Static Stability of Derrick with Double Flat Arm

Yun Liao¹, Guanglong Lin¹, Dehong Wang²*, Wenbin Li¹, Huawei Ye¹, Cheng Hua¹, Chi Ma¹, Jinlin Zhu¹, Qi Dong², Yanzhong Ju²

¹Guangdong Power Grid Energy Development Co., Ltd, Guangzhou 510160, China.
²School of Civil Engineering and architecture, Northeast Electric Power University, Jilin 132012, China.
*Corresponding author’s e-mail: hitwdh@126.com

Abstract. In order to investigate the stability of a derrick under wind load, a floor type double flat arm derrick is selected as the object, and the numerical simulation method is applied for the eigenvalue buckling analysis and the nonlinear stability analysis to get the instability mode and the critical wind speed in static stability. The results show that the position where the derrick first buckles is the connection between the derrick and the flat arm, and finally the torsional instability leads to the overall instability. The instability of the derrick without waist ring is caused by the damage of the main material of the tower leg. The mean wind speed in static instability is 56 m/s.

1. Introduction
The floor type double flat arm derrick is easy and flexible to use, and can bear the heavy load and unbalanced torque. It has been widely applied to tower construction in recent years. However, it’s very important to guarantee the security and efficiency in the tower construction. A large number of researches find that there are damage and instability under the wind load in towering structure such as derrick. Xia [1] carried out stability analysis on a derrick under working conditions, some weak positions in the derrick structure were determined and some reasonable amendments were proposed. Xu [2] carried out numerical simulation on the strength and stability of a double flat arm derrick, and studied the stability under the working condition with more dangerous stress. Roy [3] used the large displacement space truss method to analyse the stability of the structure, and obtained that many factors caused by the large geometric deformation of the structure are constantly changing with the change of the structure height and load. Le [4] analysed the nonlinear buckling of a gantry crane tower considering the nonlinear factors. The results show that the wind has a great effect on the stability of the tower, and it cannot be ignored. At the same time, the cable wind rope can effectively improve the stability of the tower.

With the increase of the height, size and weight of the derrick, the influence of wind load on the derrick is more significant. However, most of the existing research has focused on derricks with normal height. In this paper, the double flat arm derrick used in the construction of UHV transmission tower is taken as the research object. Through the establishment of the steel frame model of the derrick, the static stability analysis of the derrick is carried out, including the eigenvalue buckling analysis and the nonlinear buckling analysis, and the instability mode and the critical wind speed in instability are discussed.
2. The finite element model of the derrick

In this paper, a double arm derrick used in the construction of UHV transmission tower is taken as the research object. The total height of the derrick is 162m, the length of the flat arm is 21m, and the final use height is 153m (the distance from the lower plane of the double flat arm of the crane to the ground). In order to ensure the stability of the pole body, the waist ring needs to be installed when the derrick is raised to a certain height. There are 8 waist rings in the derrick, and the distance between the waist rings is 21m, 18m and 15m respectively. Square steel tubes are used as the material of derrick members.

The finite element model of the derrick adopts the spatial rigid frame model [1], the main material, transverse material, diagonal material and double flat arm of the standard section adopt beam188 unit, and the connection between the members is treated as rigid connection; the internal stay wire, waist ring, pull rod and other members that only bear tension adopt link180 unit, and the connection of them with the rod body and flat arm is hinged. The bottom of the derrick is fixed to the ground.

Q345 steel is adopted, with yield strength of 310MPa, elastic modulus of 206MPa, density of $7.85 \times 10^3$kg/m$^3$ and Poisson's ratio of 0.3. The stress-strain curve of steel uses bilinear following reinforcement model [6].

3. Static stability analysis

The design and check of the stability of the derrick are completed through the static stability analysis, and this paper analyses the stability under the static wind load.

3.1. Buckling analysis

According to the equivalent static analysis of the derrick [7], the most unfavourable working condition is that the swing angle of the flat arm is $0^\circ$ and the wind direction angle is $45^\circ$. In this paper, taking this condition as the research object, the wind load of each section is calculated and applied to the main material node of the corresponding height of the derrick in the form of concentrated force. The eigenvalue buckling analysis is carried out for the two cases with and without waist ring, and the eigenvalue (also known as the yield factor) is obtained when the determinant of the stiffness matrix of the linear system is zero. The buckling mode diagrams of the first six orders are shown in Figure 1, and the corresponding yield factors are shown in Table 1.

According to the results of the first and second eigenvalue buckling analysis of the derrick, it can be seen that the derrick has partial buckling at the connection between the flat arm and the body. The third, fourth and fifth modal diagrams show that the derrick has torsion accompanied by partial buckling at the flat arm, and the sixth modal diagrams show that the derrick has overall torsional instability.

It can be seen from the calculation results that the instability of the derrick without waist ring is caused by the damage of the main material at the tower leg of the derrick body, and the instability of the derrick with waist ring is caused by torsion. Comparing the eigenvalue buckling factors obtained in the two cases, the first-order yield factor of the derrick with waist ring is 7.63, and the first-order yield factor of the derrick without waist ring is 1.81. It can be seen that the yield factor of the derrick with waist ring is larger than that of the derrick without waist ring, and the existence of waist ring enhances the stability of the derrick.
(a) the first order mode  
(b) the second order mode  
(c) the third order mode  
(d) the fourth order mode  
(e) the fifth order mode  
(f) the sixth order mode

Figure 1. Buckling modes.
Table 1. The results of eigenvalue buckling analysis.

| Order | The derrick with waist ring | The derrick without waist ring |
|-------|-----------------------------|-------------------------------|
| 1     | 7.638                       | 1.813                        |
| 2     | 8.392                       | 3.981                        |
| 3     | 9.692                       | 3.986                        |
| 4     | 10.498                      | 4.643                        |
| 5     | 10.642                      | 4.649                        |
| 6     | 10.698                      | 5.019                        |

3.2. Nonlinear buckling analysis

The nonlinear buckling analysis can get the critical load and the form of instability when the structure is unstable. In this paper, geometric nonlinearity, material nonlinearity and initial defects are considered in the nonlinear buckling analysis. The specific process is as follows: the geometric nonlinearity of the derrick is set through the geometric large deformation in the ANSYS software, and the material nonlinearity is considered by the introduced BKIN model [8]; the initial defect is considered by 1% of the first-order buckling mode in the eigenvalue buckling analysis, and realized by the UPGEOM command; in order to ensure the nonlinear buckling of the structure in the calculation process, the structure is imposed twice of the eigenvalue buckling load, taken as the upper limit value of load [9,10].

The nonlinear buckling analysis adopts the system response criterion [5], which is more convenient to determine the critical load of the instability of the structure. That is to say, during the loading process, the displacement of the structure suddenly increases under the small load increment and the bearing capacity of the structure is lost, so the instability of the structure can be determined.

According to the equivalent static analysis [7], the maximum displacement of the derrick occurs at the end of the flat arm, which corresponds to Node 4846. The incremental method [9] is used for nonlinear buckling analysis to obtain the relationship between displacement and load of Node 4846 at the end of the flat arm, and the relationship between displacement and wind speed change can be obtained by converting wind load into wind speed, as shown in Figure 2(b).

![Figure 2. Displacement verse wind speed curve of Node 4846.](image)

(a) Location of Node 4846  (b) Displacement verse wind speed curve of Node 4846.

It can be seen from Figure 2 that before the displacement reaches 1.0m, the wind speed increases with the increase of displacement; after the displacement reaches 1.0m, the displacement wind speed curve tends to be flat; after the displacement reaches 1.2m, the wind speed does not change, but the displacement increases rapidly. According to the system response criterion [9], the derrick has been unstable at this time, and the critical displacement at the time of instability is 1.2m, that is, the displacement of Node 4846 at the end of the flat arm is 1.2m. Although the derrick is high, the displacement of the pole body is very small due to the role of the waist ring, almost unchanged, and the wind speed corresponding to the wind load at the time of instability of the pole is 56m/s.

4. Conclusions

Based on the eigenvalue buckling analysis of the derrick, it is found that the first buckling position of the derrick is the connection between the flat arm and the derrick body, and finally the overall instability is caused by the torsional instability. For the derrick without waist ring, the instability of the
Derrick is caused by the damage of the main material of the tower leg. It can be seen from the comparison that the waist ring enhances the stability of the derrick, and the first-order yield factors of the derrick with and without waist ring are 7.63 and 1.81 respectively. The average wind speed of static instability of derrick is 56 m/s.

Acknowledgments
The work described in this paper was fully supported by China Southern Power Grid Company Limited (Project no. GDKJXM20173029).

References
[1] Xia, S. K. (2006) Mechanical test and finite element analysis of lifting derrick of large transmission tower. Hefei University of Technology, Hefei, Anhui, China.
[2] Xu, C. C. (2014) Study on static and stability of double flat arm derrick. Hefei University of Technology, Hefei, Anhui, China, 2014.
[3] Roy, S., S. J. Fang, and E. C. Rossow, (1984) Secondary stresses on transmission tower structures. Journal of Energy Engineering, 110(2): 157-172.
[4] Y. F. Le, Guo J., and Shi, J. J. (2009) Stability analysis of large gantry crane tower. Mechanical Engineering and Automation, (1): 51-53.
[5] Zhang, A. L. and Lu, Y. (2010) Study on wind-induced dynamic stability of transmission tower. in Proceedings of the 10th National Symposium on Modern Structural Engineering, Shanghai, China, July.
[6] Chen, C. (2008) Study on nonlinear stability of self-supporting transmission tower. The World of Building Materials, 29(5): 75-77.
[7] Dong, Q. (2019) Analysis of wind stability and dynamic response of double flat arm derrick. Northeast Electric Power University, Jilin, China.
[8] Zheng, X. J., Xie, Z. Y. and Zhang. G. Z. (2007) Structural stability analysis of tower crane based on ANSYS. Construction Machinery (first half), no. 11.
[9] Feng, Z. J., Qin, Y. X., and Yang, H. L. (2013) Nonlinear buckling analysis of tower crane under full load condition. Lifting and Transportation Machinery, (6): 14-18.
[10] Xia, C. N. (2014) Wind load dynamic analysis and stability study of transmission tower line system. Zhengzhou University, Zhengzhou, China.