Numerical simulation on the deformation and failure of the goaf surrounding rock in Heiwang mine

Yandong Shang\textsuperscript{1,2}, Yanpei Guo\textsuperscript{1,2,3} and Wenquan Zhang\textsuperscript{3}

\textsuperscript{1} Taian compus, Shangdong University of Science and Technology, Taian 271019, China;
\textsuperscript{2} State Key Laboratory of Mining Disaster Prevention and Control, Qingdao 266590, China.
\textsuperscript{3} cornor@163.com

Abstract: The stability of overlying rock mass of mined-out area was simulated using finite difference software FLAC3D according to the gob distribution of Heiwang iron mine. The deformation, failure characteristics of surrounding rock was obtained. The subsidence of strata above the middle mined-out area was the biggest. The maximum subsidence of ground surface was 12.4mm. The farther away from the central goaf was, the smaller the vertical subsidence value was. There was almost no subsidence on the two lateral surrounding rock near mined-out area. There exists the potential danger when cutting along the boundary of goaf. The tensile stress appeared at the top and bottom of the mined-out area. The maximum of tensile stress was 34.7kPa. There was the compressive stress concentration phenomenon in the lateral boundary of mined-out area. The stress concentration coefficient was about 1.5 on both sides of gob. The upper section of the middle goaf was subjected to the tensile failure, and the upper rock mass of both sides was mainly subjected to the tensile-shear failure. The ore pillars on the inner side of the goaf were mainly subjected to the shear failure. When the overlying strata were complete, the possibility of sudden instability of the ore pillar and the sudden subsidence of the ground surface could not occur. The achievements can provide theoretical basis for the processing of the goaf.

1. Introduction
The processing of goaf was a technical problem of mining safety production in China. So far, the existing method on empty area treatment was hard to widely practice for its expensive costs. So, the study on the stability of the surrounding rock was very important. The influence of coal mining on the surface stability was studied by analytic method\cite{1}. A similar simulation experiment was conducted to study the horizontal and vertical deformations of strata in the coal mine\cite{2}. The numerical simulation of the stability of the goaf was carried out using three-dimensional finite element method\cite{3}. Based on fuzzy matter-element theory, the fuzzy matter-element evaluation model was constructed based on fuzzy matter-element theory. The deformation monitoring scheme in the area of going-out area was discussed\cite{4}. Other scholars had done some other researches on going-away areas\cite{5-9}. In this paper, the stability of overlying rock mass of mined-out area was simulated using finite difference software FLAC3D according to the gob distribution of Heiwang iron mine. The deformation and plastic zone of surrounding rock was obtained. The achievements can provide theoretical basis for the processing of the goaf.
2. Geological situation of construction

Heiwang iron mine was located in the middle of Zi river fault zone. The ground layer was dominated by the middle orдовикian system. The bottom part was the cold system. The fracture structure was quite developed. There was almost no alienation. The deposit was controlled by fracture structure. Since Heiwang iron mine was closed, the illegal mining and beneficiation activities were very serious. There left a large number of non-standard underground mined-out area with different sizes and shapes. And this kind of situation had a tendency to spread. Most of the empty area was not handled in time. The ore had been deformed and destroyed owing to the pressure, weathering and the influence of blasting vibration. Their location, size, shape was changed. It was easy to produce the ground collapse suddenly. This is likely to cause serious harm to the lives and property of the local people, so it was urgent to solve this problem.

3. Numerical simulation of surrounding rock stability of mined-out area

3.1. The model and parameters

The three-dimensional numerical calculation model was established according to the actual formation, it was with the length of 120m, the height of 50m, and the width of 60m. The upper boundary of the model was the free boundary, the bottom boundary was fixed, and the lateral boundary was the lateral displacement constraint. There were three mining areas in the model. The buried depth of deposits was 10m. The goaf were with the width of 4m and the height of 14m, and the width of the pillar was 8m. The 3D numerical calculation model and the size of the deposit mining were shown in Figure 1. Elastic-plastic is the most basic property of rock. In numerical simulation, the properties of almost all rock materials can be exhibited by an elastic-plastic model. So, the deposit was described by elastic-plastic model that obeys the mohr-coulomb yield criterion. The physical and mechanical parameters of rock mass were shown in Table 1.

![Image](image.png)

**Figure 1.** The 3D numerical calculation model and the size of the deposit mining.

| Rock layer | weight (kN/m³) | Bulk modulus (MPa) | Shear modulus (MPa) | Cohesion (kPa) | Internal friction Angle (°) | Poisson's ratio |
|------------|----------------|--------------------|--------------------|---------------|-----------------------------|----------------|
| Limestone  | 25.1           | 10320              | 5040               | 90            | 27                          | 0.26           |

3.2. The analysis of numerical simulation results

3.2.1 The analysis of vertical displacement of strata  The vertical displacement of stratum and surface after mining was shown in Figure 2 and Figure 3. From the two figures, the subsidence of strata above
the middle mined-out area was the biggest, and the maximum subsidence of ground surface was 12.4 mm. The farther away from the central goaf was, the smaller the vertical subsidence value was. There was almost no subsidence on the two lateral surrounding rock near mined-out area. But there exists the potential danger when cutting along the boundary of goaf. There was heave phenomenon at the bottom of the pillar. The closer from the middle of goaf was, the larger the heave was. The maximum heave value was 0.36 mm.

![Figure 2](image)

**Figure 2.** The vertical displacement of strata after mining.

3.2.2 **The analysis of vertical stress of stratum**

The vertical stress of strata after mining was shown in Figure 4. From Figure 4, the tensile stress appeared at the top and bottom of the mined-out area. The maximum of tensile stress was 34.7 kPa. There was compressive stress concentration phenomenon in the lateral boundary of mined-out area. The stress concentration coefficient was about 1.5 on both sides of gob.

![Figure 3](image)

**Figure 3.** The vertical displacement of surface after mining.
3.2.3 The analysis of plastic zone of surrounding rock

The distribution of plastic zone of surrounding rock after mining was shown in Figure 5. From Figure 5, the upper section of the middle goaf was subjected to the tensile failure, and the upper rock mass of both sides was mainly subjected to the tensile-shear failure. The ore pillars on the inner side of the goaf were mainly subjected to the shear failure, and the same, the lateral rock mass near the goaf mainly the shear failure.

4. Conclusions

The stability of overlying rock mass of mined-out area was simulated using finite difference software FLAC3D according to the gob distribution of Heiwang iron mine. The deformation and plastic zone of surrounding rock was obtained. The subsidence of strata above the middle mined-out area was the biggest. The maximum subsidence of ground surface was 12.4mm. The farther away from the central goaf was, the smaller the vertical subsidence value was. There was almost no subsidence on the two lateral surrounding rock near mined-out area. There exists the potential danger when cutting along the boundary of goaf. The tensile stress appeared at the top and bottom of the mined-out area. The maximum of tensile stress was 34.7kPa. There was the compressive stress concentration phenomenon in the lateral boundary of mined-out area. The stress concentration coefficient was about 1.5 on both sides of gob. The upper section of the middle goaf was subjected to the tensile failure, and the upper...
rock mass of both sides was mainly subjected to the tensile-shear failure. The ore pillars on the inner side of the goaf were mainly subjected to the shear failure. When the overlying strata were complete, the possibility of sudden instability of the ore pillar and the sudden subsidence of the ground surface could not occur.

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