Experimental study on grouting mortar GFRP anchor rod pulling test

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Abstract. Owing to that the anchor rod is easy to be cut through and maintains good mechanical properties, it is widely used in reinforcement engineering. In this paper, the performance of grouted mortar GFRP anchor rod was studied through laboratory experiments in terms of the ultimate pull-out resistance, stress change, bolt deformation, and surrounding soil deformation. The results showed that the pull-out force suddenly decreased when it reached the ultimate pull-out load, the displacement of the anchor head increased sharply, and the axial force on the anchor rod body decreased exponentially with the distance from the pulling point. Through these regulars, it can provide a theoretical basis for the application of anchor rods in the actual foundation pit engineering.

1. Introduction

In order to solve the safety and stability problems caused by the corrosion of steel bars, fiber-reinforced polymer (FRP) [1-2] used in civil engineering. However, among these compound materials, glass fiber reinforced polymer (GFRP) had been widely used because of its high strength, lightweight, impact resistance, corrosion resistance, good dielectric properties, easy cutting, and low cost [3-6]. In the process of pull out the anchor rod, the material of the bolt itself, the anchorage body, and the pulling out of the anchor rod are all prone to be failure [7-10]. But GFRP anchorage body is located in the soil, the latter two failures are difficult to observe, therefore most experiments were concentrated on the pulling process of the anchor rod stress distribution regular [11-12], few of them pay attention to the deformation state of the surrounding soil [13]. To better understand the performance of GFRP anchor rods in foundation pit support, we have to analyze the stress distribution of GFRP anchor rods and the deformation state of the surrounding soil simultaneously. Therefore, this paper had been improved the traditional laboratory experimental method and studied the stress distribution of GFRP anchor rods and the deformation state of the surrounding soil at the same time. The research results can provide some construction suggestions and theoretical basis, which could be conducive to the application of GFRP anchor rod in foundation pit support.

2. Experimental process

Due to the long period of this experiment, to greatly shorten the experimental period, it is necessary to arrange the experimental process reasonably. The preparation stages of this experiment were mainly...
divided into five parts: soil sample processing (1 month); tracer particles processing (7 days); stick strain
gauge (1 day); reserved holes (1 day); grouting curing (7 days). In order to improve the experiment
efficiency, which has to make full use of the time. In the stage of soil sample processing, the tracer
particles processing and stick strain gauge can be carried out at the same time. The experimental process
mainly includes the following steps: (1) Placed three 30mm thick hollow iron blocks at the pull opening
to prevent the anchorage body from withstanding the jack after being pulled out; (2) Anchorage
installation. After the jack is installed, put the anchorage on. In order to force the anchor rod quickly,
the pressure can be increased appropriately to make the jack piston and anchor closely contact; (3)
Reaction frame installation. Place the reaction frame floor on the soil, and then connect the reaction
frame to the box with threaded rods and hexagonal nuts; (4) Wire connection. Connect the dynamic
strain gauge wire in the order of labels on the wires [14-15] of strain gauge; (5) Particle Image
Velocimetry acquisition system installation; (6) Displacement measuring device installation; (7) Load
overburden pressure; (8) Turn on the Cyclic Delay Diversity industrial camera and the acquisition
frequency is once a second. Turn on the displacement meter and collect the displacement date twice a
second. Open the dynamic strain gauge analysis software, and start collecting after leveling; (9) Start
the pulling experiments and applied pressure on the anchor rod at 1kN/min. When the anchor rod was
pulled out, continue loading for some time until the pulling force does not change anymore within 10
minutes, then the test can be terminated. The experimental device and arrangement are shown in figure
1.

3. Results analysis

3.1. Anchor rod pulling results analysis

It can be seen from figure 2(a) that the pulling force was loaded once a minute, with 1kN each time.
When the force increased to 35kN, the pulling force suddenly dropped to 24kN, continue loading force,
the pulling force changed slowly and remains at about 24kN. As shown in figure 2(b), in the process of
pulling the GFRP anchor rod, the anchor head displacement was growing exponentially, and without
obvious elastic and plastic change points. On the other hand, it can be seen that before 35 mins (the time
point of the pulling force sudden change), the anchor head displacement changed slightly and the slope
of the fitted line is 0.08. After 35mins, the anchor rod displacement increased sharply and the slope of
the fitted line is 0.85, which changed were more obvious.

From figure 3(a) know that the process of pulling the anchor rod can be divided into two stages. In
the first stage, the strain increased of the anchor rod along with the pulling force constantly increased,
and the farther away from the anchor head, the smaller the strain. In the second stage, after reaching the
ultimate pull-out resistance, the strain points 5, 6, and 7 near the GFRP anchor head strain suddenly
dropped, and point 7 was most obvious. And the strain points 1, 2, 3, and 4 far away from the GFRP
anchor head the strain were no longer changed, and all strain in the balanced state. To better explain the
axial force distribution condition of the anchor rod at different stages, selected the anchor rod in three
different pulling force conditions of 27kN before the anchor rod failure, 35kN of the limit state, and 24kN after the anchor rod was the failure to analysis.

Figure 3(b) shows the anchor rod axial force distribution along the anchor rod under three pulling force conditions, and the axial force on the anchor rod body decreased exponentially with the distance from the pulling point. From the axial force change degree know that the forces of the anchor rod in the failure state were smaller than before failure and larger than after the damage. The results show that after the anchor rod pulled out the axial force became flat and the stress was no longer concentrated on the anchor head, and gradually slid toward the tail of the anchor rod.

3.2. Surrounding soil deformation analysis

For quantitative analysis of the deformation regular of the surrounding soil under the failure condition of the anchor, rod pulled out, this paper analysis the deformation of the surrounding soil along the length and vertical direction of the anchorage body.
### 3.2.1. Surrounding soil deformation analysis

In this paper, the soil deformation along the vertical height 300mm of the anchorage body was selected to study. The soil deformation in the pulling process of anchor rod along the anchorage body vertical direction shows in figure 5, where the ultimate state was represented by the solid line, and the remaining states were represented by the dashed line.

Taken overall, the soil deformation curve is convex along the vertical direction of the anchor, which means that the deformation position gradually increased from the reserved hole (vertical height 50mm) to the direction of mortar permeation, then reached the peak deformation, and finally decreased in the direction away from the anchorage body. Moreover, it can also be found that before reached to the ultimate state, the surrounding soil deformation is very small and decreased as it moved away from the anchorage body. When the critical state was reached, the surrounding soil deformation of the anchorage body suddenly increased, and the pulling force in the residual state was much less than the critical state, but the deformation of the soil around the anchorage body is greater than the soil displacement.

### 3.2.2. Soil deformation in the length direction of the anchorage body

Based on the above analysis, it can be seen that the soil deformation at the boundary of the anchorage body is relatively large, and there was an obvious change in the vertical direction. Therefore, the following content will be based on the deformation of soil at 80mm in the vertical direction of the anchorage body along the length of the anchorage body. According to the three different stages of anchorage body pulled-out failure conditions, the soil deformation diagram along the length direction of the anchorage body was drawn as shown in Figure 6.
Figure 6 show that before reached to the critical state, under the same pulling force, the soil deformation around the anchorage body along with the pulling points gradually decreased to the bottom at the end of the anchorage body. At the same time, as the pulling force increased, the surrounding soil deformation also increased, which is manifested as a step-by-step transmission along the anchorage body length direction.

Figure 6. Soil deformation in the length direction of the anchorage body.

4. Conclusion
To better understand the performance of GFRP anchor rods in foundation pit support, this paper studied the stress distribution regulars of the GFRP anchor rod during the pulling process and the deformation regulars of the soil around the anchorage body through the laboratory. The following conclusions can be drawn:

(1) It can be found that during the anchorage body pulling failure, when the pulling force reached to ultimate pull-out resistance, the pulling force suddenly decreased and the anchor head displacement increased. Continue to pull, the pulling force fluctuation was small, and maintain a fixed value in the end. But compared with the suddenly changed load, the degree of displacement increased was smaller under the same force. Moreover, the displacement of the GFRP anchor rod head decayed exponentially, and there was no obvious elasticity and plasticity point.

(2) The GFRP anchor rod pulling process can be divided into two stages. In the first stage, as the pulling force increased, the strain of the anchor rod constantly increased, and strain the farther away from the anchor rod the smaller it was. In the second stage, when the pulling force increased to the ultimate force, the strain at the strain point near the GFRP anchor rod head suddenly dropped, and the strain was no longer changed when far away from the GFRP anchor rod head, all strain reached to a balanced state in the end.

(3) During the anchorage body pulling failure process and along the anchorage body vertical direction, the soil deformation position gradually increased from the reserved hole to the direction of mortar permeation, then reached the peak deformation, and finally decreased in the direction away from the anchorage body.

(4) During the anchorage body pulling failure process and along the anchorage body length direction before reached to the critical state, under the same pulling force, the soil deformation around the anchorage body along with the pulling points gradually decreased to the bottom end of the anchorage body. At the same time, as the pulling force increased, the surrounding soil deformation also increased.

Therefore, according to the regulars of the GFRP anchor rod pulling process, the other factors affecting the pulling process can be further discussed to ensure the safety of foundation pit support.

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