FLAC3D Application on the Reinforcement Effect of Subsidence Damaged Return Air Duct

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Abstract The surface uneven subsidence is one of the important reasons that cause the buildings damaged. The numerical simulation method can be used to simulate the destruction state of the structures and forecast the developing trend of the damage. The return air shaft duct of Niuxi Coal Mine is built on the backfill land and it is seriously damaged. Mohr-Coulomb Model of the return air duct is established to simulate the subsidence and forecast the trends of subsidence and damage. The grouting holes' reinforcement has good use on the control of the subsidence trends in short terms, but the damage for the subsidence has been solved. So it is suggested that the company should contact some research institutes and engineering companies as soon as possible.

Keywords FLAC3D • Return air duct • Reinforcement effect • Subsidence

Foundation item: Inner Mongolia Autonomous Region Science and Technology Department of applied technology R & D projects (20111401)

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E. Qi et al. (eds.), *Proceedings of 20th International Conference on Industrial Engineering and Engineering Management*, DOI 10.1007/978-3-642-40063-6_15,

1 Project Background

The return air duct of Nuixi Coal Mine in Hebei Province is put into use from January 2007. The parameters of the duct are shown as below:

The total length is 33.2 m, the slope length is 14.2 m and the plane length is 19 m. the width is 3.64 m, the height is 4.82 m, the net width is 2.9 m and the net height is 2.9 m, the height over floor is 3.32 m and the underground height is 1.50 m. According to the parameters, a 3D model is built as the Fig. 1 shown.

The foundations of the duct and the fan were designed as general building foundations, which caused the subsidence and damaged the duct. The destructions and the maintenance projects are listed in Table 1. The maintenance effect is shown in Fig. 2.

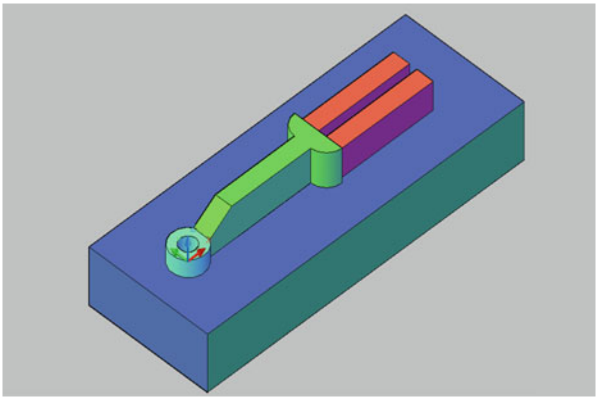

Fig. 1 The 3D model of the return air duct

Table 1 The destruction and the maintenance projects of the duct

No	Data	Destruction	Maintenance	Effect
1	July, 2007	Slight diagonal cracks on the wall	Riveting and hanging steel mesh on the wall and plastering	Did not achieve the expected results
2	June, 2008	Cracks widened and scope expanded	Adhesive two ternary resin felt on the outer wall	Good results in short times
3	May, 2010	The wall cracked again and led to air leakage	Shotcrete reinforcement on the inner wall	Good leak-proof wind in short times

Fig. 2 The photo of the return air duct after the third maintenance

2 Recording the Uneven Settlement Data

2.1 Setting Observation Points

Duct wall destruction is caused by the air duct uneven subsidence. To observe the real time subsidence, the observation points were settled on the return air duct and the fan foundation since June 2009. 22 observation points were settled and shown as Fig. 3.

2.2 Observation Data Analysis

After 7 months observation, the subsidence data are listed in Table 2. After analysis, we can see the most serious subsidence area is at the junction (points 4–13) of the return air duct and fans.

There are two reasons that lead to the most seriously uneven subsidence between observation point 4 and 13. The first reason is that the original surface altitude of the region between observation points 4 and 13 is lower than its peripheral region. So there is a great amount backfilling volume. The return air duct is built on the base of backfill without compaction. The other reason is that the region is the junction of the return air duct and the fan. The return air duct is geotechnical and the fan is metal. The density difference leads to the reasonable different subsidence.

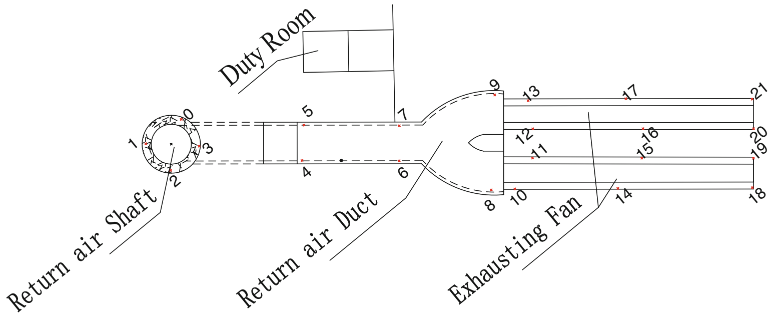

Fig. 3 Sketch map of air duct settlement observation points layout

Table 2 Observation result of may 2010

	Total movement/mm				Total movement/mm		
Point index	X	Y	Z	Point index	X	Y	Z
0	−24	24	−62	**11**	−15	50	−46
1	−44	22	−51	**12**	−23	23	−55
2	−16	25	−28	**13**	−38	25	−70
3	31	−20	−15	**14**	−52	26	−51
4	−11	−10	−28	**15**	−43	48	−54
5	30	−17	−26	**16**	−51	37	−78
6	−28	48	−45	**17**	31	90	−59
7	−9	33	−47	**18**	−37	29	−65
8	39	16	−47	**19**	−58	29	−60
9	−38	−36	−101	**20**	−48	38	−40
10	−42	92	−99	**21**	−41	72	−62

All the observation data can be used to check the results getting from the FLAC3D numerical simulation.

3 Building the Numerical Simulation Model

In order to determine the parameters of the constitutive models in the numerical model, four exploration holes are drilled around the return air duct, shown in the Fig. 4. According to the drilling data and the original terrain contour lines before backfilling, the numerical simulation model is determined and shown in Fig. 5.

Mohr-Coulomb is applies to the loosely cemented particulate material such as soil, rock, concrete, etc. (Itasca Consulting Group & Inc 2005).

So Mohr-Coulomb Model is chosen to be the constitutive model (Engineering Geology Research 1983; Peng Wenbin 2008; Chen Yumin and Xu Dingping 2009).

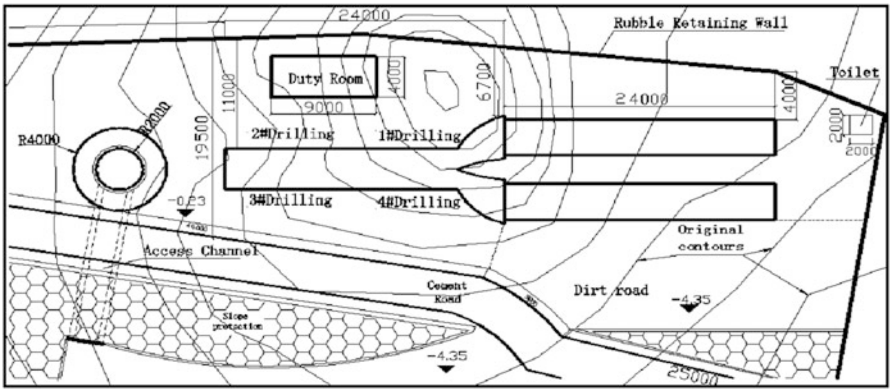

Fig. 4 Schematic diagram of drilling hole layout and the original terrain *contour lines* round the duct

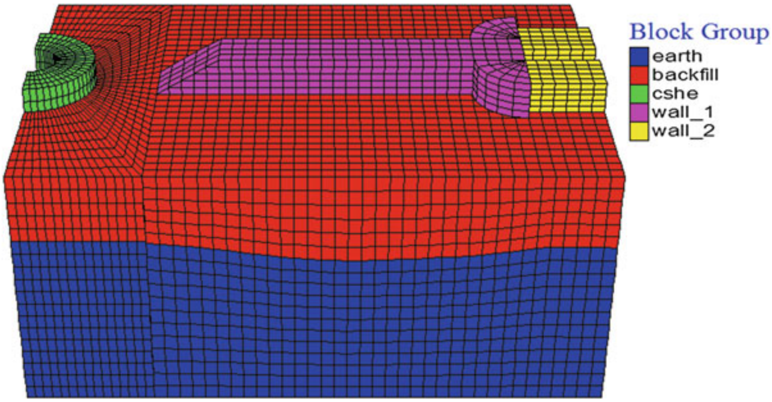

Fig. 5 The grouping result of the model parts

Table 3 Parameters of the materials

K/Pa	G/Pa	c/KPa	σ_t	ψ/°	φ/°	Group
6.67×10^7	4.00×10^7	20	2.80×10^6	15	37	Earth
1.00×10^7	1.00×10^6	8.8	0	0	30	Backfill
1.00×10^8	1.10×10^8	40	3.00×10^6	15	60	Cshe
1.60×10^7	2.00×10^6	2.1	6.00×10^5	14	34.5	Wall_1
1.00×10^8	1.10×10^8	54	7.00×10^6	15	55	Wall_2

Based on the underground strata determined by the exploration drilling holes, referring to the parameters in Engineering Geology Research (1983), the material parameters of the model are set as shown in Table 3.

4 Contraposition of Observation Points Records and the Numerical Simulation Results

The numerical simulation results is shown as Fig. 6. Analyzing the numerical simulation results, we find that the whole return air duct of the shaft is in the uneven subsidence area. The maximum Z-Displacement after 500 time steps is 103.5 mm and the actual observation Z-Displacement is 101 mm. They are basically consistent.

The largest subsidence area is at the junction of the return air duct and the fan. It is consistent that the actually observation largest subsidence is at the observation point 9. The exhaust fan is a whole metal components and the subsidence also is the overall one. This is also in line with the actual situation.

After the above analysis, the numerical simulation results reflect the destruction of the return air duct due to subsidence. It also can be used to forecast the return air duct destruction in the future. The simulation only take 500 time steps and do not meet the convergence criteria. This means the destruction of the return air duct is not stopped, so the duct still needs repair (Wang Bingwen et al. 2010; Xu Yanchun et al. 2010; Jiang Fuqiang 2007; Guo Feng-yong et al. 2005).

5 Numerical Simulation of the Effect of the Grouting Reinforcement Holes

5.1 The Fourth Reinforcing with the Grouting Holes

Due to the poor results of the previous two repair, the third reinforcement is taken.

After the previous repairs, the base sinking cracking the wall still do not be solved. With the passage of time, the deformation of the return air duct is more

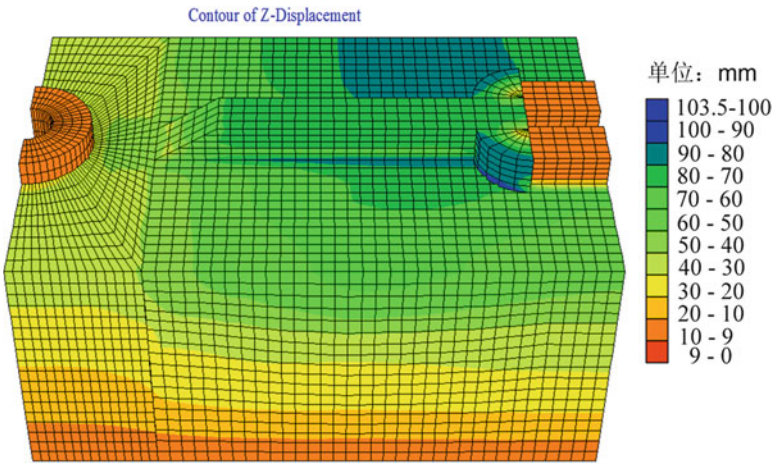

Fig. 6 Result of subsidence numerical simulation

Table 4 Punch grouting records of the air shaft

Drilling	Angle/°	Length/m	Drilling	Angle/°	Length/m
1	85	45.50	7	85	39.80
2	85	45.50	8	85	44.28
3	85	44.18	9	85	49.50
4	85	46.72	10	85	43.48
5	85	46.72	11	85	46.72
6	85	42.26	12	85	31.72
			13	85	41.04

and more serious, so the fourth repair and reinforcement are taken to the return air duct and its base. Thirteen grouting holes are lay on the two sides of the return air duct. The pitch angles of the grouting holes are −85° to the base of the return air duct. The depths of the holes are between 30 and 50 m. The parameters of the holes are listed in Table 4. Six-meter length four-inch steel pipes are fixed in the grouting hole openings. The total depth of the grouting holes is 567.42 m. 19.15 t cement is injected in total.

5.2 Numerical Simulation of the Fourth Reinforcement

There are two ways to pile axial load transmission to the ground: the surface friction and the end bearing (Xue Dong-jie et al. 2013; Wang TongTao et al. 2012; Chen Beibei et al. 2011). The grouting cement structure unit is also achieved by surface friction and end loaded reinforced. So in the numerical simulation, pile is taken as the grouting structure unit. According to the related parameters in Table 3, the parameters used in the numerical simulation for the fourth reinforcement are determined. The points on the surface around the air duct and two fans are chosen as marked points. The curve of the predicted subsidence and time (time step) is shown in Fig. 7.

6 Conclusions

1. The numerical simulation results reflect the destruction of the return air duct due to subsidence (Liao Jie et al. 2011; Zhang Xue-dong et al. 2012; Chen Bing-qian et al. 2012).
2. The grouting holes of reinforcement has good use on the control of the subsidence trends in short terms. According to the results of the numerical simulation, it can be inferred that punching grouting is not a fundamental solution to the return air duct subsidence. With the prolongation of the return air shaft and the duct, the subsidence of the duct will affect the normal production in further (Chen Xiu-liang et al. 2012).

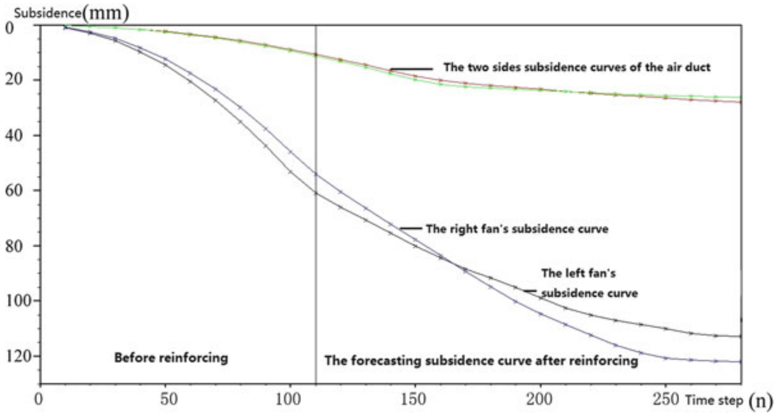

Fig. 7 Curves of return air duct subsidence simulation

3. In order to reduce the losses caused by the duct damage, it is suggested that the company should contact some research institutes and engineering companies as soon as possible, to research the further reinforcement to reduce the duct subsidence and to avoid being forced to stop production.

Acknowledgment First of all thank the editor to help me complete the paper work, followed thanks to my co-author, you provide me with the material to complete this paper are seeing now, the other would also like to thank my parents, wife support of my work, life with you, I feel honored, thank you for my support and encouragement.

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