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# *EFFECT OF DISCONTINUITY OF ROCK ON FRAGMENTATION*

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**Summary**

Two pieces *A* and *B* of marble (each has dimensions 4cm × 4cm × 30cm) have been separated by air gap ( 0, 4, 8, 16, 32mm). 10 gram of Ammon Gelatine (Shin kiri dynamite) has been blasted at one end of the specimen *A*. The primary shock wave produced within *A* by detonation reflects at another end (limited free end or face) and brings about tension fracture producing several slabs or fragments. The first slab from *A* moves with a velocity (the highest among all slabs) and it gives impact on the near end of the specimen *B*. The impact gives rise to a secondary shock wave within *B* and it reflects at another end of *B* (open end or face) producing some slabs from *B*. The velocities of each slab or fragment from both *A* and *B* have been measured by the Kodak highspeed camera and the shapes of the primary and the seondary shock waves have been estimated. Gaps between *A* and *B* have been filled with water, clay and sand respectively. In these cases the secondary shock wave becomes weaker compared with the case of air-gap, because materials other than air decelerate the impact of the first slab from *A*. By means of the pre-cut slab method the shape of a shock wave within marble has been estimated.

## § 1. Introduction.

A question has been raised what could be the effect of shock wave on fragmentation of rock when there were cracks or gaps within rock[1]. In the present paper the mechanism of fragmentation of two specimens *A* and *B* of marble with various amount of gap between them ($G$=0, 4, 8, 16, 32mm) blasted at one end of the specimen *A* has been studied by means of the experimental method and shock wave theory of blasting described in a previous paper by the present author.[2] Gap has been filled with water, clay and sand respectively and the fragmentation characteristics of marble have also been investigated. The shape of a shock wave within marble has been estimated by means of the pre-cut slab method.

## § 2. Effect of air gap.

Fig. 1 summarizes the results of ex-

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1) Prof. E. P. Pfleider, Department of Mineral Engineering, School of Mines and Metallurgy, University of Minnesota, U. S. A. Private communication. May 2, 1956.

2) Kumao Hino, Velocity of Rock fragments and Shape of shock wave: Journal of the Industrial Explosives Society, Japan Vol. 17, No. 4 1956. pp. 236~241.

periments on fragmentation patterns with air gap. The velocities of each fragment from the specimen $A$ and $B$ have been measured by means of the Kodak 16mm high speed movie camera with 3,200 pictures per second. An example of the photographs taken is shown in Fig. 2. Fig. 3 shows the relation between displacement of fragments, measured from the open end of the specimen $B$ which is opposite to the detonation point, and time $t$ measured from the instant of detonation. From the inclination of the straight lines which represent displacement-time relation the velocity $V$ of each fragment has been found as shown in Fig. 3. From Figures 1, 2 and 3 it may be seen that the behaviour of shock waves is as follows: (1) A primary shock wave produced within the first specimen A of marble by detonation of 10 grams Ammon Gelatin Dynamite (Shin-kiri dynamite) reflects at a free end of $A$ and produces several slabs or fragments according to the mechanism described in the previous paper(2). The free face or end of $A$ may be defined as a limited free face or end because the space available to the movement of the first slab from $A$ is limited by the existence of another specimen of rock $B$. (2) The first slab from $A$, which has the highest velocity among all slabs, collides with the near end of another specimen $B$ with momentum which corresponds to the peak part of the primary shock wave. This collision gives rise to a secondary shock wave within the second specimen $B$ of marble which reflects at a free end or face opposite the point of impact. This free face or end may be defined as open free face or end because there is no restriction to the movement of the slabs or fragments produced by the secondary shock wave. It must be noticed that an energy absorbing crushed zone does not appear from the action of the secondary shock wave because

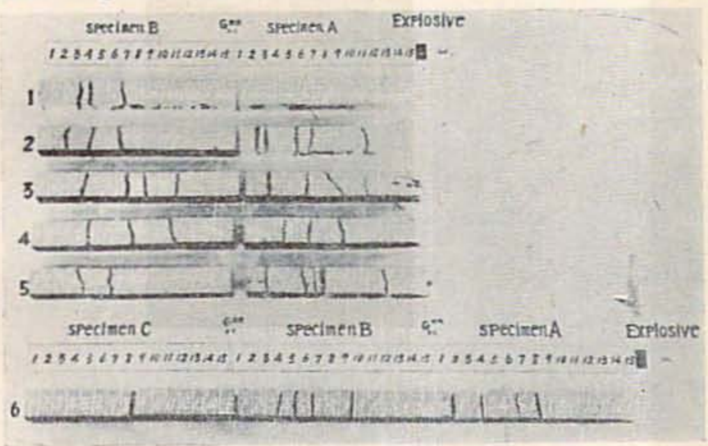



Fig. 1 Effect of gap (air) on fragmentation.

| No. | Rock | Size of specimens | ($G$mm) Gap Between two specimens |
|---|---|---|---|
| 1 | marble | $A$ 4cm × 4cm × 30cm<br>$B$ 〃 | 0mm |
| 2 | 〃 | $A$ 4cm × 4cm × 30cm<br>$B$ 〃 | 4mm |
| 3 | 〃 | $A$ 4cm × 4cm × 30cm<br>$B$ 〃 | 8mm |
| 4 | 〃 | $A$ 4cm × 4cm × 30cm<br>$B$ 〃 | 16mm |
| 5 | 〃 | $A$ 4cm × 4cm × 30cm<br>$B$ 〃 | 32mm |
| 6 | 〃 | $A$ 4cm × 4cm × 30cm<br>$B$ 〃<br>$C$ | Between $A$ and $B$ 4mm<br>Between $B$ and $C$ 4mm |

Explosive: 10g. of Ammon Gelatine (Shinkiri Dynamite)

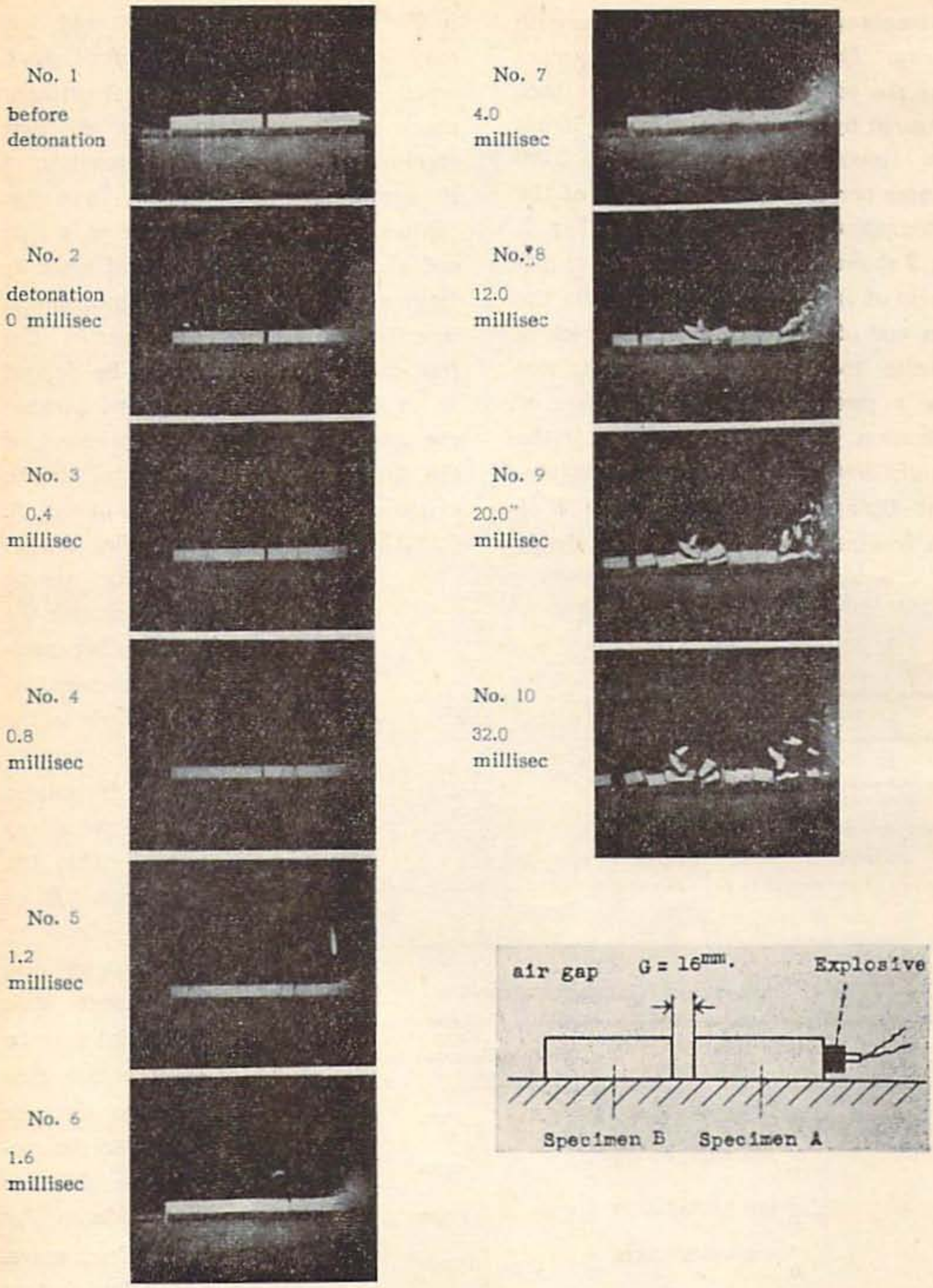



Fig. 2 Motion of rock fragments from two specimens *A* and *B* of marble.

the intensity of the secondary shock wave at its origin is smaller than the compressive strength of the rock in question. Because of this situation the efficiency of the secondary shock wave from the standpoint of fragmentation is higher than that of the primary shock wave which inevitably suffers great loss of available energy within crushed zone adjacent to a detonating charge.

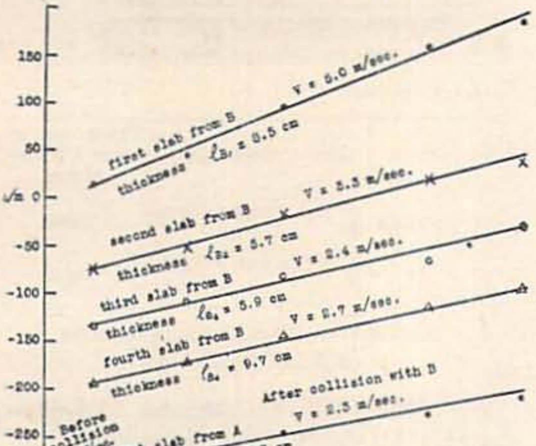



Fig. 3 Displacement of marble fragments from the first specimen $A$ and the second specimen $B$.

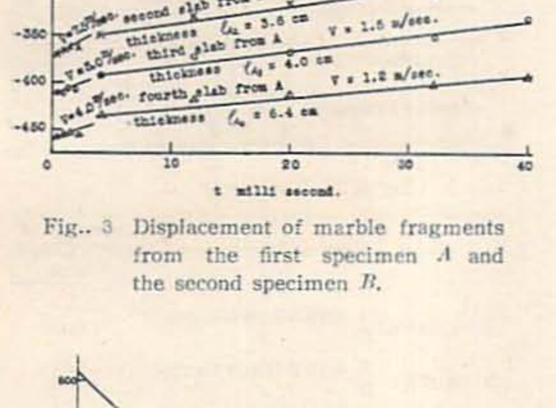



Fig. 4 Shapes of primary shock wave (within rock specimen $A$) and of secondary shock wave (within rock specimen $B$) for marble ($U$= 5,800m/sec. $\Delta=2.6\times10^{-3}$kg/cm$^3$).

The pressure $P$ of the primary and secondary shock waves may be calculated by means of the following relation[2] beween $P$ and the density of rock $\Delta$, the velocity $V$ of movement of a slab or a fragment and the velocity $U$ of a shock wave.

$$P=\frac{1}{2}\Delta U V \qquad (1)$$

To a first approximation the velocity of a shock wave may be assumed to be the same (except very near the origin of detonation) with that of a sound wave within rock. The velocities of sound waves within Marble, Sandstone and Granite have been calculated by means of the following equation[2] while the Young modulus $E$ kg/cm$^2$ has been measured by dynamic (sonic) method.[3]

$$U=\sqrt{\frac{gE}{\Delta}} \qquad (2)$$

The results of measurement and calculation on velocity have been summarized in Table 1.

The shapes of the primary and the secondary shock waves are illustrated in Fig 4. The results of the experiments on fragmentation with air gap have been summarized in Table 2.

3) Young's Modulus meter, the Nippon-Denshi-Sokuki Co. Ltd. Type CT 2.

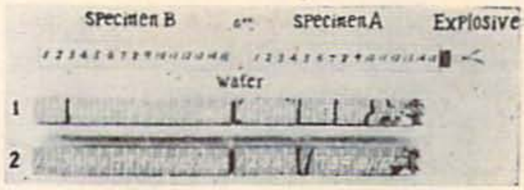
Table 1. Velocity of shock waves in various rock specimens.

| No. | Rock | Density kg/cm³ | Young's modulus kg/cm² | Velocity of wave cm/sec. |
|---|---|---|---|---|
| 1 | Marble | $2.62\times10^{-3}$ | $9.0\times10^{5}$ | $5.8\times10^{5}$ |
| 2 | Marble | $2.63\times10^{-3}$ | $6.4\times10^{5}$ | $4.8\times10^{5}$ |
| 3 | Granite | $2.17\times10^{-3}$ | $4.8\times10^{5}$ | $4.6\times10^{5}$ |
| 4 | Sandstone | $2.28\times10^{-3}$ | $3.3\times10^{5}$ | $3.8\times10^{5}$ |
| 5 | Sandstone | $2.47\times10^{-3}$ | $3.3\times10^{5}$ | $3.6\times10^{5}$ |
| 6 | Sandstone | $2.58\times10^{-3}$ | $4.3\times10^{5}$ | $3.8\times10^{5}$ |

Table 2. Characteristics of fragments or slabs in two rock pieces *A* and *B* with air gap.
(1) before collision
(2) after collision.

| No. | Air gap | | Thickness of slab | Velocity of slab | | Pressure of shock wave | |
|---|---|---|---|---|---|---|---|
| | mm | | cm | m/sec | | kg/cm² | |
| 1 | 0 | *B*-1 | 6.2 | 9.3 | | 715 | |
| | | *B*-2 | 1.1 | 8.0 | | 615 | |
| | | *B*-3 | 4.6 | 6.4 | | 492 | |
| | | *B*-4 | 17.9 | 3.6 | | 277 | |
| | | *A*-1 | 20.3 | 0.7 | | 53.8 | |
| 2 | 4 | *B*-1 | 5.0 | 8.3 | | 638 | |
| | | *B*-2 | 3.0 | 4.4 | | 338 | |
| | | *B*-3 | 3.4 | 3.6 | | 277 | |
| | | *B*-4 | 18.2 | 2.7 | | 208 | |
| | | *A*-1 | 2.7 | 2.4 | | 185 | |
| | | *A*-2 | 0.8 | 2.4 | | 185 | |
| | | *A*-3 | 4.3 | 2.4 | | 185 | |
| | | *A*-4 | 2.0 | 2.4 | | 185 | |
| | | *A*-5 | 6.7 | 2.4 | | 185 | |
| 3 | 8 | *B*-1 | 7.7 | 5.4 | | 415 | |
| | | *B*-2 | 5.7 | 3.5 | | 269 | |
| | | *B*-3 | 2.2 | 3.3 | | 254 | |
| | | *B*-4 | 5.0 | 1.9 | | 146 | |
| | | *B*-5 | 9.3 | 1.9 | | 146 | |
| | | *A*-1 | 3.5 | 2.5 | | 192 | |
| | | *A*-2 | 3.5 | 2.3 | | 177 | |
| | | *A*-3 | 8.5 | 2.2 | | 169 | |
| 4 | 16 | *B*-1 | 8.5 | 5.0 | | 385 | |
| | | *B*-2 | 5.7 | 3.3 | | 254 | |
| | | *B*-3 | 5.9 | 2.4 | | 185 | |
| | | *B*-4 | 9.7 | 2.7 | | 208 | |
| | | | | (1) | (2) | (1) | (2) |
| | | *A*-1 | 6.2 | 7.9 | 2.3 | 608 | 177 |
| | | *A*-2 | 3.6 | 7.5 | 1.9 | 577 | 146 |
| | | *A*-3 | 4.0 | 5.0 | 1.5 | 385 | 115 |
| | | *A*-4 | 6.4 | 4.0 | 1.2 | 308 | 92.3 |
| 5 | 32 | *B*-1 | 7.0 | 3.2 | | 246 | |
| | | *B*-2 | 4.6 | 2.7 | | 208 | |
| | | *B*-3 | 18.2 | 2.5 | | 192 | |
| | | | | (1) | (2) | (1) | (2) |
| | | *A*-1 | 2.8 | 14.0 | 2.5 | 1,077 | 192 |
| | | *A*-2 | 5.0 | 12.0 | 2.5 | 923 | 192 |
| | | *A*-3 | 1.7 | 11.0 | 2.5 | 846 | 192 |
| | | *A*-4 | 1.0 | | 2.5 | | 192 |
| | | *A*-5 | 8.6 | 5.0 | 2.5 | 385 | 192 |

Fig. 5 Effect of an inserted layer on fragmentation.




(1) Water

| No. | Rock | Size of Specimens | Thickness of layer (Water) *G*mm |
|---|---|---|---|
| 1 | marble | *A* 4cm × 4cm × 30cm<br>*B* 〃 | 2mm |
| 2 | 〃 | *A* 4cm × 4cm × 30cm<br>*B* 〃 | 4mm |

Explosive: 10g of Ammon Gelatine (Shinkiri Dynamite).


(2) Clay With 30% water

| No. | Rock | Size of Specimens | Thickness of layer (Clay) *G*mm |
|---|---|---|---|
| 1 | marble | *A* 4cm × 4cm × 30cm<br>*B* 〃 | 1mm |
| 2 | marble | *A* 4cm × 4cm × 30cm<br>*B* 〃 | 2mm |
| 3 | marble | *A* 4cm × 4cm × 30cm<br>*B* 〃 | 4mm |
| 4 | marble | *A* 4cm × 4cm × 30cm<br>*B* 〃 | 8mm |

Explosive: 10g of Ammon Gelatine (Shinkiri Dynamite)

(3) Dry Sand

| No. | Rock | Size of Thickness | Thickness of layer (Sand) $G$mm |
|---|---|---|---|
| 1 | marble | $A$ 4cm × 4cm × 30cm<br>$B$ 〃 | 1mm |
| 2 | marble | $A$ 4cm × 4cm × 30cm<br>$B$ 〃 | 2mm |
| 3 | marble | $A$ 4cm × 4cm × 30cm<br>$B$ 〃 | 3mm |

Explosive: 10g of Ammon Gelatine (Shinkiri Dynamite)

## § 3. Effect of gap filled with water, clay and sand respectively.

Fragmentation patterns of two pieces of marble separated through a layer of water, clay (with 30% water), and dry sand respectively are shown in Fig. 5 (1), Fig. 5 (2), Fig. 5 (3) respectively. The velocity and pressure characteristics have been summarized in Table 3. From the fragmentation patterns and the photographs taken by the Kodak high speed camera it may be seen that the gap forms a semi-free face for the specimen $A$.

The primary shock wave produced within rock $A$ by detonation of a charge reflects at the semi-free face or end and brings about tension fractures in rock $A$. A part of the primary shock wave may be transferred over the inserted layer to rock $B$ and this may reflect at an open end of rock $B$ bringing about tension fracture in rock $B$. In addition

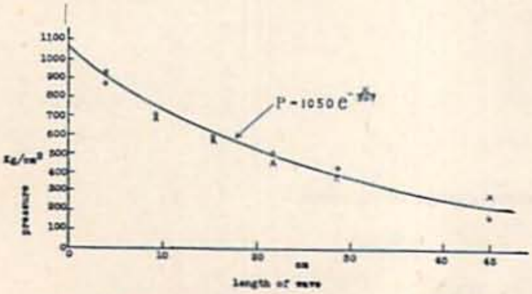



Fig. 7 Shape of shock wave within marble.

Table 3. Characteristics of fragments or slabs for two marble pieces $A$ and $B$ with gaps filled with water, clay or sand.

| No. | Gap | Thickness of slab | | Velocity of slab | Pressure of shock wave |
|---|---|---|---|---|---|
| | | | cm | m/sec | kg/cm² |
| 1 | water 2mm | $B$-1 | 5.1 | 3.5 | 269 |
| | | $B$-2 | 24.9 | 3.0 | 231 |
| | | $A$-1 | 9.9 | 3.0 | 231 |
| | | $A$-2 | 2.3 | 2.5 | 192 |
| | | $A$-3 | 2.0 | 2.0 | 154 |
| 2 | water 4mm | $B$-1 | 30.0 | 3.0 | 231 |
| | | $A$-1 | 10.1 | 2.8 | 215 |
| | | $A$-2 | 1.5 | 2.75 | 211 |
| | | $A$-3 | 10.6 | 2.5 | 192 |
| 3 | clay 1mm (with 30% water) | $B$-1 | 4.1 | 7.5 | 577 |
| | | $B$-2 | 5.4 | 3.5 | 269 |
| | | $B$-3 | 20.5 | 2.7 | 208 |
| | | $A$-1 | 19.0 | 2.25 | 173 |
| 4 | clay 2mm (with 30% water) | $B$-1 | 4.5 | 3.75 | 288 |
| | | $B$-2 | 25.5 | 3.0 | 231 |
| | | $A$-1 | 9.4 | 2.75 | 211 |
| | | $A$-2 | 5.6 | 2.5 | 192 |
| | | $A$-3 | 4.3 | 2.4 | 185 |
| 5 | clay 4mm (with 30% water) | $B$-1 | 4.6 | 4.3 | 331 |
| | | $B$-2 | 25.4 | 4.0 | 308 |
| | | $A$-1 | 10.6 | 3.75 | 288 |
| | | $A$-2 | 6.2 | 3.3 | 254 |
| 6 | clay 8mm (with 30% water) | $B$-1 | 30.0 | 3.3 | 254 |
| | | $A$-1 | 6.7 | 3.6 | 277 |
| | | $A$-2 | 3.9 | 3.5 | 269 |
| | | $A$-3 | 7.9 | 3.2 | 246 |
| 7 | dry sand 1mm | $B$-1 | 17.0 | 5.5 | 423 |
| | | $B$-2 | 13.0 | 3.0 | 231 |
| | | $A$-1 | 19.6 | 2.3 | 177 |
| | | $A$-2 | 8.9 | 1.75 | 135 |
| 8 | dry sand 2mm | $B$-1 | 17.1 | 4.0 | 308 |
| | | $B$-2 | 12.9 | 3.3 | 254 |
| | | $A$-1 | 7.5 | 2.6 | 200 |
| | | $A$-2 | 2.9 | 1.87 | 144 |
| | | $A$-3 | 7.3 | 0.75 | 58 |
| | | $A$-4 | 1.8 | – | – |
| 9 | dry sand 4mm | $B$-1 | 30.0 | 3.75 | 288 |
| | | $A$-1 | 9.0 | 3.6 | 277 |
| | | $A$-2 | 4.5 | 2.0 | 154 |
| | | $A$-3 | 5.7 | 2.0 | 154 |

to the transferred shock the secondary shock wave may be produced by an impact of the first slab from rock $A$ againt rock $B$. This impact may be reduced by the existence of a layer of water, clay or sand because materials other than air may decelerate the velocity

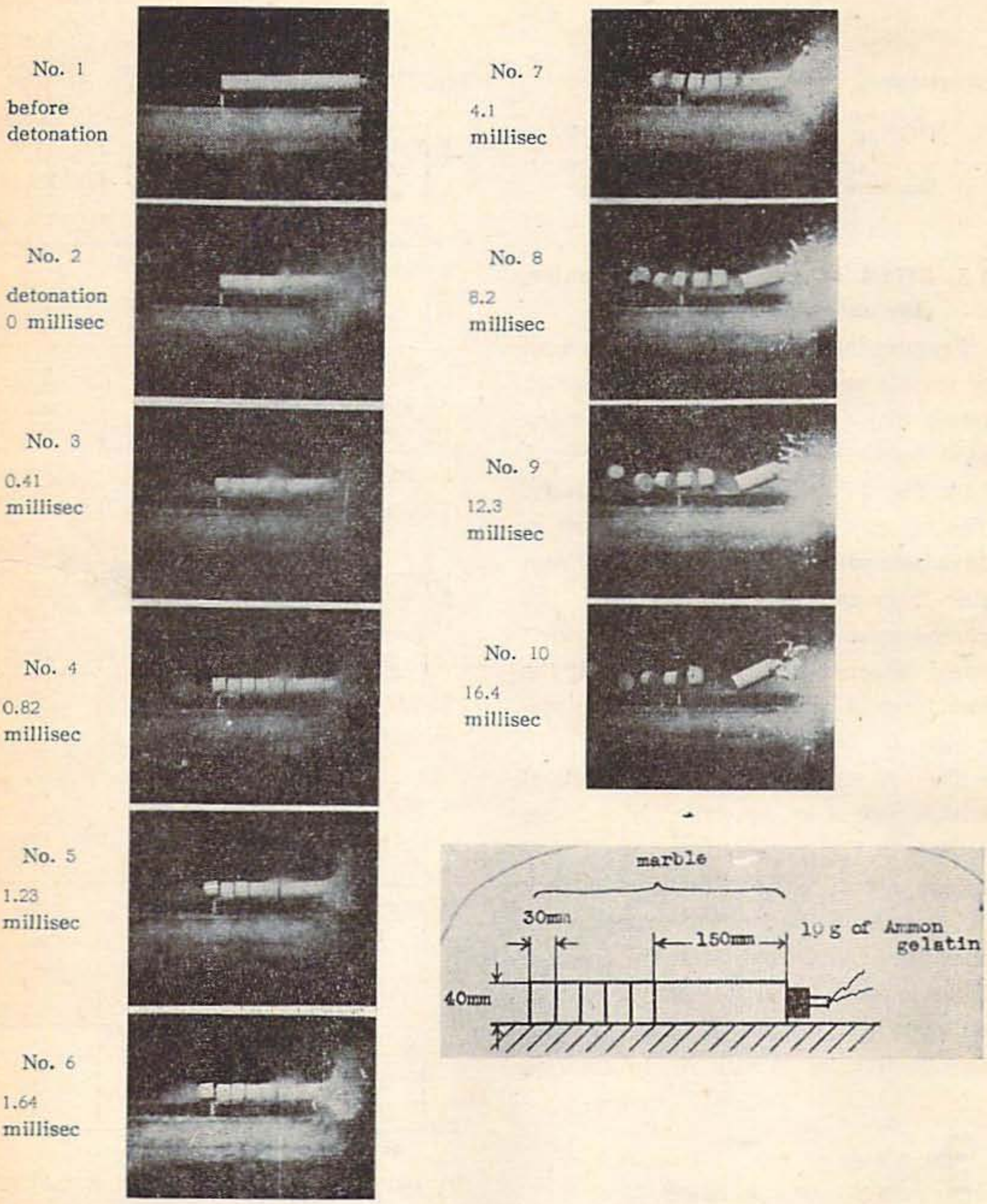



Fig. 6 Motion of multiple-time-pieces of marble.

of the first slab. In total the secondary shock effect in rock $B$ may be supposed to be smaller in the case of gap filled with water, clay or sand than in the case of air-gap.

## § 4. Shape of shock wave within marble estimated by means of pre-cut slab method.

Five short pieces (pre-cut slabs or multiple time-pieces) and one long piece of marble with circular section have been put into contact and a charge of 10 grams of ammon gelatin dynamite (Shinkiri dynamite) has been detonated at one end of the long rod. The shock wave reflects at an open end of a short piece which corresponds to the first slab in the case of a continuous rod of rock. By measuring the velocity of each piece by the Kodak high speed camera the shape of a shock wave produced within rock by detonation may be estimated according to the principle described in the previous paper (1). Fig. 6. shows an example of the photographs.. Fig. 7. illustrates the shape of a shock wave within marble. Effects of gap between a charge and rock, thickness of wrapper of a charge on the shape of the shock wave have been investigated by the same method. The result shows that the peak pressure of shock waves under various conditions remain nearly the same while the effective length cf shock waves becomes shorter when gap between rock and a charge becomes greater. This result may be considered natural because the peak pressure is chiefly determined by the compressive strength of marble and not by the pressure of a detonated charge so far as the pressure from detonation exceeds the compressive strength of rock which is usually the case.

Acknowledgement

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1957. 4. 12.

## 岩層内亀裂とショック波に依る岩石の破砕

日 野 熊 雄

日本化薬株式会社 厚狭作業所

岩層に亀裂のあつた場合，爆源から伝播するショック波はその亀裂（一般には空気）表面に於て反射し従て亀裂のある以後の岩層にはショック波は伝播せずショック波の発破効果は亀裂の存在に依り中断されるものと想像されて居た。

本研究に於てはこの影響を研究する為種々の厚さの亀裂層を有する岩石試料片に対する新桐ダイナマイトの破砕効果を高速度写真に依り観測しショック波は第一岩片の破砕に有効であるのみならず亀裂面に於て生ずる第一スラブが第二岩片に衝突することに依り極めて効率の良い（即ち粉砕層の発生を伴わない）第二次ショック波が第二岩片内に発生し総体的に言つて総合的発破効果に対するショック波の作用が増大する事を認めた。この第二次ショック波に付て亀裂層が空気，水，砂等であつた時の様子に付て報告した。