Numerical Simulation of Surface Deformation in Goaf

Dingkang Hu, Nainan He and Debin Gao

School of Chang'an University, Xian, China

*Corresponding author e-mail: 958439854@qq.com, 719016053qq.com, 1545557162@qq.com

Abstract. Coal mine goaf is a hidden, complex, surface deformation of a large range and easy to cause geological disasters of the bad construction site, the surface engineering construction of great harm. The uneven subsidence, horizontal movement, deformation, collapse and other disasters of the goaf surface have serious potential safety hazards for the construction and operation of the project. At the same time, secondary disasters such as ground collapse and collapse caused by surface movement and deformation also occur from time to time, which seriously threaten the safety of construction projects. In this paper, Flac3D is used to conduct a three-dimensional numerical simulation study on the goaf of jinjie coal mine, and the surface deformation law of the goaf is obtained by analyzing the horizontal movement, vertical settlement, horizontal deformation and inclined deformation of the goaf, which provides a theoretical basis for the surface deformation management of the local goaf.

1. Introduction
Coal mine goaf is a hidden, complex, large surface deformation range, and is a bad site that is easy to cause geological disasters, which is very harmful to ground engineering construction. Disasters such as uneven subsidence, horizontal deformation and collapse of the mined-out area have brought serious safety hazards to the construction and operation of the project [1-3]. Secondary disasters such as ground collapse, landslides, and collapses caused by surface movement and deformation also occur from time to time. The collapse of large-scale coal mine goafs may even induce earthquakes, seriously threatening project safety. The problem of coal mine goafs is a worldwide problem.

The main coal seam of jinjie coal mine is 3-1 coal seam, which is dominated by medium-thick coal seam with small thickness change and simple structure. It is mainly composed of long-flame coal with single coal type and small coal quality change. It is basically exploitable in the whole region and is a stable coal seam. At present, a large area of goaf has been formed. Among them, 31101 working face is located in the north of the goaf. The length of this working face is 160 meters and the thrust is 300 meters.

2. Establishment of numerical simulation model of goaf

2.1. Establishment of three-dimensional numerical model
Flac3D software can study and analyze the influence of longwall mined-out area on the movement and deformation of surface subsidence [4]. According to the characteristics of topography, stratum
lithology, coal mining and goaf distribution in the assessment area, a simplified engineering geological model of the goaf area in 31104 working face was established. The model was idealized and the inclined sections of the goaf were selected for analysis. The model has a total of 6 layers from the surface to the lower boundary, from top to bottom are loose layer, silty sandstone layer, mudstone layer 1, coal layer, mudstone layer 1, sandstone layer. The thickness of the formation is 17m, 21m, 77m, 3.5m, 34m and 50m respectively. Model size length x width x height = 900m x 600m x 203m, divided into 62523 units, 82463 nodes, taking the x direction as the strike direction, the y direction as the trend direction, the z direction as the normal direction. The length of 31104 working face is set as 200 meters, which is reflected in the model as 200 to 400 meters in the y direction. The goaf is excavated along the direction of the coal seam, with a length of 300 meters, which is reflected in the model as 200 to 500 meters along the x direction. Each excavation is 60m, and the excavation is divided into five steps. The four sides and the bottom of the model are constrained. The sides are constrained in the x and y directions to restrict the movement of the sides. The bottom is constrained in the three directions of x, y and z to restrict the movement of the bottom. The schematic diagram of the model is shown in Figure 1.

2.2. Parameter selection
There are 11 kinds of constitutive models provided in Flac3D [5]. All layers in the model adopt elastoplastic constitutive model, and the yield criterion adopts Mohr-Coulomb (MC) strength criterion. The physical and mechanical parameters of each layer selected for calculation are shown in Table 1.

| Geotechnical name | Modulus of elasticity $E$ (MPa) | Poisson's ratio $\mu$ | Bulk density $\gamma$ (kg/m$^3$) | Angle of internal friction $\phi$ (°) | Cohesive force $C$ (MPa) |
|-------------------|-------------------------------|---------------------|-------------------------------|-------------------------------|-------------------|
| Loose bed         | 340                           | 0.4                 | 1650                          | 26                            | 0                 |
| Silty sand rock   | 5800                          | 0.27                | 2250                          | 32                            | 3.0               |
| mudstone 1        | 5700                          | 0.24                | 2390                          | 34                            | 3.8               |
| Coal seam         | 3100                          | 0.37                | 1440                          | 37                            | 2.2               |
| mudstone 2        | 5700                          | 0.24                | 2390                          | 34                            | 3.8               |
| Sandstone         | 6800                          | 0.23                | 2510                          | 39                            | 4.2               |

2.3. Arrangement of measuring points
Two monitoring lines located on the surface are arranged in the direction of coal seam dip and strike, x=450 and y=300, respectively. One monitoring point is arranged every 20 meters. A total of 46 monitoring points are arranged in the direction of strike (x), and 31 monitoring points are arranged in the direction of strike (y). The location diagram of model monitoring line is shown in figure 1.

3. Results and analysis

3.1. Flac3D calculation results

Figure 1. Three-dimensional analysis model of goaf and layout of survey line.
Figure 2. Cloud diagram of displacement in z direction at 300 meters of excavation.

Figure 3. Cloud diagram of displacement in y direction at 300 meters of excavation.

Figure 4. Cloud diagram of displacement in x direction at 300 meters of excavation.
3.2. Surface deformation analysis of strike line

![Figure 5](image1.jpg)  
**Figure 5.** Surface subsidence on the survey line.

![Figure 6](image2.jpg)  
**Figure 6.** Deformation of the surface tilt on the survey line.

Figure 5 is a graph of surface subsidence on the strike survey line. It can be seen from the figure that on the strike survey line, the law of surface subsidence in the goaf is: the subsidence value gradually decreases from the middle of the upper part of the goaf to both sides to the impact range the boundary is reduced to 0. This is consistent with the subsidence law of the surface moving basin in the goaf. The maximum settlement always appears in the center of the surface of the mined-out area, and the surface subsidence value increases continuously as the coal seam continues to be excavated. After the first excavation of 60m, the amount of settlement reflected on the surface is very small, only 14mm. When the excavation continues to 120m, the maximum settlement of the surface increases to 33mm. The coal seam continued to be excavated, and the surface subsidence increased continuously. After the final excavation of 300m, the maximum surface subsidence reached 95mm.

Figure 6 shows the amount of ground tilt deformation on the survey line. It can be seen from the figure that the amount of ground tilt deformation can be divided into two deformation sections according to the deformation direction. Taking the zero point of the tilt deformation amount as the boundary, the positive deformation section on the left side and the negative deformation section on the right side. The zero point of surface tilt deformation in Fig. 6 basically coincides with the maximum point of surface subsidence in Fig. 5, that is, the surface tilt value at the maximum subsidence value of the surface is 0.
Figure 7. Horizontal movement of the ground surface on the survey line.

Figure 8. Horizontal deformation of the surface on the survey line.

Figure 7 is a diagram of the amount of horizontal movement of the ground on the striking side line. It can be seen from the figure that the amount of horizontal movement of the surface on the striking line can be divided into two sections according to the direction of deformation. The left side is the positive horizontal movement area, and the right side is the negative horizontal movement area. The zero point of the surface horizontal movement in Fig. 7 is basically consistent with the maximum point of the surface settlement in Fig. 5, that is, the horizontal movement of the surface at the maximum subsidence value of the surface is 0.

Fig. 8 is a horizontal deformation graph of the surface on the strike survey line. It can be seen from the graph that as the coal seam is mined, the value of the horizontal deformation of the ground surface on the strike survey line gradually increases. The zero point of the horizontal surface deformation is always close to directly above the center of the goaf. As the coal seam is mined, the zero point position continues to move to the right. When the horizontal deformation is positive, it indicates tension, and when it is negative, it indicates compression. Therefore, most of the middle area on the surface of the mined-out area is under compression, mainly on both sides, and the surface pressure stress above the mined-out area is the largest.
3.3. Surface deformation analysis of dip line

Figure 9. Surface subsidence diagram on the trend line.

Figure 10. The amount of ground tilt deformation on the trend line.

Figure 9 is a graph of surface subsidence on the surface of the trend line. It can be seen from the figure that the maximum value of the surface subsidence on the trend line is always located at the midpoint of the trend line. As the distance away from the midpoint of the trend line increases, the surface subsidence amount gradually decreases and becomes the amount of subsidence is reduced to zero, and the amount of surface subsidence is distributed symmetrically with the strike side line as the center.

Figure 10 is a graph of the amount of ground tilt deformation on the trend line. It can be seen from the figure that the amount of ground tilt deformation on the trend line can be divided into two deformation zones, the positive deformation zone on the left and the negative deformation zone on the right. In the section, the amount of ground tilt deformation at the center is zero, and the two deformation sections are symmetrically distributed in the center.

Figure 11 is the horizontal movement of the surface on the trend line. It can be seen from the figure that the horizontal movement of the surface on the trend line can be divided into two deformation zones, the positive deformation zone on the left and the negative deformation zone on the right. In the section, the amount of ground tilt deformation at the center is zero, and the two deformation sections are symmetrically distributed in the center.
Figure 12 is the horizontal surface deformation amount graph on the trend line. It can be seen from the figure that the horizontal surface deformation on the trend line is symmetrically distributed with the strike line as the symmetry axis, and can be divided into 3 deformation sections. A section with a positive horizontal deformation amount at each end is called a positive deformation section, and a section with a horizontal deformation value at a negative value in the middle of the positive deformation section at both ends is called a negative deformation section.

4. Conclusion
1) The maximum surface subsidence of the working face 31104 of jinjie coal mine is 95mm and the maximum horizontal displacement is 29mm. After the coal seam is mined, an elliptical moving basin is formed on the surface. The maximum value of surface subsidence appears in the center of the goaf, and the maximum value of horizontal movement appears near the mining boundary. The maximum ground subsidence and horizontal movement obtained through ground monitoring are 86mm and 24mm respectively, which are not much different from the simulation results.

2) Before the coal seam is fully mined, the maximum settlement on the surface gradually increases, and the position of the maximum settlement also moves towards the mining direction, and is always located above the center of the mined part. The slope deformation and horizontal movement of the earth surface are distributed symmetrically at the center of the maximum settlement point. The
maximum values of the surface tilt deformation and horizontal movement are located near the mining boundary of the goaf.

The minimum value of horizontal deformation of the surface is near the Central Line of the goaf and close to 0 near the mining boundary of the goaf.

3) The surface inclined deformation and horizontal movement are divided into positive and negative deformation sections. The intersection of the positive and negative deformation sections, namely the zero point, basically coincides with the maximum subsidence point of the surface. The horizontal deformation of the surface is divided into three deformation sections. The minimum value of the horizontal deformation gradually increases with the mining of the coal seam, and the minimum value point moves along the direction of strike.

Acknowledgments
This work was financially supported by Special assessment on the stability of foundation foundation for 330kV shen-dang line I and line II connecting jinjie transformer transmission line project (DZ2018) fund.

References
[1] LI Xiao-hong, JIN Xiao-guang, LU Yi-yu, KANG Yong, LEI Xiang-yang. Study on deformation character of surrounding rock masses and numerical modeling of tunnel through coal and working out area [J]. Chinese Journal of Rock Mechanics and Engineering, 2002, 21(5): 667–670. (in Chinese).

[2] PENG Zheng-hua, ZHENG Jun-jie. Treatment of dangerous rockbody of coal mined-out area in Lianziya of the Three Gorges of Yangtze River [J]. Chinese Journal of Rock Mechanics and Engineering, 2001, 20(5): 710–714. (inChinese) Reference to a chapter in an edited book.

[3] LIU Baochen. Ground surface movement due to underground excavation in China [C] // Comprehensive Rock Engineering. New York: Pergaman Press, 1993: 780–816. C. D. Smith and E. F. Jones, “Load-cycling in cubic press,” in Shock Compression of Condensed Matter-2001, AIP Conference Proceedings 620, edited by M. D. Furnish et al. American Institute of Physics, Melville, NY, 2002, pp. 651–654.

[4] ZHANG Jiasheng. The study on the ground movement theory and the numeric analysismethod [D]. Changsha: Central South University of Technology, 1993. (in Chinese).

[5] He Zhongming, Peng Zhenbin, Cao Pingping. FLAC3D numerical analysis of the stability of double-layer goaf excavation roof [J]. Journal of Central South University (Natural Science), 2009, 40 (4): 1066-1071.