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THEORY AND PRACTICE OF COYOTE BLASTING

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Summary

On the basis of shock wave theory of blasting which has been developed in previous papers by the present author the formulas which give the weight of charge W, spacing S_e and height of bank H for a given value of burden d_f in large scale coyote blasting (chamber blasting), have been described.

Radius of a concentrated charge a is given by:

$$\frac{d_f}{a}=D_f=\left\{\left(\frac{p_D}{S_t}\right)^{\frac{1}{n}}\left\{\left(\frac{R_f}{d_f}\right)^2+1\right\}^{-\left(\frac{1+n}{2n}\right)}\right.$$

where D_f=reduced distance, p_D=detonation pressure of explosive, S_t=tensile strength of rock, R_f=radius of a full crater, n=distance exponent of decay of peak pressure of shock wave due to distance of propagation. Taking into consideration the decrease of effective tensile strength of rock due to increase of volume V of specimen according to the Davidenkov-Fisher relation $S_t \infty V^{-\frac{1}{m}}$ (m=constant) or $S_t=S_{t0}d_f^{-\frac{3}{m}}$ the weight of charge W is:

$$W=\frac{4}{3}\pi\Delta d_f^3\left(\frac{p_D}{S_{t0}d_f^{-\frac{3}{m}}}\right)^{-\frac{3}{n}}\left\{\left(\frac{R_f}{d_f}\right)^2+1\right\}^{\frac{3}{2}\frac{1+n}{n}}$$

(Δ=loading density) or W=const. $d_f^{3-\frac{9}{mn}}$ Experiments on craters show that, to the first approximation,

$mn=10.28$ or W=const. $d_f^{2.125}$

From the co-operations between shock waves from separate charges the spacing S_e is given: $S_e=1.5\ d_f$ in case every charge is enough to produce a full crater. From the co-operations between two tension waves produced by reflections at two free faces with a single charge the relation between height of bank H and burden d is given by: $H=2\ d_f$ for a full-crater-charge.

Data of coyote blastings designed on the principles described above have been presented which may be considered to support the shock wave theory of blasting. Experimental rules with regard to d, W, H and S_e reported so far by various authors have been reviewed and been discussed from the standpoint of shock wave theory of blasting.

§ 1. Definition of coyote blasting

Coyote Blasting (Chamber blasting, Tunnel Blasting, Gopher Hole, Heading Blasts, Kammersprengung, Extraction par chamber de Sautage) is the largest scale method of blasting with concentrated charge or charges. In a unit of this method a main stem (adit, main tunnel)

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is excavated horizontally into a rock mountain and at the end of this main stem, a wing (T, cross cut) is excavated horizontally but perpendicularlly to the adit and at the end of this wing a concentrated charge of dynamite is loaded. The wing and a part of the adit are carefully stemmed with rock debris after loading and the charge is usually detonated by use of detonating fuse, which in turn is initiated by electric blasting cap.

§ 2. Characteristics of coyote blasting

The main benefits of the coyote blasting are as follows:

(1) Efficiency of blasting from the stand point of powder consumption per m^3 of rock is best because concentrated charge of explosive can be realized.

(2) Design and practice of blasting operatins are simple.

(3) The biggest amount of rock can be obtained by smaller number of firing.

The main defects of the coyote blasting are as follows:

(1) The method is rather a primitive one and there is little room for efficient mechanization of operations.

(2) As the sizes of adits and crosscuts are kept to the Minimum to allow loading and stemming operation no mechanization is realized in the stage of excavating adits and crosscuts. This operation takes time.

(3) In some structures of rock seam the coyote blasting can not be realized with success.

(4) Although the stemming is essential, this operation of stemming cannot be mechanized and take much labour and time.

(5) Secondary blasting is in general necessary to considerable extent.

§ 3. Principles for design of coyote blasting

3—1. Dimensions to be determined

Fig. 1—(1) shows a plan of a unit of a coyote blasting where d is burden for a charge C_1 or C_2 and S_c is spacing between two charges. In Fig. 1—(2) a longitudinal section in the case of one free face is shown where the variable to be determined is burden d while in Fig. 1—(3) the case with two free faces, that is, bench blasting, is illustrated where two variables, burden d and height of bench or bank H should be determined.

3—2. Selection of burden d

A. Fundamental equations in homogeneous solids

To blast a burden d successfully without use of excessive charge of explosive d should be the so-called depth of a full crater d_f while the value of d_f is uniquely given by the following equation[1]:

$$\frac{d_f}{a}=D_f=\left(\frac{p_D}{S_t}\right)^{\frac{1}{n}}\left\{\left(\frac{R_f}{d_f}\right)^2+1\right\}^{-\left(\frac{1+n}{2n}\right)} \quad \cdots\cdots(1)$$

where:

d_f=depth to a center of a charge from a free face.

a=radius of a spherical charge

D_f=reduced depth for a full crater, where "full crater" means that an apex of a crater is just on the center of a charge, exactly speak-

1) Kumao Hino: Concentrated type of No-cut round of blasting; Journal of The Industrial Explosives Society, Japan Vol. 16, No. 3, 1955 p. 173. equation (5).

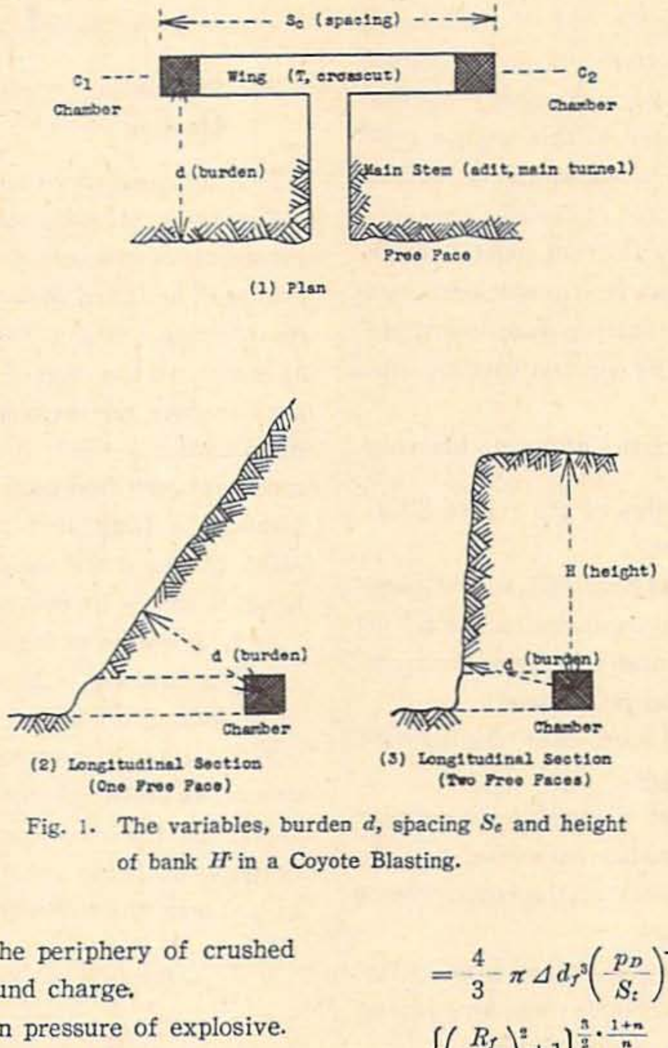


Fig. 1. The variables, burden d, spacing S_e and height of bank H in a Coyote Blasting.

ing, on the periphery of crushed zone around charge.

p_D=detonation pressure of explosive.

S_t=tensile strength of rock.

R_f=Radius of a full crater.

$\frac{R_f}{d_f}$=Radius depth ratio which is usually a constant for a given pair of rock and explosive, about 1.7.

n=distance exponent of decay of peak pressure of shock wave due to distance of propagation.

When W stands for weight of charge and Δ for its loading density.[2]:

$$W=\frac{4}{3}\pi a^3 \Delta \text{ (2) or } W$$

$$=\frac{4}{3}\pi \Delta d_f^3\left(\frac{p_D}{S_t}\right)^{-\frac{3}{n}}\left\{\left(\frac{R_f}{d_f}\right)^2+1\right\}^{\frac{3}{2}\cdot\frac{1+n}{n}} \quad \text{...............(3)}$$

or $W=Cd^3$ (4) where C is a constant for a given pair of rock and explosive.

According to the equation (1) if we find reduced distance D_f for a given pair of rock and explosive over a range near the practical operational conditions then we can easily estimate the necessary quantities for a design by use of this numerical value of D_f which is a dimensionless number and is valid, in principle,

2) equation (6) and (7) in reference (1).

Table 1. Weight of charge W (kg) for various depth d (meter) and reduced distance d/a. Loading density of charge Δ=0.9g/cm^3.

d \ d/a	18	19	20	21	22	23	24	25	26
5	79.3	68.0	60.4	49.1	45.3	37.8	34.0	30.2	26.4
6	139.0	117.0	102.0	86.9	75.6	68.0	60.4	52.9	45.3
7	219.2	189.0	162.5	139.8	120.9	105.8	94.5	83.1	71.8
8	332.6	289.5	241.9	207.0	181.4	158.7	139.8	124.7	109.6
9	472.5	400.6	344.3	294.8	257.0	226.8	200.3	177.6	154.9
10	646.3	551.8	472.5	408.2	358.0	309.9	272.1	241.9	215.4
11	861.8	729.5	627.4	540.5	472.5	412.0	362.8	321.3	287.2
12	979.0	948.7	816.4	799.3	612.3	532.9	472.5	419.5	370.4
13	1,421.2	1,209.0	1,039.5	895.8	774.9	680.4	597.2	532.9	472.5
14	1,772.0	1,508.2	1,296.5	1,115.0	971.4	850.5	748.4	665.9	589.6
15	2,184.8	1,855.9	1,595.0	1,375.9	1,194.0	1,047.0	922.3	874.8	599.3
16	2,559.0	2,256.6	1,935.3	1,669.0	1,451.5	1,270.0	1,115.0	986.5	880.7
17	3,178.0	2,702.0	2,320.7	1,996.0	1,738.8	1,527.1	1,341.0	1,186.9	1,050.8
18	3,780.0	3,209.2	2,845.6	2,359.6	2,067.6	1,738.0	1,595.0	1,409.9	1,251.0
19	4,437.0	3,780.0	3,239.4	2,800.9	2,430.5	2,132.0	1,871.0	1,659.0	1,470.4
20	5,182.3	4,399.2	3,780.0	3,262.0	2,838.7	2,479.6	2,184.0	1,935.3	1,716.0

Table 2. Values of Reduced distance $d/a=\left(\frac{4187}{C}\Delta\right)^{1/3}$ for various loading density Δ (g/cm^3) and rock, and powder-coefficient C in Hauser's cubic formula.

C \ Δ	0.9	1.0	1.45	
0.2	26.5	27.5	31.0	Soft rock
0.3	23.1	24.0	27.0	↓
0.4	21.0	21.6	24.7	
0.5	19.3	20.2	22.9	
0.6	18.2	19.0	21.5	Hard rock

irrespective of absolute values of d, burden, and a, radius of a charge. Table 1 shows the calculated values of weight of charge with loading density of Δ=0.9g/cm^3, which is a most general case in coyote blasting, for various numerical values of burden d (5m~20m) and $D_f=d/a$ (18~26). In literatures the formula (4) is often found, therefore, the relations between reduced distance d/a and C and Δ are also shown in Table 2.

B. Size or Scale effects

The tensile strength of solid rock S_t in the fundamental equation (1) etc. may be considered constant only for ideally homogeneous solid while in actual rocks this value depends on the probability of the existence of the weakest points in the solid structure and tensile strength is structure sensitive. Because of this fundamental property the values of tensile strength show fluctuation and the range of fluctuation is bigger, when size of rock specimen is smaller. Another important point is the so-called "Size effects" or "Scale effects" and because of intrinsic nature of phenomena based on probability, the effective tensile strength S_t depends on the volume of the specimen V in the following way:

$$S_t \propto V^{-\frac{1}{m}} \ldots (5) \quad \text{or } S_t = S_{t_0} V^{-\frac{1}{m}} \ldots (5)'$$

where m is constant whose value for steel

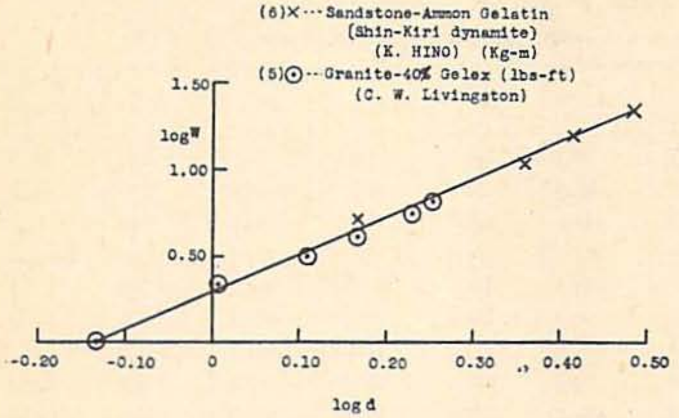


Fig. 2. The experimental relations between weight of charge W and depth to center of charge d.
W=const. $d^{3-(\frac{9}{mn})}$ or from data (6):
$W=1.91 d^{2.125}$ (kg-m).

has been found experimentally to be 23.5[3] while the same form of equation has been derived theoretically on the basis of "Nucleation theory[4]" of fracture. In (5)' S_{t_0} is the tensile strength of perfect unit of solid in question.

In Fig. 2. the experimental data on the relations between weight of charge W and depth to charge d for full craters have been plotted for a pair[5] of 40% Gelex-Granite, and a pair[6] of Ammon gelatin-Sandstone.

The data used for calculation are as follows.

W	d	Reference
(kg)	(meter)	(6) Sandstone-Shin kiri
5	1.50	(Ammon-gelatin dynamite)
10	2.30	(K. HINO.)
15	2.65	
20	3.00	
(lbs.)	(feet)	(5) Granite-40% Gelex
1	0.80	(C. W. Livingston)
2	1.10	
3	1.30	
4	1.50	
5	1.70	
6	1.80	

In Fig. 2. two sets of data (5) and (6) fall on the same straight line, however, this result should be taken as coincidence because, data (5) are plotted for lbs-feet, while (6) for kilogram-meter, and these two sets of data should be taken to represent two separate straight lines with the same inclination.

In the present author's opinion data (5) give too much weight of charge and as an approximate formula for weight of charge-depth he prefers the relation:

$$W=1.91\ d^{2.125}$$

in kilogram meter, to pound feet.

From these data the value of m is found to be $m=5.14$ for $n=2$. or $mn=10.28$.

Therefore in general the eqation (2) should be rewritten into the following functional form with regard to W and d:

$$W=\frac{4}{3}\ \pi \Delta d_f^3\left(\frac{p_0}{S_{t_0} d_f^{-\frac{3}{m}}}\right)^{-\frac{3}{n}}$$

3) N. Davidenkov, E. Shevandin and F. Wittman; Journal of Applied Mechanics. Vol. 14. (1947) p. 63.

4) J. C. Fisher; Journal of Applied Physics. Vol. 19. (1948) p. 1062. Review of the topics: Takeo Yokobori(Statistical Aspect in Fracture and Fatigue of Metallic Materials) Journal of Applied Physics, Japan. Vol. 24. No. 9. 1955 p. 351.

5) Kumao Hino: (Theory of Blasting with concentrated charge) Journal of the Industrial Explosives Society, Japan Vol. 15 No. 4. (1954) p. 237 Fig. 2.

6) Reference (1) page 172 Fig. 5.

$$\left\{\left(\frac{R_f}{d_f}\right)^2+1\right\}^{\frac{2}{3}\cdot\frac{1+n}{n}}=\left[\frac{4}{3}\pi\Delta\left(\frac{p_0}{S_{t_0}}\right)^{-\frac{3}{n}}\left\{\left(\frac{R_f}{d_f}\right)^2+1\right\}^{\frac{3}{2}\cdot\frac{1+n}{n}}\right]d_f^{\left(3-\frac{3}{mn}\right)} \quad \text{.................(6)}$$

or $W=\text{const.}\ d_f^{\left(3-\frac{3}{mn}\right)}$ ....(6)′

for $mn=10.28$, we have:

$W=1.91\ d_f^{2.125}\ (\mathrm{kg/m})$ ....(6)″

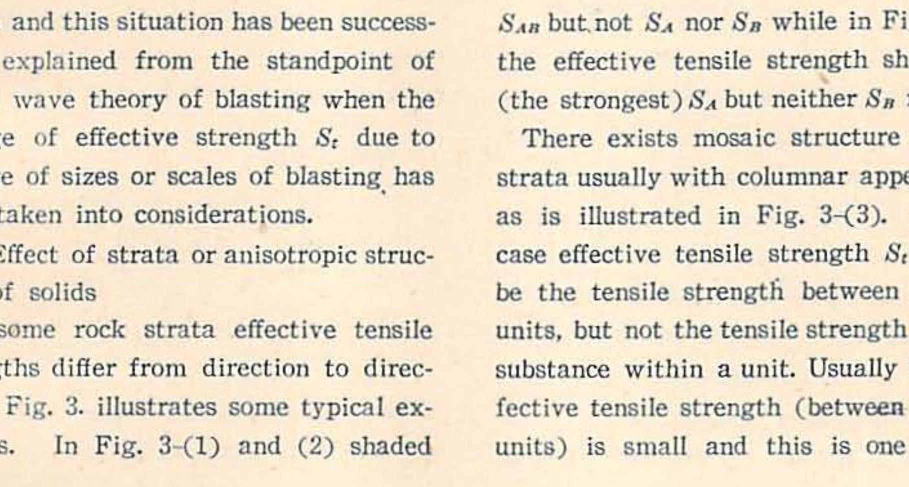
The equation (6)″ should be used instead of classical "cubic formula $W=\text{const.}\ d^3$". Actually "Square formula $W=\text{const.}\ d^2$" gives better results in calculation and this situation has been successfully explained from the standpoint of shock wave theory of blasting when the change of effective strength S_t due to change of sizes or scales of blasting has been taken into considerations.

C. Effect of strata or anisotropic structure of solids

In some rock strata effective tensile strengths differ from direction to direction. Fig. 3. illustrates some typical examples. In Fig. 3-(1) and (2) shaded parts show a kind of layer of rock (kind A) whose tensile strength is S_A while the remaining part of the whole strata (not-shaded part) (kind B) has tensile strength S_B. The tensile strength between the part A and B is represented by S_{AB}. Suppose S_A is bigger than S_B then practically S_{AB} has the the smallest value, because if S_{AB} is bigger than S_B then separation occurs within a layer of the kind B which is adjacent to the boundary of A and B.

In Fig. 3-(1) the effective tensile strength of the rock in the direction of burden d neither should be (the weakest) S_{AB} but not S_A nor S_B while in Fig. 3-(2) the effective tensile strength should be (the strongest) S_A but neither S_B nor S_{AB}.

There exists mosaic structure of rock strata usually with columnar appearance, as is illustrated in Fig. 3-(3). In this case effective tensile strength S_t should be the tensile strength between mosaic units, but not the tensile strength of rock substance within a unit. Usually this effective tensile strength (between mosaic units) is small and this is one of the



(1) Effective tensile strength. S_t is small in the direction of C → D.
(2) Effective tensile strength S_t is big in the direction of C' → D'.
(3) Mosaic structure

Fig. 3. Effective tensile strengths differ for different direction in anisotropic solid. C=center of charge, d=burden, H=height of bank or bench.

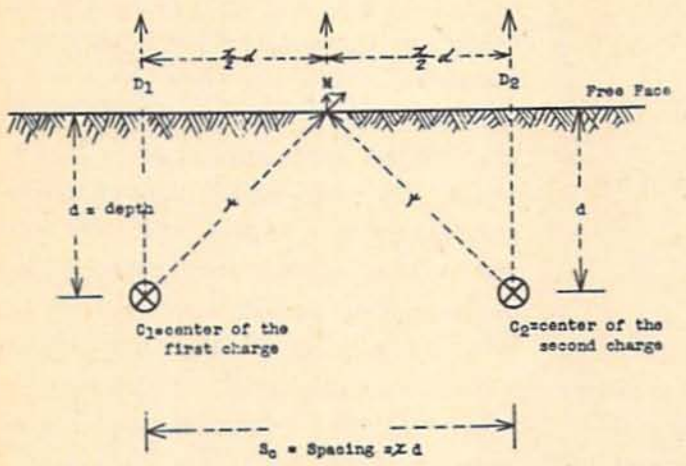


Fig. 4. Effects of shock waves in a pair of simultaneouse blasting

reasons why explosive consumption per cubic meter of rock (loading factor) in case of coyote blasting is much smaller than explosive consumption per cubic meter of the same rock in its excavation stage of establishing adits and crosscuts which needs blasting and fragmentation of mosaic unit itself which has much stronger tensile strength.

3-3. Selection of Spacing S_c

In Fig. 4. spacing between two charges C_1 and C_2 is defined by:

$$S_c = xd \qquad (7)$$

where d=depth to individual charge. The problem is to find the numerical value of x.

If the intensity of shock wave perpendicular to the free face at the middle point M between two charges is the same with that at the point D_1 (just above the center of the first charge) or the point D_2 (main ruptures first occur at D_1 and D_2) then it may be assumed that the part of the solid between D_1 C_1 and D_2 C_2 be successfully blasted. At the point D_1 or D_2 the upward intensity of shock wave (as has been indicated in Fig. 4. by upwards arrows) is:

$$p_D = p_0\left(\frac{a}{d}\right)^n \qquad (8)$$

At the middle point M the two shock waves from the two charges C_1 and C_2 arrive at the same time when both charges are simultaneously detonated by use of the same lengths of detonating fuses from a single initiator. Then the upward component of the resultant intensity of the shock wave at the point M is:

$$2p_D\left(\frac{a}{r}\right)^n\frac{d}{r} = 2p_D\left(\frac{a}{\sqrt{d^2+\left(\frac{x}{2}d\right)^2}}\right)^n \frac{d}{\sqrt{d^2+\left(\frac{x}{2}d\right)^2}} \qquad (9)$$

For a successful simultaneous blasting (8) should be equal to (9):

$$p_D\left(\frac{a}{d}\right)^n = 2p_D\left(\frac{a}{\sqrt{d^2+\left(\frac{x}{2}d\right)^2}}\right)^n \frac{d}{\sqrt{d^2+\left(\frac{x}{2}d\right)^2}} \qquad (10)$$

or

$$1 = 2\left(\frac{1}{\sqrt{1+\frac{x^2}{4}}}\right)^n \frac{1}{\sqrt{1+\frac{x^2}{4}}}$$

The numerical value of n depends on the nature of rock and explosive and is a constant for a pair of rock and explosive. Let us assume n to be 2, then,

$$\left(1+\frac{x^2}{4}\right)^{\frac{n}{2}+\frac{1}{2}} = 2 \quad \text{or } x \fallingdotseq 1.54$$

Therefore, the following approximate formula may be used for the selection of spacing S_c on condition that individual charge has a weight and depth just equal to producing a full crater respectively which means that the similitude ratio[7)] for an individual charge should be zero. In other words, spacing S_c is a function of similitude ratios of an individual charge.

$$S_c=1.5d \quad \dots\dots (7)'$$

In some cases this condition is not fullfilled and the weight of charge is too small (or depth is too deep) for individual charge then the spacing S_c must be much reduced than is allowed by the formula (7)' and the burdens at D_1, D_2 and M must be raised by cooperation of the two shock waves from C_1 and C_2, and the value of the coefficient x in (7) depends on the weight of charge and depth. x may be found approximately by graphical method case by case. In practice first of all the burden d should be determined so as to secure a full crater by an individual charge and then the spacing S_c should be determined for this unique burden.

3-4. Selection of bench or bank height H

There should exist a definite relation between height of bench or bank H and burden d from the standpoint of the shock wave theory of blasting, that is:

$$H=yd \quad \dots\dots (11)$$

The numerical coefficient y depends on the properties of rock and explosive in question. Estimation of y may be obtained by the following procedure. In Fig. 5. I_1 DEF indicates a profile of a bench of solid to be blasted. The weight of charge C is just enough to raise burden d, that is, the similitude ratio with respect to the vertical(first)free face ED is zero and we consider the case of "full crater" with respect to burden d. The bigger burden H is defined as Height in this case according to practice, which is sometimes called depth in case of drilled hole, for example, by wagon drill or churn drill. As we consider a full crater with respect to the vertical free face we may assume that the intensity of reflected tension wave at the center of a charge is:

$$p=p_D\left(\frac{a}{2d}\right)^n=S_t \quad \dots\dots (12)$$

because the shock wave has to travel over a distance d as compression until it reaches the first free face and then again comes back toward the center of charge as tension over the same distance d and at the end of travel of total $2d$ its intensity must be enough to break rock by tension. This assumption may be true in case of a single reflection while actually in case of brittle solids such as rock main fractures occur due to multiple reflections as have been described in the previous paper*, therefore, the equation (12) may represent the relation only to the approximation.

The main fracture due to this first reflected tension wave is represented by a crater DAC in Fig. 5. At the wave front (3) the intensity of tension is reduced to a half of tensile strength of rock in question. The radius r' of a spherical wave whose intensity is $\frac{1}{2}S_t$ is easily calculated as follows:

$$\frac{1}{2}S_t=p_D\left(\frac{a}{r'}\right)^n \quad \dots\dots (13)$$

7) Reference (5) pp. 237, 240.

* Reference (5) page 244.

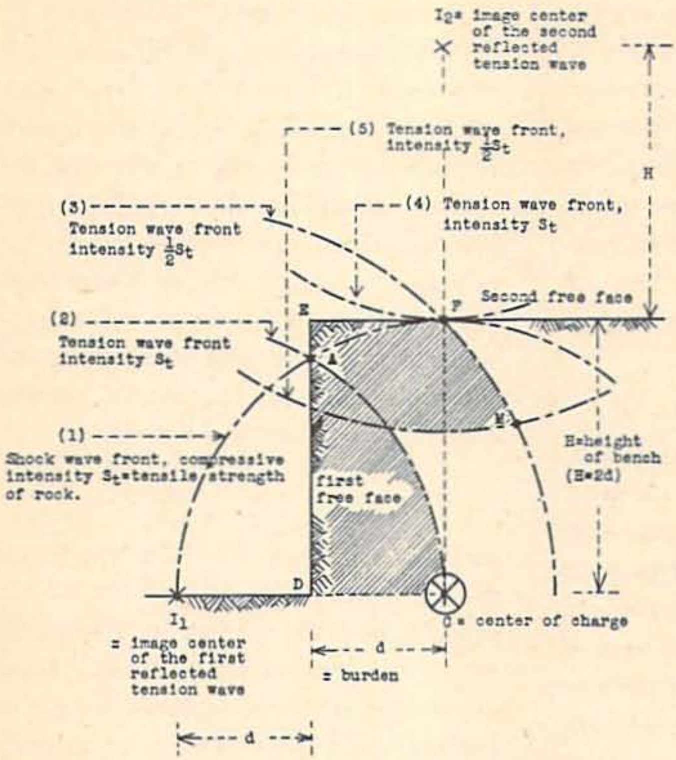


Fig. 5. Co-operation of two reflected shock waves produced on two free faces in case of bench blasting with a single charge.

In combination with the equation (12) we find:

$$\frac{r'}{2d}=2^{\frac{1}{n}} \quad \text{for } n\fallingdotseq 2,\ \frac{r'}{2d}\fallingdotseq 1.4 \ldots(14)$$

On the other hand the same compressive shock wave from the same charge reflects at the second free face EF. In Fig. 5. the height H is taken to be double of the burden d. At the point F the intensity of shock is the same with the tensile strength of rock and H may be called "the critical depth," while the reflected tension wave has intensity of $\frac{1}{2}S_t$ on the wave front (5). The portion of solid EAFM is under the co-operation of two tension waves each of which having the intensity of $\frac{1}{2}S_t$, therefore, this portion may be broken if not so co-mpletely as is in the portion of a full crater ADC.

In general the number of free faces available determines the efficiency of blasting with a single shot. Approxi-mately the number of free faces is inversely proportional to the powder consumption for cubic meter of rock broken.

In case of bench blasting we may assume the following relation:

$$H=2d \ldots\ldots\ldots\ldots\ldots\ldots(15)$$

§ 4. Practice of coyote blasting

4-1. Data

A considerable number of coyote blastings has been designed on the basis of shock wave theory of blasting in recent years with success. Some of the typical data are summarized in Table 3. In Table 4 recent data are quoted from U. S. A. practice and the corresponding values of $\frac{d}{a}$, $\frac{S_e}{d}$, $\frac{H}{d}$ have been calculated.

From Table 3 it may be considered that the adequate values of main variables in coyote blasting are:

$$\frac{d}{a}\fallingdotseq 24,\quad \frac{S_e}{d}=1,\quad \frac{H}{d}=2.$$

In Table 4 the value of $\frac{S_e}{d}$ is 0.4 which shows that in this case the similitude ratio of an individual crater is not zero, that is, full crater is not realized for individual charge and this assumption may be supported by considerably larger value of reduced distance for individual charge, which is $\frac{d}{a}=28$.

It seems a better practice to find first reduced distance $\frac{d}{a}$ for a full crater by trial shots and then estimate S_e with the relation $S_e=1.5d$, while the burden d is necessarilly restricted by the relation $H=2d$ where height H is given from other standpoints of transportation, easiness of access to the site etc.

4-2. Selection of explosives and methods of initiation

Detonating abillity of an explosive depends on its size of charge and as in coyote blasting the biggest charge is available compared with drill-holes the detonating ability of an explosive is much intensified. Because of this the amount of sensitizer in explosive mixture can be considerably reduced, thus, bringing down the cost of explosive to the minimum. On the other hand the shape of a charge in coyote blasting is usually cubic contrary to cylindrical form of charges in drilled holes. In other words, the detonation of a charge in coyote blasting spreads from a point of initiation into three dimensional divergence while in ordinary drilled holes detonation spreads from a point of initiation into one dimensional cylinder under strong confinement of rock wall. Because of this, in coyote blasting, brisant booster charge, usually high density ammon gelatin dynamite should be used.

Wooden cases for explosive cartridges should not be used in loading because wood upsets the oxygen balance of the explosive unfavourably.

As the methods of initiation of booster charges the detonating fuse should be recommended both from the standpoints of efficiency and safety. We can secure the genuine simultaneous blasting of two charges only when we use the same lengths of detonating fuses for both charges, the former in turn initiated by a single electric detonator which is initiated by an exploder from a far distant safe place of operation. In this case the two shock waves produced by separate charges synchronize, while when electric detonators are used instead of detonating fuses, then in general there exists a difference of time of initiation of two charges which amounts at least to a few milli-seconds and this difference between phases in two shock waves makes genuine synchronization impossible, therefore, the conventional simultaneous blasting in which electric detonators are used, should be defined as "pseudo-simultaneous blasting" from the standpoint of shock wave theory of blasting.

This situation is based on the structure of the present-day electric detonators where ignition or combustion of fuse head is utilized. Combustion or ignition phenomena have necessarilly tendency of fluctuation over a few milli-seconds, while by use of detonating fuses we can exclude the intervention of combustion phenomena and we can realize the synchronization of shock waves by use of shock wave phenomena through detonating fuses.

In combustion we deal with speed of propagation around 100 meter per second or less while in detonation or shock wave we deal with speed of propagation around 5,000 meter per second and the intervention of combustion phenomena makes the

Table 3. Data on

No.	Rock	Explosive					
		Chamber	Weight W	radius a	density Δ	Kind	Booster
(1)	Hard Sand Stone (Nakagawa) 1953. 12. 8.	1	Kg 90.0	m 0.238	g/cm^3 0.9	Katsura dynamite (Powdery Ammon dynamite)	Shin-Kiri (Ammon-Gelatin) 11.25kg for each chamber
		2	67.5	0.261	0.9		
		3	45.0	0.228	0.9		
		4	270.0	0.415	0.9		
		total	472.5	—	0.9		
(2)	Graphite (Hikari) 1953. 12. 11	1	225	0.415	0.9	Shin-Katsura	Shin-Kiri 45kg
		2	450	0.500	0.9	〃	45
		3	315	0.457	0.9	〃	45
		4	225	0.415	0.9	〃	45
		total	1395	—	—	〃	—
(3)	Andesite (Nukahira) 1954. 3. 8.	1	600	—	0.9	Katsura	Shin-Kiri 22.5
		2	540	—	0.9	〃	22.5
		3	470	—	0.9	〃	22.5
		4	270	—	0.9	〃	22.5
		5	337	—	0.9	〃	22.5
		6	315	—	0.9	〃	22.5
		7	1,255	—	0.9	〃	22.5
		8	775	—	0.9	〃	22.5
		9	280	—	0.9	〃	22.5
		10	360	—	0.9	〃	22.5
		total	5,202	—	0.9	—	—

Table 4. Data on Coyote blastings

Rock	Explosive					
	Chamber	Weight W	radius a	density Δ	Kind	Booster
Lime stone (Toao Island)	1	kg 5,400	—	—	Her-comite G	Gelamite 3 (45kg)
	2	2,700	—	—	〃	〃
	3	2,700	—	—	〃	〃
	4	2,700	—	—	〃	〃
	5	2,700	—	—	〃	〃
	6	5,400	—	—	〃	〃
	total	21,600	—	—	—	—

precision on the scale of shock wave quite impossible. This situation is important in connection with the mechanism of milli-second delay blasting. In this case also there can be no interference between shock waves produced by successive shots timed at milli-seconds intervals.

At to the safety of operation in coyote blasting the use of detonating fuses is coyote blastings

burden d	Reduced distance d/a	Spacing S_c	S_c/d	height H	H/d	Rock broken	loading factor
m 6.1	21.1	7.5	1.23 1.34	m 11.2	m 2.0		
5.6	21.4	5.5	0.98 0.92	12.4	2.2		
6.0	26.3	5.5	0.95	15.0	2.5		
8.5	20.4			23.8	2.8		
—	—			—	—	2,000m³	236g/m³
11.0	26.5	6.0	0.55 0.41	27.0	2.5		
14.5	28.5	11.0	0.76 0.92	24.0	1.7		
12.0	26.2	14.0	1.17 1.27	22.0	1.9		
11.0	26.5			22.0	2.0		
—	—			—	—	10,000	139
13.0	24	14.0	1.08 1.12	21.0	1.6	5,000	228
12.5	24	12.0	0.96 1.20	16.5	1.3		
10.0	24	14.0	1.40 1.17	16.5	1.7	3,500	210
12.0	24	12.0	1.00 1.20	14.0	1.2		
10.0	22	14.0	1.40 1.47	16.5	1.7	6,000	108
9.5	22	12.0	1.26 0.77	14.0	1.5		
15.5	22	14.0	0.90 1.08	23.0	1.5	9,000	220
13.0	22	12.0	0.92 1.20	19.5	1.5		
10.0	24	14.0	1.40 1.27	18.0	1.8	5,500	120
11.0	24			14.0	1.3		
—	—			—	—	29,000	180

(Explosive Engineer: 1954 : 3～4 : U. S. A.)

burden d	Reduced distauce d/a	Spacing Sc	S_c/d	height H	H/d	Rock broken	loading factor
25	22	10	0.4	m 38	1.5		
25	28	10	0.4	38	1.5		
25	28	10	0.4	38	1.5		
25	28	10	0.4	38	1.5		
25	28	10	0.4	38	1.5		
25	22			38	1.5		
—	—			—	—	96,000m³	225g/m³

much safer than that of electric initiation. The former is free from the danger of premature detonation due to stray current, electric sources such as flash lamps, electric illumination. thunder etc.

4-3. Stemming

Stemming is one of the operations which require most time and labour in coyote blasting. To reduce the labour and time the sectional dimensions of the adit and wings should be about 1.5m height × 1m width.

§ 5. Combinations of units of coyote blasting

A unit of coyote blasting may be represented by Fig. 1. According to topography of the site of blasting there may exist various combinations of units as:

(1) Single wing.

(2) Double wing.

(3) Supplementary higher coyote level.

The three types of combinations are illustrated in Fig. 6.

The single wing seems to be the most reasonable in its principle of design and the simplest to be practiced. Moreover detection of misfire may be easiest in this system. In double wing the broken rock produced by blasting of the front row remains as a pile in front of the rear row of charges and it produces the so-called effect of "buffer-shooting" in which the new free face for the rear row of charges can not be secured in a reliable way. The selection of the adequate weights of charges, burdens, spacings in the rear row also is not so reliable compared with that of single wing, moreover, detection of misfire is difficult. The use of supplementary higher coyote level is also subject to the various uncertainties. It may be best practice, from the standpoints of efficiency and safety, to perform a coyote blasting on a single wing pattern and

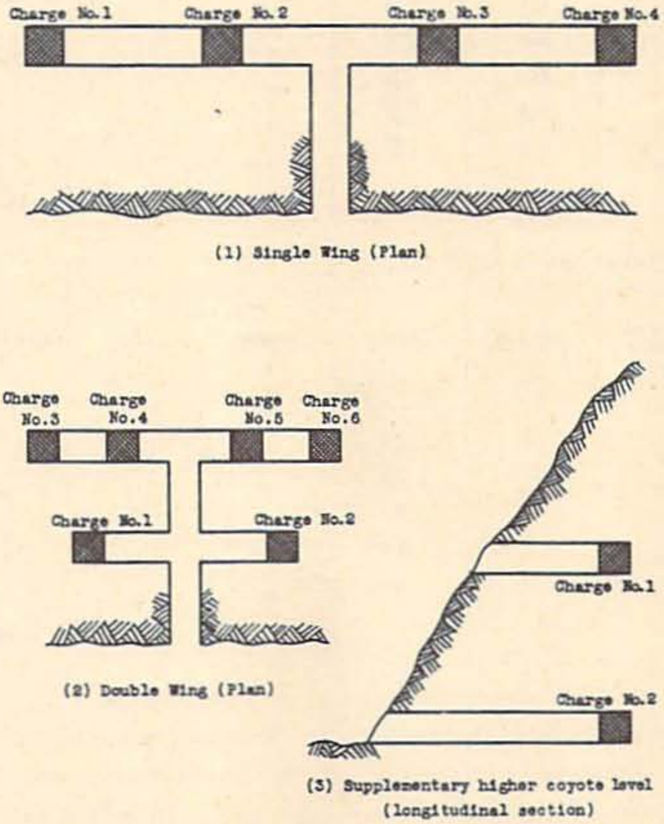


Fig. 6. Various combinations of unit coyote blastings

after the blast to remove the broken rock, to prepare the new free face as neat as possible and then to proceed to the next single wing because in this way we can secure the exact actions of shock waves.

§ 6. Previous researches on coyote blasting

Technological details of the practice of coyote blasting may be found in various handbooks on blasting[8), 9), 10)] although they give no formulas for the the designs of coyote blasting.

Robert Peele's Handbook[11)] recommends a single wing and the relation:

$H=1.5$d.

Robert S. Lewis[12)] quotes data:

$d=45$ft. $S_c=20$fs. $H=50\sim85$ft.

Heizo Nambo[13)] recommends:

$H=(2.5\sim1.7)d$, $S_c=(1\sim1.2)d$,

$W=(0.4\sim1.5)d^3$.

Sukenori Yamamoto[14)] recommends:

$H=(2.5\sim1.7)d$, $S_c=0.5d$.

$W=(0.3\sim0.5)d^3$.

Nohara[15)] recommends:

for hard stone $H=(1.5\sim2)d$, $S_c=d$, $W=0.45d^3$ (granite)

for soft stone $H=(3\sim4)d$, $S_c=(1.5\sim2)d$, $W=0.35d^3$ (limestone)

His description on main disasters in coyote blasting is a valuable one.

According to A. Heidrich Dornap[16)] 0.32kg of explosive, Donarit, is consumed per m^3 of limestone broken in coyote blasting.

D. H. Brook[17)] and D. Stenkouse give the following data for diorite and ammonal No. 3.explosive.

$H=42.7$m, $d=15{\cdot}2$m, $S_c=9.14$m,

$S_c=4.57$m, $H=2.8d$, $S_c=(0.6\sim0.3)\,d$.

They recommend 4~10 ton of rock per pound of explosive and for tight end 4.5 ton per pound of explosive while for free end 7 ton of rock per pound of explosive.

Boris J. Kochanowsky[18)] has summarized his extensive experiences in coyote blasting in his recent papers.[18), 19)]

He gives the following data:

$H=(3\sim2\sim1.5)d$, $S_c=(3\sim2\sim1)d$.

$W=0.42d^2+0.17d^3$ for Dynamit I (kg-m) and limestone.

Their results are summarized in Table 5.

8) E. I.Dupont: Blasters' Handbook; Sesquicentennial Edition, p. 191~196. Coyote blasting, p. 345~347.

9) Canadian Industries Limited 1951. Blasters' Handbook. p. 107~108.

10) Ensign-Bickford Company; Prima-cord, Bickford. p. 18~19. (Tunnel Blasts).

11) Robert Peele: Mining Engineers' Handbook, 1950. Vol. I. 5~17, 5~19.

12) Robert S. Lewis: Elements of Mining, Second Edition 1948. p. 152.

13) Heizo Nambo: Technology of Explosives for Mining (in Japanese) (Saiko-Kayakugaku) p. 266~267.

14) Sukenori Yamamoto: Outline of Industrial Blasting (in Japanese) (Sangyo Bakuha-Gairon) p. 158~162.

15) Journal of Lime-stone (in Japanese) (Sekkaiseki) Vol. 29, 1949, May. p. 31~42.

16) A. Heidrich Dornap: Nobel Hefte, 1954. Sep. p. 121~130.

17) Manual on Rock Blasting: editor in chief: K. H. Fraenkel. 1953. Rock Blasting in Great Britain by D. H. Brook and D. Stenkouse p. 8; 40~7~8, 40~11.

18) Boris J. Kochanowsky: Anlage und Berechnung von Kammerminensprengungen als Beitrag zur Ermittlung des Sprengstoffbedarfes in der Hartsteingewinnung; Dissertation: Fakultät für Bergbau und Hüttenwesen der Bergakademie Clausthal: Juli 1955.

19) B. J. Kochanowsky: Blasting Research Leads to New Theories and Reductions in Blasting Costs: Mining Engineering (U. S. A.) 1955. Sept. p. 861~866.

§ 7. Discussions

7-1. Selection of weight of a charge W

There have been two ways for the selection of weight of charge in coyote blasting. The first may be called "loading factor method". According to this method one calculates the total volume of rock to be broken and then multiply this amount by "loading factor" that is, amount of explosive necessary to raise cubic meter of rock. The values of "loading factors" must be known beforehand according to previous experience. The second may be called "cubic law method" in which one calculates weight of charge on the basis of "Hauser's cubic law" $W = \alpha d^3$. Both methods have no theoretical background and may be defined as empirical methods and because of this lack of theoretical grounds they sometimes lead to misuses and confusions. For example, some authors recommend to divide the weight of charge obtained by the methods mentioned above into several charges for the increase of fragmentation. This is an absurd idea, because if we divide the concentrated charge into smaller charges their effects are drastically reduced until they can not blast any rock.

Table 5. Ratios of height to burden H/d, Spacing to burden S_e/d, weight to cube of burden d, proposed by various authors

	Authors	Height to burden $\frac{H}{d}$	Spacing to burden $\frac{S_e}{d}$	Weight to cube of burden $\frac{W}{d^3}$
(1)	Robert Peele's Handbook	1.5	——	——
(2)	Heizo Nambo	1.7~2.5	1.0~1.2	0.4~0.5
(3)	Sukenori Yamamoto	1.7~2.5	0.5	0.3~0.5
(4)	Nohara	1.5~2.0	1	0.45 Granite
		3.0~4.0	1.5~2.0	0.35 Limestone
(5)	D. H. Brook and D. Stenkouse	2.8	0.3~0.6	——
(6)	B. J. Kochanowsky	1.5~2~3	1~2~3	($W = 0.42d^2 + 0.17d^3$)
(7)	Shock wave theory of Blasting	?	1.5	($W = 1.91d^{2.125}$)

From the standpoint of the shock wave theory of blasting this weight of charge W is uniquely determined by the given burden d according to the following formula for reduced distance.

$$\frac{d_f}{a} = \left(\frac{p_D}{S_t}\right)^{\frac{1}{n}} \left\{\left(\frac{R_f}{d_f}\right)^2 + 1\right\}^{-\left(\frac{1+n}{2n}\right)} \quad \cdots\cdots (1)$$

If we take into account the decrease of effective tensile strength of rock on the basis of the Davidenkov-Fishe formula then we have:

$$W = \left[\frac{4}{3}\pi\Delta\left(\frac{p_D}{S_{t_0}}\right)^{-\frac{3}{n}} \left\{\left(\frac{R_f}{d_f}\right)^2 + 1\right\}^{\frac{3}{2}\frac{1+n}{n}}\right] d_f^{\left(3 - \frac{9}{mn}\right)} \quad \cdots\cdots (6)$$

Experiments on craters show that to the first approximation $mn = 10.28$ then:

$$W = 1.91 d_f^{2.125} \quad \cdots\cdots (6)''$$

where 1.91 is a constant for a given pair of rock and explosive.

7-2. Effects of the conditions of faces

A few authors emphasize the importance of the regular preparation of the faces before the firing of coyote blasting. This experience seems to have a theoretical ground because from the standpoint of the shock wave theory of blasting the free faces do not only detemine the values of burdens but they also play important roles as reflecting surfaces for shock waves and the effectiveness of reflection depends heavily on the regularity of the free faces.

7-3. Selection of Spacing S_e

The spacing S_e between individual charges has been arbitrarily selected so far only on the basis of experiences while from the standpoint of the shock wave theory of blasting the value of spacing is definitely determined by the relations between weight of charges and burdens and in case of normal charge for which "a full crater" can be realized the following relation exists to the first approximation:

$$S_e=1.5d \qquad (7)'$$

As the similitude ratio (ratio of the distance between an apex of a crater and a center of charge to the depth) tends from zero (full crater) to 1 (critical depth) S_e should be decreased. The relation is based on the co-operation of shock waves from separate charges.

7-4. Selection of height of bench H

For a full crater charge following relation is expected for H and d from the standpoint of shock wave theory of blasting.

$$H=2d \qquad (15)$$

Most of the authors give nearly the same value for the ratio of H to d.

7-5. Effects of free end and tight end.

The effects of free end and tight end on the necessary amount of charge can not be estimated by the previous methods. These effects may be easily explained on the basis of Shock wave theory of blasting because in case of free end there are three free faces and the co-operation of three shock waves from a single charge (tension waves) help the rapture of rock while in case of tight end there exist only two free faces and the co-operation of tension waves as has been explained in case of bench blasting is to less extent compared with the case of free end. This situation brings about the difference of necessary weight of charges in both cases.

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