Study on the Double-Difference Hypocenter Locations based on the envelope stations underground mines

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Abstract. At present, the micro-seismic monitoring system mostly adopts the mean velocity model and the absolute location method and the focal location error is large, which seriously affects the later processing interpretation, safety evaluation, and roadway support design. To tackle this problem, this paper adopts the absolute locating method based on the average velocity model under the envelope stations, the absolute positioning method is used to obtain the initial positioning result, and then we apply distance-weighting scheme for the monitoring station and the key monitoring area. Furthermore, the Double-Difference Hypocenter Locations is used for relocation. Finally, the mine site data is used to carry out the IMS micro-seismic monitoring system positioning results and the double-difference positioning results benchmarking, and the linkage analysis with the mine site mining process. The results show that the relocation results obtained by the Double-Difference Hypocenter Locations based on the envelope stations are more reliable and more accurately match the area where the hazard source is located during mining.

Keywords. Micro-seismic monitoring technique; HypoDD; Envelope stations.

1. Introduction
At present, domestic and foreign mines mainly adopt the micro-seismic monitoring system provided by the Institute of Mine Seismology (IMS) or the Engineering Seismology Group (ESG). The 3-D envelope is formed by the monitoring station underground mine, IMS adopts the absolute locating method based on the average velocity model under the envelope stations in the actual application, resulting in the focal location error is large, which seriously affects the later processing interpretation, safety evaluation, and roadway support design.

The high precision location of micro-seismic events rely on the suitable positioning method[1-3]. The micro-seismic positioning method was originally derived from the natural seismic positioning method. The absolute positioning method is performed by solving the least-squares objective function established by the residual error between the simulated initial arrival time and the actual initial arrival time[4-5]. On this basis, various linear methods are established, such as joint positioning method and relative positioning method [6-7]. The common propagation path effect between the source and the station can be eliminated by the Double-Difference Hypocenter Locations (HypoDD), so it is less
dependent on the velocity model, which has been widely used in natural seismic location[8-10]. The accuracy of HypoDD is high, it is an important means to study the characteristics of seismic activity in specific areas and the spatial distribution of active faults. The absolute positioning method is the most widely used both in natural seismic and micro-seismic location, however, there are few studies on the HypoDD method based on the envelope stations underground mines.

In this paper, we apply distance-weighting scheme for the monitoring station and the key monitoring area. Furthermore, the HypoDD method is used for relocation, and the mine site data is used to carry out the IMS micro-seismic monitoring system positioning results and the double-difference positioning results benchmarking. Finally, we finish the linkage analysis with the mine site mining process.

2. Brief mathematical theories of Double-Difference algorithm

The arrival time $T$ can be written as:

$$T^i_k = \tau^i + \int_{u ds}$$

Where, $i$ is an micro-seismic event, $k$ is a seismic station, $\tau$ is the origin time of event $i$, $u$ is the slowness field, and $ds$ is an element of path length, $T$ is expressed using ray theory as a path integral along the ray.

The Double-Difference Hypocenter Locations (HypoDD) can be written as:

$$dr_{k}^{ij} = (t_{k}^{i} - t_{k}^{j})^{obs} - (t_{k}^{i} - t_{k}^{j})^{cal}$$

Where, $t_{k}^{i}$ is the time takes to spread from an micro-seismic event $i$ to an micro-seismic station $k$, similarly, $t_{k}^{j}$ is the time takes to spread from an micro-seismic event $j$ to an micro-seismic station $k$, $dr_{k}^{ij}$ is the residual between observed and calculated differential travel time between the two events $i$ and $j$, we define this equation as the double-difference. we can use either phases with measured arrival times where the observables are absolute travel times, $t$, or cross-correlation relative travel-time differences. It can be assumed that their ray paths to the same station are almost the same when the source positions of the two micro-seismic events are close together. The hypothesis of a constant slowness vector is valid for events that are sufficiently close to each other, but breaks down in the case where the events are farther apart.

3. Results and discussion

3.1. The micro-seismic monitoring system based on the envelope stations

The Pulang Copper Mine is located in the eastern part of Shangri-La County, Diqing Tibetan in the northwestern part of Yunnan Province. The micro-seismic monitoring system in the Pulang Copper Mine is established for analyzing the caving law of the caving roof, the structural stability, the pillar stress and roadway deformation of the bottom underground mine at 3720m and 3736m. The micro-seismic monitoring system provided by the Institute of Mine Seismology (IMS), the 3-D envelope is formed by the monitoring station underground mine as shown in the figure1. 20 micro-seismic sensors are arranged around the 3,720 m level underground mine.
3.2. Analysis of micro-seismic positioning results

In order to compare the quality of positioning results carried out by the IMS micro-seismic monitoring system and HypoDD, micro-seismic data collected continuously by the micro-seismic monitoring system of the Pulang copper mine for about one month, the mine site data is used to carry out the IMS micro-seismic monitoring system positioning results and the double-difference positioning results benchmarking. The sensor layout is shown in Figure 1. The influence of wave velocity inhomogeneity caused by anisotropy of rock mass is not considered, the uniform velocity model is obtained by the active source technology of the IMS system, $V_p = 4700 \text{ m/s}$, $V_s = 2700 \text{ m/s}$. Distance-weighting scheme for the monitoring station and the key monitoring area are applied in relocating. Positioning results for about one month collected by the micro-seismic monitoring system, micro-seismic events in the area around 3720m and 3736 m of the dislocation area in disturbed belt underground mine were delineated. The positioning results benchmarking carried out by the IMS micro-seismic monitoring system and the relocation results by HypoDD are as shown in the figure 2 and 3. The positioning results are displayed in the form of small spheres, where the color of the spheres represents the time of micro-seismic events and the sequence of micro-seismic events from blue to red indicates the sequence of micro-seismic events. Horizontal section comparison chart of positioning results are as shown in the figure2, the initial positioning results carried out by the IMS micro-seismic monitoring system are on the left, the relocation results by HypoDD are on the right. Vertical profile comparison chart of positioning results are as shown in the figure 3, the initial positioning results carried out by the IMS micro-seismic monitoring system are on the left, the relocation results by HypoDD are on the right, the green line is 3720m and the red line is 3736m.

Figure 1. The 3-D envelope is formed by the monitoring station underground mine.
Figure 2. Horizontal section comparison chart of positioning results, the initial positioning results carried out by the IMS micro-seismic monitoring system are on the left, the relocation results by HypoDD are on the right.

Figure 3. Vertical profile comparison chart of positioning results, the initial positioning results carried out by the IMS micro-seismic monitoring system are on the left, the relocation results by HypoDD are on the right, the green line is 3720m and the red line is 3736m.

According to the location results of the IMS micro-seismic monitoring system, the micro-seismic events are scattered around 3720m and 3736m underground mine, and there is no obvious distribution rule in the horizontal sections, either in the vertical sections. But, most of micro-seismic events relocated by HypoDD are concentrated on the roof above 3736m underground mine. The horizontal section shows that the events are more concentrated on the working face, while the vertical section shows that the events are concentrated on the roof above the working face, with a columnar distribution. The caving roof is mainly distributed in the height direction between 3736 and 3850m, and its height range has a high consistency with the monitoring results of borehole TV on site. In the horizontal direction, it is mainly distributed near the accumulation trough, bottom drawing and tunneling working face. According to statistics, the flying point of IMS location is about 10.5%, the flying points of HypoDD location is about 3%, and the proportion of flying points beyond the working area decreased significantly by relocation.
The results of linkage analysis with the mine site mining process show that the relocation results obtained by the HypoDD method based on the envelope stations are more reliable and more accurately match the area where the hazard source is located during mining. Therefore, in the complex rock mass environment where the surrounding rock of ore body is broken, anisotropic and the energy decaying rapidly, the HypoDD method can eliminate the path effect and reduce the positioning error caused by the uneven wave velocity, further improve the positioning accuracy of micro-seismic events in the anisotropic rock environment.

4. Conclusion
According to the study on the HypoDD method based on the envelope stations underground mines, combined with results of the actual micro-seismic data underground mines, the following conclusions are drawn:

(1) The focal location error is large with the mean velocity model and the absolute location method, there are even flying points beyond the working area underground mine.

(2) The HypoDD method improve the positioning accuracy of micro-seismic events in the anisotropic rock environment, it can eliminate the path effect and reduce the positioning error caused by the uneven wave velocity.

(3) The relocation results obtained by the HypoDD method based on the envelope stations are more reliable and more accurately match the area where the hazard source is located during mining.

Acknowledgments
This work was financially supported by national key research and development plan of china(2017YFC0804402) and research plan of BGRIMM technology group (JTKJ1816).

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