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Experimental results on the effect of Bit wear on torque response

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ABSTRACT

Percussion bits, polycrystalline diamond compact (PDC) bits and roller cone bits are widely used in well drilling. The evaluation methods for downhole conditions, such as the wear condition of drill bits and the in situ rock strength, are important issues in improving the drilling efficiency and reducing the drilling cost. In this study, drilling tests were conducted in laboratory using the three types of drill bit and various types of rock. On the basis of the results, a close relation between the bit wear condition and bit torque was found for each bit.

1. Introduction

In the development of resources such as oil and geothermal energy, it is essential to evaluate the wear of the drill bit and the in situ rock strength while well drilling. This is because appropriate control of the drilling conditions depending on the rock type, including the decision of when to exchange a worn bit for a new one, will improve the drilling efficiency and help reduce problems such as bit failure, stuck pipes and twistoff. Such a well-controlled drilling operation will reduce the total drilling cost.

The authors have conducted experimental studies on two types of well drilling method: percussion drilling [1] and rotary drilling.[2,3] In the study of percussion drilling,[1] the relationship between the bit wear condition and drilling parameters, such as the penetration rate, bit weight and bit torque, was investigated on the basis of the results of drilling tests in which hard and abrasive rock was used. The results of the percussion drilling tests and their analysis are reviewed in this study.

Bellin et al. [4] reported that polycrystalline diamond compact (PDC) bits account for an astounding 65% of the footage drilled in oil and gas applications in 2010. We conducted rotary drilling tests using granite and two PDC core bits having different types of PDC cutter. In the drilling tests, the penetration rate, not the bit weight, was kept constant. We describe the results of the tests in this study, particularly focusing on the relationship between the wear of the PDC cutters and the drilling parameters.

In our previous studies on rotary drilling,[2,3] new methods were proposed for estimating both the rock strength and the tooth wear condition while drilling using roller cone bits. In the tests, several roller cone bits having different tooth wear conditions and several types of rock having different strengths were used. In this study, we reanalyze the test data for milled tooth roller cone bits [2] on the basis of the force balance concept proposed by Warren.[5] This approach reveals that the concept is useful for evaluating the tooth wear condition of milled tooth bits.

As mentioned at the beginning of this section, it is desirable to evaluate both the bit wear condition and the in situ rock strength while drilling. This paper focuses on the relationship between the bit wear condition, which is one of the common concerns in the drilling industry, and bit torque. We investigate the effect of bit wear condition on the bit torque for three types of drill bit, i.e., percussion bits, PDC bits and roller cone bits, on the basis of our experimental drilling data.

2. Percussion Bits

2.1. Test equipment

The drill rig used for all the tests in this study is illustrated in Fig. 1. This rig allows two types of drilling method, i.e., percussion

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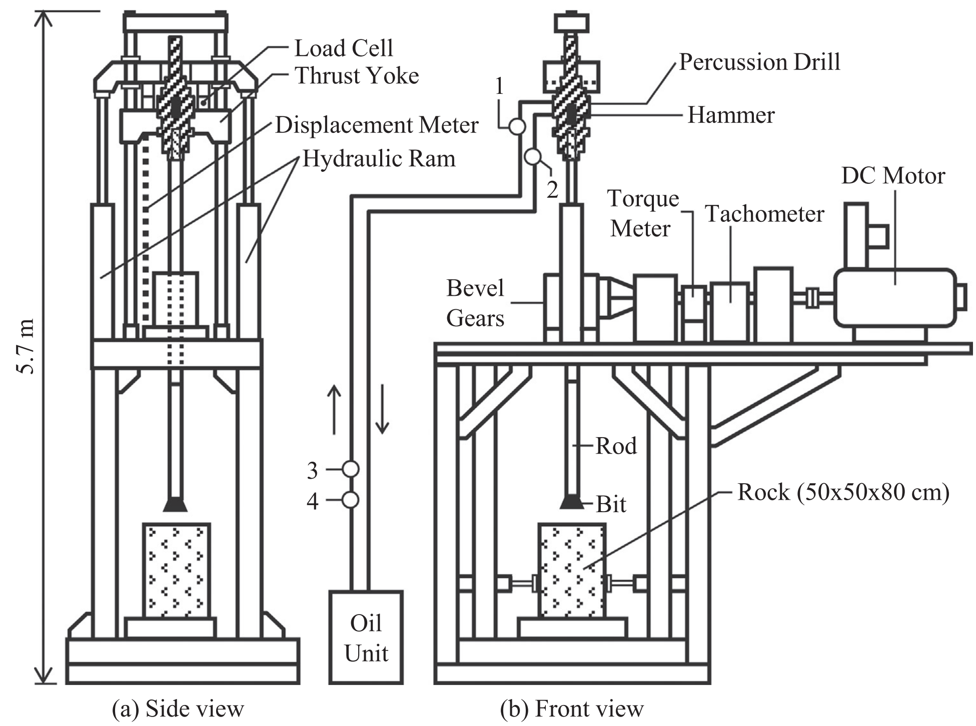

Fig. 1. Drill rig used for tests.

drilling and rotary drilling. The size of each rock block used in the tests was 50 × 50 × 80 cm. In the tests, the bit weight, the bit torque, the vertical displacement of the thrust yoke, the rotary speed and the flow rate of the drilling fluid were measured. Water was used as the drilling fluid in the tests. As can be seen in Fig. 1, the torque measured by the torque meter includes the friction at the bevel gears. Thus, the bit torque was obtained by subtracting the torque generated by the friction from the measured torque. The penetration rate was obtained by differentiating the vertical displacement of the thrust yoke with respect to time.

The percussion energy transmitted to the bit W_{out} (kN-m/min) in the percussion drilling tests was calculated from the input energy to the percussion drill W_{in} (kN-m/min) using a calibration curve prepared from the results of preliminary tests. The calibration curve represents the relationship between W_{in} and W_{out}. In the preliminary tests, the percussion energy W_{out} was measured by two-point strain measurement [6] using strain gages pasted on the drill rod above the bit. The input energy W_{in} was calculated from the inlet and outlet oil pressures and the oil flow rate of the percussion drill measured using transducers 1 to 3 shown in Fig. 1.

Three percussion bits of 65 mm diameter with the same specifications were used in the percussion drilling tests. The bit has eight cemented carbide (WC-Co) tips with 10 mm base diameter, where five and three tips are set on the gage and face parts of the bit body, respectively.

Ten blocks of Sori granite (A) and a block of Shinkomatsu andesite (A) were used in the drilling tests. The mechanical properties of Sori granite (A), shown in Table 1, were obtained from uniaxial compression and Brazilian tests on four core pieces recovered from each rock block previously used in the drilling tests. The uniaxial compressive strength of Shinkomatsu andesite (A) obtained using eight core pieces is also shown in Table 1.

Table 1
Mechanical properties of rock used for drilling tests.

Test Type	Rock	S_c (MPa)	S_t (MPa)	E (GPa)	ν
Percussion	Sori Gt (A)	219	10.9	58.4	0.317
	Shinkomatsu An (A)	192	-	-	-
Rotary (PDC)	Sori Gt (B)	219	11.0	56.3	0.305
Rotary	Oya Tf	14.0	1.54	4.25	0.246
(Roller Cone)	Kimachi Ss	44.9	4.21	7.07	0.256
	Sanjome An	118	9.06	16.6	0.208
	Shinkomatsu An (B)	113	7.67	21.6	0.282

S_c: Uniaxial Compressive Strength, S_t: Tensile Strength, E: Young's Modulus, ν: Poisson's Ratio

2.2. Test procedure

The ten blocks of Sori granite (A) were used in percussion drilling tests on two percussion bits, Bits A and B. In the tests on Bits A and B, the bit weight was set at about 6.6 kN and 13.5 kN, respectively. Up to 16 holes can be drilled in each rock block; therefore, 8 holes were drilled in each rock block using each bit so as to minimize the effect of differences in the rock blocks on test results. In the tests, the rotary speed, the inlet oil pressure of the percussion drill and the water flow rate were fixed at 75 rpm, 13.5 MPa and 60 L/min, respectively. The corresponding percussion energy W_{out} was calculated to be approximately 55 kN-m/min from W_{in} using the calibration curve described above. A third percussion bit, Bit C, was used for the drilling tests on Shinkomatsu andesite (A). The drilling conditions were the same as those in the tests on Bit A.

2.3. Test results and discussion

Fig. 2(a) shows the relationship between the drilled length and the penetration rate obtained from the drilling tests on Bits A