Study on calculation method of auxiliary materials for transmission tower

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Abstract. Comparing the provisions of domestic and foreign codes on the supporting force of auxiliary materials, the major domestic design institutes used design software, combined with the test results of the 220kV double-circuit linear tower (SZ801) true-type test, and concluded that compared with "Standard for design of steel structures", "Design of latticed steel transmission structures" and the test results, the value of the internal force of the auxiliary materials of "Technical code for the design of tower and pole structures of overhead transmission line" is conservative. The value of the internal force of auxiliary materials supported by "Industry standards" only considers the influence of the main and inclined materials, and does not consider the effect of different equal distribution methods on the value.

1. Introduction
In the design of transmission towers, it is common to adopt the support of auxiliary materials to reduce the free length of compression components, so as to improve their bearing capacity. In the classical mechanical analysis, the auxiliary material is regarded as zero pole, but when the structure reaches the unstable state, the auxiliary material must bear certain pressure, so it is necessary to consider not only the influence of slenderness ratio, but also the requirement of bearing capacity when selecting auxiliary material. Wang et al. [1] compared the provisions of domestic and foreign codes on the percentage of supporting force of auxiliary materials to that of main materials, and concluded that the provisions of GB 50017 were less safe, while the provisions of IS 802 were more conservative. Yu et al. [2] concluded that it is more reasonable to calculate the internal force of the auxiliary material as 1.5% of the internal force of the main material when the main material of the transmission tower is divided into three parts or less through the true type test of the transmission tower. In this paper, by comparing the provisions of domestic and foreign codes on the supporting force of auxiliary materials and the provisions adopted by the design institutes, combined with the data obtained from the true type test, the calculation method of auxiliary materials for the transmission tower is proposed.

2. Standard requirements

2.1 Industry standard requirements
In the "Technical code for the design of tower and pole structures of overhead transmission line" (hereinafter referred to as "the Code") DL/T 5154-2012, it has the following requirements for calculation of auxiliary materials:

Article 5.1.7 of "the Code": "the supporting force provided by the auxiliary materials of the tower at their supporting points is generally not less than 2% of the internal force of the main materials supported and 5% of the internal force of the inclined materials. When the angle between the bearing
materials is less than 25°, the bearing capacity of the auxiliary materials supporting the bearing materials shall be properly increased or determined through the test.”

The article explanation of “the Code” states that “the design provisions of auxiliary materials emphasize that the design of auxiliary materials shall meet not only the requirements of slenderness ratio but also the requirements of bearing capacity. According to the foreign design experience of towers, it adopts the provision that when the angle between the bearing materials is less than 25°, the bearing capacity of the auxiliary materials supporting the bearing materials shall be properly increased or determined through the test.”

The determination method of the supporting force of the auxiliary material to the main material is not less than 2% of the internal force of the main material: the auxiliary material is regarded as a rigid support, the minimum rigidity value of the rigid support is obtained, and then according to the deflection limit value specified in the specification, the supporting force is about 1/50 of the axial force.

[3] And the presumption that the auxiliary material supports the inclined material with no less than 5% of internal force is not well founded.

2.2 National standard requirements for steel structure

The “Standard for design of steel structures” Gb50017-2017 (hereinafter referred to as the “steel standard”) has added the auxiliary materials calculation formula of tower leg as follows:

“The auxiliary pole (Figure 1) between the main pole and the main inclined pole of the tower shall be able to bear the node supporting force given by the following formula:

![Figure 1 Diagram of the lower end of the tower](image)

1-Main pole; 2-Main inclined pole; Auxiliary pole

When the number of internodes does not exceed 4:

\[ F = \frac{N}{80} \quad (1-1) \]

When the number of internodes is greater than 4:

\[ F = \frac{N}{100} \quad (1-2) \]

Where: N - design value of main pole pressure (N).

[4] At the same time, it is specially mentioned in the article description that the formula in article 7.5.3 can also be used for the auxiliary material between two main inclined materials. At this time, N should be the sum of the pressures of the two main inclined poles.

From the above formula, it can be seen that the node supporting force that auxiliary materials should bear in the "Standard for design of steel structures" is less than that in the industry standard.

2.3 American standard requirements

“American Standard” ASCE10-97 explains the value of the supporting force in the article description. It is designed according to a certain percentage of the stress of the supported main material, and the percentage is determined according to the slenderness ratio of the supported main material. When the slenderness ratio of main material is less than 60, the percentage is 1.5%. When the slenderness ratio of main material is greater than 60, the percentage increases with the increase of slenderness ratio, and the maximum is 2.5%.

3. Design method of auxiliary materials in current engineering

At present, in the design of tower, the tower is usually simulated as a space truss structure connected by
two force poles, and its nodes are calculated by the balance method. At present, the node balance method is also used to calculate the auxiliary material, that is, the main material or inclined material including the auxiliary material is regarded as an independent truss, and the minimum supporting force required by the industry standard is applied to the supporting point of the auxiliary material for finite element analysis, so as to obtain the internal force of the auxiliary material.

According to the investigation of the major design units in China, the current use of tower calculation software and calculation theory is shown in the table below:

| Design unit       | Tower calculation software | Auxiliary material calculation software | Auxiliary material calculation theory |
|-------------------|---------------------------|----------------------------------------|-------------------------------------|
| Major design units| SmartTower or DAOPOWER    | SmartTower or DAOPOWER                 | Node balance method                 |
| Northeast unit    | TTT                       | Self-developed software                |                                     |
| Guangdong unit    | Self-developed software   | Self-developed software                |                                     |
| Zhejiang unit     | SmartTower and TST self-developed software | SmartTower and self-developed software |                                     |

The research shows that although the tower design software used by different design units is different, the calculation theory for auxiliary materials adopts the node balance method, with the support force of 2% of internal force of the main material and the 5% of inclined material.

4. Test situation
In the past, the stress law of auxiliary materials was also studied in the true type test of iron tower, taking the true type test results of 220kV double-circuit linear tower (SZ801) as an example.

The number of strain gauge for auxiliary material of iron tower is shown in Figure 2, and the strain measurement adopts data acquisition instrument. The design load tests are carried out for 12 working conditions, the last of which (control tower main material) is overloaded to 120% and the tower is not damaged.

![Figure 2 Layout of strain gauge for auxiliary material of SZ801 tower](image)
In the last working condition (control tower main material), the strain value ($\varepsilon$) of each strain gauge of the auxiliary material of the tower is listed as follows during the step by step loading from 0% to 120%.

| Loading range | 0  | 50  | 75  | 100 | 105 | 110 | 115 | 120 |
|--------------|----|-----|-----|-----|-----|-----|-----|-----|
| B10          | 175| 202 | 217 | 185 | 211 | 223 | 212 | 219 |
| B11          | -30| -73 | -96 | -126| -119| -120| -127| -126|
| B12          | 17 | -9  | -5  | -2  | 3   | 6   | 9   | 7   |
| B16          | 83 | 76  | 85  | 76  | 77  | 90  | 97  | 103 |
| B17          | -47| -53 | -75 | -96 | -92 | -95 | -92 | -95 |
| B22          | -52| -56 | -61 | -85 | -79 | -78 | -80 | -86 |
| B23          | 43 | 51  | 56  | 52  | 60  | 66  | 71  | 75  |
| B24          | -25| -33 | -32 | -43 | -39 | -44 | -45 | -47 |
| B25          | -29| -31 | -39 | -44 | -43 | -45 | -46 | -48 |
| B26          | 18 | 27  | 41  | 40  | 49  | 50  | 49  | 53  |
| B27          | -26| -37 | -49 | -78 | -74 | -77 | -82 | -82 |
| B28          | 32 | 24  | 30  | 45  | 47  | 58  | 68  | 75  |
| B29          | -20| -31 | -42 | -46 | -47 | -44 | -46 | -39 |
| B30          | -38| -58 | -65 | -76 | -88 | -86 | -87 | -91 |
| B34          | 16 | -35 | -45 | -40 | -44 | -45 | -66 | -87 |
| B35          | -205| -166| -146| -118| -110| -93 | -55 | -26 |

According to the data in Table 2, the maximum resultant force of each auxiliary material at the supporting point of the main material and the ratio of the supporting force to the internal force of the main material of the tower can be calculated, as shown in Table 3.

| Supporting form | Supporting point | Supporting force (kN) | Main material force (kN) | Percentage |
|----------------|------------------|------------------------|--------------------------|------------|
| Two parts      | Midpoint         | 1.24                   | -261                     | 0.47%      |
| Two parts      | Midpoint         | -2.33                  | -325                     | 0.72%      |
| Three parts    | First of three   | -1.91                  | -436                     | 0.44%      |
| Three parts    | Second of three  | -3.53                  | -436                     | 0.81%      |
| Four parts     | First of four    | 2.52                   | -456                     | 0.55%      |
| Four parts     | Second of four   | -5.20                  | -456                     | 1.14%      |
| Four parts     | Third of four    | -3.81                  | -456                     | 0.84%      |
| Seven parts    | First of seven   | 8.70                   | -475                     | 1.83%      |

It can be seen from Table 3-2 that the maximum value of the ratio of the supporting force of auxiliary material to the internal force of the main material of the iron tower is 0.0072, 0.0081, 0.0114 and 0.0183 under the condition of two, three, four and seven parts, respectively. It can be seen that the ratio of the supporting force of the auxiliary material to the internal force of the main material of the tower increases with the increase of the number of sections of the main material, especially the supporting point of the auxiliary material of the tower leg, which is the most stressed.

It can be seen from Table 3 that the maximum supporting force of the auxiliary material of the tower body is 1.14% of the internal force of the main material, which is lower than the value in "the code".
Only when the main material is supported by seven parts, the supporting force of the auxiliary material is close to the value in “the code”. We analyze the reasons. The measurement position of the auxiliary material of the tower leg in the test is the first auxiliary material on the upper side of the tower foot plate, which may have more stress because of the secondary moment caused by the too large angle between main inclined material and the excessive rigidity of the tower foot plate, which is consistent with the principle that the bearing capacity of the auxiliary material supporting the stressed material should be properly increased when the angle of the main inclined material is less than 25° as stated in “the code”.

5. Existing problems and follow-up suggestions

Through the above investigation and analysis, it is concluded that the domestic auxiliary material calculation theory and calculation method are unified, and the overall operation of the tower is good. However, compared with “steel standard”, “American standard” and test results, the design of auxiliary materials in “the code” has the following shortcomings:

(1) Compared with "steel standard", “American standard” and test results, the internal force value of auxiliary material in “the code” is more conservative.

(2) The internal force value of the auxiliary material in “the code” only considers the influence of the main material and the inclined material, and does not consider the influence of different equal distribution methods on the value.

It is suggested to optimize the calculation method of tower auxiliary materials through the true type test and component test of tower in the future.

References

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