The application of high-pressure rotary jet grouting curtain on the ocean engineering structure

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Abstract. The high-pressure rotary jet grouting curtain is a common water-proof structure in civil engineering. This paper analysed the application of high-pressure rotary jet grouting curtain in ocean engineering based on construction of the western man-made island of the Shenzhen-Zhongshan Channel project, modelling the pile forming, shearing strength, and water proofing effect, and emphasizes the key points in the construction.

1. Introduction
The high-pressure rotary jet grouting curtain technology is developed from the chemical grouting technology, combining with the hydraulic fracture technology, and be widely used in civil engineering, such as metro line engineering [1-3]. But the application on ocean engineering is fresh, especially in sand layer with high-pressure underground water. The Shenzhen-Zhongshan Tunnel project is another super engineering after the Hongkong-Zhuhai-Marco Bridge. The man-made island is also be used to connect the bridge and the cross-sea tunnel. In the construction of man-made island, the high-pressure rotary jet grouting curtain is used to stop seepage during the excavation inside the man-made island. This paper analysed the application of the high-pressure rotary jet grouting curtain based on this engineering case, and highlighted the advantages of this technology.

2. Brief introduction of the engineering case
The Shenzhen-Zhongshan Tunnel project locates in the middle of the core area of the middle reaches of the Pearl River, connecting the Shenzhen, Zhongshan, and Jiangmen city. The cross-sea section of this project is 22.4 km long, containing 57 plug-in steel cylinders. In order to create the dry construction environment for connecting the tunnel sections in man-made island, the high-pressure rotary jet grouting curtain, which is consist of 3 rows of high-pressure rotary jet grouting piles with the diameter of 0.8 m, is set in the inner side of the plug-in cylinder, and the depth of these piles range from 5 m higher than the bottom of the cylinders to the top of the moderately weathered rock. The coefficient of permeability of the curtain is less than 1×10^-5 cm/s, and the 28-day strength is higher than 1.0 MPa to 1.5 MPa. Fig. 1 shows the layout of the man-made island.
3. In-site testing of the piles

A serious in-site tests of the formed high-pressure rotary jet grouting piles are conducted to check the properties of the high-pressure rotary jet grouting curtain, and the details of the tests are shown in Table 1.

Table 1. Test items of the piles

| Test items                                      | Number of test samples | Test object                                  |
|------------------------------------------------|------------------------|----------------------------------------------|
| Drilling core                                   | 8 piles                | Checking the integer of piles                |
| Unconfined compressive strength test of 28-day  | 1 sample per meter in  | Testing the strength of formed piles         |
| 28-day strength                                 | horizon direction      |                                              |
| Water injection test                            | 8 piles                | Testing the water proof effect of the curtain|

There are 8 piles are selected to run the drilling core test (see Fig. 2), and the testing results are shown in Table 2.

Figure 1. Layout of the man-made island

Figure 2. Drilling core test samples
Table 2. Drilling core test results

| Test NO. | NO. of pile | Maintenance period (days) | The elevation of the top of the pile (m) | The elevation of the bottom of the pile (m) | Length of the pile (m) |
|----------|-------------|---------------------------|------------------------------------------|--------------------------------------------|-----------------------|
| 1        | B123        | 37                        | -11.43                                   | -37.50                                     | 26.07                 |
| 1        | B124        | 37                        | -11.43                                   | -37.20                                     | 25.77                 |
| 2        | B116        | 47                        | -11.43                                   | -36.70                                     | 25.27                 |
| 2        | B115        | 46                        | -11.43                                   | -37.00                                     | 25.57                 |
| 3        | B129        | 31                        | -11.43                                   | -38.40                                     | 26.97                 |
| 4        | C116        | 49                        | -11.43                                   | -37.00                                     | 25.57                 |
| 5        | B128        | 30                        | -11.43                                   | -38.10                                     | 26.67                 |
| 6        | B110        | 22                        | -11.43                                   | -37.20                                     | 25.77                 |
| 7        | B100        | 24                        | -11.43                                   | -37.00                                     | 25.57                 |
| 8        | B101        | 22                        | -11.43                                   | -37.20                                     | 25.77                 |
| 9        | B128        | 30                        | -11.43                                   | -38.10                                     | 26.67                 |
| 10       | B116        | 47                        | -11.43                                   | -36.70                                     | 25.27                 |
| 11       | B115        | 46                        | -11.43                                   | -37.00                                     | 25.57                 |
| 12       | B129        | 31                        | -11.43                                   | -38.40                                     | 26.97                 |
| 13       | C116        | 49                        | -11.43                                   | -37.00                                     | 25.57                 |
| 14       | B128        | 30                        | -11.43                                   | -38.10                                     | 26.67                 |
| 15       | B116        | 47                        | -11.43                                   | -36.70                                     | 25.27                 |
| 16       | B115        | 46                        | -11.43                                   | -37.00                                     | 25.57                 |
| 17       | C116        | 49                        | -11.43                                   | -37.00                                     | 25.57                 |

The 28-day strength test results of samples are shown in Table 3, and the strength of all samples are larger than 1.2 MPa.

Table 3. 28-day strength test results

| Pile NO. | Maintenance period (days) | Number of test samples | 28-day strength (MPa) | Percent of pass (%) |
|----------|---------------------------|------------------------|-----------------------|---------------------|
|          |                           |                        | Maximum value | Minimum value | Average value |                  |
| A125-B123-B124-B115-C116-B128-B116-B129-B100-B101-B35-B36-C81-B81-B80-B4-B5 | 53                       | 25                     | 5.4          | 1.24          | 2.04          | 100                |
|          |                           |                        | 61                       | 23             | 5.47          | 1.22          | 2.56          | 100                |
|          |                           |                        | 39                       | 20             | 6.71          | 1.54          | 3.18          | 100                |
|          |                           |                        | 42                       | 24             | 4.43          | 1.67          | 3.05          | 100                |
|          |                           |                        | 37                       | 24             | 17.2          | 1.28          | 6.83          | 100                |
|          |                           |                        | 41                       | 22             | 11.61         | 1.3           | 3.58          | 100                |

The water injection test results of samples are shown in Table 4.
Table 4. Water injection test results

| Test NO. | The elevation of the pile bottom (m) | Description of pile | Permeability coefficient (cm/s) |
|----------|-------------------------------------|---------------------|---------------------------------|
|          | Formed pile | Testing pile |                              |                                  |
| 1        | -37.2       | -37.4         | Pile is well uniform, and the bottom of pile is set on the weathered rock | 4.14×10^{-6}                     |
| 2        | -36.7       | -34.4         |                                  | 3.57×10^{-6}                     |
| 3        | -38.2       | -38.2         |                                  | 4.93×10^{-6}                     |
| 4        | -37.0       | -34.4         |                                  | 2.78×10^{-6}                     |
| 5        | -43.0       | -37.0         | Pile is well uniform, and the bottom of pile is set on the sandy solidly weathered rock | 9.36×10^{-6}                     |
| 6        | -39.4       | -37.4         | Pile is uniform, and the bottom of pile is set on the weathered rock with two drainage boards | 7.78×10^{-6}                     |
| 7        | -45.2       | -43.2         | Pile is uniform, and the bottom of pile is set on the weathered rock | 6.04×10^{-6}                     |
| 8        | -41.2       | -            | The uniformity of pile is poor, and the content of cement is little when the elevation is below -20 m. The water inject test cannot be conducted. | -                                 |

4. Conclusions
The application of the high-pressure rotary jet grouting curtain on ocean engineering is discussed in this paper based on an engineering case, and the main conclusions are as followed.

(1) The drilling core test results show that the forming of the high-pressure rotary jet grouting piles can be done with high quality in sand layer with high-pressure underground water. And the integer of formed piles is well.

(2) The 28-day strength results show that the unconfined compressive strengths of the formed piles are higher than 1.2 MPa.

(3) The water injection results show that the permeability coefficient of the formed high-pressure rotary jet grouting piles ranges from 2.78×10^{-6} to 9.36×10^{-6} cm/s, and the sealing effect of the curtain is well.

References
[1] Luan MT, Fan QL. Numerical analyses of bearing capacity of deep-embedded large-diameter cylindrical structure on soft ground against lateral loads[J]. China Ocean Engineering, 2006, 20 (4): 623-634.
[2] Wang YZ, Zhu ZY, Zhou ZR. Dynamic response analysis for embedded large-cylinder breakwaters under wave excitation[J]. China Ocean Engineering, 2004, 18 (4): 585-594.
[3] D.A.Bruce and Pellegrino. Jet Grouting for Solving Tunnelin Problems in Soft Clays, 2003.