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# Experimental Study on Ultimate Pullout Capacity of Soft Rock Tension-Type Anchor Rods

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**ABSTRACT:** This study investigates the factors influencing the ultimate bearing capacity of tension-type anchor rods in soft rock through experimental research on the ultimate pullout capacity. It provides a theoretical basis for the design and calculation of this type of anchor rod. The experiments utilized the on-site pullout force testing method commonly used in engineering, measuring the differences in the ultimate pullout capacities of anchor rods within the same rock stratum. An analysis of the discrepancies between the experimental results and recommended values in standards was conducted to identify underlying reasons. The results indicate that the ultimate pullout capacity of anchor rods is influenced by multiple factors, and calculations based solely on recommended values from standards may be inaccurate. This study contributes to the design and construction of pullout resistance for tension-type anchor rods in soft rock, offering valuable insights for reference.

**KEYWORDS:** soft rock, shear strength, pullout test, tension-type anchor rod.

## I. INTRODUCTION

The anchor rod, as an important reinforcement structure for mining, tunneling, slopes, and hydraulic engineering, may experience fracture, sliding failure at the interface between the anchor rod and the anchoring body, and sliding failure at the interface between the anchoring body and the surrounding rock due to insufficient design, confining pressure of surrounding rock, and anchor stress loss.

The ultimate pullout force of the anchor rod in the state of instability is the core technical parameter in anchor engineering design. Effectively improving the ultimate pullout force is one of the key focuses of anchor rod technology research. Early experimental studies indicated that the main factors affecting the ultimate pullout force of anchor rods are the shape of the anchor rod, grouting technology of cement slurry, and performance of grouted anchor bodies. In recent years, innovative designs of anchor rod structures have been studied. In addition to the commonly used expansion shell anchor rods in engineering, hydraulic expansion anchor rods and inflatable anchor rods do not use grouting materials but expand the surrounding rock through the anchor rod body, relying on the frictional force at the contact surface for load-bearing capacity. There are also studies on setting up wing-shaped structures or materials with a negative Poisson's ratio on the anchor rod body to increase the axial ductility of the anchor rod body, forming energy-absorbing anchor rods suitable for large deformations in soft rock.

In engineering, to facilitate design and construction, the ultimate frictional resistance standard value between the anchoring body and the surrounding rock and soil is usually directly used to determine the ultimate pullout force of the anchor rod, while ignoring the influence of other factors.

This study conducted anchor rod pullout capacity tests on multiple groups of anchor rods in a practical deep foundation support project. Through experimental research, the differences between the frictional resistance of different rock layers and anchoring bodies and the recommended values in standards were studied, and their underlying reasons were analyzed. This study aims to provide reliable references for the design and construction of anchor rods.

## II. PROJECT OVERVIEW



The Changsha International Convention and Exhibition Center Integrated Public Transport Complex project is located on the west side of Jingui Road and the north side of Xiangmu Road in Changsha County. The nearest distance from the outer wall of the basement to the boundary is 5 meters, and the excavation depth of the foundation pit is 8.5 meters.

According to the geological survey data, the site's stratigraphy includes fill soil with a thickness of approximately 3 meters, silty clay with a thickness of approximately 4.5 meters, loess with a thickness of approximately 1 meter, fine sand with a thickness of approximately 1 meter, gravel with a thickness of approximately 1.6 meters, and moderately weathered silty sandstone with a thickness of approximately 20 meters.

The physical and mechanical parameters of the soil layers are as shown in Table 1.

Table 1. Soil and Rock Physical Mechanics Properties

name of soil and rock layers	natural unit weight (kN/m <sup>3</sup> )	Cohesion (kPa)	Internal Friction Angle (°)	standard value of ultimate frictional resistance (kPa)
Miscellaneous fill soil	18	10	10	17
Silty clay	19.2	35	15	40
Loess	18.5	15	15	35
Fine sand	20	0	26	22
Gravel	21	0	40	120
Moderately weathered silty sandstone	24	240	35	150

The foundation pit project adopts the support form of prestressed anchor rods and supporting piles. The anchor rods used are tension-type anchor rods, with the rod body made of unbonded, low-relaxation, high-strength steel strands with a tensile strength standard value of 1860 MPa. The anchor cables are all pre-stressed steel strands with a diameter of 15.2mm. The anchor rod drilling diameter is 150mm, designed length is 20m, and the anchoring material is a cement slurry with a water-cement ratio of 1:0.55 of PO42.5 pure cement. The anchoring section length is 10m, and the inclination angle is 25°.

Before the construction of the anchor rods, destructive tests were conducted to determine the actual ultimate pullout force of the anchor rods, verify the design rationality, and determine the ultimate bearing capacity of the anchor rods under the soft rock conditions. A total of 4 test anchor rods were completed in the experiment, and the construction of the anchor rods was carried out strictly according to the design requirements. The anchoring sections were all set in moderately weathered rock layers, with a length of 5m for the anchoring section of the test anchor rods. The tensile tests were conducted 7 days after the completion of anchor rod construction.

### III. TEST METHOD

The loading system consists of an electric oil pump and a core-penetrating hydraulic jack, with a maximum load of 1200 kN and a maximum stroke of 250 mm. The reaction system includes box-type steel supports with sufficient stiffness and strength. The load sensing system uses resistance strain gauge load sensors connected to YJ-XZ static resistance strain gauges, with a strain gauge accuracy of  $1 \times 10^{-6}$  and a load accuracy of 0.07 kN. Displacement measurement is done using high-precision displacement sensors.

Before the formal testing, the anchor cables are pre-tensioned twice with a force of 50 kN to ensure tight contact and straightness. Afterward, the load is released to zero, and the pull-out test begins. The loading is done using the slow-speed sustained load method, with each level of loading set at 20 kN. Under each level of load, the anchor head displacement should not exceed 0.05 mm within 30 minutes. If this criterion is met, the next level of load is applied. The test continues until the



anchor head displacement increment under the last level of load is equal to or greater than twice the displacement increment under the previous level of load, or the anchor head displacement does not converge. The load at the previous stage is then considered as the ultimate pullout force of the anchor rod.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

According to the formula given in the specification for calculating the theoretical ultimate pullout force of anchor rods,  $F = \pi D L q_{sik}$ , where F is the theoretical calculation value of the anchor rod's ultimate pullout force (kN),  $\pi$  is the value of pi, D is the diameter of the anchor rod's anchoring body (m), L is the length of the anchoring body (m), and  $q_{sik}$  is the standard value of ultimate frictional resistance between the anchoring body and the soil mass.

Given that the diameter of the anchor rod's anchoring body is 150mm, and the length is 5m, and they are all located in moderately weathered rock, with a standard value of ultimate frictional resistance of 150kPa, the theoretical calculation based on the formula yields an ultimate pullout force of 353kN for the anchor rod.

Using the aforementioned test method, destructive tests were conducted on 4 anchor rods, and the construction parameters of each anchor rod are listed in Table 2. The load-displacement curve of the anchor rods during the test process is shown in Figure 1. From the graph, it can be observed that under external loading, the Q- $\delta$  curve of the anchor rod is relatively smooth overall. The maximum displacement value reaches 30.3mm within the limit load, and the maximum ultimate pullout force of the anchor rod reaches 400kN.

Table 2. Anchor Rod Construction Parameters

Anchor Rod ID	Anchor Rod Diameter D (mm)	Anchor Rod Body	Free Section Length (m)	Anchoring Section Length (m)	Pullout Force (kN)	Stop Loading Reason
A1	150	3s15.2	5	5	400	Displacement exceeds limit value
A2	150	3s15.2	5	5	400	Displacement exceeds limit value
A3	150	3s15.2	5	5	400	Displacement exceeds limit value
A4	150	3s15.2	5	5	400	Displacement exceeds limit value

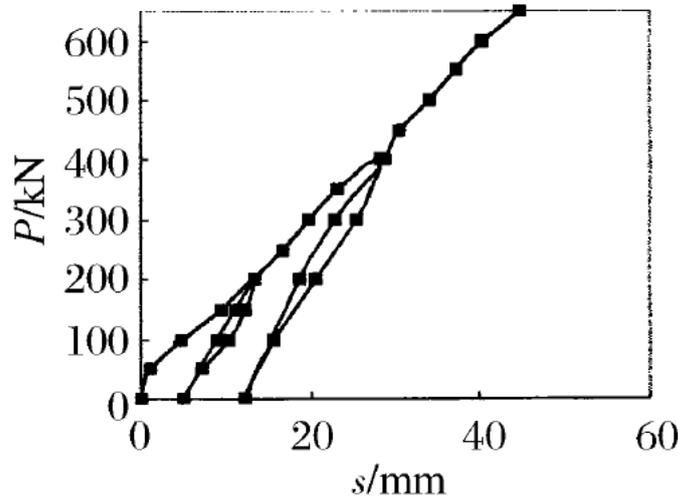


Figure 1: Anchor Rod Load-Displacement Curve

According to the  $Q-\delta$  curve, it is evident that the maximum ultimate pullout force that all 4 anchor rods can withstand far exceeds the theoretical calculation of the anchor rod's ultimate pullout force. This discrepancy is due to the fact that the standard value of ultimate frictional resistance between the anchoring body and the rock used in theoretical calculations is too small. This indicates that relying solely on theoretical formulas for calculating the anchor rod's ultimate pullout force is inaccurate, and validation should be done based on destructive tests.

Although the construction parameters of the 4 anchor rods are the same, there is a significant difference in their ultimate pullout force values. This discrepancy is attributed to differences in the construction process of the anchor rods, such as grouting pressure and grouting volume, as well as variations in the rock conditions.

While the ultimate pullout force of the anchor rod is much greater than the theoretical calculation when disregarding anchor rod displacement, it is essential to consider the displacement of the anchor rod's anchor head in engineering practice. The displacement of the anchor head is a critical parameter for ensuring engineering safety. Therefore, the magnitude of the anchor rod's ultimate pullout force should fully consider the impact of anchor head displacement. To make full use of the anchor rod's bearing capacity, it is important to regularly monitor its displacement during operation and promptly tighten the anchor head when necessary.

## V. CONCLUSION

The theoretical calculation of the anchor rod's ultimate pullout force differs significantly from the results of actual destructive tests, mainly due to the small standard value of ultimate frictional resistance between the anchoring body and the rock used in theoretical calculations. Therefore, relying solely on theoretical formulas for calculating the anchor rod's ultimate pullout force is inaccurate, and validation should be done through destructive tests.

The construction process of the anchor rod significantly affects its ultimate pullout force, including factors such as grouting pressure, grouting volume, and variations in the rock conditions. Therefore, in practical engineering, attention should be paid to the construction quality and process control of the anchor rod to ensure the reliability and stability of its bearing capacity.

Considering the importance of anchor rod displacement for engineering safety, the magnitude of the anchor rod's ultimate pullout force should fully consider the impact of anchor head displacement. During the operation of the anchor rod, regular monitoring of its displacement should be carried out, and adjustments should be made promptly to ensure the safe operation of the engineering project.



In conclusion, it is recommended to combine theoretical calculations with actual destructive test data for validating the ultimate pullout force of anchor rods. Additionally, emphasis should be placed on construction processes and displacement monitoring to ensure the reliability and safety of anchor rods in engineering projects.

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