

Numerical Simulation and Numerical Differentiation Analysis of Slope Deformation Due to Mining

Shibo LI^{1, a}, Wensheng LIU^{1, b}

¹ College of Mining Engineering, Hebei United University, Tangshan, Hebei, 063009, China

^ashiboli@sohu.com, ^bwincherlliu@163.com

Keywords: Strength reduction, Numerical simulation, Numerical differentiation, Ground subsidence

Abstract. It's important to analysis accurately the deformation of the mountain slope due to mining. An example of the iron mine in Jidong area was given, and then the stability and deformation of mountain slope influenced by mining were calculated by means of numerical simulation and numerical differentiation, and besides, basis of quantitative analysis was given for safety assessment of power line on mountain slope. The method that was validated by the effect of corresponding example was rational and efficient.

Introduction

Tangshan, Hebei Province in northern surface topography mostly is of mountains, hills, mountains are low, medium cutting, complex terrain, and rolling hills. Abundant iron ore resources within the area belonging to the Anshan-type deposit type metamorphosed sedimentary iron ore. After useful ore was mined, Rock original stress equilibrium around mining area are destructed, stress redistributing, gob rock avalanche, with rock moving and deformation. if the impact develop to the ground, it will produce a continuous or discontinuous ground deformation inducing a series of environmental geotechnical problems, causing a huge impact and loss of production and life of the people in mining area, leaving a huge hidden trouble for future mine construction projects at the same time [1] . Because the disturbance caused by underground mining of rock, its influence on the stability of rock overlying the upper slope would induce the slope body sliding, causing decreased stability of the mountain; posing the mountain slope hazards, causing mountain deformation, destroying the structure on the mountain [2]. Even deep underground mined area, the ground will cause significant movement and deformation [3]. In the mountains, research of impact mechanism has little done in secondary stress field of underground mining. Therefore, it is important to study the ground subsidence deformation influenced by under mountain gob deformation for further understanding of the basic law of mining subsidence and rational seam exploitation as well as safety assessment for the upper slopes. In this paper, taking actual situation of underground iron ore mining in a northern mountainous area of Tangshan as an example to analyze the influence the underground mining to the mountain slope.

Mine is located in the North China Platform Malan Yu Yanshan fold belt Qianxi dome anticline fold compound beam west. Strata exposed in the main mining area for the next Malan Qianxi Group Archean gneiss valley group system, mainly in the fine-grained biotite hornblende hypersthene plagioclase gneiss, hornblende-plagioclase gneiss, biotite-hornblende-plagioclase tablets Ma rocks. Followed by exposed north and south the Great Wall lines Changzhougou Formation, the lithology is basal conglomerate, conglomerate, quartz sandstone, and quartzite. Quaternary is distributed in the mountain valley areas, mainly alluvial layer, sub-plot of the residual slope and extent of the slope is not laminated. Ore bodies are buried in the hillside which is a hidden ore body, angle 60~65°, thick ore body.

There is a supply lines on the slope which is hanging wall of the mine, using concrete pole erection; there are chestnut trees and farmland on lower part of slope. Ground movement caused by underground mining can cause deformation of power lines tilt, inducing the slope upper body sliding in the condition of severe deformation, destructing the agricultural land and of trees on the lower part.

Therefore, it is necessary to analyze mountain stability and deformation due to the underground mining and determine the extent of its impact, augmenting the acceptable range to be able to take of deformation and stability, adopting necessary countermeasures in rational exploitation manner.

Stability analysis of mountain slope

On the problem of movement and deformation of rock mass and stability of ground construction due to mining, there are many studies abroad and obtained. Existing theoretical approaches of mining subsidence can be divided into two major categories: one is phenomenological research methods. It is observed from the ground moving, the ground description linked to geological and mining factors, on the basis of a large number of ground observations, predicting and describing the rock and ground deformation by statistical methods, such as the probability integration method, the typical curve, profile function method; the other method is the mechanical method, which uses the mechanical principles and methods (mechanics of materials, structure mechanics etc.), assuming a continuous medium rock, the rock is simplified as equivalent mechanical mode, continuum mechanics theory being used to study the rock[4]. In recent years, many researchers and technical personnel adopt the theory of probability and statistics-based theory to study rock mechanics and engineering geological theory. The establishment of a corresponding analysis method is studied on the base of theoretical analysis aiming at specific engineering problems [5]. But the general methods of analysis are very difficult for the stability problem of ground and ground building in mountains of undulating ground surface [6, 7].

FLAC is mainly applied to simulate the mechanical deformation of rock and the situation which soil and rock and soil reach the yield limit after the plastic flow generated. The adopted explicit Lagrangian fast algorithm, particularly suitable for simulation of large deformation and distortion, the results can become more accurate. FLAC provides a powerful ideal tool to solve geological problems [8]. Underground iron ore, ore in this Article are nearly parallel to the mountains, typical for plane strain problem. Using two-dimensional numerical simulation the mining effects can be obtained for underground mining to the upper mountain. Analyzing stability and law of mountain side rock and surrounding rock slope variation caused by underground mining in order to provide a theoretical basis to the project to reduce occurrence of secondary disasters. First, create mining model using FLAC, take a profile model at vertical ore body as shown in Fig.1. Boundary conditions imposed on the model and solved, the plastic changes for each unit displacement contour maps are gained, calculating the safety factor of mountain slope. Safety factor is calculated using strength reduction, the results shown in Fig.2, the factor of safety of slope = 2.12, slope is stable.

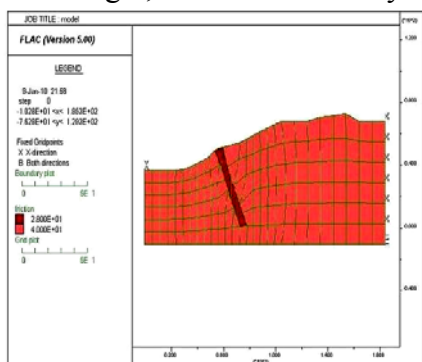


Fig.1 Calculation model

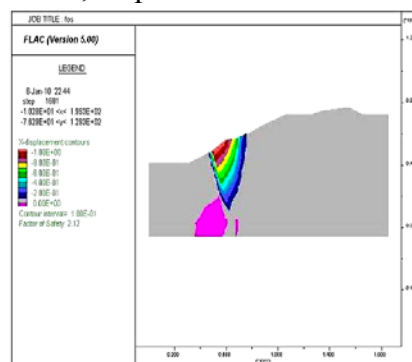


Fig.2 Calculation result

Analysis of deformation

On the hanging wall of the ore there exist power lines, erecting wire rod on the ground, the main impact of ground deformation is deformation of the ground slope, which requires calculating the size of the subsidence caused by the tilt, which is the need to find the sink deformation of the first derivative. Since the finite difference is divided according to a certain degree of mesh network, which

the numerical solution obtained of FLAC is the value of a number of discrete points. For discrete points, continuous function derivation formula is clearly not suitable, this time, the use of numerical differentiation method is more convenient and accurate [9].

From the numerical calculation, if the function $f(x)$ is given by the table, find the derivative of $f(x)$ at the junction point, often referred to as numerical differentiation. Replacing the derivative with difference is the simplest numerical differentiation formula. Show as Eq. 1.

$$f'(x_0) = \frac{f(x_0 + h) - f(x_0 - h)}{2h} + O(h^2) \quad (1)$$

Clearly, in theory, the smaller h is, the more precise differentiation approximation is. However, from view of calculation error point, the smaller the step size h is, the closer $f(x_0)$ and $f(x_0 + h)$ get. According to the error theory, subtracting two similar numbers will missing a large number of digits. To overcome these drawbacks, a natural idea is to find error asymptotic expansion of Eq.1, then using the extrapolation method to improve accuracy. According to Taylor formula:

$$f(x + h) = f(x) + hf'(x) + \frac{h^2}{2} f''(x) + \frac{h^3}{3!} f^{(3)}(x) + \dots \quad (2)$$

and

$$f(x - h) = f(x) - hf'(x) + \frac{h^2}{2} f''(x) - \frac{h^3}{3!} f^{(3)}(x) + \dots \quad (3)$$

Subtracting the Eq.2 and Eq.3, divided by $2h$, transposition:

$$f'(x) - \frac{f(x + h) - f(x - h)}{2h} = -\sum_{i=1}^{\infty} \frac{f^{(2i+1)}(x)}{(2i+1)!} h^{2i} \quad (i=1 \sim \infty) \quad (4)$$

Making $G(h)$ as second item of left hand of formula Eq.4, in the Richardson extrapolation method, taking $q=1/2$, the first derivative for extrapolation formula can be established:

$$\begin{cases} G_1(h) = G(h) \\ G_{m+1}(h) = \frac{G_m(h/2) - 4^{-m} G_m(h)}{1 - 4^{-m}} \end{cases} \quad (m=1, 2, \dots) \quad (5)$$

where: $f'(x) - G_{m+1}(h) = O(h^{2(m+1)})$

According to the formula Eq.5, if the step-size is appropriate, the higher accuracy can be obtained [10]. In Calculation, the step is from the test point spacing, obtaining the corresponding first derivative from $G_{m+1}(h)$ value, where $m=1$, extrapolating once. Ignore the high order infinitesimal; the corresponding $G_{m+1}(h)$ can be taken as a derivative. Vertical displacement contour of FLAC Simulation is shown in Fig. 2; taking 5 points near power lines and record the point value of the vertical displacement y , the history vertical displacement of the points by simulation are in Table 1. Calculated ground tilt deformation by numerical differentiation near poles can be seen in Table 2.

Table 1 vertical displacement value of ground

Point	Distance of points [m]	y displacement [m]
1	20	0.32
2	20	0.33
3	20	0.20
4	20	0.08
5	20	0.02

Table 2 First derivative of corresponding point

h [m]	formula G_1	G_1	formula G_2	G_2
h=40	$G_1 = \frac{f(x+h) - f(x-h)}{2h}$	0.0038	$G_2 = \frac{G_1(h/2) - 4^{-1} G_1(h)}{1 - 4^{-1}}$	0.0067
h/2=20		0.0060		

From the results of simulation and numerical differentiation calculation, maximum slope deformation of the ground location of power lines is 0.67%. According to "overhead transmission line operating procedures", the greatest maximum allowable tolerance of pole skew in the direction of horizontal lines is 1.0%, the calculation of the maximum slope of the high voltage line related to the direction of horizontal lines is less than 1.0%. Supply line is secure.

ore body under the hillside began to mine in December 1999, after more than 3 year of mining, ground deformation is not obvious, farm and trees grew normally, not being affected by mining; and ground deformation did not caused power line great deformation, it is running normally.

Conclusions

1) Stress and strain analysis to solve slope load, and then by using the slope stability of strength reduction is one of the more rigorous analysis. For an iron mine in Tangshan, choosing main ore body occurrence and topography first, selecting appropriate parameters and model, and then by using FLAC numerical simulation method the safety of mountain slope can be easily and efficiently demonstrated, which can provide quantitative analysis of safety assessment basis.

2) For the FLAC simulation results, further analysis and processing carry through by using numerical differentiation method. Many points nearby the point can be calculated using numerical differentiation method, by which more accurate results of ground deformation are obtained. Slope deformation size can be calculated by solving the first derivative, and ground curve deformation can be calculated by using second derivative.

References

- [1] Ji Wanlin. Collapse and hazards. (Seismological press, 1998)
- [2] HAN Fang, XIE Fang, WANG Jinan. Journal of University of Science and Technology Beijing. Vol. 28 (2006), p. 509
- [3] Wen-Xiu Li, Lei Wen, Xiao-Min Liu. International Journal of Applied Earth Observation and Geoinformation. Vol. 12 (2010), p. 175
- [4] SUN Chao, BO Jing-shan, LIU Hong-shuai. Journal of Jilin University. Vol. 39 (2009), p. 498
- [5] DAI Lan-fang, SU Sheng-xi, LI Wen-xiu. Rock and Soil Mechanics. Vol. 25 (2004), p. 1791
- [6] LI Wen-xiu. Application of Fuzzy Theory in mining and geotechnical Engineering. (Metallurgy industry press, 1998)
- [7] Jiang Chenguang, Gai Yusong, Liao Mingquan, He Yong, Liang Anbo. Chinese Journal of Rock Mechanics and Engineering. Vol. 22 (2003), p. 162
- [8] Huang Zhian, Zhang Yinghua, Li Shibo. Mining Research and Development. Vol. 26 (2006), p. 21
- [9] HUANG Zhi-an, LI Shi-bo, ZHAO Yong-xiang. Nonferrous Metals. Vol. 57 (2005), p. 95
- [10] Liu Xinsheng, Zhang Xiaodan, Wang Bingtuan. Tutorial of Numerical Computation Method. (Metallurgy industry press, 1998)