Model experimental study on GFRP anchor reinforcement and soil deformation

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Abstract. Due to the application of reinforced anchor technology in soil reinforcement, the anchor after long-term use will have serious corrosion, which greatly affects the safety of the engineering structure, leading to engineering accidents. In this paper, GFRP (Glass Fiber Reinforced Polymer) anchor is used instead of reinforced bolt for the pull-out experiment. In order to investigate the deformation of the soil around the GFRP anchor solid in the process of drawing, this paper improves the traditional indoor model pull-out experiment of GFRP anchor and introduces PIV (Particle Image Velocimetry) technology and its application to the analysis of soil deformation in the process of drawing.

1. Introduction
Geotechnical anchor technology is a construction technology widely used in the field of geotechnical engineering, especially in the shoring work of foundation pits. In fact, many engineering accidents still occur when the technology is applied to soil reinforcement, such as landslides, instability of artificial slope, and tunnel surrounding rock [1-6]. This is because the reinforced anchor is widely used in engineering. In the underground corrosive environment, if not taken enough antitrust treatment, the anchor rod will be seriously corroded after long-term use, which greatly affects the safety of the engineering structure [7]. Given the above problems, scholars are looking for a new material to replace the reinforced anchor in geotechnical anchoring engineering. GFRP anchor has the advantages of high strength, lightweight, impact resistance, corrosion resistance, good dielectric property, and easy cutting, which is an ideal substitute at present [7-9].

Most of the field pull-out experiments focus on the stress of GFRP anchors and anchoring solids [10-11]. To better control the effect of complex factors on the test results, most scholars will use the indoor model experiment to discuss the stress distribution law of GFRP anchor in the process of drawing, but rarely study the deformation law of soil around the anchor in the process of drawing. To explore the deformation of the soil around the GFRP anchor in the drawing process, the traditional indoor model pull-out experiment of GFRP anchor is improved, and the deformation of the soil around the GFRP
anchor in the drawing process can be analyzed by PIV technology.

2. Design of test model box

2.1. Box body

The model box is mainly composed of three parts: box body, grouting joint, and reaction frame. Figure 1 shows the schematic of the box body. The front side of the box body is made of transparent plexiglass with a thickness of 20 mm. The transparency of plexiglass is high, and the transmittance can reach more than 92%, which is convenient for the camera to shoot continuously. Secondly, the quality of plexiglass is about 1/2 less than that of non-plexiglass with the same thickness, which makes it easier to install and move the model box. Its toughness is more than 10 times higher than that of non-plexiglass, and it is not easy to break when subjected to extrusion and impact. The other sides of the box were made of 6 mm steel plates, and there are 1/4 round holes at the bottom and middle of the right steel plate, with a diameter of 55 mm. There are 8 M6 bolt holes evenly distributed around the two 1/4 round holes. An M20 drain hole is attached at the bottom of the left steel plate.

2.2. Grouting joint

Figure 2 is the schematic diagram of the grouting joint. The purpose of the grouting joint is to ensure that the mortar can be smoothly poured into the reserved hole in the grouting process and to ensure that the mortar does not leak from the grouting port when the grouting pressure rises. The application method is as follows: First, the GFRP anchor is extended into the grouting joint, 5 mm silica gel tablets are inserted into the two wings of the joint, and then screw the bolts into the threaded holes on the two wings, so that the upper and lower splints clamp the silica gel tablets and the anchor. It can not only protect the GFRP anchor from being crushed but also ensure that the mortar will not seep out from the gap between the anchor and the joint. Next, screw the grouting joint into the corresponding threaded hole of the box. Finally, the grouting pipe is screwed on the grouting port to carry out grouting.
2.3. Reaction frame

The reaction frame is composed of three parts, there are the upper steel plate, the lower steel plate, and the M20 threaded rod, respectively. The device is shown in Figure 3. The size of the upper steel plate is length × width × height = 375 mm × 100 mm × 5mm. To prevent the upper steel plate from bending when the jack applied the load, two steel bars with a diameter of 20 mm were cross-installed to enhance the bending rigidity of the steel plate. The size of the lower steel plate is length × width × height = 590 mm × 240mm × 5mm, and its size is slightly smaller than that of the bottom plate of the box body. Three steel bars with a diameter of 20 mm and a steel plate with a thickness of 6 mm are arranged on the plate to prevent the steel plate from being stuck in the box due to deformation after the jack is loaded. Finally, threaded rods can be used to connect the upper steel plate with the box body. When the jack is used to apply the load, due to the upper steel plate is limited to rise by threaded rods, the load of the jack will react to the lower steel plate, and then exert pressure on the soil.

![Figure 3. Schematic diagram of reaction frame.](image)

2.4. Grouting device

The grouting device used in this experiment is the combination of an air compressor and a self-designed mortar cylinder. The grouting device can press the mortar in the mortar cylinder into the reserved hole of the box body by controlling the air pressure of the air compressor. Because the mortar cylinder is sealed, it can be considered that the air pressure displayed by the air compressor is the grouting pressure at this time. The inner diameter of the mortar cylinder is 105 mm, the height is 290 mm, the outer diameter of the bottom and top of the cylinder is 135 mm, and the outer diameter of the cylinder cover is also 135 mm. The cover can just cover the top of the mortar cylinder, which is convenient for later sealing. Secondly, there are 8 M6 threaded holes on the top and cover of the cylinder. After pouring the mixed mortar, the bolts can be screwed in for sealing. Finally, there is a grouting hole with a diameter of 20 mm at 2 mm above the bottom of the cylinder, and a valve with the same diameter is equipped, which can be used to control the grouting process. Figure 4 shows the schematic diagram of the grouting device.

![Figure 4. Schematic of grouting device.](image)
3. Introduction of soil displacement test method
In the field of fluid mechanics, researchers often use the velocity-measuring procedure (i.e. PIV technology), to calculate the instantaneous velocity of fluid by tracking the marked particles in motion. The principle is to assume that the velocity of the particle to be tracked approximately represents the fluid velocity in the small area in which it is located, then select the reflective particles to be placed in the flow field, use the high-speed camera to capture the trajectory of the particles. Next, use the image processing technology to calculate the displacement changes of the particles in each picture. Since each photo has a corresponding time to it, the velocity of particles can be calculated by displacement and time.

In recent years, many scholars have successfully used PIV technology in geotechnical model experiments, making it possible to observe the internal deformation of soil. White [12-13] developed a PIV software suitable for geotechnical tests and proved the performance of the PIV system in soil deformation measurement. Liu [14] used PIV technology to analyze the soil deformation around uplift plate anchor in sand and studied the effects of particle size, soil density, and anchor embedment depth on soil deformation. Yuan [15] used PIV technology to calculate the displacement field of soil in the deflection measurement experiment of a laterally loaded pile and used finite element analysis to verify the accuracy of PIV technology. To sum up, PIV technology has been more mature in geotechnical tests. Using this technology can easily see the internal deformation of the soil, which helps to provide a more intuitive test phenomenon for model experiments.

The PIV system mainly includes marked particles, light source, high-resolution high-speed camera, computer, and image processing analysis software. The camera used in this experiment is a CDD (Charge Coupled Device) industrial camera, which has the characteristics of stability, reliability, easy installation, and long working time. Taking the GFRP anchor pull-out experiment with plain soil as an example, the tracer particles can be selected as calcareous sand with a particle size of 4~5 mm, which is slightly larger than that of plain soil, because calcareous sand is more reflective than plain soil. Before the test, the calcareous sands were dyed into two colors of green and red. After mixing, the calcareous sands were evenly and randomly distributed at the junction of plexiglass and soil, because the brightly colored and reflective particles are easier to capture by the camera. At the same time, in order to facilitate the size calibration in the image processing process, the grid was manually divided. The light source is two LED photography lights, which can provide enough brightness to make the tracer particles more obvious in the shooting process. The tripod can adjust the position, height, and angle of the industrial camera before the test to facilitate the acquisition of suitable images. Then set the appropriate shooting interval and storage path through the supporting computer software. Finally, use image processing technology to convert the collected images into digital information and obtain relevant test data. The PIV image acquisition system is shown in Figure 5.

4. Conclusions
To investigate the deformation of the soil around the anchoring solid during the GFRP anchor drawing process, a quarter model experiment was designed. This paper mainly introduces the dimensions and
design basis of the box body, grouting joint, and reaction frame of the test model box. It also describes the principle and application method of the indoor grouting device. Finally, the principle of PIV technology is explained, and the feasibility of applying PIV technology in this experiment is verified by the research status in the geotechnical field. The research in this paper has important guiding significance for the application of geotechnical anchor technology in the shoring work of foundation pits. GFRP anchor makes up for the shortage of reinforced anchor, and the application of PIV technology can monitor the soil displacement more intuitively. However, there are limitations in the model experiment, so it is still necessary to further study the soil displacement in the field anchor pull-out experiment and quantify the relationship between them.

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