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VELOCITY OF ROCK FRAGMENTS AND SHAPE OF SHOCK WAVE

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Summary

Rock specimens (Marble, Granite, Sandstone and Andesite) whose dimensions are 4cmx4cmx30cm have been blasted at one end by three kinds of industrial explosives (Ammon Gelatin, Permitted Ammon Gelatin, Permitted Ammon Dynamite) and the velocities of rock fragments have been measured by (1) high speed camera or (2) chronotron millisecond meter. Pressure of shock wave has been calculated using velocity measured. Peak pressure thus obtained is more than double of that estimated on fragmentation pattern and tensile strength of rock statically measured. Dynamical tensile strength of rock estimated on the basis of velocity measurement is more than double of that obtained statically.

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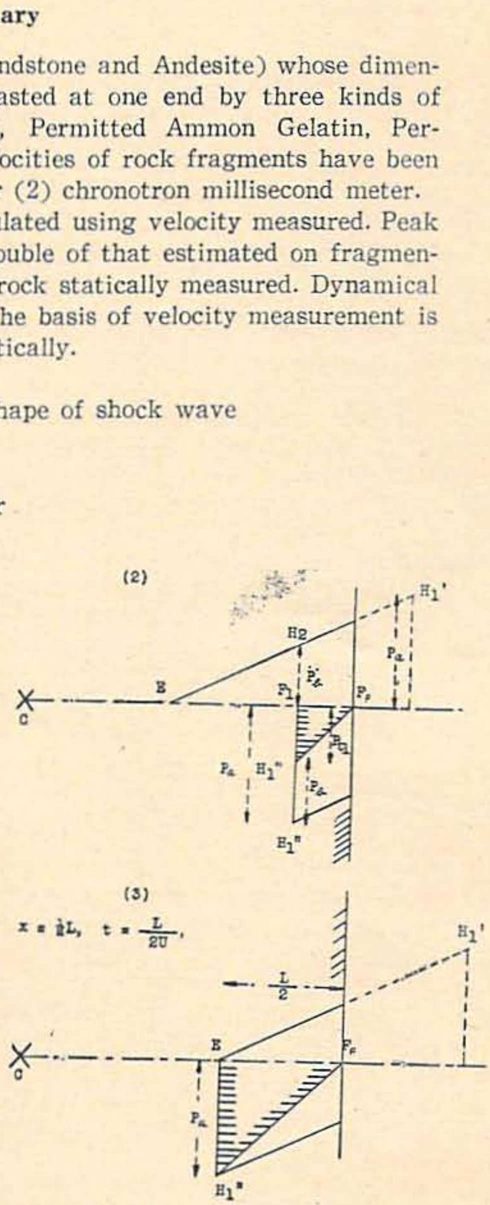
§ 1. Introduction

In a previous paper(1) on fragmentation of rock through blasting the shapes of shock waves produced within rocks by explosives have been reproduced by use of the fragmentation patterns of rock specimens. In the present paper the velocities of rock fragments have been measured by high speed camera or chronotron and by use of these velocities sha-



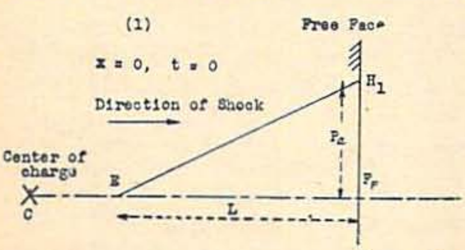


Fig. 1. Reflection of shock wave

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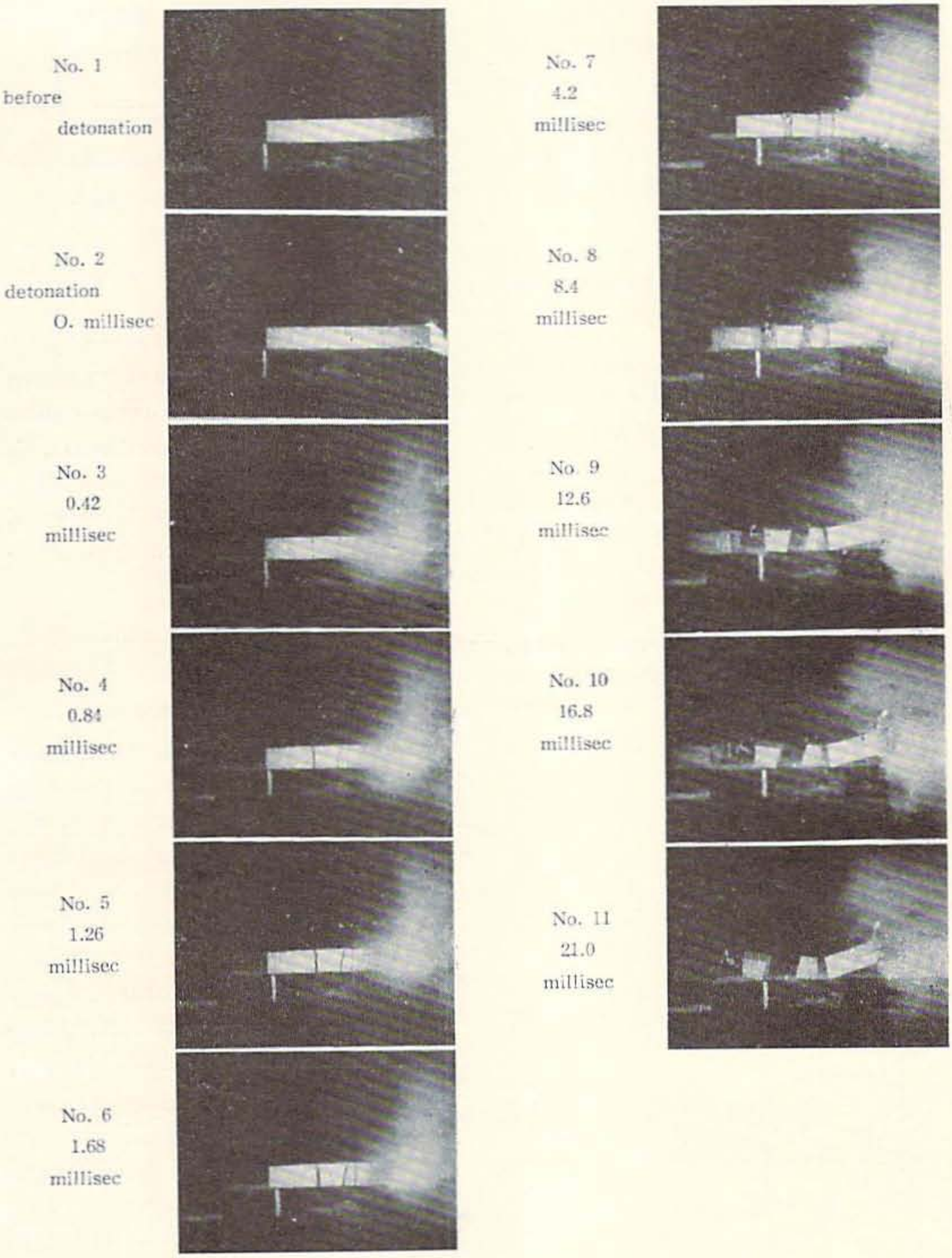

Fig. 2. Motion of rock fragments produced by detonation of Ammon-gelatin dynamite

pes of shock wave produced within granite etc. by Ammon gelatin dynamite (Shin-Kiri dynamite) etc. have been reproduced. The rock specimens and dynamite have the same characteristics with those described in the previous paper.[1)]

§ 2. Velocity of rock fragments and shape of shock wave.

In Fig. 1. (1) the wave front of a compressive shock wave $H_1\ F_P\ E$ has just arrived at a free face. In Fig. 1 (2) the wave has advanced until the effective tension P_t becomes equal with the tensile strength of rock S_t and at this point F_1 the first main fracture due to tension occurs. The thickness $F_1\ F_P$ is defined as "thickness of the first slab l",. This thickness determines the dimensions of rock fragment.

Although at a free face the effective pressure must be zero the outward velocity V of the first slab is given by:

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

where: P = mean pressure of shock wave entrapped in one slab.

Δ = density of rock

U = velocity of shock wave within rock.

The numerical coefficient 2 enters the equation (1) because incident and reflected waves must be taken into consideration. If we can measure the velocities V_1, V_2, V_3 of the first, second, third slabs and so on, then, we can reproduce the shape of original shock wave according to the following equation.

$$P_n = \frac{1}{2}\Delta U V_n \quad \cdots\cdots\cdots\cdots\cdots (2)$$

§ 3. Measurement of velocity

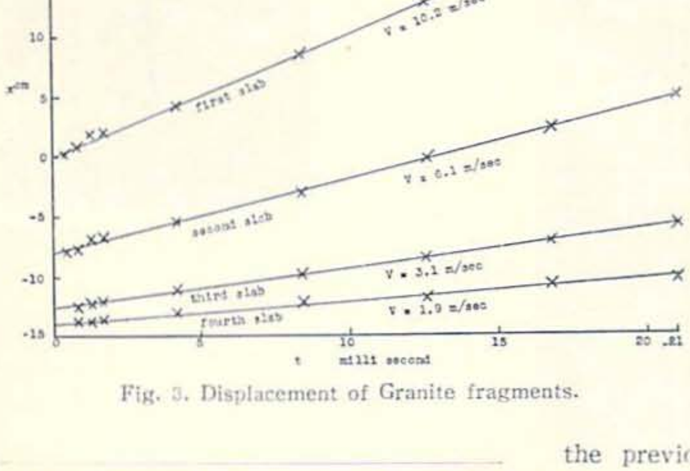

Fig. 3. Displacement of Granite fragments.

Two methods have been used to measure velocities of rock fragments. The first is the Kodak 16mm high speed movie camera with 3200 pictures per second (Eastman Kodak Company*) and the second is the chronotron millisecond meter model 25A (Electronic Instruments Ltd.◎)

3-1. By high speed camera

The arrangement of granite specimen, dynamite and electric detonator is the same with that described in the previous paper(1). The weight of charge is 10g and the dimensions of gra-

1) Kumao Hino: Fragmentation of Rock through blasting: Journal of the Industrial Explosives Society, Japan. Vol. 17. No. 1. 1956. pp 2-11.

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Table 1 Data on Granite (By high speed camera)

Experiment	Number of slab (cm)	Velocity m/sec.	Mean Pressure kg/cm²	Dynamical Tensile Strength kg/cm²
No. 1	No. (1) 8.2	9.8	695	(1) − (2) = 128
Δ=2.78g/cm³ 4cm×	No. (2) 1.0	8.0	567	(2) − (3) = 255
4cm×30cm	No. (3) 3.4	4.4	312	(3) − (4) = 99
U=4960m/sec.	No. (4) 7.0	3.0	213	
	No. (1) 7.8	10.6	753	(1) − (2) = 143
No. 2	No. (2) 1.6	8.6	610	(2) − (3) = 311
	No. (3) 9.5	2.8	199	
	No. (1) 8.0	11.1	789	(1) − (2) = 79
No. 3	No. (2) 2.7	10.0	710	(2) − (3) = 355
	No. (3) 1.6	5.0	355	(3) − (4) = 113
	No. (4)13.0	3.4	242	
	No. (1) 6.3	11.3	794	(1) − (2) = 104
No. 4	No. (2) 3.2	9.8	690	(2) − (3) = 387
	No. (3) 4.2	4.3	303	(3) − (4) = 120
	No. (4) 5.0	2.6	183	
No. 5	No. (1) 7.9	10.2	725	(1) − (2) = 296
(Fig. 2)	No. (2) 4.5	6.1	429	(2) − (3) = 211
(Fig. 3)	No. (3) 1.5	3.1	218	(3) − (4) = 83
	No. (4)11.0	1.9	135	
	No. (1) 4.5	16.6	1170	(1) − (2) = 230
No. 6	No. (2) 2.5	13.2	940	(2) − (3) = 349
	No. (3) 4.0	8.4	591	(3) − (4) = 364
	No. (4) 3.3	3.2	227	

nite specimen are: 30cm×4cm×4cm

Fig. 2. shows an example of pictures taken by Kodak high speed camera. Fig. 3. shows an example of the relation between displacement x centimeter of rock fragments and time of their travel t millisecond. The inclination of x-t line gives velocity of respective fragment. By the use of the equation (2) we may calculate the pressure of shock wave entrapped within the first slab, for example, as follows:

$$P=\left(\frac{1}{2}\,\Delta U\right)V$$
$$=\left(\frac{2.78\times 496000\times 10^{-3}}{2\times 980}\right)\times 1020$$
$$=0.704\times 1020=725\text{kg/cm}^2$$

where 980cm/sec² is a gravity constant which converts c. g. s. unit into g-cm unit.

Fig. 4. shows the shape of shock wave produced within granite by 10g of Ammon gelatin dynamite.

The measured velocities (and calculated pressure of shock wave) have been summarized in Table 1 and Table 2.

3-2. By Chronotron millisecond meter

In the chronotron millisecond meter model 25A the incoming signal causes a constant current to charge a precision capacitor. At the end of the timing per-

Table 2 Data on Marble (1) (By high speed camera)

Experiment	Number of slab	Velocity m/sec.	Mean Pressure kg/cm²	Dynamical Tensile Strength kg/cm²
No. 7	No. (1) 1.3	11.2	822	(1) − (2) = 222
$\Delta=2.7$g/cm³	No. (2) 3.0	8.18	600	(2) − (3) = 160
4cm×4cm×20cm	No. (3) 6.5	5.99	440	(3) − (4) = 102
$U=5330$m/sec.	No. (4) 6.0	4.60	338	
No. 8	No. (1) 8.0	9.02	662	(1) − (2) = 71
	No. (2) 6.5	8.05	591	(2) − (3) = 297
4cm×4cm×40cm	No. (3) 9.5	4.00	294	

iod this capacitor is isolated electronically and the voltage developed across it is automatically measured by a. d. c. valve voltmeter directly calibrated in units of time.

The meter reading is dead-beat and decays very slowly, allowing ample time for observation.

The arrangement for the measurement of velocity of rock fragment is illustrated in Fig. 5.

The results are summarized in Table 3.

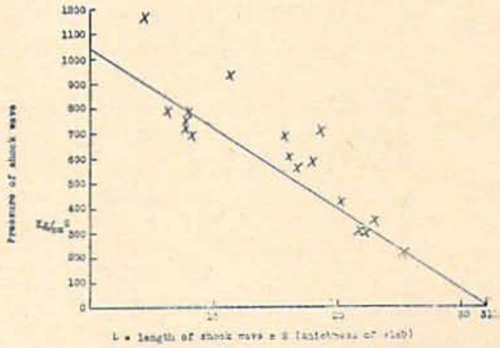

Fig. 4. Shape of Shock wave within granite reproduced by velocity measurements

Table 3 Velocity of rock fragment (first slab) measured by Chronotron (with calculated pressure)

Rock	density Δ kg/cm³	Velocity of Shock wave U* m/sec	Compressive Strength kg/cm²	Tensile Strength kg/cm²	Velocity m/sec (Pressure)		
					Ammon gelatin kg/cm²	Permitted Ammon gelation kg/cm²	Permitted Ammon dynamite kg/cm²
Marble (1) (Ômine) amorphous	2.7	5,330	815	55	8.9(653)	8.8(646)	7.7(565)
Marble (2) crystalline	2.7	5,330	670	37	9.1(668)	7.0(514)	5.4(396)
Granite (Tokuyama)	2.7	4,960	1,000	75	9.7(683)	10.0(704)	8.4(592)
Sandstone (1) (Susa)	2.4	2,350	1,700	110	16.4(472)	12.4(357)	9.0(259)
Sandstone (2)	2.6	3,780	−	−	9.7(487)	9.0(452)	4.8(241)
Andesite (Shifuku)	2.0	2,170	−	−	11.1(248)	9.9(221)	8.8(196)

* Estimated from wave velocity within rocks of similar density. (S. Kusakabe, Pub. E. I. C., No. 22 B, 1906, 27).

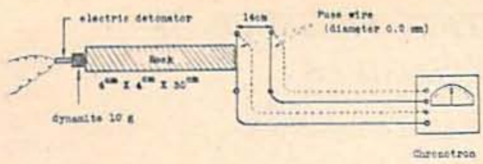

Fig. 5. Measurement of velocity of rock fragment by chronotron

§ 4. Discussions

Peak pressures of shock wave estimated by measuring velocities of rock fragments by means of (1) high speed camera or (2) chronotron are nearly the same, while peak pressure of shock wave estimated on the basis of fragmentation patterns (1) is much lower than pressure reproduced by velocity measurement. One of the main reasons for this discrepancy may be that the statically measured tensile strength of rock might be smaller than dynamical tensile strength. In other words pressure estimation by means of velocity measurement provides us with a method of measuring tensile strength of rock at shock wave velocity. For example from the data shown in Table 1 and Table 2 we may calculate dynamical tensile strengths of granite and marble as are shown in the last column of Table 1 and Table 2.

Acknowledgement.

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要　旨

岩石破断片の速度とショツク波の形状

日　野　熊　雄

（日本化薬株式会社厚狭作業所研究課）

3種類の岩石試料（大理石，砂岩，安山岩）を使用して発破の基礎研究を行った。岩石片の大きさは4cm×4cm×30cm でありその一端に於てダイナマイト（新桐ダイナマイト，白梅ダイナマイト，硝安ダイナマイト）を爆轟させ岩石片の他端より飛行する岩石破断片の速度を（1）高速度カメラ及び（2）クロノトロンミリセコンドメーターに依つて測定した。この速度から岩石内のショック波の圧力が計算された。先に筆者は同様な実験に依つて岩石の破断状況と岩石の静的引張強度の実測値を用いてショック波の波形及び波頭の圧力を計算したがこの静的測定法に比べて今回の動的測定法は2倍以上の波頭圧力値を示している。岩石の静的引張強度に比しその動的引張強度は2倍以上の値を持つものと考えられる。