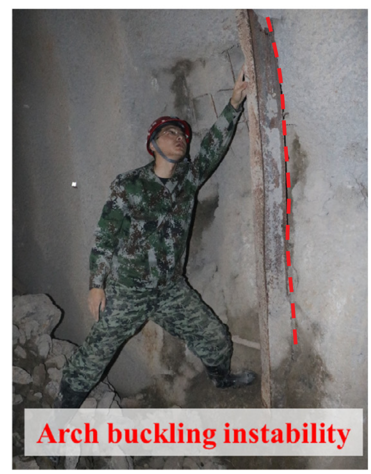
2.1. Engineering background

Located in Jinan, China, Longding Tunnel is a bi-directional eight lanes highway tunnel with large section. The tunnel is 2183 m long with its excavation width of 20.8 m and its height of 13.6 m. With a large project scale and under complex geological conditions, it belongs to a subsurface excavation tunnel which is shallow buried with a small clear spacing and a super-long span.

In the original support scheme, the combined support method of the I22b I-beam with the anchor net spray was adopted. In the early construction, the tunnel excavation resulted in a large surrounding rock disturbance, and the insufficient support strength of arch caused vault falling and buckling instability on the arch leg, as shown in Fig. 1.



(a) Arch broken and vault falling



(b) Arch buckling instability

Fig. 1. Vault falling and arch leg buckling failure in tunnel. (a) Arch broken and vault falling; (b) Arch buckling instability.

2.2. Experiment scheme

In view of the insufficient support strength of the arch at Longding Tunnel, a primary support scheme of the high-strength CC arch is put forward. To study the mechanical properties and the strength bearing characteristics of the CC and the conventional I-beam arches, laboratory and numerical comparative experiments are carried out on the two types of arches. The experiments are to make a comparative study on their deformation and failure modes, the key failure locations, the ultimate bearing capacity and other aspects.

2.2.1. Experiment object

Both of the CC and the I22b steel arches are in a shape of three-centered circular. According to the principle of similar steel content of the cross-section of the I22b steel arch, the cross-section of the square steel tube is set with its side length of 150 mm, its wall thickness of 8 mm (SQCC150 × 8) and the C40 concrete filled inside. The cross-sectional area is 4544 mm^2 for the SQCC150 × 8 steel tube and 4653 mm^2 for the I22b steel tube, the difference rate between the two is 2.34%, which guarantees the effective comparison of the bearing capacity under the same steel content. The arch dimensions are shown in Fig. 2.

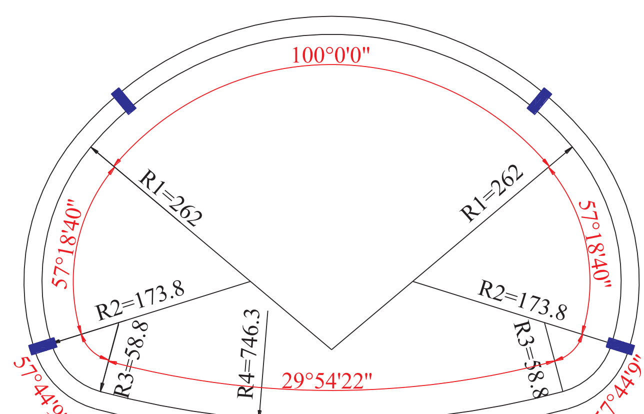


Fig. 2. Arch dimensions (cm).

2.2.2. Experiment loading scheme

Fig. 3 shows that 10 cylinders are used to load on the arch. According to the stress test results of the surrounding rock on site, the top pressure/side pressure = 1.5 is designed, and the cylinders on the bottom of the arch do not load actively but can provide passive reaction. The top pressure is provided by #1, #9, and #10 cylinders; the side pressure is provided by #2, #3, #7 and #8 cylinders; and #4, #5, and #6 cylinders provide the passive reaction on the bottom. When the