Safety Assessment of High Voltage Transmission Foundation in Goaf of Coal Mine

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Abstract. Coal mine goaf is a poor construction site with hidden, complex, large surface deformation range and easy to cause geological disasters, which is very harmful to the construction of ground engineering. Therefore, the stability of the goaf site is a prerequisite for the stability of the structure and should be evaluated before construction. Based on the topic of "stability evaluation of the goaf base of 330kV shen-dang I and II line connecting jinjie transformer transmission line project", this paper conducts a special investigation and evaluation of the transmission line through jinjie coal mine goaf in shenmu city. In the huge collection of the mining area of the regional geological and mineral constructed over the report, the coal geological exploration and mining design, on the basis of such information to goaf Kentucky lines (C14~C17) actual investigation, geological survey, engineering survey, engineering geophysical exploration (tem), find out the preliminary Kentucky goaf site engineering geological condition, hydrogeological condition, the coal mined-out area distribution and its characteristics, etc. The stability of the ground foundation site was qualitatively evaluated by the mining condition discriminant method (taking the mined-out area final mining time, roof lithology and the thickness of loose bed as factors), and the evaluation results showed that the site was in a basically stable state. Secondly, the numerical analysis method was used to calculate and analyze the surface movement and deformation of the mined-out area of the base. The stability of the mined-out area of the base was evaluated quantitatively. The results showed that the mined-out area of the base was in a basically stable state, which was consistent with the qualitative judgment. The research results have some reference value for other surface engineering construction and geological disaster prevention in jinjie coal mine of shenmu city.

1. Introduction

In China, due to the shortage of oil and natural gas resources, coal will be the main energy source for a long time to support the development of the entire national does great harm to the surface engineering construction. This problem is more serious in the loess covered areas in the northwest of China [1-4]. Therefore, in order to carry out engineering construction on the surface of goaf, the influence of goaf on engineering construction must be fully considered.

The influence of goaf on the foundation of surface structures (structures) has been widely studied all over the world. M. C. Wang [5] (1982) and others studied mining and underlying empty the impact
on the building, the study is based on the specific experimental point, main is to rely on past experience and research, and focuses on the judgement of disasters, there is no system of common law, for the upper goaf building foundation failure mechanism and building foundation disaster prevention and control measures and no in-depth research. Subsequently, Drum et al. studied the subsidence failure mechanism of rock and soil mass in goaf under elastic limit conditions and its influence on foundation engineering by establishing a simple elastic mechanics model based on the actual investigation. Due to the development of computer software, numerical simulation technology has been widely used in engineering practice [6]. Fu shigen, li quanming [7] discussed the evaluation theory and technical method of the influence of goaf on the stability of surface buildings, and proposed the theory and numerical analysis method of dividing goaf with "three belts". Wu Zhide, zhi-pei zhang [8], such as a coal mine in xuzhou as an example, also adopts the method of numerical simulation, FLAC3D is adopted to simulate, the prophase investigation of mined-out area in data input software, can be more easily used for simulating the mined-out area, and this is also the current to the coal mine goaf on the surface, stability is one of the most commonly used method.

Based on the topic of "stability evaluation of tower footing in goaf of 330kV shen-dang I and II line connecting jinjie transformer transmission line project", this paper investigated and visited the hollow-out situation of jinjie coal mine and collected the design data of transmission tower footing. The stability of the goaf site is determined by discriminating mining conditions. On this basis, the finite element numerical analysis software MIDAS is used to analyze the surface deformation law and surface movement deformation value of the goaf, and quantitatively determine the stability of the goaf site. Finally, based on the comprehensive evaluation results, reasonable Suggestions and measures are put forward for the construction of shenmu jinjie 330kv power transmission foundation.

2. Environmental geology of the research area

Jinjie coal mine [9] is located in the middle of yushen mining area in the middle coal field of northern shaanxi, west of shenmu county and east of yaozhen township in the northeast of yulin city. The mining depth is 1175-920m. The newly-built 300kv jinjie substation is located about 500m to the north of zhongmiao village, jinjie town, shenmu county, yulin city, shaanxi province. It is about 2km to the north from jinjie town and located in shenfu economic development zone. The proposed four foundations are all located in the upper part of the goaf formed after the excavation of the 31 coal seam or within the influence range of the goaf. The terrain is generally high in the northwest and low in the southeast. According to the drilling report and relevant data [10], the rock and soil covering the goaf of the coal mine is mainly medium hard rock, and only the loose layer with a thickness of about 17m is covered on the surface. The overlying rock and soil in jinjie coal mine goaf is mainly of medium and hard rock with relatively good engineering properties. Natural precipitation in the region has obvious seasonality, the annual change of precipitation and precipitation variability are large. The average annual precipitation was 440.8mm. From July to September each year, the average precipitation is 297.4mm, accounting for 69.0% of the annual precipitation. Precipitation in the form of heavy rain, easy to form floods. It is easy to reduce the stability of goaf site.

3. Goaf site stability evaluation

The stability of transmission line foundation may be affected when the foundation is under goaf. In order to provide scientific theoretical basis for the construction of power transmission foundation in this region, and to predict the goaf surface movement and deformation and their influence on the stability of the goaf foundation, this chapter USES qualitative and quantitative methods to analyze and evaluate the stability of the goaf site.

3.1. Qualitative stability analysis of goaf site based on mining condition discrimination method

The discriminant standard of mining condition discriminant method is based on engineering analogy method and experience of this area. In general, the final mining time of goaf should be taken as the main factor in the evaluation.
3.1.1. Goaf site stability analysis based on the final mining time. Mined-out area of the surface movement deformation and stopping mining time mining area has a strong correlation, usually stop by the longer surface movement is more stable, so the gob stopping mining time can be used as an important index evaluate the stability of goaf area, specific evaluation standards according to the coal mine goaf geotechnical engineering specification [11] the table 1 according to the final time to determine the stability of goaf ground level. In the table, T is the deformation time of surface movement.

Table 1. Determine the grade of goaf site stability according to the final mining time.

| Stable level | Instability | Basically stable | Stabilization |
|--------------|-------------|------------------|---------------|
| Goaf final mining time T (d) | t < 0.8T or t ≤ 365 (one year) | 0.8T ≤ t ≤ 1.2T and t > 365 | t > 1.2T and t > 730 (year) |

For longwall working face [12-15] normal large-area mining, after the underground coal seam mining is finished, the surface tends to be stable after the local surface movement continues for a period of time T. When there is no measured data, the duration T of surface movement can be calculated according to the following formula [11].

When \( H_0 \leq 400 \text{m} \):

\[
T = 2.5H_0
\]

When \( H_0 > 400 \text{m} \):

\[
T = 1000(1 - \frac{400}{H_0})
\]

Where, \( H_0 \) is the average mining depth of the working face (unit m). According to previous survey data, \( H_0 = 115 \text{m} \), then the duration of surface movement is T:

\[
T = 2.5H_0 = 2.5 \times 115 = 287.5 \text{d}
\]

The mine has finished mining the 3\(^1\) coal seam in June 2017, and the stoppage time has been 1a, 0.8t < T and > 365d. According to table 1, the grade of stability in the goaf of jinjie coal mine is basically stable.

3.1.2. Stability analysis of goaf based on roof lithology and thickness of loose layer. The stability of the goaf site is closely related to the roof lithology and the thickness of the loose bed. The specific evaluation standard is based on the geotechnical engineering survey specification of goaf in coal mine, listed in table 2. The stability grade of shallow goaf is determined according to the roof lithology and the thickness of loose strata.

Table 2. Determine the grade of site stability in shallow goaf according to the roof lithology and the thickness of loose strata.

| Evaluation factor | Instability | Basically stable | Stabilization |
|-------------------|-------------|------------------|---------------|
| Roof lithology    | No hard rock is distributed or the thin or soft - hard layers are interbedded | There are thick layered hard rocks with a thickness of 15.0m and a thickness of 5.0m | There are thick layered hard rocks with a thickness of 15.0m |
| Thickness of loose layer \( h \) (m) | \( h < 5 \) | \( 5 \leq h \leq 30 \) | \( h > 30 \) |
According to the existing exploration data, the lithology of the roof in the goaf area of jinjie coal mine is thick bedded hard sandstone, and the thickness of the loose bed is about 17.0m. According to the qualitative judgment criteria in table 2, the grade of site stability in the goaf of jinjie coal mine is basically stable.

3.2. Quantitative stability analysis of goaf site based on Midas Gtxnx

3.2.1. Generalization of goaf geological model. The geological model established in this paper is based on jinjie coal mine in shaanxi province. Based on the geophysical data results of relevant survey reports as the data source for modeling, a section is selected for analysis and modeling during modeling, and the goaf is idealized. It is believed that the shape of the goaf remains unchanged within the length range of 1m. The goaf has four strata below the surface - "loose layers (powdery sand, silty loess, and loess silty soil)", "silty sandstone", "sand-mudstone interbedded layers (with coal seams)", and "sandstone". The thickness of the formation is 17m, 21m, 114.5m and 50m respectively. Because the deepest goaf is only 115m underground, the sandstone is only 50m.

3.2.2. Establishment of three-dimensional numerical model of goaf. When using Midas software to build the 3d model, in order to facilitate the analysis and simplification of the model, the section analyzed in this paper is idealized, and it is believed that the rock mass of each formation is uniform and the physical parameters are the same. The elastoplastic constitutive model was adopted for each layer of rock and soil mass in the model, and the yield criterion was mohr-coulomb (MC) strength criterion. The model USES tetrahedral elements with six nodes to divide the grid, and the excavation part is subdivided locally. A total of 261,074 cells and 46,627 nodes were divided. The convergence condition of the model analysis is set as the unique standard 0.001m. The established simplified mechanical analysis model is shown in figure 1 and figure 2.

![Elevation of goaf Midas 3d model.](image1)

![Section of 3d model of goaf Midas.](image2)
3.2.3. Parameter selection. The physical and mechanical parameters of each rock and soil layer are determined according to the data of Shanxi Jinjie 330kV power transmission and transformation project pressing important mineral resources reserve assessment report [10] and the data of adjacent coal mines, as shown in Table 3. The rock thick is H.

Table 3. Physical and mechanical parameters of rock and soil mass in Jinjie mine area.

| Rock and soil layer                      | E (MPa) | μ   | γ (kg/m³) | φ (°) | c (MPa) | H (m) |
|-----------------------------------------|---------|-----|-----------|-------|---------|-------|
| Unconsolidated formation                | 340     | 0.4 | 1650      | 26    | 0       | 17    |
| Silty sand rock                         | 5800    | 0.27| 2250      | 32    | 3.0     | 21    |
| Sand and mudstone interbedded coal seam | 5700    | 0.24| 2390      | 34    | 3.8     | 77    |
| Sand and mudstone interbedded coal seam | 5700    | 0.37| 1440      | 37    | 2.2     | 3.5   |
| Sandstone                               | 6800    | 0.23| 2510      | 39    | 4.2     | 50    |

3.2.4. Numerical simulation results and analysis. The x- and z-direction displacement cloud maps after coal seam excavation are shown in figure 3 ~ 6.

Figure 3. Z-direction displacement cloud diagram.

Figure 4. Z-direction displacement cloud diagram of the surface of the section.
According to figure 3 and figure 4, the maximum ground subsidence of the goaf in jinjie coal mine is 153.1mm, which is located in the middle of the surface. The general law of surface subsidence is that it gradually decreases from the middle of the upper part of the goaf to the two sides, which is consistent with the subsidence law of the surface moving basin of the goaf. In addition, according to the numerical analysis results, the three zones of the goaf, namely the caving zone, the fracture zone and the bending deformation zone, can be obviously shown. Goaf ground by figure 5, and figure 6, the maximum horizontal displacement of 60.5mm, the emergence of the symmetry on both side surface, the surface horizontal displacement general rule is: on the left side of the mined-out area of the earth's surface to the right and left on the right side of the earth's surface move, on both sides of the horizontal displacement is large, middle horizontal displacement is small, with the horizontal movement regularity of surface movement basin of mined-out area is the same. The vertical displacement calculated by Midas is 153.1mm and the horizontal displacement is 60.5mm. Therefore, the stability level of the goaf site is basically stable.

4. Conclusion
(1) According to the existing research data, the thickness of 3-1 coal seam in jinjie coal mine mining is 3.34m, so the goaf is a medium-thick coal seam goaf; 3 the average mining depth of coal seam is
115.0m, which belongs to the middle and deep goaf. The mining depth and thickness ratio (H/m) is 34.0. The dip Angle of coal seam (less than 3°) is divided into horizontal (gentle dip) goaf.

2) Through the mining condition discrimination method (based on goaf final-mining time, roof lithology, loose layer thickness and other factors), the stability of the foundation site was qualitatively evaluated, and the evaluation results showed that the site was in a basically stable state.

3) The surface displacement and deformation rules of goaf site were analyzed by Midas three-dimensional numerical simulation, which was mainly reflected in the horizontal direction, with large displacement on both sides and small displacement in the middle. In the vertical direction, we have a big displacement in the middle and a small displacement on both sides. Therefore, a surface moving basin is formed at the surface, that is, the goaf surface moving basin.

References
[1] Li Xi. Research and application of the state monitoring system for over-biased load of heavy load freight trains [D]. Changsha: central south university, 2012.
[2] Yu dong, Gu peiliang, Chen zhong, et al. Study on load status monitoring and over-limit detection system of railway freight cars [J]. China railway science, 2004 (5): 4.
[3] Yang xipin, wang zhong. Design and implementation of the detection system for excessive off-side load of coal train vehicles based on lidar 3d imaging technology [J]. Science and technology communication, 2013, 5 (15): 214-215.
[4] Li xiaolu, Zeng jingjing, Wang hao, et al. Design of 3d scanning lidar system and real-time imaging technology [J]. Infrared and laser engineering, 2009, 48 (5): 35-42.
[5] Wang M c. Settlement behavior of footing above a void [a]. In: Proc.Of Geotechnical and geo-environmental Engineering [C]. New Orleans: [s.n.], 1982: 168-183.
[6] Li xiangyang, li junping, zhou chuangbing, et al. Comparative study on numerical simulation and similar simulation of overburden deformation in mining field [J]. Rock and soil mechanics, 2005, 26 (12): 1 907 ~ 1 912.
[7] Fu shigen, li quanming, wang yunhai, et al. Impact evaluation method of goaf on surface buildings [J]. Chinese journal of safety sciences, 2007, 17 (8): 143.
[8] Zhang zhipeng, wu zhide. Stability analysis of goaf in coal mine under dahe landslide in nianqiangshan mountain [J]. Coal engineering, 2008 (5): 58-61.
[9] Jia shaojie, hu dingkang, ma xuetong, et al. Stability assessment report of goaf base base of 330kV shen-dang I and II line connecting jinjie transformer transmission line project [R]. Shaanxi coalfield geological exploration research institute co., LTD, 2018.
[10] State grid shaanxi electric power company. Reserve assessment report of important mineral resources overburden of jinjie 330kV power transmission and transformation project in shaanxi [R]. Shaanxi: state grid shaanxi electric power company, 2018.
[11] China coal construction association. Code for geotechnical engineering investigation of goaf in coal mine [S]. China planning press, 2015.
[12] Yang z l. Instability of roof rock in longwall mining of shallow coal seam [J]. Acta coal sinica, 2008, 33 (12): 1341-1345.
[13] Ren yanfang. Study on structural characteristics of overlying rock in longwall mining of shallow coal seam [D]. Beijing: general research institute of coal science, 2008.
[14] Hou zhongjie. Stability analysis of key composite layers of shallow buried coal seams in thick and loose layers [J]. Acta coal sinica,2000,25 (2): 127-131.
[15] Tao zhiyong, ren yanfang. Actual measurement and analysis of pressure law of fully mechanized mining face with shallow subsurface and deep thin bedrock. Coal mining, 2009, 14 (3): 93-94.