Research on Calculation of Bearing Force of Composite Insulation Cross Arm Pressure Rod of 220kV Power Transmission Line Pole Tower

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Abstract. The lower pressure rod of composite insulation cross arm of power transmission line pole tower is connected with the pole tower body and the coupling end joint respectively. The connection pattern on both ends of lower pressure rod are connected with slot type flash board, cross type flash board, U-shaped flash board, etc. The most frequently adopted one is connecting the cross type flash board on one end with the tower body, and connecting the slot type flash board on the other end with the joint of coupling end. The lower pressure rod of this pattern is that one end is axis connection while the other end is eccentric connection, and the calculation method for axial pressure bearing force is not suitable any longer. This paper conducts pressure test and finite element analysis on the solid composite material circular core rod member which is connected with cross type flash board on one end and slot type flash board on the other end, proposes the slenderness ratio correction coefficient of lower pressure rod of composite insulation cross arm of 220kV power transmission line pole tower, and provides basis for standardization of calculation method for bearing force of composite insulation cross arm pressure rod of power transmission iron tower.

1. Introduction
Relying on the Tianzhu - Science 220kV power transmission line project in Wenzhou, this paper implements research on calculation of structural bearing force of composite insulation cross arm. This project refers to dual-loop erection on the same tower; wherein, the 2-base iron tower and the 4-base iron tower apply the composite insulation cross arm. After this Project adopts composite insulation cross arm, although the purchasing and manufacturing cost of composite material is increased, the cost in tower material, basic cubic volume and political treatment is reduced more. The overall construction cost of the circuit within the final pilot scope is saved by 4%.

The composite insulation cross arm structural pattern of angle steel tower in this Project adopts dual-column dual-cable-stayed pattern, see Figure 1(a); the structural pattern of composite insulation cross arm of steel pipe rod adopts dual-column single-cable-stayed pattern, see Figure 1(b). The composite insulation cross arm consists of suspension type composite insulator (hereinafter referred to as tension rod), column type composite insulator (hereinafter referred to as pressure rod) and end joint; the suspension type composite insulator and column type insulator are all single piece entirety, without middle joint. Both the pressure rod and tension rod are “O”-type cross section solid core rod. One end
of the pressure rod is cross type flash board, and the other end is slot type flash board. The pressure rod is connected with tower body via cross type flash board, and is connected with coupling node on the end via slot type flash board. The tension rod adopts PT adjustment plate to be connected with coupling hole of tower body, and is connected with end joint with bolt.

![Diagram](image1)

(a) Dual-column Single-cable-stayed Type  
(b) Dual-column Dual-cable-stayed Type

Figure 1. Structural Pattern of Composite Insulation Cross Arm

At present, during the design of composite insulation cross arm structure, the stable bearing force of pressure rod is calculated according to axis rod hinged on both ends. Actually, with regard to the pressure rod adopted in this Project, one end is cross type flash board, without structural eccentricity, and it is a kind of ideal axis pressure connection; the other end is slot type flash board, and there is structural eccentricity. In case of calculating the bearing force of such pressure lever exactly, it is necessary to consider reflecting the slenderness ratio correction coefficient influenced by structural deviation. In the steel pipe tower, during the calculation of pressure bearing force of steel pipe member connected with the slot type flash board, the influence of eccentricity or restraint is considered. At present, there are not many researches on calculation method for pressure bearing force of solid circular core rod for composite insulation cross arm. This paper combines application situation of composite insulation cross arm project, and implements research on the calculation method for pressure borne by solid core rod pole member of lower pressure rod.

2. Influence Coefficient of Pressure Rod of Composite Insulation Cross Arm

The end connection structure between pressure rod of composite insulation cross arm and coupling joints of tower body and end may have a certain influence on the bearing force of pressure rod. To get to know the influence on bearing force of member, this paper adopts the formulas 1)-5) for calculation; wherein, the slenderness ratio correction coefficient K in the formula 4) is the influence coefficient of joint pattern on bearing force of member.

The stability calculation of axis pressure member proposed in Q/GDW 11875-2018 Technical Code for Design of Composite Insulation Cross Arm of Overhead Power Transmission Line shall meet the following rules:

\[
\frac{N}{(\phi \cdot A)} \leq f
\]

In the formula:  
\(N\) - Axial pressure stability bearing force of composite material pole member, kN;  
\(\phi\) - Stability coefficient of axial pressure member, calculated as per formulas (2)-(5);  
\(f\) - Design value of longitudinal compressive strength, MPa;  
\(\lambda_n \leq 0.215\)  
\(\phi = 1 - \alpha_1 \lambda_n^2\)  

(2)
\[ \lambda_n > 0.215 \]
\[ \phi = \frac{1}{2\lambda_n^2} \left[ (\alpha_2 + \alpha_3 \lambda_n^2 + \lambda_n^2) - \sqrt{(\alpha_2 + \alpha_3 \lambda_n^2 + \lambda_n^2)^2 - 4\lambda_n^2} \right] \]
\[ \lambda_n = \frac{K \lambda}{\pi} \frac{f_{ck}}{E_{cx}} \]
\[ \lambda = \frac{l_0}{i} \]

3. Pressure Test of Pressure Rod of Composite Insulation Cross Arm

3.1. Test Sample

The test sample adopts the lower pressure rod of composite insulation cross arm in the Project, and the lower pressure rod refers to solid composite material circular core rod, and the specimen pressure rod specifications are φ150 and φ130. See Table 1 for the specimen No., calculated length, calculated slenderness ratio and material mechanics performances. The calculated length of specimen in Table 1 refers to the total length of spherical hinge, connection node and composite material core rod. For these materials are from the same batch, the compression strength, compression modulus and Poisson’s ratio take the average value of test. The Poisson’s ratio takes the empirical value, i.e. 0.3.

| S/N | Core Rod Diameter (mm) | No. of Test Specimen | Calculated Length (mm) | Calculated Slenderness Ratio | Compression Strength (MPa) | Compression Modulus (GPa) | Poisson's Ratio |
|-----|------------------------|----------------------|------------------------|-----------------------------|---------------------------|--------------------------|----------------|
| 1   | 150                    | 150-4950-1           | 4950                   | 132.0                        |                           |                         |                |
| 2   | 150                    | 150-4950-2           | 4950                   | 132.0                        |                           |                         |                |
| 3   | 150                    | 150-4950-3           | 4950                   | 132.0                        |                           |                         |                |
| 4   | 130                    | 150-3862-1           | 3862                   | 118.8                        | 618                       | 55.9                     | 0.3            |
| 5   | 130                    | 150-3862-2           | 3862                   | 118.8                        |                           |                         |                |
| 6   | 130                    | 150-3862-3           | 3862                   | 118.8                        |                           |                         |                |

3.2. Test Device

Considering that the boundary conditions on both ends of composite material pole member in the truss structure are hinged, both ends of specimen adopt spherical hinge for connection. One end of the specimen is cross type flash board, and the other end is solid core rod of slot type flash board. The flash boards on both ends are connected with spherical hinge, which simulates the actual restraint status of pole member.
The test is completed in the 3,000kN horizontal type test device in part laboratory of test base of ultra-high-pressure pole tower, and the test device is as shown in Figure 2(a). See Figure 2(b) and (c) for flash boards on both ends of solid core rod.

![Overall Test](image1)

![Cross Type Flash Board](image2)

![Slot Type Flash Board](image3)

Figure 2. Loading Device of Pressure Test of Pole Member

### 3.3. Test Result

See Table 2 for the maximum test load of solid circular core specimen. The destruction situations of 6 specimens are the same, and take the solid circular core rod φ130-3862-3 specimen for example, at the initial stage of loading, the deformation is not obvious, and at the later stage of test, the deflection change in the rod is obvious, and shows steady destruction form. The destruction mode is as shown in Figure 3.

![Destruction Mode](image4)

Figure 3. Destruction Mode of Solid Circular Core Rod Specimen

### 4. Numerical Simulation

#### 4.1. Modeling of Finite Element

Numerical simulation was carried out to study the axial bearing capacity of composite material solid core rod member. The composite material member adopts anisotropic material models and the maximum strain strength criterion, and its material performance index takes the material compression test result, and the elastic constant along with the amin axis direction is: longitudinal elastic modulus: 55.9GPa, and the Poisson’s ratio is 0.25. The Q345B steel sleeve and flash board adopts dual-linear isotropic strengthening model, with yield strength of 345MPa, with elastic modulus of 206Gpa. The connection between steel sleeve and composite material solid core rod adopts coupling relationship for restraint.

The composite material core rod adopts solid45 unit simulation, and the 8-node solid45 unit can be used into structural 3D solid structure; each node has 3 translational degrees of freedom. One end of the composite material adopts slot type flash board for connection, and the other end adopts cross type flash board for connection. For boundary conditions, both ends of tested member are supported by articulated restraint. Exert axis pressure on the member end, and adopt displacement control constant amplitude for loading till that there is destruction. Refer to Chinese steel structure design code, the limit bearing load of composite material core rod was calculated, considering the initial bending deflection of 1/1000. The grid division result is as shown in Figure 4.
4.2. Comparison between Finite Element Calculation and Test

From the test result and value simulation result (see Figure 1), it can be known that along with increasing of load, the terminal displacement is increased gradually; the load displacement shows linear relationship, and the test value and simulated value are consistent with each other well.

The destruction type of member is consistent with test result, and both of them has undergone global buckling. The stress cloud diagram of member is as shown in Figure 5, and the load displacement curve is as shown in Figure 6.
Through the final destruction form of finite element analysis and the stress cloud diagram, it can be known that the composite material core rod has overall instability, and the maximum stress fails to reach the yield strength.

| Member No. | Test Value N (kN) | Calculation of Finite Element F (kN) | Error (N-F)/N |
|------------|-------------------|--------------------------------------|---------------|
| 130-3862   | 577.00            | 552.438                              | 4.26%         |
| 150-4726   | 657.85            | 637.768                              | 3.05%         |

From Table 2, it can be known that the calculate values of finite element of limit bearing force of composite material core rod are all lower than test value. Compared with test value, the calculated values of finite element of limit bearing forces of 130-3862 and 150-4726 members are lower by 4.26% and 3.05% respectively. It can be known that the exactness and reliability of finite element model established in this paper are high.

5. Slenderness Ratio Correction Coefficient of Pressure Rod of Composite Insulation Cross Arm

Put the calculated values of finite element of pressure bearing force of 130-3862 and 150-4726 into the formulas 1) -5), and then work out that the slenderness ratio correction coefficient K values of pressure members 130-3862 (with calculated slenderness ratio of 119) and 150-4726 (with calculated slenderness ratio of 132) as 0.863 and 0.805 respectively.

One end of the composite material solid core rod is connected with slot type flash board, and the other end is connected with cross type flash board. The flash board structure and processing deviation cause stress eccentricity of members. Theoretically, the eccentricity may weaken the bearing force of member, but from the perspective of K value, the slenderness ratio is discounted, and this means that under such 2 kinds of slenderness ratio (120 and 130), there is restraint at the end of member, which is in favor of bearing. In this paper, for there are not many samples, so the verification to other slenderness ratios is insufficient, and further test is to be conducted for supplementation.

6. Conclusions

By combining the pressure test of solid circular core rod of composite material, this paper analyzes the influence factor of axial pressure test of main composite material at present, and proposes the slenderness ratio correction coefficient of solid circular core pressure rod of composite insulation cross arm, and main conclusions are shown as below:

(1) When the slenderness ratios of pressure member of composite material solid core connected with slot type flash board on one end and connected with cross type flash board on the other end are 119 and 132, the slenderness ratio correction coefficient K values of pressure members are 0.863 and 0.805 respectively.

(2) When the bearing force of core rod member of composite material is influenced by the connection node pattern on the end, and when the slenderness ratios are 120 and 130, it is shown as end restraint.

Acknowledgments

This work has been funded by the State Grid Corporation of China (The project name is Research on Application of key technology of composite insulation cross arm for 35kV~750kV transmission lines. The project number is GCB17201700238-01).
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