Research paper

# A study on smooth blasting technique using detonating cords

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**Abstract**

Smooth blasting technique is applied for tunnel excavation to obtain a good quality perimeter. In general, the explosives with small charge diameter are used and loaded into borehole by decoupling. However, smooth blasting technique often causes problem related to detonation failure in explosive charge. This phenomenon is well known as the channel effect. We have chosen some kinds of detonating cords as the explosives with good detonation propagation, and investigated its application for smooth blasting. Approach for its application was proceeded by three steps. At the first step, the breakage of steel pipes was investigated in laboratory scale when the bunch of detonating cords was detonated. At the next step, mini-blasting tests on small square face were conducted. And at the final step, the bunches of detonating cords were applied for the contour holes of an actual tunneling blast. Hence, it is concluded that the relationships between the total core load of detonating cords and the hole spacing have an accordance with some equation.

***Keywords***: Detonating cord, Smooth blasting, Decoupled, Overbreak, Field test.

## 1. Introduction

Today, the long borehole blasting has become possible because of the adoption of NATM, the technical development of forward exploratory equipment for face rock, and the boring accuracy improvement of the drilling rigs. Therefore, the importance for smooth blasting technique has gradually risen.

Smooth blasting technique is widely applied for tunneling road or railway construction. Smooth blasting is one of the controlled blasting techniques to control overbreak and produce a competent final excavation wall. The unexpected falling rocks are attributed to this damage at the perimeters of the excavation, and also are undesirable and fatal from the view point of safety operation. Several works on the mechanism of rock crushing have been conducted [1)-4)]. In economic aspects, smooth blasting technique as a contour blasting makes it possible to minimize the cost of concrete lining for refilling the overbreak area.

In general, explosives for smooth blasting are light density and well distributed in contour hole. Hence, explosive charge diameter is small, and the decoupled charge will be adopted. However, there is some problem for decoupled explosives in borehole. When explosives placed in the decoupled hole are detonated, a precursor air shock wave (PAS) is generated between the explosive columns and the inner wall of hole. The PAS, progressing ahead of detonation front in explosive columns, precompresses and desensitizes the explosive columns. When detonation wave reaches this precompressed point, detonation wave ceases to propagate regularly. Thus, detonation velocity decreases and detonation failure occurs. This phenomenon is well known as the channel effect.

Furthermore, it is assumed that it had better that explosive gives relatively low detonation velocity to prevent excessive stressing into the rocks. That means low detonation velocity explosives normally yield lower shock energy and make it possible to minimize the stress induced by blasting.

However, S. P. Singh [5)] elucidated that the gas energy on explosives is more effective in producing overbreak, shock energy is dissipated in a less harmful manner and the longer acting gas energy is more important from the damage point of view. Therefore, we have chosen some kinds of detonating cords as the explosives with good detonation propagation and less gas energy, and investigated its application for smooth blasting.

In this study, approach for its application was proceeded by three steps. At the first step, the breakage of steel pipes was investigated in laboratory scale when the bunch of detonating cords was detonated. At the next step, mini-blasting tests on small square face were conducted. And at the final

Table 1 Detonating cords specification.

| Cord name | Diameter (mm) | Core load (PETN) (g m$^{-1}$) |
|---|---|---|
| A | 5.4 | 10.0 |
| B | 4.0 | 5.3 |
| C | 3.7 | 3.2 |

step, the bunches of detonating cords were applied for the contour holes of an actual tunneling blast. Our investigation was focused the damage of the pipes or boreholes caused by the detonation of the bunch of detonating cords.

## 2. Experimental

### 2.1 Detonating cords

Three kinds of the detonating cords which are available in market were used. High-velocity explosive PETN is charged as core explosive, and the outer face is covered with various combinations of textiles. Waterproofing could be attributed to this structure. Several cords were bundled for adjustment of total core loads by taping in this study. Table 1 presents the specification of three kinds of the detonating cords.

### 2.2 Experimental arrangements

#### 2.2.1 Laboratory scale test

To estimate the damage caused by the detonation, the rupture and breakage test of carbon steel pipes were conducted. Two types of steel pipes with 1.5 m in length named SGP40A (outer diameter : 48.6 mm, thickness : 3.5 mm) and STK41(outer diameter : 48.6 mm, thickness : 2.3 mm) were chosen. The length of the detonating cords was adjusted to be 1.5 m by cutting. Several cords were bunched for adjustment of total core loads by taping, and initiated directly by an electric detonator. Experimental setup was buried under the depth of 30 cm in the ground. Both ends of the pipe were opened not to be plugged. A few experiments were respectively performed under each condition.

#### 2.2.2 Mini-blasting test on small square face

These series of experiments were undertaken at underground metal mine in the central of Japan. The species of rock consisted mainly of fine gneiss with very few natural cracks. The gneiss was competent with a compressive strength of about 130 MPa, a tensile strength of about 9 MPa, a seismic velocity of about 4.8 km s$^{-1}$ and a density of about 2.7 g cm$^{-3}$. Mini-blasting tests to excavate a tunnel were performed to estimate the rock damage and the best spacing between perimeter holes. The cross section of tunnel was approximately 17 m$^2$ with about 4 by 4 m in square. The borehole diameter of 51 mm, the empty hole diameter of 102 mm and a length of 4.0 m were drilled. The standard blasting design used these experiments is illustrated in Fig. 1.

A 500 g emulsion explosive was used as a primer to detonate the bunch of detonating cords with 3.7 m in length, and was initiated by non-electric detonator. All boreholes were plugged with stemming materials. In these blasting tests, the total core load : 60, 80 g m$^{-1}$ was examined. The spacing between perimeter holes was performed at the range of 500 - 900 mm, and varied at the interval of 100 mm.

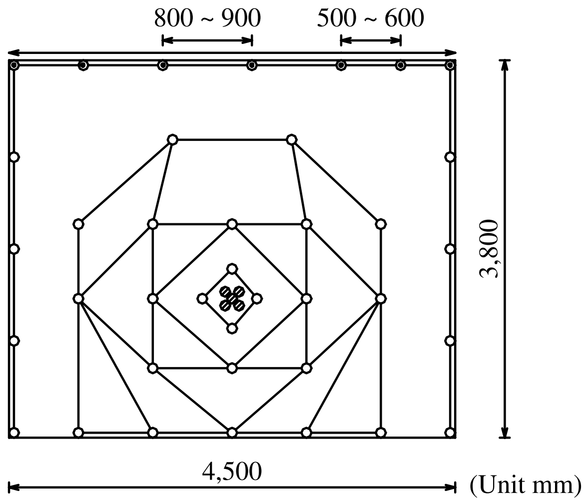


Fig. 1 Standard blasting design for mini-blasting test.

Fig. 2 Explosive setup for actual tunneling blasting test.

#### 2.2.3 Actual tunneling blasting test

These trials were performed at an actual tunneling for railway construction in the northern area of Japan. The species of rock consisted mainly of tuff andesite during test periods. The rock was competent with a compressive strength of about 100 MPa and a tensile strength of about 8 MPa. Actual tunneling blasting tests were conducted not only to investigate the rock damage and the best spacing between contour holes but also to evaluate the operation promptness for the preparation of explosive setup and the charge operation. Therefore, the bunch of detonating cords was bound up on bamboo rod with primer in advance in the explosive reserve station. Figure 2 shows the example of explosive setup.

The cross section of tunnel was approximately 73 m$^2$. The borehole diameter of 45 mm and a length of 1.8 m were drilled. The number of borehole per blast was approximately 130 holes, and the consumption of explosives was about 140 kg. The perimeter holes were initiated by No. 7 DS detonator.

## 3. Results and discussion

### 3.1 Laboratory scale test

Table 2 summarizes the damage of steel pipes after experiments in various conditions.

The detonation velocity on the bunch of detonating cords could be identified as being steady without depending on the number of the codes and the status of confinement. That

Table 2 Experimental results (Pipes damage after experiments).

| Pipes \ Conditions | | Detonating cord A | | Detonating cord B | | Detonating cord C | | | Surry explosive |
|---|---|---|---|---|---|---|---|---|---|
| | | 6 cords (60 g m$^{-1}$) | 5 cords (50 g m$^{-1}$) | 12 cords (63.6 g m$^{-1}$) | 10 cords (53 g m$^{-1}$) | 25 cords (80 g m$^{-1}$) | 19 cords (60.8 g m$^{-1}$) | 16 cords (51.2 g m$^{-1}$) | (390 g m$^{-1}$) |
| STK41 | DV (m s$^{-1}$) | 6340 | Not measured | 6940 | 7020 | Not performed | 6800 | 6770 | Not measured |
| | Damage after experiments | Reptured entirely and got blown to large pieces | Reptured entirely and got blown to large pieces | Reptured entirely and got blown to large pieces | Reptured entirely and got blown to large pieces | Not performed | Reptured entirely and got blown to large pieces | 2 portions of the opening | Unexecution |
| SGP40A | DV (m s$^{-1}$) | 6340 | 6360 | 6950 | 6940 | 6800 | 6860 | 6830 | 3840 |
| | Damage after experiments | Reptured partly | 3 portions of the opening | 4 portions of the opening | 1 portion of the opening | 1 portion of the opening | No opening, small bulge observed | No opening, small bulge observed | Got blown to small pieces |
| Open DV (m s$^{-1}$) | | Not measured | 6360 | Not measured | 6940 | Not measured | Not measured | 6750 | 3500 |

Table 3 Textile weight.

| Cord name | Core load (g m$^{-1}$) ① | Core weight (g m$^{-1}$) ② | Textiles weight (g m$^{-1}$) ③;(②-①) | Number of cords ④ | Total core load (g m$^{-1}$) ①・④ | Textiles weight of bunch (g m$^{-1}$) ③・④ |
|---|---|---|---|---|---|---|
| A | 10.0 | 25.6 | 15.6 | 6 | 60.0 | 93.6 |
| B | 5.3 | 12.6 | 7.3 | 12 | 63.6 | 87.6 |
| C | 3.2 | 11.2 | 8.0 | 19 | 60.8 | 152.0 |

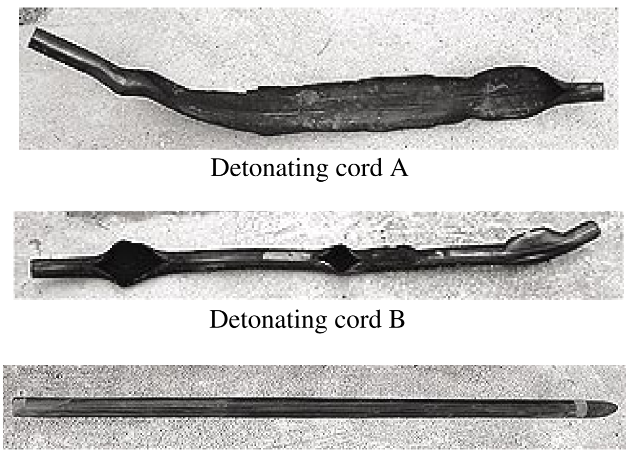


Fig. 3 Damage of pipes in three different conditions.

means the detonation propagation of detonating cord can not be influenced by channel effect.

In case that an equivalent amount of total core load was detonated, the damage of pipes can be compared in Table 2. For example, in case of the load equivalent to 60 g m$^{-1}$, the damage of pipe named SGP40A, was different between three kinds of cords. Figure 3 shows the photographs obtained in three different conditions.

So the comparative evaluation of those results was conducted based on the inside pressure of pipe. In general, a borehole pressure can be calculated by the equation of state of Abel-Nobel[6]. These equations are shown below:

$$P_s = \frac{fL}{V - \alpha L} \tag{1}$$

$$\alpha = \frac{1.5}{1.33 + 1.26\,\rho_e} \tag{2}$$

where $P_s$ is the borehole pressure [kgf cm$^{-2}$], $f$ is the explosive force [$\ell$ kgf cm$^{-2}$ kg$^{-1}$], $L$ is the explosive load [kg], $V$ is the borehole volume [$\ell$], $\alpha$ is the covolume [$\ell$ kg$^{-1}$], and $\rho_e$ is the explosive density [kg $\ell^{-1}$].

According to these equations, the inside pressures of pipe at the above-mentioned experiments were calculated as follows:

Detonating cord A ; 678 kgf cm$^{-2}$
Detonating cord B ; 720 kgf cm$^{-2}$
Detonating cord C ; 690 kgf cm$^{-2}$

These values indicate that inside pressure is almost same. However, the status of pipe damage was considerably different.

As for the next consideration, the weight of textiles that contribute to gas volume of detonation was measured. The results of measured weight indicate in Table 3.

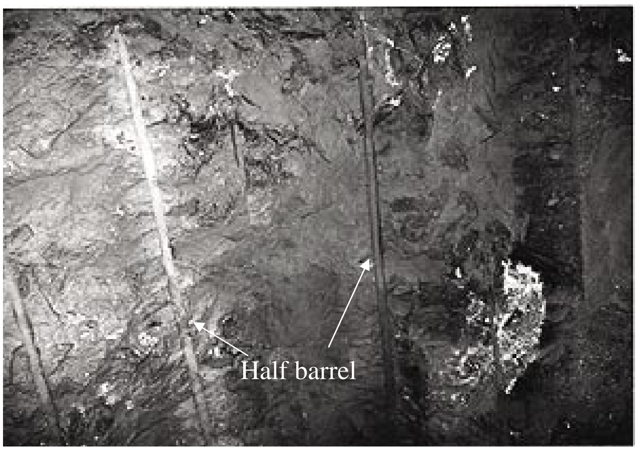


Fig. 4 Example of “half barrel”.


Fig. 5 Example of perimeter wall after blasting.

The results of measured weight do not correspond with the results from the status of pipe damage.

Furthermore, it is said that the decoupling index is the one of most important factors that influenced on the inside stress of borehole [2), 7)]. However, there was no difference regarding its decoupling index in three previous-mentioned experiments. Ultimately, the reason why there is difference in three experiments could not be confirmed.

### 3.2 Mini-blasting test on small square face

Serious overbreak at the perimeter holes could not be seen from all experiments. The wall was very smooth with “half barrel” with the exception of a few experiments. Half barrel is defined as the status that visible borehole remnants is same as the shape made by cutting column along long axial direction. Figure 4 shows the photographs of example of half barrel.

However, half barrels do not always indicate that the remaining rock is undamaged. Therefore, the damage on perimeter wall was checked by pecking in addition to the above-mentioned visual observation.

The best spacing between perimeter holes in this test was decided depending on the total core load as follows:

Core load ; 60 g $m^{-1}$ – spacing : 500 – 600 mm

Core load ; 80 g $m^{-1}$ – spacing : 600 – 700 mm

Under the condition that the core load was 60 g $m^{-1}$ and the spacing was 700 mm, the beetling rock remnants could be observed on the wall between holes.

Regarding the above-mentioned experimental results of spacing obtained form this test, its validity was verified by the next equations [8)].

$$r_t = \frac{\phi_b}{2} \left\{ 1 + 3 \left( \frac{P_s}{\sigma_t} \right)^{1/2} \right\} \tag{3}$$

$$D = 2r_t \tag{4}$$

where $r_t$ is the damage radius in rock [cm], $\phi_b$ is the borehole diameter [cm], $\sigma_t$ is the tensile strength of rock [kgf $cm^{-2}$], $D$ is the spacing that the crack can couple together [cm].

According to the above equations, the theoretical spacing was calculated as follows:

Core load ; 60 g $m^{-1}$ – spacing : 550 mm

Core load ; 80 g $m^{-1}$ – spacing : 600 mm

These values were corresponding to the experiment result well.

A. Fauske [9)] conduced the smooth blasting using the detonating cord with core load of 80 g $m^{-1}$. Under his condition that the borehole diameter was 64 mm, the best spacing could be concluded to be 95 cm.

### 3.3 Actual tunneling blasting test

The usage of slurry explosive for pre-splitting and the application of volume decoupling technique [10)] have been studied for contour hole blasting in this tunnel. However, the explosive malfunction and the local serious overbreak at the boundary of an excavation often occurred. This is the reason why the application of the detonating cords for smooth blasting was studied. The blasting design was kept as heretofore, that is, the spacing was maintained to be 70 cm, but the core load was varied to make an evaluation on smooth blasting effectiveness.

In the case of the core load of 40 g $m^{-1}$, the beetling rock remnants could be observed on the wall between holes. However, those remnants could be often broken by pecking. In the case of the core load of 50 g $m^{-1}$, the half barrel could be observed on the wall. Figure 5 shows the photographs of example of perimeter wall after blasting.

According to the calculation by the previous-mentioned four equations, the best spacing can be 68 cm in the case of the core load of 50 g $m^{-1}$.

Regarding the promptness of charge operation, there was no problem because of the in-advance preparation of the explosive setup. However, the complex work for preparation of the explosive setup annoyed the worker in the explosive reserve station. Four tunneling excavation works have been conducted in a day. The worker in the explosive reserve station was very busy with the preparation of the explosive setup and the primer charge. Because the 50 g $m^{-1}$ bunch of detonating cords with 1.4 m length was prepared by the nine-times winding of the 5 g $m^{-1}$ detonating cord with 14 m length on bamboo rod in the hand work. The worker spent long time to prepare the about 20 of explosive setup and over 100 primer charge. Therefore, the worker requested the supply of the detonating cords with large core load.

P. V. Sterk [11] concluded that the adaptation of two strands of 40 g $m^{-1}$ detonating cord was better than that of 80 g $m^{-1}$ detonating cord while the core load of 80 g $m^{-1}$ was demanded. Because the latter was inferior to the former due to cost and availability.

In Japanese explosive and blasting business field, the cord with the core load of 100 g $m^{-1}$ could be available for controlled blasting usage several years ago [12]. However, the maximum core load of the detonating cord is restricted to be 20 g $m^{-1}$ by Japanese Explosive control Law.

## 4. Conclusion

From this investigation, in spite of the same total core load and the same decoupling index in laboratory experiments, the damage of steel pipes were seriously different depending on the kinds of the detonating cords.

At the actual rock condition, the experiment results by blasting test were almost corresponding to the calculation results by Abel-Nobel equations concerning the best spacing between perimeter holes.

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# 導爆線を用いたスムースブラスティング工法に関する一検討

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スムースブラスティング工法は，トンネル掘削において最外周面を平滑に仕上げるため適用される。一般にそこで使用される爆薬は小薬径であり，穿孔内には空隙を保たれて装薬される。しかしスムースブラスティング工法はしばしば爆薬薬包の爆轟中断を生じるという問題を抱えており，この現象はチャンネル効果としてよく知られている。我々は，優れた爆轟伝播性を有する爆薬として導爆線を選定し，スムースブラスティング工法への適用性に関して検討を実施した。適用性の検討は3段階で進めた。最初は研究室レベルにおける導爆線が爆轟した時の鋼管の破断状況に関して調べ，続いて小さな正方断面の切羽における試験発破を実施し，そして最後に実際のトンネル施工現場における外周孔に導爆線の束を供して検討を行った。

これらの検討により，導爆線の総芯薬量と孔間隔との関係はAbel-Nobel方程式に従うことを確認した。

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