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Research Article

Experimental Study on Acoustic Emission Characteristics of Granite and Sandstone under Uniaxial Compression

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In order to better apply acoustic emission technology to engineering practice, this paper carried out indoor acoustic emission test, and uniaxial compression tests of granite and sandstone under monotonic loading and grading loading were carried out and monitored. The influencing factors of the acoustic emission characteristics of the two rock samples were discussed and the characteristics of the acoustic emission signals corresponding to different stages of rock failure were analyzed. The analysis of the test results includes the curve fitting relationship between the AE event count rate, energy rate, and stress time and the changes of AE event count rate and energy rate under different loading methods. The results of the study are as follows: there is a quiet zone in the acoustic emission event before the rock is destroyed and destabilized, and the higher the rock strength, the more obvious the quiet zone; this important feature can be used as a precursor feature of rock mass failure for prediction, and the rock acoustic emission energy rate is more obvious in the quiet area before destruction than the acoustic emission event rate; rock acoustic emission has experienced initial compaction zone, rising zone, peak zone, and descending zone, whether different rocks go through each stage and how long each stage lasts is related to the nature of the rock; under different loading methods, the failure mechanism of rock is different; the different loading rates of monotonic loading and grading loading will affect the change rate of acoustic emission.

1. Introduction

Acoustic emission (AE), also known as stress wave emission [1–3], refers to the deformation or crack propagation of the material locally under the action of external load or internal force; the transient strain energy generated during its failure process is rapidly released in the form of elastic waves [4, 5]. Acoustic emission technology is an unconventional dynamic nondestructive testing method; with its unique dynamic and real-time detection performance [6], it can continuously monitor the internal damage and deformation of materials [7].

The failure of rock is essentially the process of internal crack initiation and expansion until macroscopic cracks are formed; therefore, there is an inevitable connection between the acoustic emission phenomenon of rock and the force failure of rock [8, 9]. According to the indoor acoustic emission test law, the acoustic emission characteristics of different rock failure processes are studied; it plays an extremely important role in the study of rock deformation, failure, and instability; the use of acoustic emission detection technology can effectively monitor the real-time information of changes in the rock [10–12], and predicting the process of rock failure [13–15] has a wide range of engineering application value [16–18].

In recent years, more and more scholars have used different methods and lithological rocks to carry out laboratory experiments on the acoustic emission of rocks. Literature [19] proposed a new rock damage expression method by studying the acoustic emission characteristics of rock samples with different lithology under uniaxial compression and established the functional relationship between damage variables and stress. Literature [8] studied the acoustic emission characteristics of rocks based on the MTM model combined with the developed PVBM model. Literature [20] found that the existence of cracks in rock will lead to more obvious acoustic emission directivity of Kaiser effect, which provides a basis for improving the measurement accuracy of ground stress and rock fracture toughness. Yin [21] used unloading method to study the acoustic emission characteristics of rock materials, which are similar to continuous and discontinuous, discrete and nondiscrete media, using fractal theory. Literature [22] carried out uniaxial loading-unloading tests on rock samples. It is concluded that the unloading process under loading is likely to be the main reason for the different characteristics of acoustic emission. Literature [23] designed a rock tensile test device to conduct direct tensile, splitting, and uniaxial compression tests on rock samples and found that the number of events and energy rates observed under direct tensile were relatively small. Literature [24] summarized the stage acoustic emission characteristics of rock under different loading rates. Literatures [25–29] discussed the dynamic characteristics of acoustic emission b value in the process of rock fracture propagation. Literatures [30, 31] studied the relationship between peak stress and strain and acoustic emission activity of coal samples by uniaxial multistage grading loading test method. Literatures [32–34] applied rock acoustic emission to the measurement of in situ stress and the judgment of rock burst tendency. Literature [35] combined the acoustic emission test index with the integrated machine learning model and revealed the internal relationship between rock acoustic emission and rock fracture instability. Literatures [36, 37] believed that the acoustic emission phenomenon is caused by the release of the energy generated by the sudden rupture of some microelements in the rock in the form of elastic waves. Literatures [38–40] explored the relationship between rock failure mechanism and acoustic emission signal under uniaxial and triaxial compression tests at different temperatures by studying the change of acoustic emission elastic wave signal of granite. Literatures [41–43] carried out uniaxial compression test and splitting test on surrounding rock and orebody, monitored by acoustic emission technology, and discussed the relationship between the number of acoustic emission events and energy rate and rock failure mechanism.

In order to better apply acoustic emission technology to engineering practice, this paper takes standard rock samples as the research object, by performing uniaxial compression tests on two different brittle rock samples, granite and sandstone, under different loading methods; during the test, the acoustic emission instrument was used to monitor the acoustic emission activity of the whole process of rock destruction under uniaxial compression conditions and plot the fitting graph of the acoustic emission event rate, energy rate, and stress-time curve; the influencing factors of the acoustic emission characteristics of the two rock samples were discussed, and the characteristics of the acoustic emission signals corresponding to different stages of rock failure were analyzed.

Figure 1: Installation of acoustic emission sensor.

2. Description of Rock Samples and Test Equipment

2.1. Preparation of Rock Samples. In this test, two brittle hard rocks with different lithologies, granite and sandstone, are used; the sampling process takes into account the strength and uniformity, so that the rock samples are well representative. According to the relevant international rock mechanics regulations and engineering rock mass test method standards, the rock samples were processed into cylindrical standard specimens with a diameter of 50 mm and a height of 100 mm, and the dimensional accuracy met the requirements of the test regulations.

The good contact between the acoustic emission probe and the rock sample is the key to collecting the acoustic emission signal, in order to ensure that the acoustic emission signal emitted when the rock sample cracks is effectively accepted; in this test, two methods of rubber band fixing and applying high temperature vacuum silicone grease are used to couple the probe and the sample, as shown in Figure 1.

2.2. Test Equipment. This uniaxial compression test uses a css-waw 2000 dl electrohydraulic servo system as the loading device, which can provide a maximum axial pressure of 2000 KN. The acoustic emission instrument used is the SAEU2S multichannel acoustic emission system produced by Beijing Shenghua Technology Co., Ltd. The test system is shown in Figure 2.

3. Test Results and Analysis

3.1. Acoustic Emission Characteristics of Rock Uniaxial Compression. In this test, six cylindrical granite and sandstone samples with a size of $\phi 50$ mm × 100 mm were used, and the loading was controlled by axial strain, and the loading rate was 0.2 mm/min. Set the peak definition time (PDT) to 50 μs and the impact definition time (HDT) to 200 μs. The Latch Time (HLT) is 300 μs; in the test, parameters such as

(a) SAEU2S acoustic transmitter

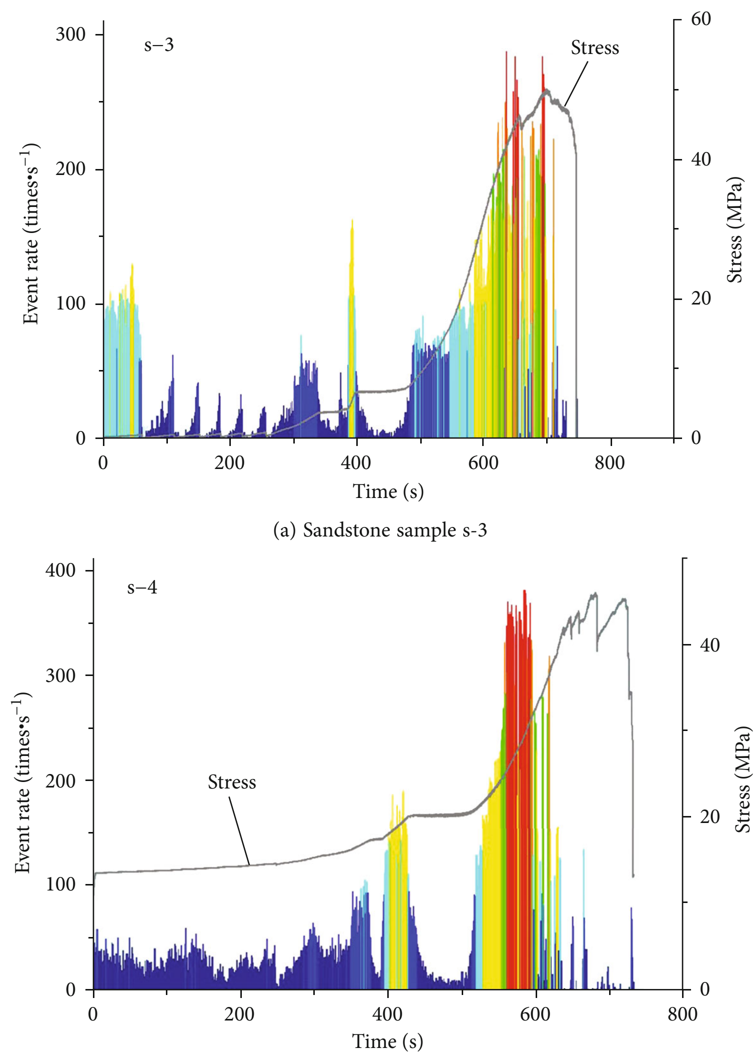
(b) css-waw 2000 dl electrohydraulic servo system

Figure 2: Test system.

acoustic emission signal, load, deformation, and time during the whole process of deformation and failure of the rock sample were measured, the acoustic emission event rate and energy rate of the two rock samples were compared, and the acoustic emission characteristics of rocks with different lithologies were summarized. The stress-time curve is fitted with the acoustic emission event rate and energy rate to analyze and study the corresponding acoustic emission activity characteristics of different rocks in different stages of the failure process.

Figure S1(a) is the curve of AE event rate and stress time variation curve of granite h-4, a small amount of acoustic emission appeared in the early stage of granite loading; this is due to partial collapse or surface caving caused by uneven local force; then, the granite undergoes a compaction stage, only a small amount of acoustic emission occurs for a long time, and the load is maintained at about 10% of the peak value; a small climax occurred at 280 s, indicating a small rupture of the sample; until 410 s, the start of an increase in the acoustic emissivity marks the rock entering an elastic stage, the load and acoustic emission rate increased sharply, and the acoustic emission rate reached the maximum value at 66% peak load; the whole rise lasted just over 100 seconds; at 75% peak load, the acoustic emission rate begins to decrease; after 83% peak load, the acoustic emission quiet period appeared in the middle and late plastic stage; until the destruction stage, only a few acoustic emission events occur; after the peak load, the load decreases rapidly, and a few acoustic emission events occur again. From figure S1(b), the acoustic emission activities of granite h-5 and h-4 are basically similar. The only difference is that the acoustic emission events increase faster in the elastic stage of acoustic emission, and the acoustic emission rate is longer and larger than that in the same stage. However, it also experienced four stages: the initial compaction zone, the rising zone, the peak zone, and the falling zone. And the quiet period of acoustic emission before destruction is also very obvious.

Figure 3(a) shows the variation curve of sandstone s-3 acoustic emission event rate and stress time; the sandstone has a high acoustic emissivity at the initial stage of loading, and then declines in a step-like manner; acoustic emission occurs intermittently throughout the compaction stage; the microcracks that appear during the loading process are also continuously expanding and penetrating to form larger



(a) Sandstone sample s-3

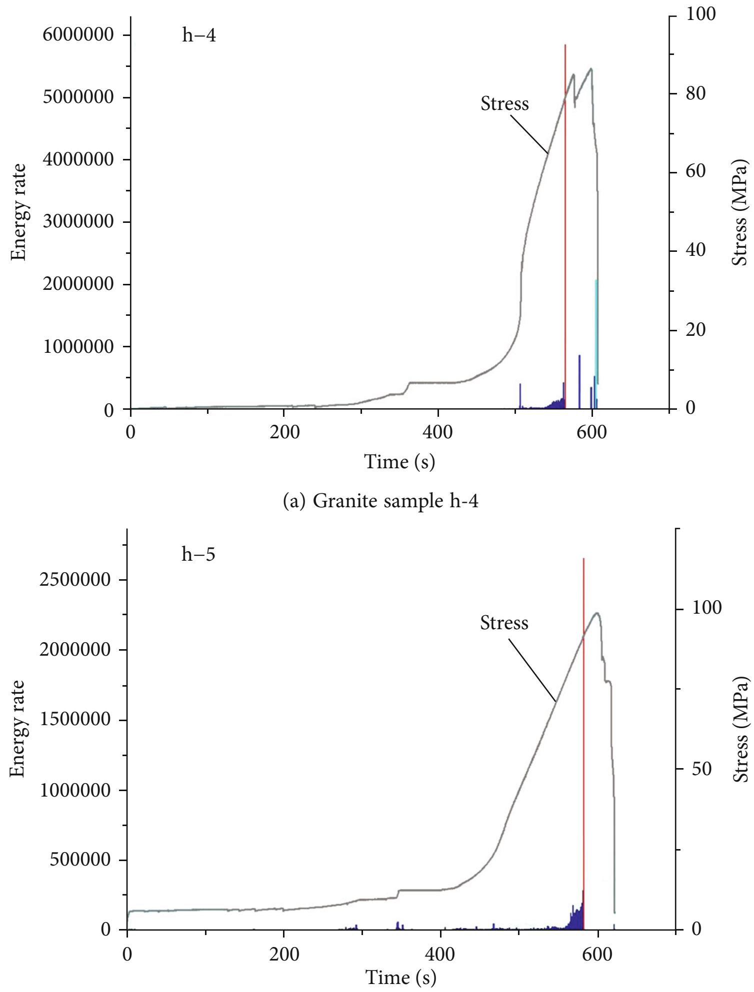
(b) Sandstone sample s-4

Figure 3: Acoustic emission event rate and stress-time curve of sandstone samples.

cracks; at 400 s, a higher acoustic emission appeared; partial collapse or surface caving may be caused by uneven local force; when the peak load is 45%, the acoustic emission rate shows an obvious increasing trend; acoustic emission rate reaches maximum at 80% peak load; the stress continued to increase at 650 s; acoustic emissivity starts to decrease, but remains high; the rock sample enters a relatively quiet period before the peak, which lasts until the peak strength of the rock; the acoustic emissivity has reached its peak again; after that, the rock strength quickly dropped to zero, and acoustic emission rate is also reduced, during which a small amount of acoustic emission activity is generated. From Figure 3(b), the acoustic emission activities of sandstone s-4 continue to appear in the whole compaction stage from the initial stage of loading, which is more obvious than that of s-3, which better explains the characteristics of microcracks in sandstone during loading.

Figure S1 and Figure 3 show that the granite mineral particles are dense and hard, high strength, and brittle, and the acoustic emission event rate during the failure process is the largest. The peak and trough of the acoustic emission event rate during the whole loading process are obvious, but the large acoustic emission rate is concentrated in a very short period of time before the failure, and the duration is very short. When the peak load is about 60-70%, there is a climax, and then, the acoustic emission rate decreases rapidly until it disappears before the failure, and there is a long period of silence, which is very obvious. The acoustic emission rate of the granite after the failure is very small. The sandstone particles are exquisite, and the particles are connected by cements. The texture is soft, the strength is low, the acoustic emission rate is the smallest, and the duration is long. Among them, the sandstone s-3 has a climax when it is loaded to 90% of the peak load and the peak load, and then, only the acoustic emission rate decreases before the failure, but it remains at a high level, and the duration is short. The acoustic emission rate of sandstone is still large after the failure.

This shows that the acoustic emission of different rocks is affected by its own strength, hardness, joint cracks, and



(a) Granite sample h-4

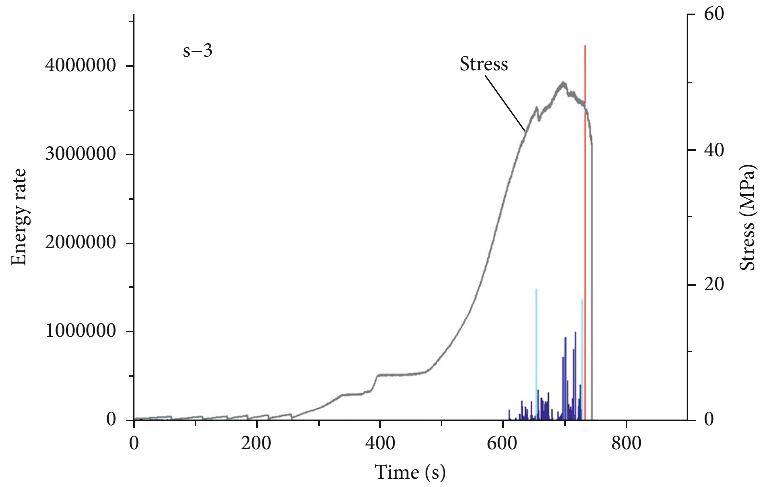
(b) Granite sample h-5

Figure 4: Acoustic emission energy rate and stress-time curve of granite.

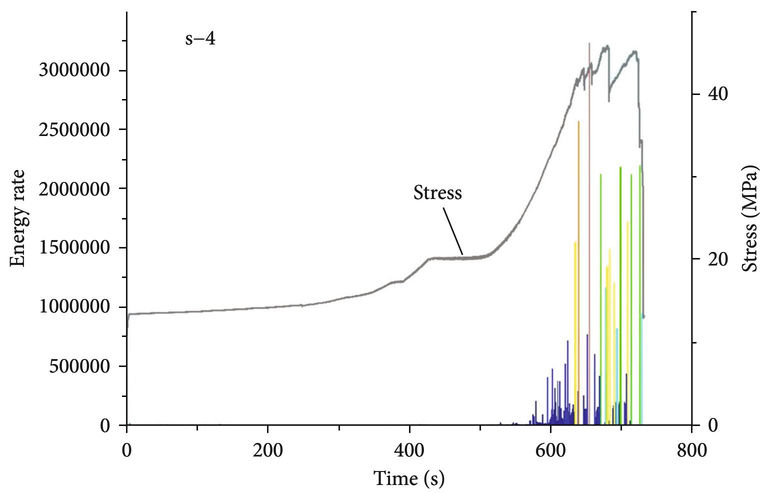
other factors, showing different characteristics, and the different processing of rock samples, different sampling sites, and other factors may affect the acoustic emission characteristics of rock.

Figure 4 is the curve of acoustic emission of granite energy rate and stress time; it is in good agreement with the acoustic emission curve; there is a phenomenon that the peak of the energy rate is slightly delayed from the peak of the acoustic emissivity; both occur at 93% and 90% of peak load; during the whole loading process, the energy rate of granite is relatively high and concentrated before the peak load. Since the energy of granite is concentrated and released before destruction, the maximum value of the energy rate is too large compared to the energy rates at other times; as a result, the acoustic emission energy rate at other times can hardly be displayed in the figure. This shows that the strength of granite is relatively large, and the energy will be released suddenly and concentratedly; when it is destroyed, this is consistent with the loud sound of the granite breaking during the test. Figure 5 is the curve of sandstone energy rate acoustic emission and stress time variation; it can be seen that the acoustic emission energy level of sandstone is lower than that of granite; the same concentration appears before and after the rock failure; and the maximum energy rate appears after the peak load.

Combined with the failure diagrams of granite and sandstone (Figures 6 and 7), and the curves of AE event rate and stress-time change (figure S1 and 3), it can be found that granite has high strength and compact structure, and there is no AE activity in a long period at the beginning of loading. However, with the continuous increase of stress, the number of AE increases suddenly and sharply, and it appears concentrated before the failure. When the failure is accompanied by a burst sound, the specimen is broken. Sandstone mineral particles are relatively hard, but the interior is mainly connected by cement, and the strength is relatively low. Therefore, the acoustic emission activity is relatively small in the loading process. The internal microcracks continue to expand into large cracks with the increase of stress. The fracture angle formed after the failure of different rocks is also different [44, 45]. In the whole process, small splitting sound can be continuously heard, and some fragments will collapse. The last main crack runs through, and the splitting sound is heard but



(a) Sandstone sample s-3



(b) Sandstone sample s-4

Figure 5: Acoustic emission energy rate and stress-time curve of sandstone.

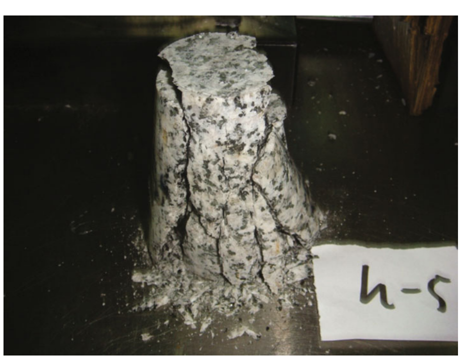


Figure 6: Granite failure diagram.

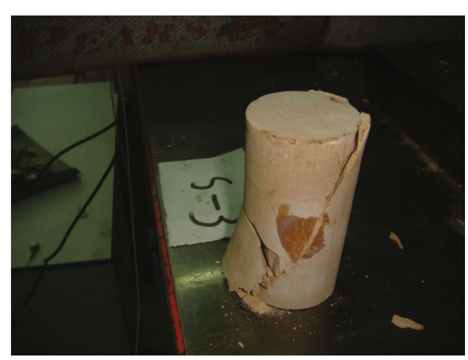
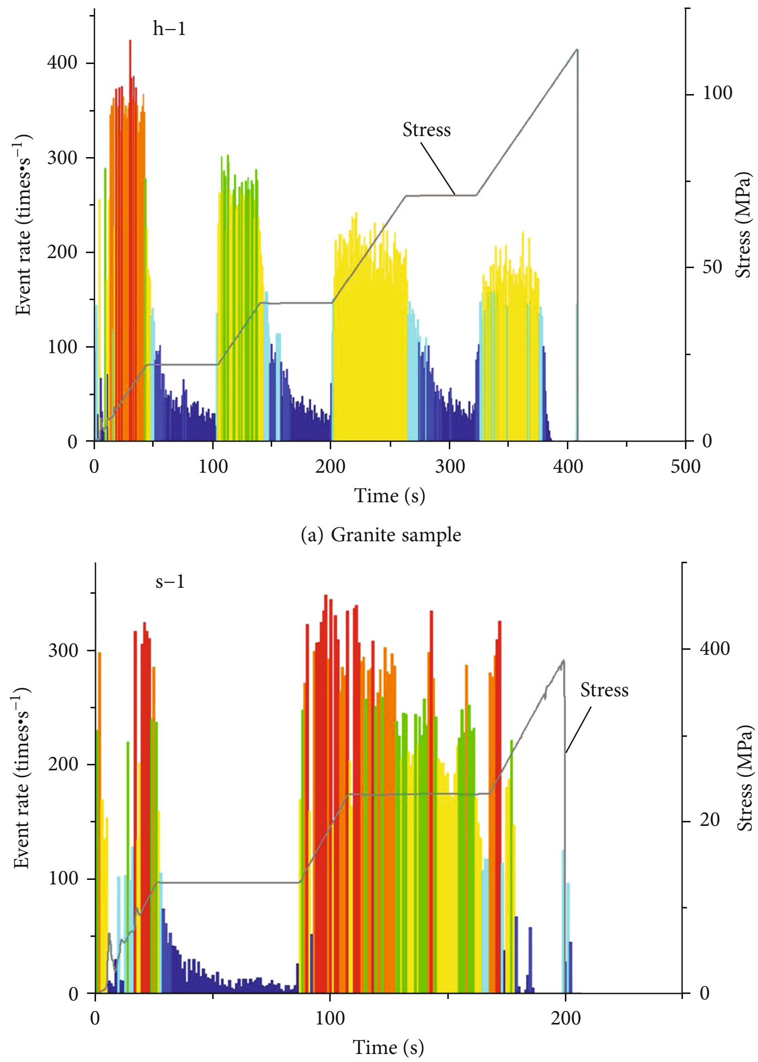


Figure 7: Sandstone failure diagram.

the sound is not large. The rock is mainly broken in the form of splitting.

From the analysis of the time change curve of the acoustic emission event rate and the time change curve of the acoustic emission energy rate, it can be known that (1) the acoustic emission energy rate of the rock is relatively consistent with the acoustic emission rate, both the acoustic emission energy rate and the acoustic emission rate can well reflect the force characteristics of the rock during the loading process, and all can be used as parameters to study the rock failure process. Combining the parameters of acoustic emission energy rate and acoustic emission rate can better



(a) Granite sample

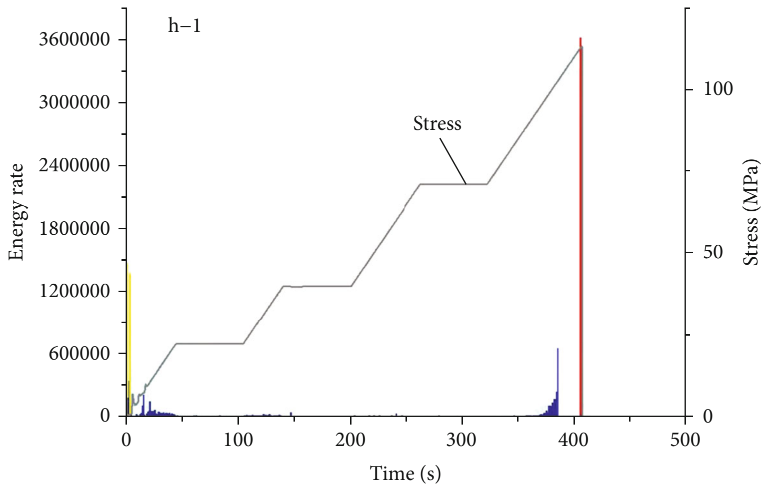
(b) Sandstone sample

FIGURE 8: Acoustic emission event rate and stress-time curve of different rocks.

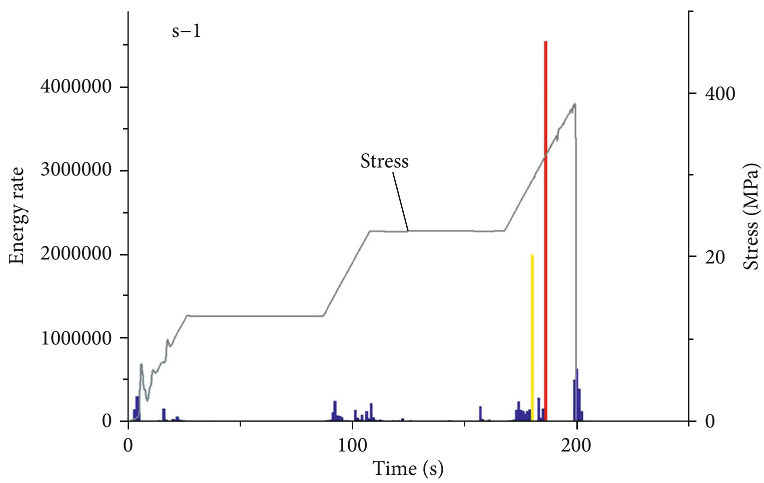
analyze various mechanical characteristics of rock. (2) An obvious quiet zone appears before the granite is destroyed; the sandstone is not obvious. The acoustic emission rate of rock in the quiet zone before the failure is more obvious than that of the acoustic emission rate; in practical engineering, this important characteristic can be used as a precursor to predict the failure of rock mass; it is of great significance for the monitoring and forecasting of acoustic emission of rock mass stability. (3) The peak AE energy rate of rock has a certain delay compared with the peak AE rate; this shows that when large-scale expansion occurs in the interior of the rock, the acoustic emission rate is high but no major fracture occurs; as the stress increases, although the event rate decreases, some large events occur at this time, so the energy released is very large.

3.2. Study on the Acoustic Emission Characteristics of Rocks by Grading Loading. In the above, the acoustic emission characteristics of the rock monotonically loaded in the laboratory were studied; however, the stress situation of rock mass in actual engineering is very complex, and the phenomenon of static load is common. On the basis of the previous research, by studying the whole-process acoustic emission test of graded loading, the acoustic emission characteristics of different rocks during the failure process are further analyzed, and the test equipment is shown in Figure 2.

In this experiment, 5 cylindrical granite and 5 sandstone test blocks with a size of $\Phi 50\,\text{mm} \times 100\,\text{mm}$ were used; in a grade loading method, stress-controlled loading was adopted, and the loading rate was 0.5 MPa/s. The loading process of granite is as follows: the loading stress levels are 22, 40, and 71 MPa, and the pressure is stabilized for 60 s until the test block fails; the sandstone loading process is as follows: the loading stress levels are 13 and 24 MPa, and the pressure is stabilized for 60 s until the test block fails. Record the acoustic emission time of each rock test block, event rate, energy rate, stress, strain, and other data; the stress-time diagram is fitted with the event rate and energy rate to further study the failure mechanism of the rock.



(a) Granite sample



(b) Sandstone sample

Figure 9: Acoustic emission energy rate and stress-time curve of different rocks.

It can be seen from Figures 8 and 9 of the acoustic emissivity and stress-time curves of rock; the acoustic emissivity of the rock increases rapidly during the loading process; during the static load process, it will obviously decrease or even disappear; when loaded again, the acoustic emission rate increases rapidly and greatly, which indicates that the acoustic emission event only occurs obviously when the load changes. Figure 8(b) shows that during the second-order dead load process of sandstone, the acoustic emission rate decreased slightly but remained at a high level; because the sandstone stress had reached a high level at this time, the internal damage accumulation degree is high, and a large number of microcracks penetrate through to form macrocracks.

From Figure 8(a), different from monotonic loading, granite produces a lot of acoustic emission in the early stage of loading; however, the acoustic emission rate decreases gradually with the increase of each level of load from the beginning of loading to the failure; before the peak load, the acoustic emission phenomenon disappeared and entered a quiet period. From Figure 9(a) of the energy rate, it can be seen that the energy rate reaches the maximum before the failure; this shows that the microcracks in the granite continued to initiate and expand in the early stage, and a large number of small damages occurred inside the rock. The acoustic emission rate is large but the energy released is not large, and the acoustic emission rate is low before the destruction, but what happens is a big event that releases a lot of energy with it. From Figure 9(b), compared with granite, the acoustic emission rate of sandstone is lower; however, it remains at the peak level during the loading process and only enters a quiet period before the failure and instability. This shows that in practical engineering with complex forces, taking the quiet period before rock failure and instability as a precursor feature of rock mass instability has extremely important application value for prediction and prediction before disasters.

The acoustic emission characteristics of rock samples were studied by using different loading methods; the analysis shows that the failure mechanism of rock is different under different loading methods. The different loading rates of the two loading methods, monotonic loading and grading loading, will affect the rate of change of acoustic emission; the increase of the loading speed leads to the increase of the damage degree of the rock; this can be found from the fact that the peak strengths of the two types of rocks under uniaxial loading are much lower than those under grading loading; in particular, there is a 30% difference in peak strength of granite under two different loading methods.

From the above analysis, it can be seen that all rock acoustic emissions experience an initial compaction zone, a rise zone, a peak zone, and a drop zone. However, there are certain differences between the two types of rocks in the peak area and the decline area. In the initial compaction stage, since the stress value is kept at a low level, the resulting acoustic emissivity is very low to none. The rising stage corresponds to the elastic stage of the rock; with the continuous increase of stress, many microcracks are generated inside the rock, the acoustic emission activity increased significantly, and the acoustic emission event rate also increased linearly. The peak area corresponds to the plastic stage of the rock; at this stage, the microcracks in the rock continue to expand and penetrate, and a large number of acoustic emission events are generated in a short period of time; the acoustic emission rate reaches the maximum. The descending zone is the stage of rock destruction, and the acoustic emission activity decreases rapidly until it disappears. Granite also experiences a quiet zone, a period of quiet acoustic emission before failure. Whether different rocks go through each stage and how long each stage lasts is related to the nature of the rock.

4. Conclusion

In this paper, through theoretical analysis and indoor acoustic emission test, uniaxial compression tests were conducted on granite and sandstone under monotonic loading and grading loading, and acoustic emission characteristics of rocks are obtained. By analyzing the acoustic emission energy rate and event rate corresponding to different failure stages of rock samples, the influencing factors of acoustic emission characteristics of two kinds of rock samples are summarized, and the failure mechanism of rock is discussed. This provides a method and theoretical basis for more accurate prediction of disasters in practical engineering. Conclusions are as follows:

(i) Under different loading methods, the failure mechanism of rock is different. The different loading rates of the two loading methods, monotonic loading and grading loading, will affect the rate of change of acoustic emission; the increase of the loading speed leads to the increase of the damage degree of the rock; this can be found from the fact that the peak strengths of the two types of rocks under uniaxial loading are much lower than those under grading loading; in particular, there is a 30% difference in the peak strength of granite under the two different loading methods

(ii) Rock acoustic emission has experienced initial compaction zone, rising zone, peak zone, and descending zone. Granite and marble also experienced the calm period of sound launch before the silent area, whether different rocks go through the length of each stage and the duration of each stage is related to the nature of the rock

(iii) The peak of the acoustic emission rate of the rock has a certain delay than the peak of the acoustic emission rate. This shows that when a large area expansion occurs inside the rock, the acoustic emission rate is high but there is no large rupture; as the stress increases the incident rate, there are some large events that occur at this time, so the energy released is very large

(iv) Rocks have a silent zone in the emission incident before destroying the loss of stability. In actual engineering, this important feature can be predicted as a precursor characteristics of rock body destruction; it has important guiding significance for monitoring and forecasting of rock body stability. The sound rate of rock acoustic emission is more obvious than the acoustic emission rate before the destruction, and it can better reflect the precursor characteristics before the rock destruction and provide a test basis for more accurate prediction and forecasting actual projects

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Yongshuai Sun is responsible for the writing—original draft and writing—review and editing; Fei Yu for the investigation, methodology, and validation; and Jianguo Lv for the data curation, formal analysis, funding acquisition, and project administration. All the authors have reviewed the final version of the manuscript and approved it for publication.

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Supplementary Materials

Figure S1: acoustic emission event rate and stress-time curve of granite samples. *(Supplementary Materials)*

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