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FRAGMENTATION OF ROCK THROUGH BLASTING

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Summary

Three kinds of rock specimens (marble, granite, sandstone) whose dimensions are 4cm×4cm×30cm have been blasted at one end by three kinds of industrial explosives (Ammon Gelatin, Permitted Ammon Glatin, Permitted Ammon Dynamite) and the fragmentation patterns have been investigated. Compressive and tensile strengths of these rocks have been measured and by use of the numerical values of tensile strengths and sizes and numbers of slabs formed by blasting the shapes of shock waves produced within rock have been estimated. The peak pressure of shock wave has been found to be chiefly determined by the compressive strength of rock. The blastability coefficient has been defined as the ratio of compressive strength to tensile strength of rock and this coefficient sets an upper limit to the maximum possible number of slabs.

§ 1. Introduction.

J. W. Landon[1] and H. Quinney had investigated the effect of a charge of gun-cotton detonated in contact with the end of a bar of concrete. Their experiments had been conducted as a part of experiments concerning Hopkinson's pressure bar. They found that the peak pressure of a shock wave was about 1,000

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1) J. W. Landon and H. Quinney; Experiments with the Hopkinson Pressure Bar; Proc. Roy. Soc. Vol. 130. 1923. pp.622-643.

psi and that the length of the shock wave to be about 42 inch for 8 ounce of gun cotton with a concrete bar of 3 feet length and 3 inches diameter whose tensile and compressive strength were 200 *psi* and 800 *psi* respectively. The number of slabs preduced was about 4.

In the light of the recent development of the shock wave theory of blasting[2] of rock this classical experiment of Landon and Quinney aquires new importance. In the present paper three kinds of rocks, marble, granite and sandstone have been tested as rock specimens of widely different mechanical strengths while three kinds of industrial explosives ammon gelatin (Shin-Kiri dynamite) permitted ammon gelatin (Shin-shiraume dynamite) and permitted ammon dynamite (Shôan dynamite) have been investigated as explosives of widely different energy contents and brisances.

From the data obtained general rules of fragmentation of rock through blasting have been deduced.

§ 2. Law of slab-formation by shock wave produced by detonation of an explosive charge.

If the shape of shock wave produced by detonation of an explosive charge is represented by a triangle $H_1\ F_P\ E$ in Fig. 1. (1) then the thickness of a slab is[2]:

$$l=\frac{L}{2}\ \frac{S_t}{p_a} \qquad (1)$$

where, L=length of a shock wave

S_t=tensile strength of rock

p_a=peak pressure of a shock wave at a free face

The number of slabs is as follows:

$$N=\frac{L}{2l}=\frac{p_a}{S_t} \qquad (2)$$

The thickness of a slab and the number of slabs for any shape of shock wave are easily calculated graphically or by equations along the same line of deduction as has been described above for the simplest case.

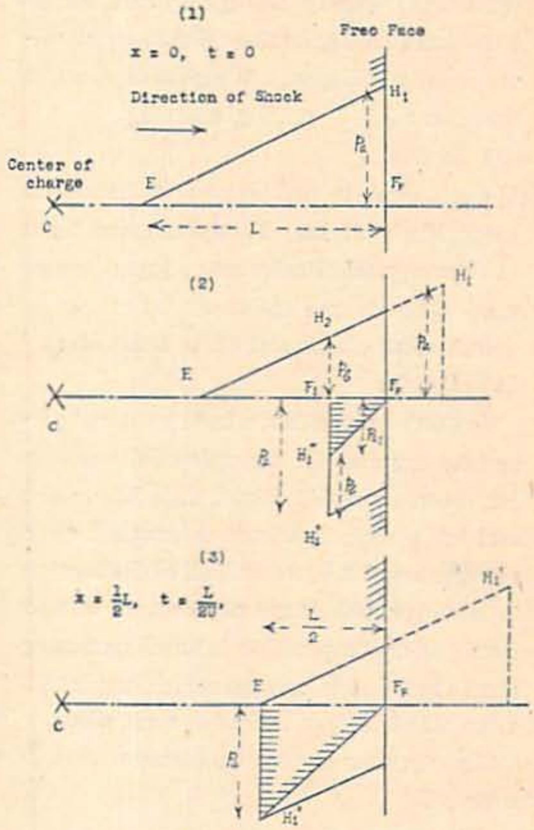

Fig. 1 Reflection of shock wave

§ 3. Experiment

3-1. Method and results of fragmentation tests.

(1) Arrangement

Fig. 2 (1) shows the arrangement of a rock piece, an explosive charge and No. 6. electric detonator used for the experi-

2) Kumao Hino: Theory of blasting with concentrated charge; Journal of the Industrial Explosives Society, Japan. Vol.15 No.4. 1954. p. 244.

ments.

(2) Explosives

Three kinds of explosives have been used. They are: Ammon Gelatin (Shin-Kiri dynamite) density 1.45 g/cm^3, Permitted Ammon Gelatin (Shinshiraume dynamite) density 1.55 g/cm^3, and Permitted Ammon Dynamite (Shôan dy namite) density 0.95 g/cm^3. Weights of charges used are: 5 g, 10 g, 20 g, and 30 g.

(3) Rocks.

Marble, Granite and Sandstone produced respectively at Isa, Tokuyama and Susa in Yamaguchi Prefecture, Japan were used. Sizes of the specimens are:

4cm × 4cm × 20cm and 4cm × 4cm × 30cm

(4) Results

Scattered pieces have been gathered after blasting and an example of the results has been shown in Fig. 2-(2). The right end of a rock specimen is crushed over the sections 10, 9, 8 and half of the section 7, however, the range of fracture due to crushing or compression is much narrower than that due to tension which originates from the left free end of a rock piece.

The number of rock specimens used is over 230.

3-2. Measurement of compressive and tensile strengths of rocks

The principle of the measurement of compressive and tensile strengths of rocks has been described by Tomio Horibe[3].

3) Tomio Horibe: Study on the compressive and tensile strengths of some sedimentary rocks by cylindrical specimens,; Journal of the Mining Institute of Japan. 1950. Vol. 66. No. 747. Page. 355.

4) J. Kuno: Application of the law of Photo elastic Extinction to some Problems; Phill. Mag. 7 series 1932/4, p. 810-824 Timoshenko; Theory of elasticity. 1934 p.82.

The compressive strength is:

$$\sigma_c = \frac{P}{\frac{\pi}{4}d^2} \qquad (3)$$

where P is the breaking load acting in the axial direction of a cylinder whose diameter is d. As σ_c varies for different ratio of length l, to diameter d of a specimen (l/d) the following experimental relation has been used to find S_c.

$$\sigma_c = \frac{S_c}{1 - B\frac{d}{l}} \qquad (4)$$

where S_c is the ideal compressive strength and B is a Rock constant.

The tensile strength was found as follows [4]:

$$S_t = \frac{2P}{\pi l d} \qquad (5)$$

where P is the breaking load acting along the diameter of a cylindrical specimen.

The dimensions of the marble specimens used for the measurement of strength are: 30mmϕ × 75mm, 30ϕ × 15, 30ϕ × 30, 30ϕ × 60, 30ϕ × 90, 30ϕ × 120.

The number of specimens used is 115. The results of measurements are summarized in Table 1.

Table 1. Mechanical Strengths of Rock Specimens

Rock	(S_c) Compressive strength	(S_t) Tensile strength	density	Blastablity Coefficient $B=S_c/S_t$
	kg/cm^2	kg/cm^2		
Marble	815	55	2.6	14.8
Granite	1,000	75	2.5	13.3
Sandstone	1,700	110	2.3	15.5

§ 4. Shape of shock wave produced within rock.

From the thickness of each slab produced by detonation the shape of shock

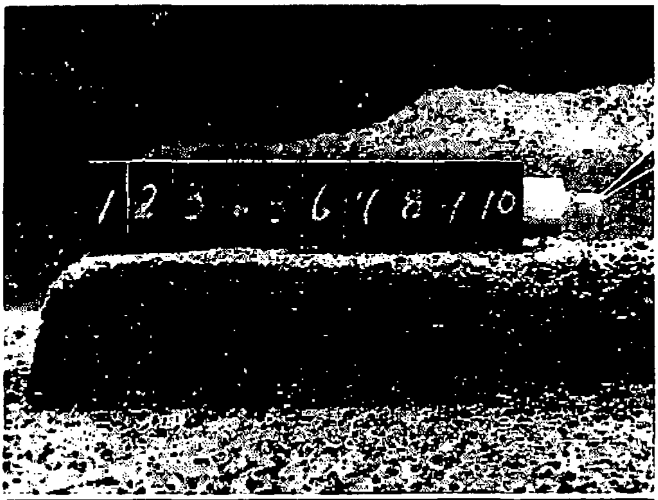

Fig. 2. (1)
Arrangement of Rock piece, Explosive and No. 6 Electric Detonator

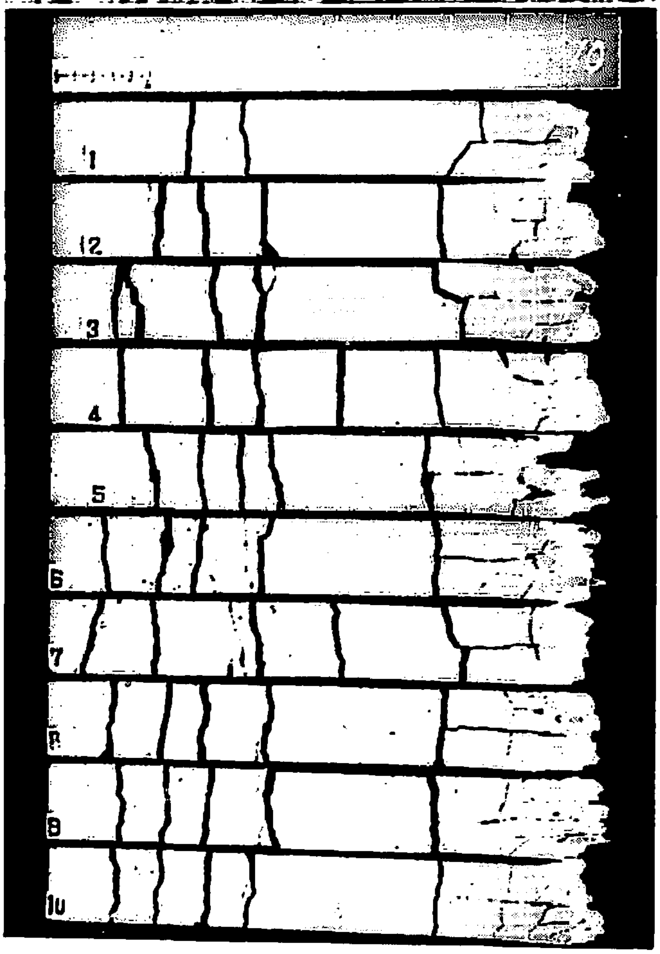

Fig. 2. (2)
Fragmentation pattern of a piece of Marble blasted by Ammon Gelatin (Shin-Kiri). Weight of charge 10g. dia. 25 mm length 14 mm. Size of rock: 4cm × 4cm × 30cm.

Table 2. Shape of shock wave for various rocks and explosives.

	Rock	Explosive	Weight of charge	Shock wave Peak Pressure	Shock wave length	Number of slabs
			g	kg/cm²	cm	
(1)	Marble	Ammon Gelatin	5	275	29	3-4-4
			10	275	27	5-5
			20	275 (330)	28	4-5-(6)
			30	275	31	3-4-5
(2)	Marble	Permitted Ammon gelatin	10	275	29	4-5
		Permitted Ammon dynamite	10	220	26	3-4
(3)	Granite	Ammon gelatin	10	375	29	4-5
		Permitted Ammon gelatin	10	375	28	3-4-5
		Permitted Ammon dynamite	10	300	32	3-4
(4)	Sandstone	Ammon gelatin	10	550	28	4-5
		Permitted Ammon gelatin	10	550	29	4-5
		Permitted Ammon dynamite	10	550	28	3-4-5

§ 5. Discussion

Some remarkable conclusions deduced from the results obtained may be discussed as follows:

5-1. Detonation pressure and shape of shock wave

The detonation pressures[5] of various explosives calculated on the basis of modern thermodynamical-hydrodynamical theory of detonation are summarized in Table 3.

Table 3 Detonation characteristics of various explosives.

	Kind	Trade name	Detonation pressure	Heat of explosion	Detonation velocity	density
			atm.	cal/g	m/sec.	g/cm³
(1)	Ammon Gelatin	Shin-Kiri	98×10^3	1060	5860	1.45
(2)	Permitted Ammon gelatin	Shin-shiraume	96×10^3	850	5250	1.55
(3)	Permitted Ammon Dynamite	Shôan-dynamite	27×10^3	700	3320	0.95

Although the detonation pressure of the explosive (3) in Table 3. is about one third of those of (2) and (1), the peak pressures of shock waves are nearly the same for explosives (1) (2) and (3). The length of shock wave is also nearly independent of the detonation pressure. So is the number of slabs.

The weight of charges seems to influence little the shape of shock wave, however, it must be taken into consideration that blasting of rock is conducted in one dimension and not in three dimensions.

5-2. Compressive strength of rock and shape of shock wave. Blastability of rock.

The Peak pressure of shock wave is proportional to the compressive strength of rock. (Fig. 8) The peak pressure of shock wave is chiefly determined by "compressive strength of rock". Around the charge there exists a "crushed zone"

5) Yasushi Kumagai: Journal of Mining Institute of Kyushu, Japan; Vol.23, No. 3 1955. p. 63.

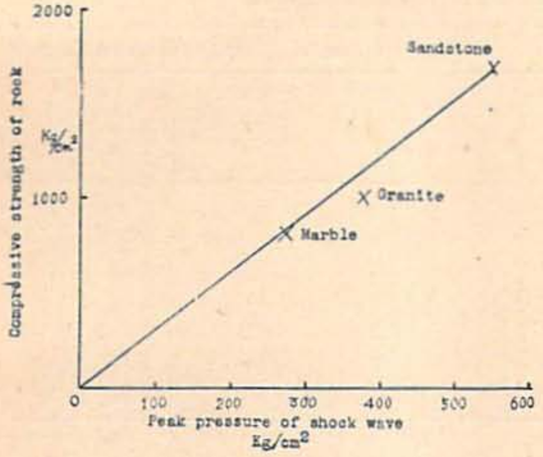

Fig. 8. Compressive strength of rock and peak pressure of shock wave.

and at the periphery of the crushed zone the pressure of shock wave is reduced just to the "compressive strength" of rock in question. The shock wave within rock originates at this end with initial pressure equal to the compressive strength of rock. Therefore the extent of the main fracture of rock due to tension,that is the pattern of slab formation or fragmentation is determined by two limits, the upper one is "compressive strength" and the lower one is "tensile strength." For this reason the "blastability coefficient" may be defined as follows:

$$B=\frac{S_c}{S_t} \qquad (6)$$

The numerical values of blastability coefficient are summarized in the last column of Table 1.

The blastability coefficients whose numerical values appear to be 13-15 for marble, granite, sandstone described in the present paper are the maximum possible numbers of slabs whereas the thickness of a slab is proportional to the size of burden of rock, or generally speaking, depth of charge.

In Table 4. blastability coeffioients are calculated for various materials.

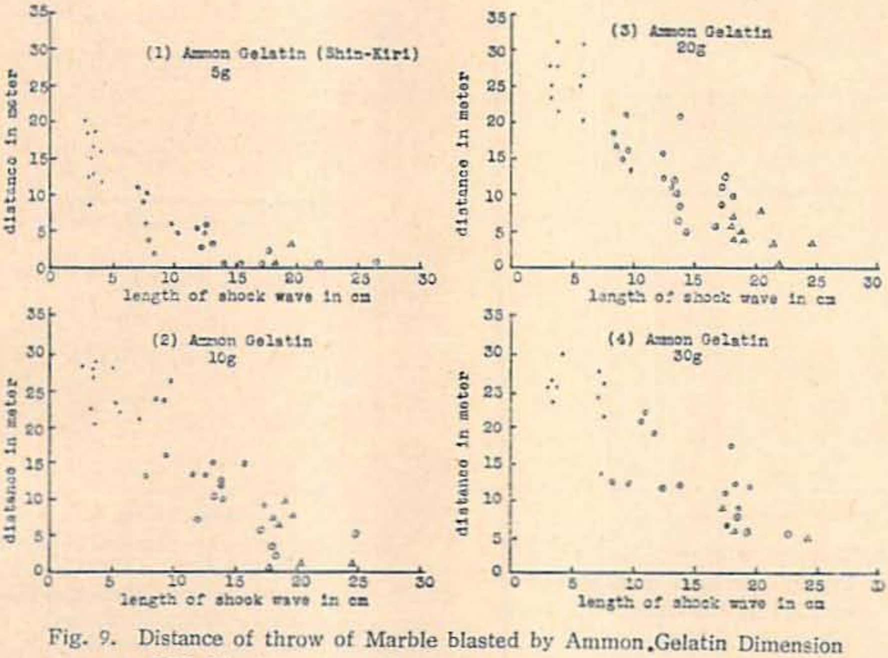

Fig. 9. Distance of throw of Marble blasted by Ammon.Gelatin Dimension of Marble 4cm×4cm×30cm.

Table 4. Blastability coefficients of various materials.

	S_c compressive strength	S_t tensile strength	Blastability coefficient
Marble	815 kg/cm²	55	14.8
Granite	1000	75	13.3
Sandstone	1700	110	15.5
Soft steel	5000	5000	1
Cast iron	6600	1400	4.7
Brass	750	1300	0.58
Concrete	250	20	12.5
Brick	150—45	9	16.7-5
Brick (over burnt)	270—100	17	15.9-5.9
Wood (pine)	411	644	0.64

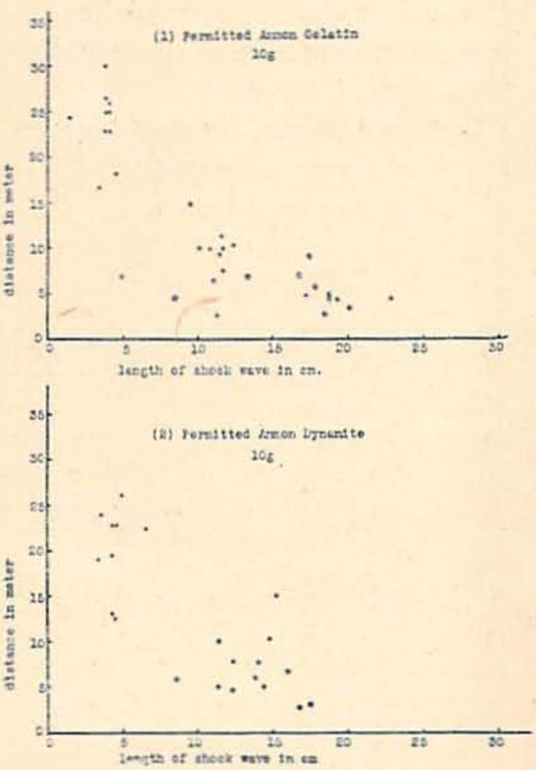

Fig. 10. Distance of throw of Marble blasted by (1) Permitted Ammon Gelatin and (2) Permitted Ammon Dynamite Dimension of Marble
4cm × 4cm × 30cm

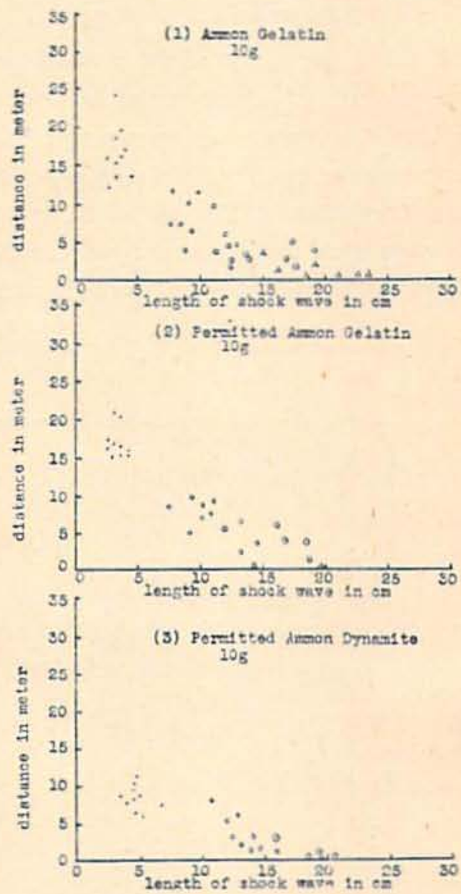

Fig. 11. Distance of throw of Granite blasted by (1) Ammon Gelatin, (2) Permitted Ammon Gelatin and (3) Permitted Ammon Dynamiae Dimension of Granite
4cm × 4cm × 30cm.

5-3. Distance of throw and shape of shock wave

Rock specimens are blasted on sand mound 5cm high and the distances of throw X of each slab are measured from the end of the first free face. The results are shown in Fig. 9, 10, 11, 12.

Mean pressure of shock wave p entrapped in one slab is represented in terms of specific gravity Δ of rock, particle velocity V and velocity of shock wave U;

$$p = \Delta VU \qquad (7)$$

As the values of Δ and U are constant for a given kind of rock V is proportional to p while V is proportional to X, therefore, p may be proportional to X.

$$p \propto X \qquad (8)$$

Comparing the Fig. 9, 10, 11, 12 with the shapes of shock waves represented in Fig. 4, 5, 6, 7 the relation (8) may be assumed to hold.

Acknowledgement.

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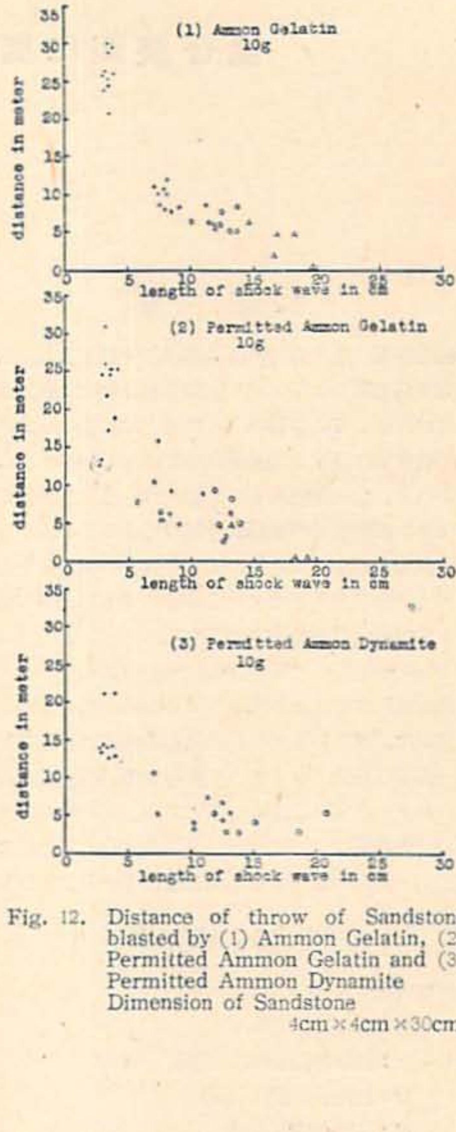

Fig. 12. Distance of throw of Sandstone blasted by (1) Ammon Gelatin, (2) Permitted Ammon Gelatin and (3) Permitted Ammon Dynamite
Dimension of Sandstone
4cm × 4cm × 30cm.