Analysis of influence of coal mining on stability of tower on Loess Slope and deformation monitoring

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Abstract: A three-dimensional geological model of Goaf is established, and the finite element analysis of Goaf deformation is carried out by using the analysis module of construction stage in Midas / GTS 2.6. The stability of the tower is demonstrated with the deformation monitoring results, and the estimated cost of route modification is saved, the optimized route has accumulated experience for transmission line engineering construction in Goaf.

1 Introduction
A 750 kV transmission line project passes through the loess slope of a coal mine in the Loess Plateau. When the coal seam is mined, a large number of tension cracks appear around the tower, which affects the safe operation of the transmission line. In order to ensure the safe operation of the line, the design puts forward two schemes, i.e. line change and governance, in which the cost of line change scheme is more than 200 million yuan. Based on the field investigation of the distribution and development characteristics of cracks, a three-dimensional finite element analysis model is established to analyze the stability of the slope where the tower is located and the uneven settlement of the tower foundation. On this basis, deformation monitoring was carried out to determine the time and amount of severe deformation of the slope after coal mining. Finally, according to the results of stability analysis and deformation monitoring, the tower rectification work is carried out. At present, the line has been running safely for nearly 10 years, and the slope stability analysis and deformation monitoring results have been well verified, which saves the estimated cost of line change and accumulates experience for the construction of transmission line in goaf. This paper takes one of the towers (Z150) as an example.

2 Project overview
Z150# tower is located in the loess slope of the Loess Plateau in Northern Shaanxi Province. Its geological structure is simple. It is a monoclinic layer inclined to the northwest. The occurrence of the stratum is generally gentle, with an inclination of 2-9 degrees. The seismic fortification intensity of the building is grade VII, without the influence of groundwater. The lithology of the formation is about 140m thick Quaternary loess layer, and the underlying Permian siltstone and mudstone. The thickness from the bedrock surface to the roof of the mining seam is about 180m. The main coal seam in this area is 5-2 layers, the thickness of the coal seam is 2.6m, the width of the working face is 120-150m, and the mining progress is generally 2m / d.

After the coal seam is mined, dozens of cracks appear on the surface near tower 150# (Fig 1).
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**Fig 1. Distribution Characteristics of fractures**

The length of crack extension is 12-167m, the maximum crack falling distance is nearly 0.7m, and the maximum crack width is 0.5m. The fractures are mainly developed around the goaf, and the angle between the fracture extension direction and the coal seam mining direction is about 25 ~ 40 degrees. The development of fractures is strong at the top of the slope, and gradually weakens to the toe of the slope. There is no development of fractures at the toe of the slope, and the staggered distance from the toe of the slope to the gob center increases. The dip angle of the fractures is from 70 ° to 90 ° and all of them are steep. Except for a small amount of ground fractures inclining to the slope, the rest of the fractures incline to the slope and extend downward, and no through slip surface is formed.

3 Three dimensional numerical simulation analysis

3.1 geologic model

According to the topographic map, the three-dimensional calculation model of the site area is established. The length of the model is 3500m in the north-south direction, 900m in the east-west direction and 900m in the calculation depth. The positive direction of X axis is due north, Y axis is due west, and Z axis is vertical up. The geotechnical materials are loess, bedrock and coal seam, and the parameters are shown in Table 1. The analysis module of MIDAS / gts2.6 in the construction stage is used for the calculation, the elastic-plastic constitutive model and D-P yield criterion are adopted, the boundary conditions are the vertical constraint of the lower boundary and the horizontal constraint of the front and rear left and right boundaries, the convergence condition in the analysis control is set as the displacement standard of 0.001M; the six node tetrahedral element is used to divide the model into 105738 meshes, 21304 meshes Nodes (Fig 2).

| stratum       | Natural weight(kN/m³) | Elastic modulus(M Pa) | Poisson's ratio | Cohesion c(kPa) | internal friction angle φ(°) |
|---------------|-----------------------|-----------------------|----------------|----------------|-----------------------------|
| Loess         | 17.0                  | 30                    | 0.35           | 25             | 28                          |
| Bedrock       | 24.0                  | 20000                 | 0.25           | 200            | 40                          |
| coal seam     | 23                    | 8000                  | 0.25           | 150            | 32                          |
3.2 Analysis of calculation results

The regional displacement distribution map (Fig. 3-5) and the section displacement along the most unfavorable slope direction of tower foundation are obtained under the condition of mining and planned mining being completed (Fig. 6-8).

It can be seen from the figure that there is no through slip surface in the slope, so the overall instability of the slope will not occur.
Fig. 5 Z-axis displacement distribution

Fig. 6 X-axis displacement diagram of the most unfavorable slope direction section of 150 # tower

Fig. 7 Y-axis displacement diagram of the most unfavorable slope direction section of 150 # tower
Because the uneven settlement caused by coal mining will also have an adverse impact on the tower foundation, the maximum settlement difference between the four tower feet of 150# tower is calculated as 91mm according to the interpolation of node deformation of numerical simulation. According to the later monitoring data, the maximum settlement difference of 150# tower foot is 85.2mm, which is basically consistent with the calculated results, indicating that the three-dimensional numerical analysis results are reliable.

4 Deformation monitoring

4.1 Monitoring programme

From January to May 2010, the settlement, displacement and inclination of 150# tower were monitored. Three sections and four tower legs were arranged, and 40 deformation monitoring points were accumulated (Fig. 9). The monitoring cycle is once a month.

4.2 Analysis of monitoring results

The settlement values, horizontal displacement values and uneven settlement results of tower legs (Table 2) of each monitoring point were obtained by deformation monitoring, and the contour map (Fig. 10 and Fig. 11) and tower top offset curve (Fig. 12) were drawn respectively.
Fig. 10 Contour map of ground settlement of 150 #tower foundation

It can be seen from Figure 10 that the maximum land subsidence is 375 mm and the minimum is only 5 mm. The closer to the goaf, the more severe the surface settlement. Affected by the large local load at the tower base, the stress concentration appears at the tower base, and the uneven mutation of the isoline appears at the tower position.

Fig. 11 Contour map of total horizontal displacement of 150# tower foundation ground

It can be seen from Figure 11 that the maximum horizontal displacement of the ground is 241mm and the minimum is 168mm. The closer to the goaf, the larger the horizontal displacement. The horizontal displacement direction of each tower leg is indicated by the red arrow in the figure below, and the displacement direction is roughly perpendicular to the contour line.

Fig. 12 Time shift curve of 150# tower top

As can be seen in FIG. 12, the offset increases with time, but the migration speed has generally begun to slow down, and the rectification work can be carried out after reaching the deformation
leveling period. The rectification work was completed on August 17th, 2010. After rectification, the deviation of the top of the tower is 12.1 mm, which meets the requirements of tower inclination.

It can be seen from table 2 that the uneven settlement mainly occurred in the early stage of surface deformation (January to March), and then the uneven settlement decreased significantly. This is basically consistent with the deformation trend of tower tilt migration.

### Table 2 Uneven settlement of 150 # tower leg(mm)

| Monitoring point number | Accumulated settlement(mm) | Jan–Feb | Feb–March | March ~ April | April ~ May | August |
|-------------------------|----------------------------|---------|-----------|--------------|-------------|--------|
| 150-1#                  | -183                       | -287    | -356      | -358.7       | -7.3        |
| 150-2#                  | -158                       | -208    | -271      | -274.2       | -6.1        |
| 150-3#                  | -137                       | -220    | -277      | -280.1       | -6.8        |
| 150-4#                  | -156                       | -292    | -356      | -359.4       | -8.8        |
| Differential settlement | -46                        | -84     | -85       | -85.2        | -2.7        |

5. Conclusion

(1) In this paper, the finite element analysis of the mining section is carried out by using the finite element method, and the X, y, z direction displacement of the tower position due to the goaf and the displacement of the tower position along the most unfavorable slope direction are calculated. The results show that the slope near the tower foundation will not form a through slip surface, the slope is stable as a whole, and the uneven settlement of the tower foundation is the main cause of the tower tilt deviation, which is the main factor threatening the safety of the tower.

(2) The deformation monitoring results show that the closer the surface settlement is to the goaf, the more severe the surface settlement is and the larger the horizontal displacement is. According to the node deformation of numerical simulation, the maximum settlement difference between the four legs of 150# tower is 91 mm. The maximum settlement difference of 150 # tower foot is 85.2mm, which is basically consistent with the calculated results, indicating that the three-dimensional numerical analysis results are reliable.

(3) Up to now, the tower has been running safely for nearly 10 years, which shows that the numerical analysis, deformation monitoring and tower rectification measures can effectively solve the problem of the influence of coal mining on the tower stability, and accumulate experience for the construction of transmission lines in goaf.

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