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CONCENTRATED TYPE OF NO-CUT ROUND OF BLASTING

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Summary

The blasting rounds which utilize neither angled cuts nor burn cuts have been defined as "No-cut rounds." No-cut rounds previously suggested have been criticized. Concentrated type of No-cut round has been presented. In this type bore holes are drilled perpendicularly to the first free face parallel to each other in a concentrated pattern but without too rigorous requirements as needed for burn cuts and the every bore hole is loaded with explosive contrary to burn cuts in which some holes are left unloaded to make them function as limited free faces. These "cut holes" are fired simultaneously by instantaneous electric detonators or by primacords. In large tunnel driving and in underground drifting the concentrated type of "No-cut round" has been proved profitable bringing about the reduction of number of bore holes, weight of charge, number of detonators, number of delays of millisecond detonators, and the increase of depth of pull. Blasting pattern can be simplified by this method. Examples have been prese nted with illustrations. The principle has wide applications to excavation.

§. 1. Definition of No-cut rounds of blasting

In ordinary blasting in drifts, tunnels etc. the first stage of blasting is the "cut" with one free face available and the methods of drilling bore holes and of determining the weights of chargse are different from those for the later stages of blasting, such as for relievers and trimmers. In angled cuts snch as draw cut, V cut, wedge cut and pyramid cut, the cut holes are drilled with angles of inclination to the free face other than 90 degrees and the effort is concentrated on converging the end points of thə bore holes to a point.

In burn cut many parallel holes are drilled at right angles to the first free face while some of the bore holes are left unloaded thus providing "limited free faceg".

In the present paper the blasting rounds without angled cuts or burn cuts are defined as "No-cut rounds of blasting" according to the classification suggested, e. g., by A. Gray. [1]

§. 2. Defects of conventional cuts

2—1 Angled cuts

Common defects of the angled cuts are;

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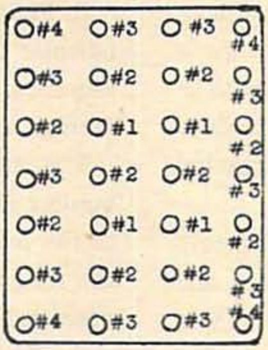
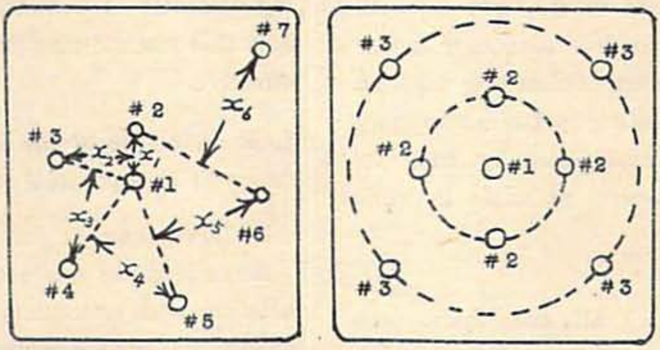
* Asa-machi, Yamaguchi Pref. Japan.

(1) Allen Gray; Lecture on "Explosives, Drilling and Blasting." 1951. Sep. 12～1952. Jan. 10. Colorado School of Mines.



(1) G. Agnew cut



(2) Spiral cut (3) Crater round

Fig. 1 No-cut rounds previously suggested (1) Agnew Cut. (2) Spiral cut (3) Crater round

(1) there are no definite principles for the determination of elements of designing, such as depth of bore holes, weight of charges, angle of inclination of bore holes, etc. (2) Skill is required to drill holes with assessed angles of inclination with perfect convergency of the end points of many holes. (3) In general the rock is not pulled out to the bottom of the bore holes and to pull to the full depth additional bore holes (relievers or openers or helpers) must be drilled near the "cuts", the fact revealing that the original cuts are not enough to produce free faces necessary to the succeeding shots. (4) A great number of bore holes must be drilled. In short the standardization of the blasting pattern is difficult.

2—2 Burn cuts

Common defects of burn cuts are: (1) the distance x between loaded holes and hollow holes cannot be theoretically determined and experiments to find them are troublesome. (2) there is no principle to find necessary and sufficient weight of charge (3) loaded holes and unloaded holes must be exactly parallel, otherwise blown-out shots or breaking through at the positions of charges occur (4) additional bore holes, rakers, are necessary near the burn cut holes to insure the advance but the distance y between the raker holes and burn cut holes is difficult to determine. (5) a great number of bore holes is required and weight of charge is rather increased. In short the standardization of the blasting pattern is not easy.

2—3 No-cut rounds previously suggested

a) W. G. Agnew cut (2)

In this method all bore holes are nearly perpendicular to the first free face and are spaced almost uniformly over the free face. The charges are initiated, for example, as shown in Fig. 1. (1) through rotation firing of milli-second delay detonators in sequence of #1, #2, ……. All bore holes are loaded. Although better over-all performance of blastiong has been claimed the blasting pattern can only be determined experimentally case by case. It lacks general principle to work on.

b) Spiral cut

In Fig. 1. (2) all bore holes are perpendicular to the first free face and the sequence of firing is indicated by the number near the opening of the holes. The larger the numbers, the easier the burdens to be broken, therefore, the burdens x may be increased step by step making the blasting pattern into a spiral. The defects of this method are: (1) Difficulty of determining x_1, x_2, (2) Difficulty of drilling according to this delicate pattern. (3) For the same diameter of bore holes the weight of charge for "the number one shot", which is really the only "cut" in its exact meaning, is necessarilly too small to pull out the full depth and the subsequent shots, number two, three…, can not increase the advance deeper than the depth pulled out by the number one shot.

c) Crater round

In Fig. 1. (3) all bore holes are perpendicular to the first free face and the sequence of firing is indicated by the number #1, #2, #3…….

The number one is the "cut" and the number two is the opener. If the diameter of the bore holes is the same for all holes the weight of charge of the first shot is necessarilly too small to produce a deep crater in practical circumstances and the expected advance can not be realized. Only if a bore hole of an extra-ordinary big diameter is available for the center hole this method may prove practical and effective.

§. 3. Principle of the concentrated type of No-cut round of blasting

3—1 Principle

According to the recent theory(3) of blasting with concentrated charge based chiefly on the characteristics of shock wave produced by detonation, the weight of chage W necessary to produce a crater, whose apex reaches the center of the gravity of the charge, is determined uniquely for a given kind of rock and explosive by a given depth of charge, vertical distance between a center of *a* charge and a free face. In other words to pull to the depth d the amount of explosive W must be concentrated at depth d. Other factors such as angles of bore holes, number of bore holes etc. are of secondary importance. What is the most important is to find this amount W for

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(2) W. G. Agnew; Mining Congress Journal 1949 Apr. p. 70. Oct. p. 30. 1950. Oct. p. 85.

(3) Kumao Hino: Theory of blasting with concentrated charge: Journal of the Industrial Explosives Society, Japan, Vol. 15. No. 4 1954. p. 233∼249.

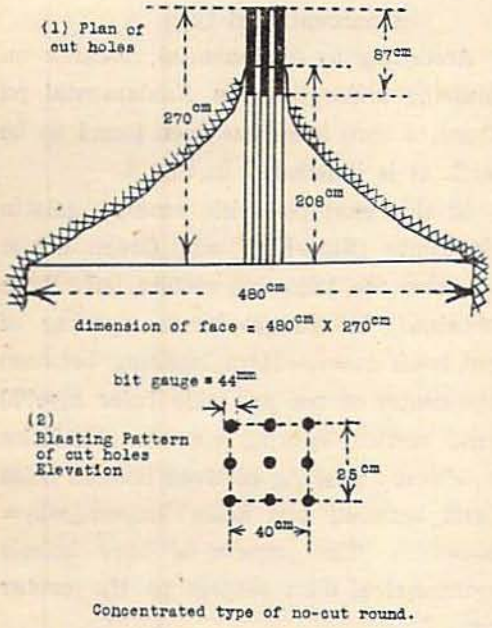


Fig. 2 Experiment on cut for Ammon Gelatin dynamite (Shin-Kiri) and Sandstone. Total weight of charge. W=13.5kg

a given value of d and to realize the relation between W and d in practice by the explosive and drill available in given circumstances. Usually the diameters of drills have a same fixed value for both cut holes and helpers etc. Therefore to realize the definite relation between W and d we must concentrate the number of bore holes on the position of the expected cut and this concentration may be realized by drilling many parallel holes straight into the solid. The number of holes to be concentrated depends on (1) the diameter of bit available (2) depth to be pulled (3) power and brisance of explosive used (4) loading density of charge and (5) tensile strength of rock.

The benefits of this concentrated type of "No-cut" round over the burn cuts are: (1) the bore holes are required to be nearly parallel while in burn cuts they should be accurately parallel. (2) distances among each hole may be arbitrary although the shorter the better while in burn cuts they should have some definite values. (3) total weight of charge which is distributed among many holes is determined by simple procedure. In burn cuts the weights of charges in various holes must be chosen carefully through experience. (4) loading of charge is simple. Charges are loaded into each bore hole as densely as possible and are stemmed as firmly as possible while in burn cuts the charges in one hole must be dispersed with cushion pieces. In the present paper previous definition of "No-not rounds" has been preserved and the "cut" means the concentrated bore holes loaded with explosive although it sounds contradictory that "No-cut round" has the cut. The more reasonable definition may be "straight cuts."

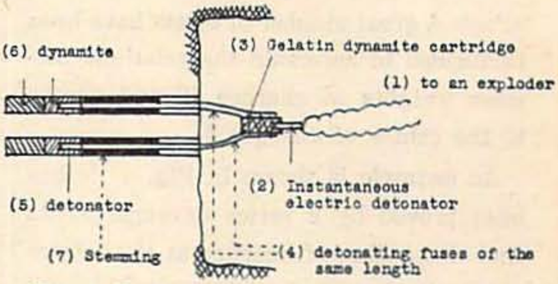


Fig. 3 Perfectly simultaneous initiation of uct holes by means of detonating fuses.

3—2 Experiments on cuts

Various dynamites such as blasting gelatin, Special Ammon gelatin (Toku-Kiri), Ammon gelatin (Kiri), *B* dynamite (gelatin dynamite composed of nitroglycerine, pentaerythritol tetranitrate, barium nitrate, aluminum powder, nitrocellulose, which is supposed to be the strongest explosive with the highest density among industrial explosives) have been tested for various rocks such as sandstone green schist. A great number of blasts have been performed to ascertain the relations between weights of charges W and depths to the center of charges d.

An example is shown in Fig. 2. It has been proved by a series of experiments that detonation of charges at the bottom of bore holes drilled straight into the solid can produce a conical shaped crater such as shown in Fig. 2. which functions as a more effective or extended cut than conventional cuts by ordinary angled bore holes or burn cuts.

Initiation of detonation of separate charges in several holes of cuts is most effectively performed by using detonating fuses of the same length which are inserted into different holes on the one hand but on the other are tied into a bundle around a small piece of gelatin dynamite which in turn is initiated by an electric detonator as is shown in Fig. 3. This method may be called "the perfectly simultaneous initiation" by means of "the synchronous detonating fuses." From the standpoint of "the shock wave theory of blasting" this is the only way to bring about the most effective cooperation of several charges, however, as this method is somewhat troublesome in practice, in the following examples described in this paper the initiation of charges in cut holes has been performed with the simultaneous firing of instaneous detonators in each hole by strong electric current supplied by a condenser discharge type exploder. As the spacing of the cut holes are small (10~20cm.) charges in different holes may be detonated by sympathetic detonation in practice.

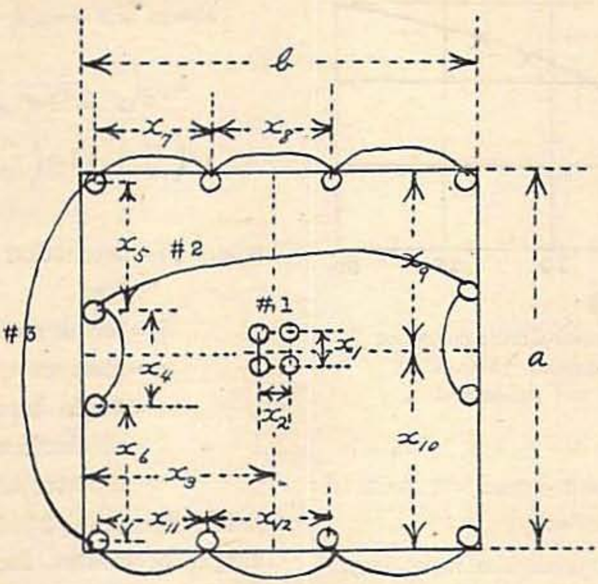
3—3 Standard pattern of No-cut round of concentrated type.

According to fundamental research on blasting underground a fundamental pattern of bore holes has been found to be such as is illustrated in Fig. 4.

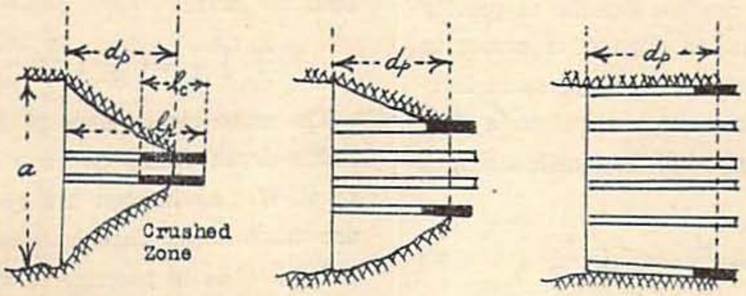
In this example with ammon gelatin dynamite (Shin-Kiri) and Green Schist (Besshi) the following results have been obtained: bit gauge=34mm., spacing of cut holes $x_1=x_2=21$cm., spacing between the center of cut and side holes $x_3\fallingdotseq100$ cm., vertical spacing between side holes $x_4=50$cm., spacing between bottom holes (and between top holes) $x_{11}=x_{12}=x_7=x_8=60$cm. The pattern of bore holesis symmetrical with respect to the center cut.

Dimensions of the face $a=200$cm., $b=200$cm. Total weight of charge for cut $W=5$kg., that is, for each hole $W_1=\frac{5}{4}=$ 1.25 kg., length of cartridges for earh cut hole $l_{c1}\fallingdotseq80$cm., weight of charge of side holes per hole $W_2=800$g., weight of charge of top holes per hole $W_3=1$kg., weight of charge of bottom holes (except corners) per hole $W_4=800$g., weight of charge of bottom corners per hole $W_5=1$kg., total weight of charge $W_t=15.8$kg., total number of bore holes $n=16$, length of bore hole $l_p=1.5$m., depth of pull $d_p=1.35$m. The kind of detonators=instantaneous electric detonators for #1 holes, millisecond delay detonators for #2 and #3 holes.

In the conventional blasting with V cuts the results are as follows: total weight of charge for cut holes $W_c=4.95$kg., weight of charges for other holes=12.05kg. Total weight of charge $W_t=17$kg., total number of bore holes $n=16$., length of bore hole $l_p=1.5$m., depth of pull d_p =1.10m., the detonators used=instantaneous and milli-



(1) Elevation or blasting pattern. # indicates sequence of firing



(2) Longitudinal section after firing Number zero detonator (instantaneous detonator) #1 in Fig. 4(1)

(3) Longitudinal section after firing number one delay #2 in Fig. 4(1)

(4) Longitudinal section after firing number two delay #3 in Fig. 4(1)

Fig. 4 Sequential effects of delayed firing in No-cut round.

second delay detonators.

3—4 Design of cut based on crater curves

For the design and practice of No-cut round of concentrated type we must find the amount of explosive W_c to produce the expected depth of pull d_p. The most practical way of doing this isto find experimentally the relation between the depth to the center of a charges (or a group of charges) from the first free face, d_c and the weight of a charge W to produce a "full crater," that is, a crater whose apex reaches the center of gravity of the charge. An example for ammon gelatin (Shin-Kiri) dynamite and sandstone (Miike) has been shown in Fig. 5. Such a crater curve may be theoretically drawn based on the theoretical formulas of shock wave theory of blas-

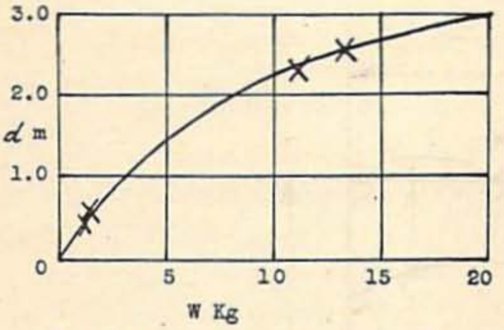


Fig. 5 Experimental Crater curve for Ammon gelatin (Shin-Kiri) dynamite and sandstone.

ting.[3]

3—5 Design of cut based on reduced depth or burden

For practical purposes the most important is the case of the full crater, the case where an apex of a crater produced by detonation reaches a center of gravity of a charge. At the edge of a crater in Fig. 6. the component of pressure intensity of shock wave vertical to a free face must be equal to the tensile strength of rock S_t.

$$\sin\alpha=\frac{d}{r}=\frac{d}{\sqrt{R^2+d^2}} \qquad (1)$$

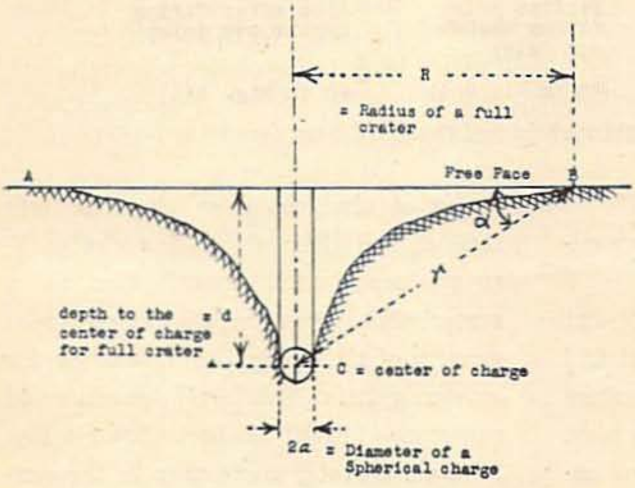


Fig. 6 Reduced depth or burden $D=d/a$ for a full crater.

$$S_t=p_r{}^*\sin\alpha=p_D\left(\frac{a}{r}\right)^n\frac{d}{\sqrt{R^2+d^2}}$$

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

$$\text{or}\left(\frac{R}{d}\right)^2+1=\left(\frac{a}{d}\right)^{\frac{2n}{1+n}}\left(\frac{p_D}{S_t}\right)^{\frac{2}{1+n}} \qquad (3)$$

where p_D=detonation pressure of explosive,

S_t=tensile strength of rock

n=distance exponent

α=angle between the direction of shock wave at the edge of a crater and a free face.

The relation (3) is valid for general shapes of craters including"full crater." If the values of R and$d$ for full craters are respectively described by R_f and d_f then we have:

$$\left(\frac{R_f}{d_f}\right)^2+1=\left(\frac{p_D}{S_t}\right)^{\frac{2}{1+n}}\left(\frac{a}{d_f}\right)^{\frac{2n}{1+n}} \qquad (4)$$

The nume rical values of R_f/d_f or the radius-depth ratios as have been found by C. W. Livingston are about 2.7 and are much larger than have been believed before, while in practice it may be adequate to assume $R_f/d_f=1.5$. In general R_f/d_f may be assumed to be constant for a pair of explosive and rock irrespective of the absolute values of R_f, d_f and a.

Therefore the following value of $D_f=d_f/a$ or reduced burden or reduced depthis constant for

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(3) p. 242. (30)

* erratum: The equation below (29) in the previous paper (3) p. 241 should read:

$$S_t=p_D\left(\frac{a}{r}\right)^n\frac{d}{\sqrt{R^2+d^2}}$$

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

full craters:

$$D_f=\frac{d_f}{a}=\left(\frac{p_D}{S_t}\right)^{\frac{1}{n}}\left\{\left(\frac{R_f}{d_f}\right)^2+1\right\}^{-\left(\frac{1+n}{2n}\right)} \quad (5)$$

d_f is defined as "burden" in the technology of blasting and has been called "the line of least resistance" in classical treatise on blasting because it has been previously assumed that the solid material which corresponds to the length d_f provides resistance as a whole to breaking at an instant of detontion which actually is not the case.

If we find the numerical value of $D_f=\frac{d_f}{a}$ for a pair of explosive and rock to be, for example, 17 then this is valid, in principle, for every value of d_f or a or weight of charge W.

The following relation exists between a and W.

$$W=\frac{4}{3}\pi a^3 \varDelta \quad (6)$$

where $\varDelta$=loading density.

From (5) and (6) we get:

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

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

or $W=\text{const.}\ d_f^3$ (7)

The equation (7) is the well known experimental formula of Hauser. Thus this "cubic law" has been deduced by shock wave theory of blasting.

Example of calculation. If it has been found for Ammon gelatin (Shin-Kiri) dynamite and granite $\varDelta=1.45$, $W=3000$g., $d_f=150$cm., then from Table 1. the radius of a spherical charge $a=7.91$cm., and we find the reduced burden: $D_f=\frac{150}{7.91}=19$. For the burden of $d_f=300$cm., the required radius of charge a is. $a=\frac{300}{19}=15.8$cm. from Table 1. we find: $W=22$kg.

The number of bore holes among which this total amount of charge should be divided depends on the gauge of bit available. If bit gauge $g=42$mm., then from Table 2. the total length of charge is: $l_c=\frac{22000}{2007}=11$m. If we divide the total charge among 9 holes then the length of charge in one hole is: $\frac{11\text{m}}{9}=1.22$m. As the center of gravity is situated at a point $\frac{1.22}{2}=0.61$m far from the bottom of a bore hole we should drill bore holes to the depth of 3m+0.61m=3.61m to make the depth of pull at least 3 meters. Actually deeper breakage may be expected

Table. 1.

Weight of charge W kg. and radius of spherical charge a cm for loading density $\varDelta=1.45$g/cm³

W	kg	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
a	cm	2.54	3.21	3.67	4.04	4.35	4.63	4.82	5.09	5.29	5.48
W		1.2	1.4	1.6	1.8	2.0	2.2	2.4	3.0	4.0	5.0
a		5.83	6.13	6.41	6.67	6.97	7.13	7.34	7.91	8.70	9.37
W		6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0	15.0
a		9.96	10.5	11.0	11.4	11.8	12.2	12.6	12.9	13.2	13.6
W		16.0	17.0	18.0	19.0	20.0	21.0	22.0			
a		13.8	14.1	14.4	14.6	14.9	15.1	15.3			

Table. 2.
Diameter of bore hole $g$mm and weight of charge Wg for 1 meter cartridge length. $\Delta=1.45\mathrm{g/cm^3}$

g mm	20	23	25	28	30	33	35	38	40	42
W g	455	602	711	892	1024	1240	1394	1644	1821	2007
g	44	45	46	48	50	52	54	55	56	58
W	2204	2305	2409	2623	2846	3080	3320	3443	3567	3828

Table. 3.
Comparison between Pyramid cut round and No-cut round of concentrated type for Granite porphyry and Gelignite.

Kind of Round		Pyramid	No-cut
length of a bore hole		3.2m	3.2m
depth of pull		3.0m	3.0m
Number of bore holes	cut	12	8
	other	55	48
	total	67	56
Weight of charge	cut	20.0kg	16.0kg
	other	82.0kg	79.0kg
	total	102.0kg	95.0kg
Explosive per cubic meter rock in solid		$1.48\mathrm{kg/m^3}$	$1.38\mathrm{kg/m^3}$
Number of detonators		67	56
Number of delays *		#10	# 7

* instantaneous detonators included.

in practice.

§ 4. Practice of No-cut rounds

4—1 Granite porphyry

Diameter of Tunnel=4.8m (sectional area=$23\mathrm{m^2}$), Rock=Granite porphyry(Hida-Hagiwara, Kumagai-gummi, Co. Ltd.) Dynamite=Gelignite (Sakura)

Detonator=Instantaneous detonators for cut holes, and Millisecond delay detonators with intervals of 20 ms.,

Exploder=condenser discharge type.

Dynamite, detonators and exploder are all manufactured by Nippon Kayaku Co. Ltd.

Bit gauge g=42mm., Denver Drifters with three deck Jumbo, 8 arms. Eimco loader, length of bore hole l_p=3.2m.

The change from conventional pyramid cut into No-cut round of concentrated type was performed in 1954, July 1~5.

The results are shown in Table 3. By use of No-cut round (1) Number of bore holes was reduced by 17% (2) weight of total charge was reduced by 7% (3) number of detonators was reduced by 17% (4) blasting pattern became simpler, easier to be realized. No limit exists to the depth of pull in No-cut rounds because the steels of drifters can be operated vertically to the first free face while in classical angled cuts the length of steels is limited because they must be handled at some angles to the first free face thus

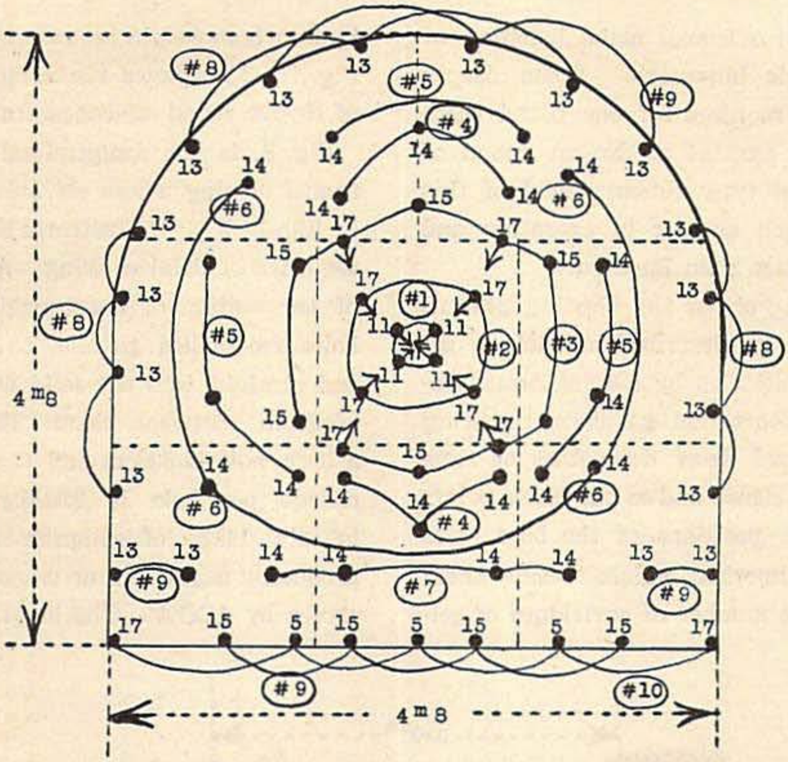

Fig.7 (1) Pyramid cut for granite porphyry and gelignite.

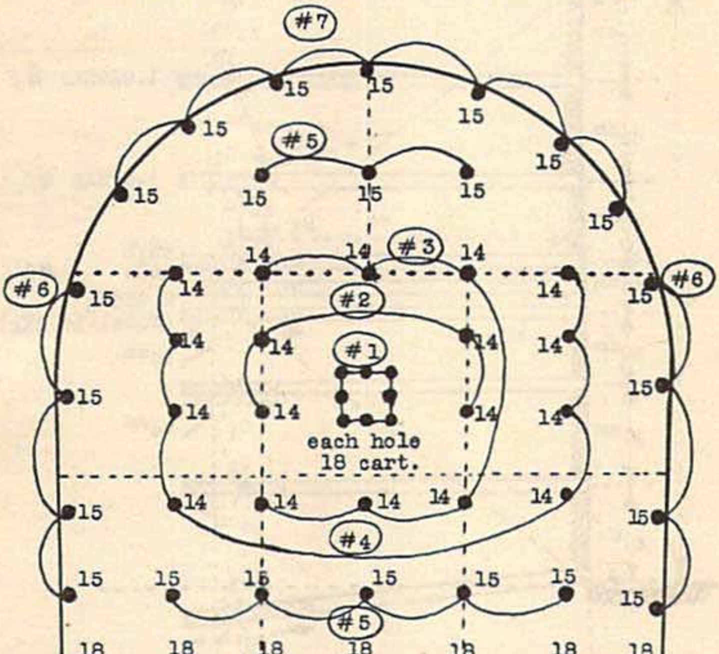

Fig. 7 (2) No-cut round of concentrated type for granite porphyry and gelignite.

the walls of a tunnel make handling of longer steels impossible. When deeper advance is required for one round there may be no parallel to No-cut round of concentrated type. No-cut round of this type is much simpler in operation and surer in effect than Burn cuts.

Fig. 7 (1) shows the blasting pattern of pyramid cut described in Table 3. ♯1 indicates initiation by instantaneous electric detonators, and ♯2 shows the firing by millisecond delay detonators at time interval of 20ms., and so on. Black points indicate the positions of the bore holes and the numerical values beside them indicate the number of cartridges of gelignite whose weight per cartridge is 112.5g. Fig. 7 (2) sghows the blasting pattern of No-cut round of concentratedtype.

Fig. 8. is the longitudinal section of tunnel driving whose elevation is shown in Fig. 7 (2). It illustrates effects of the sequence of delayed firing. At the center of the section of the tunnel eight bore holes are drilled parallel to each other and straight into the solid with spacing of 20cm. between them. The depth of a bore hole is 320cm and the weight of charge per hole is 2.025kg, therefore, in total 16kg. of gelignite is used for producing a full crater whose section is shown by ACC′A′. The length of charge

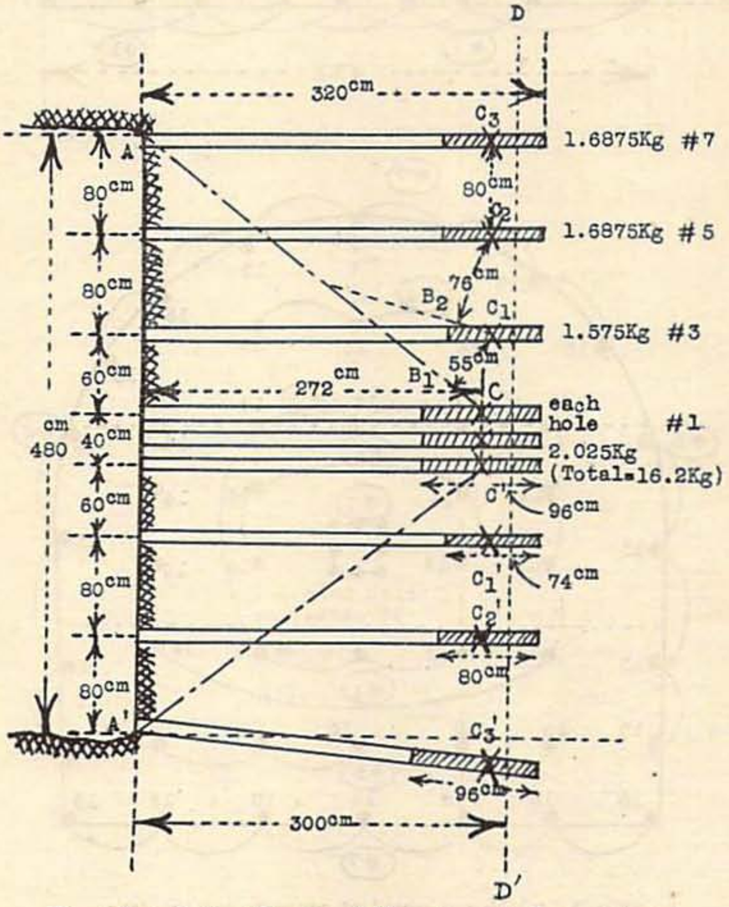

Fig. 8 Lougitudinal Section of No-cut round of concentrated type for granite porphyry and gelignite.

Table. 4.

Sequence of firing	Burden cm	Reduced burden d/a	Weight of charge kg	length of charge cm
# 1	272	20	16.2	96
# 3	55	9	1.757 per hole	74
# 5	76	12	1.688 per hole	80
# 7	80	12	1.688 per hole	80
# 7	90	13	2.025 per hole	96

is 96cm. and it has been ass umed in design that the apex of the crater reaches the center of gravity of charge, the middle point on CC′. Four side holes which are blasted by the first delay (#2) enlarge laterally the bottom of the crater and the 2nd delay (#3) is blasted at C_1 (and C_1') with a burden of C_1 B_1=55cm. As is shown in Fig. 8 the weight of charge per hole is 1.575kg and it corresponds to the reduced burden of 9 while the reduced burden for cut (#1) is 20.

The Table 4. indicates burden, reduced burden, weight of charge and length of charge per hole.

It may be possible to reduce the weights of charges for #3, 4, 5, 6, 7 as the reduced burdens for them are too small. The reduced burden or reduced depth for #1 is estimated by data of blasting of previous rounds Fig. 7. (1) because in this conventional pyramid cut, the real cut is not the the center pyramid with 4 holes but it consists of 12 holes which are shown with arrows in Fig. 7 (1) which indicate the directions of holes, therefore, in this conventional pyramid cut the actual weight of charge consumed for opening cut is 20kg. which is divided among 12 holes. In this case 20kg is necessary because they are uneconomically used under dispersed conditions in space and time while in No-cut round of concentrated type the detonation of the charge for opening cut is concentrated in time and space, therefore 16kg. of charge is enough to insure an extended cut. By this means a regular pattern of blasting can be realized as is shown in Fig. 7 (2)

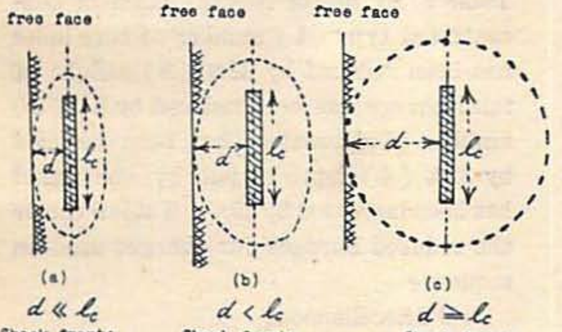

Fig. 9 Justification of the assumption of "concentrated charge" in case of: burden $d \geqq$ length of cartridge.

The depth of pull may be estimated to be C_3 C_2 C_1 C……, although in practice it has been proved to reach D-D'. as shown in Fig. 8. If the spacings among bore holes be reduced the depth of pull may reach the bottom of bore holes.

When the length of charge is nearly the same as, or smaller than, burden a cylindrical shock wave produced by a column of explosive tends to be deformed into a spherical shock wave as it advances toward a free face because decay of peak pressure in the axial direction of a column of charge is more rapid than in the lateral direction as is illustrated in Fig. 9 thus the assumption of "concentrated charge" may be

Table 5.
Comparison between Pyramid cut round and No-cut round of concentrated type for Diorite and Ammon gelatin dynamite.

Kind of Round		Pyramid cut	No-cut
length of a bore hole		2.8m	2.8m
depth of pull		2.3m	2.7m
Number of bore holes	cut	10	9
	other	55	34
	total	65	43
Weight of charge	cut	10.00kg	13.16kg
	other	43.00kg	32.24kg
	total	53.00kg	49.40kg
Explosive per cubic meter rock in solid		1.7kg/m^3	1.4kg/m^3
Number of detonators		65	43
Number of delays *		# 7	# 5

* instantaneous detonators included.

Table. 6.

Sequence of firing	Burden cm	Reduced burden d/a	Weight of charge kg	length of charge cm
# 1	247	19	13.16	66
# 2	60	11	1.0125	46
# 3	80	14	1.0125	46
# 3	75	13.6	1.0125	46
# 5	80	14	1.125	50

justified in case:

$$\text{burden } d \geqq \text{length of charge} \quad (8)$$

In Fig. 8 for the charges C_2, C_3……, there are two free faces for each charge and the blasting is the so-called "Bench blasting." If the height of bench is less than the critical depth for the charge and the burden is the "full crater depth" for the charge, then the bench may be successfully blasted.[3]

4—2 Diorite

Diameter of Tunnel=4m. (sectional area= 13.3m^2), Rock= Diorite (Yakūwa. Ōbayashi-gummi Co. Ltd.) Dynamite= Ammon Gelatin dynamite (Shin-Kiri), Detonators = Instäntaneous detonators for cut holes and millisecond delay detonators with intervals of 20ms., Exploder =Condenser discharge type. Dynamite, detonators and exploder are all manufactured by Nippon Kayaku Co. Ltd., Bit gauge g=44mm. Denver drifter and Joy loader. The results are shown in Table 5. By use of No-cut round of concentrated type (1) number of bore holes has been reduced by 32% (2) weight of total charge has been reduced by 8% (3) number of detonators has been reduced by 32% (4) depth of pull by one round has been increased by 19%. Table 6 shows the reduced burdens for charges used in sequence.

4—3 Miscellaneous

A great number of No-cut rounds of concentrated type has been performed

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(3) page. 246. the equation (53)

Table. 7.
Reduced burdens for various rocks and dynamites.

	Dynamite			Rock	Reduced burden d/a	Place
	Kinds	Weight strength	density g/cm^3			
1	Gelignite (Sakura)	55%	1.55	Granite Porphyry	20	Hagiwara
2	〃	55	1.55	Granite	22	Sakuma
3	Ammon Gelatin (Shin-Kiri)	85	1.45	Diorite	19	Yakuwa
4	〃	85	1.45	Granite	16	Kuba
5	〃	85	1.45	Sandstone	19	Miike
6	Permitted Ammon Gelatin (Shin-Shiraume)	40	1.55	Coal	21	Shinnoka
7	〃	40	1.55	Andesite	16	Shimameguri
8	〃	40	1.55	Shale	21	Sawara
9	Permitted Ammon Gelatin(Shiraume)	35	1.55	Sandstone	16	Futase
10	Permitted Powdery Ammon dynamite(Shōdai)	31	0.95	Andesite	11	Shimameguri
11	〃	31	0.95	Coal	22	Sawara

with success for various pairs of rocks and dynamites in driving tunnels, in drifting in coal mines etc. Some of the data of reduced burdens so far obtained have been summarized in Table 7.

In Table 7 the weight strength of dynamite has been estimated by ballistic pendulum. The weight strength is not the only factor which determines the effectiveness of explosives in blasting. Dynamical properties such as brisance is also of importance[3].*

As has been described in the previous paper the depth of a crater d produced by detonation of a concentrated charge is a constant for a constant weight of charge W and is independent of the depth to the center of a charge. In other words this depth of crater d is the depth to the center of full-crater-charge, d_f for this weight of charge W. By this principle the reduced burden or depth d_f/a may be easily found by a series of experiments although in principle one experiment suffices. Actually the effective strength of rock differs for different directions except in case of homogeneous rock. Moreover scale effects exist and the bigger the scale of one blast, the larger becomes the reduced burden or depth, that is, in general, explosive charges function stronger when they are used on larger scale in a concentrated way while effective strength of rock becomes weaker for bigger mass because the probability of existance of weak points becomes bigger for larger mass.

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(3) * page. 248 §. 9. A.
(3) page. 240.