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# Force-penetration curves of a button bit generated during impact penetration into rock

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ABSTRACT

To improve the performance and efficiency of percussion rock drills, it is essential to understand the impact penetration behavior of a bit drilling into rock. However, little knowledge to date has been published about the penetration behavior of the button bit, which is commonly used for hard rock. In this study, the impact penetration behavior of the button bit was investigated in laboratory tests. An impact penetration tester built from the same components used in an actual rock drill was developed and used in single-blow impact penetration tests. Unnatural fluctuations were observed in the force-penetration curves calculated using a two-point strain measurement method, which were probably due to not only the difference in rod stress as measured at two points on the rod, but also to the mismatch between the actual bit and the calculation model. A data correction method, in which the bit force calculated in a free end test is subtracted from that in the impact penetration test, was proposed using a numerical simulation. The method was applied to the measured rod stress, and force-penetration curves with a button bit were obtained from more than 40 impact penetration tests. Graph curves showed that peak force, initial slope and elastic penetration increased, while the maximum and final penetrations decreased with an increase in the secant slope. The crushing and elastic strain energies changed, but the sum of the energies was constant with an increase in the secant slope. The variations in the force-penetration curves are caused by the contact conditions between the bit and rock, the rock properties, and damage to the rock caused with each blow, not by the test conditions. The findings of this study will contribute to progress in the performance and efficiency of percussive rock drilling.



## 1. Introduction

Numerical simulation is an effective approach to estimate the performance and efficiency of percussion rock drills [1,2]. The force-penetration relationship at the end of a bit affects the simulation results of the rock drill body and damper system, the piston stroke and speed, and the blow frequency [2]. The penetration per unit time depends on both the piston speed and the blow frequency. Therefore it is important to know force-penetration curves with a bit during impact penetration into rock. Many studies have been conducted on the impact penetration behavior of wing, conical and wedge bits [3–9]. However, to date, little knowledge has been published about the penetration behavior of the button bit, which is commonly used for hard rock [10,11].

Goldsmith and Wu [8] conducted impact penetration tests with conical and wedge bits, and obtained force-penetration curves for them. In the tests, bit force was measured with strain gauges attached near the end of the bit, and penetration was measured with a capacitive displacement sensor attached to the rod. Recently, Saksala et al. [11] conducted impact penetration tests on three button tips embedded into the end of a rod (a special triple-button bit) using the same measurement method as Goldsmith and Wu [8]. This measurement method requires strain gauges to be attached near the end of the bit for eliminating the influence of elastic wave reflection between the bit and rod. Therefore the method cannot be used when the bit is in a deep borehole. As the displacement sensor is attached at a distance from the bit end, this causes measurement errors during penetration and there is low durability to elastic stress waves. Moreover, the measured bit force and penetration exhibit temporal differences in this method. To overcome these drawbacks, Karlsson et al. [9] conducted impact penetration tests with a wedge bit. They attached strain gauges to a

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rod at two points at a distance from the bit end, and calculated the bit force and penetration from the measured rod stress. This method, known as the two-point strain measurement (TPSM) method, was proposed by Lundberg and Henchoz [12], and used in impact penetration tests by Karlsson et al. [9].

Carlsson et al. [10] applied the TPSM method to impact penetration tests with a button bit, and succeeded in obtaining force-penetration curves for the bit. Although the results are valuable for an actual button bit, their equipment had two major differences from an actual rock drill. 1) The piston in their equipment was a solid cylinder having the same diameter as the rod, while the piston in an actual rock drill has an intricate shape. 2) The piston collided directly with the rod in their equipment, whereas the piston in an actual rock drill collides with a shank rod that is connected to an extension rod via a rod joint, and this collision between the piston and the shank rod in an actual rock drill generates intricately shaped elastic waves [2]. To increase the knowledge on the force-penetration curves during percussive rock drilling, it is important to assess the applicability of the TPSM method, to investigate the difference from simplified components, and to obtain force-penetration curves, using the same components in an actual rock drill.

In this study, the impact penetration behavior of a button bit was investigated by means of laboratory tests. We developed an impact penetration tester using the same piston, shank rod, rod joint, extension rod and bit as those used in an actual rock drill. Unnatural fluctuations were observed in the force-penetration curves calculated from the rod stress as measured with the TPSM method. Thereafter the reason for this was elucidated, and a data correction method was proposed using a numerical simulation. The correction method was applied to the measured rod stress, and force-penetration curves with a button bit were obtained from the impact penetration tests.

## 2. Impact penetration tester and testing method

Fig. 1 shows the impact penetration tester developed in this study and the button bit. The tester consists of the same piston, shank rod, rod joint, extension rod and bit as used in an actual rock drill manufactured by Furukawa Rock Drill Co., Ltd. All the components are replaceable. The piston, which is 710 mm in length, with maximum and minimum diameters of 52 mm and 36 mm, respectively, is reciprocated by hydraulic pressure. The shank rod, which is 790 mm in length, with maximum and minimum diameters of 51 mm and 31 mm, respectively, has splines for rotation at its end. The shank rod is a hollow tubular structure, except for the portion of the splines. The rod joint is a sleeve type with a T38 thread, which is 190 mm in length and 55 mm in outer diameter. The extension rod is a hollow cylinder, 3660 mm in length, with outer and inner diameters of 39 mm and 14.3 mm, respectively. The connection between the rod and bit is a T38 thread. Twelve carbide button tips are embedded in the bit; four of which are face tips 10 mm in diameter, while the other eight are gauge tips 11 mm in diameter. The bit, including the tips, is 64 mm in nominal diameter and 136 mm in length.

As shown in Fig. 1, strain gauges for steel (KFG-2-120-D16, manufactured by Kyowa Electronic Instruments Co., Ltd.) were attached at two points: A and B on the rod. Point A is 1000 mm from the back end of the rod, and point B is 750 mm from the front end of the rod. To cancel out the bending strain, two strain gauges were attached on opposite sides of each point in the longitudinal direction of the rod. Strain was recorded at a sampling frequency of 1 MHz on a data logger (Type 8826, manufactured by Hioki E. E. Corporation), through a strain amplifier (CDV-230C, manufactured by Kyowa Electronic Instruments Co., Ltd). The gauge factors of the strain gauges were calibrated by statically loading the rod before the tests.

The components from the shank rod to the bit are rotated in percussive rock drilling. To obtain force-penetration curves in rotary percussive drilling, it is necessary to measure rod stress with the cables from the strain gauges wrapped around the rod by a few dozen turns. However, these cables are easily cut during the test. Moreover, in rotary percussive drilling, torsional stress is included in the rod stress, which is one of the error factors in measurement. In view of these shortcomings, in this study the components from the shank rod to the bit were rotated 25.7°, which is 1/14 rotation, by hand after each penetration.

The testing procedure is as follows;

1) The piston collides with the shank rod and the bit penetrates into rock, which is called a single-blow impact penetration (SBIP) test.
2) Rock debris is removed.

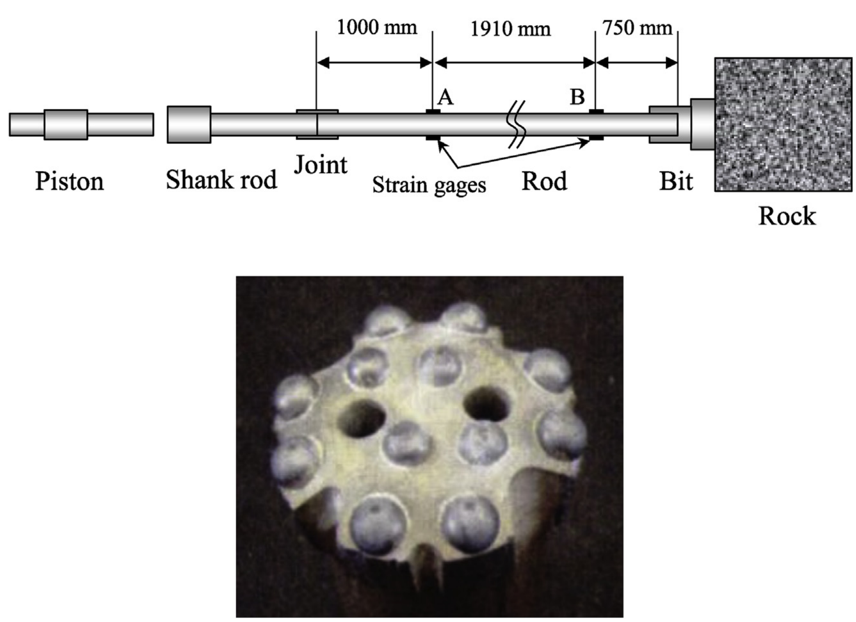


**Fig. 1.** Impact penetration tester and bit.