The influence of the high-pressure rotary jet formed sealing curtain on the stability of plug-in steel cylinder

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Abstract. The plug-in steel cylinder was widely used for man-made island construction as the bulkhead wall in nearshore soft soil area. In order to maintain the dry working condition inside the bulkhead wall, the high-pressure rotary jet formed sealing curtain should be built up under the steel cylinder and the connector between steel cylinders. During the dewatering process inside of the bulkhead wall, a water pressure difference between the inside and the outside of the bulkhead acts on the steel cylinders. This water pressure difference threatens the stability of steel cylinders, even leads to the crash of the steel cylinders when the steel cylinder was installed on the high-permeability soil layers. This paper analyzes the seepage field and the displacements of the cylinder during the dewatering process according to data from an engineering case, and highlights the effect of high-pressure rotary jet formed sealing curtain on maintaining the stability of cylinder.

1. Introduction
The steel cylinder is now widely used to form the bulkhead wall of the man-made island due to its high-efficiency and reliability. The dewatering process may affect the stability of cylinders, and the installation of the sealing curtain can mitigate this effect. The high-pressure rotary jet formed sealing curtain was developed from chemical grouting method and the high-pressure waterjet cutting technology [1-2]. The applications of high-pressure rotary jet formed sealing curtain in plug-in steel cylinder are widely analyzed in recent years [3]. This paper analyzed the stability of steel cylinders during the dewatering process and shows the benefit of high-pressure rotary jet formed sealing curtain.

2. Profiles of the engineering case
The cross-river tunnel between Shenzhen and Zhongshan locates in the central part of the Zhujiang River. The steel cylinders are installed as the bulkhead wall. The outer diameter and wall thickness of the steel cylinder are 20.0 m and 19 mm, respectively. The elevation of the top of the cylinder is +3.5 m, and the average clear distance between cylinders is 2.0 m.
In order to remain the dry construction environment inside the bulkhead wall, the high-pressure rotary jet formed sealing curtain is installed from the depth which is 5 meters above the bottom of cylinders to the depth which is the top of intermediary weathered rock layer. The sealing curtain contains 3 rows of 0.8 m wide high-pressure jet grouting piles, and the lap width of piles is 0.2 m. The permeability of the sealing curtain is lower than \(1 \times 10^{-5}\) cm/s, and its 28d strength is higher than 1.0MPa~1.5MPa. Figure 1 shows the layout of the sealing curtain.

![Figure 1. Layout of the sealing curtain.](image)

### 3. The analysis models

The numerical simulation research on the stability of steel cylinder was conducted based on the software PLASXIS 3D. The model is 300 m long, 30 m wide and 60 m deep. The detail parameters of soil layers are shown in Table 1.

#### Table 1. Information of the soil layers.

| Layer                  | Thickness | Weight | Shearing Strength | Young’s Modulus | Permeability | Interface Reduction Coefficient |
|------------------------|-----------|--------|-------------------|-----------------|--------------|---------------------------------|
|                         | m         | kN/m3  | kPa               | kN/m2           | m/d          | m/d                             |
| Filled sand            | 2         | 16.2   | 1 25              | 8980            | 0.287        | 0.287                           | 0.67                           |
| ②1 Mud                | 6         | 15.4   | 4.1 4.4           | 1800            | 1e-5         | 1e-5                            | 0.67                           |
| ②21 Mucky silty clay  | 2.5       | 17.6   | 9.3 15            | 2800            | 1e-3         | 1e-3                            | 0.67                           |
| ②2 Mud                | 1.7       | 16.3   | 6.7 11.8          | 1930            | 1e-5         | 1e-5                            | 0.67                           |
| ②21 Mucky silty clay  | 5.2       | 17.6   | 9.3 15            | 2800            | 1e-3         | 1e-3                            | 0.67                           |
| ③6 medium sand        | 1.2       | 19.4   | 12.6 32           | 12420           | 0.5          | 0.5                             | 0.67                           |
| ⑥1w4 Fully weathered rock | 8.2     | 18.9   | 12 29.3           | 7000            | 0.2          | 0.2                             | 0.67                           |
| ⑥12 Intermediary weathered rock | 7.46 | 20.6   | 0 38              | 30000           | 0.5          | 0.5                             | 0.67                           |
The parameters of steel cylinder and connector between cylinders is listed in Table 2, and the detailed information of sealing curtain is displayed in Table 3.

### Table 2 Information of the steel cylinder and connector

|                | Thickness | Weight | Young's Modulus | Poisson’s Ratio |
|----------------|-----------|--------|-----------------|-----------------|
| Steel cylinder | 0.019     | 78     | 21e7            | 0.15            |
| Connector      | 0.014     | 78     | 21e7            | 0.15            |

### Table 3 Information of sealing curtain

|                              | Outer Diameter | Lap Width | Weight | Young’s Modulus | Permeability | Poisson’s Ratio |
|------------------------------|----------------|-----------|--------|-----------------|--------------|-----------------|
| High-pressure jet grouting pile | 0.8            | 0.2       | 25     | 3e7             | 1e-5         | 0.25            |

4. **Analysis results**

4.1. **Stability of cylinders without installation of high-pressure jet grouting piles**

The steady seepage field around the cylinder, the distributions of the lateral and vertical displacements of the cylinder, and the reduction of the stability of the cylinder are shown in Figure 2, 3, 4, and 5, respectively.

![Figure 2](image1.png)  
**Figure 2.** The distribution of pore pressure

![Figure 3](image2.png)  
**Figure 3.** The distribution of lateral displacement

![Figure 4](image3.png)  
**Figure 4.** The distribution of vertical displacement

![Figure 5](image4.png)  
**Figure 5.** The reduction of stability

Figs. 2 to 5 show that the maximum pore pressure is 605.6 kPa. The maximum lateral and vertical displacements of the cylinder are 26 cm and 159 cm, respectively. The safety coefficient is 1.2.
4.2. Stability of cylinders after installation of high-pressure jet grouting piles

The steady seepage field, the distributions of the lateral and vertical displacements, and the reduction of the stability of the cylinder after the installation of the sealing curtain are shown in Figure 6, 7, 8, and 9, respectively.

![Figure 6. The distribution of pore pressure](image1)
![Figure 7. The distribution of lateral displacement](image2)
![Figure 8. The distribution of vertical displacement](image3)
![Figure 9. The reduction of stability](image4)

Figs. 6 to 9 show that the maximum pore pressure is 600 kPa. The maximum lateral and vertical displacements of the cylinder are 14.3 cm and 9.1 cm, respectively. The safety coefficient is 2.286, which is much higher than the cylinder without the installation of sealing curtain.

5. Conclusion

This paper reveals the influence of sealing curtain on the stability of steel cylinders, the main conclusions are as followed.

(1) The strength reduction method based on finite element analysis software can be used in the analysis of plug-in steel cylinders;
(2) The dewatering process inside of the bulkhead wall will cause huge reduction in the safety coefficient of steel cylinders and leads to larger lateral and vertical displacements when the high-pressure jet grouting piles are not installed;
(3) The safety of cylinder is much improved due to the benefit of sealing curtain. The high-pressure jet grouting piles which are installed from 5 m above the bottom of cylinders to the top of intermediary weathered rock layer, can effectively stop the seepage cross the bulkhead wall. Therefore, the lateral and vertical displacements are much lower than cylinder without sealing curtain.

References
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