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Development of a Split Hopkinson Pressure Bar (SHPB) System for Dynamic Rock Fracture Testing with Integrated Electromagnetic Radiation (EMR) Monitoring

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Abstract

Predicting short-term precursors of underground structural failures is essential for minimizing human and economic losses. Among various sensing techniques, electromagnetic radiation (EMR) has shown potential as a non-contact method for detecting precursors to rock failure. While its behavior under quasi-static loading is relatively well understood, EMR characteristics under dynamic conditions remain unclear. To address this, a Split Hopkinson Pressure Bar (SHPB) system was developed with integrated EMR monitoring for dynamic rock fracture testing. Dynamic Brazilian tensile tests on granite successfully captured EMR signals near the fracture point. Fast Fourier Transform (FFT) analysis revealed peaks at 70–220 kHz, which are typical of rock failure, and additional high-frequency components at 0.7–1 MHz. These findings validate the system's capability and provide new insights into EMR generation mechanisms under dynamic loading conditions.

Keywords: Dynamic Rock Fracture, Electromagnetic Radiation (EMR), Split Hopkinson Pressure Bar (SHPB)

1 Introduction

The ability to predict short term precursors of underground structural failures, particularly within a time frame of several weeks, is critically important for minimizing both human casualties and economic losses. These failures are often triggered by external dynamic disturbances such as rock excavation, seismic events, blasting operations, and accidental mechanical impacts. Therefore, the development of reliable and responsive monitoring techniques is a priority in geotechnical and rock engineering.

In recent years, electromagnetic radiation (EMR) has received growing attention as a promising non-contact indicator of rock fracturing. Compared to conventional monitoring approaches such as acoustic emission (AE) techniques and seismic observation methods, which typically require direct sensor installation and are more appropriate for medium to long term forecasting, EMR offers the advantage of detecting failure precursors over shorter timescales without requiring physical contact with the rock mass. This makes it particularly suitable for applications near excavation sites and in situations requiring short term hazard prediction.

Despite its potential, the physical mechanisms responsible for EMR generation during rock fracturing remain poorly understood. In particular, most previous investigations have focused on EMR behavior under quasi static loading conditions, even though many important stress disturbances in the field are dynamic in nature. As a result, the characteristics and underlying mechanisms of EMR generation under dynamic loading, such as those caused by blasting or seismic shocks, have not been systematically studied.

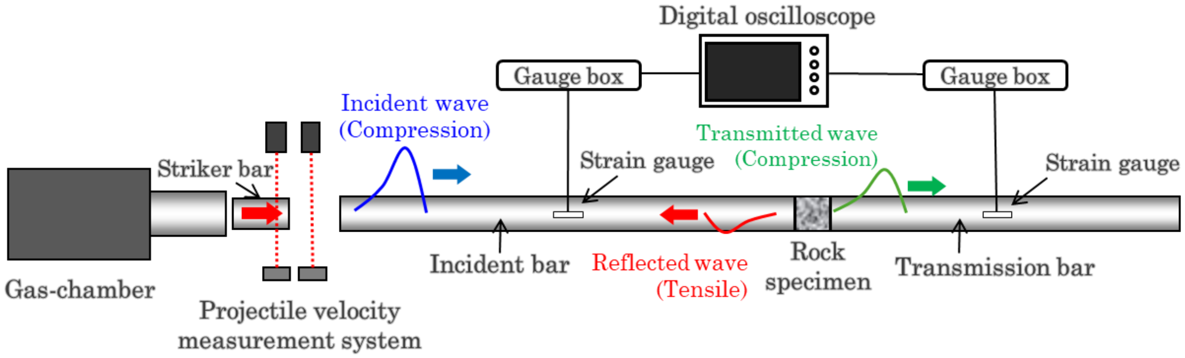

Figure 1: Schematic Diagram of SHPB System

To address this research gap, the present study developed a Split Hopkinson Pressure Bar (SHPB) system designed for dynamic rock fracture testing, with an integrated EMR monitoring setup. A dynamic Brazilian tensile test was conducted using this system on a selected rock type to assess its capability in capturing EMR signals generated during rapid failure. The experimental results offer new insights into the nature of EMR emissions under realistic and high strain rate loading conditions, contributing to the development of more effective EMR based early warning systems for underground structural failure.

2 SHPB System with Integrated EMR Monitoring: Design and Configuration

To clarify the mechanism of EMR generated during dynamic rock fracturing, we developed a SHPB system integrated with an EMR monitoring setup.

2.1 SHPB System for Dynamic Loading

To apply dynamic loading to rock specimens, an SHPB system was developed. Figure 1 shows a schematic diagram of the SHPB system used in this study. As shown, the SHPB system consists of three main bars: a striker bar, an incident bar, and a transmission bar. The striker bar is driven at several meters per second using a gas chamber and collides with the incident bar. This collision generates a compressive stress wave that travels through the incident bar toward the specimen.

When the wave reaches the specimen, part of it is reflected as a tensile wave due to the mismatch in mechanical properties, particularly the acoustic impedance, between the steel bar and the rock. The remaining compressive wave is transmitted through the specimen and continues into the transmission bar. Semiconductor strain gauges are mounted at the center of both the incident and transmission bars to measure the stress wave signals. These signals are collected by a data acquisition system and converted into axial stresses (incident, reflected, and transmitted), which are then used to evaluate the specimen's dynamic strength and the corresponding strain rate.

2.2 EMR Monitoring System

To monitor EMR during the rock fracturing process, an EMR monitoring system was developed, as shown in Fig. 2. The system consists of a loop type antenna (SAS-560, manufactured by AH Systems), a preamplifier (SA-240F5, manufactured by NF Corporation), a data acquisition system, and an electromagnetic shield. The loop antenna is positioned near the rock specimen to detect EMR signals in the frequency range of 20 Hz to 1 MHz. Because the signals are typically weak, they are amplified using the preamplifier before being recorded by the data acquisition system.

The EMR monitoring is synchronized with the SHPB system to correlate the detected signals with the stress wave behavior during rock fracturing. To minimize external electromagnetic noise, a shielding structure was installed around the specimen and antenna. The shield mainly consists of polycarbonate panels covered with copper-based EM sheets on the outside.

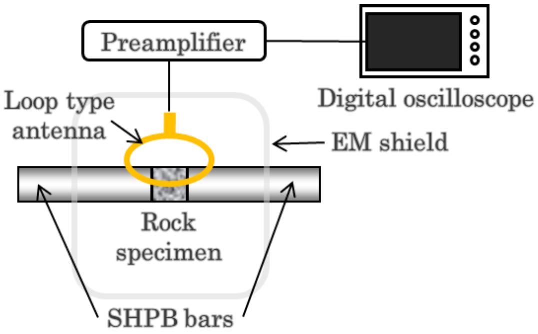

Figure 2: Schematic of the EMR Monitoring System Integrated with the SHPB Setup

3 Experimental Procedure: Dynamic Fracture and EMR Monitoring

In this study, dynamic Brazilian tensile tests were conducted using granite specimens. Although dynamic uniaxial compression (UCS) tests are more common in SHPB experiments, the Brazilian test was chosen to clarify EMR signals associated with tensile failure, as UCS tests often involve mixed shear and tensile failure modes.

The granite had a density of 2650 kg/m³. From quasi-static tests, its Young's modulus was 27 GPa, Poisson's ratio 0.2, UCS 67 MPa, and tensile strength 8.3 MPa. Cylindrical specimens (⌀30 mm × 30 mm thick) were used.

Dynamic loading was applied at a striker velocity of approximately 10 m/s. Preliminary tests without a specimen were also conducted to evaluate background EMR generated by the SHPB apparatus.

4 Results and Discussion

Figure 3 shows the stress wave signals obtained from the strain gauges on the SHPB system and the EMR monitoring system during the dynamic Brazilian tensile test. As illustrated, an incident wave is first generated in the incident bar, followed by a reflected wave after the specimen is contacted, and then a transmitted wave is observed in the transmission bar. Notably, EMR was detected around 12.1–12.3 ms, corresponding to the time between the arrival of the incident wave and the reflected/transmitted waves, which indicates the moment of primary rock fracturing.

Based on these results, FFT analysis was conducted, as shown in Figure 4. A comparison between the tests without a specimen (Figure 4a) and with a granite specimen (Figure 4b) revealed that additional EMR signals appeared in the frequency ranges of 70–220 kHz and 0.7–1 MHz when the specimen was present. According to previous studies, EMR generated during rock fracture typically falls within a frequency range from several Hz to a few hundred kilohertz [1-2]. Therefore, the EMR observed in the 70–220 kHz range in this study is considered to be directly associated with the rock fracturing process. In contrast, the 0.7–1 MHz components lie beyond the commonly reported range and may originate from other mechanisms or interactions under dynamic loading, suggesting the need for further investigation.

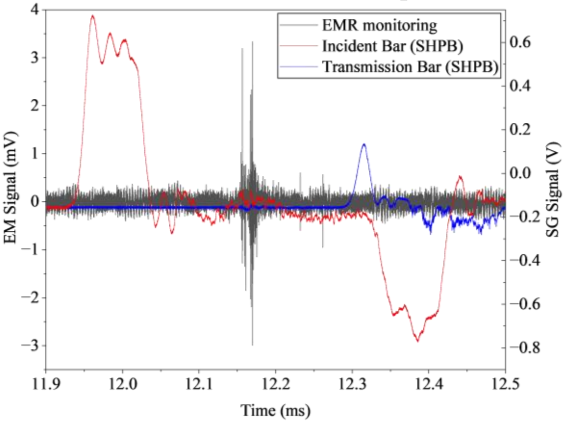

Figure 3: SHPB Stress Waveforms and Corresponding EMR Signals during Brazilian Test

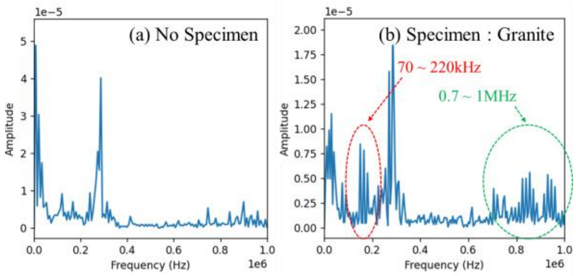

Figure 4: FFT Analysis of EMR Signals: (a) Without Specimen; (b) With Granite Specimen

5 Conclusion

A SHPB system with EMR monitoring was developed to examine EMR during dynamic rock fracturing. Tests on granite captured EMR near the fracture point. FFT analysis showed peaks at 70–220 kHz (typical of rock failure) and 0.7–1 MHz, suggesting additional high-frequency components. The results validate the system and provide insight into EMR behavior under dynamic loading.

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