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Finite Element Analysis of K-node of Curved Arm of Transmission Tower

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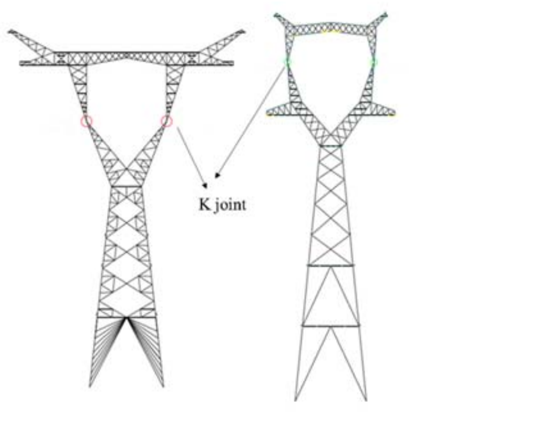
Abstract: The stress on the key nodes of transmission towers is complex, which plays a vital role in the stress and stability of the whole structure of transmission towers. Due to the larger negative head of the link and the larger connecting plate at the K node of the curved arm of the transmission tower, the actual stress of some components is quite different from the theoretical calculation results. At the same time, the load value of the smaller part is not clear when the included Angle of the stressed material at the K node is less than 25°.In this paper, the difference between the stress of the bar at the K node of the curved arm and the ideal model is studied, and the stress status of the position with small Angle is analyzed, and the reasons for the difference and the suggested value of the position with small Angle are analyzed.

Keywords: Transmission tower, K node of curved arm, Finite element method.

1. Introduction

With the continuous development of China's economic construction, the energy demand of all walks of life is also increasing, in which electricity plays a vital role. At the same time, the power grid lines have been continuously upgraded, and the section of transmission tower members has become increasingly complex. In the power industry, the transmission tower mainly has two types of sections: angle steel and steel pipe. The angle steel tower has the advantages of convenient connection and low cost. However, the turning radius and shape of the angle steel section are not good, which may affect the integrity of the transmission tower [1]. The steel tube tower has the advantages of large section bending stiffness and good section characteristics.

The key nodes of transmission tower are very important for the stress and integrity of transmission tower. Once the node fails, local damage will occur at the node, which will affect the use of the transmission tower. The K node of the transmission tower's curved arm is a key part of the tower window's upper and lower curved arms connecting the wine glass tower and the cathead tower. As shown in the figure below:



a) Wine glass tower b) Cathead tower

Figure 1. K node in the wine glass tower and cathead tower

Due to the structural reasons, the actual structure of the tower is inevitably different from the ideal design model. At the K-joint of the curved arm, due to the large negative head of the member, the large connecting plate or the use of the fire curved plate, the actual force of some members is quite different from the theoretical calculation results. Secondly, for a long time, the main materials of the K-joint of the crank arm are selected according to the full stress. When the front inclined material (brace) of the crank arm is zero, its bearing capacity is checked according to the supporting capacity of the auxiliary materials, and the bars near the sharp corner of the K-joint are strengthened. This ideal treatment ignores the influence of large gusset plates of K-joints on the overall stiffness of nearby members [2], and there may be differences between the internal forces of actual members and those of the ideal member system model.

In addition, according to the specification [3], if the included angle of the stressed material at the node of the transmission tower is less than 25 °, it can be regarded as the part with small included angle, but the specification does not provide a specific value method. In the past engineering design, designers often artificially strengthened the design of auxiliary materials near the K-joint of the bent arm, such as adding another specification based on the selection of materials according to the internal force of 1/50 main materials. It is unknown whether the structure is safe after one gear is increased.

To solve these problems, this question studies the difference between the force of the bar at the K-joint of the crank arm and the ideal model through finite element simulation, and studies the value of the supporting force of the auxiliary material at the position through the entity simulation analysis of the position with small angle of the stressed material.

2. Finite Element Model

The research object of this paper is the bent arm K node of a 1000kV angle steel tower ZB29105. Using the large-scale general finite element software ANSYS, the finite element model of the whole tower and the multi-scale detailed node model are established to analyze the internal force distribution of the members near the K node, the difference between the calculated axial force and the beam member element model, as well as the force status of the k node under small angle conditions under the main working conditions such as strong wind, icing, and broken wire.

2.1. Model overview

The finite element model used is shown in Figure 2. For the K-node structure of the bent arm and its two adjacent nodes, a refined solid model is established, and the shell element Shell181 is used for solid modeling. Other parts still use the traditional beam and pole model, and adopt the beam 4 and beam 188 elements for modeling. The coupling element MPC184 uses the multi-point constraint coupling method to combine the two [5] to form a multi-scale model for finite element analysis, which can greatly reduce the computational complexity while ensuring the accuracy of the node model.

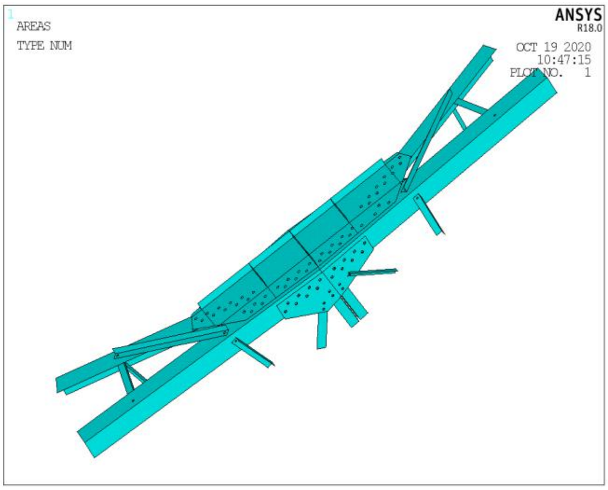


Figure 2. Multi scale solid model

In order to verify the correctness of the multi-scale model, modal analysis was carried out on the beam bar model and the multi-scale model, and the vibration modes and natural frequencies of the two models were compared [5].

Table 1. Comparison of Natural Frequencies

Order	Multi scale model frequency /Hz	Beam bar model frequency /Hz
1	1.3218	1.3200
2	1.3972	1.3936
3	1.8544	1.8438
4	1.9349	1.9325
5	2.5543	2.5517

It can be seen from the above table that there is little difference between the first five vibration modes of the multi-scale model and the beam and rod model. The frequency of the multi-scale model is slightly higher than that of the beam and rod model. The reason may be that the stiffness of the multi-scale model is slightly higher than that of the beam and rod model, so the frequency is increased. However, the relative error between the two models is only 0.6%, which shows that the structural characteristics of the multi-scale model are consistent with that of the beam bar model.

2.2. Multiscale nonlinear analysis of nodes

The solid curved arm K node established by shell element (shell 181) is loaded into the whole tower through multi-point constraint coupling method, and the multi-scale finite element model of the whole tower is established. The nonlinear static analysis of the whole tower structure with joints is carried out, focusing on the analysis of the internal force distribution of the members near the K-joint and the difference between the calculated axial force and the beam member model.

This paper lists the force on the K-node of the crank arm under the 60 ° wind condition. The following figure shows the stress cloud diagram of K-node of the bent arm under 60 ° wind condition:

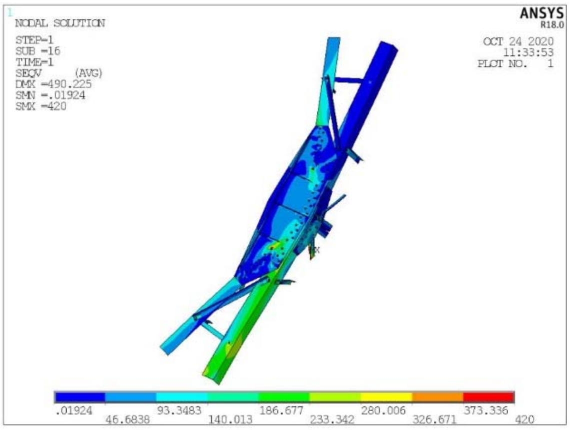


Figure 3. Node Stress Cloud Chart under 60 ° High Wind Condition

It can be seen from Figure 3 that due to stress concentration, the maximum stress occurs at the bolt at the lower end of the side diagonal member, and the maximum stress exceeds 420MPa. The empirically calculated bolt tensile connection strength meets the bearing capacity requirements of Code for Design of Steel Structures (GB50017-2012). The stress of the main material of the outer lower crank arm is relatively large, and the section stress is about 230Mpa. There is a large margin relative to the yield strength of the material, and the stress of the other main materials is relatively small.

The following figure shows the stress distribution of gusset plate:

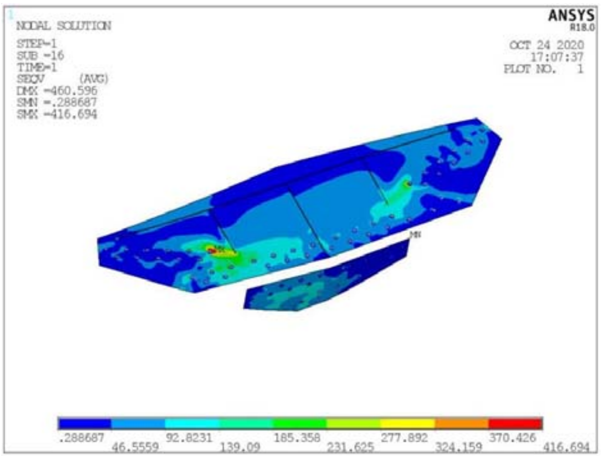


Figure 4. Cloud Chart of Nodal Plate Stress under 60 ° High Wind Condition

It can be seen from the stress nephogram of gusset plate that the stress at the connection with the main material is relatively large, especially the stress concentration at the end bolt hole at the intersection of the main material below the node. The maximum stress reaches 416MPa, and the maximum stress at the part where no stress concentration occurs is about 280MPa.

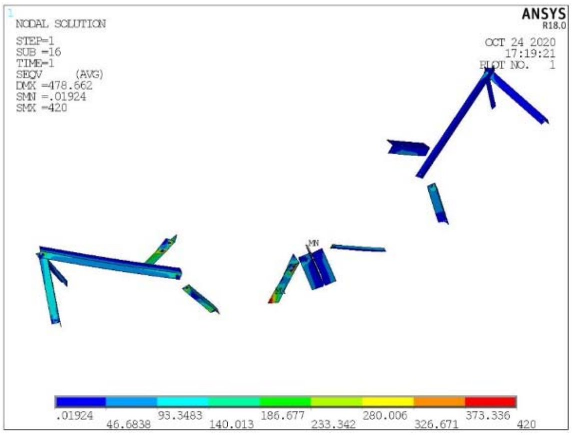


Figure 5. Stress Cloud Chart of Auxiliary Materials under 60 ° High Wind Condition

It can be seen from Figure 5 that under the 60 ° wind condition, the auxiliary materials at the lower part of the K-shaped joint are under great stress. Some areas at the ends of some inclined materials have reached the yield state, while the stress concentration at the bolt holes of other inclined materials is different, but the stress of the inclined materials themselves has not reached the yield state.

2.3. Static analysis and summary

The axial force values of each member of the K-node of the bent arm under the conditions of 60 ° wind, icing, right conductor disconnection and right conductor suspension are extracted respectively. The ratio of the axial force of the solid model to the axial force of the theoretical model of each stressed material under the maximum internal force working condition is listed and sorted out as follows:

Table 2. Axial Force Ratio of K-Node Members of Crank Arm under Four Working Conditions of 60 ° Wind, Icing, Broken Right Guide and Hoisting Right Guide

position	Ratio of axial force
Outer main material of	85.8%
upper crank arm	85.5%
Inner main material of	115.4%
upper crank arm	119.5%
Outer main material of	100.8%
lower crank arm	101.0%
Inner main material of	93.4%
lower crank arm	102.7%
Upper crank arm outer	118.8%
inclined member	74.6%
lower crank arm outer inclined member	115.6%

It can be seen from the above table that under the four main working conditions of 60 ° wind, ice coating, right conductor breaking and right conductor lifting, the axial force of the solid model of the main material outside the upper bent arm is 15% less than that of the beam rod model, and the axial force of the main material inside the upper bent arm is 15% greater; The axial force of the solid model of the main material of the lower crank arm is basically equivalent to that of the bar model; The difference between the solid axial force of the upper and lower bent arm inclined materials and the bar model is discrete, ranging from 75.6% to 118.8%. In general, the axial force of the solid model is slightly greater than that of the beam bar model.

According to Article 5.1.7 of DL/T 5154-2012 Technical Code for Design of Tower Structures of Overhead Transmission Lines, the supporting force provided by tower auxiliary materials at their supporting points is generally not less than 2% of the internal force of the supported main materials and 5% of the internal force of the inclined materials. When the included angle between the stressed materials is less than 25 °, the bearing capacity of the auxiliary materials supporting the stressed materials shall be appropriately increased or determined through tests. According to the specification, if the included angle of the stressed material is less than 25 °, it can be regarded as the part with smaller included angle, but the specification does not provide a specific value method. For this purpose, the axial force between the vertical brace on the front of the upper and lower booms and the main material is extracted respectively, and the axial force ratio is calculated. The extracted member position is shown in the following figure:

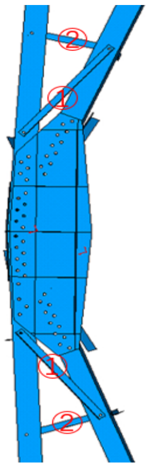


Figure 6. Schematic Diagram of K node

For the inclined material on the front of the bent arm, under the above four main working conditions, the ratio of the internal force of the solid model to the internal force of the supported main material is shown in the following table:

Table 3. Ratio of the support force of the inclined bar at the front of the bent arm under four working conditions of 60 ° wind, icing, right guide disconnection and right guide hoisting

position	Maximum axial force of solid model (kN)	Maximum axial force of supported material (kN)	Support force ratio
Front vertical brace of upper crank arm	-68.7	-1711	0.04 (1/25)
Front vertical brace of lower crank arm	-58.8	-1695	0.035 (1/29)

It can be seen from the above table that the supporting force of single diagonal bar perpendicular to the main material at the sharp angle of the K node of the crank arm exceeds 0.02 (the value in the specification is 1/50) of the main material to be supported, reaching 1/29~1/25. At this time, the included angle of the crank arm is small, only 18.3 degrees. Considering that the included angle of the main material at the K-joint of the conventional tower's bent arm is not large, the ratio of the axial force of the member and the axial force of the main material at this position may exceed the value of 1/50 in the specification, which should be paid special attention in the engineering design.

3. Conclusion

In this paper, the multi-scale finite element model is used to simulate the K-joint of the curved arm, the difference between the axial force of the solid model of the bar near the K-joint of the curved arm and the beam model is analyzed, and the value of the inclined material of the curved arm under small angle is analyzed. The conclusions are as follows:

(1) Under the four main working conditions of 60 ° wind, icing, right conductor breaking and right conductor hanging, the axial force of the solid model of the main material outside the upper crank arm is about 15% less than that of the bar model, and the axial force of the main material inside the upper crank arm is about 15% greater; It is suggested that when calculating and selecting materials according to the link model, the design value of the internal force of the external main material of the upper boom should be reduced, and the reduction coefficient should be 0.9; The design value of the internal force of the main material in the upper boom is multiplied by the safety factor of 1.1.

(2) The axial force of the solid model of the front inclined member at the K-joint of the crank arm is greater than that of the member model, exceeding 1/50 of the axial pressure of the supported main member, reaching 1/29~1/25. Therefore, it is recommended to strengthen the design of the member at this position. It is suggested in this paper that when the included angle of the stressed material is 17-18 °, the auxiliary material should be taken as 1/25 of the stressed material.

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