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To cite this article: Wei Qin *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **526** 012148

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Analysis on the Mechanical Stability of the Leg Joints in UHV Transmission Tower

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Abstract. Transmission line pole tower, whose safety and reliability will directly affect the safe and stable operation of the entire transmission line, is a rod-shaped and tower-shaped structure that supports overhead transmission line conductors and ground lines and maintains a certain distance between them and the ground. Moreover, the stress stability of the leg structure joints in UHV transmission towers is mainly analyzed in the paper. With the help of the finite element analysis software, taking the arrangement of the long and short legs in the actual structure of the tower as an example, the influence of different angles of the tower on the bending moment is compared and analyzed under the condition that the main material slenderness ratio is the same. Meanwhile, in order to eliminate the influence of horizontal force on the height of different tower legs, only the bending moment generated by the structural system at the tower legs under axial pressure is considered to continuously improve the stability and reliability of the line pole tower structure, so that the power safety can be guaranteed to a large extent.

1. Introduction

Based on the UHV transmission tower, the vertical displacement and lateral displacement of a single compression member under vertical load are interrelated, which can be said that lateral displacement causes vertical displacement. If the bending rigidity is large, the vertical displacement will be small, and if the bending rigidity is small, the vertical displacement will be large. Moreover, it can be seen from the aforementioned force performance of the tower legs that since the section of the tower legs changes linearly along the height direction, its bending stiffness also changes accordingly. Therefore, if the auxiliary materials are properly arranged, the bearing capacity and displacement of the tower legs will be generally controlled by the joints with less rigidity in the structure. In addition, through previous analysis and tests, it is found that the control joint is generally the second joint from the bottom of the tower leg structure. Meanwhile, it can be deduced from what is mentioned above that one of the reasons why the bearing capacity of the tower leg structure decreases with the increase in the number of tower leg divisions is that the increase in the division number weakens the bending stiffness of the tower leg control joint[1-3].

According to the characteristics of the electrical clearance, the research on the arched leg structure of the ultra-high voltage tower wine glass is conducted in the paper, which can make full use of electrical clearance to reduce tower height. Meanwhile, considering the influence of multiple separation and multiple bearing capacity, appropriate design margin should be left for the main materials of the multiple separation tower legs.



2. Layout Design of Tower Leg

2.1 Inclined Material Angle of Tower Leg

When the angle between the main inclined materials of the tower legs is small, the bending moment at the bottom of the tower legs will be large, while the bending rigidity of the structure section will be small, so the bending stress is relatively large, which is easy to cause instability in bending. Moreover, when the angle between the main inclined materials of the tower legs is large, the bending moment value will be small, and the bending stiffness of the cross section will be large, so it is not easy to produce bending and instability. Therefore, when designing the long and short legs of the tower, the angle among the long legs should not be too small, and it is recommended that it should not be less than 20° . If the included angle is small, such as less than 20° , it is recommended to use the beam-and-bar element system to calculate the axial force and bending moment of the main material in the tower leg, and design is performed according to bending structure[4-6].

The bending moment at the connection between the first and second sections of the tower legs with different main inclined materials included in the axial compression is gradually reduced with the increase of the angle, and the change trend is shown in Table 1.

Table 1 Changing Trend of Axial Compression Tower Legs under Axial Pressure

Design angle	Contrast angle	Bending moment change
19.5°	16.5°	97%
23.5°	14.5°	87%
30.5°	17.5°	63%

2.2 Optimal Layout of the Legs in the Two-legged Angle Steel Tower

When the main material of the tower legs is combined angle steel, the single-angle steel is connected as a whole by the slab, and the distribution of stress on the cross-section of the combined angle steel is obviously uneven. Therefore, optimizing the placement of slabs and improving the internal and external angle steel stress have become a significant part in the optimization of the tower leg structure[7-8]. Besides, by establishing the tower leg finite element model, the analysis draws the following conclusions.

(1) Double-combination angle steel is provided with two sets of filler plates at the one-third equal point within the inter-node.

(2) The comparative analysis on the different forms of fillers shows that the adoption of "cross" fillers is more uniform than that of single fillers. However, the increase in its bearing capacity is not obvious, and the number of packing plates has doubled, resulting in an increase in tower weight. Therefore, it is recommended to adopt a staggered arrangement of single-filled plates, which can not only play the role of connection and shear, but also reduce the number of filled plates, so that the weight of the tower can be reduced.

2.3 Tower Leg Auxiliary Materials

The layout optimization selects the following two types of auxiliary materials for comparative analysis, as shown in Figure 1.

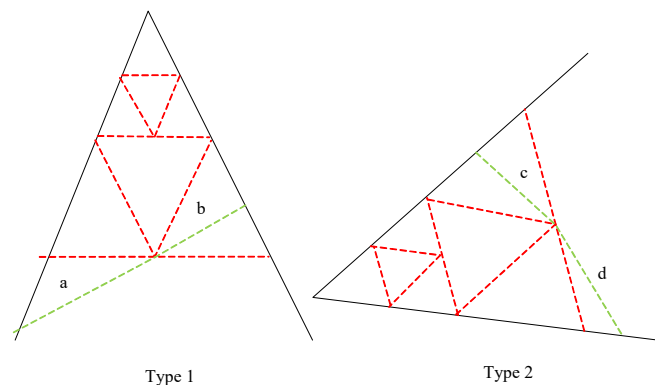


Figure 1 Comparison and Analysis on Two Types of Auxiliary Materials

Type 2 is used in mid-line UHV projects, and the layout of the two types of "V" profile is the same. Besides, main material and inclined material of Type1 are connected in a straight line by "Z" profile, as shown in a and b rod of Figure 1. In addition, the c and d rods in the upper section of Type2 are connected by a broken line, where the force is not clear, the force transmission is not clear, and the arrangement of the rods is more messy. Moreover, Type 1 supports the main and inclined materials better, and in actual engineering, the a and b rods are set long, whose connection performance is better than the disconnected c and d rods.

Meanwhile, each auxiliary material of Type1 is a zero bar, which is a real auxiliary material, and Type2 part of the bar, as shown in the green part of bar in Figure 2,

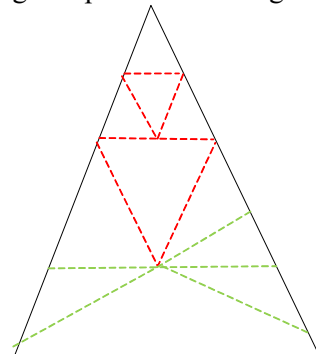


Figure 2 Layout of Auxiliary Materials

will be stressed, and the supporting effect of these bars on the main inclined material will be greatly reduced in actual structure. When the main inclined material is stressed, the deformation will be larger. Moreover, Type1 layout type or similar type is adopted in the project, and a and b rods are required to be arranged as long as possible. Meanwhile, the length must not have a positive error.

From the perspective of the overall structure, the tower legs belong to variable cross-section compression lattice columns, and the load on the upper part of the tower body is mainly transmitted to the foundation through the main materials of the tower legs and the inclined legs of the tower legs. What's more, the auxiliary materials of the tower legs connect the main materials and the inclined materials to form an overall cooperative work. Now 4-part tower leg is took as an example to conduct a preliminary analysis of its bearing capacity performance.

3. Experiment Analysis

The load-bearing performance of the tower legs is the same as that of the buckling members, and the type of failure is extreme-value type instability, which is due to the initial defects imposed on the structure during the analysis and calculation. Moreover, the buckling modal structure of the tower leg undergoes overall bending deformation under load. Since the section of the tower leg changes linearly

in the height direction and the stiffness also changes with the change of the section, its deformation is not a sinusoidal half-wave deformation curve of a compression member of equal cross-section. In particular, the lower cross-sectional width of the lower part has a larger lateral displacement than the upper part, which becomes the weak link of the entire tower leg structure.

From the characteristics mentioned above, not only the strength and stability of its components, but also the overall stability of the tower leg structure should be considered during the design of the transmission tower. In addition, attention should be paid to the decrease in the overall bearing capacity of the tower leg structure due to changes in the bending stiffness along the height direction.

In order to investigate the influence of the number of tower leg divisions on the bearing capacity of the tower legs, the tower legs with the same calculated length for the 3-7 divisions and each division are analyzed and calculated in the paper. The calculation results are shown in Table 2.

Number of divisions	3separate	4separate	5separate	6separate	7separate
Ultimate bearing capacity P (N)	243511	239684	235107	231342	225117
Sectional strength $P_u(N)$	245971	244576	242379	240982	239487
P/P_u	0.99	0.98	0.97	0.96	0.94

Judging from the ratio of the numerical calculation results to the cross-sectional strength, as the number of divisions increases, the height of the tower legs increases as well, while the bearing capacity of the tower legs gradually decreases.

The main material specification of the tower legs in the calculation model is L200x20, and the calculated length of each partition is 1470mm. Then the specification is checked to get the stability coefficient $\varphi = 0.99$. Compared with the numerical calculation results, it can be seen that the bearing capacity of the three-divided tower leg is the same as that of the single member, and the bearing capacity of the 3-7 divided tower leg is lower than that of the single member. Moreover, the increase has a tendency to accelerate and decrease. From the above analysis, it can be seen that the overall stability of the tower leg structure exists. The greater the number of divisions is, the more prominent the stability problem will be.

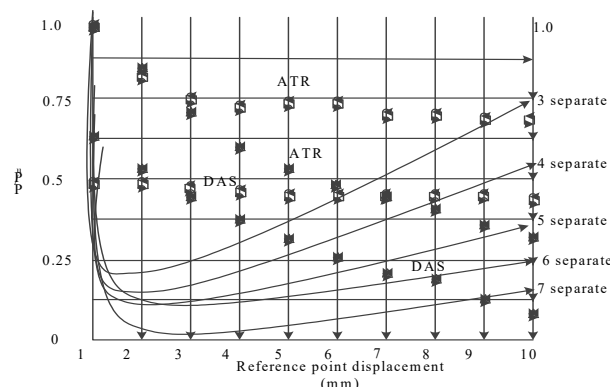


Figure 3 Load-displacement Curve of Tower Legs with Different Division Numbers

Figure 3 shows the load-displacement curve of the legs in the 3-7 separating tower. The figure shows the law that the bearing capacity of the tower legs gradually decreases as the number of divisions increases. If the load displacement-slope of the curve is used to represent the stiffness of the tower leg structure, it can be seen from the figure that the stiffness of the tower leg also gradually decreases with the increase of the number of divisions. As a result, the displacement of the tower leg structure under the same load increases as the number of divisions increases.

Another important reason why the bearing capacity of the tower leg structure decreases with the

increase in the number of tower leg divisions is that the increase in the number of tower leg divisions leads to an increase in the height of the tower leg, which strengthens the $\rho - \Delta$ effect of the tower leg structure, resulting in decline.

4. Conclusion

The analysis results show that under the action of axial compression, the bending moment between the two nodes at the bottom of the tower leg is large, so the bending stress at this part is also large, the deformation is more serious, and it is easy to produce bending buckling, which is consistent with the phenomenon exhibited by the true-type test. Then, with the setting of the transition section, the cross-sectional size of the tower legs is reduced, which leads to the bending stiffness of the weak joints is weakened again. Therefore, although the 6-dividing tower leg and the 7-dividing tower leg after the addition of the transition section have the same height, their bearing capacity still decreases to a certain extent. Comprehensively considering previous research results and design experience, treatment measures are recommended as follows.

Since the bending moment between the two nodes from the bottom of the tower leg is large, and the overall instability of the tower leg mostly occurs at the first and second inter-nodes at the bottom, it is recommended to consider the arrangement of encryption auxiliary materials between these two nodes in the design or increase the specifications of auxiliary materials between the first and second nodes from the bottom of the tower leg structure.

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