Experimental Study on Bench Cut with Demolition Agent

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(Received July 15, 1983)

Synopsis

Demolition agent can fracutre rock and concrete by static expansive pressure generated by the hydration of CaO.

In this study, three series of model experiments were conducted on the bench cut with demolition agent. They are composed of the experiments on the clarification of crack propagation mechanism, on the determination of hole diameter to spacing ratio and on the improvement of toe breaking techniques.

The experimental results were discussed from the point of practical use of demolition agent in open pit or underground stopes.

1. Introduction

Because of the noise and the vibration, blasting is often prohibited in construction operations near the residential area. The improvement of rock excavation or demolition techniques without blasting is earnestly desired in these days.

Demolition agent, which is developed in order to fracture rocks or concretes by static expansive pressure, is used increasingly because of the simplicity and the safety for handling. At the present time, however, neither the pressure generation mechanism of the agent nor the rock fracturing mechanism has been explained clearly. For the effective use of demolition agent in excavation of rocks or demolition of concrete structures, there is a lot of problems to be solved. In these circumstances, it seems to be important to accumulate fundamental informations on the fracture of rocks or concretes by demolition agent.

In this study, experimental study was conducted to get the fundamental informations on the bench cut with demolition agent. The experiments were divided into three parts as follows:

(1) Clarification of crack initiation and propagation mechanism produced by the expansive pressure of the agent.

(2) Determination of borehole diameter, burden and spacing for the effective bench cut operation.

(3) Examination of borehole inclination and toe hole effects on the toe break in bench cut operation.

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2. Bench cut with demolition agent

Bench blasting is one of the most usual types of blasting techniques. It is usually defined as the blasting of vertical or inclined drill holes in one or more rows against a free surface (Fig. 1). In most practical blasting works, the technique of bench blasting is also used in adapted forms.

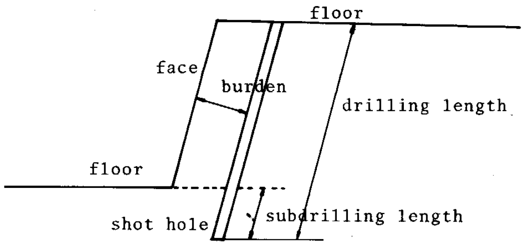


Fig. 1 General view of the bench cut.

There are a lot of factors which affect the blasting characteristics in bench blasting. They are succinctly divided into three parameters as explosive parameters, charge loading parameters and rock parameters. Among the charge loading parameters, borehole diameter, burden, hole spacing and hole length may be the most important factors which are determined by blasting engineer. A round consisting of closely spaced and small diameter holes with the same specific charge provides considerable better fragmentation of the rock than a round made of a widely spaced holes of large diameter. Subgrade drilling is the drilling below the lower bench floor. It can accomodate the plenty of bottom charge which is enough to break the toe burden.

In the bench cut operation using demolition agent, these factors may play different roles. In blasting, shock wave generates a lot of cracks in surrounding rocks and gas pressure opens them. The surrounding rocks of the blast hole are heavily damaged over considerably wide area. In demolition with demolition agent, the expansive static pressure opens the cracks which propagated radially from the hole. Only the cracks connecting the adjacent holes grow remarkably and others stop to propagate.

In the practical design of bench cut with demolition agent, followings may be considered to be important;

(1) Determination of hole diameter, spacing and burden.
(2) Improvement of techniques to break the toe burden.

3. Experimental study

As mentioned previously, there are several problems to be solved in order to manage the bench cut with demolition agent effectively. Three series of experimental studies were conducted to obtain fundamental informations on the bench cut with the agent.

In the experimental studies, cement mortar specimens were used as model rock. After the remoulding, specimens were kept in moistured condition for about four weeks and then they were tested. 24 hours before filling up the boreholes with demolition agent slurry, the specimens were moved into the constant temperature and humidity chamber (15±1°C, 60±5%). The development of the expansive pressure of the material was monitored by the strain measurements on the surface of a steel cylinder. The inner and outer radius of the cylinder are 19.1 mm and 27.4 mm respectively. The mix ratio of the demolition agent (Brister 150) and water is 1: 0.3 by weight.

3–1 Crack propagation mechanism from the boreholes

(1) Purpose

The purpose of this experiment is to make clear the crack propatagion mechanism in bench cut with demolition agent. The initiation and propagation of cracks from the boreholes were detected by the strain distributions.

(2) Experimental procedures

The cement mortar was made from normal Poltland cement and sea sand. The mix proportions, cement: sand: water, are 1: 2: 0.47 by weight. Tensile and uniaxial compressive strength of the cement mortar are 42.1 kgf/cm^2 and 411 kgf/cm^2 respectively. For the assessment of the tensile strength of the cement mortar, the diametral compression test of cylindricul specimen was adopted.

A bench model (Fig. 2) was provided to simulate the bench cut in open pit or underground stopes. The placement of the specimen was divided into three steps. At first, cement mortar was placed up to 27.5 cm height of the mould. Then the strain gauges were settled at the designed position of the upper surface. Secondly, 7.5 cm height cement mortar mass was jointed on the previous part and the settlement of strain

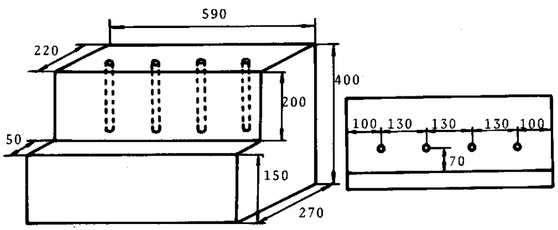


Fig. 2 The specimen for the investigation on crack propagation mechanism.

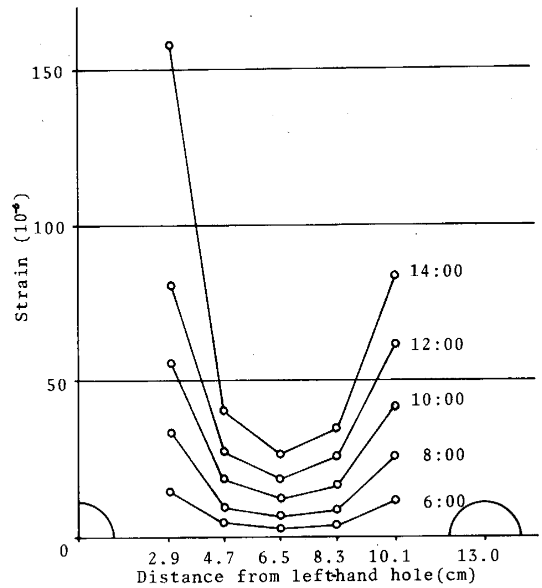


Fig. 3 Strain distribution on the upper surface along the section expected to fracture against the elapsed time.

gauges was repeated. Finally, the remained part of the mould was filled with the cement mortar.

Borehole diameter, hole spacing and burden are 2.2 cm, 13 cm and 7 cm respectively. Demolition agent slurry was poured into the holes. The hole wall was protected by a polyethylene tube in order to prevent the the moisture of the slurry from permeation into the cement mortar. Strains were automatically measured at predetermined time intervals. The number of measuring points is 21 (7 points $\times 2$ levels inside the specimen and 7 points $\times 1$ level at the uppear surface of the specimen).

(3) Results and discussions

In Fig. 3, strains along the designed demolition contour at the upper surface are shown as a function of elapsed time after the mixing of the agent with water. Between the adjacent boreholes, the strain is high at both sides and low at the middle. As the time proceeds, strain at each measuring point increases gradually. During the initerval between 12 and 14 hours, the strain increases markedly at 2.9 cm point from the left hole. This marked strain increment shows that crack initiated from the left hole. Strain measured by the gauges inside the specimen show similar tendencies as shown in Fig. 3.

Fig. 4 shows the strains at the middle point between two central boreholes against the expansive pressure of the agent. The expansive pressure is calculated from the strains at the surface of steel pipe. In the figure, three pressure-strain curves show similar tendencies. It means that cracks at different height of the specimen initiated almost simultaneously in this test.

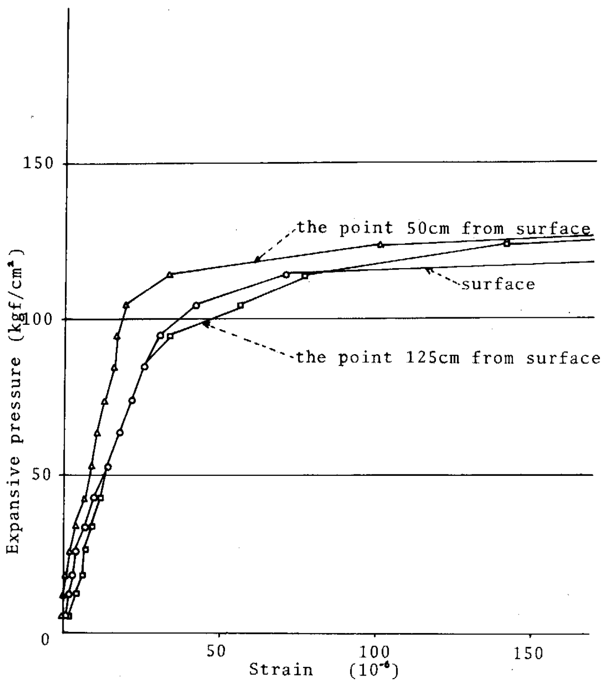


Fig. 4 The relation between strain at the center of spacing and the expansive pressure.

3–2 Spacing, burden and borehole diameter

(1) Purposes:

In bench blasting, blast cracks not only tear off the rock along the blast holes but also break the toe burden. The rock mass removed by blasting is broken into small fragments by shock wave and following gas pressure. In the bench cut with demolition agent, a part of rock (fragment) is teard off from the intact rock mass by the cracks opened by the expansive pressure of the agent. Usually the fragments are large boulders and they must be crushed into small blocks by a breaker. When the burden is large, the tearing effect of cracks is not sufficient for the following crushing operation by a breaker. It is expected that borehole spacing, diameter and burden have direct effects on the tearing results of fragments by cracks. In the model study, they were discussed from the point of crushing operations by a breaker.

(2) Experimental procedures

In this experimental study, specimens were made by ready mixed cement mortar. The tensile and uniaxial compressive strength of the material at 28 days are 21.9 kgf/cm^2 and 395 kgf/cm^2 respectively.

The width of the specimen is proportional to the borehole spacing S. The specimen

Table 1. Hole diameter, spacing and burden used in experiment.

No.	D(mm)	S(cm)	W(cm)	S/D
1	18	14	8	7.78
2	18	14	6	
3	18	14	4	
4	13	14	8	10.77
5	13	14	6	
6	13	14	4	
7	18	12	8	6.67
8	18	12	6	
9	18	12	4	
10	13	12	8	9.23
11	13	12	6	
12	13	12	4	
13	18	10	8	5.56
14	18	10	6	
15	18	10	4	
16	13	10	8	7.69
17	13	10	6	
18	13	10	4	

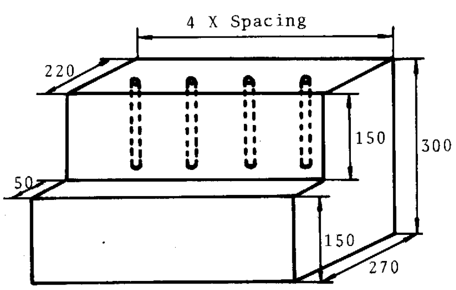


Fig. 5 Specimen for the discussion on spacing, hole diameter and burden.

(Fig. 5) has 4 vertical boreholes. The borehole length coincides with the bench height (zero subarade drilling). Borehole diameter, spacing and burden of each specimen are shown in Table 1.

(3) Results and discussions

In Fig. 6 the strains at middle point of central spacing are shown as a function of the expansive pressure. In this figure, borehole diameter and burden are kept constant. This figure shows that the strain for close spacing is higher than that for wide spacing.

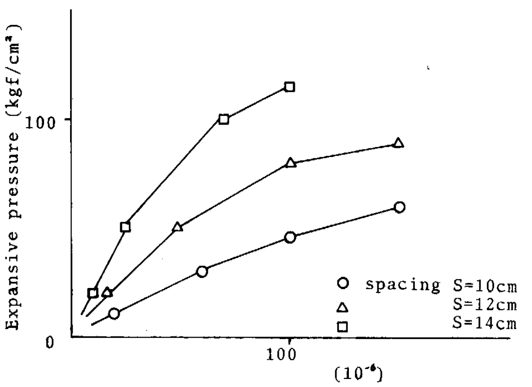


Fig. 6 The relation between strain at center of spacing and the expansive pressure when hole diameter and burden are constant but spacing changes.

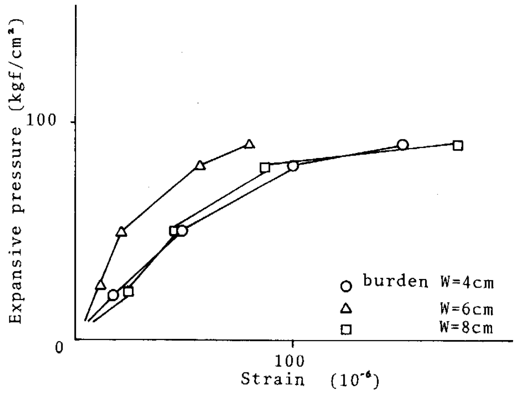
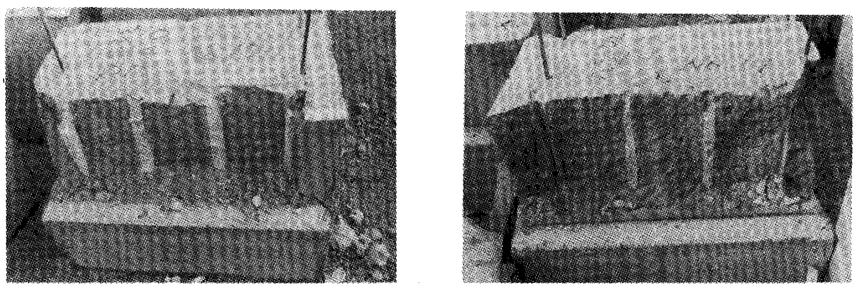


Fig. 7 The relation between strain at center of spacing and the expansive pressure when hole diameter and spacing are constant but burden changes.

In Fig. 7, the strains at middle point of central spacings are shown for the specimens with different burden values. The measured strains for the specimen with $W=4$ or 6 cm are much higher than that with $W=8$ cm. This means that the larger burden produces the poor results in crack formation. Wrenching trial with crowbar was given to the specimen in order to remove fragments from the intact part of the specimen. With the largest burden (8 cm), the fragments of the specimen with all spacings could not be removed. The fragments of the specimens with S/D of 5.56, 6.67, 7.78 were easily teard off for the smaller burden (4 or 6 cm). With these smaller burdens, however, the specimens with S/D of 9.93 and 10.77 required considerably large removal



(A) (B)

Fig. 8 Typical fructured specimens. (A) Spacing S=10 cm, Burden W=4 cm, Hole Diameter D=13 mm (B) S=10 cm, W=4 cm, D=18 mm.

effort of fragments. Typical specimens after the removal of the fragments are shown in Fig. 8.

The condition dividing a rock mass into two by expansive pressure of demolition agent can be given by the relation;

$$knD\sigma_i=(l-nD)\sigma_t \qquad \cdots\cdots\cdots(1)$$

where k is the material constant. Let n=number of boreholes, D=borehole diameter and l=length of the block to be divided into two. σ_t and σ_i are the expansive pressure of the agent and the tensile strength of rock like material respectively. $nD\sigma_i$ gives the dividing force of the expansive pressure along the borehole plane and $(l-nD)\sigma_t$ gives the resisting strength of the material along the plane. The equation gives the equilibrium condition of seperating force and resisting strength.

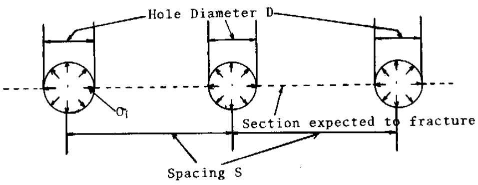


Fig. 9 Fracture factor.

The equation is arranged into the form,

$$(S-D)/D=k\sigma_t/\sigma_i \qquad \cdots\cdots\cdots(2)$$

where S is the borehole spacing. This equation gives the equilibrium condition per each hole.

The applicability of the relation to the slabbing of rock like materials has been verified by serieses of experiments for concrete, cement mortar and granite blocks. Fig.

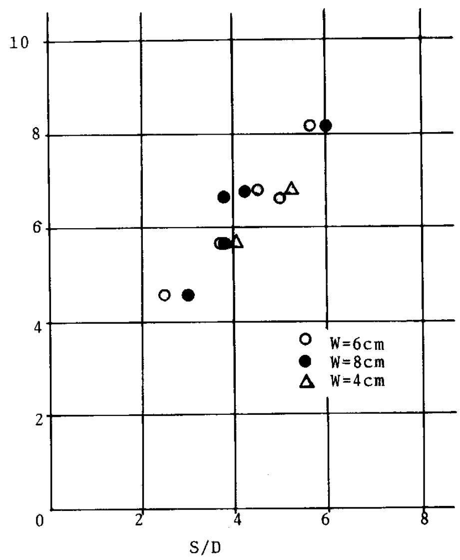


Fig. 10 The relation between (S–D)/D and σ_i/σ_t.

10 shows that the dividing condition in bench cut is given by equation (2). In this test, the division of the specimen into two was defined when the strain at the middle point of the central spacing reached to 100 microstrain.

3–3 Technical improvement of the toe breaking

(1) Purpose

Previous test results show that the fragments are not easily removed from the intact part of the specimen. In practical bench cut with demolition agent it is supposed that greatest effort is required in order to fragment the designed part by rock breaker. This also means that the unbroken toe is usually left. The special techniques are required to be developed in order to manage this problem.

In usual bench blasting, several techniques are employed in order to break the toe. These techniques involve subgrade drilling, angle drilling and toe hole blasting, etc.. In the case of bench cut with demolition agent, the efficiency of above techniques are questionable. In this section, a series of experiments were conducted in order to examine the efficiency of these techniques.

(2) Experimental procedures

The specimens were made of ready mixed cement mortar. The tensile and uniaxial compressive strength of material are 30.8 kgf/cm^2 and 390 kgf/cm^2 respectively. The typical specimen is shown in Fig. 11. Borehole diameter (13 mm) and borehole spacing (14 cm) are kept constant. Table 2 shows the test conditions of the specimen.

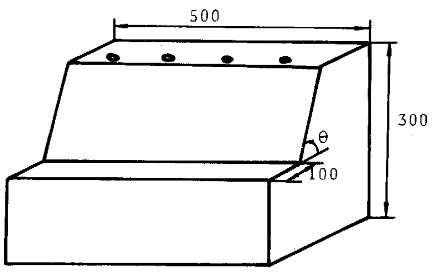


Fig. 11 The shape of specimen used in experiment for the toe cut.

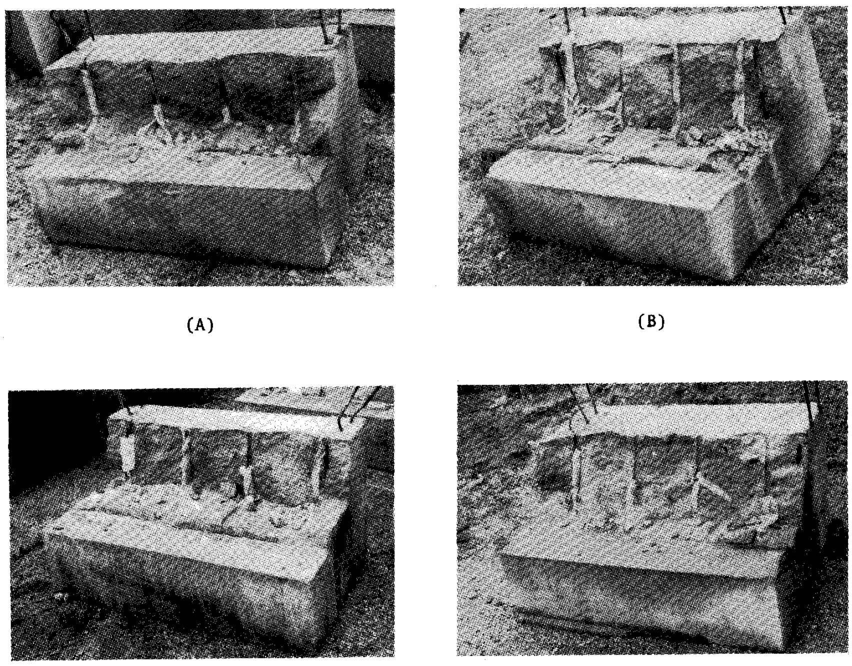
Table 2. The inclined angle and burden used in experiment and the existence of toe hole.

No.	Angle	W(cm)	Notes
1	90	4	
2	90	4	Toe hole
3	90	8	
4	90	8	Toe hole
5	75	4	
6	75	8	
7	75	12	
8	75	12	Toe hole
9	60	4	
10	60	4	Toe hole
11	60	8	
12	60	8	Toe hole
13	60	12	
14	60	12	Toe hole

(3) Results and discussions

In all specimens with toe holes, the fragments were easily removed without any additional devices. In the specimens without toe hole, the fragments were removed easily only when the hole inclination angle is 60°. In the other specimens, a great effort was required to remove the fragment.

The cracks from toe holes and boreholes completely separate the fragments from the intact part of the specimen. At the removal of the fragment, it is not necessary to break any part of the specimen. When the toe hole method is applied to the practical bench cut, the cracks which developed along the toe hole help the breaker to crush the rock at the toe burden.



(A) (B)

(C) (D)

Fig. 12 Typical fractured specimens. (A) Inclined Angle $\theta=90°$, Burden W=8 cm, toe hole. (B) $\theta=75°$, W=8 cm, toe hole. (C) O=75°, W=12 cm, toe hole. (D) $\theta=60°$, W=8 cm.

The inclination of the borehole makes the angle between the cracks and the bench floor smaller than 90°. When cracks propagate from small inclination boreholes, they extend and approach to bench floor. In practical application, the curved surface of the crack may behave like the cracks which propagated from the toe holes. The smaller the angle is, the more effect can be expected on breaking the toe.

In this study the effect of subgrade drilling was not examined. Subgrade drilling in bench cut with demolition agent only extend the vertical cracks deeper. The cracks does not help the toe breaking in itself.

4. Conclusions

Three series of experiments were conducted in order to make clear the bench cut mechanism with demolition agent. The results may be summarized as follows:

(1) The cracks from the boreholes propagate towards the adjacent boreholes. It initiates almost simultaneously at each depth of borehole.

(2) The larger burdens produce the poorer results in crack formation. At the largest burden (8 cm), the fragments can not be removed from the intact specimens with all spacings. The fragments of the specimens with S/D of 5.56, 6.67 and 7.78 were easily removed for the smaller burden (4 or 6 cm). With S/D of 9.23 and 10.8, however, the specimen required considerably large effort for removal of fragments.

(3) The dividing condition equation (2) is applicable to ensure the crack contour formation in bench cut. It must be awared that the seperation condition ensures only the continuous crack formation which seperates fragment from the intact rock.

(4) In the bench cut with demolition agent the toe breaking is troublesome problem. Among several techniques to improve the toe breaking operation, it was shown that the toe hole technique is extremely effective.

References

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