Measured Deformation of Pipe-Roof during Box Culvert Jacking in Soft Ground

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Abstract. RBJ method is suitable for shallow covering and micro-disturbed underpassing project. In this paper, the pipe deformation induced by box culvert jacking is analyzed. The research shows that: (1) The closed pipe-roof frame presented a phenomenon of expanding outward, namely the uplift of top pipe and the settlement of bottom pipe. (2) Along the jacking direction, the deformation of pipes was positioned over the box culvert structure and about 10m in front of the excavation face. (3) Due to the bounded constraint of diagram wall, it’s prone to be a reverse deformation at joint between pipe and diagram wall, and resulting in a wave-type deformation pattern.

Keywords. RBJ method, squeeze effect, measured deformation.

1. Introduction
Pipe Roof-Box Culvert Jacking (RBJ) method is suitable for shallow covering and micro-disturbed underpassing project [1-4]. Firstly, pipes are successively jacked by microtunnelling machine, and connected by locking notch to form a closed structure. Then the box culvert is jacked under the protection of a previously created pipe roof structure [5-8].

Jacking of pipe group and box culvert are two key processes of RBJ method. The pipe-roof is used as pre-support for box culvert tunneling, sheltering from the ground deformation. On the other side, the pipes are prone to be deformed during box culvert jacking, especially the poor controlment of jacking pressure and vertical attitude. However, most of the researches had focused on the interaction between deep excavation and pile group. Huang et al. [9] proposed a simplified analysis method of lateral response of pile groups due to excavation-induced soil movement. Liu et al. [10] analyzed the sheltering effect of existing subsurface structures on displacement of retaining wall of foundation pits. A few researchers investigated the deformation mechanism of pipe roof. For instance, Xiao et al [11-12] made a complete analysis about the support effect and deformation prediction of pipe roof during box culvert jacking. But for earth pressure balanced tool head of box culvert, it’s distinctly different from a lattice one. Due to lack of engineering application, especially field measured data, the pipe deformation induced by box culvert jacking is analyzed in this paper. The relevant conclusions drawn from the paper can provide practically targeted references for engineers in similar projects.

2. Engineering Background
The pipe-roof box culvert project of an underpass was consisted of 62 parallel pipes under urban
expressway in Shanghai, China. As figure 1 shows, the scale of pipe roof structure was 21.648 m wide and 8.148 m high. These steel pipes with external diameter of 824 mm were jacked over 85 m in soft ground by four slurry pipe jacking machines at a depth of 6.3 m under the urban expressway.

![Figure 1. Cross section of the pipe roof.](image1)

After the formation of pipe roof frame, the box culvert can be continuously jacking in an isolated area. As shown in figure 2, the scale of box culvert was 19.8 m wide and 6.4 m high. The entire jacking process was divided into 5 steps, the length of first section was 12.4 m and the other 4 sections were 18.8m. An earth pressure balanced tool head was adopted in this project.

![Figure 2. Longitudinal section of the box culvert jacking.](image2)

### 3. Deformation of Pipe-Roof Induced by Box Culvert Jacking

#### 3.1. Monitoring Scheme

Fiber grating sensor has the advantages of high precision, low weight and miniature size. By the application of wavelength-division multiplexing technology, the transmission of multiple sensors can be used in single fiber. Pipe T7 and B7 were selected for the measurement of vertical displacement during box culvert jacking. Along the jacking direction, monitoring points were arranged at intervals of 9m and the installation process was showed in figure 3.
3.2. Monitoring Results
The jacking process of first section lasted 10 days with a length of 12.4m. Figure 4 showed the deformation of pipe T7 and B7 with a range of 0–30 m during the jacking process. As for pipe T7, monitoring points located at 1m, 10 m and 19m along jacking direction had a more obvious deformation. It increased sharply to a peak value of 20 mm at the first 7 days, then began to decline gradually until remained at about 13 mm. Meanwhile, bottom pipe had a tiny deformation no more than 5 mm, but on the whole they reflected the squeeze effect of box culvert jacking on the existing pipe roof. It can be inferred that the pipe roof frame kept expanding outward manifested by upheaval of top pipe and settlement of bottom pipe.

![Figure 3. Installation process of monitoring device.](image)

![Figure 4. Deformation of T7 and B7 induced by box culvert jacking of first section.](image)

![Figure 5. Deformation of T7 and B7 induced by box culvert jacking of second section.](image)
The jacking process of first section lasted a week with a length of 18.8 m. As figure 5(a) showed, the front section of 10 m had a relative small deformation because of the restraining effect of diaphragm wall. While the section of 10~40 m continued to uplift during the jacking process, until reaching to the deformation of 13 mm. Similar with box culvert jacking of first section, the bottom pipe showed a downward trend with the scope of 10~30 m. The maximum settlement could reach 20 mm. However, the value measured by monitoring point at 10 m decreased firstly and then increased due to the bounded constraint.

4. Conclusions
Based on the measured data of pipe roof deformation induced by the box culvert jacking of first two sections, some conclusions are summarized as follows:

(1) Because of the pressure holding of earth pressure balanced tool head at excavation face, the surrounding ground will be squeezed during the box culvert jacking. The closed pipe-roof frame presented a phenomenon of expanding outward, namely the uplift of top pipe and the settlement of bottom pipe. By sharing the squeeze effect induced by box culvert, the pipe-roof contributed to the controlment of ground deformation. (2) Along the jacking direction, the deformation of pipes was positioned over the box culvert structure and about 10m in front of the excavation face. In addition, the scope of deformation gradually moved forward with the jacking process.

(3) Due to the bounded constraint of diagram wall, it’s prone to be a reverse deformation at joint between pipe and diagram wall, and resulting in a wave-type deformation pattern.

Acknowledgements
The authors grateful acknowledge the engineers from Shanghai Urban Construction Municipal Engineering (Group) Co., Ltd. for their sincere help in providing relevant data and materials.

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