

Numerical Simulation and Reinforcing Technology Research on Collapse of Weak Interlayer Shaft

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Abstract: The three-level shaft of the mixed pit shaft of Yixin Mine, built in 1983, failed continuously due to the influence of geological structure and the effect of water, which formed a collapsed space with a length of 18m, a depth of 12m, and a height of 12m at the level of -255m and to the southwest end. The 54m pit shaft below the -258m elevation of the pit shaft was filled with collapsed rocks forming a large loose body. The comprehensive processing plan for falling grouting and anchoring was proposed according to the geological conditions of the vertical shaft of the mixed pit shaft, adopting three-dimensional numerical simulation software as well as calculating the mechanical state of the vertical pit shaft surrounding rocks and using 3 to 5 parameters of Williams-Warnke failure criterion.

Keywords: Vertical Shaft, Collapse, Numerical simulation, Reinforcement

Publication date: September, 2019

Publication online: 30 September 2019

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1 Introduction

The Yixin Mine mixed pit shaft was built in 1983. Its ground elevation is +292m, the three-level elevation is -252.8m, the bottom elevation is -311.8m, the depth of the pit shaft is 603.8m, and its net diameter is $\Phi 7$ m. The area under -50m of the second level was drownd at some point. Due to the influence of weak rock masses and the force of water^[1], three-level structure of the pit shaft continued to drop in June of one year, which finally led to a massive collapse of the pit shaft (Figure 1).

(1) At the -255m elevation of the third level, there is a goaf area of 18m \times 12m \times 12m to the southwest end of the pit shaft caused by the collapse of surrounding

rocks.

(2) The 54m-shaft below -258m elevation of the pit shaft was filled with collapsed rock.

(3) A deep slump loose body was formed below the collapse area. No bedrock was found within 14m with the pit shaft detection.

(4) Cracks appeared on the arch of the 13-m wall of the pedestrian path on the east side of third level.

(5) Oblique cracks occur on the shaft wall which is 12m above the collapsed area.

2 Engineering geology overview

The landforms of the Yixin mine are undulating hilly grounds by tectonic denudation. Its east part is a conglomerate of the Muling group with a strong erosion resistance; the middle part is a coal formation with weak erosion resistance forming a shallow slope with a higher in both of the east and the west, and a lower one in the middle. The highest ground elevation is 325m, the minimum elevation is 245m, the average elevation is 270m, and in a relative height difference over 80m. The geological conditions within the area are complex and affected by faults. The size of the coal blocks is small, with a spreading length mostly between 100 and 300m, slopes mostly between 100 and 200m, as well as most of the secondary faults. The hydrological and geological conditions in the mine field are relatively simple, without major river system, while only in the middle there is a Shitou river, flowing from the north to the south. It belongs to the seasonal stream, flowing eastwards into the Songhua River.

There is a complex rock mass near the pit shaft of the mixed shaft, the strength of single rock mass being high, but weak as a whole. The monitoring data revealed the stress distribution of the surrounding

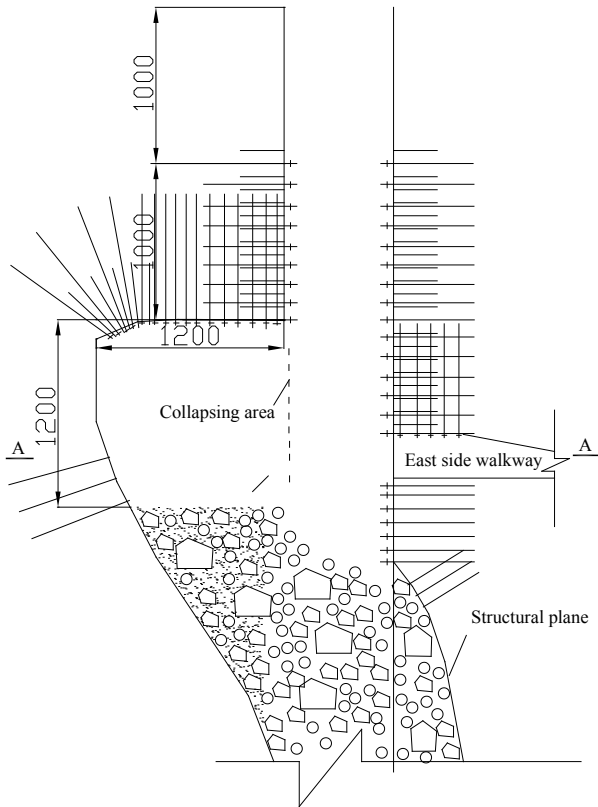


Figure 1. Sketch map of the collapsed pit shaft

rocks of the shaft has a strong time effect. The stress of the surrounding rocks showed an obvious stage as time went by. In general, the pattern is that pressure comes quickly, and the initial pressure is large until the collapse which will go through a stress adjustment period and the stress keeps increasing with time, while the speed rate decreases; then the surrounding rocks stress gets into the equilibrium for a longer period. These characteristics reflect the obvious Rheological properties of the surrounding rocks and reveal the characteristics of the soft rock^[2].

3 Numerical simulation analysis

3.1 Model building

According to the research requirement, a three-dimensional rock mechanics collapse model was established based on collapsed parts. The computational model was divided into 38,525 hexahedral units and 41,136 nodes. There is restriction on horizontal movement and vertical movement for the side and bottom of the 3D model respectively. The upper part of the model is applied to the self-weight s_z ($s_z = \bar{g}gH = -14.6596\text{MPa}$) of the rock mass from +292m to -255m. According to the structural stress

characteristics, in the simulation calculation, the horizontal stress $s_x = 1.5s_z, s_y = 2.0s_z$.

3.2 Failure criterion

The rock mass involved in this project is mainly Nanling conglomerate, with a small amount of argillaceous sandstone. It is more realistic to combine with the main mechanical properties of the reinforced concrete wall structure within the depth range and adopt the 3 to 5 parameters of the Williams-Warneke failure criterion^[4-8]. Therefore, in the formula, F1 is the function of main stress s_1, s_2, s_3, S is the main stress s_1, s_2, s_3 and the failure surface represented by 5 material parameters $f_t, f_c, f_{cb}, f_1, f_2, f_c$ is the ultimate uniaxial compressive strength, f_t is the ultimate uniaxial tensile strength, f_{cb} is the ultimate biaxial compressive strength, f_1 is the ultimate compressive strength of a biaxial compressive stress state under hydrostatic pressure, f_2 is the ultimate compressive strength under uniaxial compressive stress conditions at hydrostatic pressure, r_1 and r_2 are the failure surfaces at similar angles of 0° and 45° , respectively, $\frac{1}{2} < \frac{r_1}{r_2} < \frac{5}{2}$.

3.3 Simulation calculation process

The mechanical behavior of rock masses and support structures is closely related to the history of handled stress. The simulation calculation must objectively and truly reflect the mechanical state of rock masses and the engineering structure at different stress stages, analyzing the rock mass, the structure stress, the deformation and failure mechanism in order to evaluate the stability and reliability of the engineering structure.

According to the test results, the mechanical parameters of the mixed rock masses in the Nanling conglomerate and argillaceous sandstone are programmed as follows:

Elastic modulus: $E=4.371 \times 10^4 \text{MPa}$, Poisson's ratio: $\nu=0.3$, Cohesion force: $c=21.5 \text{MPa}$, Internal friction angle: $f=31.8^\circ$, Unidirectional compressive strength: $f_c=153.52 \text{MPa}$, Uniaxial tensile strength: $f_t=6.94 \text{MPa}$, Average -weight: $\bar{g}=2.68 \times 10^3 \text{kg/m}^3$.

3.4 Calculation results and analysis of mechanical state after pit shaft collapse

The display and analysis of calculation results are based on visual graphs and described with appropriate text. The full understanding and mastering the initial mechanical state of the rock mass is the basis and foundation for designing and implementing effective

rock mass control technology. According to actual conditions of the project, the mechanical state of the surrounding rocks after the collapse of the pit shaft is obtained through simulation calculation:

(1) Above the collapsed goaf area, the maximum principal stress s_1 of the shaft wall and surrounding rocks mass is mainly concentrated at the interface between the goaf area roof of collapse and the shaft wall, where the rock mass stress is mainly formed by the tangential stress concentrated above the shaft wall at the shaft collapse site and the stress concentration around the roof of the collapsed goaf area. The calculation results show that the maximum principal

stress s_1 of the rock mass in the plane of the collapsed goaf area roof is -56.85 MPa (the specified compressive stress is negative, the tensile stress is positive, the same below), which is 3.9 times more than the self-stress of the deep rock mass s_2 . There is a large range of tensile stresses in the rock mass at the edge of the collapse area (Figure 2 and Figure 3). The maximum tensile stress is 5.3 MPa. The main direction of the surrounding rocks movement is towards the collapse area, with a maximum displacement of 12.7 mm. After the pit shaft collapses, there is still a plastic zone in the rock mass of the partially sustained pit shaft which has a range of about 2m.

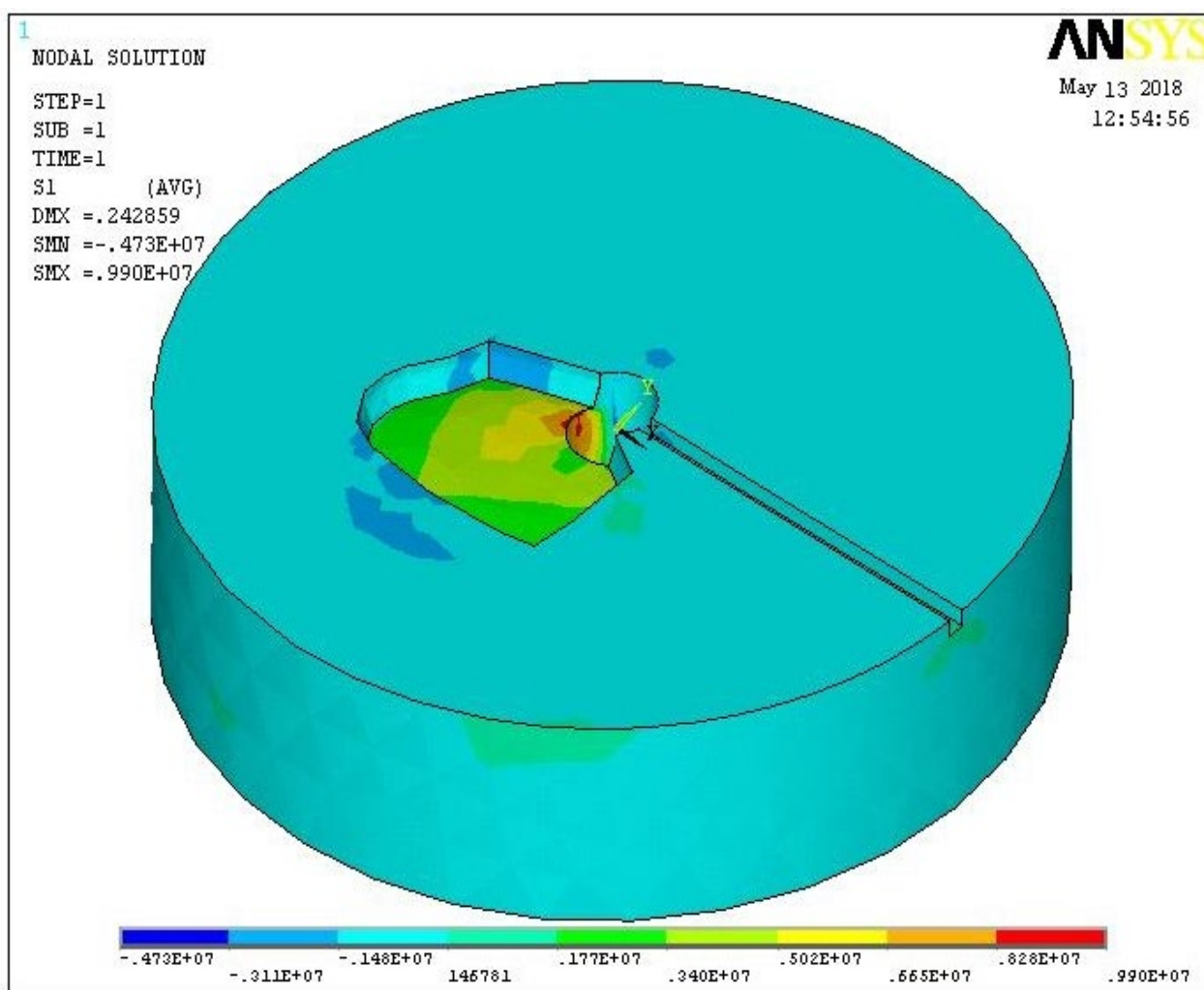


Figure 2. The map of 3D's distribution that the maximum principal stress for Pit shaft & collapsing area

(2) The stress state of the rock below the collapsed goaf area is basically unaffected by the collapsed body, and the stress distribution of the surrounding rocks mass is mainly determined by the collapsed shape of the pit shaft (Figure 4). The maximum principal stress s_1 at the corner

of the collapsed shaft wall is 64.71 MPa. The tensile stress value in the rock mass at the shaft wall edge is reduced at a maximum of 0.79MPa. The shaft wall rock still moves in the direction of the collapsed pit shaft space with a maximum displacement of 10.7mm.

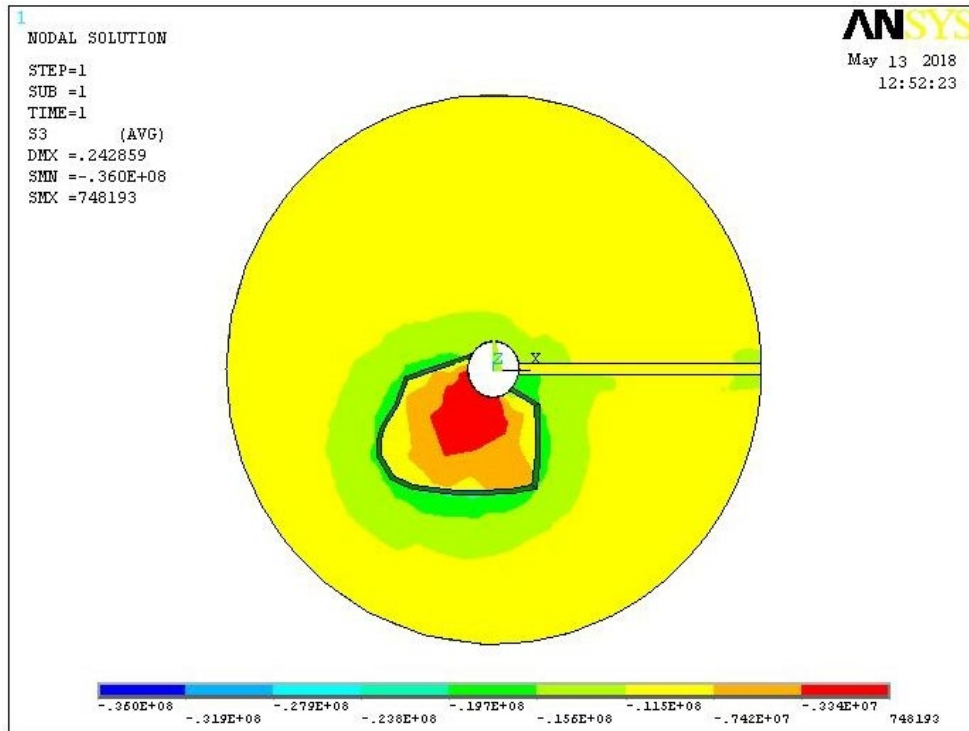


Figure 3. The transverse section map of the maximum principal stress which in the collapsed pit shaft location

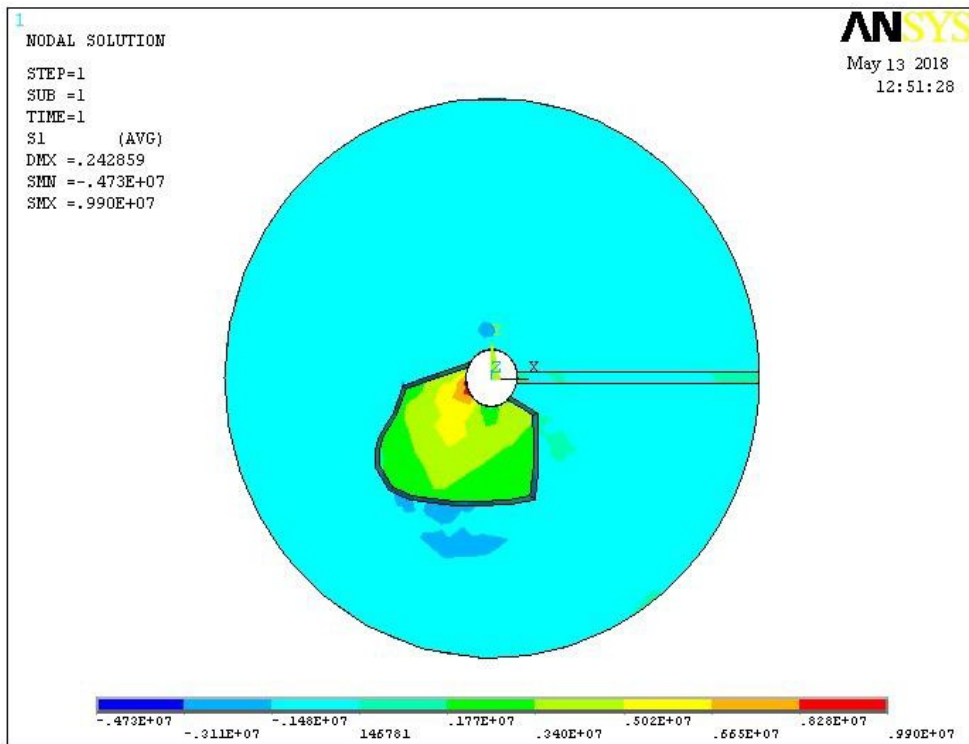


Figure 4. The transverse section map of the maximum principal stress which in the pit shaft & under the collapsing area

(3) The main direction of motion of the upper and lower shaft surrounding rocks mass in the collapsed area is in the vertical direction (Table 1). Therefore, the

urgent reinforcement measures for anchoring grouting should be adopted to control the further development of rock and soil around the shaft wall.

Table 1. The summarizing stress and deformation of pit shaft surrounding rock after collapsing

Stress & displacement	Goaf area roof of collapse	Surface of collapse	Above collapsed of pit shaft goaf area which inside of the shaft wall
X- Displacement /mm	-12.5 — 17.1	-8.4 — 6.9	-7.3 — 1.4
Y- Displacement /mm	-10.3 — 19.5	-6.2 — 9.4	-8.6 — 11.9
Z- Displacement /mm	-1.4	-1.2	-1.8
Normal stress s_x /MPa	-1.1 — 0.3	-0.9 — 0.2	-0.7
Normal stress s_y /MPa	-1.4 — 0.2	-2.6 — 0.5	-2.7
Normal stress s_z /MPa	-3.1 — 0.1	-2.4 — 0.2	-0.5 — 0.7
Shear force t_{xy} /MPa	-0.4 — 0.8	-0.6 — 0.8	-0.3 — 0.1
Shear force t_{xz} /MPa	-0.3 — 0.5	-0.4 — 0.1	-0.2 — 0.3
Shear force t_{yz} /MPa	-0.9 — 0.8	-1.3 — 1.2	-0.6 — 1.2

4 Reinforcement scheme

Overall scheme:

First, consider the comprehensive processing of grouting and anchoring of collapsed bodies, and then close the collapsed area with reinforced concrete, finally, after the above scheme is completed, digging down the pit shaft and implementing a side support while digging.

The specific reinforcement scheme is as follows (Figure 5-7):

(1) Arrange 5 rows of anchor holes in the collapsed body from outside to inside (relative to the center of the pit shaft), where the outer 3 rows are lateral, the hole depth is 12m (according to the results of numerical simulation, beyond the slip line 3m), and the inner 2 rows are vertical hole, with a depth of 11m. Implement two-fluid grouting, insert ribs afterwards which should use two rebars with a diameter $\phi 25\text{mm}$ and welded together.

(2) At the closed part of the reinforced concrete structure in the collapse area, the reinforced concrete is 100cm thick, the new shaft and the baseplate are chamfered at 45° with built-in steel bars to prevent the shearing and pulling failure of the joints under the surrounding rocks stress. According to the results of numerical calculations, the plastic zone in the rock mass of the non-collapsed pit shaft is only about 2m and the anchoring segment of the original design anchoring cable is still in the stable surrounding rocks. Therefore, the anchoring anchor in the original design can be extracted and locked on the inner wall of the pit shaft after the concrete curing period.

(3) After the above construction is completed and the curing period is due, the pit shaft can be dug down and the side supports can be implemented. After a year, the mixed pit shaft had completed the reinforcement

construction, and the long-term monitoring of the stress state of the anchor cable and the displacement of the pit shaft was conducted. The results show that the displacement and deformation of the shaft wall rock of the pit shaft have been effectively controlled, and no maintenance was performed after the project recovery. In addition, the anchor cable has taken about 50% of its breaking force, which still has a high strength reserve to ensure the safety of the reinforcement work.

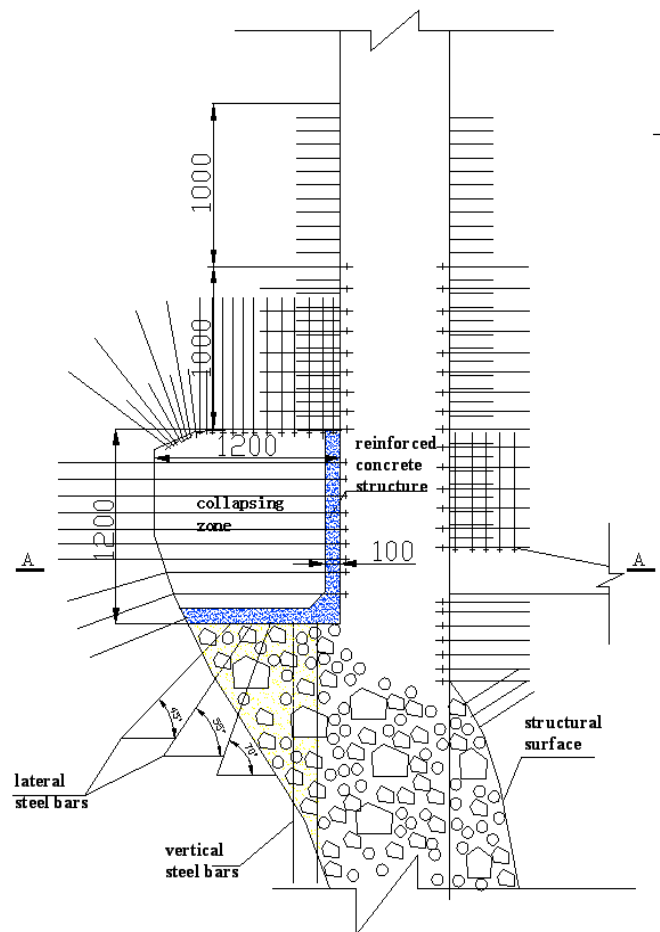


Figure 5. The transverse section map of the maximum principal stress which in the pit shaft & under the collapsing area

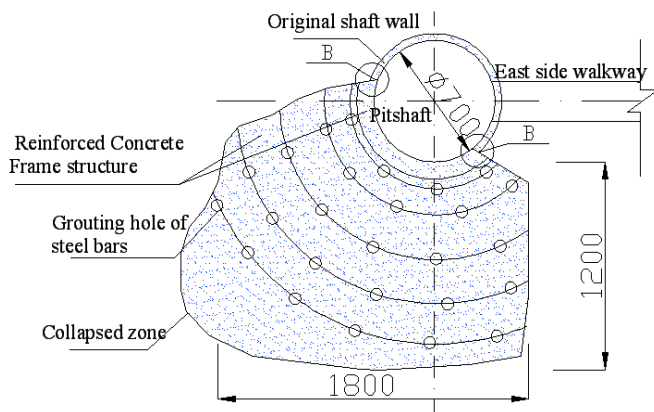


Figure 6. A-A Transverse section map

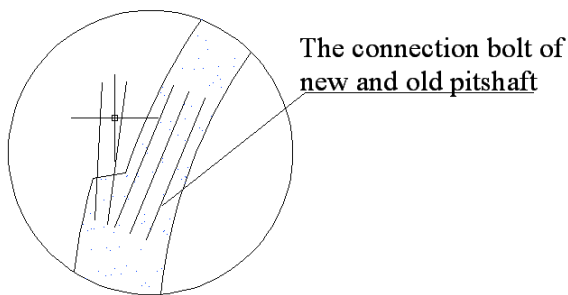


Figure 7. B dot's map of enlargement

5 Conclusion

(1) The surrounding rock mass of the pit shaft of the Yixin mixed shaft is obviously characterized as soft rocks, and its collapse occurs under the combined effect of weak interlayer and water.

(2) Numerical simulation results show that the main direction of movement of surrounding rocks in the collapse area is towards the collapse goaf, and the plastic zone of the non-collapsed shaft wall is about 2m. The main moving direction of the surrounding rocks of the upper and lower shaft wall in the collapse area is vertical.

(3) On the basis of numerical simulation, a comprehensive processing plan with collapsed body grouting and anchoring was adopted to reinforce the design and construction, something that has been proved by long-term monitoring as a reliable reinforcement scheme. (Figure 8-10)

Funding: This work was supported by Jiangxi Province Educational Science “13th Five-Year Plan” in 2019 (19YB205).

Yichun University Local Development Research Center Project (DF2018020)

The Science and technology research project of Jiangxi Provincial Education Department (No. GJJ170913).

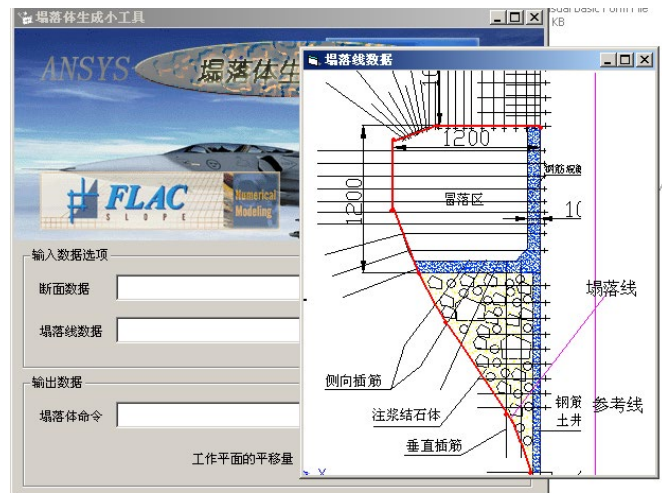


Figure 8. Tools for building collapse body model



Figure 9. ANSYS file-neutral file conversion tool



Figure 10. ANSYS-FLAC3D file conversion tool

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