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Research Article

Microseismic Monitoring, Positioning Principle, and Sensor Layout Strategy of Rock Mass Engineering

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Microseismic monitoring technology can start from the most initial stage of rock deformation and track and monitor the progressive failure process of rock mass from the fracture of rock blocks to the instability of rock mass. Thus, the scientific nature of monitoring work is greatly promoted, and the accuracy and advance of the prediction of engineering and geological disasters are improved. In this paper, the fracture and instability of rock can be analyzed by analyzing the microseismic signals produced by rock failure; The location of microseismic source can be determined by multipoint synchronous data acquisition to determine the time when each sensor (at least 5) receives microseismic signals; Combined with practical engineering experience for underground engineering in growth, heading tunnel, put forward only sensor arrangement to take mobile, follow the semienclosed layout network. We hope to give some reference to the researchers who are concerned with microseismic monitoring technology.

1. Introduction

In recent years, microseismic technology has been gradually used as an early warning method for underground engineering safety monitoring and has conducted research on related microseismic activities. Germany has established the first mine microseismic station in the world [1]. The application of microseismic monitoring technology in several mines in Australia has achieved good results [2, 3]. In the research and application of microseismic monitoring technology in China, Tang et al. [4–7] have made some progress.

From the application of microseismic monitoring, it can be seen that microseismic monitoring has changed from "unrealistic expectations" to an organic part of the mining process and has high positioning accuracy, which has become the main technical means of mining-induced dynamic disaster monitoring. Using the microseismic monitoring system, sensors are deployed in the mine where microseismic activity occurs to detect the stress wave emitted by microfracture, determine the location of seismic wave, and give the strength and frequency of seismic activity. Through the distribution position of microfracture obtained by microseismic monitoring, the potential rock burst activity law can be judged, and the prediction can be realized by identifying the law of mine rock burst activity.

Therefore, based on the microseismic monitoring, combined with the latest scientific and technological achievements of other disciplines, it is an important research trend to fully understand and understand the geotechnical engineering disasters, especially the quantitative monitoring and prediction. In recent years, microseismic monitoring has been gradually carried out in geotechnical engineering such as petroleum, water conservancy, civil engineering, and mining, and valuable experience has been obtained. Some scholars at home and abroad have adopted the method of microseismic monitoring to study the fracture and instability of rock (coal) within the three-dimensional overlying rock spatial structure of mine stope and achieved certain results [8]. However, most of the tools and methods used in mining microseismic monitoring are transplanted from the earth

earthquake, and the microseismic monitoring technology is still in the primary stage of application in China, resulting in its accuracy cannot meet the requirements of precise positioning of mine rock mass fracture, and also lack of fast microseismic positioning and tracking monitoring required by microearthquake for accurate positioning of mine rock mass fracture. It will be the key and research focus of microseismic monitoring technology to explain and deal with mining problems in the future.

The development and application of modern mine high-precision microseismic monitoring technology began in the mid-1980s. It mainly uses the high-precision microseismic monitoring technology to evaluate the short-term and medium-term disaster of the microearthquake in the rock mass caused by mining, so as to reduce the casualties and equipment damage caused by the abovementioned disasters. The principle of this technology is to obtain the location, size, energy, inelastic microseismic body strain, and focal mechanism of microseismic events by monitoring the stress wave generated by rock fracture in the process of stress redistribution caused by mining activities and then calculate the changes of stress field, displacement, and rheological parameters in rock mass, so as to judge the stability of rock mass. Microseismic monitoring technology can start from the initial stage of rock mass deformation, track and monitor the progressive failure process from the unit rock block fracture to the whole rock mass instability, which greatly promotes the scientific of monitoring work and improves the accuracy and advance of engineering and geological disaster prediction. Compared with the traditional rock mass stability monitoring technology, the biggest advantage of microseismic monitoring technology is that it can accurately give the spatial location of rock mass instability and make disaster prediction in advance. Therefore, technical and management personnel can have sufficient time to take emergency measures to avoid or greatly reduce the loss of life and property and improve the safety of staff and the public.

In this paper, the principle of microseismic monitoring and positioning is introduced, and the composition of the ESG microseismic monitoring system and the layout strategy of sensors are introduced in detail combined with practical engineering experience. It is hoped that this paper can provide some reference for the relevant personnel who study microseismic monitoring technology.

2. Microseismic Monitoring

In the study of rock mechanics, one of the most important problems is the instability mechanism of coal and rock mass. The macroscopic failure of the rock mass is closely related to its internal microstructure and defects. In order to understand the instability mechanism of coal and rock mass, it is necessary to study the generation, propagation, and failure process of microcracks in rock from the microperspective of coal and rock mass fracture. However, there is no good research method for the generation and propagation of microcracks in coal and rock mass, which requires the help of some tools. At present, acoustic emission (microseismic) is a good tool to study the instability and fracture process of rock mass.

There are two conditions for the appearance of acoustic emission (microseism): first, the material is subjected to external load; second, the internal structure of the material is uneven or defective. Qin et al. and Yin [9, 10] analyzed the mechanism of acoustic emission; as shown in Figure 1, the acoustic emission signal is caused by four factors, namely, plastic deformation, phase transition, apparent effect, and fracture. Plastic deformation includes crack closure, twin deformation, and slip deformation due to the movement of displacement. Fracture includes fracture of cement or inclusion fracture and the formation or propagation of cracks. Based on the above mechanism, acoustic emission can be used to provide dynamic information for the microdeformation and cracking of materials and the occurrence and development of cracks. Acoustic emission source is often the source of material catastrophic damage. Because the activity of acoustic emission often appears long before the material is destroyed, according to the characteristics and intensity of these acoustic emissions, we can not only infer the current state of the acoustic emission source but also know its formation history and predict its development trend, so as to carry out condition monitoring and fault diagnosis.

Rock failure under the action of stress produces microseismic (acoustic emission), by arranging multiple sets of sensors in a certain area and collecting microseismic data in real-time, the location of fracture can be determined after data processing and displayed in three-dimensional space. Compared with the traditional technology, microseismic location monitoring has the characteristics of long-distance, dynamic, three-dimensional, and real-time monitoring and can also determine the rupture scale and property according to the source condition. This technology is developed rapidly on the basis of the rapid development of computer and data acquisition technology in recent years.

2.1. Principle of Microseismic Monitoring. The microseismic mechanism itself is a nonlinear problem [11], which is related to the dynamic fracture of materials and is very complex. According to different types of rock and concrete samples under different conditions, the basic characteristics of rock deformation and failure under tensile, compression, and bending loads are studied by using the acoustic emission technology of rock, to establish the correlation between acoustic emission signal and rock properties. Study the mechanism of acoustic emission of rocks, the relationship between acoustic emission signals, and the process of rock breaking, and try to obtain the rules of acoustic emission in the process of rock failure. Then, combine with field test data or experience and judge for inner conditions of rock mass in mines. Laboratory results often differ from actual results because of the scale effect and condition differences. This aspect uniaxial test has done the most, the results are also the most, so that the understanding of this aspect gradually deepened. Due to the complex diversity of rock materials, many experiments have been done by scholars at home and abroad. These experimental processes showed that the occurrence of AE was roughly similar, but varied according to

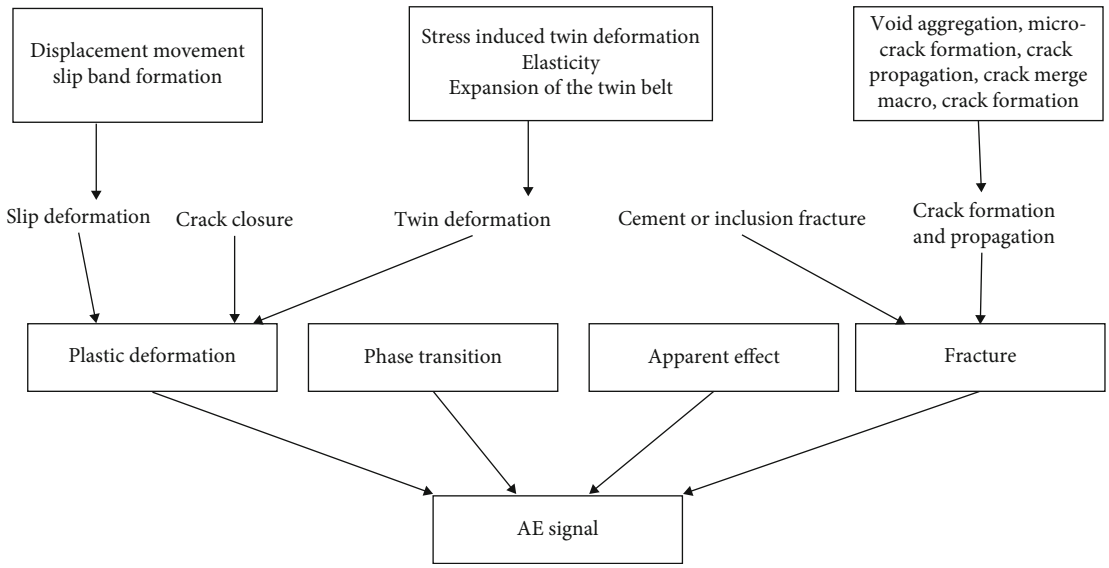


Figure 1: AE (MS) signal generation mechanism.

different situations. Most of the research conclusions are similar, but in some cases, the conclusions vary widely or even widely, reflecting the discreteness and huge differences of AE rules of different rock materials. These studies on the brittle failure mechanism of rock based on acoustic emission characteristics reveal the development process of rock failure. Typical AE wave curves and sound emission events vary with stress-strain, as shown in Figures 2 and 3.

Generally speaking, rock failure caused by excavation activity of microseismic mechanics mechanism can be divided into the following four types, as shown in Figure 4:

(1) High vertical stress, low lateral pressure of shear failure (A class). This kind of stress environment mainly exists on the coal body in the front of the working face and on both sides of the goaf. The stress and stress difference are mainly determined by the mining depth and the movement law of the overburden roof structure

(2) High vertical stress, low lateral pressure of shear failure (B class). High levels of stress comes from the thick layers of hard rock layer (key) fracture before and after fracture in the rock mass structure of horizontal thrust tectonic stress or regional level

(3) In-layer and interlayer shear failure caused by bending moment during the subsidence of single or composite rock layers (Class C). Most of this damage occurs in the rock above the gob, but some occurs in the rock above and in front of the coal wall

(4) Tensile shear coupling produced tensile and shear failure (Class D). This type of damage mainly refers to the failure of the upper hardening of the thick hard rock near the coal wall first, and then the shearing of the full thickness. This kind of damage is more common in the shallow buried thick hard rock stope [12]

Among the above four mechanical mechanisms, the energy level, density, and monitorability of microseismic events are A > B > C > D in this order. In view of the complex geological stress conditions of coal mines, this classification provides a basis for judging whether geological disasters have occurred. The actual observation results show that the shear plane is the main form of sliding, and it first appears at one end of the sample and then forms the shear plane extending from one end and the inside to the other end, and finally, the shear plane breaks through and forms a unified sliding surface. Using microseismic technology to monitor the state of deep rock mass is an effective method.

Microseismic is essentially a process of continuous stress accumulation and intermittent release. In the larger mining scale, the formation and propagation of rock mass cracks will also produce microseisms. Fracture failure is basically divided into the following three stages: cracks or defects develop into nucleus; crack propagation; and fracture failure stage. At the tip of the slippage displacement field, due to obstacles in the slippage movement, stress concentration is generated; when the stress concentration reaches a certain limit, cracks are suddenly stretched and formed, resulting in microseisms. The phenomenon of microseismic is the process of energy release. After each energy release, the rock mass reaches a temporary equilibrium. After that, the energy continues to accumulate. When the rock mass cannot continue to absorb the elastic deformation energy (no load applied during the experiment), it means that the rock mass is already unstable and damaged.

The acoustic emission signal generated during the rock failure process is mainly due to the elastic waves of different frequencies excited by the rock fracture point (surface). The elastic wave propagates in the rock and is received by the acoustic emission probes fixed at different positions. At the same time, a lot of rock fracture information is also transmitted in the acoustic emission signal, and the acoustic emission signal is interpreted to obtain information, and the rock fracture and instability are analyzed with the help of this. For an acoustic emission signal is true, there is a lot of information comprising an acoustic emission signal, as shown in

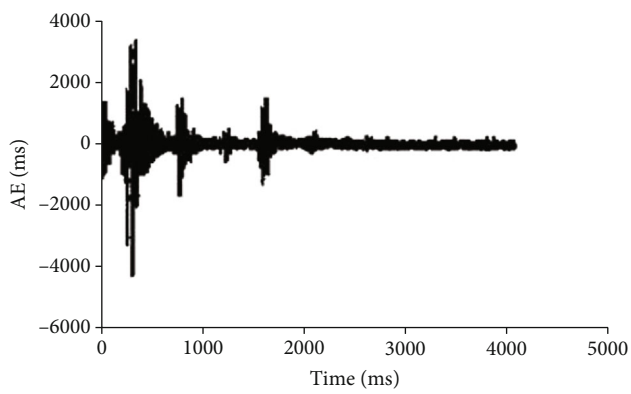


Figure 2: The typical AE wave curve.

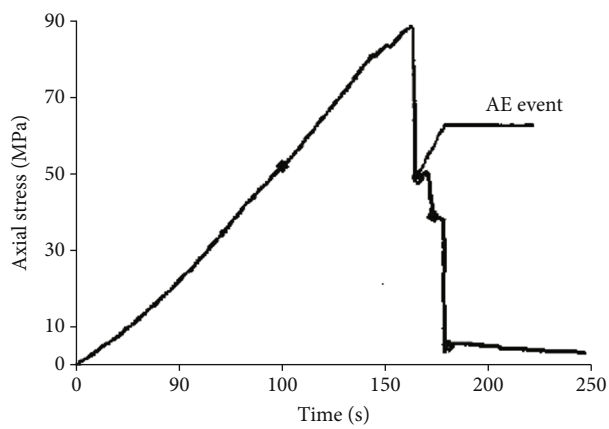


Figure 3: The variation of AE events with stress-strain.

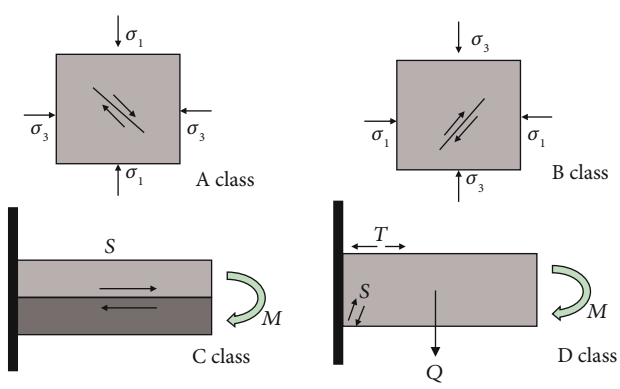


Figure 4: Mechanical mechanism of rock fracture resulting from excavation.

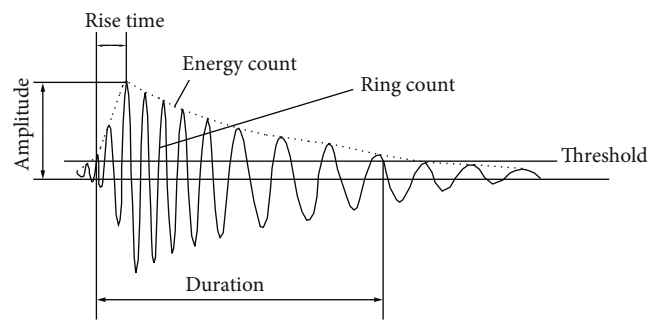


Figure 5: Characteristic parameter of burst signal.

Figure 5. This information is also called the characteristic parameter of acoustic emission.

When the energy accumulates to a certain critical value, it causes the generation and expansion of microcracks. The generation and expansion of microcracks is accompanied by the rapid release and propagation of elastic waves or stress waves in the surrounding rock mass. The release process of this elastic wave or stress wave is relative to larger-scale rock masses. Due to the high-frequency decay fast, the frequency of the detected signal is relatively low but the energy is large, usually in the range of 20 to 200 Hz, which is called microseismic; sometimes, for small-scale rock samples, the frequency of the detected wave is usually greater than 200 Hz and the energy is very small. It is called Acoustic Emission (AE). The properties of the two are the same in many aspects, and there is no very clear classification boundary. In fact, the real source signals of AE and MS are not available to people. What the laboratory or the field gets is the signal picked up by the detector. No matter in the laboratory or in the field, high-frequency and small-energy acoustic emission events are very dense, and data processing is more difficult. The signal parameters of microseismic events are as follows:

(1) Event counting, a local change of a material that generates a microearthquake becomes an MS event, which can be divided into the total number of events and the event rate, the former is the cumulative number and the latter is the number of AEs per unit time

(2) Event growth rate

(3) The number of ringing, that is, the number of MSs that exceed the threshold signal, can be divided into total count and count rate

(4) Duration, the time interval between the first time the signal crosses the threshold and finally decreases to the threshold

(5) Energy counting, the area under the signal detection envelope, can be divided into total counting and counting rate

Generally, the stability of a rock mass can be described by stiffness, that is, the rock mass's ability to resist deformation due to increased resistance stress. When the total stiffness of the rock mass remains unchanged, the total microseismic potential is proportional to the mining excavation volume, $\Sigma P \sim V\,m$. With continuous mining, the total stiffness of the rock mass gradually decreases, and the change of the total potential of the unit volume of rock mass will accelerate. As the stiffness decreases further, the rock mass exhibits nonlinear deformation. As the activity rate (t/1) increases, the potential release acceleration $\Sigma P \sim (\Sigma Vm)\,\gamma$ indicates that a large rock mass instability may occur. The dynamic process of rock mass instability can be expressed by the apparent stress $\sigma = E/P$, which depends on the ratio of the stiffness of the rock mass to the surrounding rock mass. The greater the stiffness ratio, the more energy released by the inelastic deformation of the unit volume of rock mass in the source

area. Based on these phenomena, looking for signs of the stress softening stage during the microseismic instability process evolves to find the development law of the energy index and cumulative apparent volume change with time, instead of the development of microseismic stress and strain with time [13]. The cumulative apparent volume ratio accompanied by an increase in energy index indicates the strain hardening process; the apparent volume accompanied by accelerated development indicates the strain softening, which indicates that the rock mass enters an unstable working state. The high-precision microseismic monitoring system can monitor the above rock mass deformation stable process.

Research on mine dynamic disasters shows that whether it is a disaster problem such as rock burst, rock burst, and mine shock in a noncoal mine, or coal and gas outburst (or gushing) and water inrush in the coal mine; they are all the results of the instability of the rock rupture process caused by microfracture initiation, development, and penetration caused by the disturbance of the stress field during the mining process. No matter what kind of mine power disaster, in most cases, there are signs of microrupture before the power disaster occurs. The direct cause of the microfracture activity is the result of increased stress or strain in the rock or coal layer. Especially in the prediction of mine dynamic disasters, it is necessary to find the essential mechanism and precursor law of disaster-induced disasters and to strengthen the study of the law of microseismic activity induced by mining stress-induced high-stress disturbance.

A significant feature of the microseismic monitoring technology is that it can monitor the rock mass properties in three dimensions in real-time. Through the collection and analysis of microseismic waves, the location, magnitude, energy release of the rock mass, and development of nonlinear strain associated with microseisms in rock mass can be determined.

The traditional on-site rock mass engineering stability judgment is based on the analysis of in situ rock mass deformation monitoring data. Generally, according to the importance of engineering buildings, choose to bury deformation monitoring instruments (such as inclinometer, multipoint displacement meter, anchor rod, and anchor cable meter) at locations (or sections) with poor geological conditions or uncertain geological structures. Appearance deformation monitoring points is used to monitor the behavior of the rock mass during construction and operation, so as to determine whether the rock mass at the location of interest is in a safe working state. Traditional rock mass monitoring technology has accumulated decades of experience, and there have been corresponding specifications and technical standards and a large number of engineering summaries to guide installation, data collection, and analysis. Therefore, as long as the instrument is properly selected and the embedding is careful and reasonable, the traditional monitoring technology has the advantages of high monitoring accuracy and reliable data through data sorting and analysis. The major disadvantage of traditional monitoring technology is that the location of observation points or observation sections is relatively scattered, and it is difficult to obtain the mechanism of stress, strain change, and displacement development in various parts of the rock body in the form of space. Usually, the choice of layout point (or section) is based on the knowledge of limited engineering geological survey results. It is inevitable that there are some unclear or missing important geological structures, so that the selected monitoring section sometimes fails to reflect the large deformation in time, endangering the safety of the project. The ideal monitoring technology should be able to respond to the rock mass in the area of interest to the engineering construction and should be able to obtain the evolution process of stress and strain in the rock mass, especially the activation of geological structures (such as faults) caused by engineering activities. According to the current international achievements, the microseismic monitoring technology has fully exerted its comprehensive monitoring of rock mass response. It has unique advantages in short-term rock mass excavation safety early warning forecast, medium, long-term disaster classification, and stability assessment.

2.2. Principle of Microseismic Positioning. Rock mass acoustic emission and microseismic monitoring technology are technical methods for monitoring the stability of engineering rock mass by using the sound waves and microseisms emitted during the process of deformation and destruction of rock mass. Acoustic emission and microseismic phenomena were discovered by L. Albert and W.L. Duval in the United States in the late 1930s. M. Cai and P.K. Kaiser classify all vibration events according to the fluctuation frequency, as shown in Figure 6, so as to generalize different phenomena such as acoustic emission, microseismic, rock burst, and earthquake into vibration events with different vibration frequencies.

From the microscopic view of the rock, the rock is a nonuniform material, and there are many defective structures in the rock. These microdefects are mainly point defects (vacancies, gap filling, substitutional impurities); line defects (dislocations); plane defects (crystal planes, double crystal planes, phase interfaces, stacking faults, and cracks themselves); and body defects (cavities, bubbles, precipitates, and dopants); these defects constitute the microstructure of the rock [14]. The acoustic emission event is mainly caused by the dislocation of microcracks inside the rock. Under the load, when the strength of the rock is less than the external load, initial cracks appear inside the rock; when the microcracks inside the rock are brittlely fractured, elastic waves of different frequencies will be quickly generated. This elastic wave propagates all around in the rock sample and continuously reflects and refracts. A large amount of research data at home and abroad shows that before destruction, the rock body must continue to release the accumulated energy in the form of sound for a period of time. The intensity of this energy release changes as the structure is approaching instability. Each acoustic emission and microseism contains rich information about the internal state changes of the rock mass. Processing and analyzing the received signals can be used as a basis for evaluating the stability of the rock mass, as shown in Figure 7.

Therefore, the rock mass acoustic emission and microseismic characteristics can be used to monitor the stability

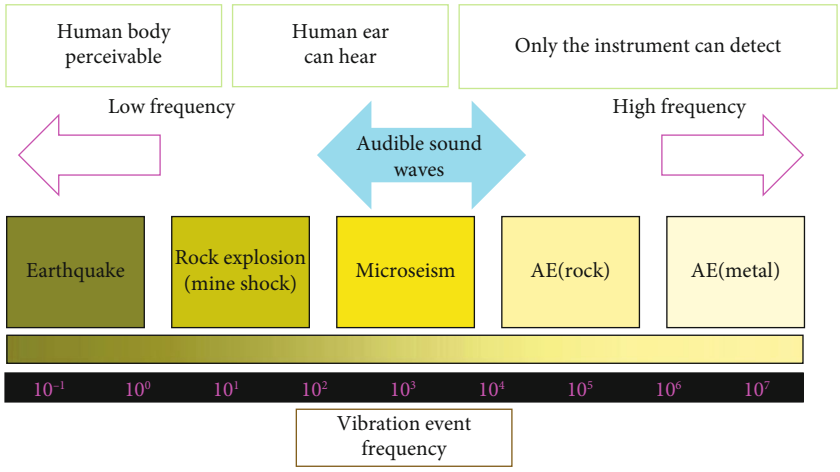


Figure 6: Vibration event frequency.

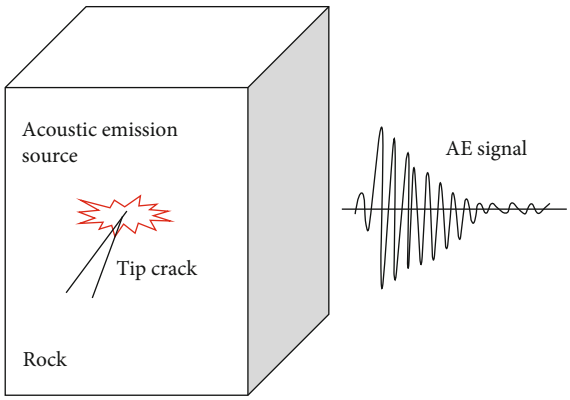


Figure 7: AE signal generation principle and its characteristic pattern.

of the rock mass, so as to predict the rock pressure such as collapse, roof collapse, ledge, landslide, and rock burst. Indoor research shows that when the load of the rock specimen is increased, the number of acoustic emission and microseisms before the failure of the specimen can be observed to increase sharply. Almost all rocks have acoustic emission and microseismic phenomena when the load reaches 60% of their breaking strength. Some of these rocks can also have this phenomenon even if the load reaches 20% of their breaking strength. The frequency is about 2~104 Hz. Based on the above, we can use instruments to monitor rock mass acoustic emission and microseismic phenomena. According to the rock block test conducted by the laboratory and the actual monitoring results at the mine site [15], the acoustic emission and microseismic signals of the rock mass have the following obvious characteristics: (1) the signal is random and nonperiodic; (2) the signal frequency range is very wide, and the upper limit can be as high as tens of thousands of hertz, or even higher; (3) the signal waveform is different, and the energy disparity is large; (4) the amplitude quickly attenuates with increasing distance. In the rock mechanics experiment, the macroscopic failure modes of rock under uniaxial compression mainly include brittle tensile failure, uni-inclined shear failure, and X-shaped conjugate-inclined plane shear failure; as far as rock microfractures are concerned, the main manifestations are crack propagation, grain slip (dislocation), and tearing, as shown in Figure 8.

It can be seen that the generation of acoustic emission signals is directly related to the deformation of the rock and the propagation of internal microcracks and the loading condition of the rock. Through experimental observation, it is found that the generation of acoustic emission signals mainly depends on the following factors:

(1) The acoustic emission event generated when the rock is initially loaded is mainly caused by the compaction of microcracks (or microholes) existing inside the rock. Once the rock is under overload in the elastic stage, that is, the rock is compacted in the elastic range, the rock is loaded in the elastic range again, and the acoustic emission events generated by the rock are few; it can be seen from this that within the elastic deformation range, the acoustic emission event is mainly caused by the compaction of microcracks (or microholes) existing in the rock

(2) When the load on some crystals in the rock exceeds a certain value, a dislocation source is generated (the initial stage of microcracks), and slips on a low exponential defined the surface with a large shear stress component. The role of a dislocation source causes a grain to yield to an acoustic emission event, and as many dislocation sources as possible can produce as many acoustic emission events

(3) After the formation of microcracks, the gradual expansion of the initial cracks under external load is also the main source of acoustic emission events

When the material or structure is under the action of external force, internal force, or temperature change, a local elastoplastic performance concentration phenomenon will occur inside it. When the energy accumulates to a certain critical value, it will cause the generation and expansion of microcracks and the phenomenon of acoustic emission. For the coal (rock) body, it generally refers to the small-scale or small-scale rupture phenomenon; while the microseismic relative to the larger-size coal (rock) body, if the acoustic

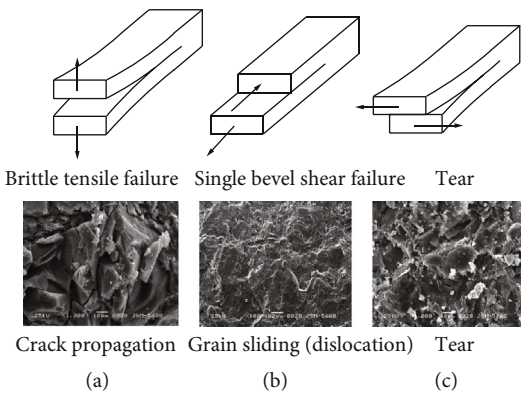


Figure 8: Microscopic failure modes of rock (SEM).

emission energy reaches a level that can cause a slight earthquake, this is geologically called a microearthquake. From the point of view of the generation mechanism, the nature of acoustic emission and microseismic in the rock mass is not substantially different, but the name is different. Acoustic emission and microseisms now have a complicated mechanism for characterizing the stability of rock masses. Acoustic emission and microseismic monitoring techniques of rock masses analyze the signal waveform to obtain the information contained therein to help people make proper judgments and predictions on the stability of rock masses.

For these types of signal characteristics, the following statistically significant quantities are generally recorded and analyzed: (1) event rate (frequency) refers to the number of acoustic emission and microseismic events per unit time, the unit is times/min, it is the most commonly used parameter when evaluating the state of rock mass by acoustic emission or microseismic. For a burst signal, after envelope detection, the waveform exceeds a preset threshold voltage to form a rectangular pulse; such a rectangular pulse is called an event. The number of these event pulses is the event count, and the cumulative count is called the total number of events. (2) Amplitude distribution refers to the amplitude distribution of acoustic emission and microseismic incident per unit time. Amplitude distribution is also called amplitude distribution. It is considered as a processing method that can reflect more information on acoustic emission and microseismic source. Amplitude refers to the peak amplitude of the acoustic emission and microseism waveforms. According to the set threshold, an event can be divided into small events or large events. (3) Energy rate refers to the sum of acoustic emission and microseismic energy per unit time. Energy analysis is performed on the signal output by the instrument. (4) The rate of event change and energy rate change reflects the rate of change of the state of the rock mass. (5) The frequency distribution and the characteristics of acoustic emission and microseismic signals are determined by the nature of the source, the nature of the rock mass, and the distance from the monitoring point to the source. The basic parameters are closely related to the stable state of the rock mass, which basically reflects the destruction status of the rock mass. The changes of event rate and frequency reflect the deformation and failure process of rock mass, and the amplitude distribution and energy rate mainly reflect the deformation and damage range of rock mass. When the rock mass is in a stable state, the event rate and other parameters are very low, and there is little change. Once it is disturbed by the outside world, the rock mass begins to break down, and the microseism activity increases accordingly. The event rate and other parameters also increase accordingly. Before the occurrence of dynamic disasters, the microseismic activity increased significantly, but the frequency of microseismic activities decreased instead when the dynamic disaster is approaching; when the internal stress of the rock mass returns to equilibrium, its value also decreases. If a certain number of sensors are arranged around the source with a certain degree of network to form a sensor array, and when acoustic emission and microseisms occur in the monitoring body, the sensor can pick up the signal and convert this physical quantity into a voltage quantity or a charge quantity. Point synchronous data collection measures the time when each sensor receives the signal, and the coordinates of each sensor and the measured wave velocity are substituted into the equation group to solve, and the spatiotemporal parameters of the acoustic emission source can be determined to achieve the purpose of positioning. Rocks will generate microfractures under stress, and potential energy will be released in the form of elastic waves. Install sensors and form a good spatial array in the three-dimensional space of the monitored area to determine the location of microfractures, as shown in Figure 9.

For a long time, many seismologists and rock mechanics have made many contributions to the research of microseism incident localization technology. The microseism incident localization methods used are the least square method (Fedorow, 1974), Bayesian localization method (Tarantola and Valette, 1982), relative positioning technology (ATD), Geiger (1912) positioning method, etc. Since the beginning of research on AE in rock mechanics experiments in the 1960s, researchers have tried to improve the positioning algorithm, from the earliest two-channel line positioning, four-channel surface positioning, to linear least square fitting multichannel, and the introduction of various seismic positioning methods is constantly improving the positioning ideas. At present, several commonly used positioning methods are the least square method, joint inversion method, slowness deviation Method, relative positioning method, and simplex positioning method.

(1) For the full-waveform AE acquisition system, the huge amount of data makes the method of manual on-time identification unsuitable. Therefore, an automatic reading program is developed to effectively identify the original signal and automatically read it when it arrives. Obtaining high-accuracy data on time is the first step of positioning work

(2) As the number of channels in the AE acquisition system continues to increase, the positioning method must effectively use the advantages of multiple channels, identify the occasional large errors that may occur in the AE data, delete the malformed equations in the overdetermined equations, and improve the accuracy of positioning results

(3) In the overdetermined system of positioning models, there may be multiple numerical solutions that

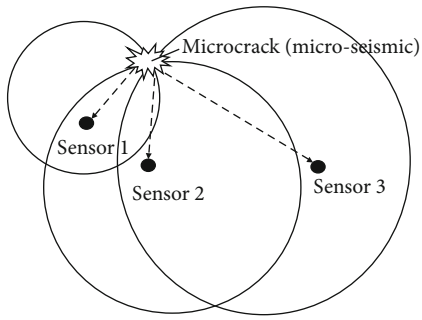


Figure 9: Location illustrative diagram of microseismic events.

approximately satisfy the minimum condition of the system of equations, that is, multiple solution problem. How to judge the true understanding of objects in these numerical solutions is a question worthy of study.

Using acoustic emission and microseismic techniques for stability prediction, our concern is whether such activity occurs in the rock mass, or even the location, time, and degree of instability that may cause the ground pressure phenomenon. Among them, the precise positioning of acoustic emission and microseismic sources is one of the key technologies of this method. When acoustic emission and microseism phenomena occur in the rock mass, what we know is the coordinates of each sensor and the time of the signal it receives, but what we do not know is the location and time of acoustic emission and microseism. Let the spatial coordinates of the source location be (x, y, and z), the time of occurrence is t, the coordinate of the i-th sensor is (xi, yi, and zi), the time detected by the sensor is ti, and the average speed of sound wave propagation is v. The travel time equation between the source and the i-th sensor is

$$(xi - x)2 + (yi - y)2 + (z\,i - z)2 = v2(ti - t)2(i = 1, 2, \cdots \cdots, m). \tag{1}$$

In the formula, m is the number of sensors that received the signal, and (x, y, z, t) is the spatiotemporal parameters of the source.

This equation is a nonlinear system, and it will be very difficult to solve it directly. It is necessary to find a linear system to replace this nonlinear system. A linear system can be obtained by subtracting the travel equation of the k-th measurement point from the travel equation of the i-th measurement point:

$$\begin{aligned} &2(xi - xk)x + 2(yi - yk)y + 2(zi - zk)z - 2v2(ti - tk)t \\ &\quad = xi2 - xk2 + yi2 - yk2 + zi2 - zk2 \\ &\qquad - v2(ti2 - tk2)(i, k = 1, 2, \cdots \cdots, m). \end{aligned} \tag{2}$$

Through different combinations of i and k, $m\,(m-1)/2$ linear equations can be generated, of which only $m - 1$ linear independent equations. It is required to solve the equation system composed of independent equations; there must be more than 4 independent equations, which means that at least 5 sensors are needed to receive the same signal.

It can also be seen from the geometric relationship that the coordinate position (x, y, and z) of a point in three-dimensional space requires three fixed points, that is, three sensors are needed to receive a microrupture signal during the microseism monitoring process to locate a microseism event. For this system of linear transcendental equations, whether all or part of the equations is adopted, which part of them will be used, and what impact will it have on the positioning results, this raises some questions. For this, it is necessary to study a set of Algorithm to solve the problem of acoustic emission source localization. The characteristics of the algorithm are (1) adopting the primary positioning and the modified positioning secondary positioning method; (2) based on the assumption that the P wave propagates in the rock mass media at a constant velocity; (3) iteratively solving the conditional equation using a normalization process; (4) doing a variety of data weighted; and (5) give quality assessment to the positioning results. The spatial positioning of seismic events is the main technical indicator of mine microseism monitoring, the first step in the study of mine seismic activity monitoring, and an important indicator for detecting and evaluating the application performance of a set of microseism monitoring systems. The positioning accuracy of seismic events is affected by many factors such as the on-site geological environment, the hardware performance of the equipment, and the positioning algorithm. The monitoring equipment for different purposes has different focuses. For a long time, seismologists have been continuously improving or proposing new positioning methods, hoping to obtain higher seismic positioning accuracy. In general, there is a close relationship and conversion relationship between the various parameters such as magnitude, energy, waveform, wavelength, and duration, as shown in Figures 10 and 11.

There are many methods of earthquake monitoring and positioning, and there are many methods for analyzing the location error of the source. At present, the positioning error is mainly composed of two factors: (1) due to the error of the measurement when the signal arrives; (2) due to the ability of the rock sample type to propagate the signal between the source of the acoustic emission event and the sensor. But for all positioning methods, the time difference is mainly taken into account to calculate the location of the acoustic emission event.

Acoustic emission source spatial positioning error, its method is to obtain its final numerical solution by iterative calculation from an initial experimental solution. In each iteration, a correction vector (Δ_x, Δ_y, Δ_z, and Δ_t) is calculated based on the least square technique and added to the previous solution to form a new solution. This calculation is continued until the correction vector meets a predetermined error criterion. The error analysis is expressed by the square and root mean square of the residual value of time as:

$$E = \left[\frac{1}{N}\sum_{i=1}^{N}(T_{oi} - T_{ci})^2\right]^{1/2}. \tag{3}$$

In the formula, N is the observed number; T_{oi} is the observed time or travel time of the i-th sensor; and T_{ci} is the calculated time or travel time of the i-th sensor.

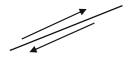
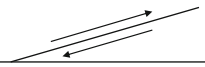
Magnitude	Examples of damage locations	Event source radius	Example of event frequency
−2		0.75 m	1000 Hz
−1		1.25 m	500 Hz
0		5 m	100 Hz
1		12.5 m	50 Hz
2		25 m	25 Hz
3		75 m	10 Hz

Figure 10: Examples of microseismic energy and failure displacement.

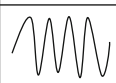
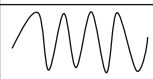
Magnitude	Waveform example	Frequency example	Event duration	Wavelength
−2		1000 Hz	0.02 sec	5 m
−1		500 Hz	0.04 sec	10 m
0		100 Hz	0.2 sec	50 m
1		50 Hz	0.4 sec	100 m
2		25 Hz	0.8 sec	200 m
3		10 Hz	2 sec	600 m

Figure 11: Example of microseismic energy and signal wavelength.

After calculating the error of each grid point, the error is actually mapped on the three-dimensional space, which is called the error space. In theory, the smallest error space is the best estimate of the location of real events.

2.3. Introduction to ESG Microseismic System

2.3.1. System Composition. The monitoring equipment used in this project is the mine microseism monitoring system produced by the Canadian ESG company. The system composition is shown in Figure 12. The system mainly includes Hyperion digital signal processing system, Paladin digital signal acquisition system, acceleration sensor, cable and optical cable, data communication modem, and MMS-View 3D visualization software based on remote network transmission developed by Lisoft Technology (Dalian) Co., Ltd. The sensor can continuously monitor the microfracture events generated by the rock mass for 24 h, obtain a large number of microseismic events such as spatiotemporal data, errors, magnitude, and energy and other source parameters, and filter the collected data to provide users with complete waveforms of source information with the spectrum analysis chart; it can automatically identify the type of microseism events and eliminate noise events through filtering, threshold setting, and bandwidth detection.

ESG stands for Engineering Seismology Group (Earthquake Engineering Group). In 1993, ESG cooperated with Queen's University of Canada, known for its long history of running schools and leading in science and technology, to create an enterprise dedicated to the development and research of mine microseismic systems. So far, the company has 28 experts in coal mine safety, microseismic, etc., and more than 100 outstanding technical engineers all over the world. After 17 years of development, the MMS (Microseismic Monitoring System) microseismic system developed and produced by ESG has developed to the seventh generation of products.

(a) Hyperion digital signal processing system

(b) Paladin digital signal acquisition system

(c) Accelerometer

Figure 12: Microseismic monitoring system composition.

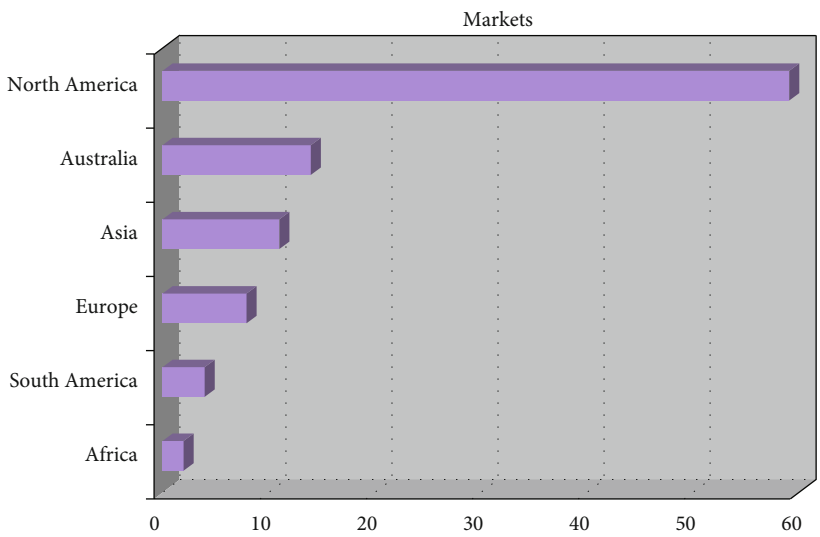


Figure 13: ESG market distribution by continent.

At present, ESG's products are widely recognized and applied in the United States, Australia, Asia, and Europe with their good reputation and excellent technology, as shown in Figure 13.

The sensors equipped with the ESG system have multiple functions according to user requirements. According to the sensor test axis, it can be divided into a single-axis sensor and a three-axis sensor. At present, the sensors usually adopt a three-dimensional spatial arrangement method in large-scale spatial arrangements, that is, the sensors are evenly arranged in a space. With this arrangement, the use of single-cycle sensors can also achieve spatial positioning testing. For a measuring point, the three-axis sensor can simultaneously test the vibration data in the three directions of X, Y, and Z in a position, but from the perspective of accuracy, it is slightly lower than the single-axis sensor using the three-dimensional space arrangement; according to the sensor test frequency can be divided into 3 Hz~2 kHz frequency band sensor and 15 Hz~2 kHz frequency band sensor, the level of signal frequency depends on the magnitude of energy release per unit time when microseismic occur. The greater the energy release per unit time, the greater the possibility of generating a low-frequency signal; the smaller the energy release per unit time, the more the signal is biased toward the high-frequency band. The harder the rock mass, the stronger the penetration ability of the vibration wave, and the more favorable it is for the propagation of high-frequency signals. On the contrary, the softer the rock mass, the weaker the high-frequency penetration and the stronger the attenuation of the vibration wave. According to the definition of acoustics, a signal with a frequency between 200 Hz and 2 kHz is called an acoustic wave. According to the actual test needs, the

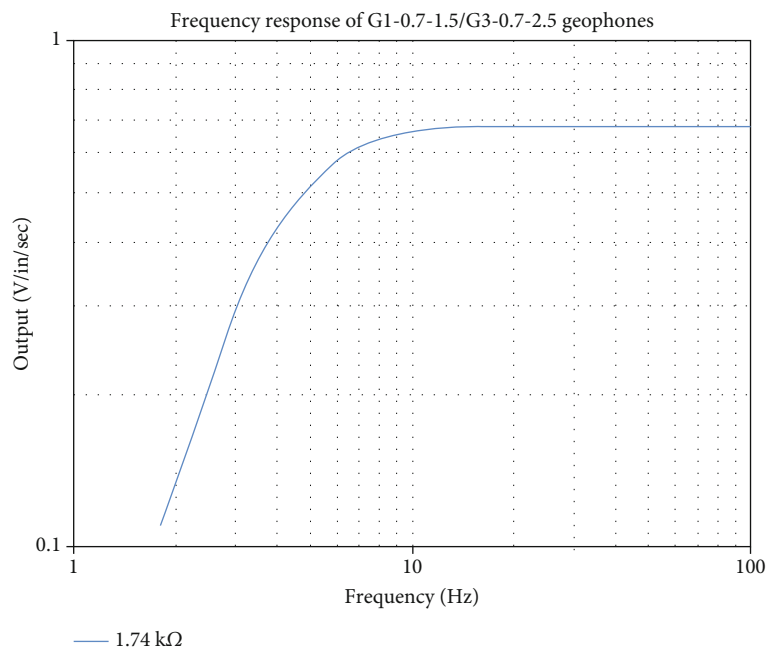


Figure 14: Frequency response curve of geophone type sensor.

Table 1: System configuration list.

Item	Description	Quantity
A	Sensor	
1	Uniaxial 15 Hz geophone	6
B	Cable and optic fiber, twist-pair	
1	Optical cable for tunnel	
2	3-core shielded communication cable for tunnel, section 0.75 mm^2-1.00 mm^2	5000 meters
3	Network cable with RJ45	20 meters
C	MMS microseismograph	
1	Paladin (v. 2)–24-bit seismic recorder w/6 channels, included PAL, Paladin acquisition software (per channel, installed on each Paladin recorder)	1 item
2	Junction box with sensor terminations, DIN rail, IS barriers, AC/DC, etc.	1 piece each.
D	Acquisition and processing server-on surface	
1	PC/ power cut	1 set
2	Data storage and transmission server	1 set
3	Seismic acquisition workstation, mounted in 19” rack on surface w/ win XP, MS Office, HNAS—Hyperion network acquisition software, HSS standard v. 16 processing and analysis software, w/software installation and configuration	1 set
4	Seismic processing computer, FRT-view processing and analysis software, w/ software installation and configuration.	1 set
E	Installation tool kit	
1	SIK-10-sensor installation kit	1 item

system sets the test frequency band (for example: select 3 Hz~200 Hz for testing), and the frequency band signal outside the setting will be filtered out by the system; according to the physical quantity of the sensor test, it can be divided into acceleration sensor and motion detector. The system uses a single-axis sensor, and the specific performance index performance curve is shown in Figure 14.

The complete set of microseismic monitoring system used in the Shaanxi Province Han to the Wei River project is shown in Table 1. Among them, the optical cable is laid for data transmission and real-time monitoring of the system’s operating status [16], because the project is in the test phase to reduce costs, transmission data, and system monitoring adopt manual operation.

2.3.2. System Functions. The main functions of the system are

(1) Real-time and continuous collection of various trigger or continuous microdamage signal data generated on the spot, real-time location of the temporal and spatial distribution of microdamage, and analysis of the possibility of potential major damage

(2) The remote wireless transmission system can be used for remote wireless transmission of microseismic data where conditions permit, allowing users to view the data information collected from remote sites at any time around the world

(3) Automatically record, display, and permanently save the waveform data of microseismic events

(4) Automatic and manual dual pickup of system-acquired source, which can perform source location correction and calculation of various source parameters and realize automatic identification of event types

(5) The software's filter processor, threshold setting, and bandwidth detection function can be used to correct the event waveform and eliminate noise events

(6) Use batch processing to process data lists generated over multiple days

(7) The configured MMS-View visual analysis software can import geometric 3D graphics such as chambers, roadways, and slopes within the range to be monitored, provide a visual 3D interface, and display the spatiotemporal location, magnitude, and magnitude of the generated microseismic events in real-time and dynamically source parameters and other information and can view the information of historical events and realize the dynamic demonstration of monitoring information

(8) In the interactive three-dimensional display, events can be relocated

(9) The system can select various types of events that need to be viewed within the user-defined event range and output MS Word or MS Excel reports including event location maps, cumulative number of events, and various source parameters. Need to view event information

(10) Visualization software MMS-View is a microseismic data visualization analysis software specially developed by Mechsoft for the ESG microseismic monitor. It can realize the remote transmission of data and can more intuitively demonstrate the temporal and spatial distribution of microfractures inside the stratum. The microseismic monitoring system equipped with MMS-View helps engineers make predictions about the evolution of microseismic activities. Effectively monitor and analyze the stability of rock or concrete engineering structures such as slopes, tunnels, mines, and dams

2.3.3. System Hardware and Software. The ESG microseismic monitoring system adopts a modular design and implements a remote acquisition PC configuration. Its composition mainly includes

(1) In the software part, the Paladin standard version monitoring system is equipped with HNAS software (real-time signal acquisition and recording SeisVis software (three-dimensional visualization of events)), WaveVis software (waveform processing and event repositioning), ProLib software (seismic parameter calculation), Spectr spectrum analysis software, DBEidtor software (data filtering and report generation), Achiever software (data archive), MMS-View software (remote network transmission and three-dimensional visualization), and other complete monitoring system, see Figure 15

(2) The hardware part is composed of a 30-channel accelerometer, Paladin sensor interface box with power supply and signal waveform trimming function, Paladin seismic recorder, Paladin master control time server, software operation monitoring card WatchDog, and other hardware facilities, see Figure 16.

The technical parameters of each component of the system are shown in Table 2.

2.4. Construction of Microseismic Monitoring System

2.4.1. Selection of Monitoring Method. Affected by high ground stress and other geological factors, the No. 4 branch tunnel in the Qinling section of the Han to the Wei River project in Shaanxi Province has suffered from rock burst many times during the excavation process. It shows the phenomenon of bursting, loosening, spalling, or throwing during blasting and support operations or after the completion of construction, and even a large number of rock collapses. With the gradual progress of the excavation of the No. 4 branch tunnel, it is expected that the impact of rock bursts will become increasingly severe. In order to accurately predict the location of the rock burst disaster, the Canadian ESG company's microseismic monitoring system was introduced to conduct real-time rock burst risk assessment and early warning. For the construction of the microseismic monitoring system, the traditional installation method is a fixed, three-dimensional, mesh arrangement (as shown in Figure 17). According to the stress wave propagating in space in the form of a sphere, this network and three-dimensional microseismic arrangement can ensure that all sensors receive microfracture signals from the interior of the rock mass at the same time. This arrangement is the most effective in microseismic monitoring projects.

However, for the grown-up and single-headed tunnels in underground engineering, the traditional installation method of the microseismic monitoring system is powerless and can only adopt mobile and following semienclosed network layout. As shown in Figure 18, the microseismic monitoring network layout method was adopted for the simultaneous exploitation of multiple tunnel diversion tunnels of the Jinping secondary water gate in the Yalong River Basin. Figure 18(a) shows the layout of the follow-up sensor. With the progress of the mining process, remove the sensor farther back and keep it close to the tunnel face, and keep the distance of the sensor closest to the tunnel face at no more than 50 m. The arrangement of sensors that changes while advancing the tunnel face is the arrangement of follow-up measuring points. Figure 18(b) shows the arrangement of semienclosed sensors. As the excavation progresses, the sensors are always placed on the side of the tunnel face and behind the tunnel face. When the sensor farthest from the tunnel face is greater than 200 m, move the sensor to the front to ensure the best monitoring effect. Such a sensor

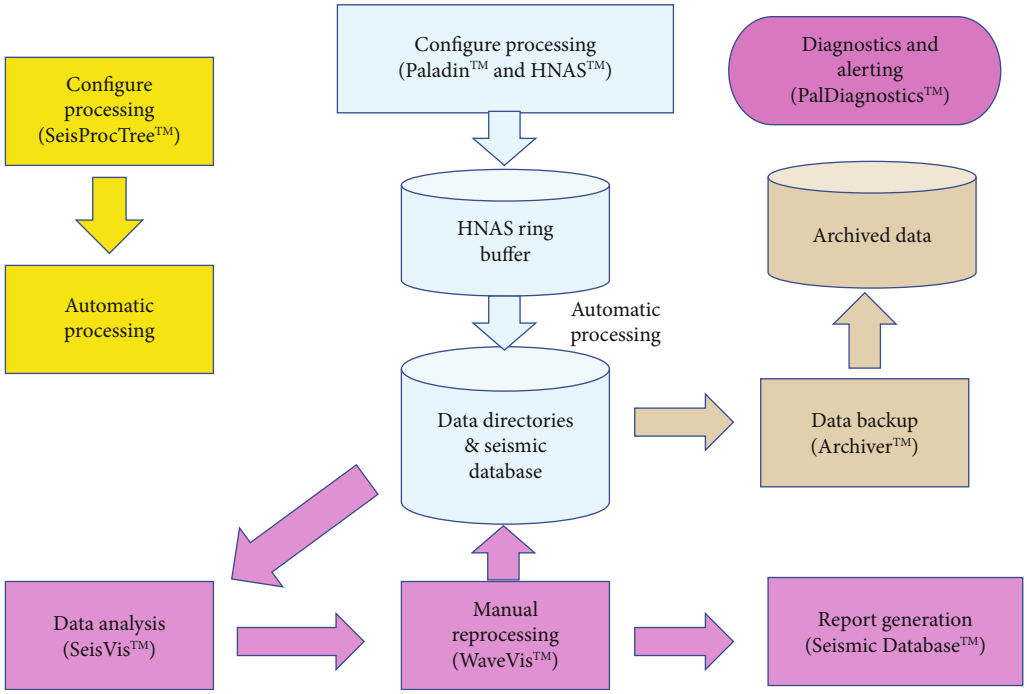


Figure 15: ESG microseismic monitoring system analysis module.

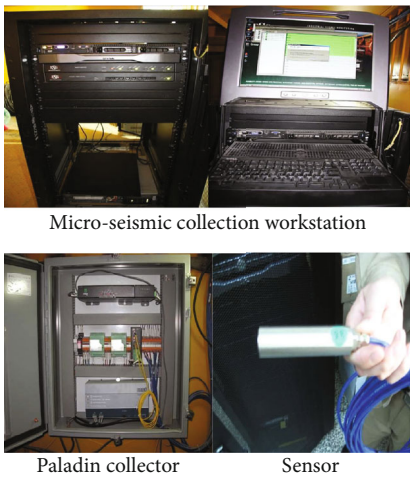


Figure 16: Workstation sampling instrument sensor diagram.

arrangement can make all sensors in the most sensitive monitoring range.

Figure 19 is a schematic diagram of the No. 4 branch tunnel and the main hole in the Qinling section of the Han to the Wei River project in Shaanxi Province. This monitoring and testing project starts at slope 3 + 970 and ends at slope 4 + 335. There is only one inclined hole going forward, and there are no microseismic monitoring sensors that can be installed in other adjacent tunnel sections. Therefore, in view of this construction environment, the Microseismic Monitoring Project Team of Dalian University of Technology adopted the follow-up microseismic monitoring arrangement method based on the experience of rock burst monitoring of the Jinping secondary diversion tunnel in the Yalong River Basin [17]. Figure 20 is a complete network schematic diagram of the sensor layout and data acquisition, transmission, and processing of the No. 4 branch tunnel microseismic monitoring system of Shaanxi Han to the Wei River Project.

In the picture, a total of 6 sensors are installed, and 3 are installed on the walls of both sides of the tunnel at about 1.5 m. The distance between adjacent sensors is controlled at about 50 m. The first two sensors are controlled at 50 m-80 m from the tunnel face to ensure the complete set the microseismic monitoring system obtains the most sensitive monitoring distance. Each sensor is installed in a hole drilled in advance and ensures that the end of the sensor is in close contact with the bottom of the hole. Each sensor is connected to the signal mining host through a three-core cable to convert the acoustic emission signal generated by the microfracture in the rock body into an electrical signal. The electrical signal is converted into a digital signal through the acquisition system, receiving system, and conversion system, and then transmitted to the data processing system. The traditional data transmission uses the optical cable connection method, this project is a test project, and the cycle is short. Considering the high cost of construction and maintenance of the optical cable, manual data acquisition is adopted for data transmission and equipment maintenance. Data processing includes manual noise removal, sound source localization, equipment status monitoring, and other works. The results of the data processing are reflected in the form of sound files, pictures of microseismic events, and tables of microseismic statistics, with the help of simple text descriptions. These data are stored in the workstation on the site of No. 4 branch tunnel and are automatically transmitted to the Dalian server. Researchers in Dalian read the data and assist in the systematic analysis of microseismic events by

Table 2: Technical parameters of each component.

Name	ESG microseismic monitoring system (MMS)
Digitization	24-bit analog-to-digital conversion
Sensor	The sensor has a sensitivity of 30 V/g and a maximum output signal of ±5 V. 30-channel accelerometer
Network expandable channels	Powerful integrated functions can be expanded to 256 channels
Signal trigger mode	Threshold or STA/LTA
Signal voltage	DC ≤ 24 V
Power supply voltage	220VAC
Dynamic response range	>115 dB
Data storage	Data storage can be expanded to 256 MB of 32 MB internal solid-state storage (USB, HDD can be selected), can record, and save continuous data
Data storage format	Binary and access files to facilitate users to obtain information on up to 16 event characteristics
Signal sampling rate	50 Hz-10 kHz
Signal bandwidth	DC-1/4 sampling rate
Signal gain	0, 6, 20, and 40 dB
Auxiliary gain	6-72 dB
Energy consumption	<10 W
Power supply	12VDC

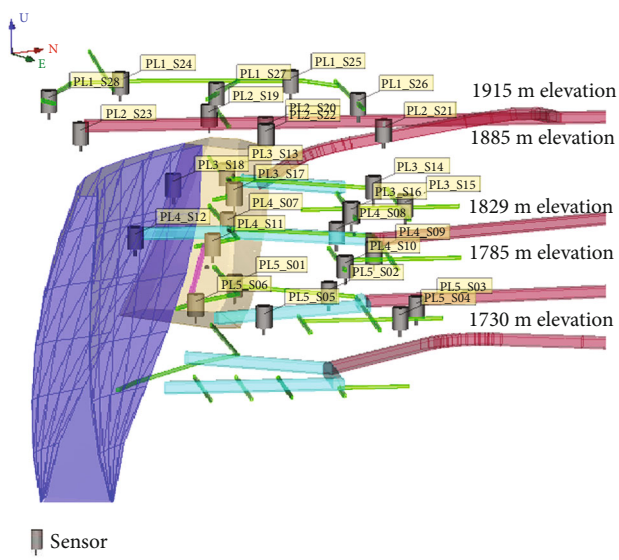


Figure 17: Stability monitoring of left bank slope stability monitoring (sensor space array distribution) in Jinping Primary Diversion Hydropower Station in Yalong River.

means of software simulation and technical consultation and give recommendations. The report can be transmitted to the Han to the Wei River daheba branch, the Design Institute of China Railway First Bureau, and Project Department of China Railway Tunnel Group through the Internet and other channels, as guidance suggestions for the project site, design, and work scheduling.

2.4.2. Preparation before Installation. Since the excavation tunnel needs to be continuously excavated, slagged, sprayed, mixed, and supported, the cable connecting the sensor will inevitably be damaged frequently. Therefore, for excavation tunnels such as the No. 4 branch tunnel, a large amount of cables and electrical tapes needs to be prepared during the microseismic monitoring process. When the cables are damaged or sprayed into the concrete, they need to be replaced and repaired in time to keep the continuity of data collection as much as possible. In order to make the installation of the whole system smooth, in addition to the special tools for sensor installation, the installation process also needs to prepare: pens or ballpoint pens, labels, gloves, screwdrivers, pliers, tape, anchoring resin, and other items.

2.4.3. Installation of Data Acquisition Instrument. In the ESG system, Paladin is an important device that converts current waves into data signals. Too long a sensor cable will greatly increase the cost, and it will also make the signal attenuation more and more severe. Therefore, in order to ensure the normal transmission of the signal, Paladin cannot be installed at a distance of more than 1000 m from the sensor. However, for the safety of Paladin, Paladin cannot be installed too close to the work surface. Therefore, during the monitoring process, the microseismic monitoring team usually installs Paladin at a position about 200 m away from the tunnel face. As the tunnel face advances, the cable movement sensor is increased. When the cable is greater than 800 meters, Paladin is moved forward. Therefore, when installing equipment in the No. 4 branch tunnel, install the data acquisition instrument near the oblique 3830 (Figure 21).

2.4.4. Installation of Sensors. Since rock burst monitoring and prediction is a worldwide problem, Dalian University of Technology and Lisoft Technology (Dalian) Co., Ltd. carried out more successful rock burst prediction and prediction based on microseismic monitoring technology in the deep-

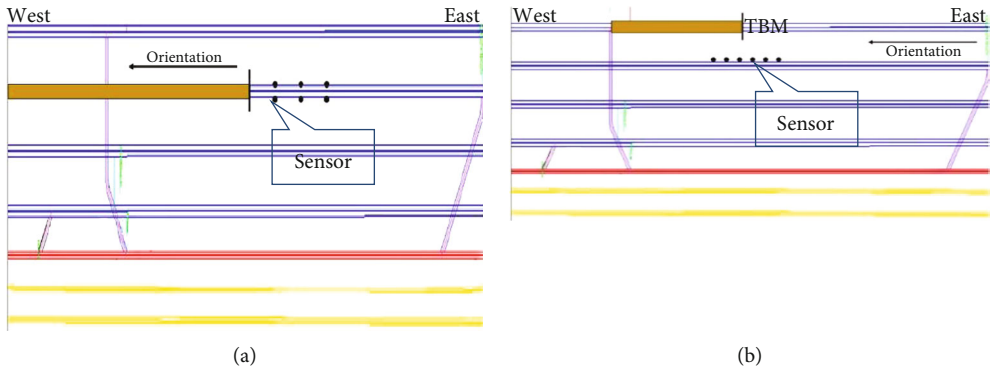


Figure 18: A map of the monitoring system of the microseismic monitoring system of the hydropower station in Jinping hydropower station of Yalong River Basin.

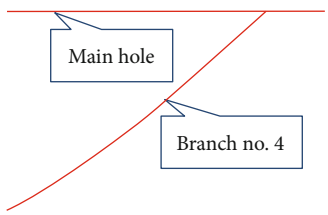


Figure 19: Sketch map of No. 4 branch and main tunnel of Qinling Mountains section of Han to the Wei River project in Shanxi.

buried tunnel group of Jinping secondary hydropower station. However, the diversion tunnel of Jinping secondary hydropower station is mainly dominated by marble, while the No. 4 branch tunnel of Qinling in Shaanxi Han to the Wei River Project is mainly granite, and the No. 4 branch tunnel is an inclined shaft with a slope of more than 10%.Therefore, the layout of the microseismic monitoring sensors and the installation location of the equipment also need to be constantly explored and improved.

The tunnel diameter of Jinping secondary hydropower station is large, the slope is small, and it is close to horizontal in a small range. At the same time, due to the large number of anchors on the wall, the sensor is installed at the exposed end of the anchor, which greatly improves the efficiency of sensor installation and recovery utilization. However, there are few anchors on the wall of No. 4 branch tunnel, so this sensor installation method cannot be adopted. Therefore, the sensors are installed in boreholes with a depth of 1.5 m, an aperture of 40 mm, and a height of 1.5 m above the ground (as shown in Figure 22), and are arranged 50 m~80 m behind the tunnel face, three on each side, 50 m apart Left and right, the tunnel face forward for about 50 m, and moved the back sensor to the front, and repeated this to form a mobile microseismic monitoring system that followed the tunnel face.

During the installation process, connect the components together in the order shown in Figure 22(a) and confirm that the sensor is working properly. Put an appropriate amount of fixing resin into the paper cup at the end of the sensor and send this device into the hole. After the fixing resin solidifies, remove the sensor mounting rod. The advantages of this installation method are the least interference from outside noise and construction; the disadvantage is that the installation is time-consuming and complicated.

2.4.5. Communication Line Detection. After the laying of the line is completed, start testing the communication lines of the monitoring network. The communication line detection is divided into three steps: the first step is to check whether the communication indicator of the Paladin box, the timer, and the photoelectric transceiver is normal; the second step is to perform the time delay detection (see Figures 23–25 for the test results); the third step is to perform light attenuation detection.

Communication line test results: the communication indicator lights of the Paladin box, the timer, and the photoelectric transceiver are normal; the network transmission volume and delay both meet the system operation requirements; the third step, the loss of each fusion joint is less than 0.02 dB, the overall path test. The loss of each core in each optical fiber is less than 20 dB.

2.4.6. System and Sensor Parameter Setting. The setting of system and sensor parameters is mainly the main task of ESG common system debugging, and its rationality will be reflected in Appendix I——ESG's debugging report. The system and sensor parameter settings are shown in Figures 24 and 25.

2.4.7. System Trial Operation. The results of system trial operation are shown in Figures 26–28. Among them, SeisVis is three-dimensional visualization software, HNAS is data acquisition software, and WaveVis is a waveform display software. Figure 26 shows that the sensor coordinates are correct, properly arranged, and 354 trigger events are generated. Figure 27 shows that the data collection is correct, the time of the collector and the host is synchronized, the data transmission is normal, and the microseismic event is normal. Select a blue trigger event and observe the waveform monitored by sensor 1-6 for the trigger event. See Figure 28, it can automatically locate the position of the P wave and can display typical microseismic waveform information, indicating that the acquisition device is completely normal. Through the trial operation of the system, it can be found that the system

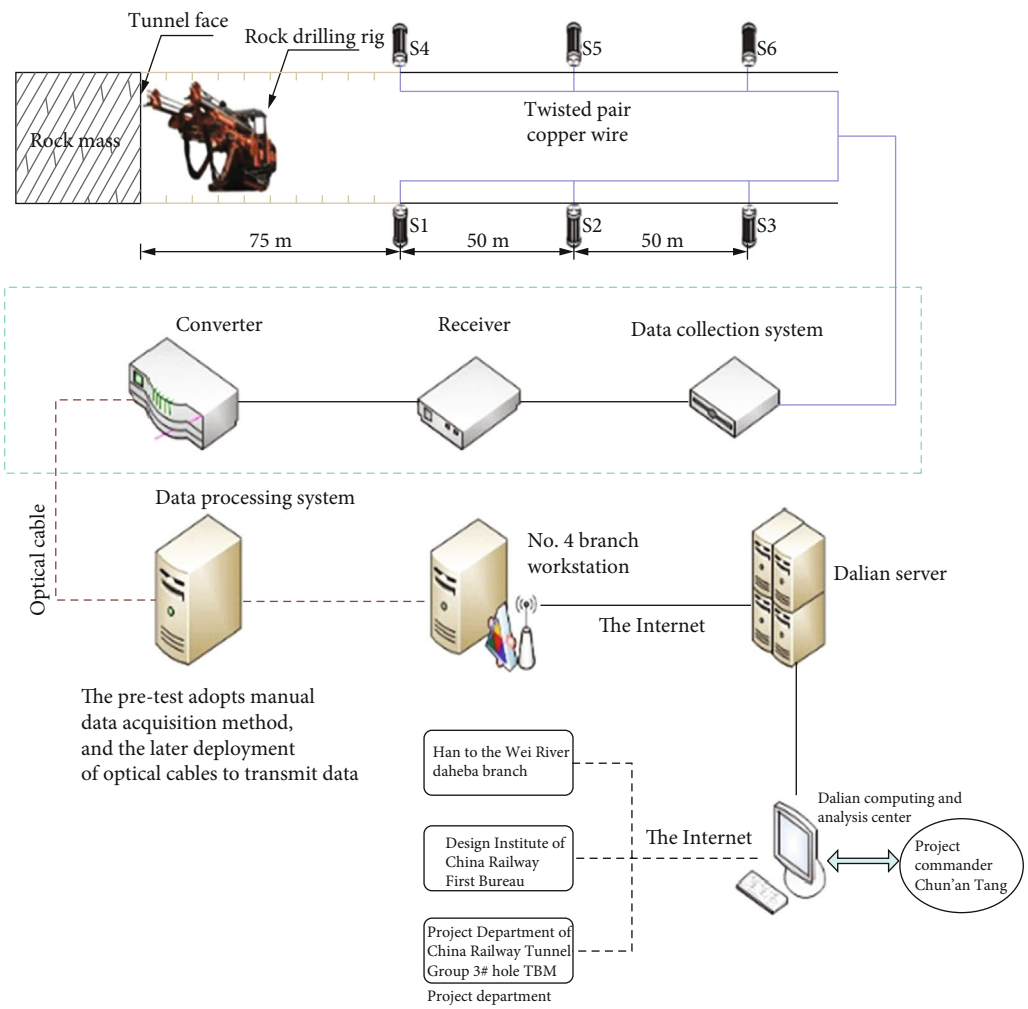


Figure 20: A complete network schematic of sensor layout and data acquisition, transmission, and processing of the microseismic monitoring system in the Han to the Wei River Qinling tunnel no. 4, Shanxi province.

Figure 21: The data acquisition instrument (Paladin) is installed at the No. 4 branch tunnel of the Qinling Mountains of Han to the Wei River project in Shaanxi Province.

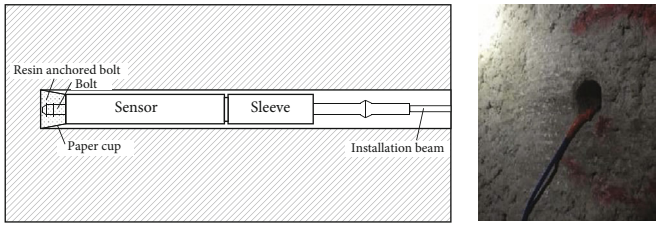
software and hardware are operating normally, and the system can perform microseismic monitoring normally.

2.4.8. Signal Filtering

(1) Monitoring Signal Filtering. There are many situations in the tunnel that will cause waveform interference to the microseismic monitoring, and some situations (such as blasting, mechanical work, etc.) will also cause the occurrence of microseismic events, because these conditions interfere with the microseismic monitoring in the form of acoustic or electromagnetic waves. If these noise disturbances cannot be filtered out very accurately, it will seriously affect the effectiveness and accuracy of microseismic monitoring. According to this feature, the sound wave frequency monitoring range can be set in the microseismic monitoring system to filter out most interference signals except the microseismic signal.

(2) Hardware Filtering. In this system, hardware filtering first passes the signal through the band-pass active band-pass filter Butterworth, and then through double integration A/D conversion to eliminate the interference signal on the useful signal, so that most of the low frequency and the ultra-high frequency signal is filtered out, and the microseismic signal is retained. It is mainly used to extract the signal within a required frequency range from the input signal and attenuate the signal in other frequency bands.

(3) Software Filtering. Using pure hardware circuit filtering, it is easy to filter out useful signals if it is not processed well,



(a) (b)

Figure 22: Sketch map of installing sensor in the drilling hole.

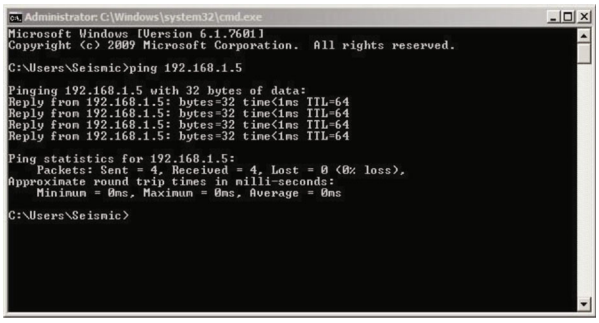


Figure 23: Workstation delay monitoring results.

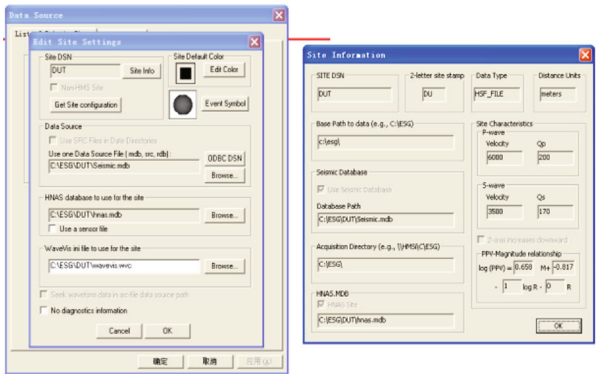


Figure 24: System parameter setting.

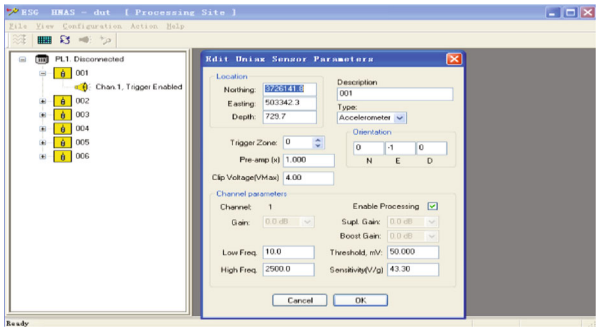


Figure 25: Sensor parameter setting.

supplemented by software filtering, which is unique to smart sensors. It filters various interference signals including very low frequencies (such as 0.01 Hz). A digital filtering program can common for multiple input channels. Common filtering methods are average filtering, median filtering, limiting

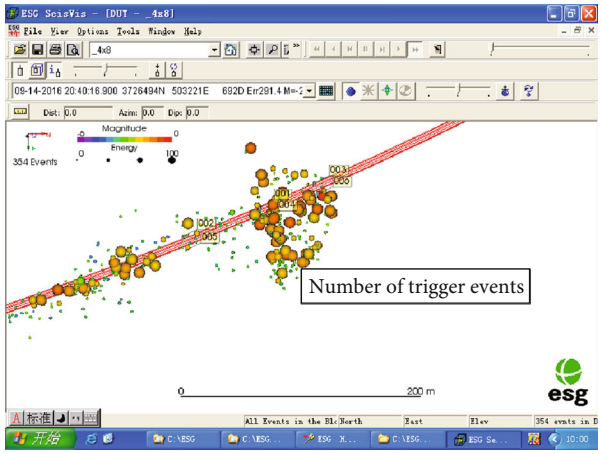


Figure 26: SeisVis interface figure.

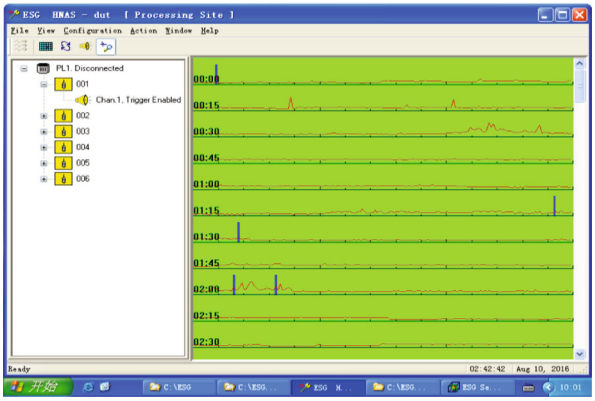


Figure 27: HNAS interface figure.

amplitude wave filter, and inertial filtering. In this system, the amplitude is greater than the sampling period and the normal rate of change of the real signal to determine the maximum possible difference between two adjacent samples as noise processing.

2.4.9. Waveform Recognition. For the microseismic monitoring at the construction site, a key issue is the identification and elimination of noise. As the tunnel excavated by TBM is less disturbing noise than the tunnel excavated by drilling and blasting, the main difference is the waveform of blasting, rock burst, and microseism.

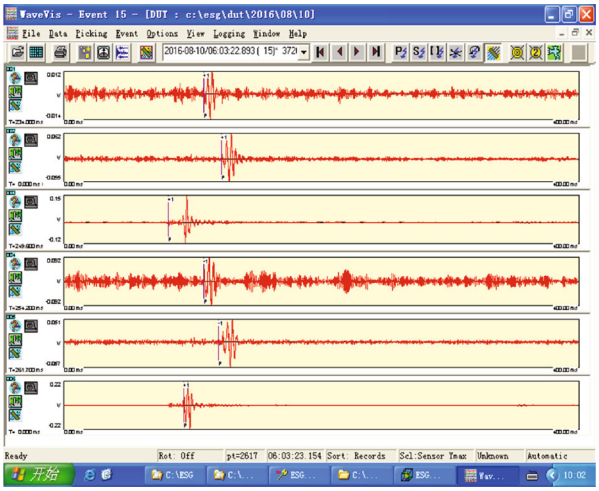


Figure 28: The waveform of sensor 1-6 on a trigger event.

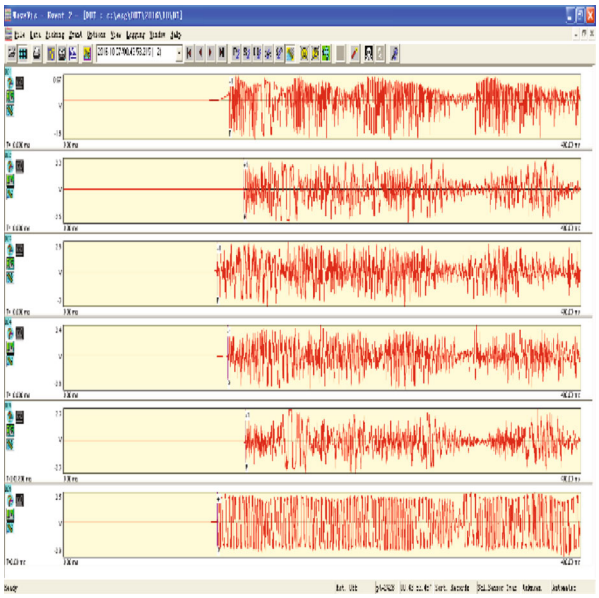


Figure 29: Blasting event waveform.

(1) Blasting Waveform. As shown in Figure 29, the waveform generated by blasting has a voltage amplitude of -3 to 2.5 V, with a large amplitude, a long period, and a gradual attenuation.

(2) Microseismic Event Waveform. As shown in Figure 30, the amplitude of the microseismic event is small, the period is short, and the attenuation is fast. For the event caused by the microfracture of the rock, the amplitude of the voltage value is high or low, and the arrival of some P waves and S waves is obvious, and the arrival of some P waves is obvious but the arrival of S waves is not obvious. Therefore, the judgment cannot be generalized, and it needs to be comprehensively judged according to the time, the size of the voltage value, and the waveform. In order to more accurately locate the microseismic event, it is necessary to ensure the number of sensors that work normally as much as possible, but from the monitoring data, the distance between the sensors must not be too small; otherwise, it will affect the positioning effect.

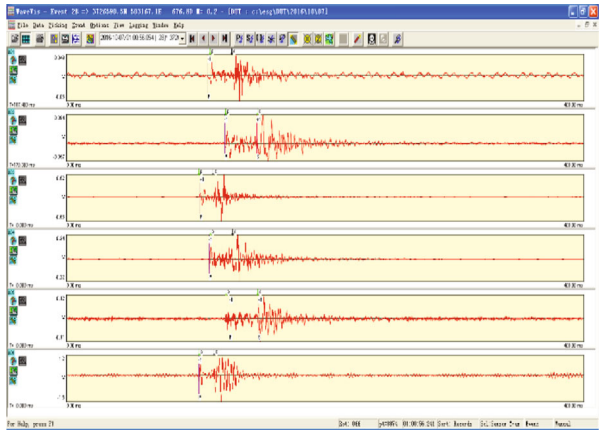


Figure 30: Microseismic event waveform.

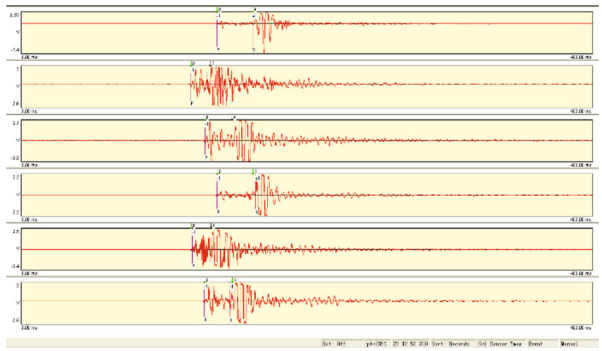


Figure 31: Slight rock burst waveform.

(3) Rock Burst Waveform. There are two types of waveforms generated by rock burst, they are a slight rock burst waveform and a strong rock burst waveform.

So far, there is not much information about the rock burst in the No. 4 branch tunnel, and as can be seen from Figure 31, the generated rock burst grade is not strong, so the generated rock burst has similar characteristics except that the amplitude of the voltage value is larger than that of the microseismic event.

To distinguish between slight rock burst waveform and microseismic waveform, the voltage amplitude must be judged at first. The amplitude of the slight rock burst waveforms is larger than that of the microseismic waveform. Secondly, from the comparison of their waveform diagrams, it can be found that the microseismic waveform will have a longer small amplitude waveform before the maximum amplitude, so the generation time of the microseismic waveform will be longer than that of the slight rock burst waveform.

The waveform of a strong rock burst is shown in Figure 32. Its waveform characteristics are relatively close to the blasting waveform, with large amplitude, long period, and slow attenuation.

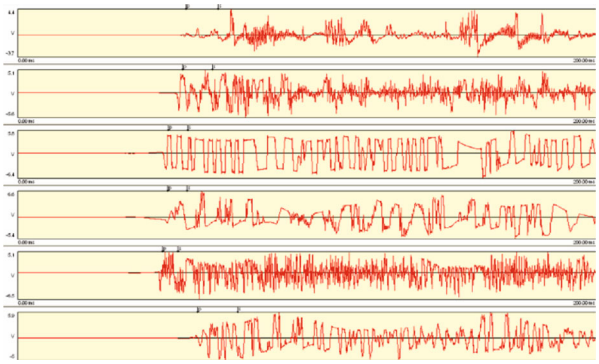


Figure 32: Strong rock burst waveform (9 October 2009 in a tunnel).

3. Conclusion

Microseismic is essentially a process of continuous stress accumulation and intermittent release. In a larger scale, the formation and propagation of rock mass cracks will also produce microseismic. This paper makes corresponding research on the monitoring and positioning of microseisms and the arrangement of sensors and draws the following conclusions:

(1) For the microseismic signal generated during rock failure, it is mainly due to the elastic wave of different frequencies excited by the rock fracture point (surface). The elastic wave propagates in the rock and is received by sensors fixed at different positions. There is also a lot of information on rock failure and interpretation of microseismic signal parameters (event count, event growth, number of rings, duration, and energy count) to obtain information, which can be used to analyze rock failure and instability

(2) A certain number of sensors are arranged around the source with a certain degree of network to form a sensor array. When acoustic emission and microseism occur in the monitoring body, the sensor can pick up the signal and convert this physical quantity into a voltage quantity or a charge quantity, measure the time when each sensor (at least 5) receives the signal through multipoint synchronous data collection, and substitute the coordinates of each sensor and the measured wave velocity into the equation group to solve; you can determine the spatiotemporal parameters of the acoustic emission source to achieve the purpose of positioning

(3) For the grown-up and single-headed tunnels in underground engineering, the sensor arrangement can only adopt mobile and following semienclosed network arrangement. As the excavation progresses, remove and install the sensor farther back in the vicinity of the tunnel face. Always keep the distance of the sensor closest to the tunnel face no greater than 50 m. This sensor is constantly moving and changes as the tunnel face advances. The arrangement is the follow-up measuring point arrangement. The arrangement of the semienclosed sensor is that as the progress of mining progresses, the sensor is always arranged on the side of the tunnel face and behind the tunnel face. When the sensor farthest from the tunnel face is greater than 200 m, move the sensor to the front to ensure the best monitoring effect

Data Availability

In this paper, the principle of microseismic monitoring and positioning is introduced, and the composition of ESG microseismic monitoring system and the sensor layout strategy are introduced in detail based on practical engineering experience, hoping to provide reference for relevant personnel studying microseismic monitoring technology.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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