

Study of the Distribution of Initial Stress for Mechanical Properties of Guyed Transmission Tower

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Abstract—Under the influence of the wind loads, the prestress of guy in the guyed door type transmission tower has a great impact on the mechanical properties of its structure. In order to study this effect, The paper establishes the appropriate nonlinear finite element model of the guy-door- type transmission tower through the use of structural analysis software, analysis the mechanical properties of the tower structure under different initial stress on the condition of the most negative angle of attack, obtain the rule that the changes of initial stress of guy has an influence on the support reaction of guyed transmission tower, the maximum displacement of tower nodes and the bar axial stress , providing the available value for the design and construction of tower structure ,and ensuring transmission tower structure self-reliance, stability and well run.

Keywords—structure nonlinear; prestress of guy; guyed door type tower; negative angle of attack; wind load

I. INTRODUCTION

The guy can be thought as flexible cable structure in the guyed door type transmission tower, The tower is mainly composed of varieties of bars and steel nodes, if the initial stress of guy is only exerted sufficiently, the guy has sufficient stiffness to tension the tower and the tower works safely, which under the condition of various types of load.

Generally in the design of practical engineering, when the value of the initial stress is smaller or larger, it is negative. If the value is smaller, the node displacement will be larger, the node stiffness will be poorer and transmission tower structure will be unstable, If the value of initial stress is larger, the displacement of nodes will be smaller, the stiffness of nodes will be better, but the axial force of tower structure will increase significantly, the chord will be instable under pressure. So the stiffness and stability of the transmission tower will be directly affected by the initial stress of guy under the horizontal loads.

Base on the importance of initial stress of guy, in this paper, Principle of finite-element method is applied to deduce the stiffness matrix which is based on UL (Update Lagrange Description) method with the consideration of bi-nonlinearity, and the stiffness matrix of beam element with one rigid joint and one hinged joint is worked out. Taking a guyed transmission tower as an example, cable-beam assembly nonlinear finite element model is built by using general finite analytic software ANSYS , through analysis and comparison, finding the law which between the distribution of initial stress and the pull of transmission tower on the condition of the most negative angle of attack.

II. FINITE ELEMENT MODEL

A. Establish the Finite Element Model

It is a kind of isotropical hardened material in keeping with V. Mises initial yield condition and interrelated flow rule. The movement of the structure is characterized by large displacement and small deformation. Component processing, the installation of the initial error and material defects are neglected. Nodes are ideal space rigid joint or ideal space hinged joint. Bar unit endures axial force, and cable unit endures pulling force, and beam unit is Timoshenko beam unit whose shear strain and section warping is ignored.

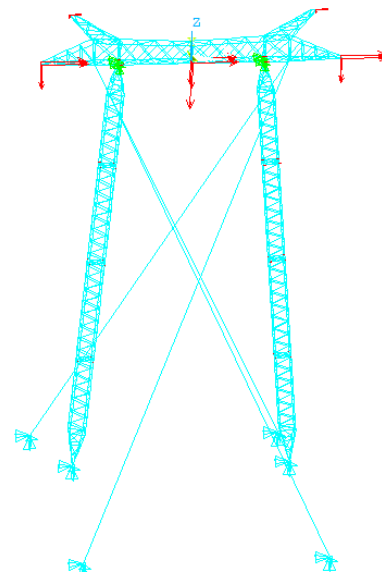


FIGURE I. ELEMENT MODEL

B. Element Stiffness Matrixes for Bar Unit Based on the Material Nonlinearity and Geometric Nonlinearity

There is derivation of element stiffness matrix for bar unit with the consideration of geometric nonlinearity.

$${}^t[K] = {}^t[K_L] + {}^t[K_N] \quad (1)$$

$${}^t[K_L] = \int_V [B_L]^T [D_T] [B_L] \cdot {}^t dV \quad (2)$$

$$\begin{aligned} {}^t[K_N] &= \int_{t_V} \left([B_L]^T [D_T] [B_N] + [B_N]^T [D_T] [B_L] \right) \cdot {}^t dV \\ &+ \int_{t_V} [B_N]^T [D_T] [B_N] \cdot {}^t dV \end{aligned} \quad (3)$$

Where: ${}^t[K_L]$ is linear stiffness matrix, and ${}^t[K_N]$ is nonlinear stiffness matrix. $[B_L]$ is linear strain matrix, and $[B_N]$ is nonlinear strain matrix. $[D_T]$ is linear elastic matrix.

According to [6], equilibrium equation described by geometric nonlinearity holds even for bi-nonlinear problem if the linear elastic matrix $[D_T]$ is replaced by elastic plastic matrix $[D_T^{ep}]$ in rigidity matrix. Furthermore, elastic plastic matrix can be regard as an superposition of elastic matrix and plastic matrix, and the following expressions are valid.

$$\begin{aligned} {}^t[K_L^p] &= \int_{t_V} [B_L]^T [D_T^{ep}] [B_L] \cdot {}^t dV \\ &= {}^t[K_L] - \int_{t_V} [B_L]^T [D_T^p] [B_L] \cdot {}^t dV \end{aligned} \quad (4)$$

$$\begin{aligned} {}^t[K_L^p] &= \int_{t_V} [B_L]^T [D_T^{ep}] [B_L] \cdot {}^t dV \\ &= {}^t[K_L] - \int_{t_V} [B_L]^T [D_T^p] [B_L] \cdot {}^t dV \end{aligned} \quad (5)$$

$$\begin{aligned} {}^t[K_N^p] &= \int_{t_V} \left([B_L]^T [D_T^{ep}] [B_N] + [B_N]^T [D_T^{ep}] [B_L] \right) \cdot {}^t dV \\ &+ \int_{t_V} [B_N]^T [D_T^{ep}] [B_N] \cdot {}^t dV \\ &= {}^t[K_N] - \int_{t_V} [B_L]^T [D_T^p] [B_N] \cdot {}^t dV \\ &- \int_{t_V} \left([B_N]^T [D_T^p] [B_L] + [B_N]^T [D_T^p] [B_N] \right) \cdot {}^t dV \end{aligned} \quad (6)$$

Where: $[D_T^p]$ is plastic matrix, and its expression as

$$[D_T^p] = \frac{\alpha [D_T] \{\nabla f\} \{\nabla f\}^T [D_T]}{h + \{\nabla f\}^T [D_T] \{\nabla f\}} \quad \text{Here } \alpha \text{ is material constant, and } h \text{ is plastic modulus.}$$

$$\{\nabla f\} = \left\{ \frac{\partial f}{\partial \sigma_x}, \frac{\partial f}{\partial \sigma_y}, \frac{\partial f}{\partial \sigma_z}, \frac{\partial f}{\partial \tau_{xy}}, \frac{\partial f}{\partial \tau_{yz}}, \frac{\partial f}{\partial \tau_{zx}} \right\}^T$$

Therefore, element stiffness matrixes for bar unit with the consideration of bi-nonlinearity which is based on UL method can be expressed as:

$$\begin{aligned} {}^t[K^p] &= {}^t[K_L^p] + {}^t[K_N^p] \\ &= {}^t[K_L] + {}^t[K_N] - {}^t[K_P] \end{aligned} \quad (7)$$

$$\begin{aligned} {}^t[K_P] &= \int_{t_V} \left([B_L]^T [D_T^p] [B_L] + [B_L]^T [D_T^p] [B_N] \right) \cdot {}^t dV \\ &+ \int_{t_V} \left([B_N]^T [D_T^p] [B_L] + [B_N]^T [D_T^p] [B_N] \right) \cdot {}^t dV \end{aligned} \quad (8)$$

Here ${}^t[K_P]$ is plastic correction matrix. The expression of beam element stiffness matrixes with the consideration of bi-nonlinearity can be deduced in a similar way therefore will not be discussed here.

III. CALCULATING EXAMPLE

A. Summarization

Taking LM21 (33m) guyed tower in Dong-Chang-Ha transmission line as an example, establish a finite element model. Principals and diaphragm were simulated by Beam189 in the model, auxiliary bars are simulated by Link8, and stay guys are simulated by Link10. The pre-stress of stay guys was carried out by using the method of initial strain simulate, this method can consider the contribution of cable element stiffness on global stiffness of the structure. Furthermore, it can solve two problems: balance of node prestress and the deformation harmony of cable. Hinge between cross arm and main column was carried out by means of freedom degree coupling Abbreviations and Acronyms .The figures of top viewport and bar and node number as follow.

When the guyed tower under the state of the initial stress and 90°wind loads which is the most negative angle of attack in this type of tower after analysis, considering different initial stresses of guy which have a compact on the tower. We select nine different values of the initial stress, they are 50MPa, 100 MPa, 120MPa, 150 MPa, 200 MPa, 250 MPa, 300 MPa, 350 MPa, 400 MPa. Wind speed base on the actual site is taken to 28.6m/s, having a comparison and analysis on the numerical calculation which about support reaction, nodal displacement and bar axial stress.

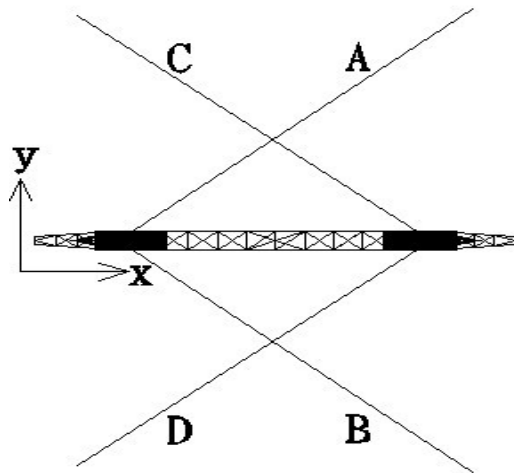


FIGURE II. TOP VIEWPORT

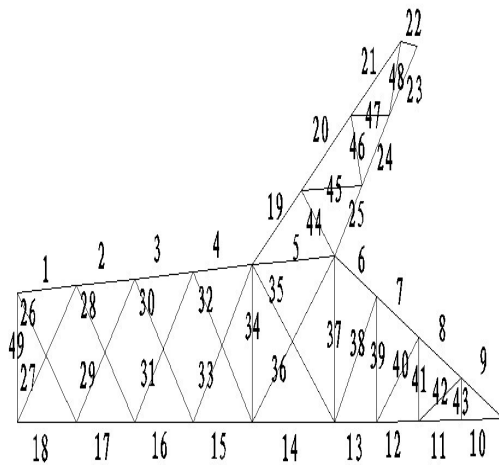


FIGURE III. BAR AND NODE NUMBER

B. The Effect of the Bar Axial Stress Which Cause by Initial Stress of Guy

From the Figure4 we know, when the guyed transmission tower under the state of initial stress, the bar axial stress of tower which effected by initial stress of guy is linearization, and bar axial stress increases significantly with the increase of the initial stress of guy.

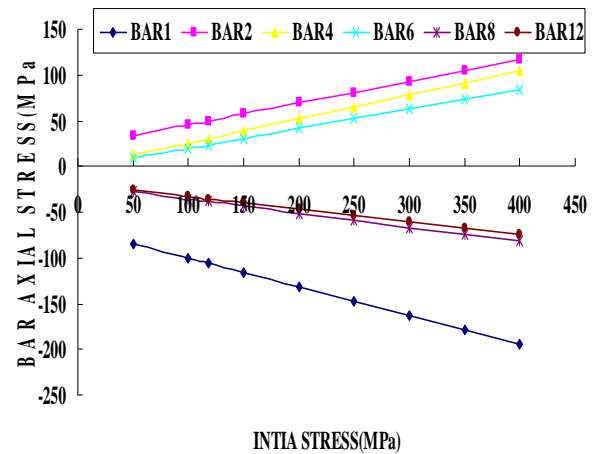


FIGURE IV. THE LAW BETWEEN BAR AXIAL STRESS AND INTIA STRESS IN THE STATE OF INTIA STRESS

From the Figure 5 we can see, when the guyed transmission tower under the state of load condition, the initial stress of guy have Non-linear effect on the bar axial stress, when the value of initial stress below 250MPa, bar axial stress decreases with the increase of the initial stress of guy, but the change is small, and the initial stress is more than 250MPa, with the increase of initial stress, the bar axial stress of tower increases significantly.

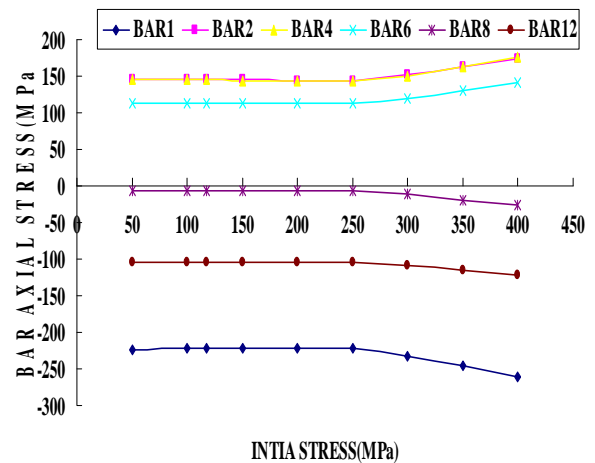


FIGURE V. THE LAW BETWEEN BAR AXIAL STRESS AND INTIA STRESS IN THE STATE OF LOAD

C. The Effect of the Maximum Displacement of Tower Nodes Which Cause by Initial Stress of Guy

From the Figure 6 we know, when the guyed transmission tower under the state of initial stress of guy, the displacement of tower nodes which effected by initial stress of guy is linearization, and node displacement increases with the increase of the initial stress of guy.

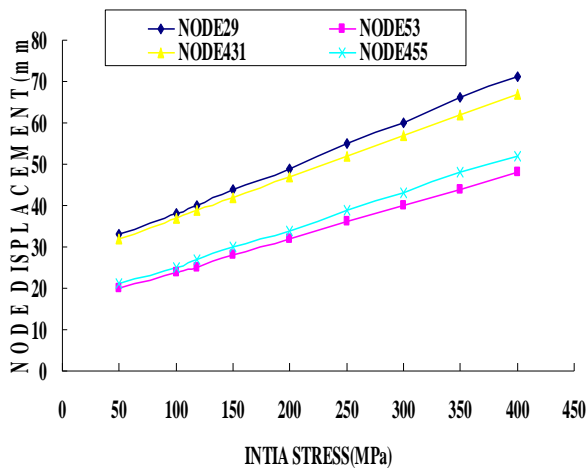


FIGURE VI. THE LAW BETWEEN INTIA STRESS AND NODE DISPLACEMENT IN THE STATE OF INTIA

From the Figure 7 we can see, when the guyed transmission tower under the state of load condition, the initial stress of guy have Non-linear effect on the node displacement, when the value of initial stress below 250MPa and under the state of load condition, node displacement reduces significantly with the increase of the initial stress of guy, but the initial stress is more than 250MPa, with the increase of initial stress, the initial stress have little effect on the node displacement.

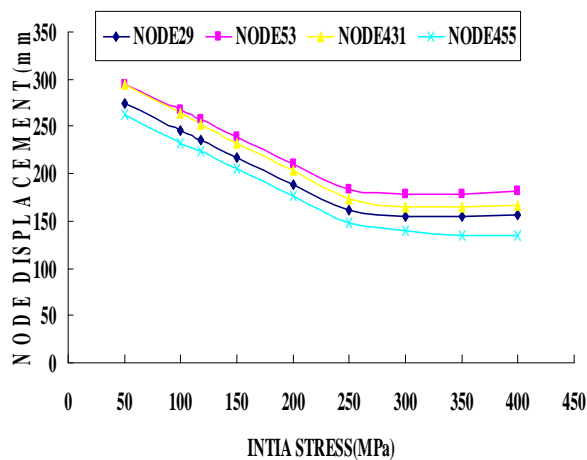


FIGURE VII. THE LAW BETWEEN INTIA STRESS AND NODE DISPLACEMENT IN THE STATE OF LOAD

D. The Effecton of the Support Reaction of Guyed Transmission Tower Which Is Caused by Initial Stress of Guy

From the Figure 8 we can see, when the guyed transmission tower under the state of initial stress, the support reaction which effected by initial stress is linear increment with the increase of the initial stress.

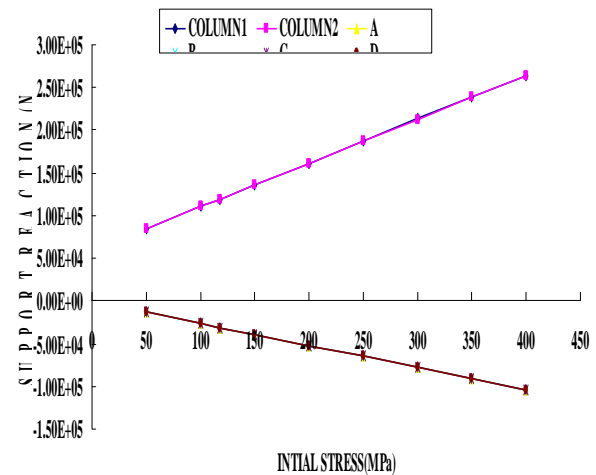


FIGURE VIII. THE LAW BETWEEN SUPPORT REACTION AND INTIA STRESS OF THE GUY IN THE STATE OF INTIA

From the Figure 9 we can see, when the guyed transmission tower under the state of load condition, the initial stress have non-linear effect on the support reaction, when the value of initial stress below 250MPa and transmission tower under the state of load condition, the initial stress have little affection on the support reaction, but when the initial stress is more than 250MPa, with the increase of initial stress, the support reaction also increases.

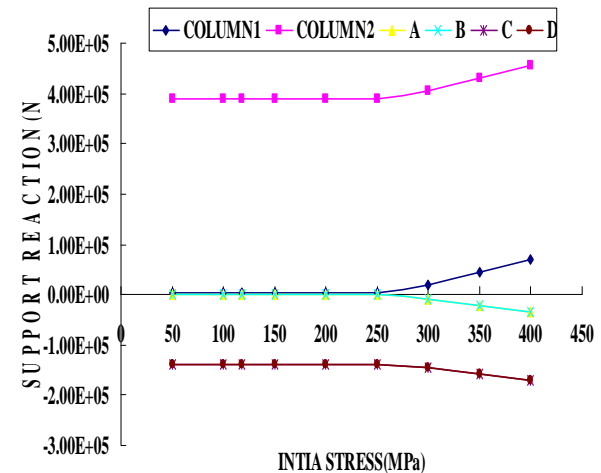


FIGURE IX. THE LAW BETWEEN SUPPORT REACTION AND INTIA STRESS OF THE GUY IN THE STATE OF LOAD

IV. CONCLUSION

The selection of initial stress has a certain impact on the mechanical properties of the guyed transmission tower. when the guyed transmission tower under the state of initial stress, the initial stress have linear impact on the support reaction, node displacement and bar axial stress, but having nonlinear impact on the mechanical properties. So in order to play the economic advantages of prestress structure, for the guyed transmission tower, the value of initial stress should be optimized, the convenience of the extent of construction should

be considered comprehensively, a reasonable value should be determined.

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