Research on Elevation Effect of Blasting Vibration in Step Slopes

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Abstract: Vibration caused by blasting is an important factor affecting the safety of blasting production and the stability of slope rock mass. This paper conducts on-site blasting vibration measurement and concrete model blasting vibration test. It is concluded that the elevation has both amplification and attenuation effects on blasting vibration. And the attenuation effect is dominant, and the amplification effect is supplemented. In the region where the elevation amplification effect appears obvious, the magnification increases with the increase of the elevation. The law of change is first increased and then decreased.

1. Introduction

In large open pit mines, the blasting scale is generally large, and the blasting operations are also frequent. Therefore, the vibration caused by blasting is an important factor affecting the safety of blasting production and the stability of slope rock mass. The accurate prediction of blasting vibration is an important work in the practice of mine blasting production, and it is also an important issue in the research field of blasting vibration control technology.

At present, with the further study of blasting vibration in blasting of open pit mines, people gradually realize the elevation effect of blasting earthquakes. Guo Xuebin et al.\textsuperscript{[1]} analyzed the blasting vibrations elevation amplification effect of different types of slopes, according to different blasting vibration test examples. Tan Wenhui et al.\textsuperscript{[2]} explored the basic laws of the influence of height on k and a through on-site measurement, and studied the effect of slope elevation on blasting vibration. Havenith et al.\textsuperscript{[3]} performed finite element numerical analysis on the slope of the Anaaevo rock slide, and found that the amplification of the vibration wave and the localization of the strain have a great relationship. Chen Ming et al.\textsuperscript{[4]} used finite element numerical simulation to study the elevation amplification effect of rock slope excavation blasting. Rao Yunzhang et al.\textsuperscript{[5]} used SPSS software to calculate the attenuation law of blasting vibration velocity. Hu Jianhua\textsuperscript{[6]} used multiple linear regression methods to analyze the vibration attenuation law under single-hole blasting conditions. Lu Wenbo et al.\textsuperscript{[7]} improved the peak vibration attenuation formula of particles based on various stress wave theory. Lu Tao et al.\textsuperscript{[8]} used the nonlinear fitting method to study the relevant parameters of the blasting vibration attenuation formula.

Although people have some research on the blasting vibration elevation effect, they are basically studied by on-site measurement, numerical simulation, or Sa's formula correction. In view of this, this paper will study the relationship between the blasting vibration elevation effect and the horizontal
distance from the explosion source and step height through the combination of on-site blasting vibration measurement and concrete model blasting vibration test.

2. Open-pit mine blasting vibration measurement

2.1 Blasting vibration test data monitoring

Jinou Coal Mine is located near Xilai Peak, Qipanjing Town, Etuoke Banner, Erdos City, Inner Mongolia. It is an open-pit mine with a high level of mechanization. The mine adopts step mining, deep hole differential blasting, and step height is 8-10m. The TC-4850 blasting vibrometer produced by Chengdu Zhongke Measurement & Control Co., Ltd. was used in this test. Since October 2018, more than 20 blasting vibration test experiments have been carried out. The data obtained from monitoring on October 18 are shown in Table 1.

| Date  | Single dose (Kg) | Measuring point number | Distance from the source (cm) | Particle peak velocity (cm/s) |
|-------|------------------|------------------------|-------------------------------|-------------------------------|
|       |                  |                        | horizontal | vertical |                                |
| 10.18 | 160              | 1                      | 80    | 0       | 4.021                           |
|       |                  | 2                      | 111   | 0       | 2.123                           |
|       |                  | 3                      | 133   | 0       | 2.024                           |
|       |                  | 4                      | 142   | 25      | 3.157                           |
|       |                  | 5                      | 162   | 25      | 1.092                           |
|       |                  | 6                      | 198   | 25      | 1.243                           |
|       |                  | 7                      | 210   | 60.8    | 1.585                           |
|       |                  | 8                      | 241   | 60.8    | 1.159                           |
|       |                  | 9                      | 252   | 60.8    | 1.145                           |
|       |                  | 10                     | 344   | 118     | 0.887                           |
|       |                  | 11                     | 354   | 118     | 0.768                           |
|       |                  | 12                     | 393   | 165     | 0.223                           |

2.2 Analysis of test results

The data in Table 1 is collated, and the relationship between the peak velocity of the measuring point and the horizontal distance and elevation difference from the explosion source is plotted by the origin data processing software, as shown in Fig. 1.

Fig.1 Distribution law of vibration velocity of slope measuring point

It can be seen from Fig. 1 that the overall vibration velocity gradually decreases with the increase of the horizontal distance, and the amplification effect appears at the individual measurement points. Compared with the measuring point 3, the measuring point 4 has a horizontal distance and an elevation difference greater than the measuring point 3, but the vibration speed of the measuring point 4 is greater than the vibration speed of the measuring point 3, and an amplification effect occurs.
Comparing the measuring point 6 with the measuring point 7, the horizontal distance and the elevation difference of the measuring point 6 are larger than the measuring point 7, but the vibration speed of the measuring point 7 is greater than the vibration speed of the measuring point 6, and the amplification effect occurs, but the amplification effect is not very high obvious. When the measuring point 12 is compared with the measuring point 11, the elevation of the measuring point 12 is larger than the measuring point 11, but the vibration speed of the measuring point 12 is significantly smaller than the vibration speed of the measuring point 11. It shows that the elevation amplification effect exists, and the amplification effect is not infinitely magnified, that is related to the height of the step.

3. Concrete model blasting vibration test

3.1 Model geometric parameters
The test model uses concrete blocks of stepped shape and rectangular parallelepiped shape. The specific dimensions of the concrete model are shown in Figure 2, Figure 3, Figure 4, Figure 5, Figure 6. The model is made of water, ordinary silicate 32.5 (R) cement and fine sand at a water-cement ratio of 0.45:1:3. The uniaxial compressive strength of the model is 34.32MPa. The density is 2156.44 Kg/m³.

3.2 Blasting test design
This test designed four different heights (30cm, 40cm, 50cm and 60cm) step model blasting test and flat model blasting test. The detonation point of the flat model is set at 40cm from the right boundary, and the position is centered before and after, as shown in Figure 7. The starting point of the step model is set at the lower step, 40 cm from the right boundary, and the position is centered before and after, as shown in Figure 8. Each model is arranged with one blasthole, the blasthole depth is 18cm, and the tamping height is 12cm. Only one 8# instant detonator is installed in each blasthole. The model blasting test used the TC-4850 blasting vibrometer for the blasting vibration test. All sensors X-axis is facing the source. The arrangement of measuring points is shown in Figure 7 and Figure 8.
3.3 Test results and analysis

After the explosion, the concrete model was basically intact, and it did not suffer too much damage, and did not affect the position of the measurement point. After the blasting of each group of tests, the results are shown in Table 2.

Table 2 Model test particle peak vibration velocity results

| Model number | Measuring point number | Horizontal distance (cm) | Vertical distance (cm) | Vibration speed (cm/s) |
|--------------|------------------------|--------------------------|------------------------|------------------------|
| 1-0          | 1                      | 146.8                    | 15                     | 1.596                  |
|              | 2                      | 120                      | 15                     | 2.112                  |
|              | 3, 4                   | 90                       | 15                     | 2.412                  |
|              | 5                      | 60                       | 15                     | 5.412                  |
|              | 6, 7                   | 30                       | 15                     | 13.897                 |
|              | 9                      | -26.8                    | 15                     | 15.534                 |
| 1-1          | 1                      | 146.8                    | 75                     | 1.289                  |
|              | 2                      | 120                      | 75                     | 1.658                  |
|              | 3                      | 93.2                     | 75                     | 2.512                  |
|              | 4                      | 86.8                     | 45                     | 2.601                  |
|              | 5                      | 60                       | 45                     | 4.005                  |
|              | 6                      | 33.2                     | 45                     | 5.987                  |
|              | 7                      | 26.8                     | 15                     | 15.234                 |
|              | 9                      | -26.8                    | 15                     | 16.672                 |
| 1-2          | 1                      | 146.8                    | 95                     | 1.196                  |
|              | 2                      | 120                      | 95                     | 1.489                  |
|              | 3                      | 93.2                     | 95                     | 2.906                  |
|              | 4                      | 86.8                     | 55                     | 2.495                  |
|              | 5                      | 60                       | 55                     | 3.122                  |
|              | 6                      | 33.2                     | 55                     | 5.012                  |
|              | 7                      | 26.8                     | 15                     | 18.165                 |
|              | 9                      | -26.8                    | 15                     | 17.123                 |
| 1-3          | 1                      | 146.8                    | 115                    | 1.102                  |
|              | 2                      | 120                      | 115                    | 1.315                  |
|              | 3                      | 93.2                     | 115                    | 3.153                  |
|              | 4                      | 86.8                     | 65                     | 2.293                  |
|              | 5                      | 60                       | 65                     | 3.078                  |
|              | 6                      | 33.2                     | 65                     | 4.231                  |
|              | 7                      | 26.8                     | 15                     | 16.012                 |
|              | 9                      | -26.8                    | 15                     | 14.231                 |
| 1-4          | 1                      | 146.8                    | 135                    | 1.002                  |
|              | 2                      | 120                      | 135                    | 1.212                  |
From the data in Table 2, the distribution law of the vibration velocity with the horizontal distance from the blasting source can be plotted as shown in Fig. 9. It can be seen from Fig. 9 that the overall vibration velocity gradually decreases with the increase of the horizontal distance, and the amplification effect appears at the individual measurement points. In the measuring points with the same horizontal distance, the vibration velocity of the flat model is slightly higher than the vibration velocity of the step model, except for the region where the elevation effect is obvious. When the measuring point 6 is compared with the measuring point 7, the appearance of the elevation difference causes the vibration speed to decrease rapidly. The areas where the elevation effect is more obvious are mainly concentrated on the measurement point 3. The curve of the magnification of measuring point 3 with the elevation difference is shown in Fig. 10. The elevation is increased from 30cm to 60cm, and the magnification is increased first and then decreased. When the elevation difference is 50 cm, the magnification reaches a maximum of 1.375.

4. Conclusion
(1) On the step slope of the positive height difference, the vibration peak velocity generally shows the attenuation trend. Under a certain horizontal distance and elevation difference, the particle velocity is magnified.

(2) Overall, the velocity of the step model is lower than that of the flat model when the distance from the source is equal, and the area where the elevation amplification effect is obvious is excluded.

(3) The elevation has both amplification and attenuation effects on the blasting vibration, and the attenuation effect is dominant, and the amplification effect is supplemented.

(4) In the region where the elevation amplification effect appears obviously, as the elevation difference increases, the magnification increases first and then decreases.

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