Experimental Study on Expansion Anchor Head at the bottom of Rock Anchor System

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ABSTRACT: Rock anchor foundation is an economy and advanced foundation form which is especially applicable for wind tower construction in mountain area. Installation of expansion anchor head at the bottom of full length grouted rock anchors can serve to reduce the anchorage length and increase pullout resistance of anchor system. Numerous groups of anchor rods have been tested to study the effect of anchor head on pullout resistance, including two anchor rods with expansion anchor head. The failure condition and limit pullout resistance of headed anchor has been analyzed with respect to different geological condition and different anchor length, comparing with the anchors without expansion heads. The measured values from the experiments have been compared with the calculated values by the standard formula. It is concluded that, the anchor rods with expansion anchor head could satisfy the engineering precision and is applicable for wind tower foundation construction.

INTRODUCTION

Rock anchor foundation is defined as the steel anchors placed in pre-drilled hole on the rock and then filled with cement mortar or fine aggregate concrete. The rock anchor foundation can give full play of mechanical properties of undisturbed rock mass, and meanwhile, provide good pullout resistance. Wind power has the greatest development scale among the current renewable power. At present, wind farms in the continental region of China are mainly located in the mountain area. For the high bearing capacity geological condition such as rock, the independent extended foundation is usually controlled by the percentage of zero stress area on the foundation bottom surface. High bearing capacity of the foundation can not be fully utilized. The wind load applied on the upper part of the wind tower is the primary consideration for the foundation design. Therefore, the use of anchor foundation can not only display good mechanical properties of the rock mass, but also provide reliability and safety. Furthermore, the use of anchor foundation will reduce the material cost and the environmental hazard. Thus, it could result in apparent economic and social benefits. Installation of expansion anchor head at the bottom of full-length grouted anchors can serve to reduce the anchorage length and increase pullout resistance of anchor system.

At the present time, very few research has been done on the effect of anchor head attaching on the bottom of full-length grouted anchor. It becomes very significant to evaluate the improvement caused by the anchor heads during the anchor design process. In this paper, combined with the field test results, the anchoring effect of anchor head is analyzed and evaluated.

experiment set-up and experiment content

Experiment Objective

Two groups of rock anchor foundation specimens are prepared for the field test. At the bottom of one group of specimen, the expansion anchor head are installed, whereas the other group is without anchor head, providing that all other set-up is the same. The change of load vs. displacement curve is analyzed after the installation of anchor head. The curve of axial load with respect to depth under gradually changing load is derived and the mechanism of expansion anchor head is analyzed by the changing curve.

Field Test

(1) Test Set-up: Two fields in the mountain area of Yantai are selected to conduct the field tests. The anchors used in the test consist of 42CrMo anchor bolt with 60mm diameter. The diameter of the drilled hole is 150mm. Test Field One: The anchorage depth is 5 meters; the geological condition on site is characterized as intensely weathered quartzite. 3 expansion anchors have been tested. Test Field Two: The anchorage depth is 8 meters; the geological condition on site is characterized as moderately weathered siliceous slate. 3 expansion anchors have been tested. Six anchors have been tested in total; three of them are expansion anchors, whereas the other three are straight anchors. The boring direction is vertically downward.

(2) Material Properties: The adhesive used for the anchor system is C40 fine aggregate concrete. The rock on the site has been tested under point load. The saturated uniaxial compressive resistance of the rock is obtained as 265Mpa.

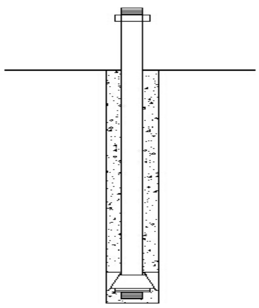
(3) Loading Method: Lifting jacks are placed at both ends of the steel beam. The anchor rod is drilled through the center of the beam and properly fastened by the bolt which is cushioned by a steel plate.

According to the design code, the repeated load applied by the jack increased gradually, until the failure appears or the displacement is over the limit.

(4) Anchor Head Configuration

As shown in Figure 1:

Figure 1: anchor head configuration



Convergence Determination

According to “ Technical code for building slope engineering” (GB50330—2002）[2]

The anchor failure can be identified with any one of the following conditions: 1）The anchor system displacement caused by the sequential level load is two times greater than the displacement caused by the previous level load. 2) The anchor system displacement does not converge. 3) The total displacement of the anchor head exceeds the allowable design displacement which is determined as 10mm by experimental experience. The previous level tensile load meets the above termination conditions can be identified as the anchor ultimate load.

Experiment Results and Analysis

Experiment Results

The anchors in F09 experimental zone were tested by the cyclic loading until the anchors failure appears. The test results are shown in Figure 2, Figure 3 and Table 1.

Figure 2 01# Anchor Test Result

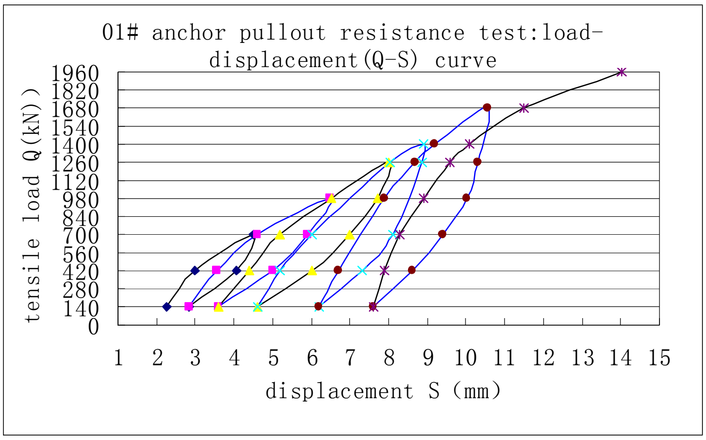


Figure 3 02# Anchor Test Result

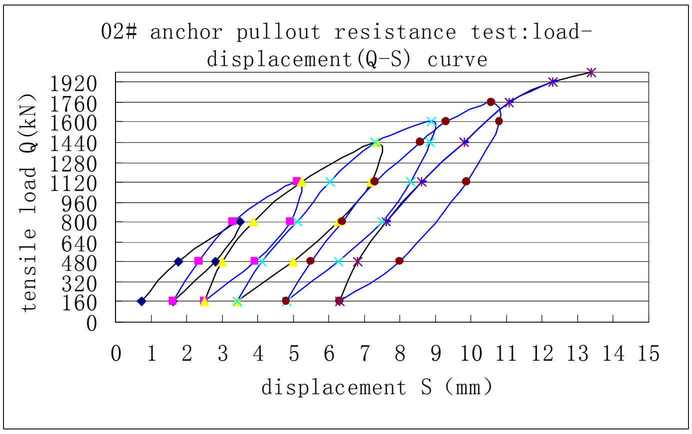


Table 1: Summary of the Anchor Tests

Anchor number	Anchor diameter (mm)	Anchor length (m)	Load level	Maximum load (kN)	Failure mode	Limit pullout resistance (kN)	Corresponding displacement (mm)	Remark
1	60	5	16	1200	Rock breakout	1134	10.54	With expansion
2	60	5	16	1200	Rock breakout	1134	9.05	With expansion
3	60	5	16	1200	Rock breakout	1134	10.0	With expansion
01#	60	8	24	1800	Displacement over limit	1680	10.55	With expansion
02#	60	8	24	1800	Displacement over limit	1680	10.9	With expansion
03#	60	8	24	1800	Displacement over limit	1680	9.8	With expansion
A01#	60	8	18	1400	Displacement over limit	1260	10.02	Without expansion
A02#	60	8	18	1400	Displacement over limit	1260	9.95	Without expansion
A03#	60	8	18	1400	Displacement over limit	1260	10.57	Without expansion

Analysis of Test Results

(1) For the anchors tested on strong weathered rock, since the mortar and the rock interacted first, the pullout displacement was small under tensile loading. While the tensile load increased gradually,

the surface mortar cracked or the small radial cracks appeared on rock surface, the pullout displacement increased; with the increase of the tensile load, the cracks grew rapidly or the radial cracks extended continuously until the failure occurs. Whereas for the anchors tested on moderately weathered rock, the pullout displacement under tensile loading was small for all the time. While the tensile load increased gradually, eventually, the total displacement of anchor head exceeded the design allowed value which is 10mm.

(2) The ultimate pullout resistance of full-length grouted anchors with expansion anchor head is 1.3 times to the anchors without expansion anchor head tested under the same geological condition. It can be seen that the expansion anchor head can share the pullout load effect, and it can increase the ultimate pullout resistance of the anchor system.

(3) It can be seen from the failure mode that, the expansion anchor head can increase the bond force between anchor and grout. In addition, the expansion anchor head can decrease the displacement between anchor and rock, and improve the safety factor of the anchor system.

Anchor Effect Theory and Design Code

Currently, the equation used by "technical regulation for designing foundation of overhead transmission line" for single anchor is given by:

$$g_f T_E \le p h_0 t_s (D + h_0) \quad (1)$$

Where g_f is foundation additional coefficient, T_E is foundation pullout load, h_0 is effected anchor length, t_s is rock ultimate shear strength, D is single anchor bottom diameter.

According to "Design regulations on subgrade and foundation for WTGS of wind power station", Clause 9.4.3, the calculation model of the single anchor uses the friction between anchor and rock to resist the pullout load, the factored pullout resistance is obtained from the following equation:

$$R_t \le 0.8 p d_1 l f \quad (2)$$

Where R_t is factored pullout resistance of single anchor, d_1 is anchor hole diameter, l is effected anchor depth (m), f is factored bonding strength between mortar and rock.

Substitute the test data from Test F09 into equation (1) and (2), the calculated results were compared with the experimental ultimate pullout resistance and factored pullout resistance, which is shown in Table 2.

Table 2: Comparison of Test Data and Calculated Value

Anchor Number	Experimental ultimate pullout resistance （kN）	Anchor length （m）	t_s /kPa	f/MPa	Calculated factored ultimate shear resistance （kN）	Calculated factored frictional pullout resistance （kN）	Relative displacement between anchor and rock when failure occurs （mm）	Overall anchor system displacement when failure occurs （mm）
1，2，3	1134	5	17	0.2	1116.9	376.8	8.54	10.54
01#，02#，03	1680	8	30	0.4	5404.7	1205.7	2.70	10.55
A01#，A02#，A03#	1260	8	30	0.3	6141.8	904.32	5.56	10.02

From Table 2, it can be seen that, 1) When the anchor length is around 5 meters, the experimental ultimate pullout resistance of the single anchor with expansion anchor head accords well with the calculated design value of ultimate shear resistance, but higher than the calculated frictional pullout resistance, which illustrates that the frictional pullout resistance calculation has certain safety redundancy. When the anchors with expansion head tested on moderately weathered rock reach the convergence condition, the relative displacement between the rock and the anchor was far less than the overall displacement of the anchor system, which illustrates that the rock was not damaged, the displacement was resulted from steel elastic displacement, hence does not accord very well with the calculated value from design regulation and code. 2) The experimental data showed that the increase of anchor length can not improve the ultimate pullout resistance effectively. 3) From the calculation by design code and test results analysis, it is known that, if the calculation model recommended by "technical regulation for designing foundation of overhead transmission line" was adopted, although the change of calculation model was very convenience, but the rock mass considered in the model was significantly greater than the rock mass which actually provided the pullout resistance. This may result in unsafe design results. 4) The expansion anchor head attached at the bottom of the anchor can shear the pullout load, which leads to the improvement of ultimate pullout resistance.

conclusions

(1) For the full-length grouted anchor system, the load is transferred from the top to the bottom of the anchor, the failure also happens from the top part to the bottom part. Therefore, for the ultimate elastic resistance of the anchor system, the installation of the expansion head at the bottom of the anchor could enhance the ultimate resistance of the anchor system. In conclusion, the installation of expansion anchor head has the effect of improving construction safety.

(2) The expansion head at the bottom of full-length grouted anchor system has the effect of sharing pullout load. This effect depends not only on the anchor length and pullout load, but also on the shearing rigidity coefficient between grout and anchor, as well as the anchor diameter.

(3) For engineering construction, the installation of expansion head has the effect of reducing the anchor length, which could make economic sense by saving construction cost. Especially for the wind tower foundation in the mountainous area, when the anchor system surface damaged, expansion anchor head can delay the complete failure of anchor system, in order to provide valuable time for the repair work. Therefore, installation of expansion anchor head is necessary for the system safety from the perspective of engineering safety and economy.

References

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