Bearing Performance Analysis of Anti-slip Connector

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Abstract. The performance of anti-slip connector determines whether the mounted load can be reliably transmitted to the main body of transmission tower. In this paper, the specific design process for each part parameter of anti-slip connector is given, and the bearing performance of anti-slip connector is analysed by theoretical/finite element method. The results show that: The influence of the distance between rectangular steel pipes on the bearing capacity of anti-slip connector is related to the bolt grade. When the bolt grade is lower, the initial stiffness of anti-slip connector mainly depends on the rotational stiffness of two-plate connection. When the bolt grade is higher, the change of the distance between rectangular steel pipes causes the change of the linear stiffness of mounted iron bar, which leads to the obvious change of both initial stiffness and plastic bearing capacity of anti-slip connector. Meanwhile, the influence of bolt grade on the initial stiffness of anti-slip connector is also related to the distance between rectangular steel pipes. When the distance between rectangular steel pipes is smaller, the initial stiffness of anti-slip connector is greatly affected by the bolt grade. When the distance between rectangular steel pipes is larger, the initial stiffness of the anti-slip connector model is basically unchanged under the change of bolt grade. In practical engineering, when the mounted distance is limited, the corresponding bolt grade must be matched, so that the bearing capacity of anti-slip connector can be effectively performed.

1. Introduction
The shared tower integrates power/communication equipment as one. Since the interaction between these two types of equipment is not considered at the beginning of design, two kinds of technical problems (i.e., the bearing capacity of connecting device and the bearing capacity of tower structure) need to be solved first in the application process. In order not to affect the initial design indexes of transmission tower, the communication equipment and the transmission tower rely on the anti-slip connector to connect with each other. The normal use of communication equipment requires that the anti-slip connector has sufficient resistance reserve. Under normal operating conditions, the performance of anti-slip connector determines whether the mounted load can be reliably transmitted to the main body of transmission tower.

This paper focuses on the research of the first type of technical problem, that is, the bearing capacity related factors of anti-slip connector. Through in-depth research, this paper provides theoretical basis and technical support for the promotion and application of shared tower, gives the design method of connecting device, and clarifies the influencing factors of the bearing capacity of anti-slip connector.
2. Design Method of Anti-slip Connector

In order to avoid drilling holes in the materials of transmission tower and not affect the design objective of the initial bearing capacity of transmission tower, the design of anti-slip connector requires that the materials of transmission tower and the anti-slip connector only use friction force to balance the mounted load. An anti-slip connector is designed, whose structure is as shown in figure 1. The communication equipment is hung to the mounted iron bar. To prevent the relative slip between the mounted iron bar and the U-shaped screw, a groove is set up on the mounted iron bar. The mounted iron rod can be connected with the rectangular steel pipe through U-shaped screw, and both ends of rectangular steel pipe are welded with the corresponding connecting plates. The two-plate connecting device relies on the pre-tightening force of the bolt to form a friction force with the main materials of transmission tower to balance the mounted load.

![Figure 1. Schematic diagram of anti-slip connector](image)

The key parameters that affect the formation of friction force between the anti-slip connector and the main materials of transmission tower include: parameters of the bolts for two-plate connection (bolt grade and bolt diameter $d$), thickness of the two-plate $t$ (the thickness of the front plate is the same as that of the rear one) and overhanging length of the two-plate $e$. In order to avoid the plastic deformation of anti-slip connector under the mounted load, the above parameters can be preliminarily designed according to the elasticity theory.

2.1. Parameters of bolts for two-plate connection

First, the mounted weight $G$ and the angle between the main materials of transmission tower type to be mounted on and the ground $\theta$ shall be determined, where the mounted weight $G$ is the sum of the weight of communication equipment, the weight of mounted iron bar and the weight of U-shaped screw connecting device. The friction force between the fixture and the main materials of transmission tower must be greater than the component of mounted weight in the direction of the main materials of transmission tower. Whether the connector has enough friction force depends on the pre-tightening force of the bolt, which requires that the pre-tightening force of the bolt meet Formula (1):

$$G \sin \theta \geq \sqrt{2u \left(\frac{G}{2} \cos \theta + 3P_f \right)}$$

(1)

Wherein: $u$ is the friction coefficient of contact surface between the fixture and the main materials of transmission tower; $P_f$ is the design value of pre-tightening force of the bolt, which can be obtained by referring to the table, and according to which the corresponding specifications of bolt can be selected.

For the checking calculation of bolt strength, it shall be ensured that the bolt strength meet Formula (2):

$$P(d_1 + \frac{D_2}{D_1}d_2) \geq L \frac{G}{2} \sin \theta$$

(2)
Wherein: \( P \) is the design strength of the bolt; \( D_1 \) and \( D_2 \) are the distances from the uppermost bolt to the lowermost bolt/the lower end of connecting plate respectively; \( d_1 \) and \( d_2 \) are the distance from each bolt to the centre line of the plate respectively; among which, \( D_1 \), \( D_2 \), \( d_1 \) and \( d_2 \) are the distances as shown in figure 2. Through the calculation by the above two formulas, the more conservative bolt parameters are used to select the bolts for the connector.

![Figure 2: Calculation parameters](image)

2.2. Thickness of two-plate \( t \) and length of effective overhanging \( e \)
Under the action of mounted weight, Plate 2 is required to be free of plastic deformation, and the thickness of the plate \( t \) and the length of effective overhanging \( e \) must meet \( t \) Formula (3) [1-3]:

\[
\frac{ht^2 f_y}{3e} \geq \frac{GL}{2d_1} \sin \theta
\]  

(3)

Wherein: \( f_y \) is the yield strength of the materials of Plate 2.

In the actual production process, the bolt parameters can be first determined to match the plate thickness \( t \) which meets the structural requirements of steel structure specification/standard, and then the value of \( e \) will be determined by the above formula.

2.3. Cross-section of rectangular steel pipe
Under the action of mounted weight, the end of rectangular steel pipe is required to be free of plastic deformation, and the section modulus of rectangular steel pipe must meet Formula (4):

\[
W \geq \frac{LG}{2} \sin \theta / f_y
\]  

(4)

According to the value of \( W \), the type of rectangular steel pipe is selected from the structural steel able.

Through the above three steps, we can determine and check the cross-section specifications of each part connecting the fixture to ensure that the anti-slip connector is still in the elastic stage under the action of the mounted weight, to avoid any plastic deformation of each part, so that the anti-slip connector can have a high resistance reserve.

3. Analysis on the Factors Influencing the Bearing Capacity of Anti-slip Connector
Combined with the design method of anti-slip connector in Section 1, the specific dimensions of anti-slip connector are given (as shown in figure 3). The mounted iron bar is welded with the rectangular steel pipe through U-shaped screw connecting device. Because the groove is set up on the mounted iron bar, the integrity of the U-shaped connection and the mounted iron bar is better. The rectangular steel pipe can be directly welded with the mounted iron bar (realized by Command Tie), so as to reduce the contact relationship and improve the calculation efficiency. In order to analyse the development law and failure mode of the bearing capacity of substructure model under the condition of large deformation, and avoid the non-convergence problem of the model caused by the initial slip and steel fracture, ABAQUS/Explicit dynamics static method [4-6] is used for analysis and solution, where C3D8R solid unit is used for simulation of all parts; for the main materials of angle steel, connecting plate and high-strength bolt, all the contact surfaces are of general contact; isotropic Coulomb friction contact is
adopted in the tangent direction, and "hard" contact is set at the normal direction; the friction coefficient is taken as 0.3. By applying pressure to the upper/lower surface of high-strength bolt, the influence of the pre-tightening force of high-strength bolt on the plate to be connected is simulated. The constitutive relationship of steel materials adopts a widely used multi-segment four-broken line model, as shown in figure 4(a); the three-broken line constitutive model suggested in the references of [7] is used for that of high-strength bolt. The boundary conditions and mesh generation of the model are as shown in figure 5.

Figure 3. Model dimensions of anti-slip connector

Figure 4. Stress-strain relationship of materials

Figure 5. Unit division and boundary conditions of numerical models

Figure 6 shows the comparison of the model load-displacement curves at different distance between rectangular steel pipes under three bolt grades (Grade 6.8, Grade 8.8 and Grade 10.9). Combined with table 1, it can be seen that the distance between rectangular steel pipes d has less influence on its initial stiffness when using the anti-slip connector model connected with Grade 6.8/Grade 8.8 bolt. In the anti-slip connector model connected with Grade 6.8 bolt, when the distance between rectangular steel pipes is 1,500mm, the model presents better plastic bearing capacity. In the anti-slip connector model connected with Grade 8.8 bolt, the plastic bearing capacity is basically the same as that of the anti-slip connector model connected with Grade 6.8 bolt. In the anti-slip connector model connected with Grade 10.9 bolt, the influence of the distance between rectangular steel pipes on the initial stiffness is more obvious; when the distance between rectangular steel pipes is 2,000mm, the initial stiffness and plastic bearing capacity of anti-slip connector model decrease obviously. This is because the steel pipe is too large, which leads to the weakening of linear stiffness of the mounted iron bar, and the mounted iron bar cannot bear the force together with the cantilever rectangular steel pipe. According to the above analysis, the influence of the distance between rectangular steel pipes on the bearing capacity of anti-slip connector is related to the bolt grade, which directly affects both rotational stiffness and anti-slip
performance of two-plate connection. The above analysis requires that when the mounting distance is limited, the corresponding bolt grade must be matched, so that the bearing capacity of anti-slip connector can be effectively performed.

![Figure 6. Comparison of load-displacement curves at different intervals](image1)

**Table 1. Analysis of the results at the limit points of the load-displacement curve.**

| Margin | 6.8   | 8.8   | 10.9  |
|--------|-------|-------|-------|
| d/mm   | 1000  | 1500  | 2000  |
| v/mm   | 224   | 212   | 242   |
| p/kN   | 55    | 59    | 56    |

Figure 7 shows the comparison of the model load-displacement curves at different distance of rectangular steel pipe spacing (three kinds of distance of rectangular steel pipes: 1,000mm, 1,500mm and 2,000mm). Combined with Table 1, it can be seen that when the distance between rectangular steel pipes is 1,000mm and 1,500mm, the change of bolt grade has obvious influence on the initial stiffness and plastic bearing capacity of anti-slip connector, whose change law is that the initial stiffness and plastic bearing capacity of anti-slip connector will increase with the increase of bolt grade. When the distance between rectangular steel pipes is 2,000mm, the increase of initial stiffness of anti-slip connector with the increase of bolt grade is basically the same as that when the distance between rectangular steel pipes is 1,000mm and 1,500mm, meanwhile its plastic bearing capacity wills increases accordingly.

![Figure 7. Comparison of load-displacement curves at different bolt levels](image2)

**4. Conclusions**

(1) The design method proposed in this paper can ensure that the anti-slip connector and the main material of the transmission tower do not slide relative to each other under the mounted load, and avoid any plastic deformation of anti-slip connector, so that the anti-slip connector can have a high resistance reserve.

(2) According to the elastic theory analysis, the stiffness of anti-slip connector is independent of the distance between rectangular steel pipes \(d=l\); and the increase of bolt grade leads to the increase of rotational stiffness \(k_r\) of two-plate connection, resulting in the increase of overall stiffness of anti-slip connector. The influence of the distance between rectangular steel pipes on the overall stiffness of anti-slip connector is affected by the rotational stiffness of two-plate connection, but if the rotational stiffness is larger and the connection between the rectangular steel pipe and the main materials is more rigid, the above assumed analysis will change.
(3) The influence of the distance between rectangular steel pipes on the bearing capacity of anti-slip connector is related to the bolt grade. When the bolt grade is lower, the initial stiffness of anti-slip connector mainly depends on the rotational stiffness of two-plate connection. When the bolt grade is higher, the change of the distance between rectangular steel pipes causes the change of the linear stiffness of mounted iron bar, which leads to the obvious change of both initial stiffness and plastic bearing capacity of anti-slip connector. Meanwhile, the influence of bolt grade on the initial stiffness of anti-slip connector is also related to the distance between rectangular steel pipes. When the distance between rectangular steel pipes is smaller, the initial stiffness of anti-slip connector is greatly affected by the bolt grade. When the distance between rectangular steel pipes is larger, the initial stiffness of the anti-slip connector model is basically unchanged under the change of bolt grade. In practical engineering, when the mounted distance is limited, the corresponding bolt grade must be matched, so that the bearing capacity of anti-slip connector can be effectively performed.

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