2015

Numerical Simulation of Seismic Dynamic Response of Ground Surface Above Mined-Out Area

Xiaoming Zhang
Liaoning Technical University

Xiaochen Yang
DFmc Technology Co. Ltd.

Zuo Wang
Liaoning Technical University

Kyuro Sasaki
Kyushu University

Publication Details

Xiaoming Zhang, Xiaochen Yang, Zuo Wang and Kyuro Sasaki, Numerical Simulation of Seismic Dynamic Response of Ground Surface Above Mined-Out Area, 15th Coal Operators' Conference, University of Wollongong, The Australasian Institute of Mining and Metallurgy and Mine Managers Association of Australia, 2015, 230-236.

NUMERICAL SIMULATION OF SEISMIC DYNAMIC RESPONSE OF GROUND SURFACE ABOVE MINED-OUT AREA

Xiaoming Zhang[1], Xiaochen Yang[2], Zuo Wang[3] and Kyuro Sasaki[4]

ABSTRACT: Most coal mines are in the seismic intensity 7（12 degree evaluation or even higher in China. Large-scale mined-out spaces formed in the strata have been increased, because of excessive coal mining exploitation. The seismic response of mine surface will be different from other places because of the impact of the mined-out area on the seismic wave's propagation. This paper studies the seismic response acceleration, peak acceleration and displacement at the ground surface above unstable and compacted mined-out areas by FLAC3D numerical models for various conditions. The results of the numerical simulation are consistent with the surface seismic response of Zhaogezhuang Mine in the Tangshan earthquake, 1976. It has been shown that the seismic damage to the surface above the mined-out area especially to the surface above the boundary of the mined-out area was slightly less than those in other places at the ground surface, and the seismic damage to the surface which is 2-3 times the size of mined-out area's width, away from the mined-out area boundary was more severe than those in unexploited places. The surface area which is more than 4 times the size of the mined-out area's width away from the mined-out area boundary was not affected by seismic damage.

INTRODUCTION

The effect of underground structure such as roadway and chamber in coal mine on the seismic wave propagation is little because the size of them is smaller than the seismic wavelength. However, if the size of underground structure (such as large-scale mined-out area) and seismic wavelength are in the identical order of magnitude, the propagation of the seismic wave will be changed because of the mined-out area. A series of complex reflection and transmission are generated because of the different wave impedance in rock medium and the impact of mined-out area space .In addition, scattering will occur around irregular boundary of the mined-out area. These phenomena may generate large impacts on the dynamic seismic response at the ground surface. Previous studies have investigated the earthquake effect on the underground structure and the dynamic response of ground surface above shallow-buried chambers. This paper aimed to study the effect of deep mined-out area in coal mines on the dynamic response of the surface with the combined method of measured data and numerical simulation. The measured data about the dynamic response of ground surface in coal mine is deficient. In view of some detailed data of surface damage are recorded when a great earthquake happened in Tangshan city（China, 1976） where many collieries are located. This paper collected and studied the measured data of Zhaogezhuang Mine recorded by China Seismological Bureau in Tangshan to analysis the impact of the mined-out area on dynamic response of the ground surface. The measured displacement on the ground above the mined-out area and surrounding terrain which is near the mined-out area, and the destruction degree of the industrial square and civil buildings nearby is emphatically analysed. In addition, the seismic response of the ground surface above the mined-out area has been simulated by and analyzed by FLAC3D models for various conditions. The conclusions will give reference for the site selection of industrial and civil buildings near coal mines, stability of the buildings located near coal mines and coal mine reconstruction after earthquake.

DYNAMIC RESPONSE OF GROUND SURFACE IN ZHAOGEZHUANG MINE

Distribution of mine-out area

Zhaogezhuang Mine is located in Guye, northeast of Tangshan in Hebei province. The strike length of mine field is 9050 m and mining area is 31.55 km^2. The deep boundary of mine field is -1200 m around. The coal mine has mined ninth level when the earthquake happened in Tangshan, 1976. The mining

[1] *Institute of Engineering and Environment Liaoning Technical University, Huludao 125000, China.Email: xiaochen2024@163.com*
[2] *DFmc Technology Co., Ltd., Department of Communication Navigation, Dandong 118000, China*
[3] *College of Mining Engineering Liaoning Technical University, Fuxin 123000, China*
[4] *Kyushu University, Faculty of Engineering, Nishiku, Fukuoka 819-0385, Japan. Email: krsasaki@mine.kyushu-u.ac.jp*

depth is -735 m. The strike length is 4.5 km. The tendency length is 1.6 km. The mined-out area went up to 7.2 km^2 whose distribution is show in Figure 1.

Figure 1 shows the change rule of mined-out area distribution with time flow. The distribution arrangement of mined-out area is large because the coal mine has a long history of about one hundred years. At present, the mined-out area is about 10.02 km^2, of which east flank is 5.54 km^2 and west flank is 4.48 km^2.The mined-out area had gone up to 7.2 km^2 when the earthquake happened in Tangshan. This paper reports on the study by the seismic geological brigade of Chinese seismological bureau, comparing the local coordinates of the area based on the survey of surface deformation after the earthquake,. The surface deformation of the industrial square, surface above mined-out area, the surface above the mined-out area boundary and the village surface nearby are shown in Table 1.

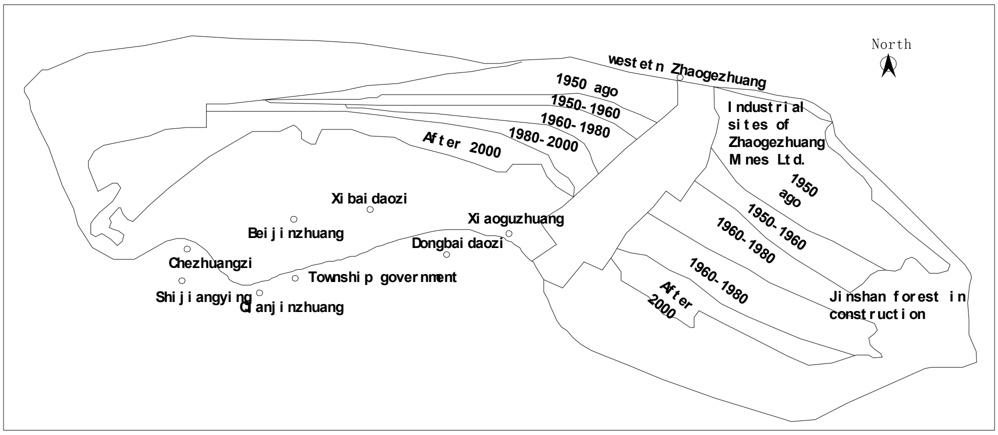


Figure 1: Distribution of mined-out area in Zhaogezhuang Mine

Displacement of surface and house collapse rate after earthquake

In order to analyze the influence of mined-out area on the dynamic response of the ground surface, this paper selects the surface deformation, houses collapsing rate of Zhaogezhuang Mine and the village nearby, which is based on seismic exploration value on surface deformation by Chinese seismological bureau.

Table 1: Surface destruction of Zhaogezhuang Mine and nearby

Ground surface above mined-out area	N39°33.318′, E118°6.846′	Surface Deformation，Horizontal displacement:36cm
Northern Industrial Square of Zhaogezhuang Mine	N39°36.418′, E118°11.834′	Ground crack and terrain scarp， Horizontal displacement:50cm
Southern Industrial Square of Zhaogezhuang Mine(mined-out area boundary)	N39°36.365′, E118°11.846′	Horizontal displacement:35cm
North of west Zhaogezhuang	N39°36.401′, E116°10.335′	Ground crack，2m fall in NW side，Horizontal displacement: 47cm
South of west Zhaogezhuang	N39°36.385′, E116°10.465′	1m fall in NW，Horizontal displacement: 38cm
Xiaoguzhuang	N39°36.105′, E118°11.643′	Ground crack，Horizontal displacement: 58cm
Qianjinzhuang	N39°35.505′, E118°9.193′	Horizontal displacement: 60cm，1m fall in NW

According to Table 1，the horizontal displacement of surface above mined-out area is 40 cm. The horizontal displacement of Industrial square boundary and southern surface of west Zhaogezhuang located in north flank boundary is 35 cm and 38 cm, respectively. However, the horizontal displacement of northern industrial square and northern surface of west Zhaogezhuang is 50 cm and 58 cm, respectively, which is significantly greater than the surface displacement in mined-out area boundary. The surface horizontal displacement of village further from mined-out area boundary is 58 cm and

60 cm, which is greater than the surface at mined-out area boundary, while is almost the same as horizontal displacement of other place in the mine field.

It can be concluded from Figure 2 that the surface horizontal displacement near mined-out area is small relatively. The displacement of other mine field and village far from mined-out area is similar which shows that dynamic influence of mined-out area on the ground surface will disappear with the increasing distance from the mined-out area. According to the Figure 3, the house collapsing rate at mined-out area boundary is 76% , which is less than the rate in other places and villages far from coal mine. The house damage amplitude of west Zhaogezhuang at mined-out area boundary is significantly smaller than the Xiaoguzhuang village. The earthquake makes the abscission in pool periphery wider, while not obvious. Light railway subgrade, which is used to deliver coal gangue beside the pond, slipped in the direction of the pond, while the degree of bend is slightly smaller than the track in other places.

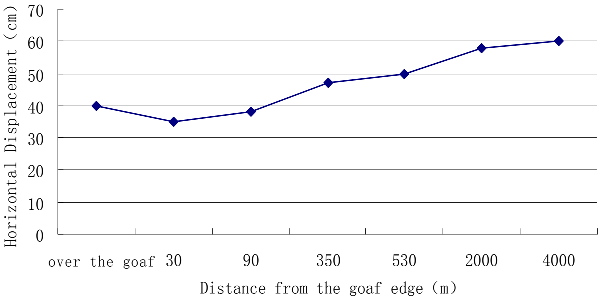


Figure 2: Horizontal displacement of surface near Zhaogezhuang Mine

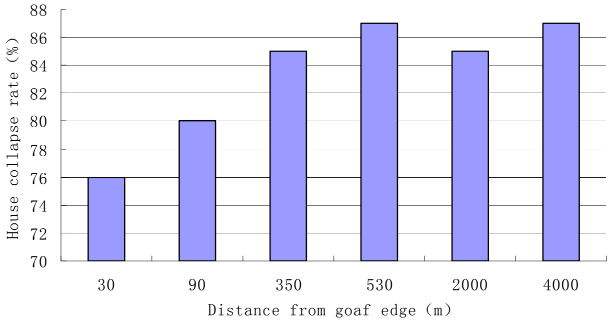


Figure 3: House collapse Rate of ground Zhaogezhuang Mine and near villages

NUMERICAL SIMULATION BY FLAC3D

Because of the FLAC3D is widely applied in rock mechanics and dynamic issues, this paper analyzes the seismic dynamic response of ground surface above mined-out area by FLAC3D.

Model of numerical simulation

The dimension of the model is 1600 m long in x direction, 430 m high in z direction and 100 m wide in y direction respectively. Since the effect in y direction is not considered, the model is simplified in quasi three dimension .Coal seam thickness is 4 m ,the mined-out area is set in the middle of the coal seam with 200 m long,100 m wide .The gangue height collapsed by roof is 3 m, the space not filled is 1 m. Elasto-plastic Constitutive Model and Mohr-Coulomb failure criterion are employed in this study. Elastic model is applied in gangue which is considered as support and space uses null model. Monitoring points from 1-9 are set on the ground surface in which point 1 is set above the mined-out area, point 2 is set above the boundary of the mined-out area, point 3 to 9 are set above the virgin areas . Properties of material used in calculation are the simplified rock parameter of Zhaogezhuang Mine. The model and monitoring points are presented in Figure 4.

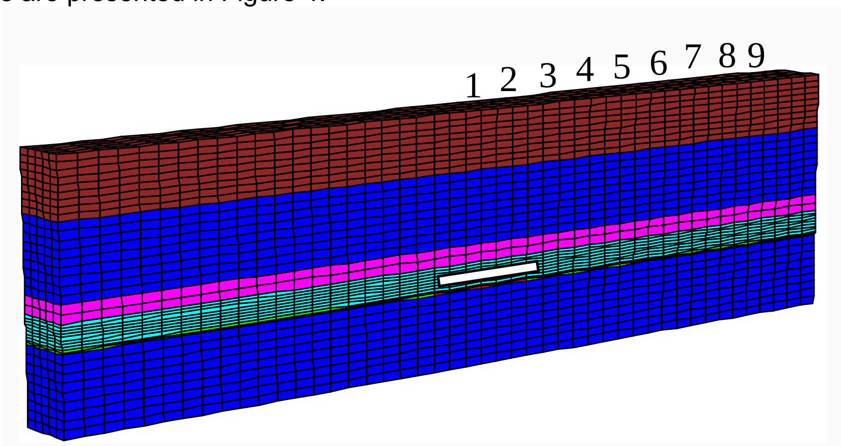


Figure 4: Mesh diagrams

Input waves and dynamic parameters

This paper adopts approximated acceleration waves of the Tangshan earthquake in E-W direction (Figure 5) and the peak value is 633.092 cm/s^2.The waves from 30s to 60 s are chosen in calculation. Acceleration spectrum shows that most of the power (approximately 95%) is made up of components of frequency 15 Hz (Figure 6).Therefore, cut-off-frequency is 15HZ and the dimension of the element is restrained as 10 m. The center frequency is defined as 0.6 Hz .For geological materials, damping commonly falls in the range of 2 to 5% of critical level. In the present study, 5% is chosen for calculation. The acceleration needs to be converted to stress when seismic wave is applied into the bottom of the model which is set as viscous boundary. Since S-wave is used in this paper, the acceleration-into-stress transformation formula is expressed as follows:

$$\sigma_s = -2v_S\sqrt{G\rho} \quad (1)$$

Where, v_S is the input shear particle velocity obtained by integration, ρ is the density of the base of the model, G is the shear modulus of the base of the model

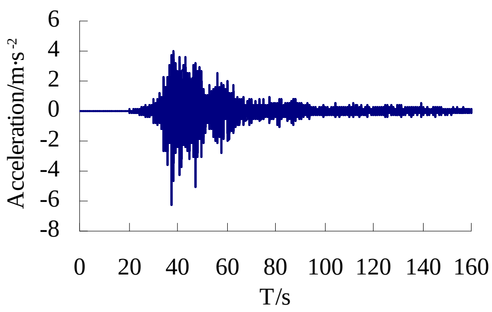


Figure 5: Seismic acceleration waves

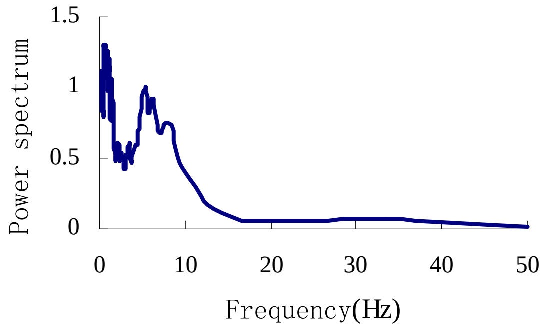
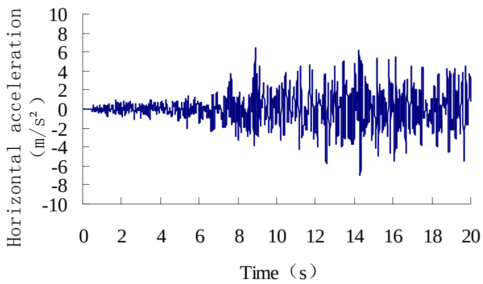


Figure 6: Plot of power spectrum versus frequency

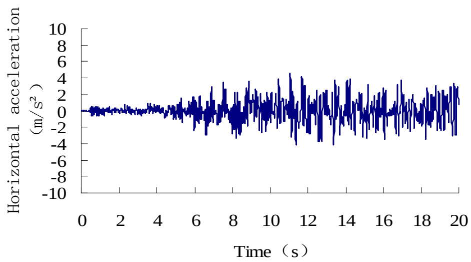
NUMERICAL SIMULATION RESULTS AND DISCUSSION

Response acceleration of the ground surface

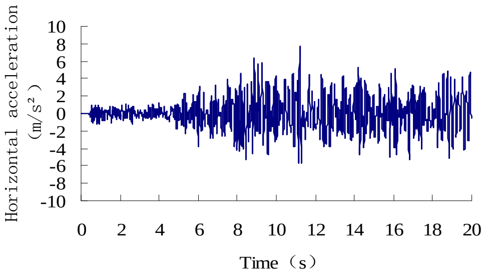
Figure 7 shows the acceleration-time curve of the monitoring points at the ground surface when mined-out area is 200m long and 350 m deep. It can be clearly shown that acceleration amplitude of the points above the mined-out area is smaller than those above the virgin coal seam. The peak accelerations of point 1 and point 2 are 6.47 m/s^2 and 5.56 m/s^2, respectively. It can be seen that the acceleration amplitude of point 2 which is above the boundary of mined-out area is smaller than that of point 1 above the mined-out area centre. The acceleration amplitudes of the point 3 to point 9 at the ground surface above the virgin coal seam are 7.08 m/s^2, 7.42 m/s^2, 7.54 m/s^2, 7.55 m/s^2, 7.67 m/s^2, 7.19 m/s^2, 7.10 m/s^2 with the trend of increasing at first then decreasing. The acceleration amplitude of point 6 increases significantly, while point 8 and point 9 which is farther from the mined-out area shows the decreased trend. The peak acceleration of point 9 which is the farthest point from mined-out area is basically identical to the peak acceleration of the ground surface in the free-field condition.



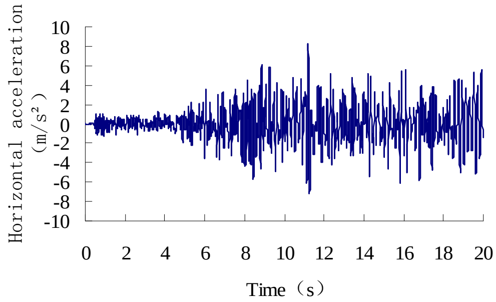
(a) Point 1



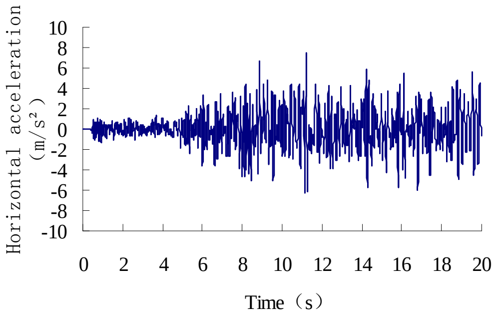
(b) Point 2



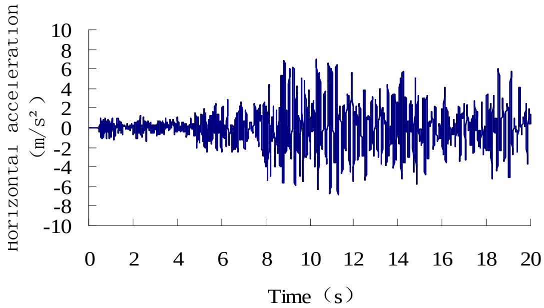
(c) Point 4



(d) Points 6



(e) Point 8



(f) Free-field

Figure 7: Response acceleration time-history curves of monitoring points

Peak acceleration of the ground surface at different depth of mined-out area

Figure 8 shows the peak acceleration of the monitoring points at the ground surface when the depth of mined-out area is 200 m, 250 m, 300 m, 350 m and 400 m.When the mined-out area is 200 m deep, the peak accelerations of point 1 to point 9 are 4.73m/s^2, 4.36 m/s^2, 5.73 m/s^2, 6.12 m/s^2, 6.62 m/s^2, 6.62 m/s^2, 6.27 m/s^2, 5.93 m/s^2, 6.44 m/s^2 which are all smaller than that of the ground surface in free-field conditions. It can be considered that the mined-out area which is 200m deep decrease the response acceleration at the ground surface. When the mined-out area is 250m deep, the peak acceleration values of point 1 to point 9 are all higher than those when the mined-out area is 200m deep, while they are still smaller than the peak acceleration of the surface points in free-field condition. When the mined-out area is 300m deep, the peak accelerations of point 1 to point 9 are 6.08 m/s^2, 5.55 m/s^2, 7.05 m/s^2, 7.13 m/s^2, 7.32 m/s^2, 7.56 m/s^2, 7.42 m/s^2, 6.85 m/s^2, 6.83 m/s^2 which get further increased .The peak accelerations of the points 1 and 2 are smaller than the surface points in free-field condition, while the values of points 5, 6, and 7 are higher than the free-field surface points. Finally, when the mined-out area depth reaches 350-400 m, the peak acceleration further increases and the trend of change is consistent with the values when mined-out area is 300 m deep.

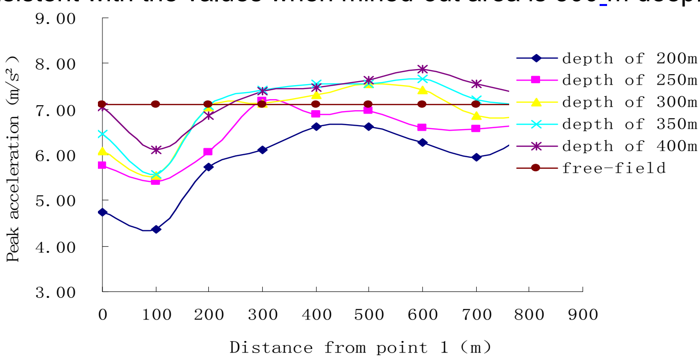


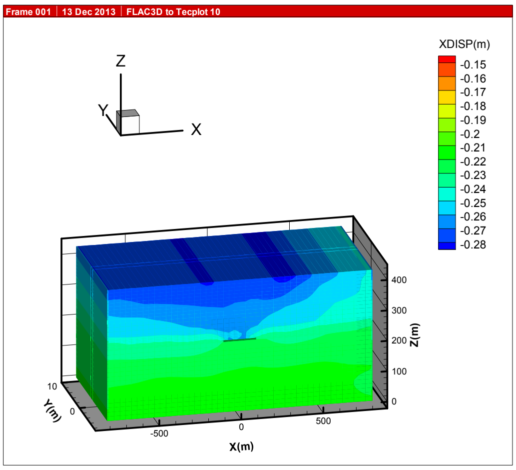
Figure 8: Peak acceleration of monitoring points at different depth of mined-out area

In general, the peak acceleration values of point 1 and point 2 become higher with the increasing mining depth, and they are lower than the peak acceleration of ground points in the free-field condition. It shows that the mined-out area reduces the response acceleration of the ground surface above it. When the mining depth reaches 300 m or deeper, the mined-out area magnifies the response acceleration of the points above the virgin coal. However, the peak ground acceleration which is 4 times the mined-out area size away from the mined-out area boundary declines to the peak ground surface in the free-field condition.

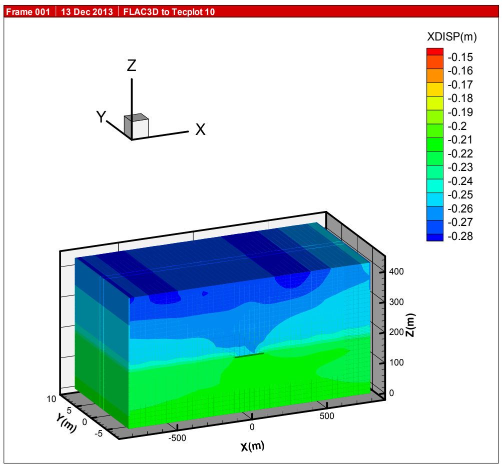
Seismic displacement of ground surface

The Figure 9 shows that the surface displacement near the mined-out area will be different when an earthquake happens. The displacement values above the mined-out area are lower than thoseabove the virgin coal seam. The maximum displacement above the mined-out area, above the virgin coal seam, and the surface displacement in free-field are 0.260 m,0.280 m and 0.270 m which shows that the displacement values above the mined-out area becomes lower and the displacement above the virgin coal gets higher compared with the free-field surface displacement. When mining depth is 250m, 300 m and 350 m, the Figures show that the minimum displacement is at the point 1 with the values of 0.260 m, 0.260 m and 0.265 m. The maximum displacement is 0.28 m which is at 340 m, 450 m, and 550 m away from the mined-out area boundary. Therefore, the value and position of minimum displacement is little affected by mining depth with the value of 0.260 m above the centre of the mined-out area. The maximum displacement is 0.28 m which moves away from the mined-out area with the increasing mining depth.

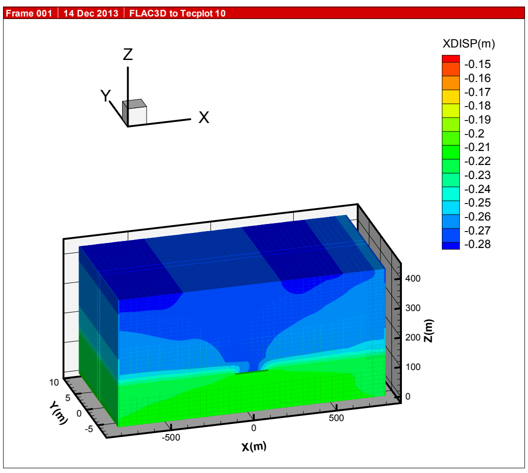
From the results of the numerical simulation, the seismic response of the ground surface above the mined-out area is smaller than that away from the mined-out area, and the seismic response of the ground surface in a certain range above the virgin coal seam is larger than that of the area away from mined-out area. The analysis results above are consistent with the surface damage of Zhaogezhuang Mine in Tangshan earthquake.



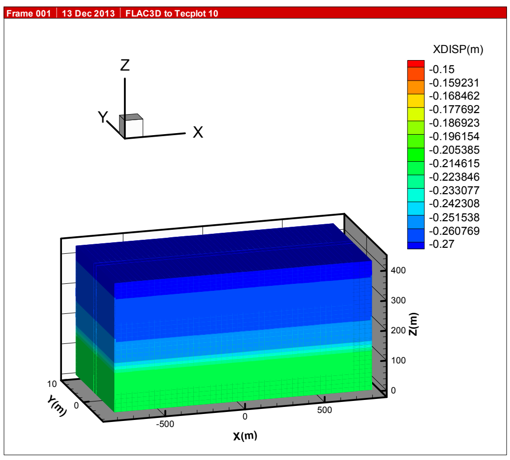
(a) Depth of 250m



(b) Depth of 300m



(c) Depth of 350m



(d) Free field

Figure 9: Contour band of surface displacement at different depth of mined-out area

CONCLUSIONS

This paper uses numerical simulation to analyse the seismic dynamic response of the ground surface of a coal mine. Some conclusions have been drawn as follow:

When unstable mined-out area exists in the strata, the seismic damage at the ground surface which is above the mined-out area is about 10% less than that of the district which has no mined-out area in the strata, and the surface damage above the boundary of the mined-out area is the least with a 15% decline. When mined-out area is deep, the seismic damage of the ground surface, which is 2-3 times of the mined-out area size away from the mined-out area, becomes worse in comparison with no mined-out areas, and the increase amplitude of the damage is about 8%. The region at the ground surface which is greater than four times of the mined-out area size away from the mined-out area is not affected and the seismic damage in this region is consistent with the area without a mined-out area in the strata.

REFERENCES

Wang, L L. 1985, Foundation of Stress Wave, pp 105-112 (National Defence Industry: Beijing).

Li, H B, Ma, X D and Li J R. 2006, Study on influence factors of rock cavern displacement under earthquake, *Chinese Journal of Geotechnical Engineering*, 28(3): 358–362.

Summary of damage in Tangshan earthquake. 1978, (Earthquake Press: Beijing).

Itasca Consulting Group Inc. 2012, PFC user manual.