

Comparison and experimental verification of embedded parts of straight anchors under shear and tension-shear

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Abstract. As one of the important components of the joint connection in the steel-concrete structure, the embedded parts of straight anchors have a great influence on the safety performance of the structure. People have different opinions on the mechanism of the force of the embedded parts, and the calculation method of the bearing capacity of the embedded parts is also different. In this paper, the research on the theory of the sheared and tension-sheared parts of embedded parts of straight anchors in the previous literature and the current norms is conducted, and the existing calculation methods of the ultimate bearing capacity are compared. The calculation method is compared with the experimental results, and the theoretical verification analysis is performed. The research results show that: Nowadays, the calculation of the shear capacity of the anchored parts of the anchors is conservative, and there are some factors that have not been considered, so they are much smaller than the actual bearing values. For the shearing ability, the two are the calculated values which are close to the correlation between the pulling and shearing. When the embedded parts are damaged, the anchors fully give full play to the tension-shear effect, which can be used in the project.

1 Introduction

The embedded parts of straight anchors are made up of concrete, consisting of anchor plate and anchor, external steel structure and other structural connecting parts. In recent years, in the context of the rapid development of steel-concrete composite structures and fabricated buildings, embedded parts are widely used in super high-rise building structures, tunnels and building machinery due to their advantages of good force transmission performance and convenient construction. Embedded parts of straight anchors are the most widely used embedded parts. As one of the components of the steel-concrete structure connection node, the influence of the embedded parts on the safety of the building structure is self-evident.

The existing research has made a detailed study on the mechanical model and bearing capacity calculation formula of the embedded parts of straight anchors. The experimental research group and the theoretical analysis of the embedded parts research group put forward the various mechanical properties and design methods of the embedded parts [1]. Wang Baozhen, Zhao Mengmei et al. [2-3] studied the calculation method of the mechanical properties of embedded parts and related construction measures. In recent years, Zhu Hongjian, Wang Wei et al. [4-5] also made corresponding research and analysis on the practical calculation of embedded parts. However, due to the different understanding of the force model of the embedded parts, the existing calculation methods for

the bearing capacity of the embedded parts are not the same.

In this paper, the mechanical model of the embedded parts of straight anchors under the two conditions of shear and tension-shear is studied, and the existing calculation methods of ultimate bearing capacity are compared. The existing calculation methods are compared with the experimental results, conducting theoretical verification analysis research.

2 Specimen design

The anchor rib in the embedded parts of straight anchors of the test is steel with a diameter of 20 mm; the anchor plate is made of manganese steel plate with a thickness of 12 mm according to the specification requirements; the end plate of the component is also a manganese steel plate with a thickness of 12 mm. The manufacturing process of the embedded parts is as follows: the piercing plug is used between the anchors and the anchor plate; the end plate of the anchor plate and the overhanging plate are welded by the groove. To ensure the axial force during loading, the positioning of the force-transmitting steel plate is strictly controlled during processing. The concrete base adopts structural reinforcement, and the test piece is made by tying the steel bar, the supporting formwork and the embedded part, and then pouring the C40 commercial concrete. At the same time, the concrete test block is reserved, and the test piece is naturally cured under the same conditions. The compressive

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strength of the cube measured before the test is 60.5 MPa; the anchor rib is HRB335.

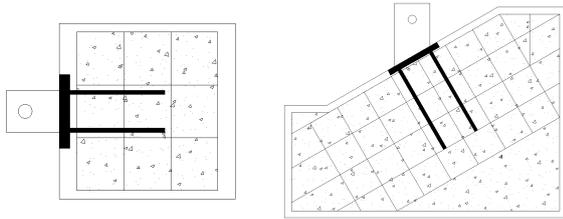


Fig. 1. Schematic diagram of embedded parts under shear and tension-shear

3 Comparison and verification of shear calculation methods

3.1 Shear formula one

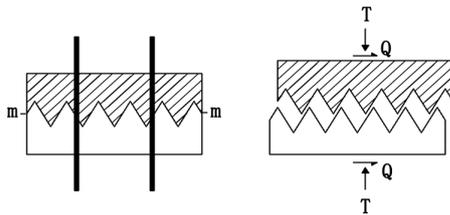


Fig. 2. Shear friction assumption

According to the "shear-friction" theory [2][1], as shown in the above figure, the above figure shows the whole concrete block, assuming the shear force Q , along with the shear plane. There is a crack in $m-m$, and the interface of the crack is rough. When the crack appears to slip, the concrete on both sides of the crack should be relatively away from the σ distance. The concrete is separated to make the steel bar generate tensile force T , which in turn is the two. A staggered concrete block creates a gripping force that creates a pressure (ie, a positive pressure) on the failure surface. This pressure exerts resistance (ie, friction) to the crack by the friction of the rough failure surface, assuming that the concrete block is sufficiently separated, When the steel bar is pulled to the yield point σ_s , the ultimate shear force is applied.

$$Q = \mu A_g \sigma_s \quad (1)$$

Where:

A_g —cross-sectional area of the steel bar.

μ —a constant similar to the coefficient of friction.

σ_s —the yield strength of the steel.

3.2 Shear formula two

According to the fact that after applying a layer of butter between the anchor plate and the crucible (eliminating the frictional force), the shearing force is reduced by 22%, it means that the bearing shearing force V_u is mainly borne by the anti-pressure F_1 of the anchor rib, and the friction force F_2 . Only a small part, for the convenience of calculation, F_2 is calculated as 20% of V_u . And merge it into F_1 , then

$$V_u = F_1 + F_2$$

$$= \frac{1}{1-0.2} \sqrt{2(0.78+1)M_0 \times 8.8 f_{cu} \bullet d} \quad (2)$$

Where:

f_{cu} —the cube strength of concrete.

When the ratio of the lateral margin s of the anchor rib to the diameter d is $s/d < 5$, V_u decreases as s/d decreases, and is more pronounced at $s/d < 3$. The main reason is that after the anchor ribs are too close to the edge, the concrete is cleaved and destroyed. At this time, the above formula is calculated by the following formula.

$$V_u = 3.7 \beta A_s \sqrt{f_s \bullet f_{cu}} \quad (3)$$

Where:

A_s —the cross-sectional area of the anchor rib.

β —the coefficient of the transverse script of the anchor and the influence of the diameter d on the shearing force.

(1) When the s/d is an arbitrary value,
 $\beta = 0.45 \sqrt{s/d} \leq 1$;

(2) When $d^2/s \leq 1$, $s \geq 4$ cm,
 $\beta = 1.2 - 0.65 d^2/s$;

When $d^2/s < 0.2$, take $d^2/s = 0.2$, (d, s in cm).

3.3 Shear formula three

According to the experimental research and theoretical analysis of the embedded parts of the straight anchor ribs. According to the domestic 151 sheared embedded parts tests, these test pieces are all normal reinforcement, the concrete is C25~C45, and the straight anchoring bars are mainly II deformed steel bars. The relationship between the shear strength V_u of the embedded part and the diameter d of the anchor is: the construction manual V_u

is proportional to $1/\sqrt{d}$, and V_u is proportional to $1/\sqrt[3]{d^2}$.

Through experimental analysis, the relationship between V_u and $1/\sqrt{d}$ is in good

agreement. Therefore: $\xi = \frac{V_u}{A_s} \sqrt{\frac{d}{f_u f_{cu}}}$, the regression analysis of the test points can obtain the relationship between V_{u15} and the lateral margin of the steel bar c :

$$V_{u15} = (3.44 + 0.143 \frac{c}{d}) \sqrt{\frac{f_u f_{cu}}{d}} A_s \quad (4)$$

Where:

c —the lateral margin of the anchor.

d —the diameter of the anchor (in cm).

f_u —the tensile strength of the anchor.

f_{cu} —the compressive strength of the concrete cube.

A_s —the total area of the anchor.

3.4 Comparison and analysis of test data and calculation formula

Table 1. Comparison of test data and calculated values

Num ber	Formula 1 /kN	Formula 2 /kN	Formula 3 /kN	Measured ultimate load/kN
A-1	248.2	328.9	414.1	380.5
A-2	248.2	328.9	414.1	397.3
A-3	248.2	328.9	414.1	402.7
A-4	248.2	328.9	414.1	390.5
A-5	248.2	328.9	414.1	387.2

The strength of the ultimate load measured by the large-diameter anchored ribs in this experiment is much higher than the value of the ultimate load calculated by the formulas in [2]. The value of the yield strength of the embedded part calculated by the "shear-friction" theory proposed is relatively conservative. According to the obtained test results, the literature believes that the shear strength V_u is proportional to $1/\sqrt{d}$, and overestimates the influence of the increase of the diameter of the anchorage on the shear bearing capacity, so that the theoretical calculation value of the test is much smaller than the actual value. test value. The literature [1] ignores the influence of the diameter of the anchorage on the shear strength, so that the value of the ultimate load measured in practice is lower than the calculation result. The semi-empirical and semi-theoretical formulas are proposed and the literature have the same tensile and compressive strength status of the steel bars, which is not in accordance with the failure mode of the test piece in the test. Therefore, the large-diameter anchorage embedded parts have higher values of shear capacity and can be implemented in engineering. The current application of the specifications and the anti-shear formula of the embedded parts in the literature are more conservative in the calculation of large-diameter anchors.

4 Comparison and verification of pulling shear calculation methods

4.1 Pulling shear formula one

Wang Baozhen and Zhang Kuanquan's team studied the "shear-friction" theory of reinforced concrete. Based on this theory and combined with the test of the mechanical properties of embedded parts, in 1980, the embedded parts were put forward in various stresses. The calculation formula of the anchor under the state. At the same time as the stress performance test of the embedded parts, the shear transmission test of the reinforced concrete was carried out. Through the test analysis, the calculation formula of the anchor of the embedded parts under various stress states is proposed, and the anchor of the axial shearing is now calculated. The embedded part is subjected to axial shearing, and the external force P is first decomposed into tensile force $N=P \cdot \sin \alpha$ shearing force $Q=P \cdot \cos \alpha$. The shear transmission test has proved that the steel bars that are formally subjected to shear force work under the tension force. Therefore, both the tensile force N and the shear

force Q cause the anchorage to generate tensile stress, and the tensile force and shear force cause the stress generated by the anchorage. They are respectively

$$\sigma_1 = \frac{N}{A_g} = \frac{P \cdot \sin \alpha}{A_g}, \quad \sigma_2 = \frac{Q}{\mu_1 \mu A_g} = \frac{P \cdot \cos \alpha}{\mu_1 \mu A_g}$$

then the anchorage stress algebra generated by the two forces is synthesized, and the total stress of the anchorage is controlled to not exceed the tensile strength of the tensile design R_g . This leads to the calculation formula:

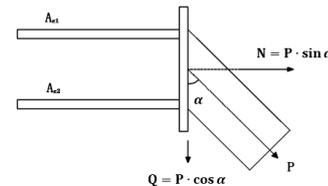


Fig. 3. Pulling shear formula one force diagram

$$K_1 \leq \frac{A_g R_g}{\sin \alpha + \frac{\cos \alpha}{\mu}} \quad (5)$$

Where:

K_1 —the safety factor of tensile shear strength design.

A_g —cross-sectional area of all anchors.

α —the angle between the external force P and the plane of the anchor plate.

μ —coefficient of friction coefficient reduction due to the effect of tension.

4.2 Pulling shear formula two

Under the action of the external force of pulling and shearing, the damage of the embedded parts is controlled by the largest row of anchor ribs, and any external force acting on a row of the anchor can be transformed into a shear force V and a normal force N_1 . Therefore, the calculation formula of the sheared embedded parts is also calculated by the maximum row of anchors. The force mode of the embedded part is shown in Figure 18, and the calculation diagram is shown in the figure. From the balance condition of point A:

$$-\frac{M_A}{W_0} + \frac{N_1}{A_{s1}} = f_{st} \quad (6)$$

$$M_A = \left(1 - \frac{N_1}{A_{s1} f_{st}}\right) M_0 = \epsilon M_0 \quad (7)$$

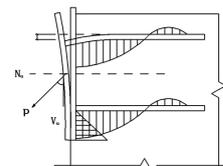


Fig. 4. Pulling shear formula two force diagram

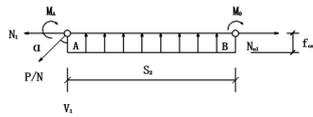


Fig. 5. Pulling shear formula two calculation sketch

According to the domestic Yin Zhilin research team, a large number of tensile shear tests were carried out on the embedded parts. These test pieces are normal reinforcements, the concrete is C25~C45, the straight anchor bars are grade 1 deformed steel bars, and the diameter of the anchor bars is $d = 12\text{mm}$, $c / d = 2.5 \sim 6.67$, anchor length is $l = 20d \sim 25d$. According to the formula (8) and the test analysis results, the $N/N_{u0} - V/V_{u0}$ shown in Fig. 98 can be drawn. The relationship curve can be seen from the figure. The tensile strength of the embedded parts is calculated by the formula (8). Most of the test points are safe except for a few test points. Since the first item on the left side of (8) is a quadratic square and the second term is a quadratic square, the design application is not convenient enough. After experimental analysis, it can be simplified into a formula:

$$\left(\frac{V}{V_{u0}}\right)^2 + \frac{N}{N_{u0}} = 1 \quad (8)$$

$$\frac{V \cos \alpha}{V_{u0}} + \frac{N}{N_{u0}} = 1 \quad (9)$$

Where:

V_{u0} — pure shear strength of the entire embedded part.

N_{u0} — tensile strength for the entire embedded part.

$$V = P \cos \alpha ; \quad N = P \sin \alpha$$

4.3 Comparison and analysis of test data and calculation formula

Table 2. Comparison of test data and calculated values

Num ber	Formula 1 /kN	Formula 2 V_{u01} /kN	Formula 2 V_{u02} /kN	Measured ultimate load/kN
B-1	230.61	302.7	313.6	309.6
B-2	230.61	302.7	313.6	310.3
B-3	230.61	302.7	313.6	309.8
B-4	230.61	302.7	313.6	311.0
B-5	230.61	302.7	313.6	310.1

In the table, V_{u01} in Equation 2 takes the calculated value, and V_{u02} in Equation 2 takes the measured value.

Through the test of five test pieces, the test data was obtained, and the ultimate load measured in the test was much higher than the calculated value of the given formula 1. According to the value of V_{u0} in formula 2, the theoretical calculation value is substituted, and the calculation result is lower than the measured value; if the value of V_{u0} is substituted according to the measured limit load, the calculated result is very close to the measured value. In general, the measured ultimate load varies between 309.6 and 311.0, with little change. The formula for the shear-correlation given in the literature is also applicable to the embedded parts of large-diameter anchors. The large-diameter anchorage embedded parts

have high bearing capacity under the combined action of tensile force and shearing force. The anchoring ribs can fully play their role during the failure and can be used in engineering.

5 Conclusion

- For sheared embedded parts, the calculated values obtained by the three formulas are smaller than the actual bearing values. Equations 1 and 3 are derived using semi-empirical and semi-theoretical theory. The compressive strength of concrete is equal to the tensile strength of steel. While Equation 2 does not take into account the correlation between the diameter of the anchor and its shear strength. In general, the current specifications and previous literature are too conservative for the shear strength of anchors.

- For the tension-sheared embedded parts, the calculated value of Formula 4 is much lower than the measured ultimate load value, and the calculated value obtained by Formula 5 is close to the actual value, which indicates that Formula 5 is more suitable for the correlation of the shearing shear. The embedded part has a high tensile shearing capacity, and the anchors can fully play its role when the damage is broken. The embedded parts of straight anchors can be used in actual engineering.

- The existing research formulas and calculation methods in China are quite limited. The concrete structure design specification only states that the diameter of the embedded parts should not be less than 8 mm and should not be greater than 25 mm. However, when it is necessary to design special embedded parts such as bridges, the existing calculation methods cannot meet the actual needs, and in the future research, detailed research can be done.

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