Transactions on Engineering and Technology Research
ISSN: 2960-1797, eISSN: 2960-2246 | Volume 4
ACEGE 2024

The Dangerous Points of Dry Type Transmission Tower under Ice Load Based on COMSOL

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Abstract. With the continuous and rapid development of the energy industry, the application of transmission poles and towers is more and more widespread. In some areas prone to ice and snow disasters. It is necessary to explore the distribution of hazardous points under snow and ice phenomena. In this paper, a simplified model of dry-type strain tower was established based on COMSOL software, and the gradient analysis of transmission tower and cable icing load was carried out. The results show that the connection of the transmission tower and the transmission cable is most prone to damage, and when the ice thickness reaches more than 60mm, the transmission tower will reach the dangerous critical point. This study provides the damage analysis and optimization of dry type tensile tower after ice.

Keywords: Transmission tower, Finite Element Analysis, Ice Load, Stress Analysis.

1. Introduction

With the rapid development of energy industry, power transmission poles and towers are more and more widely used. According to the data released in China's Power Industry Annual Development Report 2023 released by the China Electricity Council[1], by the end of 2022, the circuit length of 220kV and above has reached 880,000 kilometers. In some areas prone to ice and snow disasters, transmission towers and transmission lines are seriously affected by ice and snow disasters, that is, lines and towers, which can easily lead to the inclined collapse of transmission poles and towers, resulting in the interruption of transmission lines, as shown in Figure 1. Since 2008, the extreme ice disaster in southern China has led to a large number of power transmission poles and towers[2-3], cain a large area of power failure, it can be seen that the prediction analysis of the displacement of the transmission tower and the damage position under the icy snow load is of great significance to the protection of people's personal safety and the protection of the country and people's property safety.

In response to the national "carbon peak, carbon neutral" development requirements[4].In the field of power transmission, dry type poles and towers are named because their shape is similar to the Chinese character "dry", and are widely used in high voltage and UHV transmission lines for its advantages such as clear and direct force, stable structure, high cost performance, wide range of application and convenient construction and maintenance. Liu Wenjing studied the strength and stiffness stability of the 220kV linear cat head tower under different ice loads, and found that the head of the wiring tower was the place where the maximum stress and maximum displacement occurred[5]. Jia Yuzhuo et al. used ANSYS and MATLAB to study the static and spontaneous vibration characteristics of straight towers and straight towers under strong wind conditions[6]. Huang Mingxiang et al. used ANSYS model and AR method to study the structural wind resistance performance and wind vibration coefficient of 1000kV dry iron tower, and found that the wind vibration coefficient of dry iron tower showed a nonlinear and zigzag increase with the increase of height[7]. However, at present, there are few related studies on the displacement, stress response and danger point prediction and damage prediction of dry type rods and towers under different ice load conditions.

Based on the above considerations, this paper builds a dry-shaped strain tower model suitable for 220kV and above voltage levels in the COMSOL simulation software, and analyzes the strength and stiffness of the dry-shaped strain tower under different icing load conditions. It provides a reference for the possible damage prediction of dry-shaped strain towers in areas prone to ice and snow disasters.

Figure 1 Power transmission tower collapsed by snow and ice disaster

2. Model Construction and Methods

2.1. Model construction

At present, the transmission lines put into use in China are mainly high voltage, ultra-high voltage transmission as the main transmission modes of the national grid, while high voltage transmission is the most basic and common transmission mode[8]. And the tower is usually a lattice type steel tower[9]. The physical drawing of dry type tensile tower is shown in Figure 2 and Figure 3. In this paper, a 220kV double loop dry type transmission tower is selected as the research object, and the simplified model is shown in Figure 4 and Figure 5. The full height of the tower is 13m, the shout height is 9m, the cross arm length is 6.9m, and the straight side root is 4m. The actual parameters of transmission towers are summarized in Table 1. In this paper, a simplified model of dry tensile iron tower is built based on COMSOL Multiphysics simulation software.

In order to obtain the simulation results and simplify the calculation amount, on the basis of retaining the basic tower type:

(1) Minor displacement of some poles at the end points of three or more poles.

(2) The tensile iron tower of the dry character type is built symmetrically.

(3) The materials of dry type tensile tower are only Q345 steel and Q235 steel.

(4) The equal angle steel of the dry font tensile tower is replaced by a solid uniform round rod with a diameter of 64mm.

(5) The load generated on the transmission cable is replaced by the centralized load at the connection point.

Finally, the dry-type transmission tower model is shown in Figure 6.

This dry type transmission tower adopts angle steel structure in practical application, and in order to facilitate calculation, the Angle steel part is replaced by solid circular rod. Rigid connection is used at the connection of the rods, the main material of the whole tower is Q345 steel, the auxiliary material is Q235 steel, the reinforcement between the rods is welded, but actually most of the connections are bolted, and rigid contact is used in this paper. In this paper, the steel of the dry type transmission tower and the material parameters used in the simplified model are as follows in Table 2[10].

Figure 2 Physical drawing of transmission tower

Figure 3 Physical drawing of the dry font tensile iron tower

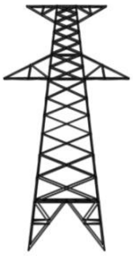

Figure 4 Front view of simplified model of dry font tensile tower

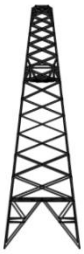

Figure 5 Simplified model side view of dry font tensile tower

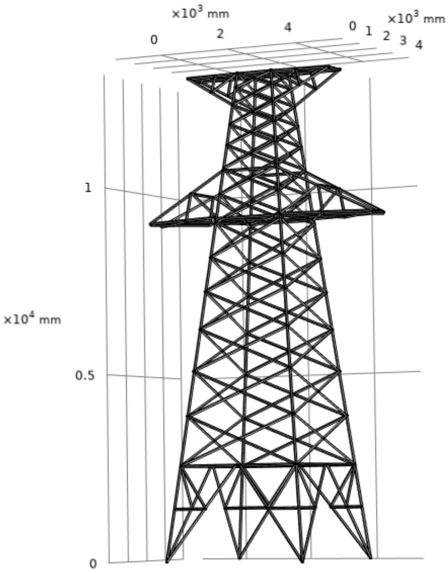

Figure 6 Modeling of dry-type transmission tower

Table.1. Modeling parameters of transmission tower[11]

Tower type	tower height /m	Hugao / m	Cross bear length / m	Positive lateral root open / m	Main material	Slant material
Dry type	13	9	6.9	4	Q345	Q235

Table.2. Steel parameters used for transmission poles and towers

model	Poisson ratio	Density / (kg/m³)	Young's modulus / (N/mm²)	Initial submission stress /MPa
Q345	0.3	7850	20600	345
Q235	0.3	7850	20600	235

Transmission pole tower using steel for Q345, Q235, has easy processing, good mechanical properties, high strength, welding is not easy to crack, reduce cost, especially Q345 high strength steel can very good in low temperature keep good toughness, this characteristic makes the transmission tower in cold low temperature environment to maintain the stability of its structure.

2.2. Simulation data

The ice load is replaced equally, and in the premise, the ice load is applied by the gradient, and then the target data is obtained by simulation calculation.

(1) Calculation formula of the dead weight of the transmission cable in the transmission line $G_{self-weight}$

$$G_{\text{self-weight}} = \frac{\pi D^2 \rho g_b L}{4} \tag{1}$$

D represents the calculated diameter of the transmission cable, ρ represents the density of the transmission cable, g_b represents the local gravity acceleration, L represents the length of the transmission cable between two adjacent transmission towers (take Wuhan as an example $g_b = 9.79361\ m/s^2$) [12].

Suppose 4 bars are 100m long with a nominal section of 50mm^2 of the 26-35kV 3-core YJV power cable, according to the reference data[13], can get the weight of one transmission cable of

$$G_{self-weight} = 6.592\frac{kg}{m} \times 100\ m \times 9.79361 m/s^2 \approx 6455.95\ N \tag{2}$$

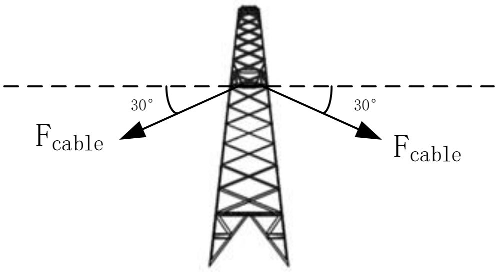

Figure 7 Schematic diagram of the cable tension of the transmission poles and towers

The cable generation load is as Figure.7.

(2) Calculation formula of ice-cover load M:

$$M = \sum_{i=1}^{N} 0.9\pi g_b b_i l_i (b_i + D) \times 10^{-3} \tag{3}$$

b_i represents the ice thickness on the length segment l_i , D represents the calculated diameter of the cable, g_b represents the local gravitational acceleration

(3) The calculation formula of uneven ice load into the thickness of uniform distributionb_u

$$b_u = \frac{\sqrt{D^2 + \frac{4M}{0.9\pi}} - D}{2} \tag{4}$$

M represents an ice-cover load[14].

After calculation with gradually increasing ice thickness, the ice load on a single transmission line is shown in the following Table.3.

Table.3. Gradient arrangement is covered with ice

Ice-thickness bu (in mm)	Single transmission cable covered with ice load (in N)$-M_1$
20	1549.576
40	5314.415
60	11294.515
80	19489.879
100	29900.504

A computational expression that can be obtained from cable transfer order and Pythagoras theoremF_{cable}

$$F_{cable} = \frac{\frac{1}{2}(G_{self-weight}+M)}{\sin 30°} \tag{5}$$

(4) In order to obtain the change of tower load under different working conditions. Finite element method (FEM) is a useful numerical calculation method to solve the acupoint learning problem. In particular, it is particularly good in solving the approximate solution of the preparation problem of partial differential equations. Its basic theory includes variational principle and weighted residual method. Through these principles, the complex continuous solution domain is discretized into a finite simple sub-regions (i.e., finite units), and a simple approximate equation is established on each finite unit, so as to solve the numerical value of the complex problem on the whole domain. The basic steps of the finite element method are divided into seven steps: establishing the integral equation, the regional cell section, determining the cell basis function, cell analysis, overall synthesis, treating the boundary conditions, and solving the finite element equation[15].

3. Experimental results and analysis

After the static analysis of solid mechanical interface is calculated by COMSOL simulation software, the model diagram of gradient increased ice load and the maximum stress and displacement maximum are as follows from Figure 8 to Figure 18.

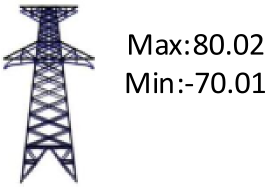

Figure 8 stress diagram ①

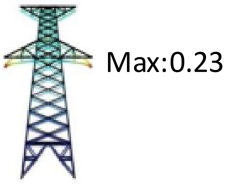

Figure 9 displacement diagram ①

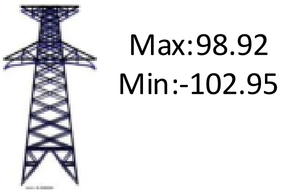

Figure 10 stress diagram ②

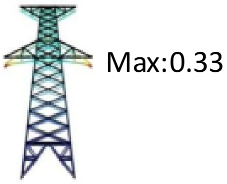

Figure 11 displacement diagram ②

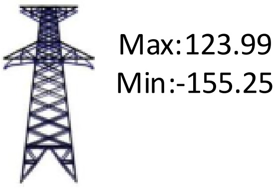

Figure 12 stress diagram ③

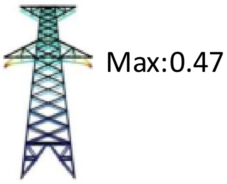

Figure 13 displacement diagram ③

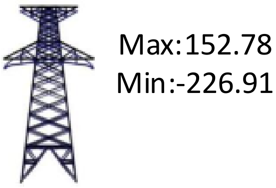

Figure 14 stress diagram ④

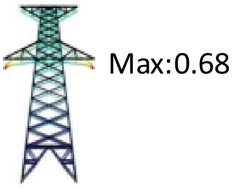

Figure 15 displacement diagram ④

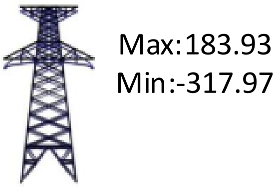

Figure 16 stress diagram ⑤

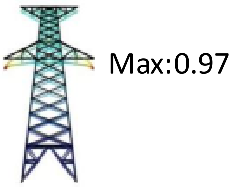

Figure 17 displacement diagram ⑤

After finite element calculation, when the ice thickness is 20mm, the total ice load of a single transmission cable is calculated to be 1549.576N. After converting the triangle function, the load F directly acting at the junction of the transmission cable and the transmission tower is loaded with 8005.526N, the maximum tensile stress can be obtained through the stress calculation is 80.02MPa, appearing at the connection of the cable and the tower, the maximum compressive stress is 70.01MPa, the bending and extrusion of the rod at the connection of the transmission cable and the transmission tower, the maximum displacement is 0.23mm, and the connection of the transmission cable and the transmission tower, along $F_{load.}$ The direction of the occurrence. The remaining data are listed in Table 4.

Table 4 model simulation

Load application serial number	Ice thickness (unit:mm)	Total ice cover load of a single cable (unit:N)	F_{load} (unit:N)	maximum tension stress (unit:MPa)	maximum crushing stress (unit:MPa)	Maximum displacement (in mm)
①	20	1549.576	8005.526	80.02	70.01	0.23
②	40	5314.415	11770.365	98.92	102.95	0.33
③	60	11294.515	17750.465	123.99	155.25	0.47
④	80	19489.879	25945.829	152.78	226.91	0.68
⑤	100	29900.504	36356.454	183.93	317.97	0.97

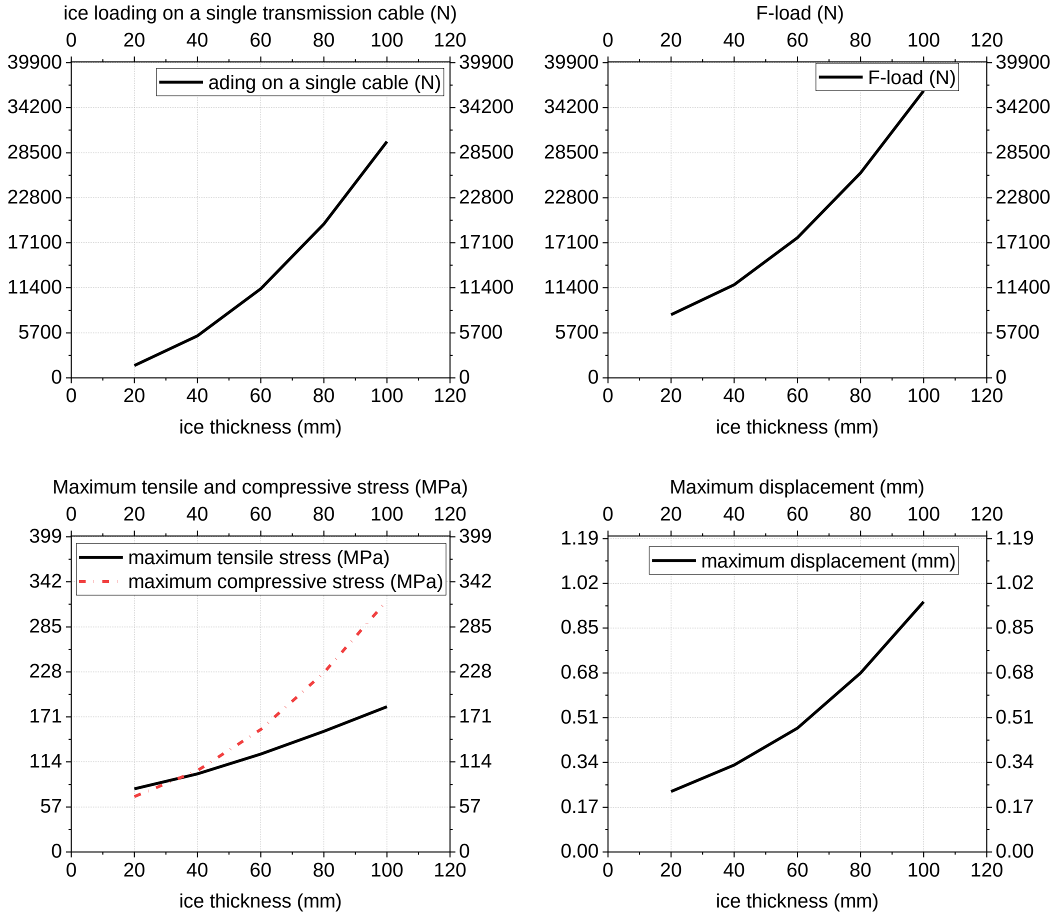

Figure 18 Line graph of related data

When the average ice cover of the dry type tensile tower reaches 20mm, the maximum compressive stress is greater than the maximum tensile stress, while the subsequent four groups of data are that the maximum compressive stress is greater than the maximum tensile stress, and the maximum compressive stress increases rapidly. It is worth noting that the maximum tensile stress and maximum displacement occur at the connection points of transmission cables and transmission towers. In addition, with the increase of ice cover thickness, the total load of ice cover also increases, and the growth rate is gradually accelerated, and the relevant data also show a trend of gradually accelerating the growth rate. For example, when the ice thickness increases from 20 mm to 40 mm, the displacement increases by 0.1 mm, while from 40 mm to 60 mm, the displacement increases by 0.14

mm, from 60 mm to 80 mm, the displacement increases by 0.21 mm, and from 80 mm to 100 mm, the displacement increases by 0.29 mm. The displacement with the ice thickness showed a nonlinear increase trend using the quadratic polynomial fitting, The data graph fitted by a quadratic polynomial with consideration of maximum displacement is shown in Figure 19:

$$f_{\mathrm{displacement}}(x) = 0.000080357x^2 - 0.00049286x + 0.212 \tag{6}$$

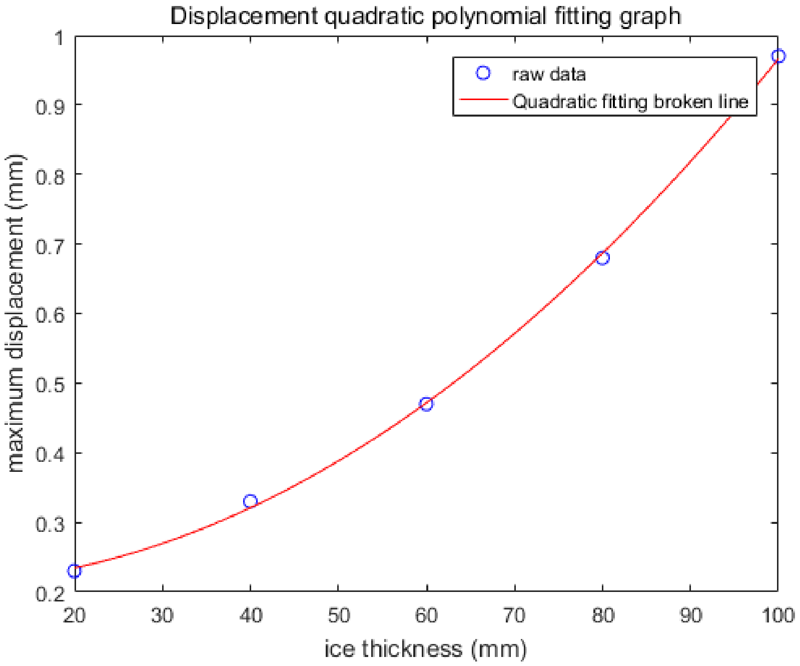

Figure 19 Data graph fitted by a quadratic polynomial with maximum displacement

4. Discussion

Q345 steel is used for main materials, and Q235 steel is used for inclined materials and auxiliary materials. In order to ensure the safety of the structure, a certain safety margin is often reserved in the design of the stress standard[16]. In this paper, the safety factor is assumed to be 1.4, and then

$$[\sigma_{Q345}] = 345 \div 1.4 = 246.4\ (MPa) \tag{7}$$

$$[\sigma_{Q235}] = 235 \div 1.4 = 167.8\ (MPa) \tag{8}$$

$[\sigma_{Q345}]$and$[\sigma_{Q235}]$ It represents the allowable tensile stress of Q345 steel and Q235 steel, and this value is also used as the dangerous critical value

According to the above simulation calculation results, the maximum tensile stress and the maximum displacement point are at the wiring point of the transmission cable and transmission tower. If Q235 steel is used in this area, the design allowable tensile stress of Q235 when the ice thickness reaches 60mm, and the dangerous critical point will be reached. If Q345 steel is used, it will also be dangerous when the ice thickness reaches 80mm. In the snow disaster environment in southern China in 2008, taking Chenzhou, Hunan province as an example, a large number of transmission cables and towers covered with ice thickness reached 60mm～100mm, making the original weight of 6 tons of double loop tower reach 50 tons, far exceeding the design load. In this simulation, it is also concluded that in the range of 80mm～100mm, even if Q345 steel is used, the stress of the bar has reached the dangerous value only by the static analysis. In the real environment, temperature stress, ground subsidence, snow shock and other factors will inevitably destroy the structural poles, and then lead to the tilt or even collapse of transmission poles and towers. Therefore, in order to deal with the possible similar or even beyond the 2008 snow disaster, and from the economic point of view, in the design and construction of transmission tower, higher strength materials can be used at the wiring, or local section enhancement, so that they have stronger tensile resistance in the wiring area.

5. Conclusion

In this study, COMSOL software was used to establish a dry-shaped tension tower model, and the load of the tower before and after icing was calculated and analyzed based on the finite element principle.

(1) When the ice thickness reaches above 60mm, the maximum stress reaches 155.25MPa, the connection of the transmission cable and transmission tower will reach the dangerous critical point of Q235 steel; when the ice thickness reaches above 80mm, the maximum stress reaches 226.91MPa, and the connection of the transmission cable and transmission tower will reach the dangerous critical point of Q345 steel.

(2) In the extreme weather of snow and ice, transmission poles and towers are often damaged at the wiring points of transmission cables and transmission poles and towers, which leads to the destruction of rod system and the interruption of transmission lines.

(3) In order to avoid local damage, the wiring should be strengthened during design and construction. If we want to carry out a more detailed calculation of the above dry type tensile tower model, such as the calculation of overlapping contact points of multiple rods, the combination calculation of transmission tower and transmission cable system, and the local strengthening system calculation of transmission tower, etc. The follow-up work can be more practical modeling and calculation on the equipment with stronger computing power, and further carried out from the calculation of transmission tower and transmission cable system.

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