Experimental Study on Spacing Calculation and Ultimate Pull-Out Bearing Capacity of Multi-Expansion Anchor Rod

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Abstract. The multi-expansion anchor rod is a new type of anchor rod, which is designed to solve the problems of insufficient anchorage force and limited anchor rod length in traditional anchor rods used in slope support applications. The multi-expansion anchor rod expands the contact area with the rock and soil mass by installing multiple expansion plates in the anchorage section, enhancing the bearing capacity and anchoring force of the anchor rod, and thus improving the overall support effect. This makes the anchor rod to adapt to more complex slope support requirements, especially in high steep slopes or soft rock strata, where its application has significant advantages. In this paper, the specific calculation formula of the independent working spacing of the expansion disk at different burial depths is derived by simplifying the mechanical model, and the pull-out test pieces were made by similar principle and the pull-out test was carried out to obtain the corresponding load-displacement curve. The error between the predicted value of the formula and the experimental result is small, which verifies the validity of the formula. When the grouting expansion bolt is in the loess, the anchoring section between the expansion plates mainly serves to connect the expansion plates, and provides a limited role for the overall ultimate bearing capacity of the bolt, and it can be saved some materials; according to the buried depth, the spacing of support disks is adjusted, and the anchoring force of the expanded disk anchor rod in the soft soil layer is about four times that of the ordinary conventional anchor rod with the same length, which effectively improves the anchoring capacity of the expanded disk anchor rod. The formulas proposed in this paper provide a theoretical basis for the application of expanded anchor bolts in practicall engineering design, and provide a feasible reference for further optimizing the support design and improving the slope stability.

Keywords: expanded plate anchor rod; expansion disk spacing; ultimate bearing capacity; pull-out test; loess

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1 Introduction

With the increase of the number of push-mountain reclamation projects, the geological disaster problems exposed by the high slopes are becoming increasingly prominent[1], and the anchoring system can improve the stability of the soil slope[2]. The bearing capacity requirements for support structures are also increasing, and the innovative application of combined support structures is becoming more and more widespread[3]. In recent years, with the development of technology and materials, in order to enhance the performance and usage effect of the anchoring structure, and improve the safety and reliability of slope support, the application of new expanded head anchor bolts in slopes has become increasingly widespread and has achieved good results. Liao.[4] et al. established a numerical model of the auger-type anchor rod in sandy soil, and the numerical analysis results show that soil along the lower hinge body does not show a gradualing yield phenomenon, and a smaller lower expansion angle can significantly improve the pull-out resistance of the anchor rod. Tang Chun'an[5] et al. used multi-point wedge expansion to make the contact between the anchor rod and the surrounding rock more closely, thereby improving the mechanical properties of the anchor rod. Chen Haohua[6] et al. verified through experiments that it is feasible to open the anchor grab of the ship anchor type grouting type soil anchor and form an enlarged head through grouting pressure. Sabermahani[7] introduces a new type of plate anchor, which increases its bearing cross-sectional area during the pull-out process and proposes a calculation method for its ultimate pull-out load. Zha Wenhua[8-10] et al. studied a new type of large deformation resistant twisted bolt, which makes it more able to adapt to the large deformation characteristics of the surrounding rock, and significantly improves the anti-deformation ability and shear resistance of the anchor rod. Guo[11] et al. expounded on the load-bearing mechanism of an expanded anchor rod. The multi-disk anchor rod was developed by Yang Jian, Jian Wenbin[12-13], etc., and the self-expanding hole equipment was used to form multiple disk cavities in the soil layer, and was constructed a multi-branched disk anchorage system through cleaning and grouting, which is innovative and has superior engineering performance. Lin[14] et al. investigated a new type of expansion shell bolt, and the study showed that the grouting material and anchoring length had little effect on the pullout bearing capacity of the anchor shell. Shi Jingfeng[15] et al. proved through indoor tests and discrete element numerical simulation that changing the diameter, length and other factors of the anchor rod can improve the peak load of pull-out. Yu[16] et al. found that the expansion structure can exert radial compression on the surrounding medium of the anchor rod, improving the anchoring performance of the anchor rod. The above research can all show that changing the length and stressed area of the anchor rod can effectively improve the bearing capacity of the anchor rod.

However, there are few experimental studies on the expansion disk combination form of the supporting disk anchor rod, and the spacing of the expansion disk depends on the experimental data, and there is a lack of clear formula for the theoretical calculation of the spacing of the expansion, and the contribution of the anchorage section between the expansion disks to the bearing capacity of the anchor rod is still not clear. This paper makes an in-depth study of the above problems, on the basis of the simplified mechanical model, the spacing parameters of the expansion disk under different depths of the anchor rod are calculated. The experimental research was carried out by similar model to obtain the bearing capacity change of the expansion disk anchor rod under different structural forms to verify the calculation results.

2 Anchoring Mechanism of Expansion Anchor Rod and Calculation of Expansion Spacing

The multi-disk anchor rod consists of a free section and an anchor section, the free section is a steel bar, and the anchoring section is composed a disk and a common anchor section, where the ordinary anchorage section is the part of the anchorage section except for the expanded disk (its anchorage section is shown in Figure.1).

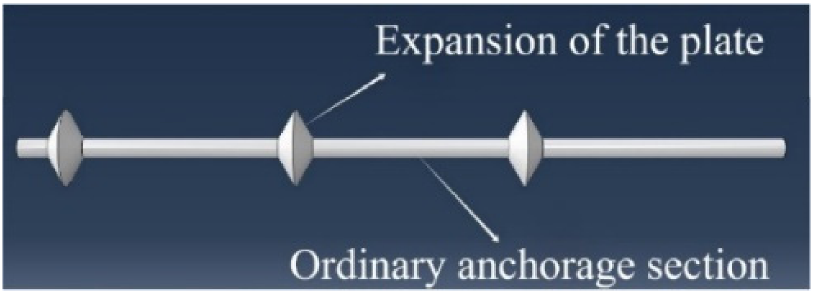


Fig. 1. The schematic diagram of the anchorage section of expansion anchor rod

2.1 Ultimate Pull-Out Capacity of Multi-Anchor Rods

In slope support, anchor rods are widely used key structures for reinforcement and support, and their ultimate pull-out load is a core indicator for evaluating the performance of anchor rods, which directly reflects the quality and design rationality of anchor rods. In the daily use of multi-expansion anchor rods, since the burial depth of anchor rods is much greater than the diameter of the expansion disk, the influence of the weight of the soil on the pull-out bearing capacity of the expansion disk is neglected in the calculation process. Based on the Prandtl and Terzaghi limit equilibrium theory [17-18], the following assumptions are made for the calculation of multi-anchor rods: ① The influence of the shear strength of the soil at the non-directly loaded end of the anchor plate on the overall bearing capacity is not considered; ②Under the action of the ultimate load, the overall shear failure of each expansion disk of the multi-expansion anchor rod occurs. ③ The failure surface of the expanded anchor rod is the cylindrical surface formed between the two expanded plates when it reaches the ultimate bearing capacity, as shown in Figure. 2.

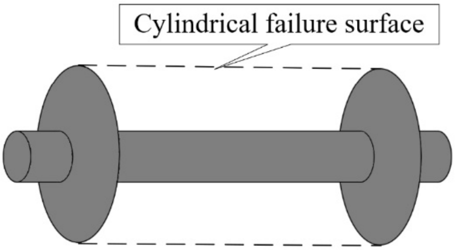


Fig. 2. Schematic diagram of the failure surface of the expanded disk

The load of the multi-expansion anchor rod is mainly composed of two parts, which are the sum of the front soil pressure of each expansion disk and the side friction resistance of the ordinary anchorage section, and its calculation model is shown in Figure.3, so the formula for calculating the ultimate bearing capacity of multi-expansion anchor is:

$$Q = N + nP \tag{1}$$

Q in equation (1) is the ultimate pull-out capacity of the the multi-disk anchor rod; *N* is the frictional resistance of the ordinary anchorage section; *P* is the end resistance of the single expansion disk anchor; *n* is the number of expansion platters.

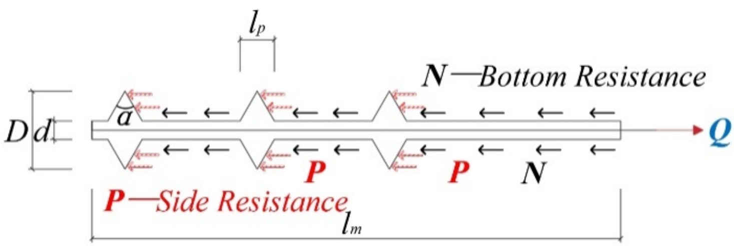


Fig. 3. Mechanical model of expansion anchor bolt

The conventional anchor section mainly provides side friction resistance, which can be expressed as:

$$N = \pi d\left(l_m - nl_p\right)b_s \tag{2}$$

Where,
l_m = total length of the anchorage section
l_p = the overall width of the single expansion disk
n = the number of the expansion platters
d in equation (2) is the diameter of the ordinary anchorage section of the anchor rod; b_s is the bonding strength between the anchor solid and the surrounding soil.

Huang Wei et al.[13] gave the calculation method of the end resistance of a single disk in the limit state of a single expansion disk anchor rod, that is

$$P = \frac{\pi\left(R^2 - r^2\right)\left[\left(1-\xi\right)K_0 K_P \sum \gamma H + 2c\sqrt{K_P}\right]}{\left(1-\xi K_P\right)\tan\alpha} \tag{3}$$

R in Eq. (3) is the radius of the expanded disk; r is the radius of the ordinary anchorage section; ξ is the increment coefficient[21] which can be expressed as $\xi = \left(0.5 \sim 0.95\right)K_a$, where K_a is the Rankine active earth pressure coefficient; K_0 is the coefficient of static earth pressure of the front soil of the expanded disk, and its calculation formula is $K_0 = 1 - \sin(1.3\varphi)$; K_P is passive earth pressure coefficient of the front soil of the expanded disk; H is the burial depth of the expanded disk, that is, the distance from the geometric center of the expanded disk to the ground; γ is the unit weight of the overlying soil on the rod; α is the expansion angle of the expanded disk; c is the cohesion of the soil in front of the expanded disk.

2.2 Calculation of the Spacing of the Expansion Disk

The relevant calculation of anchor rod expansion disk spacing is mainly based on the geometric size of the anchor rod components and a certain safety reserve, the disk spacing diagram is shown in Figure.4. In order to achieve the full play of the bearing capacity of the expansion anchor rod, it is necessary to ensure that each expansion disk can work independently, so that the soil around the expansion disk can be sheared and destroyed, the critical condition for the independent work of the expansion disk in the soil is judged according to the balance between the shear resistance of the soil on the cylindrical formed by the expansion disk connected along the direction of the anchor rod and the passive earth pressure at the expansion disk. According to the effective stress method of shear strength the relationship between them is expressed as

$$T >= P \tag{4}$$

Wherein

$$T = Ll\tau_s \tag{5}$$

$$l \geq \frac{P}{L\tau_s} \tag{6}$$

Where, l is the spacing of the expanded disk, P is the single disk end resistance of the anchor rod in the limit state, T is the shear resistance of the soil along the failure surface, τ_s is the shear strength of the soil, and L is the circumference of the expanded disk.

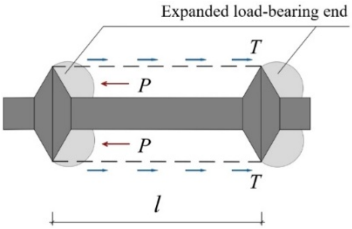


Fig. 4. Calculation diagram of expansion spacing

3 Multi-Expansion Disk Anchor Rod Pull-Out Test

The new type of expanded head anchor rod support is a key technology in geotechnical engineering, and significant progress has been made in theoretical in recent years. At present, the research on anchor rod expansion mainly relies on field tests and numerical simulation, while there are few studies based on laboratory tests. It is seen from the research results of Yao Guoqiang et al.[19] that the physical and mechanical properties of similar materials can reflect the characteristics of materials well, and it is feasible to carry out anchor similar model tests using similar materials. Therefore, this test was based on the similarity theory[20], the test satisfied the similarity relationship between the model and the actual component, so that the results of the model tests co truly reflect the situation of the original component when it was working. The dimensional analysis method in the similarity criterion was used as the method of equal proportion scaling for this test, and the bearing capacity of the anchor rod under condition of high backfill was simulated by the model box.

3.1 Test Equipment

The equipment for this laboratory expansion anchor pull-out test includes a pull-out meter, a model box, an axial force meter, and a dial indicator. The model box is a rigid structure with a length of 1.70 m, a width of 0.90 m, and a height 1.05 m, the structure of the model box is shown in Figure. 5. The dial indicator and the axial force meter are the monitoring equipment for this test. Wherein, the dial indicator monitors the drawing displacement, and the data is recorded manually. The axial force generated during the pull-out process is monitored by the axial force meter, and the data is measured by the DH3816N static strain testing system.

Fig. 5. Model box diagram

3.2 Anchor Rod Model

In order to study the influence of the spacing of the expanded section and the non-expanded section of the anchor rod on the overall bearing capacity of the anchor, the anchor rods of different specifications ware used for research. The size of the test model was as follows: the expansion disk used a grouted expansion disk with a diameter 60 mm, and the HRB400 hot-rolled ribbed steel bar with a diameter of 6 mm was used as the pull rod of anchor rod to transfer the axial stress, and the cement mortar with a strength of M30 was used to complete the pouring of all the anchor segments of the model. In actual engineering, the expansion of the anchor rod can be expanded by the drilling equipment developed by Yang Jian et al.[12]. The length of the anchorage section of the test group was determined according to the design requirements, and the total length of the model anchor rod is 1600mm,and there are four types of anchor rods in this test: ① Anchors with ordinary anchorage section ends at the spacing of empirical expansion disk, which are referred to as end-anchored anchors in the following, i.e., anchors A1, A2, and A3 ② The anchor rod without common anchorage section end under the experience expansion disk spacing, which is simply referred to as the anchor rod without end anchorage in the following text, that is, anchor rod B1, B2 and B3; ③ The anchor rods under the theoretical calculation of the expansion disk spacing, namely anchor rods C1, C2 and C3; ④ Conventional anchor rods without expansion, namely rods D1, D2 and D3. The schematic diagram of the anchor rod with end head and the anchor rod without end head is shown in Figure. 6, the parameters of the anchor rods are detailed in Table 1.

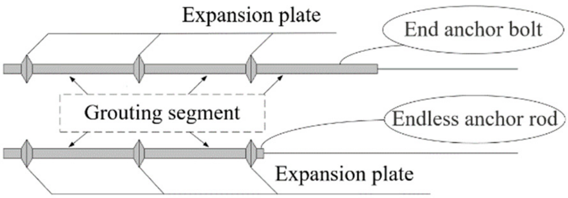


Fig. 6. The schematic diagram of end bolt and endless bolt

Table 1. Expansion data

Anchor rod type	Anchor rod description	Anchor length/mm	Expansion spacing/mm	Embedding depth/m
A1	Experience spacing with end	800	240	0.2
A2	Experience spacing with end	800	240	0.5
A3	Experience spacing with end	800	240	0.8
B1	Experience spacing with end	550	240	0.2
B2	Experience spacing with end	550	240	0.5
B3	Experience spacing with end	550	240	0.8
C1	Theoretical spacing	800	230	0.2
C2	Theoretical spacing	800	222	0.5
C3	Theoretical spacing	800	214	0.8
D1	Conventional control	800	——	0.2

D2	Conventional control	800	——	0.5
D3	Conventional control	800	——	0.8

3.3 Test Conditions

The soil used for the test was taken from a construction site in Gansu Province, and the specific physical properties of the soil are shown in Table2.

Table 2. Physical property parameters of loess

Soil body	Severe /(kN·m^{-3})	Angle of internal friction /(°)	Cohesion /kPa	Poisson's ratio	Maximum dry density /(g·cm^{-3})
Loess	17.8	24	28	0.35	1.66

3.4 Test Process

The test was conducted after 28 days of curing following the casting of the anchor rod model. The prepared loess was filled into the model box layer by layer and compacted, and the test anchor rods were arranged at the preset positions. After the entire model box was filled with soil, the top layer was covered with lead blocks, totaling 128 blocks with a total weight of 128 kg. After consolidation for more than 24 hours, the lead blocks were removed, and the pull-out test was started. The pullout process was carried out by the method of step-by-step loading, with each load level being 0.2 kN, the loading time interval between adjacent load levels was 2 min, and the load and displacement at this time were recorded every 2 min. Until the soil around the anchor rod underwent shear failure or the anchor rod was damaged. The criterion for judging the shear failure of the soil around the anchor rod was that during the loading process, the displacement of the anchor rod end continued to increase, and the axial force of the anchor rod gradually decreased or remained basically unchanged. The test site is shown in Figure.7.

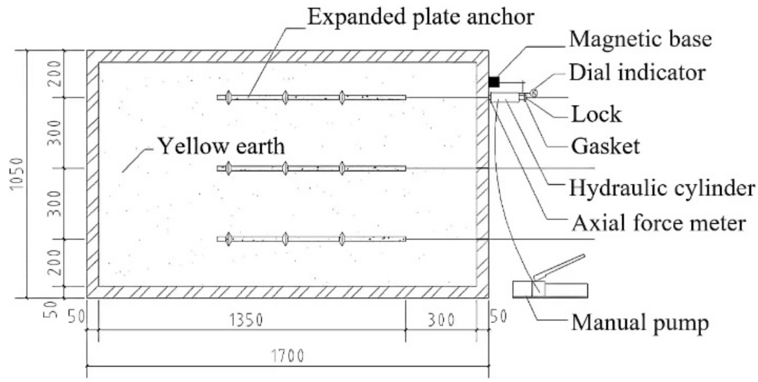


Fig. 7. Test schematic diagram

3.5 Analysis of the Test Results

3.5.1 The Influence of the Expansion Disk on the Surrounding Loess

During the test, since the size and shape of each expansion disk were kept consistent, the stress mode of each expansion disk was also approximately the same. In the pull-out test, when the anchor rod was subjected to external force, there would be interaction between the expansion disk and the surrounding soil. In this case, the soil would suffer shear failure due to the force transmission from the anchor rod expansion disk. Specifically, the soil around the expanded disk would produce a cylindrical cavity in the opposite direction of the load on the support disk, which was due to the gradual reduction in the shear strength of the soil when it was subjected to the tensile force of the expanded disk, resulting in its sliding and forming a cavity, the shear failure pattern of the soil in the test fully shown the stress distribution characteristics of the surrounding soil. As shown in Figure. 8.

Fig. 8. Failure phenomenon of the soil around the expansion plate

This failure pattern indicated that the load of each expanded disk was independent, and its influence range was limited to the soil mass near the expanded disk, and it did not directly affect the soil mass deep in the anchor rod, so the soil mass between adjacent expanded disks did not occur combined failure or bonding phenomenon. This phenomenon was closely related to the mechanism of anchor rod failure. When the anchor rod was stressed to a certain extent, the interface between the anchor rod and the soil would fail, that was, the interface sheared failure. During the pull-out process of the anchor rod, due to the interaction force between the expansion disk and the soil, the entire failure process showed a relatively obvious independent failure area, and the failure pattern of the soil was consistent with the working hypothesis of the anchor rod (i.e., the independent working of the expansion disk), that was, the result pattern of the soil failure near the expansion disk was consistent with the prediction result pattern of the theoretical model.

3.5.2 Comparison of Theoretical Calculation and Experimental Results

Through detailed analysis and processing of the experimental data, the key conclusion is drawn. For the expanded disk model anchor rod with a diameter of 60mm, the expanded disk can fully play its independent bearing capacity in the soil when is arranged according to the theoretical calculation spacing. The theoretical calculation spacing is optimized based on the shear strength of the soil and the stress characteristics of the expanded disk, ensuring that the interaction between the expanded disk and the surrounding soil can maximize the bearing capacity of the anchor rod.

The spacing calculation method in this paper is fully considered the influence of burial depth on the bearing capacity of anchor rods. In actual construction, the burial depth would significantly affect the contact area between the expands disk and the soil and the formation of its shear interface, which in turn affects the overall bearing capacity. By introducing the burial depth factor into the calculation, not only the support capacity of the expanded plate to the anchor rod is effectively improved, but also the capacity distribution of the soil is further optimized, which enables the anchor rod to bear greater tension within the design range, thus the accuracy and reliability of the test are improved. The theoretical calculation and the test comparison are shown in Table 3, and the error of the data obtained in the laboratory is within 16%. The anchor rod with too large error may be due to the non-homogeneity of the soil used in the test. The test results show that the ultimate bearing capacity of the expansion anchor rod under the calculated spacing and the theoretical spacing is close, that is, the spacing calculated can ensure that the expansion of the anchor rod can work independently. The theoretical ultimate bearing capacity of various anchor rods obtained from the test is compared with the test ultimate capacity, when the anchor rod adopts the spacing of the theoretical calculation as the expansion spacing and there is no ordinary anchor section end, the anchor rod can not only reduce the consumption materials, but also play its anchoring role well.

Table 3. Comparison of calculated and experimental values of uplift capacity of expansion anchor bolts

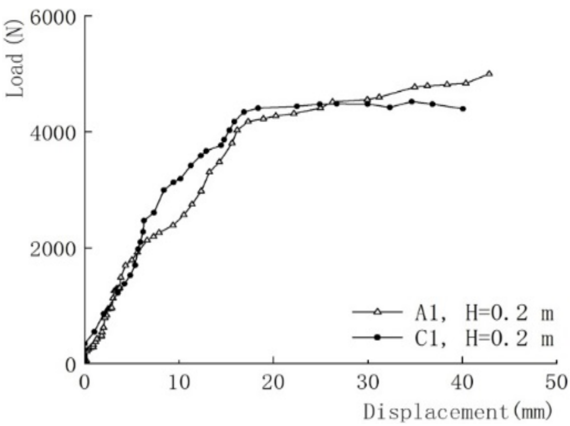
Anchor rod	Buried depth/m	Expansion spacing/mm	Theoretical ultimate bearing capacity/N	Test ultimate bearing capacity/N	Error rate/%
A1	0.2	240	4802.32	4177	-13
A2	0.5	240	4965.67	4425	-11
A3	0.8	240	5129.02	5506	7
B1	0.2	240	4503.23	4244	-6
B2	0.5	240	4666.58	4383	-6
B3	0.8	240	4829.93	5445	11
C1	0.2	230	4802.32	4026.6	-16
C2	0.5	222	4965.67	5227.7	5
C3	0.8	214	5129.02	6192.77	21
D1	0.2	——	957.1	1007.8	5
D2	0.5	——	957.1	1128.8	18
D3	0.8	——	957.1	1025.5	7

3.5.3 Calculate the Influence of Spacing on the Bearing Capacity of Anchor Bolts

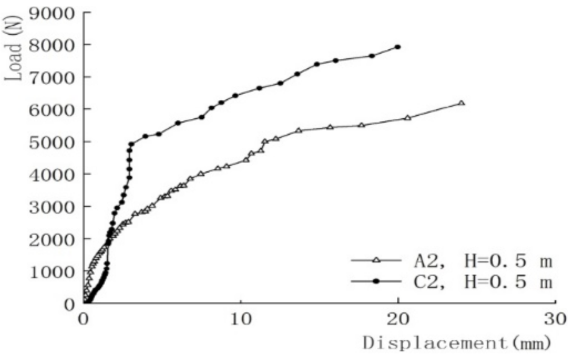
At present, the spacing between the expanded plates of the expansion anchor rod is an empirical spacing obtained through laboratory tests to ensure that each expanded plate of anchor rod can work independently, and in the actual construction operation, with the change of burial depth, the spacing that makes the expanded disk work independently is variable rather than a fixed value and the spacing obtained by theoretical calculation will be more accurate.

In this test, the anchor bolts with empirical expansion disk spacing and the anchor bolts with expansion disk spacing calculated theoretically are compared and verified, as shown Figure.9. During the pull-out process, the displacement was small in the early stage, and the curve showed a steep linear growth characteristic, and The load was almost proportional to the displacement, at this time, the bonding strength between the anchor rod and the surrounding loess was playing a role, and the anchor rod was still in the elastic deformation stage, and no slip or damage occured. As the displacement gradually increased, the anchor rod entered the elastic-plastic stage, and the curve began to show nonlinear growth, with a relatively slowed growth rate, in this stage, local slip occured between the anchor rod and the surrounding rock and soil, and some of the anchorage interface began to soften, while anchor rod material might locally enter the elastic-plastic state. When the displacement further increased, the curve tended to be gentle as a whole (slip stage),which was characterized by a slow increase in load, or even tended to be stable. At this time, the anchor rod and the surrounding loess underwen slip failure, and the bonding strength of the anchorage interface was gradually completely destroyed. At the end of the curve, the load curve showed large fluctuations, which indicated that the anchorage interface was close failure, and the displacement continued to increase.

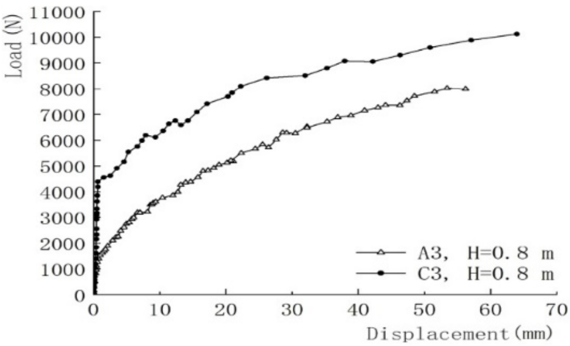
Compared with anchor bolts A1, A2, and A3, the curve of anchor bolts C1, C2, and C3 has larger slope in the initial stage, and the curve fluctuates less in the later stage, indicating that after the calculation and adjustment of the expansion disk spacing, the anchor structure is more stable and has better load-bearing capacity.



(a) A1, C1 comparison



(b) A2, C2 comparison



(c) A3, C3 comparison

Fig. 9. Pullout-displacement curves of calculated spacing anchor rod and theoretical spacing anchor rod

When the burial depth is 0.8 m, as shown in Figure. 9(c), the curves of anchor bolts A3 and C3 are relatively smooth, and the fluctuation amplitude is relatively small, indicating that the interface slip and damage are more uniform. At this time, the pull-out tensile performance of the anchor rods is relatively close, showing better anchoring capacity, that is, with the increase of the burial depth, the expanded anchor rods can better reflect their unique advantages.

3.5.4 Influence on the Anchorage Force of the Anchor Rod with Presence or Absence of an End Head on the Anchoring Section

The anchorage section of the expanded anchor rod is longer than the connected section of the expanded disk after the expanded disk is arranged, and it is not yet clear whether this part has a significant impact on the overall bearing capacity of the anchor rod. In the case of the same expansion disk size and expansion disk spacing, the pull-out test is carried out, and the pull-out-displacement curve is drawn, as shown in Figure. 10, the comparison between the end-free anchor rod and the end-bearing anchor rod is carried out, and the whole pull-out process and the cause of failure are analyzed, and the anchoring performance of the anchor rod is compared according to the change trend and the increase of the displacement and load.

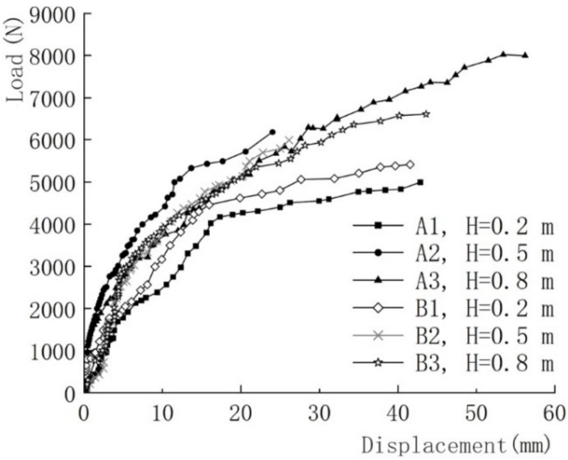


Fig. 10. Pullout-displacement curves of end-anchored rods and non-end- anchored rods

At the same burial depth, the curve trend of the end-anchored rods A1, A2, A3 and the non-end- anchored rods B1, B2, B3 is basically consistent, and the ultimate bearing capacity is shown in Table 4, and the difference in ultimate bearing capacity of the two anchor rods is within 0.1 kN.

Table 4. Comparison of ultimate bearing capacity between end-expanded rods and non-end-expanded rods

Buried depth/m	Ultimate bearing capacity/N		The difference between the two/%
	A	B	
0.2	4177	4244	+1.6
0.5	4425	4383	-0.9
0.8	5506	5445	-1.1

It can be seen that the side friction resistance of the expansion anchor rod can not play an effective role except for the part connecting the expansion disk grouting body. The main bearing capacity of the expansion anchor rod in loess is provided by the expansion disk, that is, when designing the expansion anchor rod, the extra end of the anchor rod anchorage section can be removed to reduce the consumption of materials. At the same time, the number of expansion disks can be increased according to the calculation when designing the anchor rod, so as to improve the overall bearing capacity of the anchor rod.

3.5.5 Comparison of Expansion Anchor Bolts with Traditional Anchor Bolts

The traditional conventional anchor bolts have low initial costs and are relatively simple construction, making them suitable for environments with good geological conditions and low bearing requirements. However, in complex geological conditions or high bearing demands, their insufficient performance may lead to potential hidden dangers. Expansion anchor bolts, although with higher initial costs and greater construction difficulties, can effectively save space and have better resistance to deformation. By comparing the pull-out-displacement curves of the expansion anchor bolts C1, C2, C3 under the theoretical calculation of the expansion spacing and the traditional conventional anchor bolts D1 D2, D3, as shown in Figure. 11, it can be clearly concluded that the bearing capacity and anchoring capacity of expanded anchor bolts are significantly better than those of traditional conventional anchor bolts, and the ultimate bearing capacity is basically 4 times that of the conventional anchor bolts of the same length.

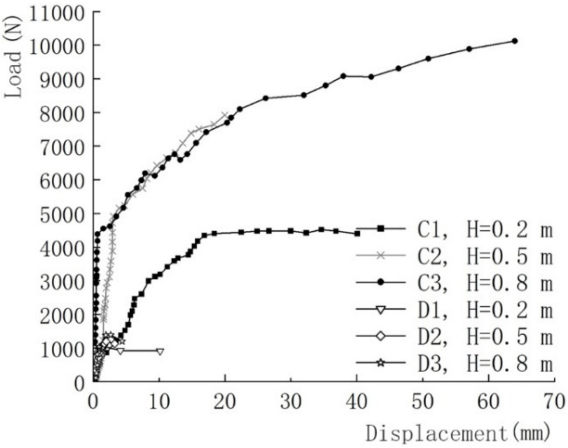


Fig. 11. Pullout-displacement curves of expansion anchor bolts and conventional anchor bolts at theoretical spacing

4 Conclusions

(1) The ordinary anchorage section of the expanded anchor rod only needs the connecting section between the expanded plates, and the extra ordinary anchorage section plays a smaller role and does not play a major role. In actual operation, it is recommended to use the end-free anchor rod with the theoretical spacing of the expansion disk, which can reduce the use of materials and save costs.

(2) The theoretical calculation results are basically consistent with the experimental results, which verifies the effectiveness of the calculation formula and provides a theoretical basis for the application of expanded anchor rods in actual engineering design.

(3) In practical engineering, the spacing of multi-disk anchor bolts that can work independently is not a fixed value, and the spacing between the expanded disks changes according to the theoretical calculations with the increase of the anchor rod burial depth, which has better anchoring capacity and better control of the expanded disk spacing than anchor rods with empirical spacing.

(4) The conventional anchor rod has the limitation of the effective length of the anchorage section, especially the grouted anchor rod often fails due to the excessive length of the anchorage section in the loess area, and its pull rod can not provide the corresponding axial force. Through the test, it can be seen that the expansion anchor rod greatly improves the bearing capacity of the anchor rod in a limited length in the collapsible loess. When facing a large demand for bearing capacity, the long conventional anchor rods can be replaced by a shorter expansion anchor rods, which not only ensures the bearing capacity but also reduces the use of anchoring space and construction materials.

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