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その他のタイトル	打撃式油圧さく岩機の穿孔過程に関する研究
学位授与年月日	2017-03-23
URL	http://doi.org/10.15083/00075699

論 文 の 内 容 の 要 旨

論文題目　　Study on the drilling process with the hydraulic percussion rock drill

(打撃式油圧さく岩機の穿孔過程に関する研究)

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Hydraulic percussion rock drills have been used in a wide variety of application, e.g., drilling holes for blasting and for rock bolting at mining or construction. In addition, they have been used to drill sounding holes in advance of a tunnel front for collecting geological information in order to reduce operational risks and avoid unexpected rock problems. The performance and efficiency of the drills affect directly the cost and time of projects. For this reason, many researchers and engineers continuously engaged in the advancement of rock drilling performance. The drilling process with the hydraulic percussion rock drill is a complicated process involving many components and interactions among them. In general, components related to the process include a drill body, a piston, a shank rod, rods, rod joints, a bit and rock. The piston in the drill body is reciprocated by hydraulic pressure and collides with the shank rod a few thousand times per minute. Stress waves generated by the collision propagate and attenuate in the rods and rod joints, and then reach the bit. The bit penetrates and crushes rock. The penetration rate depends not only upon the blow frequency and the impact force per blow, but also upon many other factors. However, it is difficult to investigate all factors, which may have an influence on the penetration rate, one by one with the experimental method because it is a time-consuming and costly process. Thus, it is really necessary to investigate the drilling process and optimize rock drills with the aid of numerical simulation. But existing numerical models can hardly meet the demand of accurate investigation of the drilling process with the hydraulic percussion rock drill due to the reason that they have been simplified.

The aim of the present paper is to construct a new numerical model of continuous percussive drilling, which is based on the previous Okubo-Nishimatsu’s model and much closer to actual percussive drilling than it.

This paper consists of seven chapters. Chapter 1 is the introduction, which describes the aim of the study and the composition of this paper. The mechanism of drilling process with the hydraulic percussion rock drill was introduced in chapter 2.

In chapter 3, the modified 1D models of the piston, rods and joints were used for accurately reproducing stress waves measured in the drilling test. Moreover, the axisymmetric finite element models of the components were created. The dynamic responses of stress waves in axial direction have been calculated with the axisymmetric finite element models, and compared to the numerical results of the 1D model and the experimental results. The comparison showed that the performance of the numerical results derived from the axisymmetric finite element model are better than those based on 1D theory of elastic waves, especially on reproducing the lateral-inertia effect. However, the numerical results of the axisymmetric finite element models are sensitive to mesh scale and time step size. For coarse-mesh scale, too small time step do not improve the simulation accuracy, but cause the undesirable high-frequency vibration in numerical results. It is recommended that using 1D model of piston, rods and joints for simulating stress wave from propagation for decreasing computational complexity

In chapter 4, 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 to investigate the impact penetration behavior of a button bit. Single-blow-impact-penetration (SBIP) tests provided highly reproducible results under constant blow conditions and with tightening of the threads after each blow. Unnatural fluctuations were observed in the force-penetration curves calculated with the two-point-strain-measurement (TPSM) method. This is probably due to not only the differences in the rod stresses measured at the two points on the rod, but also to the mismatch between the actual bit and the calculation model. The data correction method, in which the bit force calculated in the Free-bit-end (FBE) test is subtracted from that in the SBIP test, was proposed using a numerical simulation. The correction method was applied to the measured rod stresses, and the force-penetration curves were improved remarkably. However, the slopes of the curves changed unnaturally just before the peaks, which was probably due to the change in the contact conditions at the connection between the rod and bit in the SBIP and FBE tests. Thereafter, the bit force calculated in the simulation of the

FBE test was subtracted from the bit force calculated from the measured rod stresses in the SBIP test when the bit force was high. The additional correction with threaded bit model is just for the threaded bit-rod connection used in this study. The corrected force-penetration curves are smoother in the SBIP tests than those in static penetration tests in previous studies, which indicate that impact penetration is not accompanied by large rock chipping. The peak force, slopes, penetrations and three types of energies were obtained from the force-penetration curves in more than 40 SBIP tests. The variations in the force-penetration curves are probably caused by the contact conditions between the bit and rock, the rock properties and damage to the rock with each blow.

In chapter 5, the impact penetration of a bit into rock was investigated for the modeling of the bit-rock interaction. Impact penetration tests on Inada granite were carried out with six rod-bit configurations which were composed of four kinds of button bits and two kinds of rods. In the calculation of force-penetration curves from the measured rod strains, the bit model constructed from the acoustic impedance was simplified, and the empirical data correction method proposed in chapter 4 was applied to all the rod-bit configurations. The force-penetration curves for the six rod-bit configurations showed that the bit force in loading phase was approximately proportional to the square of the penetration. The curves in unloading phase had a linear relation between the bit force and the penetration. The final penetration of each blow had a linear relation with the maximum penetration, and the measured borehole depth was proportional to the maximum penetration. The effect of rod diameter on the force-penetration curves was not obviously observed. However, the bit force corresponding to the same penetration increased and the specific energy decreased with an increase in bit diameter or in the number of button tips on the bit. These findings will contribute to the improvement of the accuracy in the simulation of percussive rock drilling.

In chapter 6, the improved models associated with stress wave generation, propagation and attenuation, as well as the bit-rock interaction was integrated into the new numerical model of the continuous percussive drilling. With the model, the continuous percussive drilling was simulated under various drilling conditions.

In chapter 7, results obtained from chapter 3 to chapter 6 are summarized as the last conclusion of this paper.

In this study, elastic wave propagation is precisely simulated using models of the same shape as the actual components of a rock drill. The accurately calculated force-penetration curves were obtained from the impact penetration tests with different rod-bit configurations. The new bit-rock interaction model was proposed based on the improved force-penetration curves. These findings will contribute to progress in the performance and efficiency of percussive rock drilling.