Experimental research on bearing capacity of special anchor

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Abstract. The bearing capacity of anchor can be greatly improved by adding anchor gills on the basis of traditional anchor. Taking the smaller particle pea stone concrete as anchoring cartridge, this paper conducted the bearing capacity pull-out test on special anchor with additional anchor gills and studied the relationship between bearing capacity of special anchor and layers of anchor gills, strength of pea stone concrete, the size of the block. The test results have revealed that adding anchor gills in anchoring section has an obvious effect on improving the bearing capacity of anchor and the bearing capacity of single-layer rod is 1.2 times - 1.7 times that of finishing rod. There is a non-linear relationship between the bearing capacity of special anchor and the strength of pea stone concrete when the strength of anchor gill is constant. However, as the concrete strength increases, the improvement of bearing capacity becomes smaller. Under the condition of single-layer rod, the bearing capacity of anchor increases with the increase of the size of the block, which shows that the bearing capacity of anchor is positively correlated with the thickness of concrete when the strength of anchor is constant.

1. Introduction
With the increasing number and scope of geotechnical projects, the application of geotechnical reinforcement technology becomes more extensive, such as tunnels, mine roadways, open slopes, underground works. However, the deficiencies of traditional anchor rod are that the stress distribution in the anchoring section is uneven and the local stress concentration phenomenon will occur [1-2]. Additionally, mortar or cement mortar is often used as anchoring agent in engineering, which has some problems, such as low strength and large amount of cement. Therefore, taking the smaller particle pea stone concrete as anchoring cartridge, this paper designed four kinds of concrete strength with different mix ratio and discussed the structural type and failure mode of increasing the bearing capacity of anchor from the aspect of the structural type of anchor rod. By the pull-out test of the bearing capacity of special anchor, the relationships between bearing capacity of special anchor and layers of anchor gills, strength of pea stone concrete, the size of the block were obtained, which provides a direction for the development of anchor strengthening new technology [3-4].

2. Design of test scheme
In general, mortar or cement mortar is often used as anchoring agent in engineering [5-6]. Despite their advantages, such as convenient grouting and less controlled factors, they usually consume a large amount of cement and their project costs are high. Therefore, based on the characteristics of anchor grouting, this paper adopted smaller particle pea stone concrete as anchoring cartridge to conduct the bearing performance experiment of special anchor. According to the requirements of concrete strength and the requirement of self-compacting property, four different mix ratios were designed and the
parameters of mix ratios were shown in Table 1. Among them, 42.5 grade ordinary Portland cement was selected; the particle size of peastone aggregate was equal to or less than 10 mm; the medium sand was selected and its fineness modulus was 2.6; the water reducing agent was Naphthalene superplasticizer, whose dosage was 1% cementitious material and water reducing rate was 20%.

Table 1. The parameters of mix ratios

| test group number | collapsed slump /mm | mix ratios | water reducer | Compressive Strength /MPa |
|-------------------|----------------------|------------|---------------|--------------------------|
| S1                | 200                  | 1:1.71:2.73:3.62 | No            | 36.10                    |
| S2                | 180                  | 1:1.98:3.15:4.18 | Yes           | 41.20                    |
| S3                | 180                  | 1:2.22:2.16:3.67 | No            | 46.55                    |
| S4                | 200                  | 1:2.55:2.48:4.22 | Yes           | 50.70                    |

The test used three kinds of rid forms, including smooth straight rod, single-layer anchor bolt and double-layer anchor bolt. The diameter of smooth straight rod is φ20 and its length is 350mm; the diameter of anchor bolt is φ10 and its length is 50mm. The test blocks are test cube whose side lengths are 100mm, 150mm and 200mm respectively. The end type of special anchor rod is shown in Figure 1.

![Figure 1. Traditional anchor and special anchor](image)

(a) the smooth rod. (b) the single-layer anchor bolt. (c) double-layer anchor bolt

The universal testing machine and block grip adopted in the test are shown in Figure 2. When loading, the test block was fixed on the universal testing machine with special fixing clamp and testing machine held the anchor rod in the test block. The pull-out test was conducted based on central loading mode, whose loading rate was 5mm/min. Until the test block or anchor rod was damaged, the variation curve of drawing force \( F \) and displacement \( s \) at the top of anchor rod was recorded.

![Figure 2. Pull out test apparatus](image)

(a) universal testing machine. (b) clamp

3. Bearing capacity test and result analysis of special anchor

3.1. influence of concrete strength and rod shape on the bearing capacity of special anchor
After the processing and analysis of the pull-out test data, the test results are shown in Table 2-4 and Figure 3-5. Table 2, Table 3, Figure 3 and Figure 4 show the test results whose side length are 100mm and 150mm respectively. From the test results, it is seen that the drawing force of the smooth rod and the single-layer anchor bolt increase with the increase of peastone concrete strength. Under the condition of the same strength of peastone concrete, the bearing capacity of the single-layer anchor bolt is 1.2 times that of the smooth rod. Therefore, the bearing capacity of anchor rod has been improved to a certain extent by changing the structure type of anchor rod.

### Table 2. Ultimate pulling force of 28d (test block side length are 100mm)

| rod shape                  | S1   | S2   | S3   | S4   |
|----------------------------|------|------|------|------|
| the smooth rod             | 16.38 kN | 17.66 kN | 20.71 kN | 21.09 kN |
| the single-layer anchor bolt| 19.45 kN | 22.73 kN | 24.53 kN | 24.33 kN |

![Figure 3. Variation curve of ultimate pulling force of anchor (test block side length are 100mm)](image)

From Table 4 and Figure 5, it is known that when the side length of block is 200mm, the bearing capacity of the single-layer anchor bolt is 1.7 times that of the smooth rod under the condition same strength of concrete. The bearing capacity of double-layer anchor bolt is 1.06 times that of the single-layer anchor bolt. Therefore, compared with the single-layer anchor bolt, the improvement of the bearing capacity of the double-layer anchor is limited. The main reason for this is that the anchor gill is made by punching and welding the anchor in the straight rod. The double-layer anchor bolt causes the reduction of the effective area on the straight rod, thus reducing the bearing capacity of the anchor rod. In addition, with the increase of concrete strength, the double-layer anchor bolt is broken at the anchoring section, as shown in Figure 6.

From the analysis above, when the side length of block is increased from 100mm to 150mm, the bearing capacity of single-layer anchor bolt is increased by 20%, compared with smooth rod. When the side length is increased from 150mm to 200mm, the bearing capacity of single-layer anchor bolt is increased by 70% compared with smooth rod. This shows that the bearing capacity of the anchor gill is related to the thickness of the concrete and the bearing capacity increases nonlinearly along with the increase of the block size within the range of anchor gill strength, as shown in Figure 7.
Figure 4. Variation curve of ultimate pulling force of anchor (test block side length are 150mm)

Table 4. Ultimate pulling force of 28d (test block side length are 200mm)

| group number | rod shape                      | S1     | S2     | S3     | S4     |
|--------------|--------------------------------|--------|--------|--------|--------|
|              | the smooth rod                 | 46.17 kN | 49.56 kN | 54.43 kN | 57.21 kN |
|              | the single-layer anchor bolt    | 73.98 kN | 85.65 kN | 95.08 kN | 99.90 kN |
|              | double-layer anchor bolt        | 79.33 kN | 91.32 kN | 99.09 kN | 104.11 kN |

Figure 5. Variation curve of ultimate pulling force of anchor (test block side length are 200mm)

Figure 6. The collapse mode of test blocks
(a) the smooth rod. (b) the single-layer anchor bolt. (c) double-layer anchor bolt
Figure 7. Variation curve of ultimate pulling force of anchor

From Figure 8, it is found that when the side length of block is 200mm, the bearing capacity of single-layer anchor bolt is improved significantly under the condition of the same concrete strength. The improvement of the bearing capacity of double-layer anchor bolt is smaller because the anchor bolt is broken at the anchoring section and the strength of pea stone concrete has not been fully utilized. Therefore, the bearing capacity of anchor rod can be significantly improved by changing the structure of anchor rod.

Figure 8. Variation curve of ultimate pulling force of anchor with rod shape(test block side length are 200mm)

3.2. Regression analysis of relationship between bearing capacity of anchor, concrete strength, and anchor gills

When the size of block was 200mm×200mm×200mm and testing time was 28 days, the regression analysis was constructed on the experimental data of smooth rod, single-layer anchor bolt and double-layer anchor bolt. The results are shown in Figure 9-Figure 11.
Figure 9. Relationship between pulling force of anchor (the smooth rod) and concrete Strength

From Figure 9, the regression equation (1) was obtained after the experimental data regression analysis of smooth rod. Its result demonstrates that the capacity of conventional anchor rod is linearly related to the strength of concrete when the strength of anchor gill is certain, that is, the larger the concrete strength, the larger bearing capacity of anchor.

\[ y = 0.7841x + 16.67 \]  
\( (1) \)

where \( x \) represents the strength of concrete.

Figure 10. Relationship between pulling force of anchor (the single-layer anchor bolt) and concrete Strength

From Figure 10, the regression equation (2) was obtained after the experimental data regression analysis of single-layer anchor bolt. The results show that under the condition of single-layer anchor bolt, its bearing capacity has a non-linear relationship with the strength of concrete and the the improvement of bearing capacity decreases with the increase of concrete strength.

\[ y = -0.0581x^2 + 6.8958x - 98.95 \]  
\( (2) \)

where \( x \) represents the strength of concrete.

From Figure 11, it is found that the regression equation (3) was obtained after the experimental data regression analysis of double-layer anchor bolt. From Figure 11 and equation (3), it is seen that under the condition of double-layer anchor bolt, its bearing capacity has a non-linear relationship with the strength of concrete and the the improvement of bearing capacity decreases with the increase of concrete strength.

\[ y = -0.0345x^2 + 4.4703x - 33.916 \]  
\( (3) \)

where \( x \) represents the strength of concrete.
4. Conclusions

Based on the smaller particle pea stone concrete, the relationship between bearing capacity of special anchor and layers of anchor gills, strength of pea stone concrete, the size of the block was studied via the inside experimental methods. The conclusions are made as follows:

(1) The bearing capacity of anchor is greatly improved by changing the structural style of anchor. With the same concrete strength, when the size of the block is 100mm×100mm×100m and 150mm×150mm×150mm, bearing capacity of single-layer anchor bolt is 1.2 times that of smooth rod. When the size of the block is 200mm×200mm×200mm, the pullout force of single-layer anchor bolt is 1.7 times that of smooth rod.

(2) The bearing capacity of special anchor, including single-layer anchor bolt and double-layer anchor bolt, has a non-linear relationship with concrete strength. With the increase of concrete strength, the bearing capacity increases, but its improvement decreases gradually.

(3) The bearing capacity of single-layer anchor bolt increases with the increase of the size of block, which proves that its bearing capacity has a positive correlation with the thickness of concrete when the strength of anchor is constant.

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References

[1] Cheng L K, Hu J L, Zhang P W. The new development of ground anchorage. China Academic Journal Electronic Publishing House[J]. 2010,40(01):98-101
[2] LIU Q S, LEI G F, PENG X X. Advance and review on the anchoring mechanism in deep fractured rock mass[J]. Chinese Journal of Rock Mechanics and Engineering. 2016,35(02):312-332
[3] Yi Y N. The Research of Disc Anchor in Engineering Application[D]. Beijing: North China University of Technology, 2015
[4] Xin F C. Experimental Research on Matching the Strength of Anchor Plate and Anchoring Unit of the Disc Anchor[D]. Beijing: North China University of Technology, 2013
[5] National Energy Administration. DL/T 5083-2010 Specification of prestressing tendon construction for hydropower and water resources project [S]. Beijing: China electric power press
[6] National Energy Administration. DL/T 5703-2014 Technical specification for cement anchoring agent for prestressed anchor of hydropower and water conservancy engineering[S]. Beijing: China electric power press