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# THE DESIGN AND EXPERIMENTAL STUDY ON ANCHORING PERFORMANCE OF BOND-TYPE ANCHORAGE OF A NEW TYPE BFRP CABLE

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*Aiming to study the anchoring performance of bond-type anchorage of Basalt Fiber Reinforced Polymer (BFRP) cable and its influencing factors, a kind of spiral steel straight pipe bond-type anchorage is designed, and 10 sets of bond-type anchorage are tested with the bonding medium, anchoring form and the number of cable as variables. The experimental analysis shows that there are three failure modes of the general anchoring type for bond-type anchorage, among which the reinforcement blasting is the ideal failure mode, and the anchoring performance of the anchorage is reliable when this kind of failure occurs. The key factors affecting the anchoring performance of bonded straight barrel anchorage of BFRP cable include mechanical properties of bonding medium, properties of anchor pipe, anchorage mode, numbers of bars and anchorage length, etc. According to the test data, the influence law of these factors on the anchorage performance of bonded anchors is analyzed in detail. These conclusions are indispensable theoretical basis for the design of new BFRP bar cable and its application in engineering.*

**Keywords**: Basalt Fiber Reinforced Polymer cable; bond-type anchorage; anchoring performance; failure form

## 1. Introduction

Since the service of Three Gorges Dam project, extremely high requirements have been put forward for the long-term stability and durability of the bank slope in reservoir area in the effect of the water level cycle during the impoundment operation period [1]. The natural conditions in the area where Three Gorges Dam is located have the following characteristics: the humid and hot climate, complex hydrogeology and complex composition of groundwater. Under such natural conditions, the anchor rod for slope reinforcement will undergo corrosion when the underground corrosive agent reaches its surface, which brings some unfavorable

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social impacts. Engineering accidents have occurred due to such corrosion of anchor system [2-3]. Therefore, the application of steel anchor cables in slope support engineering in above environment is greatly limited. Therefore, the new anchorage materials such as Fiber-reinforced polymer [4] and Negative Poisson's Ratio Materials [5-6] have been explored and investigated by relevant scholars. Meanwhile, the mechanical properties and engineering applications of these new anchorage materials for anchor rods have been studied by some researchers [7-8].

Basalt Fiber Reinforced Polymer (BFRP) is a late-model of composite reinforcement. Its base material is synthetic resin, and organic high-strength basalt fiber raw materials and appropriate amount of auxiliary agents are added to the base material. Compared with steel bars, tensile strength of BFRP materials is higher, and its durability is better, and at the same time it is a new type of material with strong environmental adaptability. The advantages and disadvantages in anchorage performance of BFRP anchors and steel ones have been gradually studied. The excellent resistance of corrosion of BFRP ensures the durability of structural system in strong corrosive environments such as acids, alkalis, and chlorides and potassium ions, which is unparalleled in steel [8]. Wu et al [9], Wang et al [10], and Zhao et al [11] investigated the slope reinforcement using the BFRP anchors and steel ones, respectively, which shows the feasibility that BFRP anchors take the place of steel ones for slope reinforcement with various vibration. Moreover, tensile experiments of BFRP anchors of various anchor cable diameters and lengths have been conducted. The results show that the compressive strength and shear strengths of BFRP bars are both low, generally not exceeding 10% of its tensile strength owing to its obvious anisotropic characteristics. Therefore, BFRP anchor cables is easy to be crushed due to stress concentration in the clamping section when traditional metal clip anchors are used for anchorage. To solve this drawback, it is necessary to design suitable anchorage based on the above mentioned characteristics of BFRP [12].

At present, some achievements have been made in the development and research of anchorage of BFRP cable. According to the anchoring mechanism, it is mainly divided into mechanical clip-type anchorage and bond -type anchorage.

Although the traditional steel clip anchorage is easy to install, it is easy to cause stress concentration on BFRP bars in the anchoring section, resulting in low anchoring efficiency. In order to prevent the stress concentration, researchers have designed different types of clip anchorage for FRP bar and made a series of improvements. Al-Mayah et al [13] have proposed a design method of variable angle clip anchorage. Terrasi et al [14] have sprayed quartz sand on the surface of CFRP bars and optimized and improved the anchorage system.

Bond-type anchorage belongs to grouting anchorage and is mainly composed of metal sleeve and bonding medium which is taken as a "load transfer medium".

The tensile stress of BFRP bars is gradually transmitted from the filling medium with low elastic modulus to the metal sleeve with high elastic modulus. The resistance force of bond-type anchorage to external load is mainly composed of three parts. They are chemical adhesive force, friction force and mechanical bite force generated by contact with rough interface between bonding medium and BFRP bars. The advantage of bond-type anchorage is that the circumferential pressure on BFRP bars is small, which avoids the clamp damage to BFRP bars, and the anchoring efficiency is higher. Compared with clip-type anchorage, bonded anchorage is more suitable for BFRP bars.

Recently, some researchers have studied the anchorage performance of bonded anchors of BFRP cable. Mei et al [15] have studied three types of bond-type anchorage systems of CFRP bar, namely, straight cylinder type, inner cone type and inner cone-straight cylinder type. The researches show that the mode of the load transfer with the inner cone-straight cylinder type anchorage is reliable and reasonable, and can effectively solve the stress concentration at the end. Chen et al [16] have studied the anchoring performance of wedge-shaped bond-type anchorage and its influencing factors through static load tests. The results show that the ultimate load of anchorage can be effectively improved by increasing internal inclination angle and anchoring length of anchorage. Zhang and Benmokrane [17] have carried out research on resinous bond-type anchorage, and the results have showed that the minimum bonding length is 0.5m. The resin filling medium with low elastic modulus can reduce the peak shear stress of FRP surface, while the high elastic resin can control the creep of anchors system more effectively and has better long-term stability.

At present, although certain achievements have been made in the research and development of bond-type anchorage for BFRP bars, there are few research results on the anchoring properties of single and multiple bundles of BFRP bars under the combination of multiple parameters including bonding medium, anchor tube performance, anchoring mode and anchoring length. Based on the project of reinforcement of slope of deterioration zone in the Three Gorges Reservoir area, a new bond-type anchorage of BFRP cable is designed and mechanical property tests for this single cable and three cables have been carried out and analyzed with different bonding media, anchor pipe characteristics, anchoring form and anchoring length. These results can provide the basis for engineering application of BFRP cable.

## 2. Design and manufacture of bond-type anchorage

### 2.1 Design of bond-type anchorage

Based on references 4 and 12, a new type of bond-type anchorage with spiral steel tube of BFRP cable is designed and its structure can be seen in Figure 1. The

BFRP cable is composed of steel pipe, bonding medium and BFRP bars. At both ends of BFRP cable, the bar is bonded centrally by bonding medium to steel pipe. The steel pipe is threaded inside and outside the wall, the pattern is shown in Figure 2, and the pitch of thread is 1mm in the test. The thread can increase contact area and roughness between the steel anchor pipe wall and bonding medium. The exterior wall of a single steel pipe is installed with two nuts in contact with each other. There is a steel backing plate at the inner side of the two sets of nuts. When the bonding anchoring system is stretched, the through-core jack directly imposes the load on the steel backing plate, and the steel backing plate transfers the load to the spiral steel tube through pushing nut to realize the tension of the BFRP bars. This design can effectively weaken the stress concentration of anchoring system, and the BFRP bars can avoid the transverse fracture.

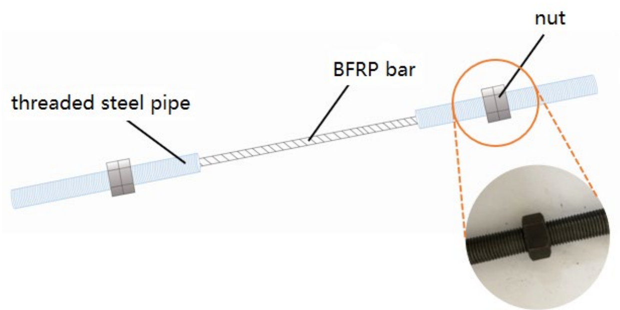


Fig.1.Structure diagram of bond-type anchorage

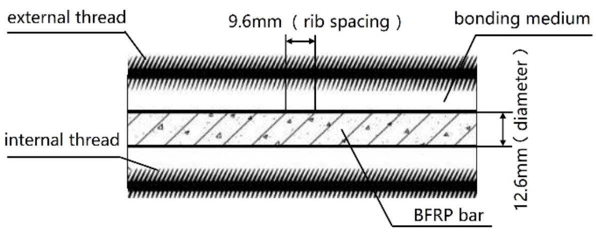


Fig.2. Steel anchor pipe style and BFRP bar

### 2.2 Making of bond-type anchorage

The key of this experiment is the manufacture of bonded anchorage. The steps of production of the specimen is as follow.

The first step is that a good ribbed BFRP bar with a diameter of 12.6mm is selected and the rib spacing of is 9.6mm, shown in Fig 2. Its mechanical properties which are provided by the manufacturer are shown in Table 1, and the corresponding length is cut out using a cutting machine according to the test scheme.

*Table 1*

**Mechanical properties of BFRP bar**

| Diameter /mm | Tensile strength /MPa | Elastic Modulus /GPa |
|---|---|---|
| 12.6 | 1170 | 45 |

The second step is to remove oil and rust inside the steel pipe.

The third step is to match BFRP bars with steel pipe and to seal one of bottom of steel anchor pipe with plastic sheet and fix vertically.

The fourth step is to prepare appropriate amount of epoxy resin binder according to different mix ratios. The mix ratio of the binder is shown in Table 2. Pour epoxy resin into the steel anchor pipe with a funnel, then insert BFRP bars into the steel anchor pipe, and make it sink slowly until the epoxy resin overflows automatically. Because the epoxy resin has the property of shrinking after curing, some filling medium is added to the steel anchor pipe after curing and solidifying to ensure that anchor pipe is filled.

The fifth step is to remove the plastic sheet.

The last step is that the specimen is cured naturally until the binder reaches the final strength. Then the other bottom of the steel anchor pipe is sealed and poured epoxy resin in the same way as above.

*Table 2*

**Mix proportion of binder**

| Bonding medium | Material composition | Mix ratio | Compressive strength/MPa |
|---|---|---|---|
| Resin type 1 | Epoxy resin: curing agent: accelerator | 100:75:3.5 | 24 |
| Resin type 2 | Epoxy resin: curing agent: accelerator: basalt fiber (length about 1cm) | 100:75:3.5:0.7: Sufficient quantity | 63 |
| Resin type 3 | Modified epoxy resin: curing agent | 100:10 | 91 |
| Resin type 4 | Modified epoxy resin: curing agent | 100:50 | 105 |

## 3. Mechanical testing of anchorage properties

### 3.1. Experiment design

The tests are designed with the bonding medium type, anchoring form and the number of cables as variable parameters. There are four main types of bonding media. The composition and mix ratio of bonding medium are shown in Table 2. The anchoring forms are divided into ordinary anchoring forms and special anchoring forms in which the length of 6mm at the central of a single bar is thinned into 6mm, as shown in Figure 3. The specific parameters of specimens are shown in Table 3. In the table, 45 steel is carbon structural steel with carbon content of 0.45% which is widely used in the manufacture of structural parts and low grade plastic molds and 40Cr is a high-quality alloy structural steel, with a certain degree of harden ability and good comprehensive mechanical properties, widely used in the manufacture of various mechanical parts. Each group of specimens is tested 3-5 times.

(a) Trim the middle of a single bar

(b) Trim the middle of three bars

Fig.3. Special preparation of bars for test

*Table 3*

**Parameter design table of specimen for experiment**

| Specimen number | External diameter pipe/mm | Internal diameter pipe/mm | Anchorage length/mm | Steel pipe material | Bonding medium | Anchorage form | Number of bars |
|---|---|---|---|---|---|---|---|
| N1 | 30 | 15 | 300 | 45 Steel | Resin type 1 | ordinary | 1 |
| N2 | 30 | 15 | 300 | 45 Steel | Resin type 2 | ordinary | 1 |
| N3 | 30 | 15 | 300 | 45 Steel | Resin type 3 | ordinary | 1 |
| N4 | 30 | 15 | 300 | 45 Steel | Resin type 4 | ordinary | 1 |
| N5 | 22 | 15 | 300 | 45 Steel | Resin type 4 | ordinary | 1 |
| N6 | 22 | 15 | 300 | 45 Steel | Resin type 4 | thinner | 1 |
| N7 | 30 | 18 | 300 | 45 Steel | Resin type4 | ordinary | 1 |
| N8 | 30 | 18 | 300 | 45 Steel | Resin type 4 | thinner | 1 |
| N9 | 42 | 32 | 400 | 40Cr | Resin type 4 | ordinary | 3 |
| N10 | 42 | 32 | 400 | 40Cr | Resin type 4 | thinner | 3 |

### 3.2 Experimental method

According to the above method, the prepared bond-type anchorage has been cured for 28 days and the tension test has been carried out. A through-core jack is selected for graded loading in the test (Fig. 4). The load gradient of a single stage is 26.3kN, and the load of each stage is held for 10 minutes. According to Fig.4, the pressure value which the pressure sensor measured is equal to the load value which the core jack supply.

In this test, the length of basalt fiber bar is 90cm and the length of tension zone is 50cm. The test will be stopped when the fracture of reinforcement or anchorage damage occurs during the test.

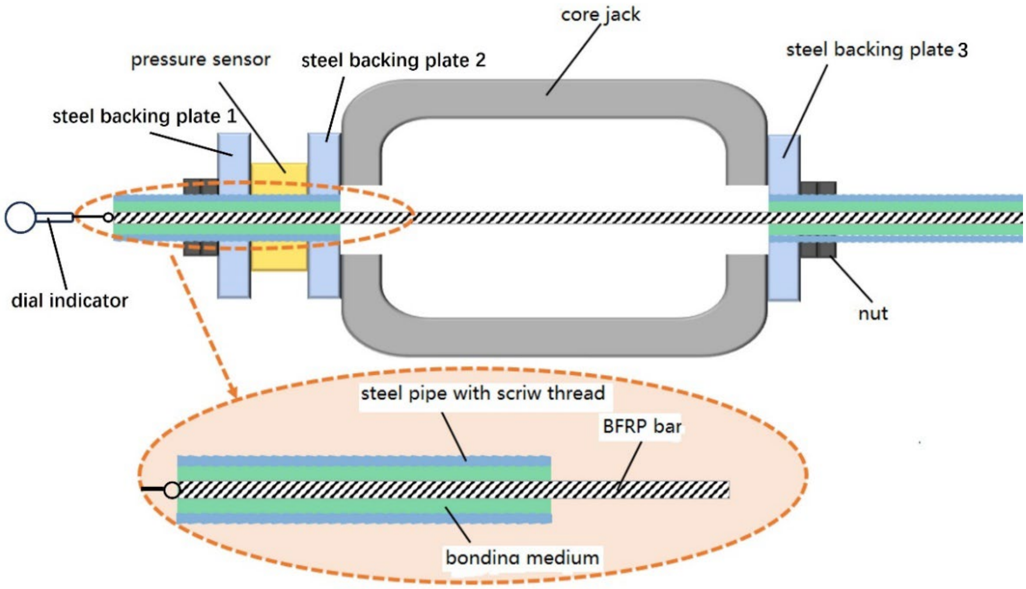


Fig. 4. Schematic diagram of tensile test of screw tube bonded anchorage

### 3.3 Test results and analysis

For bonded BFRP cable system, anchoring efficiency system is an important parameter to evaluate the anchoring effect, and it can be calculated from formula 1 and 2.

$$\eta_a = F_{Tu} / F_{ptk} \quad (1)$$

$$F_{ptk} = A_{pk} \times f_{ptk} \quad (2)$$

Elements in the formula are explained as following.

$\eta_a$ __ Anchoring efficiency coefficient;

$F_{Tu}$ —Measured limit tensile force (kN) of BFRP anchorage （kN）；

$F_{ptk}$ —The nominal limit tensile force of prestressed BFRP bar（kN）；

$A_{pk}$ —The nominal cross-section area of the prestressed tendon（$mm^2$）；

$f_{ptk}$ —Nominal tensile strength of prestressed tendons（MPa）.

In addition, when BFRP bars slip and fail along the bonding medium or bar was blast, the longitudinal shear stress on the contact surface between the BFRP bar and the bonding medium can be obtained. That is, the so-called ultimate bonding stress.

The test results of bonded anchoring system are shown in Table 4.

*Table 4*

**Test results of bond-type anchorage system**

| Specimen number | Ultimate bearing capacity /kN | Ultimate tensile strength/MPa | Anchor efficiency coefficient | Ultimate bond stress/MPa | Failure mode |
|---|---|---|---|---|---|
| N1 | 100.13 | 803 | 69.06% | 7.06 | Bonding medium slip |
| N2 | 143.55 | 1152 | 99.00% | Greater than10.16 | Bar was blast |
| N3 | 133.03 | 1067 | 91.74% | 9.41 | Bonding medium slip |
| N4 | 148.38 | 1191 | 102.33% | Greater than10.50 | Bar was blast |
| N5 | 126.45 | 1015 | 87.21% | -- | Steel pipe crack |
| N6 | 133.03 | 1067 | 91.74% | -- | Pulling bar core 、Steel pipe fracture |
| N7 | 139.61 | 1120 | 96.28% | -- | Bar was blast |
| N8 | 133.03 | 1067 | 91.74% | -- | Pulling bar core |
| N9 | 389.61 | 1042 | 89.57% | -- | Bar was blast |
| N10 | 389.61 | 1042 | 89.57% | -- | Bar was blast |

In Table 4, the value of Ultimate bond stress is Calculated by formula 3.

$$\tau = \frac{P}{\pi d L} \tag{3}$$

Where, τ is the ultimate bond stress of the specimen, *P* is the ultimate bearing capacity of the specimen, d is the diameter of the Internal diameter pipe, and *L* is the anchoring length. This formula is only suitable for sliding failure of the medium. Therefore, for specimen 1 and specimen 3 where slip failure occurs, the specific ultimate bond stress is calculated according to the formula. For other failure forms, the specific ultimate bond stress cannot be measured in detail. In some cases, only the ultimate bonding stress under the action of lower loads can be measured, so it can be inferred that the ultimate bonding stress is greater than a certain value.

### 3.3.1 Failure form and mechanism analysis

Four failure modes of anchoring occur during the test, as shown in Fig.5. In the tests of N1 to 4 group, the failure of specimens in N1 group are all bonding medium slipping along the inner wall of the anchor pipe, shown in Figure 5 (b). The specimens in groups N2 and N4 have been all destroyed by blasting off the BFRP bars, as shown in Fig.5 (a). The blasting failure in Fig. 5(a)is a typical failure mode. The resin has cracked, the fibers have broken in the middle and the BFRP bars have exploded in a "lantern shape", which is an ideal failure mode, indicating that the ultimate bearing capacity of the specimen is determined by the tensile strength of

BFRP bars, thus confirming that the anchorage performance is reliable indicating that the bond strength between epoxy resin type 2 or 4 and steel pipe is sufficient to ensure the BFRP bars against tensile failure. The steel pipe of the third anchor cable in group N6 is broken because the thickness and the thread cannot meet requirement, as shown in Figure 5 (c). To reduce the shear lag, the ordinary anchorage form was changed to trimmed steel bar. Cutting a single anchor cable thinner does not reduce shear lag, but reduce the bearing capacity, so the core-pulling damage occurs in N8, as shown in Fig.5(d).

（a）The bar was blast （b）Bonding medium slip

（c）Anchor pipe fracture （d）Core of bar was pulled thinner

Fig.5. Failure forms

### 3.3.2 Analysis of influence factors

There are many factors affecting the anchoring performance of bonded anchors, and the type of bonding medium, anchor pipe, anchoring length and anchoring form are the main factors affecting the performance of anchor cable. According to the test, the influence of the following factors on the anchoring performance is analyzed respectively.

1）Bonding medium

The elongation of the specimen is measured by a dial indicator fixed to the end of the test anchor, shown in Fig.4. In the course of the test, the force value and elongation value of each stage can be recorded. The relationship between load and slippage of BFRP bar in different bond media can be seen in Fig.6. According to Fig.6 and combining with the failure forms of specimens, it can be known that the slippage of specimens 2 and 4 with blasting failure is more uniform and stable under each order load, and the ultimate bond stress of resin type 2 and resin type 4 is greater than 10MPa. The slippage of specimen 1 under the first two loads is about

0.6mm, and the slippage of specimen 1 under the third load has suddenly increased to about 2mm, indicating that the slippage increased greatly under this load. As a result, failure of bonding medium slip occurs in specimen 1, and the ultimate bond stress of resin type 1 is 7.06 MPa. Under the fourth grade load, the slippage of specimen 3 surges, about twice as much as that of the upper load, and the slip growing rate increases with increasing of the load. As a result, the colloid slip failure has occurred in specimen 3, and the ultimate bond stress of resin type 3 is 9.41MPa. Under the same conditions of other parameters, the anchorage effect of resin type 1 and 4 are the best, followed by resin type 3 and resin type 2.

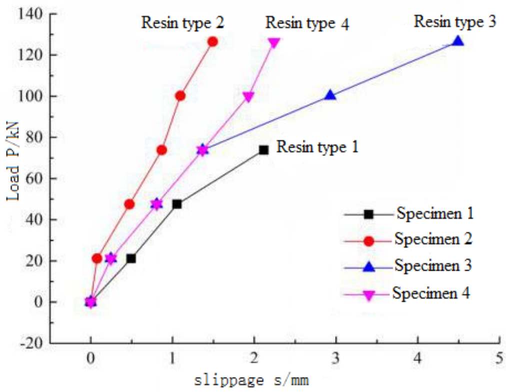


Fig.6. Relationship between load and slip under different bond media

When the load is large, shear failure occurred between the adhesive medium and the steel pipe with the thread, and the medium of the specimen will crack and slip. At this time, the greater the shear strength of bonding medium, the smaller and more uniform the slip amount of the anchor. Therefore, the shear strength of the bonding medium has an impact on the ultimate bearing capacity of the specimen. The greater the compressive strength, the higher the ultimate bearing capacity. As can be seen from Table 2 and Table 3, the descending order of compressive strength of the bonding medium is resin type 4, resin type 3, resin type 2 and resin type 1. The order of ultimate bearing capacity is similar, but resin type 2 is an exception. The compressive strength of resin type 2 is 63MPa, whose compressive strength is less than resin type 3 whose compressive strength is 91MPa, but the specimen with resin type 2 is destroyed by blasting. Based on the material composition in Table 2, it can be seen that resin type 2 is based on epoxy resin and added a large number of short basalt fiber fibers, resulting in a much higher elastic modulus than other epoxy resin bonding medium. Therefore, the resin type 2 whose composition and elastic modulus is similar to BFRP bars has a small relative sliding trend with steel pipe, so that it has a good coordination deformation ability with BFRP bars. Therefore, specimen using epoxy resin 2 has been destroyed by cracking BFRP bar.

In addition to having high ultimate bearing capacity, the anchor cable used for support should also have good extensibility to adapt to the deformation of slope. Under the condition that the anchor cable is destroyed by blast, the overall extension of the anchor cable can be improved by increasing the slip between the anchor and the cable body. Therefore, in terms of overall extensibility, resin type 4 is better than resin type 2 as the bonding medium of anchorage.

2）Anchor pipe

Anchor pipe has many effects on the anchoring performance of bond-type anchorage. In this test, the thickness of anchor pipe and the length of anchor pipe thread are mainly studied. N5~6 group, the spiral steel pipe with the external diameter of 22 mm and internal diameter of 15 mm and BFRP bars are selected for bonding. In group N5, slip occurs along interface the steel anchor pipe. Two specimens in N6 group also slip along interface, this is because when the tensile load imposed by the jack gradually increases, the friction force and chemical bonding force of the interface between the bonding medium and the steel pipe gradually become weaken with the deformation of the material until the interface is damaged. In this process, the BFRP bars do not fail. The steel pipe fracture appeared in the third specimen in group N6, as shown in Figure 5(c). This is because only 1mm thickness thread has been processed within 8cm of both ends of the steel pipe in the third anchor cable, and no thread is set in the middle section of the steel pipe. When the steel pipe is bonded, the thickness of the adhesive medium at both ends of the steel pipe is slightly greater than that at the center of the steel pipe. This causes the shear strength of the adhesive medium at the end and the center to be different, which is not easy to be continuously cut and is not easy to form slip damage. However, the third anchor cable in N6 finally has failed due to steel pipe fracture, which indicates that the steel pipe with external diameter of 22mm and internal diameter of 15mm is not strong enough, which affects the anchoring performance of the cable. Therefore, the thickness of bond-type anchor pipe has the minimum effective requirement. Specimens in N7 and N4 have the same failure mode of blasting bar, which indicate that its anchorage performance is reliable. But the average ultimate bearing capacity of the specimens in N7 which is three-cable is slightly smaller than that of group N4, indicating that the reduction of thickness of steel tube has a negative effect on the ultimate bearing capacity of BFRP.

3）Number of bars

Comparing specimen 9 with specimen 10 which are anchor cables with the three BFRP bars, they have the same bearing capacity of 389.61kN, and all of them had burst failure. But the average ultimate bearing capacity of a single BFRP bar is only 129.86kN which is lower than average bearing capacity of single cable of specimens 2 and 4. This is because there is a "short plate effect" when multiple BFRP bars are loaded at the same time. When one of BFRP bars fails first, the tensile load of the other two BFRP bars instantly exceeds the ultimate tensile strength of the BFRP bars, and all the three BFRP bars break. So, the ultimate bearing capacity of the cable is controlled by the BFRP bar with the lowest strength.

4）Form of anchorage

The reinforcement of specimen in N7 has burst. But the core-pulling damage occurs in specimens in N8 which is cut thinner in order reduce the retardation of shear. The test results show that the ultimate bearing capacity of N7 is higher with 6.58kN than that of N8. So cutting a single anchor cable thinner will reduce the bearing capacity, not reducing the retardation of shear.

5）Anchoring length

According to the results of test, it is known that there is an effective anchorage length, the ultimate bearing capacity of the specimen will not be improved by increasing the anchoring length which is beyond the effective length. In this test, the anchoring lengths of single anchor cable and three anchor cables are respectively 300mm and 400mm. The thinner cutting of the BFRP bars results in the reduction of the bond area of the anchoring section and the cross section of the reinforcement material. The core pulling failure of the reinforcement material occurs due to the insufficient actual anchoring length of the single anchor cable, and the anchoring length of the three anchor cables after the cutting is still greater than the effective anchoring length. So, in the test, the anchoring length of 400mm for three anchor cables can be optimized and shortened to find the optimal value of anchoring length.

## 4 Conclusions

Through the tensile test of bonded anchorage system of BFRP bar, it can be seen that bonded anchorage system is ideal anchorage system. Four failure forms of anchoring occur during the tensile test and the most ideal failure form is to blast the bar, which suggests that BFRP bars play a dominant role. The anchoring performance of the system is affected by many factors such as bonding medium, anchoring pipe, anchoring length and anchoring form. For the bonded anchorage system, the bonding force of epoxy resin adhesive as the bonding medium is mainly affected by its elastic modulus and shear strength. When the bonding medium adopts epoxy resin adhesive with small elastic modulus, high shear strength or similar elastic modulus to BFRP, the ultimate bearing capacity of the cable is larger. For this test, the anchorage performance of the steel adhesive is the best. The influence of anchor pipe thickness and material on the performance of anchoring system is also analyzed in the test. According to the test, it is known that the steel pipe with external diameter of 22mm and internal diameter of 15mm is not strong enough, the performance of 40Cr is better than that of 45 steel. As for the anchoring form, the shrinking neck of the reinforcement in middle cannot reduce the shear lag effect of BFRP, and can not improve the ultimate bearing capacity of the cable, and easily lead to the core pulling failure of the reinforcement due to the shrinking neck. And finally the anchorage length is insufficient, and its bearing capacity can be reduced. In the test, the anchoring length for three anchor cables can be optimized can be optimized between 300mm and 400mm. When multiple bundles of reinforcement act together, the average ultimate bearing capacity is smaller than that of a single cable due to the efficiency reduction caused by the short plate effect. In this test, the anchoring efficiency coefficient is around 0.9. During the experiment, the stress-strain relationship under different media has not been analyzed, and the constitutive model could not be established to further analyze the mechanical properties of the adhesive anchorage. In the analysis of its influencing factors, insufficient measurement data is also an aspect to be further improved.

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## REFERENCES

[1] *B Huang, Y Yin, J Tan,* Risk assessment for landslide-induced impulse waves in the Three Gorges Reservoir, China. Landslides (Springer), **vol.16**, no.3, Jan. 2019, pp. 585-596.

[2] *S A Benz, P Blum,* Global detection of rainfall-triggered landslide clusters. Nat Hazard Earth Sys, **vol.19**, no.7, Mar.2019, pp.1433-1444.

[3] *GY Fu, R Deo, J Jian, Jayantha Kodikara,* Failure assessment of reinforced rock slopes subjected to bolt corrosion considering correlated multiple failure modes. Computers and Geotechnics **vol**.132, 2021: 104029.

[4] *JF Zhao, KH Mei, J Wu,* Long-term mechanical properties of FRP tendon–anchor systems - A review, Construction and Building Materials, vol.230, 2020：117017

[5] *C Zhu, MC He, XH Zhang, ZG Tao, Q Yi, LF Li,* Nonlinear mechanical model of constant resistance and large deformation bolt and influence parameters analysis of constant resistance behavior, Rock Soil Mech **vol.**42, no.07, 2021 pp. 1911-1924. (In Chinese)

[6] *M He, SL Ren, HT Xu, L SL Luo, ZG Tao, C Zhu,* Experimental study on the shear performance of quasi-NPR steel bolted rock joints. Rock Mechanics and Geotechnical Engineering, **vol**. 15, Jau,2023, pp:350-362

[7] *ZG Tao, Q Geng, C Zhu, MC He, H Cai, SH Pang, XZ Meng,* The mechanical mechanisms of large-scale toppling failure for counter-inclined rock slopes. Journal of Geophysics and Engineering **vol**.16, 2019, pp.541–558.

[8] *F Elgabbas, E A Ahmed, B Benmokrane,* Physical and mechanical characteristics of new basalt-FRP bars for reinforcing concrete structures, Construction & Building Materials, **vol.95,** Jul, 2015, pp.623-635.

[9] *H Wu, ZX Wu, H Lei, TW Lai,* Application of BRFP New Type anchor cable material in high slopes against earthquakes. Advanced Civil Engineering, **vol**.2021, Feb 2021, pp. 1-19.

[10] *CT Wang, H Wang, YF Zhang, WM Qin, H Min,* Model test and numerical simulation study on the mechanical characteristics of the anchored slide-resistant pile for stabilizing the colluvial landslide. Rock Soil Mech, **vol.** 41, no.10, 2020, pp. 3343-3354. (In Chinese)
[11] *W Zhao, H Wang, Y Chen, Y Hu,* Laboratory and field tests use of BFRP anchor bolt in supporting soil slope. Journal of Engineering Geology, **vol**.24, no.05, 2016, pp.1008-1015. (In Chinese)
[12] *J W Schmidt, A Bennitz, B Täljsten, P Goltermann, H Pedersen,* Mechanical anchorage of FRP tendons-A literature review, Construction & Building Materials, **vol**.32, 2012, pp.110-121.
[13] *A Al-Mayah, K Soudki, A Plumtree,* Novel anchor system for CFRP rod: finite-element and mathematical models. Journal of Composites for Construction, **vol.**11, no.5, 2007, pp:469-476.
[14] *G P Terrasi, C Affolter, M Barbezat,* Numerical Optimization of a Compact and Reusable Pretensioning Anchorage System for CFRP Tendons. Journal of Composites for Construction, **vol.**15, no.1, 2011, pp.126-136.
[15] *KH Mei, ZT Lv, JW Zhang,* Experimental Study of CFRP bars Bonded Anchorage and Its Application Analysis on Real Bridge, Journal of China Highway**, vol**.29, no.01, 2016, pp.53-60. (in Chinese)
[16] *H Chen, YJ Chen, B Xie, PK Wang, LN Deng,* Analysis of anchoring performance of Bonded wedge anchorage of CFRP bars, Journal of Guangxi University (Natural Science Edition), **vol**.44, no.03, 2019, pp.798-807 (in Chinese).
[17] *B Zhang, B Benmokrane, A Chennouf,* Prediction of Tensile Capacity of Bond Anchorages for FRP Tendons. Journal of Composites for Construction, **vol.**4, no.2, 2002, pp.39-47.