Study on shear stress distribution of glass fiber reinforced polymer soil nail in foundation pit support pullout test

Xiang-li Wang1, Chun-gang Deng2, Yue Qin3*, Gang Shen3 and Chao Chen4

1China Highway Engineering Consulting Group Co., Ltd, Beijing, 10089, China
2Wuhan Port and Shipping Development Group Co., Ltd., Wuhan, Hubei, 430403, China
3School of Civil Engineering and Architecture, Wuhan University of Technology, Wuhan, Hubei, 430070, China
4Agile Real Estate Property Co., Ltd., Guangzhou, Guangdong, 510623, China
*e-mail: yqin@whut.edu.cn

Abstract. To solve the problem of reinforcement bolt corrosion caused by the safe stability problem in geotechnical engineering, and engineering red line in geotechnical engineering, the fiber-reinforced composite material is gradually applied to the civil engineering field, and glass fiber reinforced polymer has high strength, light quality, corrosion resistance, the advantages of easy cutting has been widely used. In this paper, the stress distribution and deformation characteristics of GFRP anchors in the process of pipe pulling are studied through the excavation tube pulling test of GFRP anchors in actual working conditions. Secondly, the performance difference between the GFRP bolt and reinforced bolt in foundation pit engineering is analyzed. The results show that the axial force of the GFRP anchor bolt decays fastest near the anchor head, and decreases with the increase of anchor depth. The shear stress distribution is convex. With the increase of the drawing load, the shear stress peak will increase, and the influence range of the shear stress will also increase. With the increase of the load, the shear stress peak of the GFRP bolt and the anchor solid will shift to the position far away from the anchor head.

1. Introduction

With the continuous development of China's economy, the infrastructure is also in rapid progress, and engineering geological problems also often occur. Geotechnical anchor rod anchor technology is a construction technology that has been widely applied in the geotechnical engineering field, especially in the process of foundation pit supporting, the rock mass to make use of embedded in the soil layer anchor reinforcement, namely by perfusion slurry external structures and rock mass by closely connecting bolt, and grouting mortar and anchor rod anchor solid and the surrounding soil is formed by the friction, when the friction is greater than the soil of the limit fracture load of the instability occurs, it can guarantee the stability of rock mass.

Reinforced bolt is widely used in foundation pit support engineering nowadays, and the reinforced bolt is also known as the "time bomb" in engineering because of its easy corrosion characteristics. In order to ensure the long-term safety of engineering construction, it is urgent to study the GFRP bolt. Therefore, it is necessary to conduct in-depth research on the performance of GFRP bolts in the process of foundation pit supporting, to provide a theoretical basis for the practical application of GFRP bolts in foundation pit engineering.
The basic mechanical properties, deformation properties, and failure characteristics of the GFRP bolt can be studied by drawing tests. For example, under the same test conditions, the average nominal bond stress of reinforcement was greater than that of GFRP bars, while the slip of GFRP bars relative to the concrete surface was greater than that of reinforcement bars [1,2]. Under sufficient constraints, concrete strength had no obvious influence on the shear strength and failure mode of GFRP bars compared with steel bars [3,4]. In order to give full play to the material advantages of the GFRP bolt, higher strength mortar should be perfused. On this basis, used the modified pull-out test model to conduct an experimental study on the bonding mechanism of GFRP bolt anchored by high strength mortar [5]. measured the slip of GFRP anchor bolt and the ultimate bearing capacity of external anchorage through the self-designed tensile test of large indoor components, and analyzed the external anchoring performance of GFRP anti-floating anchor bolt [6]. On this basis, we combined with the fiber grating sensing technology, field experiments were carried out to study the stress and strain state of GFRP bolt at work, and compared with the reinforcement bolt support case, to provide data support and theoretical basis for the future field use of GFRP bolt.

2. Field study
The site of this field test is located in the E1F1 section of Dongfeng Electric Vehicle construction site, Caidian District, Wuhan City. The anchor layer of the GFRP bolt test is mainly plain fill. The GFRP bolt with a length of 13m and a diameter of 25mm is selected. The surface of the bolt was polished and the strain gauge was pasted. After the preparation of the specimen of the bolt was completed, the GFRP bolt and the grouting pipe were tied and put into the hole together to wait for mortar pouring.

The hollow hydraulic jack used in this test is an HC-30 type anchor puller produced by Haichuang Hi-Tech Company. Before the test, the bearing surface of the jack at the drawing point should be leveled to make the counterforce of the jack evenly distributed in the soil during the drawing process. The drawing test shall be conducted following the Technical Specification for Monitoring and Monitoring of Bolts (JGJ/T 401-2017) [7]. The GFRP bolt was loaded by stages, and the load classification was calculated according to 10%, 30%, 50%, and 60% of the ultimate drawing load of the bolt, that is, the load was carried out according to 12kN, 36kN, 60kN and 72kN, and the loading time was maintained for 2 minutes each time, and the dial gauge reading was recorded. Field instrument arrangement is shown in figure 1.

Figure 1. The layout of the field pull-out test instrument.
3. Results analysis

3.1. Study on Q-S curve of GFRP bolt
As can be seen from figure 2, the Q-S curve of the GFRP bolt in the drawing process is relatively flat without an obvious turning point, which indicates that the GFRP bolt material has no obvious elastic and plastic stage. Secondly, the displacement of anchor head of GFRP bolt was compared with that of Paper [9][25 mm diameter under different drawing load can be found: comparison between the displacement of the steel anchor head in the case of the same displacement under the condition of GFRP bolt the need of load value is less than what the steel anchor load values, the reason is that compared to the same diameter GFRP bolt and steel bolt, the elastic modulus of GFRP bolt is far less than the elastic modulus of steel. This experimental phenomenon is associated with the results obtained by indoor GFRP bar and bar drawing test are consistent [2].

![Figure 2. Q-S curve of GFRP bolt in the drawing process.](image)

3.2. Research on axial force distribution of GFRP bolt
In this paper, a strain gauge was used to collect the strain variation of five strain gauges pasted on the GFRP anchor rod. Through Equation (1), The axial forces of different parts of the GFRP bolt body can be obtained.

\[ N = A \cdot \Delta \varepsilon \cdot E_S \]  

(1)

where \( A \) is the cross-sectional area of the GFRP anchor bolt, \( \Delta \varepsilon \) is the collected micro-strain, \( E_S \) is the elastic modulus of the GFRP bolt.

As shown in figure 3, the distribution law of axial force along the rod body in the drawing test is the same, and the axial force is mainly distributed around 0–4m. With the increase of the depth of the anchor bolt, the attenuation rate of axial force is also slowing down. In the part after 4m of anchor head, the change of axial force is almost in a stable state. This shows that in the process of drawing, the cohesive force of bolt anchor from head to tail transmission, therefore, the nearer the anchor head anchor rod body of the axial force, the greater the deformation, the greater the anchor solid friction and mechanical bite with GFRP bolt is, the greater the axial force of the attenuation rate will present a fast after a slow first rule, the anchor rod body axial force tend to be stable. According to the laboratory model test, there is a critical bond length of the GFRP bolt, and the axial force decreases rapidly with the increase of embedded depth, and the decreasing trend shows the same exponential curve form [5].

On the other hand, according to Figure 4, it can be known that through with the field pull-out tests of 25mm diameter reinforced bolt were compared and analyzed [9]. It can be seen that the axial force...
variation trend of GFRP bolt and reinforced bolt is similar, and the axial force attenuation rate slows down until stable with the increase of bolt depth. The main distribution range of the axial force is about 0~4m. However, compared with the reinforced bolt, the axial force of the GFRP bolt body is larger than that of the reinforced bolt at the same position and under the same load. The reason is that the elastic modulus of the GFRP bolt is smaller than that of the steel bolt, so the bite force between the GFRP bolt and mortar is smaller, and the resistance of the bolt body is also smaller. The axial force attenuation rate of the GFRP bolt is slower than that of the steel bolt.

![Figure 3](image1)

**Figure 3.** Distribution curve of GFRP bolt axial force along rod body: (a) 1#GFRP anchor; (b) 2#GFRP anchor; (c) 3#GFRP anchor.

![Figure 4](image2)

**Figure 4.** Comparison of axial force of GFRP bolt and reinforced bolt under 60 kN.

### 3.3. Study on shear stress distribution of GFRP bolt

The load transfer path of the GFRP bolt anchorage system is from the anchor rode to the anchor solid and then to the foundation pit soil. The failure modes can be summarized into the following three cases: (1) shear failure of the interface between bolt and grouting body due to insufficient bond strength; (2) The interface between the grouting body and the soil is damaged due to insufficient shear strength; (3) The GFRP anchor bolt is damaged due to its insufficient strength. According to the balanced condition of the force, the average shear stress of the bar is calculated by measuring the difference of the axial force between the two adjacent points of the bar [9], as shown in Formula (2):

$$\tau_i = \frac{N_i - N_{i+1}}{\pi d \Delta l}$$  \hspace{1cm} (2)
where \( N_i \) is the axial force of the bolt body at point \( i \), \( N_{i+1} \) is the axial force of the bolt body at the point \( i+1 \), \( d \) is the diameter of the anchor rod body, \( \Delta l \) is the distance between two adjacent measuring points.

The shear stress of the anchor bolt is measured according to the related fiber grating technology [10-13], according to Figure 5, the shear stress between the GFRP bolt body and the anchor solid increases sharply from zero to the maximum value at the anchor head. After reaching the peak value, the shear stress presents an exponential decay with the increase of the distance from the anchor head, and finally approaches zero. At the same time, the peak shear stress of the GFRP bolt is at 0.5m and 1.5m, respectively, which is consistent with the calculated peak stress position of 0.5m–1.5m.

On the other hand, in the drawing process, the distribution of shear stress about GFRP bolt is "convex", as the drawing load increases, by the increase of the peak shear stress, the influence of shear stress increases. It is named with the increase of drawing load shear stress zero-point moves away from the position of the anchor head. In addition, the shear stress curve shows that shear stress of "convex" vertex as load increases continuously move to the right, it shows that in the process of drawing, with the increase of load, the GFRP bolt and anchor solid shear stress peak value will shift to stay away from the position of the anchor head.

![Figure 5. The distribution curve of GFRP anchors shear stress along the rod body.](image)

4. Conclusions

Based on the analysis of field test data, this paper studies various factors of stress distribution in the process of GFRP bolt drawing, and draws the following conclusions:

1) By comparing with the reinforced bolt with a diameter of 25mm, it is found that there is no obvious turning point in the Q-S curve of the GFRP bolt in the drawing process, and the displacement of the GFRP bolt's anchor head is larger than that of the reinforced bolt under the same load.

2) During the drawing process, most of the axial force of the GFRP bolt is distributed around 0–4m, and the axial force of the GFRP bolt body decreases the fastest near the anchor head, and the axial force attenuation rate decreases with the increase of anchor depth.

3) In the drawing process, the shear stress between the GFRP bolt body and the anchor solid increases sharply from zero to the maximum value at the anchor head, and then decreases exponentially with the increase of the distance from the anchor head after reaching the peak value, and finally approaches zero. Its shear stress peak is not at the anchor head, and the real shear stress peak should be between 0.5-1.5m. The shear stress distribution of the GFRP bolt in the process of drawing is convex. With the increase of the drawing load, the shear stress peak will increase, and the influence range of the shear stress will also increase, and with the increase of the load, the shear stress peak of the GFRP bolt and anchor solid will shift to the position far away from the anchor head.
In this paper, the stress distribution and deformation characteristics of GFRP bolt in the process of pipe pulling in the foundation pit are studied through the excavation pipe pulling test of the GFRP bolt, which provides a favorable basis for ensuring the stability of rock mass in the process of foundation pit supporting by GFRP bolt.

Of course, in the process of drawing, due to the complexity of the quantitative relationship between the variation of the bolt drawing load, the variation of the bolt axial force, and the deformation of the soil around the anchor solid, it is still necessary to make further in-depth research.

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