On Bearing Capacity of Power Tunnel Angle Steel Brackets

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Abstract: Based on the typical power tunnel project in Guangzhou, a finite element analysis model is established based on full-scale test. The stress, strain and displacement of the support under end load are studied. The results show that the length of the bracket and the thickness of the angle steel have great influence on the bearing capacity of the support, and the relationship between the length and the bearing capacity is basically linear. The model is used to analyze the parameters of the bracket, and the optimal structure form is obtained to achieve the goal of economic and efficient.

1. Introduction
The experience of urban development in developed countries abroad shows that the urban integrated pipe veranda is an important symbol of urban modernization and an inevitable outcome of the development of modern cities[1]. With the acceleration of urbanization, urban construction land is expanding, and China's existing land resources are very limited, it is difficult to adapt to urban development needs for land[2]. At present, the development scale of urban underground pipe network, the impact on urban traffic and environment during the process of pipeline laying, maintenance and replacement, and the interference to people's lives and work are increasingly serious. The traditional construction technology of underground pipeline for trenching and buried pipe has a great impact on the ground transportation, which makes the already crowded urban traffic worse, and brings many inconveniences to the citizens' work and life, especially in densely populated cities and traffic-stricken areas, as well as lots that are not allowed to be excavated, this contradiction is more prominent. Moreover, with the rapid development of China's urban economy, the contradiction between urban electricity (transmission) demand and land resources is increasingly prominent, and society's requirements for urban power supply reliability are getting higher and higher. Therefore, underground power tunnels and cable brackets are widely used in urban power transmission projects to solve the above contradictions[3].

So far, Guangzhou has adopted an arc cable bracket system in the circular section tunnel in the urban power supply line. The bracket system has the advantages of simple installation, short
construction period, corrosion resistance, etc. and is widely used. However, the ultimate bearing capacity of the bracket system has not yet been clearly tested, and when the cable system is installed, the bracket system is liable to cause the cable bracket to sag, which is not conducive to cable placement, this is a real problem with the system\cite{4}. In addition, in line with the principle of green energy-saving, the bracket system urgently needs to further optimize the design to improve the bearing capacity and save material usage.

Through visiting the construction and operation and maintenance units, the shortcomings and operation and maintenance requirements of conventional cable bracket were investigated. Through research methods such as model test, numerical simulation analysis and optimization design, a series of researches on key technical issues such as structural form of the bracket, cable laying and embedded structure are carried out. In order to improve the cross-section utilization of circular power tunnels, optimize the construction environment, ensure construction quality and work efficiency, improve corrosion resistance, and facilitate operation and maintenance management\cite{5}\cite{6}. In this paper, the finite element analysis model is established to analyze the deflection curve of the bracket during the loading process, the stress and strain curves of each part, and then use the model to analyze the parameters of the bracket to obtain the optimal bracket structure, in order to guide the design and construction.

2. Full-scale Test

The load value is considered as follows: the single weight of the 220kV high-voltage cable is about 40kg/m, the single weight of the 550kV high-voltage cable is about 50kg/m, the length of the cable joint is about 2m, and the weight is about 180-200kg/m. Each cable per bundle on the cable bracket contains 3 cables. If it is a long bracket, 2 bundles of cables on the bracket, or 1 bundle of cables + 1 connector. Consider the dynamic effect of the installation process of cables and cable joints, and adopt the pseudo-static method, taking the dynamic coefficient as 2.0. The longitudinal cross arm bracket distance is 1.25m, so the short bracket load is 3.75kN and the long bracket load is 7.75kN.

Based on the typical cable bracket type in the power tunnel project in Guangzhou\cite{7}, combined with the characteristics of the cable bracket, the following new cable bracket model is designed.

The test cable bracket is installed in the form of bilateral symmetry, which plays the role of controlled trial. The test cable bracket has 4 layers and is installed in 1-4 layers.

Adhesive strain gage, long bracket and short bracket on the surface of the steel circle beam and cable bracket, two long brackets and six short brackets were selected for strain monitoring, and the strain gage were arranged as shown in Fig. 1 and Fig. 2.

Figure 1. Long bracket (No. 1th) Strain Gage Layout
The strain gage H32 and H36 at the variable cross section of the bracket 1 symmetric bracket corresponds to the H17 and H13 of the bracket 1. The strain gage H49 and H53 at the variable cross section of the bracket 2 symmetric bracket corresponds to the H27 and H31 of the bracket 2.

The vertical displacement of the test cable bracket is measured by a displacement meter (percentage meter), and the installation position is shown in Fig.3.

Before each bracket is loaded, arrange 8-10 displacement meters below it to measure the vertical displacement of the bracket in real time. The bracket numbering rules are: from top to bottom, the brackets are 1, 2, 3, and 4, respectively. The displacement meter numbering rule is: 1, 2, 3, 4, 5, 6, 7, 8 from the left bracket to the right bracket.

Long bracket: 1kN for initial loading, 1kN for each stage in the later stage, until the cumulative load is 12kN. The load of each stage was held for 3 minutes, and the strain gage and displacement meter data were collected before and after the load.

Short bracket: 1kN is initially loaded, and 1kN is added for each stage in the later stage, until the cumulative load is 6kN. The load of each stage was held for 3 minutes, and the strain gage and displacement meter data were collected before and after the load.
3. Finite Element Analysis

3.1 Boundary conditions and loading method
The boundary conditions of the steel bracket model are set as follows: taking the semi-structure analysis, fixed constraints are set at the concrete cut, in order to make the calculation easy to converge, temporary boundary conditions are set at the beginning of the analysis, so that the contact relationship of each part is established smoothly, the temporary boundary conditions are mainly set at the free end of the angle steel bracket. The load is divided into two parts, one is the bolt load and the other is the concentrated load on the steel bracket. Bolt load setting is divided into three steps: 1) A small load value is set on the middle section of the bolt, so that each contact surface smoothly establishes a contact relationship; 2) Set the predetermined bolt load to reach the bolt preload value; 3) Fix bolt length. The steel bracket load adopts the displacement loading method, and the displacement value equivalent to the experimental value can be set at the reference point of the bracket. The loading sequence of the brackets is applied according to the construction sequence, that is, the No. 4 bracket load is applied in the first step, the No. 3 bracket load is applied in the second step, the No. 2 bracket load is applied in the third step, and the No. 1 bracket load is applied in the fourth step. Finite element division adopts C3D10M solid unit and the hexahedral structural division technique for steel bracket, steel ring and concrete pipe joint, steel bars use T3D2 truss elements.

3.2 Test and simulation results analysis

![Figure 5. Bracket 1 Test and simulated displacement comparison](image)
Figure 6. Bracket 2 Test and simulated displacement comparison

Figure 7. Test and simulated strain contrast of Bracket 1 variable section

Figure 8. Test and simulated strain contrast of Bracket 2 variable section
According to the above data comparison analysis, the simulation data of each bracket displacement is better than the experimental data, and the displacement data has a maximum difference of 12.8%. When the steel is in the elastic stage, it can be well matched with the simulation data. When the steel enters the plastic zone, the deformation grows rapidly and the real change cannot be measured. Based on the comprehensive displacement measurement data, it is considered that the simulation data can better reflect the deformation state of the steel.

The finite element model stress, strain, and displacement cloud diagrams are shown in Fig. 11-14.

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Figure 9. Bracket 3 Test and simulated displacement comparison

Figure 10. Bracket 4 Test and simulated displacement comparison

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Figure 11. Stress cloud of steel ring and bracket
It can be seen from Fig. 11 and Fig. 12 that the maximum value of the bracket stress is located at the variable section of the web, the left side of the upper bolt hole, and the upper right corner of the lower bolt hole, and the stress of the upper bolt hole is generally greater than the stress of the lower bolt hole, which is consistent with the stress process of the bracket trend. Therefore, under the vertical load, the upper left corner of the upper bolt hole is in contact with the screw, and the upper right corner of the lower bolt hole is in contact with the screw, resulting in a large stress in the two positions, and the load is first transmitted to the upper screw hole, so the upper screw The hole stress is greater than the lower screw hole stress. As the end of the bracket changes its angle as the shape of the steel ring changes, the contact orientation of the upper screw and the bolt hole also changes, and the upper left corner of the bracket 1 gradually changes counterclockwise. Among them, the bracket 1 has three bolt holes in the web, but the intermediate bolt hole has less stress and has less influence on the bearing capacity of the bracket.

Figure 12. Stress cloud of bracket

Figure 13. Stress cloud picture of concrete reserved bolt hole

It can be seen from Fig. 13 that the impact of the bracket load on the bolt hole is small, under the full load of the bracket, the stress near the bolt hole is about 10 MPa on average, indicating that the reserved bolt hole design meets the bracket bearing requirements and will not have a devastating effect on the pipe section. In the lower half of the pipe section, there is also a partial stress distribution in the middle of the left and right bolt holes, indicating that the end of the bracket has compressive stress on
According to the analysis of Fig. 8, Fig. 9, and Fig. 10, the bearing capacity of the bracket 4 is obviously larger than that of the bracket 2 and the bracket 3, that is, the compressive stress generated on the concrete end of the bracket is beneficial to the improvement of the bearing capacity. Therefore, in the design of the bracket, the end form of the bracket should be considered, and the steel ring can be well fitted, and the bearing capacity of the bracket can be improved.

Figure 14. Stress cloud of steel ring

Based on the above results, the finite element model can effectively simulate the stress process of the steel bracket. The following changes the steel bracket parameters to analyze the force state of the steel bracket under different parameters, so as to provide strong support for optimizing the steel bracket design.

4. Optimization Design

4.1 Angle steel bracket optimization

By changing the parameters of the steel bracket, the stress state of the steel bracket under different parameters is analyzed to optimize the steel bracket design.

By changing the angle of the web corbel and the thickness and length of the angle steel, the variation of the bearing capacity and the stress distribution of the bracket under different conditions were analyzed to obtain the optimal bracket type.

The different bracket parameters are shown in the table below:

| Number | Angle steel thickness (mm) | Angle steel length (mm) | Bracket web corbel angle (°) |
|--------|----------------------------|-------------------------|-----------------------------|
| 1      | 8                          | 550                     | 60                          |
| 2      | 10                         | 550                     | 60                          |
| 3      | 12                         | 550                     | 60                          |
| 4      | 14                         | 550                     | 60                          |
| 5      | 10                         | 450                     | 60                          |
| 6      | 10                         | 550                     | 60                          |
| 7      | 10                         | 650                     | 60                          |
| 8      | 10                         | 850                     | 60                          |
The displacement-load curve and stress distribution of different angle steel thicknesses are as follows:

![Diagram of load-displacement of angle steel bracket with different thickness](image1)

**Figure 15.** Diagram of load-displacement of angle steel bracket with different thickness

![Relationship between thickness and load of angle steel](image2)

**Figure 16.** Relationship between thickness and load of angle steel
It can be seen from Fig. 17 that when the other parameters of the angle steel are unchanged, the bolt type is the same, and the thickness of the angle steel is 10 mm, the optimal bearing capacity requirement can be achieved.

The displacement-load curve and stress distribution of different length angle steel brackets are as follows:

Figure 17. Stress Cloud Chart of angle steel bracket and bolt with different thickness

Figure 18. Diagram of load-displacement of angle steel bracket with different lengths
It can be seen from Fig. 18 that the bearing capacity of the angle steel bracket decreases with the increase of the length of the angle steel. As can be seen from Fig. 17 to Fig. 20, in order to fully exhibit the characteristics of the steel material while the other conditions are not changed, the length should be controlled between 450 mm and 650 mm.

The displacement-load curve and stress distribution of angle steel brackets with different web lengths are shown in Fig. 19 and Fig. 20 respectively. The angle steel bracket length and load relation diagram is shown in Fig. 19. The stress cloud of angle steel bracket with different lengths is shown in Fig. 20.

Figure 19. Angle steel bracket length and load relation diagram

Figure 20. Stress cloud of angle steel bracket with different lengths

a—length 450mm angle steel; b—length 650mm bolt
angles are as follows:

![Image of load-displacement diagram with different angles]

Figure 21. Diagram of load-displacement of angle steel bracket with different webs
It can be seen from Fig. 21 and Fig. 22 that the web angle is 45° steel, which can achieve better bearing capacity requirements, and at the same time, can fully utilize various parts of the steel to reach an equilibrium state.

Studies [9-10] have shown that the stiffness of the bolted joints is often in the middle of the rigid and the hinge, showing semi-rigid performance [11]. According to the above analysis, the reasonable type of angle steel bracket should be: the thickness of the angle steel is 10mm, the length is between 450-650mm, and the angle of the web is 45°. If you need to lengthen the length of the angle steel to meet the operation and maintenance requirements, you can thicken the thickness of the angle steel or use a higher grade steel, such as Q345, etc. If the thickness of the angle steel is thickened, a higher grade bolt is required to meet the bearing capacity requirements.

4.2 Bracket system design
According to the finite element results, the short bracket design of the original design has too much design redundancy, especially the test No. 4 bracket. Now optimize it: the short bracket section size is 100×70mm, the length is 450-550mm, the length of the long bracket is 100×140mm, the length is 1050mm, and the angle of the web corbel is 45°. The steel circle beam is made of symmetrical equilateral angle steel with a section size of 100×100×7mm; the bolt sleeve is 80mm long and 20mm in diameter. The connecting bolt between the cross arm bracket and the steel circle beam is M16, and the connection between the steel circle beam and the concrete is 8.8 grade M20 bolt.

The short bracket load is 6kN, and the long bracket load is 8kN. The modeling process is the same as above. The relationship between the load and displacement of the bracket and the bending moment of the steel circle are shown in the following figure:
5. Result

1) Parameter analysis of the bracket. The results show: 3m inner diameter concrete pipe jacking section angle steel bracket reasonable type should be: The angle of the angle steel is 10mm, the length is between 450-650mm, and the angle of the web is 45°. If you need to lengthen the length of the angle steel to meet the operation and maintenance requirements, you can thicken the thickness of the angle steel or use a higher grade steel, such as Q345. If the thickness of the angle steel is thickened, it is necessary to use a higher-grade bolt to avoid the shear failure of the bolt and meet the bearing capacity requirements.

2) The three weak points of the bracket under the load are the contact between the two screw holes and the screw, and the variable cross section of the bracket. Among them, the variable section of the bracket 1 is the most sensitive, and the central screw hole of the bracket 1 is less stressed, and has little influence on the bearing capacity, and the design can be cancelled.

3) In the design of the bracket, the end form of the bracket should be considered, which can fit the steel ring well and improve the bearing capacity of the bracket;

4) Under the condition of full load of the bracket, the stress near the bolt hole averages about 10 MPa, which indicates that the reserved bolt hole design meets the bracket bearing requirements and does not have a destructive effect on the pipe section;

5) The stress generated by the steel ring and the concrete at the junction 3 is the largest, which is the tensile stress. Each bracket has the greatest influence on the two connection junctions in the vicinity. And the loading of the previous bracket will reduce the stress at the junction below it., reduces the influence of bolts on the concrete, and has a positive effect on concrete cracking.

6) Based on the experimental and finite element results, and the optimization design of the bracket system is known. The short bracket section size can be 100×70mm, the length is 450-550mm, the length of the long bracket can be 100×140mm, the length is 1050mm, and the angle of the web is 45°. The steel circle beam is made of symmetrical equilateral angle steel with a section size of 100×100×7mm, and the bolt sleeve is 80mm long and 20mm in diameter. The connecting bolt between the cross arm bracket and the steel circle beam is M16, and the connection between the steel ring beam and the concrete is 8.8 grade M20 bolt.

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