Acoustic Emission Activity in Bed Rock Surrounding Underground Working Faces in Deeplevel Coal Seams

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Abstract

The acoustic emission activity in the bed rocks surrounding faces in deeplevel coal mining operations such as cross cutting, drifting, hydraulic mining and relief boring was observed with the original acoustic emission monitoring system in Sunagawa Coal Mine and Akabira Coal Mine, Hokkaido. This monitoring system allowed for monitoring acoustic emissions created in the bed rock. The method had sufficient sensitivity for practical application.

Consequently, it was recognized that acoustic emission technique was useful as a method for estimating the degree of instability of the bed rock surrounding working faces in deeplevel mining. Especially, these observational results provided a new interpretation for predicting the occurence of violent underground disturbances such as rock and coal bursts.

1. Introduction

Recently, the acoustic emission technique has attracted special interest as a method for estimating the degree of instability of the rock structure surrounding underground working faces in deeplevel mining[1,2,3,4].

The primary objective of this research is to clarify whether the acoustic emission technique is useful as a method for predicting the occurrence of violent underground disturbances such as rock and coal bursts. The observations were conducted in Sunagawa Coal Mine and Akabira Coal Mine from 1976 to 1978.

Acoustic emissions created by deeplevel ($-700 \sim 900$ m) mining operations such as cross cutting, drifting, hydraulic mining and relief boring were observed with sufficient sensitivity for practical use by the original acoustic emission monitoring system. In practice, acoustic emission signals were detected by the vibration sensors cemented into the boreholes in the solid rock surrounding underground mining operations. The electrical signals were amplified by the preamplifier placed in a flame-proof box, and were transmitted as the input signals of the monitoring facility on the ground surface. Therefore, this original monitoring system allowed for a satisfactory analyzation of parameters associated with acoustic emission activity with real time.

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As these analytical results, the parameters such as count rate, events and relative energies associated with acoustic emission activity increased greatly as the rock in the vicinity of an underground working face became more highly loaded. Consequently, these parameters appeared to be a factor indicative of the degree of instability of the rock in highly stressed zones. Furthermore, it was shown that acoustic emission techniques were useful as a method for identifying the occurrence of gas outburst induced by blasting and observing the effects of stress relief by boring.

2. Instrumentation

Figure 1 presents a block diagram of the acoustic emission monitoring system in Sunagawa Coal Mine. This original system consists of a basic 4-channel system, and included in the basic system are 4 vibration sensors, 4 preamplifiers, a monitoring facility which accepts 4-input, a data recorder and analyzing facilities which both accept 2 input, and a real-time spectrum analyzer.

These vibration sensors have a high sensitivity of 250 mV/g and a flat frequency response from 2 to 3,000 Hz. They were cemented into the boreholes prepared in the solid rock around underground mining openings, or fixed to the end of steel pipes about 5 m in length cemented into the boreholes as shown in Fig. 2. The preamplifiers placed in a flame-proof box were connected to the vibration sensors with 2 conductor shielded cables, and these circuits were intrinsically safe. Between

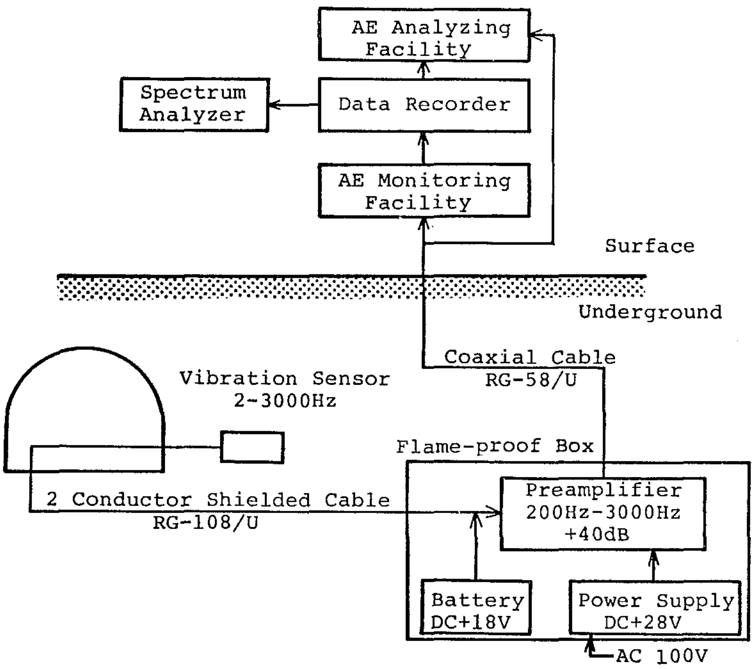

Fig. 1. Overall acoustic emission monitoring system in Sunagawa Coal Mine.

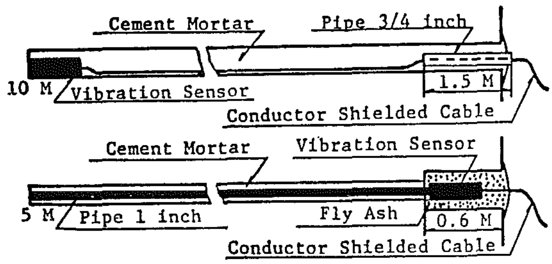

Fig. 2. Cemented methods of vibration sensor in borehole.

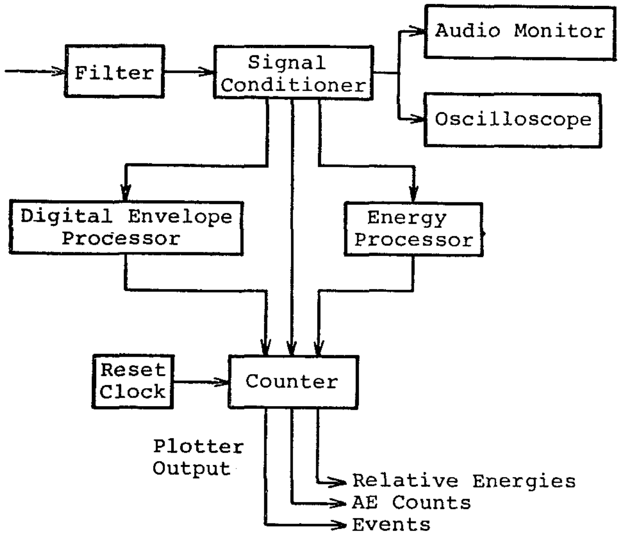

Fig. 3. Block diagram of acoustic emission monitoring facility.

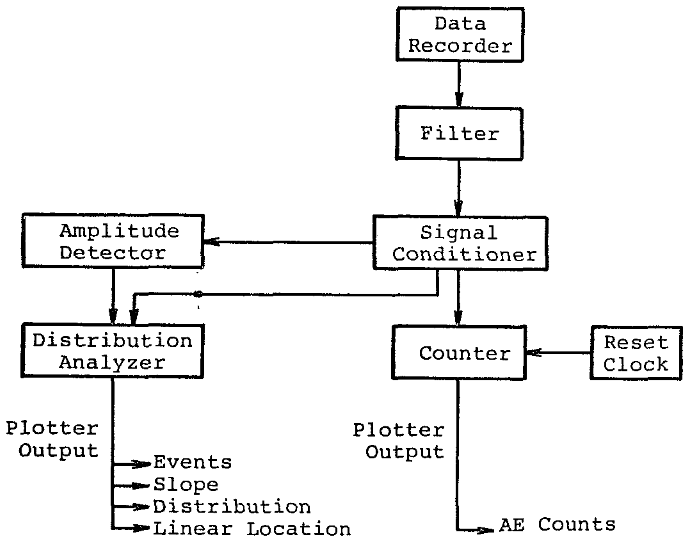

Fig. 4. Acoustic emission analyzing facility.

the flame-proof box underground and the monitoring facility on the surface four coaxial cables were installed in the main level, incline shaft and vertical shaft.

Acoustic emission signals are detected by the vibration sensors. After detection, the electrical signals are amplified by the preamplifier which has a fixed gain of 40 dB, and are transmitted as the input signals of the monitoring facility on the surface.

Fig. 3 and 4 show functional block diagrams of the monitoring facility and analyzing facility made by Dungan/Endevco respectively. The electrical signals obtained from the preamplifier are amplified again by the signal conditioner which contains two secondary amplifiers of variable gain (0–60 dB in 1 dB steps), and only signals that exceed one volt peak are converted to digital pulses. These pulses are routed to the digital counters as acoustic emission pulses directly and as events pulses through the digital envelope processor. Furthermore, the signals amplified by the signal conditioner are converted to energies pulses through the energy processor, and routed to the digital counter. Each counter sums all pulses received and provides a DC output of acoustic counts, events and relative energies. In this manner total cumulative acoustic emission data are obtained. Command pulses from the reset clock provide an acoustic emission rate plot. In the analyzing facility of Fig. 4, the distribution analyzer performs a distribution of acoustic counts, pulse width, amplitude or relative energies with the signal conditioner, amplitude detector or energy processor. Additionally the distribution analyzer allows for a linear location.

The important acoustic emission signals were recorded as necessary, and analyzed in detail by the spectrum analyzer and the analyzing facility. In practice the analytical results by the spectrum analyzer give the optimum conditions such as a frequency band, a gain of amplification or a threshold level in analyzing the parameters associated with acoustic emission activity.

3. Acoustic emission activity during cross cutting

Fig. 5 shows typical acoustic emission signals recorded during observations in cross cutting and their frequency spectrum. L and R respectively are the signals detected by the vibration sensor cemented directly into the borehole and fixed to a steel pipe. The signal of L was composed of a frequency content under approximately 5,000 Hz, while the signal of R was under approximatley 3,000 Hz. Fig. 6 presents the acoustic emission signals recorded immediately after blasting in the coal seams. In this case many events occurred in a few brief moments, and the background noises are negligibly small compared with the acoustic emission signals. To observe such reliable signals, special attention was paid to the selection of the vibration sensor locations and cable routes.

Fig. 7 (a) shows the acoustic emission activity of the solid rock in the vicinity of a working face after blasting in cross cutting, and Figure 7 (b) shows the acoustic emission activity at the boundary between the rock and the coal seam. In Fig. 7 (a) no acoustic emission activity was found after blasting, but in Fig. 7 (b) the curves such as accumulated counts, events and relative energies steepen rapidly immediately after blasting and become flatter with the lapse of time. Generally, the curve of the accumulated values associated with the acoustic emission activity shows a pattern such as seen in Fig. 7 (a) in the case of blasting solid rock and a pattern such as Fig. 7 (b) is seen in the case of blasting rock adjacent to a coal seam. From these observational results, it is suggested that in solid rock fractures do not occur at the stress level induced in the process of stress redistribution, and that in weak rock many fractures occur at that stress level.

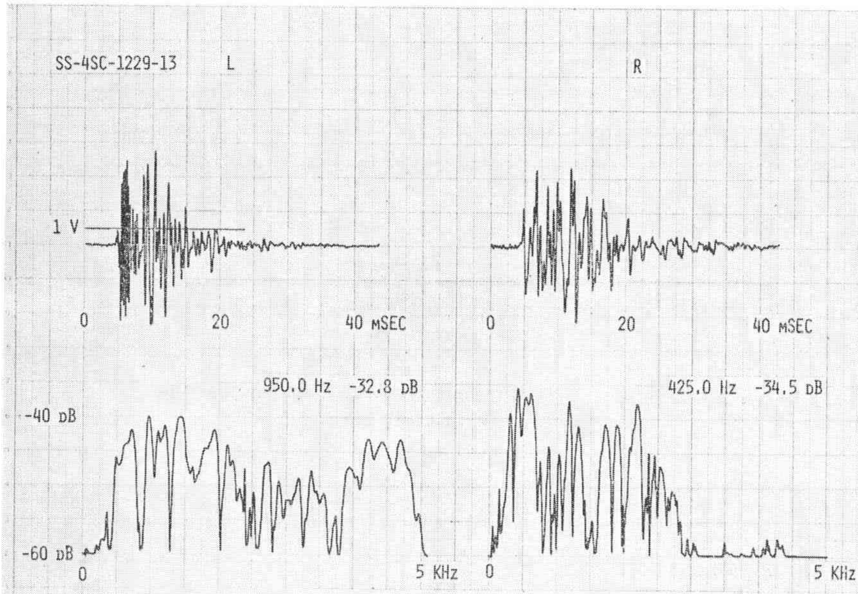

Fig. 5. Typical acoustic emission signals and their frequency spectrum.

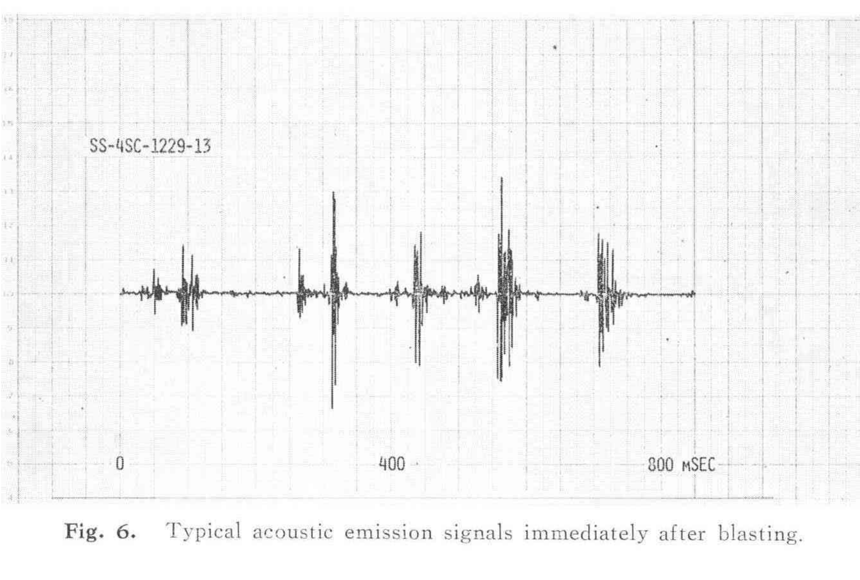

Fig. 6. Typical acoustic emission signals immediately after blasting.

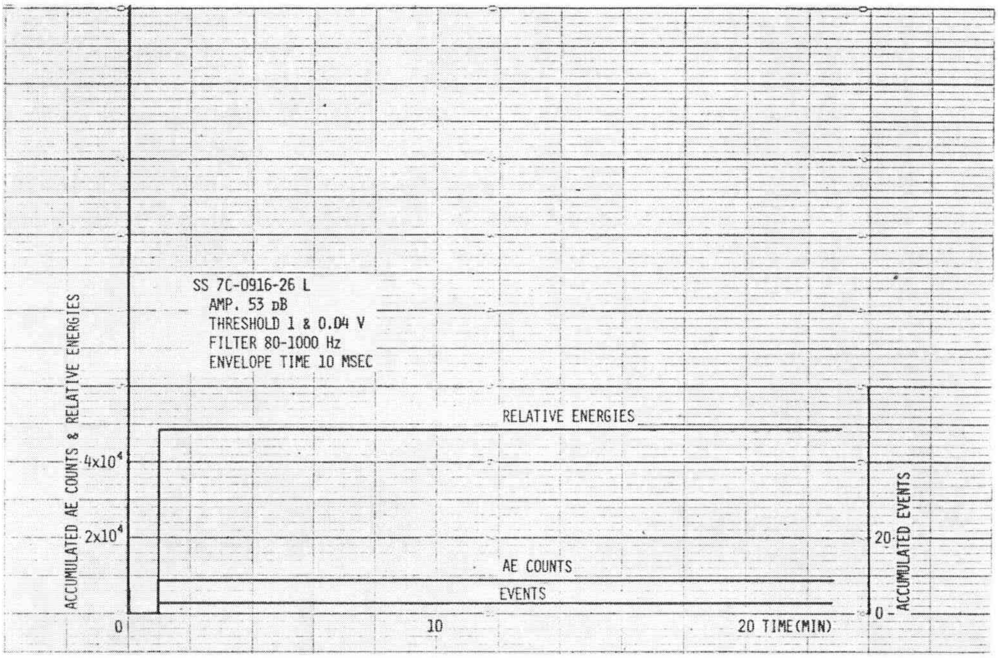

Fig. 7 (a). Acoustic emission activity after blasting solid rock in cross cutting.

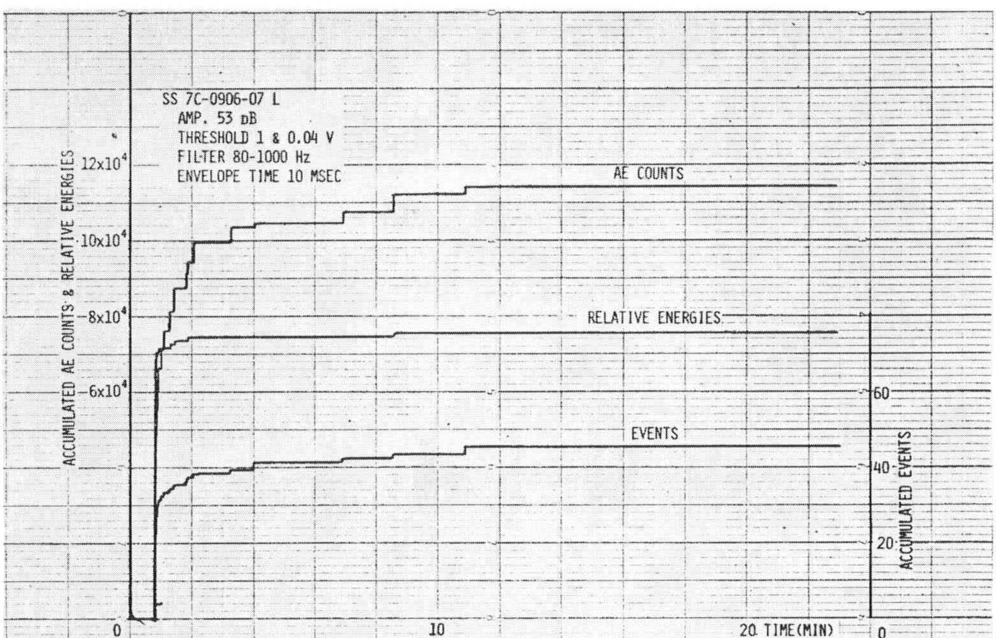

Fig. 7 (b). Acoustic emission activity after blasting rock adjacent to coal seam in cross cutting.

Fig. 8 and 9 present the arrangement of the vibration sensor relative to the coal seams during cross cutting and the various examples of the observations involving the acoustic emission activity after blasting in the crosscut face. In Fig. 8 the numbers which show the section of working face advanced correspond to those in Fig. 9 (a)-(f). Until the crosscut advance on number 2, the acoustic emission activity is limited only after blasting as shown in Fig. 9 (a), but with the crosscut advancing on the number 3, much successive activity is found for a considerable length of time as shown in Fig. 9 (b). However, subsequently, the activities decrease with the advance of the crosscut as shown in Fig. 9 (c). Especially, no acoustic emission activity is found after blasting in Figure 9 (d). This is an abnormal phenomenon during cross cutting in these coal seams. At the next blasting corresponding to number 9 in Fig. 8, the acoustic emission activity increases rapidly as shown in Fig. 9 (e) and a gas outburst occurred at that instant. Fig. 9 (f) shows the acoustic emission activity at the instant of the gas outburst on a magnified time scale. Here, acoustic emission counts are illustrated per unit time. From this histogram it is confirmed that the gas outburst began to occur after approximately 10 seconds after blasting and maintained its activity for about 10 seconds. In this gas outburst about 35 m^3 of powedered coal burst out with a large amount of gas.

Fig. 10 illustrates the variation of accumulated events per 40 minutes after blasting with each advance of crosscut. Here, the horizontal axis shows the section of the crosscut. Two peaks of acoustic events are distinguished in each cross cutting of No. 2, No. 7 and No. 4 SUB, and the locations of these peaks correspond to the section where the face approaches the geologically weak band of a seam with mylonite. But in the crosscut of No. 4 a clear peak is found at the

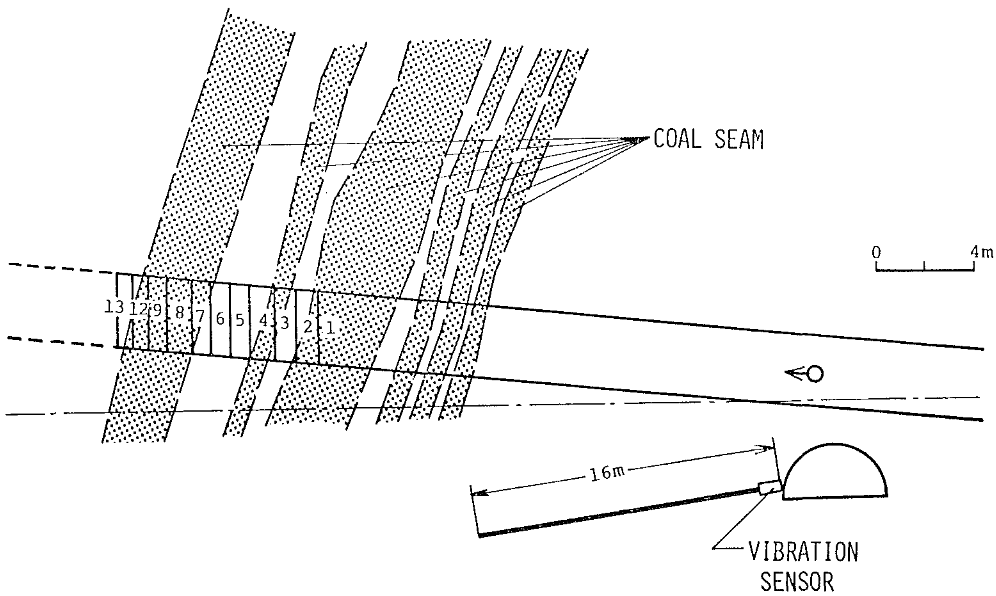

Fig. 8. Arrangement of vibration sensor for detection of acoustic emission during cross cutting.

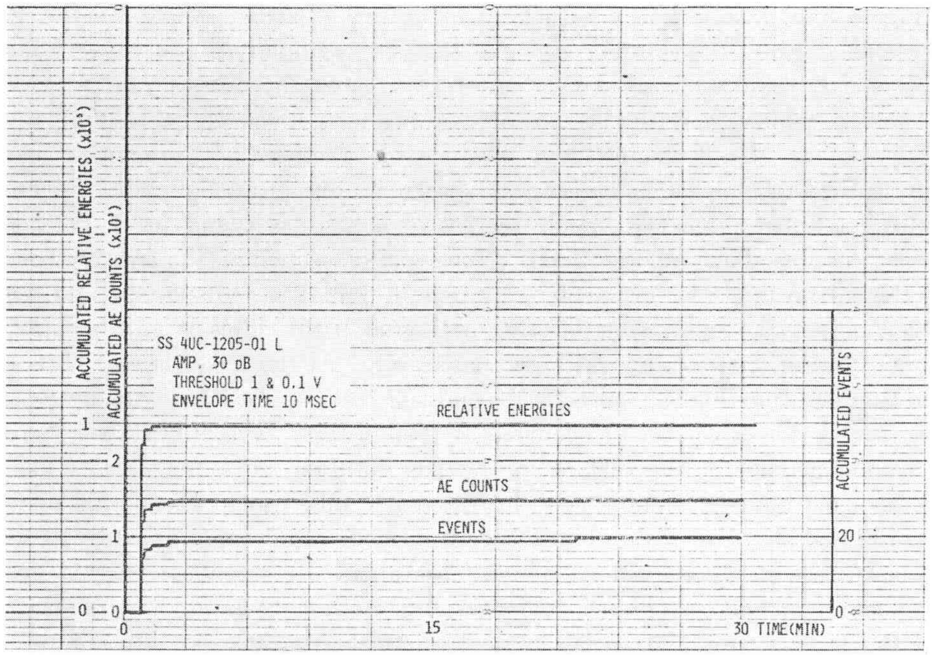

Fig. 9(a). Acoustic emission activity after blasting in cross cutting.

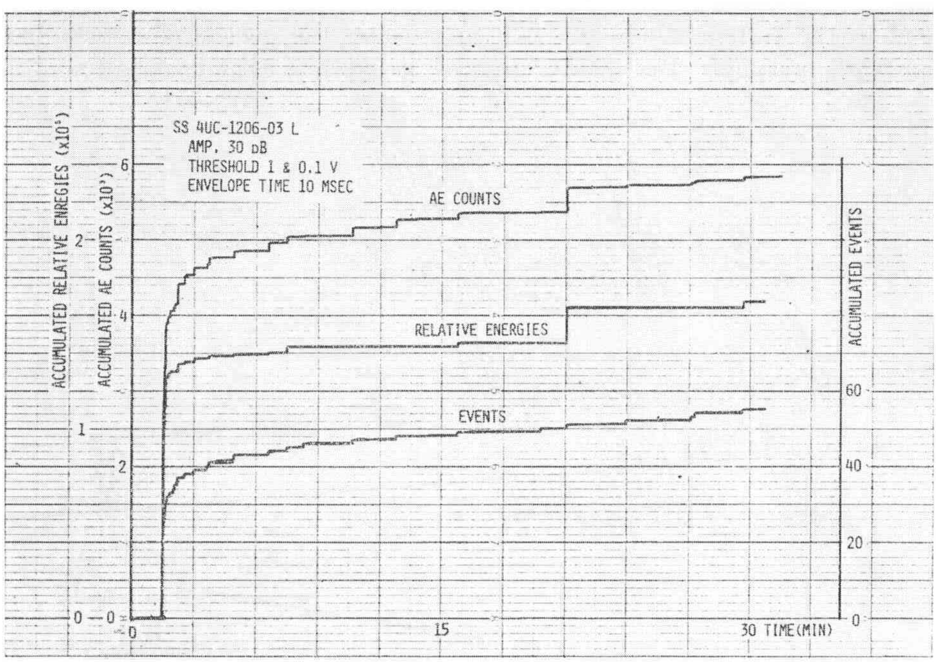

Fig. 9(b). Acoustic emission activity after blasting in cross cutting.

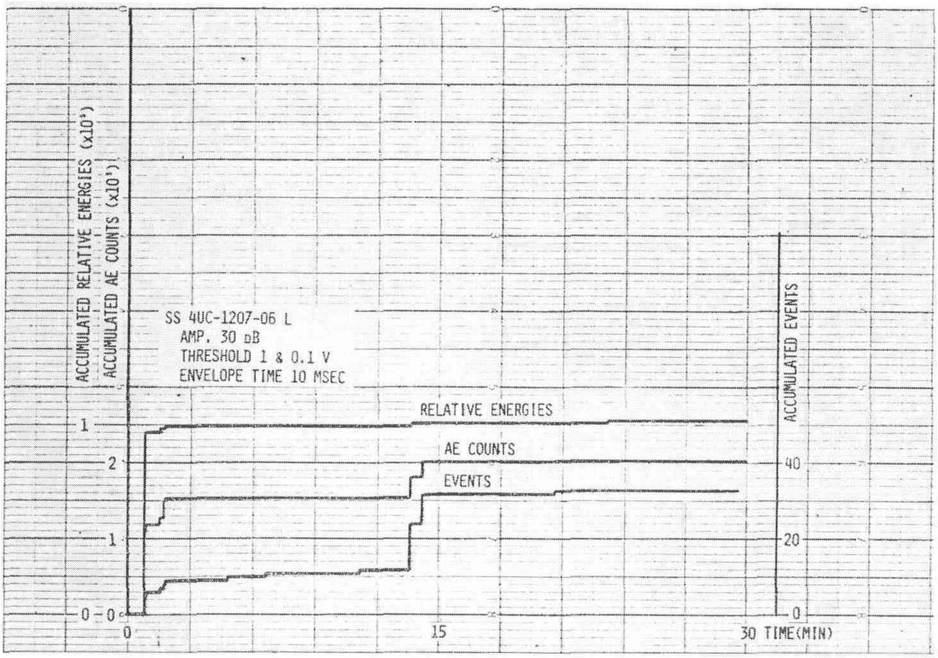

Fig. 9(c). Acoustic emission activity after blasting in cross cutting.

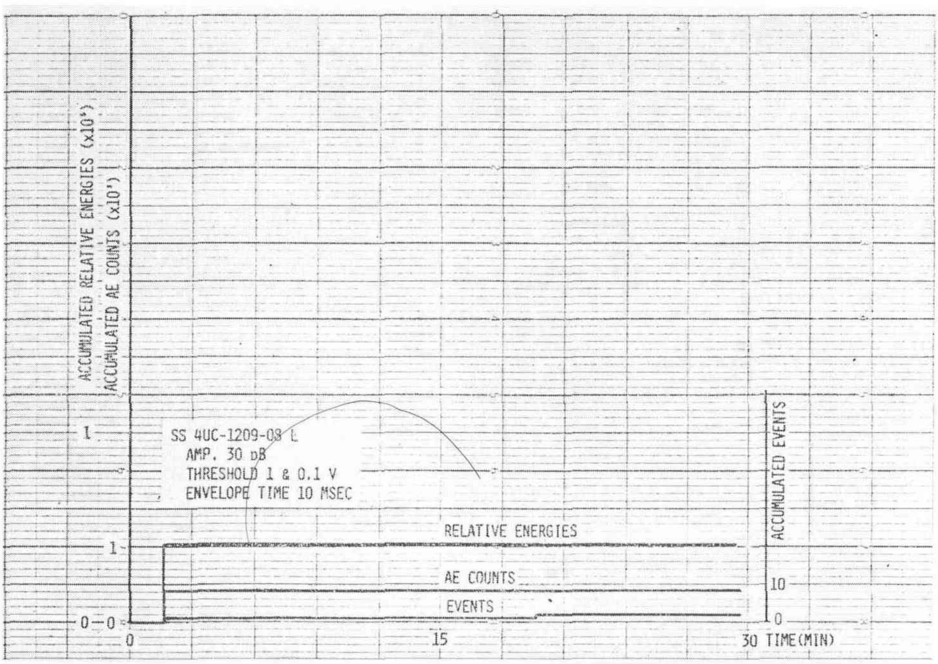

Fig. 9(d). Acoustic emission activity after blasting in cross cutting.

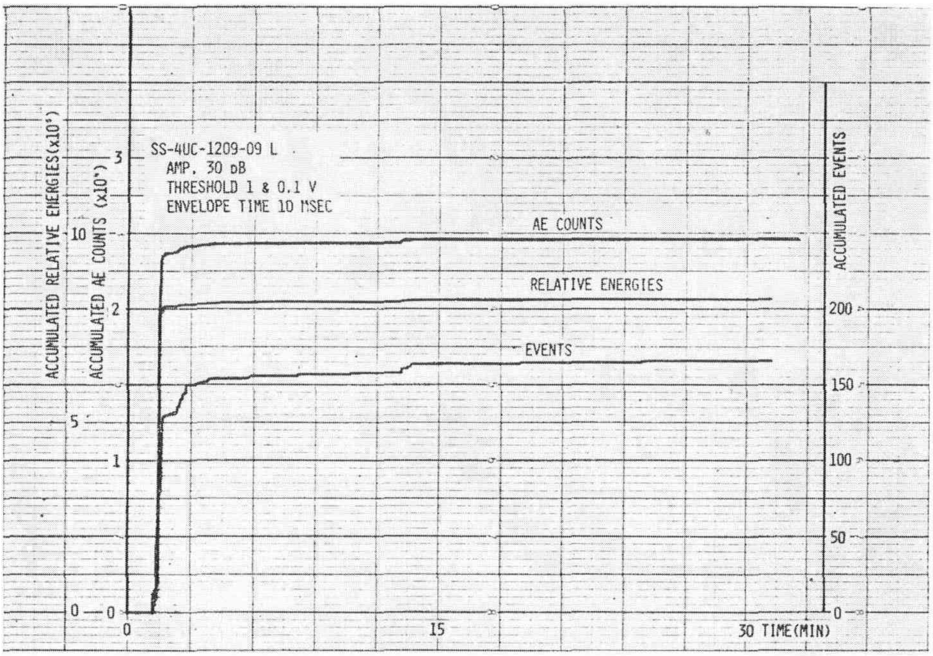

Fig. 9(e). Acoustic emission activity after blasting in cross cutting.

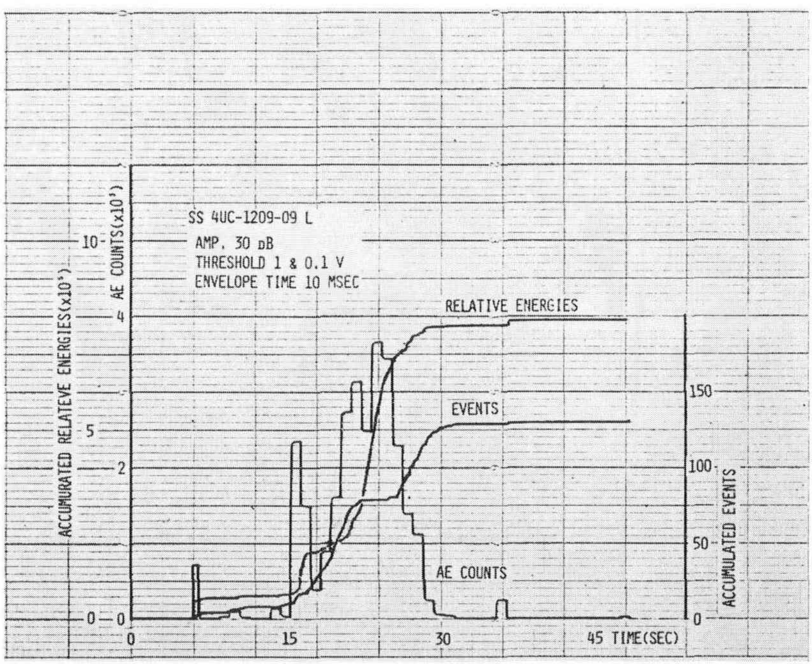

Fig. 9(f). Acoustic emission activity after blasting in cross cutting.

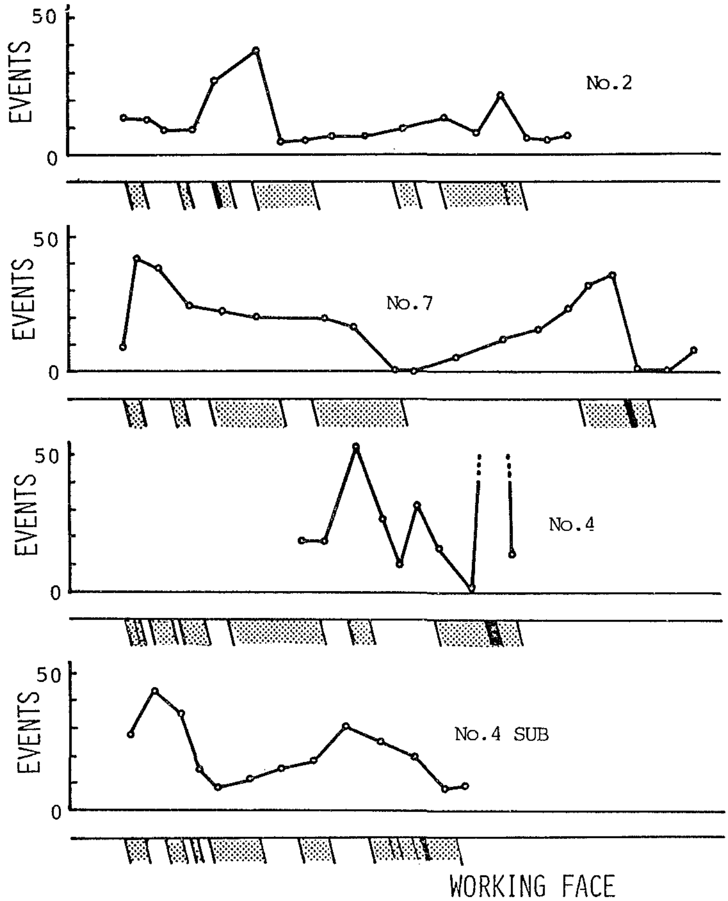

Fig. 10. Variation of accumulated events per unit time with advance of working face in cross cutting.

location where a geologically weak band does not occur. Additionally, acoustic events vanished although the face was advancing into the upper coal seam. These facts are abnormal compared with the case of the other three crosscuts, and suggest the possibility of predicting a gas outburst after blasting.

4. Acoustic emission activity in drifting and hydraulic mining

Fig. 11 shows the arrangement of vibration sensors for acoustic emission in drifting of a sublevel and the results of observations of acoustic events per 15 minutes after blasting with each advance of drift. Here, two sensors were cemented directly into boreholes, at a distance about 33 m apart, which were drilled in a vertical direction of the sublevel from the other level.

Fig. 12 (a) and (b) are examples of results of observations in drifting. More successive acoustic emission activity is found after blasting in Fig. 12 (a) corresponding to number 10 in Fig. 11, while no acoustic emission activity is found after blasting in Fig. 12 (b) corresponding to number 13. In these cases, the pattern of acoustic emission occurrence after blasting is very similar to that of cross cutting. A line graph as shown in Fig. 11 is obtained by plotting the number of events per 15 minutes after blasting with each advance of drift. Acoustic emission activity after blasting was high in the first half of drifting, and was low in the second half of drifting. From this line graph it may be considered that there was a highly stressed zone due to mining conditions in the first region.

Fig. 13 shows the arrangement of vibration sensors for acoustic emissions in hydraulic mining and the results of observations of acoustic events in each mining panel. The sensors cemented to detect the acoustic emissions in drifting were used in these observations. Fig. 14 (a), (b) are examples of results of observation in hydraulic mining. The acoustic emissions created by caving were monitored very well. More successive acoustic emission activity during hydraulic mining is found in Fig. 14 (a) corresponding to number 0 of mining panel in Fig. 13. Acoustic emission activity during hydraulic mining is not found a great extent in Fig. 14 (b) corresponding to number 1 of mining panel compared with that in number 0. A line graph as shown in Fig. 13 is obtained by plotting the number of acoustic events per 6 hours in each mining panel. This line graph indicates that a highly stressed zone was induced by caving fast at the beginning of hydraulic mining.

As the results above mentioned, the parameters such as count rates, events and relative energies associated with acoustic emission activity appear to be factors

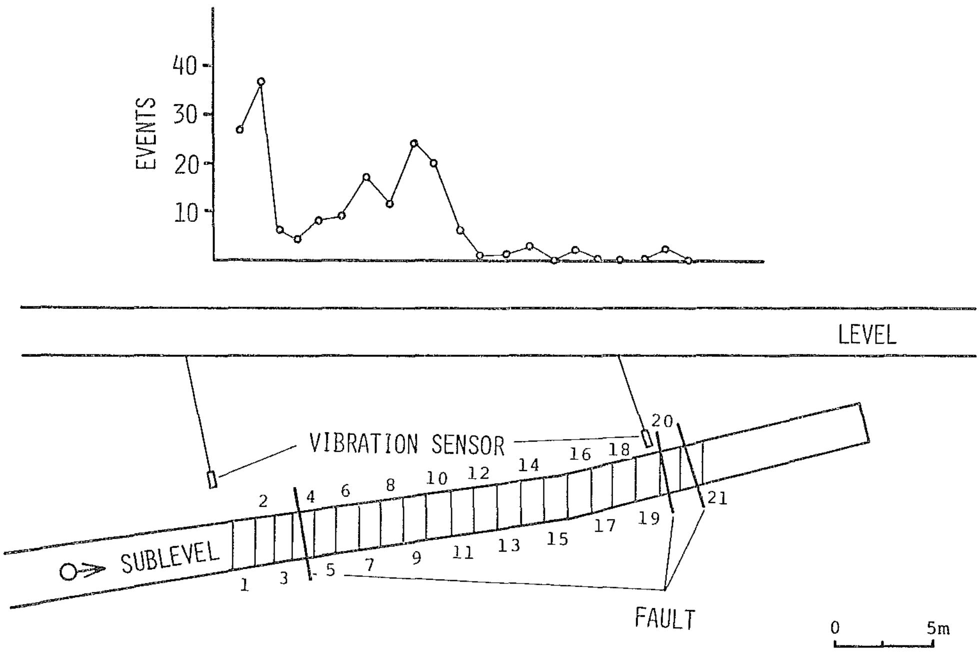

Fig. 11. Variation of accumulated events per unit time with advance of working face in drifting of sublevel.

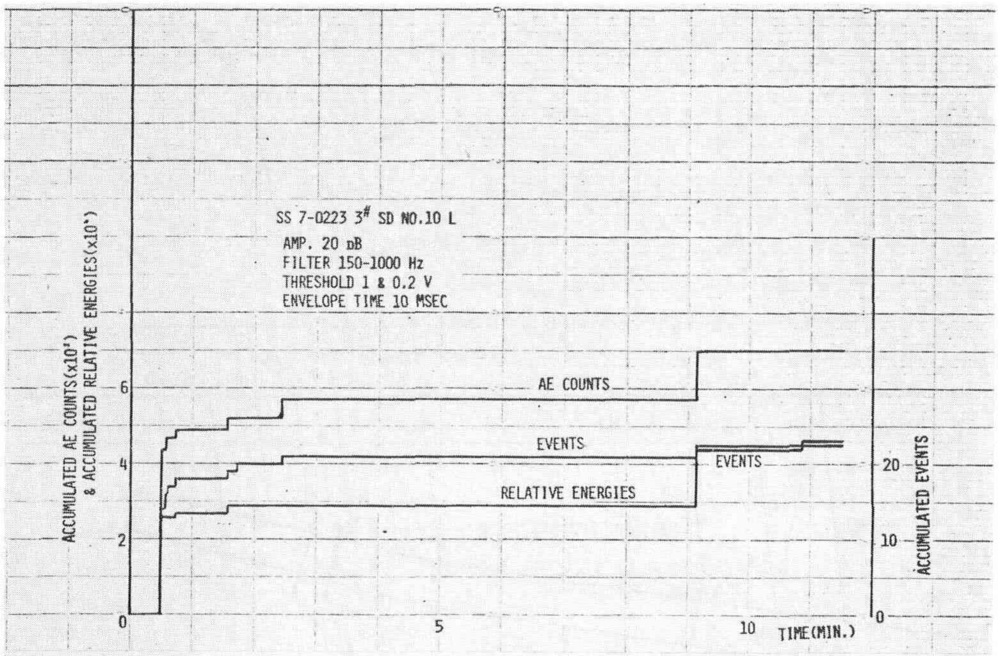

Fig. 12 (a). Acoustic emission activity after blasting in drifting.

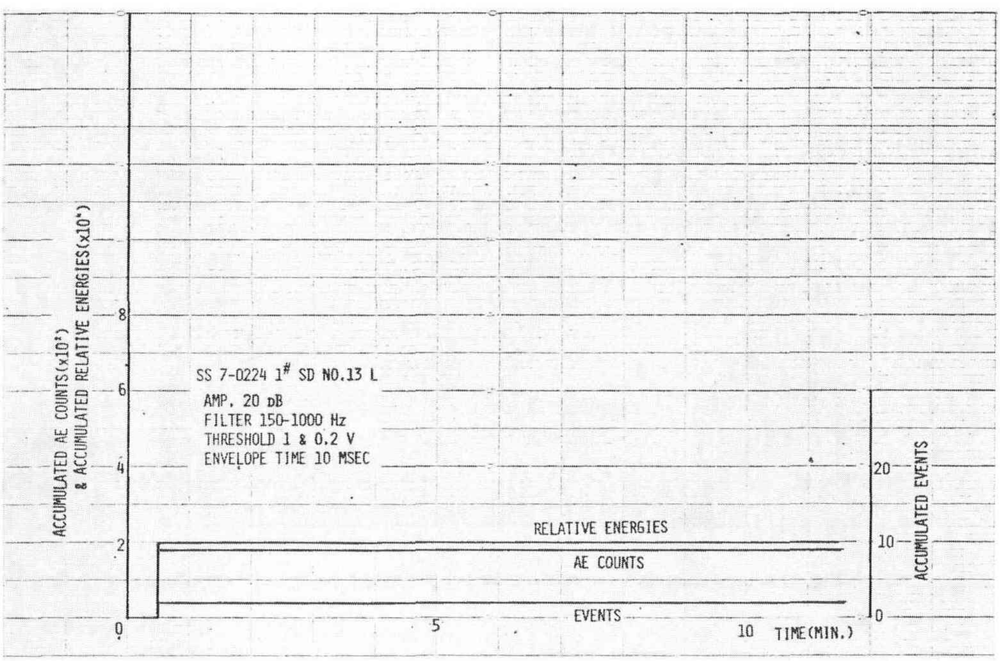

Fig. 12 (b). Acoustic emission activity after blasting in drifting.

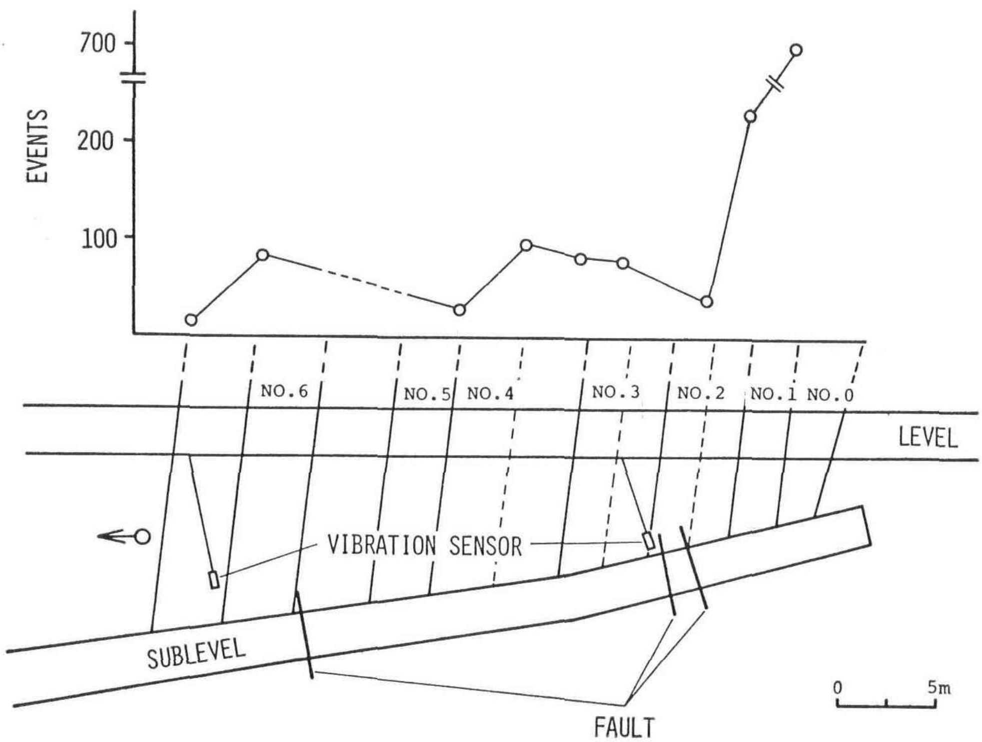

Fig. 13. Variation of accumulated events per unit time with advance of working face in hydraulic mining.

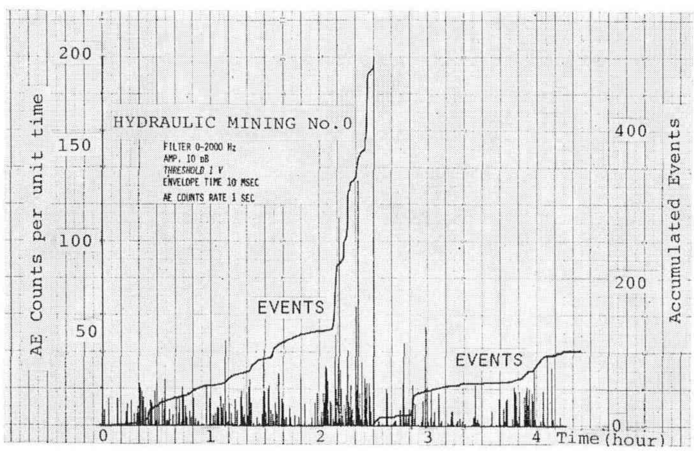

Fig. 14 (a). Acoustic emission activity during hydraulic mining.

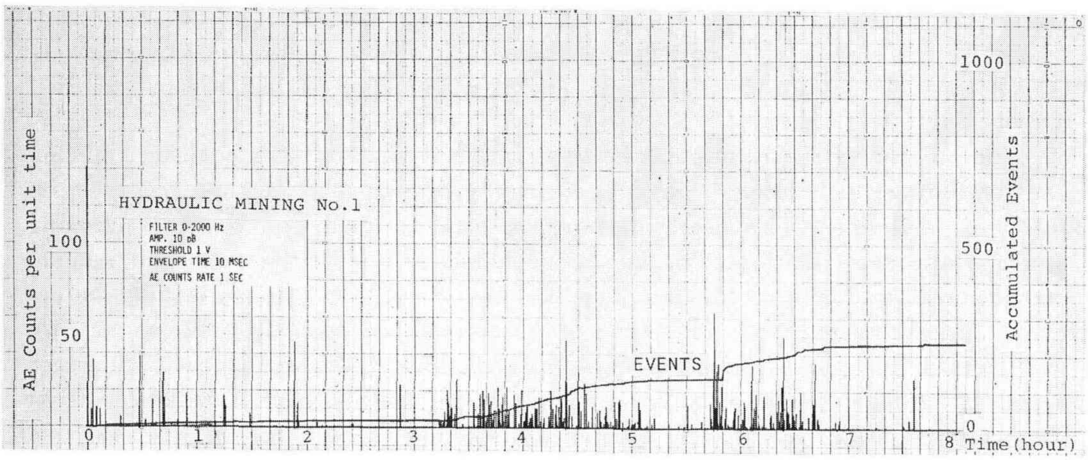

Fig. 14 (b). Acoustic emission activity during hydraulic mining.

indicative of instability of the bed rock around underground mining operations.

5. Acoustic emission activity in boring

The observations of acoustic emission activity in boring were carried out to assess the effects of stress relief in Akabira Coal Mine. Fig. 15 shows the arrangement of a vibration sensor for the detection of acoustic emission during boring. This boring was conducted by using an air boring machine of 12 PS. The borehole

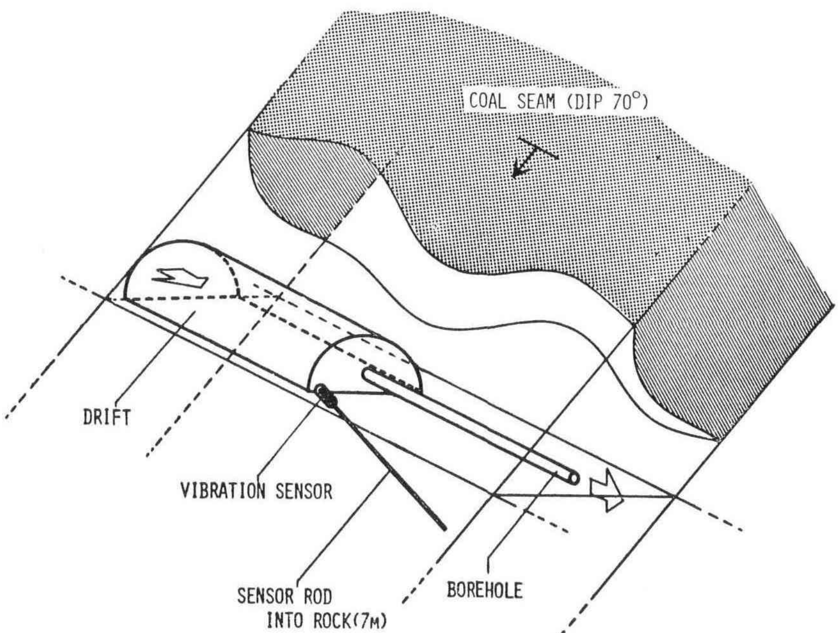

Fig. 15. Arrangement of vibration sensor for detection of acoustic emission during relief boring.

was drilled in a coal seam by boring with 250 mm in diameter and the spiral rods of 1 m in unit length. Acoustic data recorded in magnetic tapes underground were played back on the surface, and presented for the analysis of acoustic emission activity.

Fig. 16 shows the results of the observation associated with acoustic emission activity during this boring. The noises of the boring machine are recorded on the horizontal line. The depth of borehole can be read out by discriminating among these noise marks. The curves depicting accumulated events and relative energies rise gradually as the borehole becomes deep, and steepen rapidly immediately prior to jamming. This type of observation of acoustic emission activity was carried out several times, and all results showed the tendency to increase rapidly at an inner region 5 to 15 m away from the working face of drifting. From these observational facts it was confirmed that there was a highly stressed zone in the region of the depth where the curves illustrating acoustic emission activity steepen rapidly.

In Fig. 16 the strongest correlation was observed between the accoustic emission activity and the volume of cuttings. Therefore it can be considered that the value of accoustic emission measurements is useful as a method for estimating the effects of stress relief by boring.

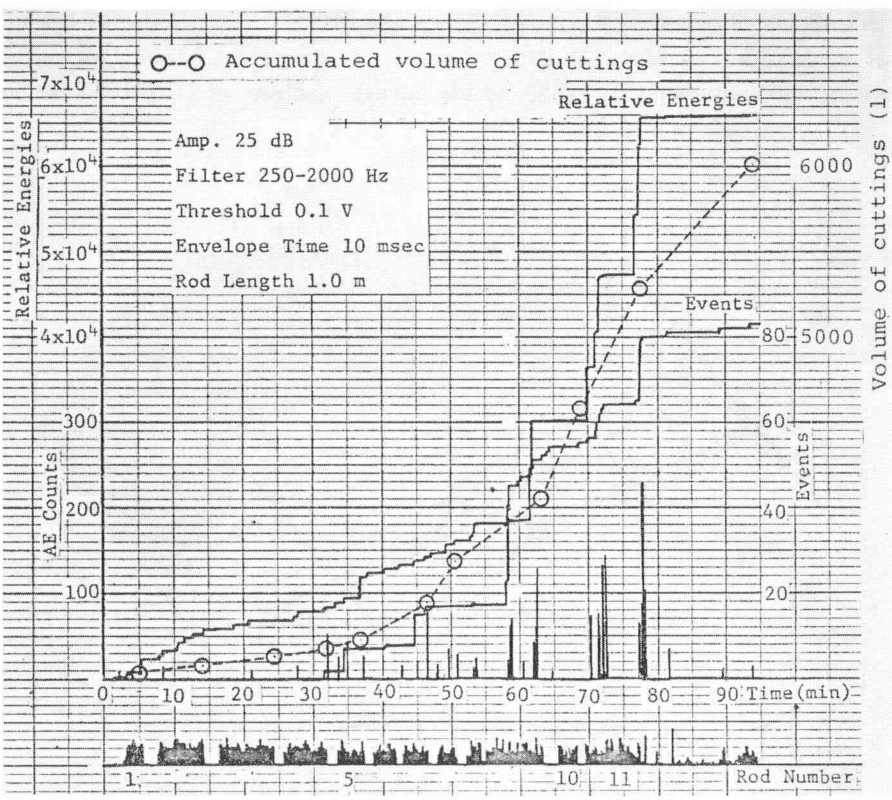

Fig. 16. Acoustic emission activity during boring in Akabira Coal Mine.

6. Concluding remarks

As mentioned above, the acoustic emission activity in the bed rock around working faces in deeplevel mining operations such as cross cutting, drifting, hydraulic mining and relief boring was observed with the acoustic emission monitoring system in Sunagawa Coal Mine and Akabira Coal Mine, Hokkaido. Consequently, it was recognized that acoustic emission technique is useful as a method for estimating the degree of instability of the bed rock in deeplevel mining. The following conclusions can be drawn from the observational results presented:

(1) It was confirmed that the original acoustic emission monitoring system used in the present observations allowed for an accurate monitoring of acoustic emission created by mining operations.

(2) The parameters such as count rate, events and relative energies associated with acoustic emission activity appear to be factors indicative of the degree of instability of the bed rock.

(3) In deeplevel mining the existence of highly stressed zone or geologically weak band can be presupposed from the degree of acoustic emission activity.

(4) Generally in cross cutting, no acoustic events are created after blasting solid rock but many events are created after blasting the bed rock adjacent to coal seam. From these observational results it is suggested that in solid rock fractures do not occur at the stress level induced in the process of stress redistribution, and that in weak rock numerous fractures occur at that stress level.

(5) In the latter case the curves of the parameters associated with acoustic emission activity steepened rapidly immediately after blasting and became flatter within about 10 minutes after the blasting. This is useful as a criterion for judgment of the commencent of the next working cycle safely in cross cutting which has a danger potential of gas outburst.

(6) During the observations in cross cutting the acoustic emission activity accompanying a gas outburst was recorded successfully. According to the analytical results of these records, the gas outburst was triggered approximately 10 seconds from blasting and maintained its activity for about 10 seconds.

(7) Additionally, acoustic events vanished completely for about eight hours before the occurence of gas outburst although they are intermittent up to that time. This fact is abnormal compared with the examples of other observations, and suggest the possibility of predicting a gas outburst.

(8) According to the observational results in relief boring, the strongest correlation is observed between the acoustic emission activity and the volume of cuttings. Therefore it can be considered that the value of acoustic emission measurements is useful as a method for estimating the effects of stress relief by boring.

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