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# Application Practice of SHPB Experimental Technology in "Blasting Engineering" Teaching

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**Abstract:- The course of "Blasting Engineering" is a highly practical professional course in the field of civil engineering. In order to help students deeply understand and comprehend the propagation and attenuation mechanism of stress waves during rock blasting process, as well as the influence of rock dynamic characteristics on blasting rupture effect, SHPB impact compression experimental technology is introduced into the teaching of "blasting engineering". Firstly, the structure, experimental process, and principles of SHPB equipment were introduced, allowing students to have a better understanding of the experimental principles of SHPB and the theoretical calculation methods of rock dynamic parameters. Then, by combining SHPB experiments with the theoretical course of "Blasting Engineering", the teaching mode can solve students' difficulties in learning blasting theory, exercise their scientific research and exploration abilities, expand their innovative thinking, and cultivate their ability to propose and solve key scientific problems. This helps to unleash students' subjective initiative in conducting experimental research independently and improve teaching effectiveness.**

***Keywords:-*** *SHPB; Blasting Engineering; Experimental Teaching; Application Practice.*

## I. INTRODUCTION

Blasting is currently the most widely used construction method in geotechnical engineering, and is an indispensable and important means for urban underground space development, slope and foundation pit engineering, and foundation engineering. Therefore, "blasting engineering" has become one of the core courses in engineering majors such as civil engineering, geological resources and geological engineering, and mining engineering in most universities.

The theory and methods of blasting engineering are important components of the knowledge system for undergraduate students majoring in civil engineering. Compared to other undergraduate courses, blasting engineering has the characteristics of profound theoretical foundations, abstract teaching processes, and difficulty in conducting experimental practices, which leads to a lack of rational understanding of rock blasting mechanisms among students. Therefore, Wang et al. [1] analyzed the problems in teaching content, teaching methods, and teaching tools of blasting engineering, and discussed measures for teaching reform in mining engineering majors. Wang [2] proposed to reform blasting engineering teaching from six aspects: selecting typical cases, discussing and analyzing teaching, applying numerical simulation software, and reproducing experimental processes. Xiao et al. [3] applied high-speed photography to observe and record multiple experiments in blasting engineering, improving the teaching effectiveness of abstract theories such as explosive detonation theory and blasting rock breaking mechanism for students, and enhancing their learning interest.

In summary, the difficulties in teaching "blasting engineering" have received attention from many teachers in related majors in universities. However, due to the danger and theoretical abstraction of blasting experiments, the effectiveness of undergraduate teaching in "blasting engineering" is still constrained. Therefore, based on the main teaching objectives of undergraduate students in civil engineering, this article aims to address the problem of students' difficulty in understanding the theory of shock wave propagation and its rock breaking mechanism in the teaching process of "blasting engineering". The SHPB experimental

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system is introduced into undergraduate "blasting engineering" teaching, allowing students to more intuitively perceive the propagation process of stress waves, understand the failure process of materials under dynamic impact, and master the basic dynamic mechanical properties of rock materials.

## II. SHPB TEACHING DESIGN

➢ *Teaching Objectives of Blasting Engineering*

The teaching objectives of blasting engineering in civil engineering major are: to master the basic theories and knowledge of blasting engineering design and construction; Familiar with blasting equipment, methods, and rock blasting fragmentation mechanisms; Master the theory and methods of smooth blasting and micro difference blasting; Master the blasting construction technology of underground and open-pit engineering, and be able to carry out specific blasting engineering design; Familiar with monitoring and controlling the harmful effects of blasting, understanding the basic principles and design methods of demolition control blasting; Having the basic skills of independently designing blasting engineering lays the necessary foundation for engaging in professional engineering technology and scientific research work.

➢ *SHPB Teaching Content*

According to the teaching objectives of blasting engineering, blasting theory and methods are the foundation for independently designing blasting engineering. Due to the complex and abstract nature of blasting theory, it is not conducive to learning and developing skills. Therefore, through SHPB experiments, students can have an objective understanding of the dynamic characteristics and failure laws of rocks, thereby strengthening their understanding of the propagation and attenuation of stress waves inside rocks during the explosion process. The specific content includes:

- Provide teaching guidance to students based on the principles and methods of SHPB. Detailed introduction of conventional methods for studying the dynamic mechanical properties of rocks and their applications in practical engineering, and explanation of relevant precautions for SHPB.
- To teach students the knowledge of aspect ratio design, preparation methods, rock mechanics performance testing, and data analysis of rock specimens in theoretical classrooms, so that students can proficiently master the basic principles and operating steps of SHPB, and achieve the goal of solving dynamic performance testing and data processing problems.
- Lead students to design a teaching plan for rock dynamic compression performance experiments, conduct impact experiments, and carry out teaching work during the experimental process.
- Visually display the strain rate effect and damage mode of various rocks. Enable students to have a better understanding of various dynamic parameters of rocks, enhance their comprehension of the mechanism of dynamic impact, and cultivate their comprehensive abilities and spirit of scientific exploration.

## III. EXPERIMENTAL CONTENT AND PROCESS

➢ *Experimental Instruments*

A typical SHPB device consists of a loading system, a control system, a speed measurement system, a compression rod system (impact rod, incident rod, transmission rod, absorption rod), a damping system, and a data recording system. The compression rod system comes in two types: steel and aluminum, with rod diameters of 37mm, 50mm, and 74mm. Generally speaking, the test objects of small-diameter compression rod systems are mainly ceramic materials with relatively uniform materials; For rock and concrete materials, to overcome measurement errors caused by uneven material quality, large-diameter SHPB systems are generally used.

Fig. 1 shows the SHPB test apparatus system of the Impact Dynamics Laboratory, Anhui University of Science & Technology.

Fig.1 SHPB test apparatus system [4]

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The cemented sand similar material has low wave impedance, so the semiconductor strain gauge technology was adopted to measure weak transmission signals and resistance strain gauge was still used for the incident bar. A piece of paper [5] was used as a pulse shaper and pasted on the end of the incident bar to improve the loading waveform of the incident pulse and prolong the rising time of the incident pulse.

➢ *Experimental principle*

➢ *Basic Principle*

The SHPB experiment is based on two basic assumptions: (1) the one-dimensional stress wave assumption, which means that the cross-section of the compression bar remains flat during deformation, with only uniformly distributed axial stress on the cross-section; (2) The assumption of uniform stress is that the specimen is short enough to be in a uniform stress state after multiple reflections of stress waves.

According the basic assumptions [6,7] of the SHPB test technology, the dynamic mechanical parameters like stress $\sigma(t)$, strain $\varepsilon(t)$ and strain rate $\dot{\varepsilon}(t)$ could be calculated according to the test stress waveform, see the following Equation:

$$\sigma(t) = \frac{E_0 A_0}{2A_s}[\varepsilon_I(t) + \varepsilon_R(t) + \varepsilon_T(t)] \quad (1)$$

$$\varepsilon(t) = -\frac{C_0}{L_s}\int_0^\tau [\varepsilon_I(t) + \varepsilon_R(t) - \varepsilon_T(t)]\,dt \quad (2)$$

$$\dot{\varepsilon}(t) = -\frac{C_0}{L_s}[\varepsilon_I(t) + \varepsilon_R(t) - \varepsilon_T(t)] \quad (3)$$

Where: $A_0$ and $A_s$ were the cross section areas of the pressure bar and the specimens respectively; $E_0$ and $C_0$ were the elastic modulus of the pressure bar and the longitudinal wave velocity respectively; $L_s$ was the specimen length; $\varepsilon_I(t)$, $\varepsilon_R(t)$ and $\varepsilon_T(t)$ were the incident, reflected and transmitted stress waves respectively. The compressive stress was positive; t was the duration of the stress wave.

Fig. 2 shows the collected three waveforms of the incident wave, reflected wave and transmitted wave during the test.

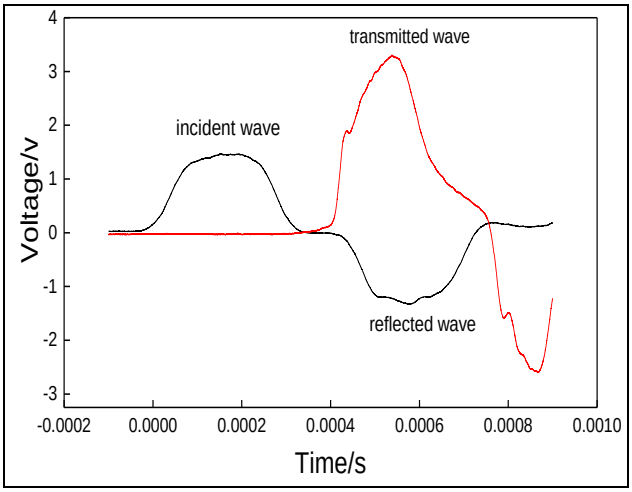


**Fig. 2** Acquisition Waveform of Impact Compression Test [4]

➢ *Energy Calculation*

During the impact test for the cemented sand specimens performed with the SHPB test apparatus, it was assumed that the energy consumption between specimen and input / transmission bars was negligible, the energy $W_L$ absorbed by the cemented sand specimens and the specific energy absorption value SEA [4] could be obtained according to:

$$W_L = W_I - (W_R + W_T) \quad (4)$$

$$SEA = W_L / V_s \quad (5)$$

Where, $W_I$, $W_R$ and $W_T$ were the incident stress wave energy, reflected stress wave energy and transmitted stress wave energy respectively; $V_s$ was the volume of the cemented sand specimens. $W_I$, $W_R$ and $W_T$ could be calculated according to the following Equation.

$$W_I = \left(\frac{A_0 C_0}{E_0}\right)\int \sigma_I^2\,dt \quad (6)$$

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$$W_R = (\frac{A_0 C_0}{E_0}) \int \sigma_R^2 \, dt \quad (7)$$

$$W_T = (\frac{A_0 C_0}{E_0}) \int \sigma_T^2 \, dt \quad (8)$$

Where: $A_0$, $C_0$ and $E_0$ were the cross sectional areas of the input bar, the acoustic wave transmission velocity and the elastic modulus of the input bar respectively; $\sigma_I$, $\sigma_R$ and $\sigma_T$ were the stress time-history records of the incident stress wave, reflected stress wave and transmitted stress wave respectively.

➢ *Experimental Course Process*

- Firstly, introduce the composition of SHPB experimental equipment, experimental operation process, and precautions. Including: ① checking the integrity of experimental equipment: attaching strain gauges and ensuring sufficient gas supply; ② Push the bullet to a fixed position and turn on the speedometer; ③ Air collision inspection, stress leveling; ④ Apply Vaseline to both sides of the specimen, clamp and place the incident rod and transmission rod, and ensure that the incident rod specimen transmission rod are on the same axis; ⑤ Ensure personnel stay away from the control panel, open the gas cylinder valve to inflate the gas chamber, and push the bullet to impact the incident rod. ⑥ After the test is completed, save the bullet velocity and original voltage waveform, and collect the rock after impact.
- Then show students how to process the data collected during the experimental process. Including: ① Stress balance verification. Based on the basic principle of incident wave+reflected wave=transmitted wave, determine whether the stress equilibrium state is reached at both ends of the specimen during SHPB impact process. ②According to the three wave method calculation formula in Section 2.2, the stress-strain curve of the sample is obtained by calculating the incident wave, reflected wave, and transmitted wave collected in the experiment.
- Group the students and design an experimental plan to conduct impact compression tests in sequence. At the same time, assign homework for students to independently process data and draw stress-strain curves, calculate the basic mechanical parameters of the corresponding specimens, and generate a report.

## IV. ANALYSIS ON THE TEACHING EFFECT OF EXPERIMENTAL COURSES

Based on SHPB experiments, students can learn stress-strain curves, stress peaks, strain rates, and other knowledge more intuitively during the teaching process. To cultivate students' ability to design experiments, collect, process, analyze, and interpret data based on scientific principles, and to obtain reasonable and effective conclusions through information synthesis.

Through students' reports, it was found that they were all able to objectively record experimental data and complete experimental report writing. In addition, feedback from communication with students indicates that they have a strong interest in the SHPB impact experiment course. Among them, about 20% of students are still self-taught in wave dynamics or elastic wave theory, and based on consulting relevant literature, they have gained a deep understanding of the assigned tasks, and have made relevant deductions and explanations.

This indicates that introducing SHPB experimental teaching in "blasting engineering" can stimulate students' learning enthusiasm, promote and enhance their participation in experiments, and exercise their scientific research hands-on abilities. At the same time, it proves that this teaching method enables students to intuitively perceive the propagation process of stress waves, clearly understand the dynamic failure mechanism of rocks, master the relationship between the dynamic mechanical properties of rock materials and strain rates, lay the foundation for further learning of blasting engineering theory, and provide a reform path for the "Blasting Engineering" course in civil engineering.

## V. CONCLUSIONS

By combining the "Blasting Engineering" course with SHPB experiments, civil engineering students can be trained, and the SHPB teaching platform can effectively enhance their comprehensive practical abilities.

- Practical ability. Students can actually participate in the experimental process: from scheme design, specimen

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preparation, dynamic impact experiments to data analysis, allowing students to use their hands to drive their brains and guide their hands during the experimental process, improving their practical operation ability and gaining a deeper understanding of dynamic knowledge.

- Theoretical application ability. Through the Hopkinson pressure bar experiment, provide students with a detailed explanation of stress wave theory, SHPB testing principles, damage mechanisms, and constitutive relationship analysis. Combined with experimental testing principles, analyze the collected data. Intuitively understand concepts such as stress-strain curve and strain rate, and enhance students' understanding of theoretical knowledge.

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