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The anti-deformation performance of composite foundation of transmission tower in mining subsidence area

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Abstract

To improve the design method of foundation of transmission tower in mining subsidence area, and considering the interactions of transmission tower, ground and foundation, this paper presents a contrast research on the anti-deformation performance of two types of foundation (i.e. independent foundation and composite foundation with protecting apron) by finite element simulation. For valid simulation, we put forward the methods and principles of simplifying foundation and sand cushion. The research results indicate that, if the ground deforms in patterns of negative curvature, tension or compression, the structure stress and the horizontal support displacement of transmission tower can be reduced by 25% and 40% respectively by using composite foundation compared with independent foundation. If the ground deforms in pattern of positive curvature, the tower can be also protected by using the composite foundation instead of the independent ones, but the effect is less than that in the former three deformation patterns. The research findings provide the basis for improving the design method of transmission tower foundation in mining subsidence area.

Keywords: mining subsidence area; transmission tower; composite foundation with protecting apron; anti-deformation performance; analysis

With the construction of transmission tower in mining subsidence area in recent years, researches on the anti-deformation techniques for transmission tower in mining subsidence area have been made and some achievements obtained [1-8]. One of those anti-deformation techniques is to use the composite foundation with protecting apron in mining subsidence area. However, research on the anti-deformation performance of the composite foundation has not been reported before. Therefore, it is necessary to study the anti-deformation performance of composite foundation to make sure that the transmission tower in mining subsidence area operates reliably and safely.

Considering the interactions among transmission tower, ground and foundation, the paper analyzes the anti-deformation performance of the composite foundation of typical transmission tower in a mining subsidence area with ANSYS software. The research provides some basis for improving the modified design method of transmission tower foundation in mining subsidence area.

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1. Foundation and its geometric model

The composite foundation investigated in this paper is the foundation of high voltage transmission tower KT16 in a mining subsidence area. The construction of the composite foundation is illustrated in Fig.1, from which we can see that the lower part is a cast-in-place reinforced concrete slab, the upper part includes four single footings, and the part between the slab and the footings is a 100mm thick sand cushion. The bottom size of each single footing is 5600mm×5600mm.

Some simplifications of the foundation must be made to meet the requirement of FEM calculation according to the following principles.

(1) The base areas of foundation and of its model must be the same so as to satisfy the requirement of equal bearing capacity.

(2) The lateral area of foundation must be equal to that of foundation model so that the resistances of ground to the lateral area are the same for the foundation and its model in case of ground deformation.

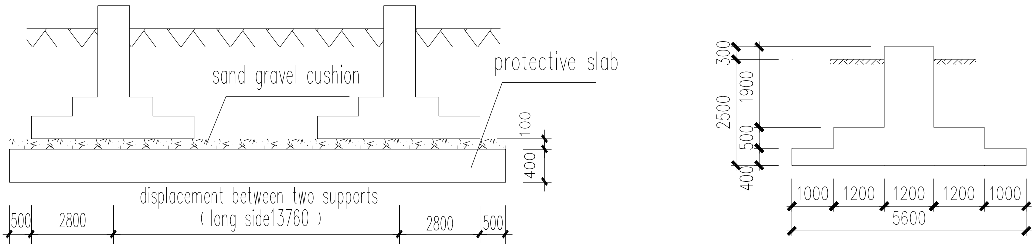

Fig. 1. Composite foundation with protecting apron of KT16 tower (a) Assembly drawing of composite foundation; (b) Form of single footing

The lateral area of each single footing is $5.6\times0.4+3.6\times0.5+1.2\times1.9=6.32\text{m}^2$. Because the bottom size of model should be equal to that of prototype, the width of the model is set to be 5.6m. Accordingly, the height of model is $6.32/5.6=1.13$ m. Allowing for other influence factors, the height of model is taken as 1.2m.

(3) According to the design regulation for the foundation of overhead power transmission lines, the action of soil above foundation should be simplified as the pressure equivalent to the soil weight.

Based on these principles, the upper independent foundation is simplified as four square footings with bottom size of 5600mm×5600mm and height of 1200mm. Since the lateral load is not considered in the analysis, it is supposed that the top of foundation model is at the same level as ground surface. The simplified composite foundation model is shown in Fig. 2.

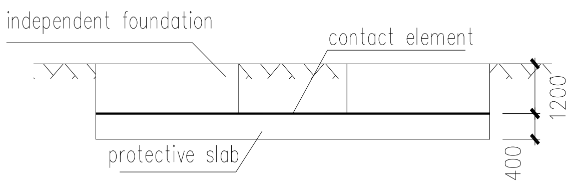

Fig. 2. Simplified model of a composite foundation with protecting apron

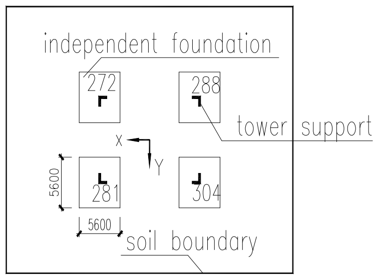

Fig. 3. Simplified model of a independent foundation

In order to analyze the influence of different foundation types on the deformation of transmission tower, the contrast analysis is carried out between the independent foundation and the composite foundation. The layout plan of independent foundation is plotted in Fig. 3, in which the surrounding thick line represents ground boundary, independent foundation (includes four single footings) is in the middle and the number beside each tower support corresponds to the serial number of support node in FEM.

2. Establishment of FEM model

2.1. Determination of parameters for FEM calculation

It is supposed that the foundation is always in the elastic state and do not failure. The strength grade of concrete is C_{20} whose elastic modulus, Poisson's ratio and unit weight are 2.55×10^{-4}N/num^2, 0.2, and 25kN/m^{3}respectively.

(1) Elements and parameters of ground

The element Solid45 is used to simulate the ground. And the constitutive relation obeys the Druker-Prager model.

According to the geological properties of ground where the foundation is located, the parameter values of soil in calculation are taken as the weighted average of main soils influenced by the foundation. The unit weight, cohesion, internal friction angle, dilation angle, elastic modulus and Poisson's ratio are 18.3kN/m^3,10KPa, 17°, 0°, 25N/mm^2, 0.25 respectively.

The soil depth is taken as 10m in order to reduce the influence of model size. On the basis of Rankine soil pressure theory, the least length of model in horizontal direction should be 13.5m. The size of ground model is set as 49.6 m×40 m×10m.

(2) Contact elements between ground and foundation

The interaction between ground and foundation can be simulated with contact elements. The element type used in the calculation is 3D contact pair Targe170 and Conta173. The rigid surface is regarded as target surface that is simulated with Targe170 and the flexible surface is contact surface simulated with Conta173. The constitutive relation of the interface conforms to M-C model.

The major parameters of contact element involved in the calculation are coefficient of sliding friction MU, contact stiffness FKN, sliding viscous resistance COHE, and maximum allowable shear stress TAUMAX. Based on the "Code of Foundation Design for Buildings" (GB50007-2002), the values of MU, FKN, COHE and TAUMAX are taken as 0.35, 3× 104kN/m3,10kPa and $\sigma_y/\sqrt{3}=$7.06× 10-3 respectively, where σ_y is the Mises yield stress of soil.

(3) Contact elements between upper independent foundation and lower concrete slab

As the sandy gravel is a kind of discrete material with large discreteness, there is no corresponding element in ANSYS for its simulation. The interface element is used to approximately simulate the cushion layer. The parameters of cushion layer are set as the same as those of sand.

According to foundation design code, the values of MU and FKN are set to be 0.45 and 3× 104kN/m^3 separately. Accordingly, the cohesion and internal friction angle are set as 10 Pa and 1° respectively. The values of COHE and TAUMAX are calculated as 10Pa and 6.70× 10-6 with the same calculating method as above.

(4) Parameters and Boundary Conditions of Models

The parameters of independent foundation and composite foundation are listed in Table 1.

The hinge joint between tower support and foundation is simulated by sharing node, through which the degrees of freedom of displacement in three directions can be coupled between the elements of tower support and those of foundation. The ground is constrained unidirectional on its four sides and the corresponding constraints should be removed when exerting deformation.

Table 1. Model parameters

Model	Component	Element type	Model size /m	Remark
Independent foundation	Ground	Solid45	49.6×40×10	silt
	Contact	Conta174＋Target170		
	Foundation	Solid65	5.6×5.6×1.2	4，C20 concrete
	Upper structure	Beam188＋Link180	The same as prototype	Q235 and Q345 steel
Composite foundation	Ground	Solid45	49.6×40×10	silt
	Contact of ground and foundation	Conta174＋Target170		
	Contact of independent foundation and protective slab	Conta173＋Target170		
	Foundation	Solid65	19.36×15.08×1.2	C20 Concrete

	Upper structure	Beam188＋Link180	The same as prototype	Q235 and Q345 steel

2.2. Establishment of FEM model

The FEM model and loading diagram are demonstrated in Fig. 4. There are four ground deformation patterns: tension, compression, positive curvature and negative curvature. The deformation values exerted on the ground are ±6mm/m for patterns of tension and compression and $\pm1.2\times10^{-3}$/m for patterns of positive and negative curvature. The deformations of tension and compression are loaded on two sides of the ground, and the deformations of positive and negative curvature are loaded on the bottom of the ground. The transmission tower is under normal operating state (15℃，calm).

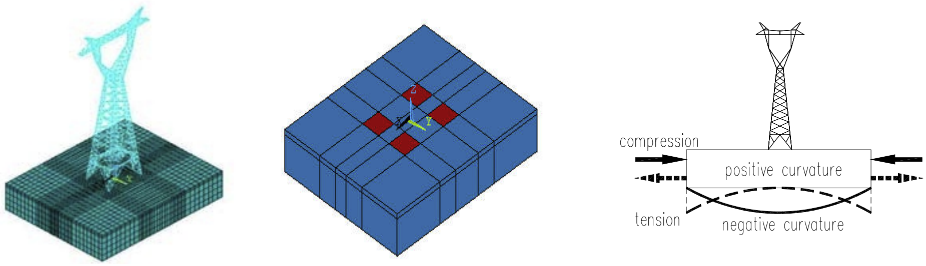

Fig. 4. ANSYS model and loading diagram (a) Integral model; (b) Independent foundation/Composite foundation; (c) Schematic diagram of deformation

3. Results and analyses

3.1. Influence of different types of foundation on structure stress

Table 2 and Fig.5 present the maximum stress of upper structure fixed on independent foundation and composite foundation under different ground deformation patterns.

Table 2. Maximum stresses of upper structure caused by different ground deformation patterns

Ground deformation pattern	Independent foundation (MPa)		Composite foundation (MPa)		Composite foundation deformation/ independent foundation deformation	
	Longitudinal	Transversal	Longitudinal	Transversal	Longitudinal ratio	Transversal ratio
Initial	92.75	92.75	92.75	92.75	1	1
Negative curvature	235.00	196.16	126.56	96.45	0.539	0.492
Tension	207.94	122.17	126.36	92.77	0.608	0.759
Compression	197.56	142.95	98.49	92.76	0.499	0.649
Positive curvature	215.15	135.59	177.15	122.93	0.823	0.907

As seen from table 2, when negative curvature, tension and compression deformations occurs longitudinally (along the length direction of the foundation), the maximum stress of upper structure fixed on composite foundation can be reduced by 40% compared with that on independent foundation. When negative curvature, tension and compression deformations occurs transversally (along the width direction of the foundation), the maximum stress in upper structure fixed on composite foundation can be less as much as 25% than that on independent foundation.

Other conditions being equal, the structure stress induced by negative curvature ground deformation is greater than the stress induced by other deformation patterns. The influence of negative curvature deformation on the transmission tower fixed on independent foundation is the greatest, and the stress in some tower members reaches the yield stress. When positive curvature deformation occurs, the use of composite foundation instead of independent ones can also reduce the stress in tower members, but the reducing extent is less than that occurred in other three deformation patterns.

From Fig. 5 we see that the influence of longitudinal ground deformation is much greater than that of transversal deformation. As to independent foundation, the maximum structure stress caused by longitudinal negative curvature deformation is 1.2 times of that by transversal one; and for composite foundation, it was 1.32 times.

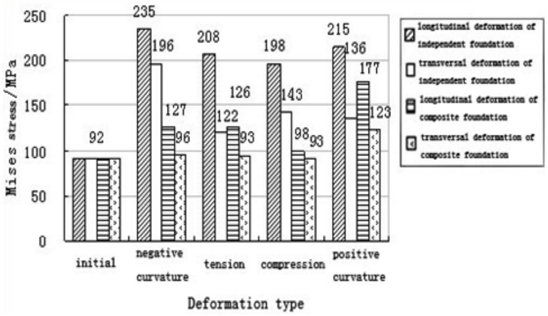

Fig. 5. Maximum structure stresses caused by different ground deformation patterns

3.2. Influence of different types of foundation on support displacement

Fig.6 gives the support displacements of transmission tower fixed on independent foundation and composite foundation under the condition of longitudinal ground deformation (X direction, perpendicular to transmission line). In order to contrast conveniently, all the numbers in Fig. 6 are taken from the absolute values of displacement without considering the direction. When the ground deformation is along X direction, the displacement in the X direction is much greater than that in the Y direction (Transversal direction, along transmission line).

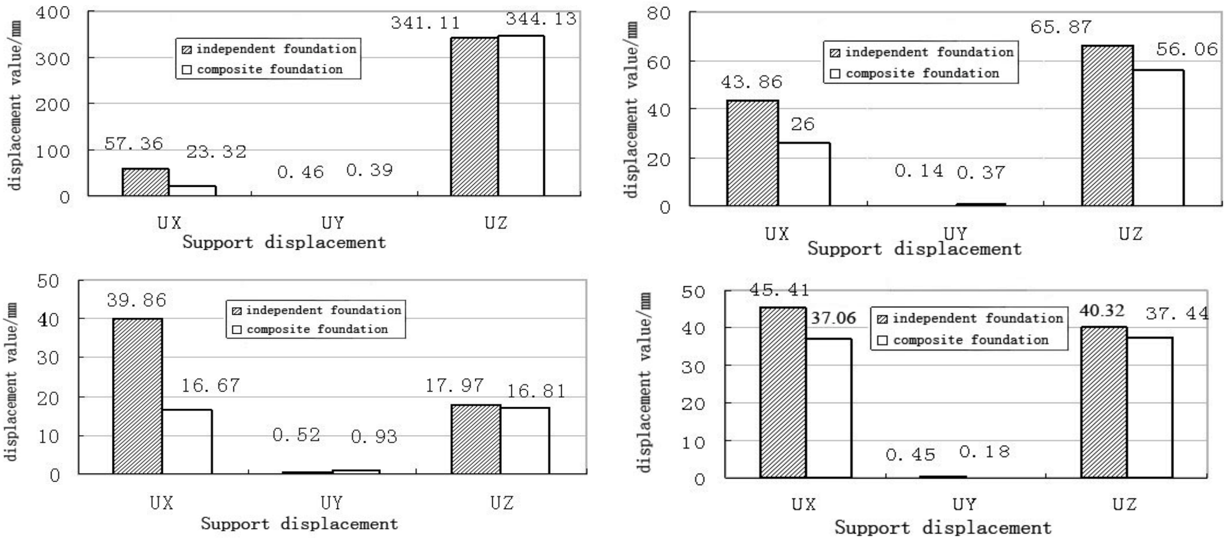

Fig. 6. Comparison of displacements of supports under conditions of different ground deformation patterns (a) Contrast of displacements of supports under condition of negative curvature ground deformation; (b) Contrast of displacements of supports under condition of tension ground deformation; (c) Contrast of displacements of supports under condition of compression ground deformation; (d) Contrast of displacements of supports under condition of positive curvature ground deformation

By contrasting the displacements of supports fixed on two different foundations under various ground deformation patterns, we know that the anti-deformation performance of composite foundation is much better in X direction. For all the deformation patterns except positive curvature, the X directional displacement of support on composite foundation is 40% less than that of support on independent foundation as listed in Table 3.

The foundation type has little influence on its anti-deformation performance in vertical direction (Z direction) under conditions of four ground deformation patterns. Although the bottom areas of two types of foundations are different, the vertical displacements of supports on different foundations are almost the same because both weight and resistance are directly proportional to the bottom size of foundations. In addition, the deformations are loaded symmetrically on the foundations in that the transmission tower is in the middle of ground model. Therefore, the vertical displacements of four supports on a certain type of foundation are also nearly the same.

Table 3. Displacements (X Direction) of supports under conditions of different ground deformation patterns

Ground deformation pattern	Independent foundation (mm)	Composite foundation (mm)	Composite foundation deformation/independent foundation deformation
Negative curvature	57.36	23.32	0.407
Tension	43.86	26	0.593
Compression	39.86	16.67	0.418
Positive curvature	45.41	37.06	0.816

4. Conclusions

(1) The paper has studied the interaction of ground, foundation and upper structure under different ground deformation patterns (tension, compression, positive curvature and negative curvature) for independent and composite foundations using ANSYS and put forward the foundation simplifying method and the treatment of sandy cushion in modeling with ANSYS.

(2) The influence of negative curvature ground deformation on the structure stress of tower members is greater than that of other ground deformation patterns, and the influence reaches the maximum when using independent foundation. The members of transmission tower yield only under conditions of longitudinally loaded negative curvature ground deformation and of using independent foundation.

(3) Under conditions of most ground deformation patterns except positive curvature, the structure stress and support displacement (X direction) of transmission tower using composite foundation can be 25% and 40% less than that using independent foundation respectively. Compared with independent foundation, composite foundation can also reduce the stress and displacement of transmission tower under positive curvature ground deformation, while the reduction extent is smaller.

(4) The influence of longitudinal ground deformation on the structure is much greater than that of transversal one.

Acknowledgements

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