Study on the blasting vibration test of an open pit mine

Yutao Ma¹, Xiaopeng Shi¹ and Kaiming Jin¹
¹ BGRIMM Technology Group, Beijing, 102628, China

Abstract. Blasting vibration is one of the important factors affecting the stability of open-pit slope. It is necessary to evaluate and analyze its harmful effect and the influence on slope stability. Blasting vibration monitoring is an effective technical means. Through the fitting analysis of enough data obtained from key location monitoring, the site coefficient K value and attenuation index α value of the monitoring range were regressed to obtain the blasting vibration attenuation law, which provided the test basis for reducing or controlling the harm of blasting vibration, and provided the basis for blasting design to promote mine safety in production.

1. Introduction
Blasting has harmful effect on structure, such as blasting vibration, shock wave, flying rock, toxic and harmful gas, noise. Blasting vibration is affected by many factors such as source location, charge size, propagation medium, geological structure, which can be divided into three aspects: blasting source, propagation medium and acceptor. The material characteristics, structural characteristics and geological conditions of acceptor are internal conditions. Therefore, the harmful effect of blasting is a comprehensive phenomenon of structure itself and its external factors[1].

"Technical code for slope engineering of non coal open pit mine" (GB51016-2014) requires blasting vibration monitoring. "Blasting safety regulations" (GB6722-2014) has made corresponding provisions on the peak vibration velocity and main vibration frequency of different types of buildings or structures. The impact of blasting vibration on ground buildings or structures is mainly based on the ground particle vibration velocity corresponding to different main vibration frequencies[2].

2. Blasting vibration monitoring
Blasting vibration monitoring is mainly used to analyze the impact of blasting vibration wave on surrounding buildings and structures. According to the standard in the code, whether the vibration wave exceeds the standard is judged.

The monitoring system generally consists of sensors, monitors, storage and computers. The vibration parameters are divided into velocity, acceleration and displacement. Theoretically speaking, the vibration parameters of velocity, acceleration and displacement can be transformed into each other through integral and differential. However, due to the problems of bandwidth, noise, linear error, sensitivity and limitation of input and output amplitude, each instrument has a certain monitoring range and resolution. If the maximum amplitude measured by the instrument is 100 mm, the amplitude of 1 mm is close to the judgment error. Therefore, when the frequency component of large amplitude is measured, the frequency component of small amplitude has been masked by noise and error. Therefore, in the specific project monitoring, we should select the appropriate monitoring system and determine the reasonable measurement range according to the actual needs[4].

The measuring range and sensitivity of the instrument have a very important influence on whether the blasting vibration data can be obtained. It is necessary to pay attention to their minimum and...
maximum measurable ranges. For instruments with differential and integral transformation process, such as speedometer, it is necessary to pay more attention to its measurable range. There is a differential energy conversion process between the input and output. Under the action of the same input, the output size is directly proportional to the first power of frequency[6]. The relationship is as follows:

\[ V_m = 2\pi f A_m \]

\( V_m \), maximum displacement range.

\( A_m \), maximum displacement range of displacement pendulum.

\( f \), frequency.

The mini blast I blasting vibration monitoring system was adopted in this stage of blasting vibration monitoring, its technical indexes are listed in Table 1.

| Collection mode            | Full parallel synchronous acquisition |
|----------------------------|---------------------------------------|
| Input impedance            | 1MΩ/20pF                              |
| A/D                        | 24bit                                 |
| Sampling rate              | 10000 sps                             |
| Dynamic range              | 100dB                                 |
| Range                      | ±10V                                  |
| Vibration velocity         | 0.001 ~ 35 cm/s                       |
| Frequency response         | 5 ~ 300Hz                             |

3. Data analysis
According to the principle of "close dense and far sparse", the six measuring points were respectively arranged at the foot of each step according to the blasting position and the production situation on site, and they were respectively arranged in three different lithologic areas. From March 22 to 23, 2016, four times of monitoring were carried out as shown in the figure 1.
The monitoring data of each measuring point in the first test were summarized as follows:

| Channel name | Maximum (cm/s) | Maximum time (s) | Half wave frequency (Hz) | Main frequency (Hz) | Range (cm/s) | Sensitivity coefficient (V/m/s) |
|--------------|----------------|------------------|--------------------------|---------------------|--------------|--------------------------------|
| X direction  | 0.0329         | 1.193            | 66.0                     | 34.4                | 35.186       | 28.420                           |
| Y direction  | 0.2163         | 0.405            | 11.2                     | 10.5                | 36.062       | 27.730                           |
| Z direction  | 0.0264         | 0.241            | 9.9                      | 8.3                 | 35.298       | 28.330                           |

Table 2. Monitoring data of typical measuring point in the first test.

![Figure 2. Typical waveform of typical monitoring point.](image)

| Point | Vibration measurer | Peak velocity (cm/s) | Main vibration frequency (Hz) | Maximum time (s) | Three direction synthetic velocity (cm/s) |
|-------|-------------------|----------------------|-------------------------------|------------------|-----------------------------------------|
| 1     | 0560              | X 0.0130             | 18.1                          | 1.1822           |                                         |
|       |                    | Y 0.5246             | 18.1                          | 0.7054           | 0.5245                                  |
|       |                    | Z 0.0088             | 18.1                          | 1.1821           |                                         |
| 2     |                   | X 0.6296             | 25.5                          | 0.2570           | 0.7908                                  |

Table 3. Monitoring data of typical measuring point in the first test.
4. Data fitting analysis

4.1. Fitting of particle vibration velocity and horizontal velocity

For specific conditions of seismic wave propagation, the particle vibration velocity is mainly affected by the blasting charge and the distance between the measuring point and the blasting source. The mathematical relations between the peak vibration velocity of particle and charge, distance, site coefficient $K$ and attenuation index $\alpha$ are as follows\[7\]:

$$V = K \left( \frac{Q^{1/3}}{R} \right)^\alpha = K \rho^\alpha$$

(1)

$V$, Particle peak vibration velocity, cm/s. Take the maximum value of three component data;
$Q$, Explosive quantity, it is the total charge when blasting at the same time, millisecond delay blasting is the maximum charge, kg;
$R$, Distance between measuring point and center of explosion source, m;
$K$, Site coefficient, it is related to rock properties and blasting methods;
$\alpha$, Seismic wave attenuation index, it is related to geological conditions;
$\rho$, Proportional dose, $\rho = \frac{Q^{1/3}}{R}$.

Because $V$ and $\rho$ are not linear in the above attenuation formula, it is necessary to convert the formula into a linear relationship in order to get the corresponding $K$ and $\alpha$ values. Take logarithm on both sides of the formula to obtain the following linear form:

$$\log V = \alpha \log \rho + \log K$$

(2)

When the available data are sufficient, the above equation can be regressed by the least square method \[8\]. For $n$ groups of monitoring data:

$$\log K = \frac{\left[ \sum (1g \rho \cdot 1g V) \times 1g \rho - \Sigma 1g V \times \Sigma (1g \rho)^2 \right]/\left[ (\Sigma 1g \rho)^2 - \Sigma (1g \rho)^2 \right]}{\left[ (\Sigma 1g \rho)^2 - \Sigma (1g \rho)^2 \right]}$$

(3)

$K$ and $\alpha$ are obtained as follows:

$$K = 10^{\log K}$$

(4)

$$\alpha = \frac{\left[ \sum 1g \rho \times 1g V - \Sigma (1g V \cdot 1g \rho) \right]/\left[ (\Sigma 1g \rho)^2 - \Sigma (1g \rho)^2 \right]}{\left[ (\Sigma 1g \rho)^2 - \Sigma (1g \rho)^2 \right]}$$

(5)
After eliminating obvious data noise, $K$ and $\alpha$ were fitted: $K=54.28$, $\alpha=1.46$. The attenuation law of blasting vibration particle vibration velocity within the monitoring area was obtained as follows:

$$V = 54.28 \times \left( \frac{Q^{1/3}}{R} \right)^{1.46}$$  \quad (6)

Based on the above fitting data of particle vibration velocity and horizontal velocity, the attenuation law of particle horizontal vibration velocity was obtained as follows:

$$\lg V = 1.73463 + 1.45804 \times \lg \rho$$

$$\lg V = 1.45224 + 1.2894 \times \lg \rho$$

4.2. Main vibration frequency fitting

The basic form of the relationship between the main vibration frequency of blasting vibration and the peak value of particle vibration velocity is as follows:
\[ \frac{f_R}{V} = k \left( \frac{Q^{1/3}}{R} \right)^{a} \]  

The formula shows that the main vibration frequency is related to the proportional charge and the proportional velocity. Under different blasting conditions, the particle velocity peak value at the same distance may be quite different. The peak value of particle velocity is the direct reflection of geological conditions, medium properties and site conditions. The fitting formula for the main vibration frequency of open-pit deep hole blasting is given in the implementation manual of blasting safety regulations.

Based on this test, fitting the relationship between the main vibration frequency of blasting vibration and the peak value of particle vibration velocity is of great significance to predict the main vibration frequency by using the peak value of particle vibration velocity, and has a direct role in analyzing the impact of blasting vibration on slope stability.

\[ \lg(f_R/V) = 1.03957 - 1.96302 \times \lg(\frac{Q^{1/3}}{R}) \]

![Figure 5. Frequency fitting straight line.](image)

If \( y = \frac{f_R}{V} \), \( a = \log k \), \( b = a \), \( x = \log \left( \frac{Q^{1/3}}{R} \right) \), Then formula (8) can be transformed into a linear equation of one variable:

\[ y = a + bx \]  

The regression analysis results are shown in Fig. 5, and the main vibration frequency formula obtained by fitting was as follows:

\[ f = 10.95 \times \left( \frac{\sqrt[3]{Q}}{R} \right)^{-1.96} \]  

4.3. Application of monitoring results

According to the requirements for blasting vibration of open pit mine in technical code for slope engineering of non coal open pit mine (GB51016-2014) and other national standards, it was suggested to use formula (6) to guide each blasting design. The design shall meet the following conditions:

During blasting operation, the allowable vibration velocity at the foot of slope shall be taken as the warning index, and the allowable vibration velocity of working slope stability shall be determined according to the table below.
Table 4. Allowable vibration speed.

| Risk level of slope landslide | Slope stability coefficient | Allowable vibration velocity (cm/s) |
|-------------------------------|----------------------------|-----------------------------------|
| 1                             | F<1.05                     | controlled blasting               |
| 2                             | 1.05≤F<1.1                 | 22~28                             |
| 3                             | 1.1≤F<1.3                  | 28~35                             |
| 4                             | 1.3 ≤F                     | 35~42                             |

During the blasting of open-pit slope, the vibration velocity of the particle on the side slope should be controlled to make it less than 24cm/s.

5. Conclusion

The blasting vibration monitoring system was used to test the blasting vibration for four times according to the blasting vibration measuring points set according to the specifications, and the attenuation law of blasting vibration was obtained by fitting. The conclusions were as follows[3][5]:

The harmful effect of blasting vibration was not only related to blasting parameters and blasting mode, but also closely related to regional geological structure and rock mass structure. Therefore, the influence mechanism and degree of different places were different, and each place needed specific analysis.

The blasting distance and the maximum blasting intensity were often determined by the blasting distance. Therefore, in blasting production, when the distance between the surrounding site and the slope was fixed, the blasting vibration must be controlled by controlling the maximum charge of a single section to prevent the superposition effect of blasting vibration. In order to reduce the blasting vibration as much as possible, multi-stage detonators were used for blasting operation.

By analyzing and fitting the blasting vibration data, the attenuation law formula of blasting vibration in the monitoring area of the copper mine was obtained, this formula can be used to guide the blasting design of the copper mine.

\[ V = 54.28 \times \left( \frac{Q^{1/3}}{R} \right)^{0.46} \]

Production blasting design must meet the requirements of national standards for blasting vibration particle velocity of open-pit mine, so as to ensure the slope stability of open-pit stope and meet the requirements of safety production.

Acknowledgments

This research was financially supported by the National Key Research and Development Project of China (2017YFC0602904).

References

[1] Liu, D.Z., Yang, S.C. (2003) Practical Manual for Engineering Blasting. Metallurgical Industry Press, Beijing.
[2] Wang, X.G., Yu, Y.L., Liu, D.Z. (2004) Implementation Manual of Blasting Safety Regulations, People's Communications Press, Beijing.
[3] Tian, Y.S., Wang, X.G., Yu, Y.L. (2004) Response of site conditions to blasting vibration of buildings. Engineering Blasting, 10: 65-68.
[4] Chen, B.L. (2004) Test and analysis on blasting vibration of mine slope. Mining Express, 11: 13-15.
[5] Wang, X.G., Yu, Y.L. (2001) Several problems on safety criterion of blasting vibration. Engineering Blasting, 7: 89-92.
[6] Zong, Q., Wang, H.B., Zhou, S.B. (2008) Study on monitoring and control technology of blasting seismic effect. Journal of Rock Mechanics and Engineering, 27: 942-944.
[7] Peng, W., Jiang, X.G., Shi, X.P., Sun, H.F. (2012) Study on blasting vibration test of Zhouyoufang Iron Mine. Nonferrous Metals (mine part), 1: 48-50.
[8] Shi, X.P., Wu, C.P. (2014) Monitoring and control of blasting vibration effect in an iron mine. Modern Mining, 2: 128-131.