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Influence of Tower Line Coupling Effect on Stress of Iron Tower in Mining Area

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Abstract. During the deformation process of power transmission iron tower base along with the ground surface settlement, the conductor and ground wire can support the iron tower structure to some extent. Through defining the influential coefficient of coupling effect of tower line, we have obtained the influential coefficients of coupling effect of tower line under two working conditions, i.e. base settlement and horizontal slipping, and evaluated the influence of the tower line coupling effect on bearing performance of iron tower during the base deformation process. The research shows that the shaft force of main material of tower leg during the base deformation process is slightly increased, and the increasing amplitude is within 10%, and the influence of the tower line coupling effect on the bearing performance of iron tower during the base deformation process can be neglected basically.

1. Introduction

With the promotion of engineering construction of the “nationwide interconnection, west-to-east power transmission and mutual supply between south and north”, more and more power transmission lines are erected on the mining area of instable foundation. However, in Inner Mongolia, Xinjiang, Shaanxi, Anhui, Guizhou, Shanxi, Heilongjiang Provinces, the damage of power transmission iron tower of the mining area has occurred successively. The power transmission lines include No. 50 iron tower of Wuhai Yigong line of Inner Mongolia, No. 25 iron tower of north-west line of Xi’an City, No. 021 iron tower of Ji I circuit of 220kV power transmission line station in Guizhou Province, No. 2-No. 6 iron towers and No. 17-No. 44 iron towers of Kuxiang Line in Shanxi Province. To reduce the loss caused by such disasters, the scholars at home and abroad have implemented relatively many researches on the settlement monitoring, stress analysis, reinforcement reconstruction scheme of iron tower in the mining area. Li Pengyun^[1] took some 220kV power transmission tower as object, adopted the optical level measurement method to monitor the displacement of support of the iron tower, established finite element model, exerted deformation monitoring data, and then obtained the stress analysis result of the iron tower. S.Matsuo^[2], N.BenKahla^[3], F.G.A. Albermani^[4] et al. proposed the modeling analysis method which conforms to actual stress status to a greater extent with regard to the stress of power transmission iron tower under base deflection conditions. Yang Fengli^[5-6] took the southeastern Shanxi Province-Nanyang 1,000kV UHV power transmission iron tower in the mining area as the research object, and conducted analysis on the internal force of tower rack after deformation of ground surface. The research pointed out that the hazards of inclination along with the line direction, inclination along with the horizontal line direction, uneven settlement of 4 foots and horizontal slipping to the bearing force of iron tower are increased successively. Jiang Hui^[7] took the No. 53 deformation iron tower of the 500kV Xuliao Line as prototype, adopted the numerical analysis method, established the finite element analysis models under different wind load and ice coating load conditions and under the joint function of ground surface settlement, inclination and guying, and gave the limit values of displacements under various different working conditions. Guo Wenbing^[8] established the theoretical model of joint function of power transmission iron tower - base - foundation in the mining area based on the theoretical research, and the result shows that the model can calculate the deformation and stress of iron tower under the function of mining area well. Shu Qianjin^[9]



researched the anti-deformation performance of tower rack and base of the coal mining subsidence area; he believed that the large board base could be adopted to reduce the stress strain of iron tower, gave the suggested value of thickness of protection plate, and conducted assessment to the bearing performance of iron tower.

The power transmission line is the iron tower- conductor and ground wire – insulator coupling system, and during the deformation process of power transmission iron tower base along with the ground surface settlement, the conductor and ground wire can support the iron tower structure to some extent. In this paper, through defining the ratio of the axial force (or stress) of tower line model pole member to the axial force (or stress) of single tower model pole member as the “influential coefficient of tower line coupling effect”, the influential coefficients of tower line coupling effect under two working conditions i.e. base settlement and horizontal slipping are obtained, and the influence of the tower line coupling effect on the bearing performance of iron tower during the base deformation process is evaluated.

2. Analysis Model of Tower Line System

The power transmission line is the iron tower- conductor and ground wire – insulator coupling system, and during the deformation process of power transmission iron tower base along with the ground surface settlement, the conductor and ground wire can support the iron tower structure to some extent. Take some 220kV dual-circuit section for example, adopt the general finite element software ANSYS to establish tower line system analysis model, and research the influence of the tower line coupling effect on the bearing performance of power transmission iron tower with base deformation in the mining area. The maximum design wind speed of this line section is 30m/s (15m reference height), and the maximum design ice coating is 10mm. See Table 1 for the detailed meteorological conditions. The conductor model is 2xLGJ-240/30, and one piece of ground wire refers to OPGW, while the other piece refers to common steel strand GJ-50. The structures of conductor and ground wire and their mechanical performances are as shown in Table 2.

Table 1. Design Meteorological Conditions

Calculation Condition	Air Temperature (°C)	Wind Speed (m/s)	Ice Coating Thickness (mm)
Maximum Air Temperature	+40	0	0
Minimum Air Temperature	-40	0	0
Maximum Wind Speed	-5	30	0
Maximum Ice Coating	-5	10	10
Installation	-15	10	0
Average Air Temperature	-5	0	0
External Overvoltage	+15	10	0
Internal Overvoltage	-5	15	0
Annual Number of Thunderbolt Days		40	
Ice Specific Gravity		0.9	

Table 2. Table of Conductor and Ground Wire Structures and Mechanical Characteristics

Model	Cross Area (mm ²)	Diameter (mm)	Line Weight (kg/m)	Elastic Modulus (GPa)	Line Expansion Coefficient (10 ⁻⁵)	Comprehensive Breaking Force (kN)	Safety Coefficient
LGJ-240/30	275.976	21.6	0.9222	73	1.96	75.62	2.65
GJ-50	48.35	9	0.3849	185	1.15	119.81	4.2
OPGW	128.2	15.2	0.681	119.5	1.47	100.4	4.2

Adopt general finite element software ANSYS to establish the finite element model of tower line system, and main material of iron tower adopts BEAM4 beam unit for simulation, and diagonal material and auxiliary

material adopt LINK8 pole unit for simulation; the insulator adopts LINK8 pole unit for simulation, and the conductor and ground wire adopt LINK10 unit for simulation. The LINK8 unit has three degrees of freedom on each node, translating along with the X, Y and Z directions of the coordinate system of node, and this unit has the function of stress stiffening and large deformation functions.

See Figure 1 for the finite element model and model coordinate system of the tower line system, and the iron tower elevation and span length are all consistent with the actual situation. Assume that the iron tower base has no damage or displacement under the function of strong breeze, the self-supporting iron tower foot is connected firmly. The insulator length takes the value of 2.6m, with weight of 93.1kg and elastic modulus of 118GPa. The conductor refers to double split, and the finite element model is simplified into single piece of conductor (the cross section area is twice as large as that of single conductor), and after neglecting the influence of model on the conductor rigidity, the unit length of conductor and ground wire generally takes the value of 10m. For the rise-span ratio of each span of the line section is relatively small, the geometric model of conductor and ground wire adopt the parabolic equation.

The initial tension of conductor and ground wire of line section are determined according to the typical span length $l_r=442.6\text{m}$ and meteorological conditions of installation working conditions. The initial tension of conductor (single conductor) takes the value of 16.765kN, the initial tension of ground wire is 9.72kN, and the initial tension of OPGW is 19.310kN. See formula (1) and formula (2) for the calculation methods of span length.

(1) The frequently adopted typical span length is obtained from the situation when the height difference of suspension point is not taken into consideration, and its formula is:

$$l_r = \sqrt{\frac{l_1^3 + l_2^3 + l_3^3 + \dots + l_n^3}{l_1 + l_2 + l_3 + \dots + l_n}} \quad (1)$$

In the formula: l_r -typical span length, m; l_1, l_2, \dots, l_n -length of each span within the strain section, m

(2) With regard to the typical span length l_r and typical height difference angle β_r which take the height difference influence into consideration, its formula is:

$$l_r = \frac{1}{\cos \beta_r} \left(\frac{l_1^3 \cos \beta_1 + l_2^3 \cos \beta_2 + \dots + l_n^3 \cos \beta_n}{\frac{l_1}{\cos \beta_1} + \frac{l_2}{\cos \beta_2} + \dots + \frac{l_n}{\cos \beta_n}} \right)^{\frac{1}{2}} \quad (2)$$

In the formula: $\beta_1, \beta_2, \dots, \beta_n$ -height difference angle of each span within strain section

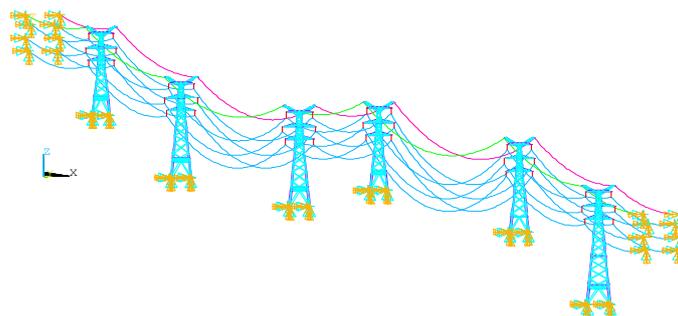


Figure 1. Finite Element Model of Tower Line System

3. Analysis on Influence of Tower Line Coupling Effect

Analysis Result of Single Tower Model

The key point of research in this paper refers to the influence of tower line coupling effect on the bearing performance of iron tower during the base deformation process, so the combination with normal load working condition is not taken into consideration; the considered content refers to calculating the ratio of axial force to stress of typical pole member of power transmission iron tower when the N33 iron tower has base settlement and horizontal slipping, and the distribution and number situations of leg and body pole members of N33 iron

tower are as shown in Figure 2. See Figure 3 for the finite element model of single tower, and the dead weight of conductor and ground wire is exerted at the hanging point in the way of centralized load. When the single leg settlement is 30mm and the single leg horizontal slipping is 100mm, see the ratios of axial forces to stresses of tower leg and tower body pole members are as shown in Table 3 and Table 4 respectively. See Figure 4 and Figure 5 for the axial force and deformation cloud charts of N33 iron tower pole member under two working conditions.

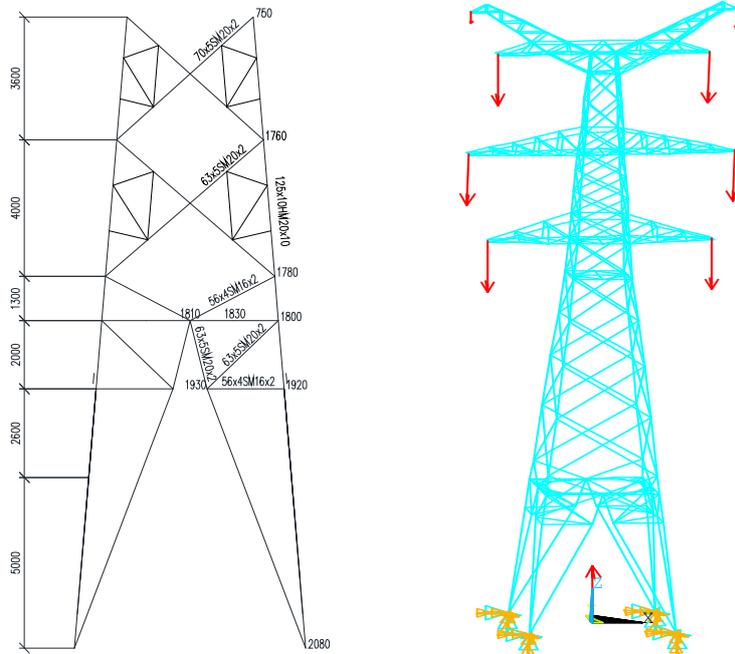
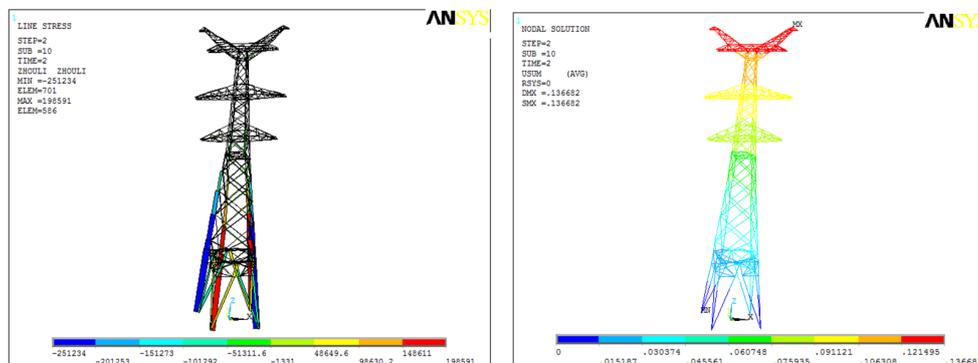


Figure 2. Scheme of Pole Member Distribution **Figure 3** Finite Element Model of N33 Tower

Table 3. Ratio of Axial Force to Stress of Pole Member of N33 Iron Tower (Single Leg Settlement 30mm)

No. of Pole Member	Position of Pole Member	Axial Force (kN)	Stress Ratio
1922-2082	Main material of tower leg	-251.2	0.42
1932-2082	Diagonal material of tower leg	-80.4	1.23
1760-1782	Diagonal material of tower body	-15.4	1.00



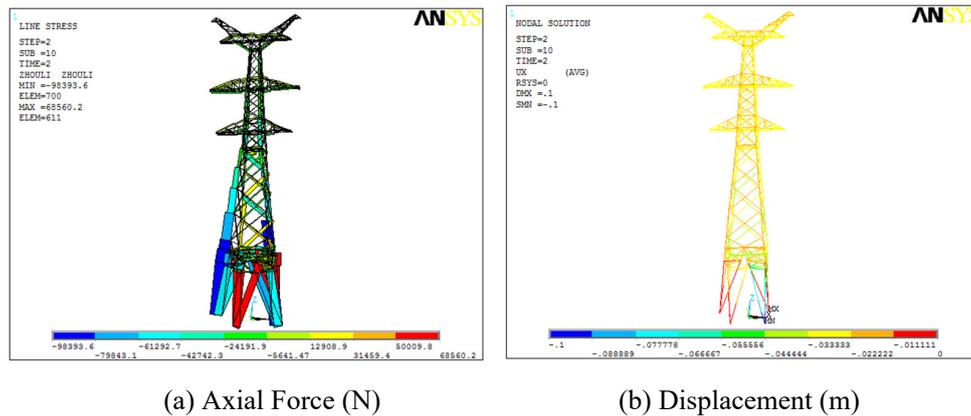
(a) Axial Force

(b) Displacement (m)

Figure 4. Axial Force and Displacement Cloud Chart of Iron Tower with Single Leg Settlement

Table 4. Ratio of Axial Force to Stress of Pole Member of N33 Iron Tower (Single Leg Horizontal Slipping 100mm)

No. of Pole Member	Position of Pole Member	Axial Force (kN)	Stress Ratio
1922-2082	Main material of tower leg	-98.4	0.16
1932-2082	Diagonal material of tower leg	-67.5	1.03
1762-1780	Diagonal material of tower body	-4.9	0.32

**Figure 5.** Axial Force and Displacement Cloud Chart of Iron Tower of Single Leg Horizontal Slipping*Analysis Result of Tower Line Coupling Model*

See Figure 1 for finite element model of tower line system of line section where the N33 tower is located, and under the joint stress of the whole tower line system, and when the single leg settlement of N33 tower is 30mm and the horizontal slipping of single leg is 100mm, the ratios of axial forces to stresses of tower leg and tower body pole members are as shown in Table 5 and Table 6 respectively; see Figure 6 and Figure 7 for the axial force and deformation cloud charts of N33 iron tower pole member under two working conditions.

Table 5. Ratio of Axial Force to Stress of N33 Iron Tower Pole Member (Single Leg Settlement 30mm)

No. of Pole Member	Position of Pole Member	Axial Force (kN)	Stress Ratio
1922-2082	Main material of tower leg	-277.2	0.46
1932-2082	Diagonal material of tower leg	-76.0	1.16
1760-1782	Diagonal material of tower body	-15.3	0.99

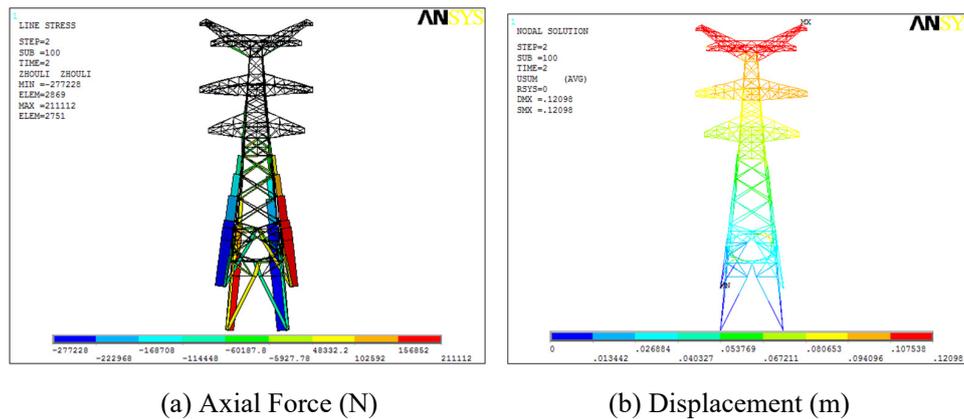


Figure 6. Axial Force and Displacement Cloud Chart of Iron Tower with Single Leg Settlement

Table 6. Ratio of Axial Force to Stress of Pole Member of N33 Iron Tower

No. of Pole Member	Position of Pole Member	Axial Force (kN)	Stress Ratio
1922-2082	Main material of tower leg	-103.5	0.17
1932-2082	Diagonal material of tower leg	-65.1	1.00
1762-1780	Diagonal material of tower leg	-4.5	0.29

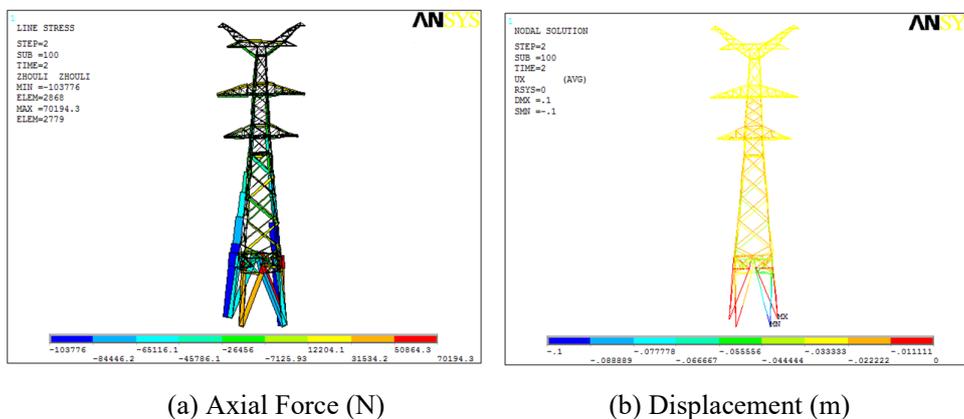


Figure 7. Axial Force and Displacement Cloud Chart of Iron Tower with Leg Horizontal Slipping

4. Analysis on Influence of Tower Line Coupling Effect

The ratio of axial force (or stress) of tower line model pole member to axial force (or stress) of single tower model pole member defined in this paper refers to “influential coefficient of tower line coupling effect”. From the analysis result of single tower and tower line system, the influential coefficients of tower line coupling effect under two working conditions, i.e. base settlement and horizontal slipping are obtained (see Table 7). From Table 7, it can be known that after considering the tower line coupling effect, the axial force of main material of tower leg is increased slightly, with the increasing amplitude within 10%; the axial forces of diagonal material of tower leg and axial force of diagonal material of tower body are reduced slightly, with the reduction amplitude within 5%. Generally speaking, the influence of tower line coupling effect on the bearing performance of iron tower during the base deformation process is not great.

Table 7. Influential Coefficient of Tower Line Coupling Effect

Name of Working Condition	Number of Pole Member	Position of Pole Member	Influential Coefficient of Tower Line Coupling Effect
Single Leg Settlement	1922-2082	Main material of tower leg	1.10
	1932-2082	Diagonal material of tower leg	0.95
	1760-1782	Diagonal material of tower body	0.99
Horizontal Slipping of Single Leg	1922-2082	Main material of tower leg	1.05
	1932-2082	Diagonal material of tower leg	0.96
	1762-1780	Diagonal material of tower body	0.92

5. Conclusions

This paper implements the research on influence of tower line coupling effect on the bearing performance of iron tower with base deformation in the mining area, analyzes the stress and deformation of iron tower with base deformation before and after considering the tower line coupling effect, determines the influence law of tower line coupling effect to the bearing performance of iron tower with base deformation in the mining area. After considering the tower line coupling effect, the axial force of main material of tower leg during the base deformation process is increased slightly, with the increasing amplitude within 10%; and the axial forces of diagonal materials of tower leg and tower body are reduced slightly, with the reduction amplitude within 5%. The influence of tower line coupling effect on the bearing performance of iron tower during the process of base deformation can be neglected basically.

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