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THE HAZARD OF FLYROCK IN ROCK BLASTING

Nils Lundborg

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Summary

The maximum throw occurring from explosive rounds was determined as a function of stone size using borehole diameter as a parameter. Experiments indicate the maximum throw to be given by

$$L_{\max} = 260 d^{2/3}$$

with $L_{\max}$ in metres and d in inches. The diameter of these stones is given by

$$\varnothing = L_{\max} / \rho$$

with $\varnothing$ and $L_{\max}$ in metres and ρ in kg/m^3 .

This work is presented in Swedish at the Swedish Rock Blasting Committee in Stockholm 1974.

Introduction

Flyrock that occurs in rock blasting has been a serious problem since blasting began a hundred years ago. Men have been killed and buildings, equipment and materials destroyed. These hazards are greatest in urban areas, but as the blasting rounds become even greater with larger diameter boreholes it is now a serious problem even outside urban areas, such as around open pit mines where the flyrock has been known to travel a kilometre or more from the blast site.

At the Swedish Detonic Research Foundation we have started to investigate the risks from various types of blasting as a first step to define the so called dangerous area. Investigations have shown that it is convenient for this purpose to separate blasting into two categories: bench blasting and crater blasting.

This investigation was initiated by conducting interviews with about 25 people representing various agencies and companies. The general opinion obtained was that shallow blasting and large borehole blasting were the most dangerous, that is, blasting with a low ratio between bench height and borehole diameter, or what is generally called crater blasting.

Flyrock in Bench Blasting

Figure 1 represents a borehole in a common bench blast situation, with the bottom charge and the column charge indicated. An uncharged length of the borehole equal to the burden or about 40 times the diameter of the borehole is recommended. If this precaution is taken there will be little chance of crater blast causing flyrocks at the top end of the borehole.

A very important factor determining the burden velocity is the specific charge (the amount of explosive per cubic metre of rock to be loosened). An increase in the specific charge results in a higher burden velocity as well as a smaller average fragment size. This can be seen in Figure 2 which shows the results of model scale blasts in plexiglass obtained with high speed photography. All of the models shown were plexiglass blocks 100 x 60 x 60 mm. with a 15 mm burden. The holes were drilled in the 60 x 100 mm face in the center of the 60 mm dimension. Figure 2a was taken before the test began. Figure 2b was taken 210 μ sec after detonation of a 2 mm diameter borehole. Figure 2c and 2d were also taken after 210 μ seconds and represent results obtained from boreholes 2.8 mm and 4.0 mm in diameter respectively. Figure 3 is a plot of the burden velo-

city of the plexiglass material versus the relative specific charge. The velocity of the plexiglass material is rather high compared to the ordinary burden velocity in rock which is 5-20 m/s. A. Ladegaard-Pedersen and A. Persson have conducted a series of bench blast tests with a single hole in rock boulders. The borehole diameter was 1" and high-speed photography was used to study the movement of the rock fragments. The experimental arrangement is shown in Figure 4. After each shot the distance from the shot hole and the angles of the flyrocks were determined. A typical flyrock scatter pattern is shown in Figure 5 with the borehole at the origin. Note in particular the position of the center of gravity of the flyrocks and the positions of the individual flyrocks. The maximum throw as determined in these tests is plotted versus the specific charge in Figure 6. As can be seen from the diagram it is possible to avoid flyrock if the charge is smaller than a critical charge size (in this case 0.2 kg/m^3). However, it will hardly be possible to determine this critical charge size as there will always be different rock strengths, variations in burden, faults in the rock and so on which cannot be predicted. Therefore the specific charge will be increased beyond the critical charge size in order to avoid missed rounds.

Flyrock in Crater Blasting

Figure 7 depicts the type of blasting called crater blasting. Although the charge is assumed to be a point charge it has in reality a length of up to 6 borehole diameters.

Figure 8 gives the crater volume for different charge depths at constant weight. L_o is the optimum depth and L_k is the critical depth. For depths greater than L_k the blasting is considered to be bench blasting. Figure 9 shows the charge depth versus the charge weight. Various transition lines are given such as critical depth, where doming begins, the optimum depth where the crater volume has its maximum, and the shallow depth where most of the energy goes into the air as shock effects. As started earlier at a depth greater than the critical depth the area of bench blasting begins wherein the breakage is towards the bench face.

In most open cut mining the trend nowadays is to use large borehole diameters (7-10") and a bench height of 10 to 15 metres. These conditions result in maximum burdens (V) of from seven to ten metres with the hole spacing $E = 1.25 V$. In ordinary bench blasting the unloaded hole length is

equal to the maximum burden, which is about 40 times the borehole diameter. In blasting situations where the ratio between the hole depth and the hole diameter is low it is not possible from an economic point of view to keep the unloaded hole length equal to the burden since this would cause unsatisfactory fragmentation and raise the costs because of secondary blasting. This is unfortunate since a charge placed too near a free surface results in flyrock throw from the upper end of the borehole. In granite, under no circumstances should the distance from the charge to the free surface be less than 50% of the maximum burden if the cratering effect is to be suppressed. Most of the flyrock comes from the surface but it is also possible to obtain crater effects from the front of a round if the burden is reduced because of inhomogenities. Figure 10 depicts examples of how crater effects could occur in bench blasting. Figure 11 presents photographs of a blasted round which utilized boreholes with 7 1/2" diameters. The ratio between unloaded hole length and hole diameter was 10. The lower limit to avoid crater effects is 20-30 while the recommended value is 40. Figure 12 depicts crater effects obtained in granite with fully loaded 1" boreholes. Note that top initiated holes give greater crater depths as well as greater removed volumes.

Crater blasting is sometimes used in shaft sinking situations but mostly it is used in benching at places isolated from urban areas where flyrock can be tolerated. To avoid flyrock and still get good fragmentation it is necessary to have the length of the unloaded part of the hole deeper than the critical depth. The critical depth depends on what type of explosive is used, the hole diameter and the type of rock. Experiments in plexi-glass also show that the crater depth is greater and the crack lengths are shorter if the charge is top initiated.

Theoretical Relations between Flyrock Velocity and Borehole Diameter

Figure 13 shows a number of boulders of different size surrounding a spherical charge. The impulse density (i) from a spherical charge may be written

$$\int p dt = i \sim \frac{Q^{2/3}}{R} \quad (1)$$

where p is the pressure, Q the charge, and R the distance from the charge. For a constant value of the scaled distance $r = R/Q^{1/3}$ we get

$$i \sim Q^{1/3} \sim d \quad (2)$$

where d is the charge diameter.

Equation (2) shows that the impulse density is proportional to the charge

diameter when r is constant.

It may easily be shown that this also holds for a cylindrical charge.

The force (F) on the boulders is proportional to the impulse density and the projected area of the boulders, that is

$$F \sim i \phi^2 \quad (3)$$

where ϕ is the mean diameter of the boulders.

The total impulse of a boulder now is

$$I = \frac{\pi \phi^2}{4} i \quad (4)$$

It is well known that the impulse also may be written

$$I = mv \quad (5)$$

where m is the mass and v the velocity of a body. This yields

$$\frac{\pi \phi^2}{4} i = \frac{4\pi}{3} \rho \frac{\phi^3}{8} v \quad (6)$$

where ρ is the density of the rock

or

$$i = \frac{2}{3} \phi \rho v \quad (7)$$

and from (2)

$$d = c \phi \rho v \quad (8)$$

where c is a constant.

To determine the constant c measurements of $\phi \rho v$ were made for different d -values. By doing so the relation

$$\frac{\phi \rho v}{2600} = 10 d \quad (9)$$

was obtained where ρ is the density of the rock in kg/m^3 , ϕ the diameter in metres, v the velocity in m/s , and d the borehole diameter in inches. 2600 kg/m^3 is the average density of granite. Equation (9) is shown in Figure 14.

Measurements of the Flyrock Velocity and Maximum Throw

To investigate the validity of equation(9) and to determine the factor of proportionality several blasted rounds were photographed and the fly-rock velocities measured. In a number of these rounds the maximum throw and the diameter of the stones including the furthest were also measured.

From these values the velocities were calculated assuming initial throw angles of 45° as giving a maximum throw. These values are also shown in Figure 14. The many low values are due to the fact that the initial throw angles of these stones were not 45° . The approximate upper limit of the $\emptyset \rho v$ - values obtained is seen to be given by equation (9).

Calculation of the Throw

From the previous section it is known that $\emptyset \rho v$ is a function of d . As the density of the rock is known we may choose a value of ρ which yields a given velocity v . Utilizing a computer we can then calculate maximum throw as a function of stone diameter with d as a parameter. These results are given in Figure 15. From the calculations, the maximum throw is

$$L_{\max} = 260 d^{2/3} \quad (10)$$

The diameter of these stones are

$$\emptyset = 0.1 d^{2/3} \quad (11)$$

where $\emptyset$ is in metres and d in inches.

Conclusion

From Figure 15 and equations (10) and (11) it is shown that some boulders are thrown quite far. For example, with 10" boreholes the maximum throw is about 1300 m, with the stone diameter of half a metre. This means that very large areas must be evacuated to avoid accidents. People must be protected against flyrock, no matter the cost. Since the enclosed area is great the probability of hitting a single spot is small but this cannot be taken as an excuse not to protect people in the area. An alternative may be to reduce the throw. It has been found that bench blasting always gives a shorter throw than crater blasting. It can be shown that the same dependence of throw on hole diameter that was found for crater blasting can be used to give the maximum throw for bench blasting. For a specific charge of $.5 \text{ kg/m}^3$ for example (see Figure 6).

$$L_{\max} = 40 d^{2/3}$$

Compared with equation (10) the throw is smaller by a factor of approximately 6. One way therefore to reduce throw is to avoid crater effects.

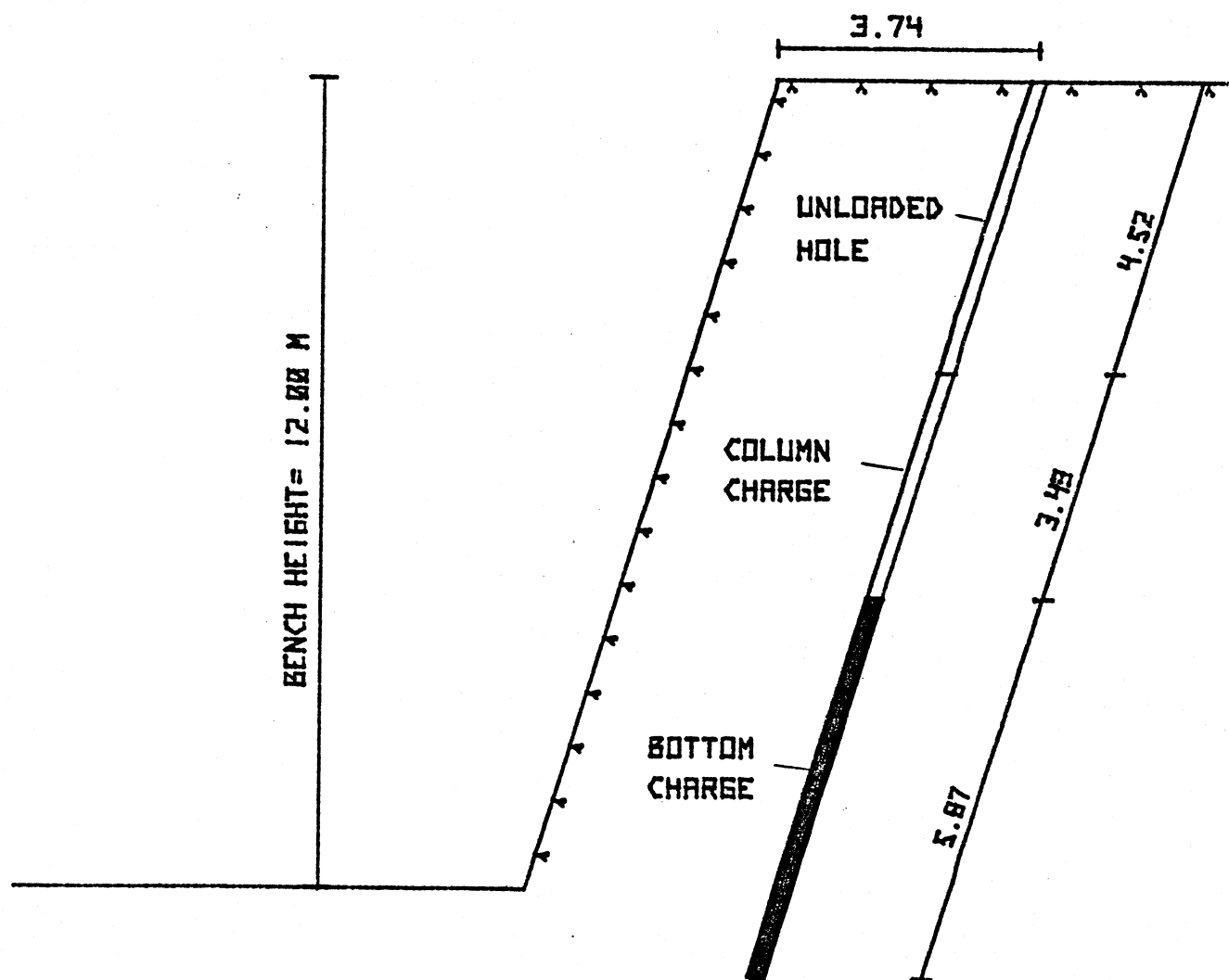
Another way is to cover the rounds, but in practice it is recommended that the weight of the cover should be equal to the weight of the round blasted, which is impossible for large rounds.

Acknowledgment

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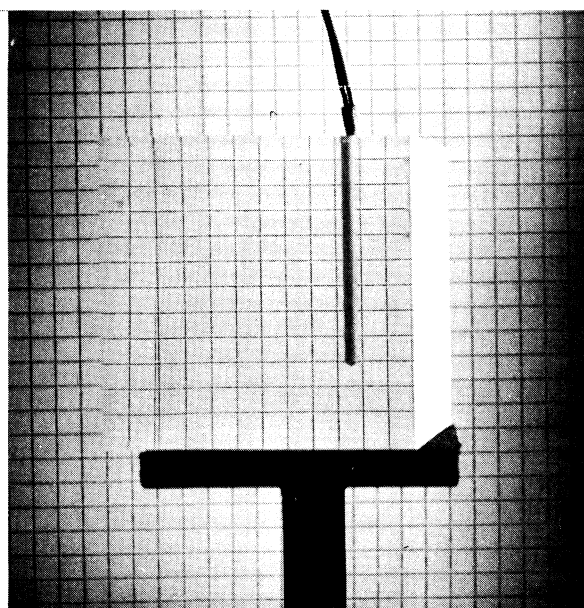
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DIAMETER	Ø.100 M	BURDEN	3.59 M
ROCK CONSTANT	Ø.40	DEVIATION, BOTTOM	Ø.35 M
W-STRENGTH BOTTOM	Ø.95	HOLE DEPTH	13.88 M
W-STRENGTH COLUMN	Ø.80	BOTTOM CHARGE PER M	9.42 KG
HOLE INCLINATION	Ø.30 M/M	COLUMN CHARGE PER M	6.28 KG
ANGULAR DEVIATION	Ø.02 M/M	BOTTOM CHARGE	55.35 KG
COLLARING DEVIATION	Ø.10 M	COLUMN CHARGE	21.93 KG
DEG. OF PACK. BOTTOM	1200.00 KG/M ³	SPACING	4.48 M
DEG. OF PACK. COLUMN	800.00 KG/M ³	AVERAGE BOULDER SIZE	1.10 M

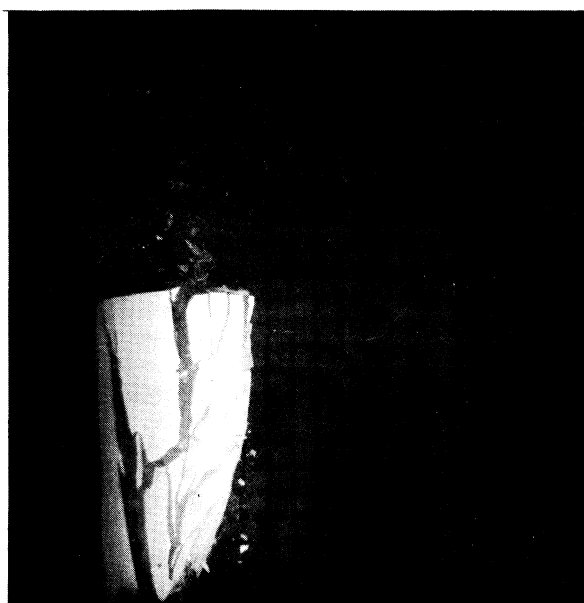
Fig. 1. Borehole in bench blasting with bottom charge, column charge and unloaded hole.



a)



b)



c)



d)

Fig. 2. Plexiglass block 100 x 60 x 60 mm.
The hole is drilled with 15 mm burden from the longer side.

- a) before shot
- b) 2.0 mm hole 210 μ s after initiation
- c) 2.8 mm hole 210 μ s after initiation
- d) 4.0 mm hole 210 μ s after initiation

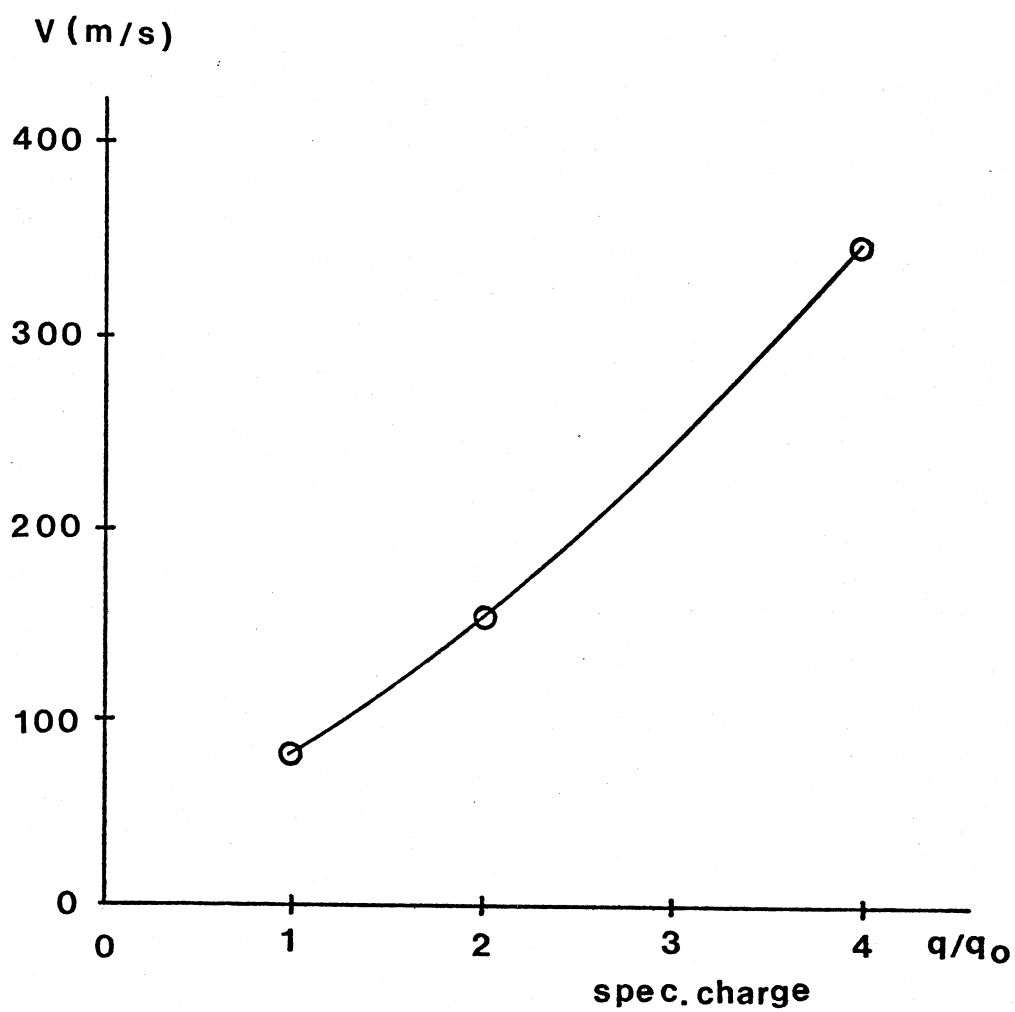


Fig. 3. Particle velocity of plexiglass according to fig. 2 versus specific charge.



Fig. 4. Arrangement at bench blasting.

• < 0.5 kg

• < 5 -

• > 5 -

○ BOREHOLE

⊕ CENTER OF GRAVITY

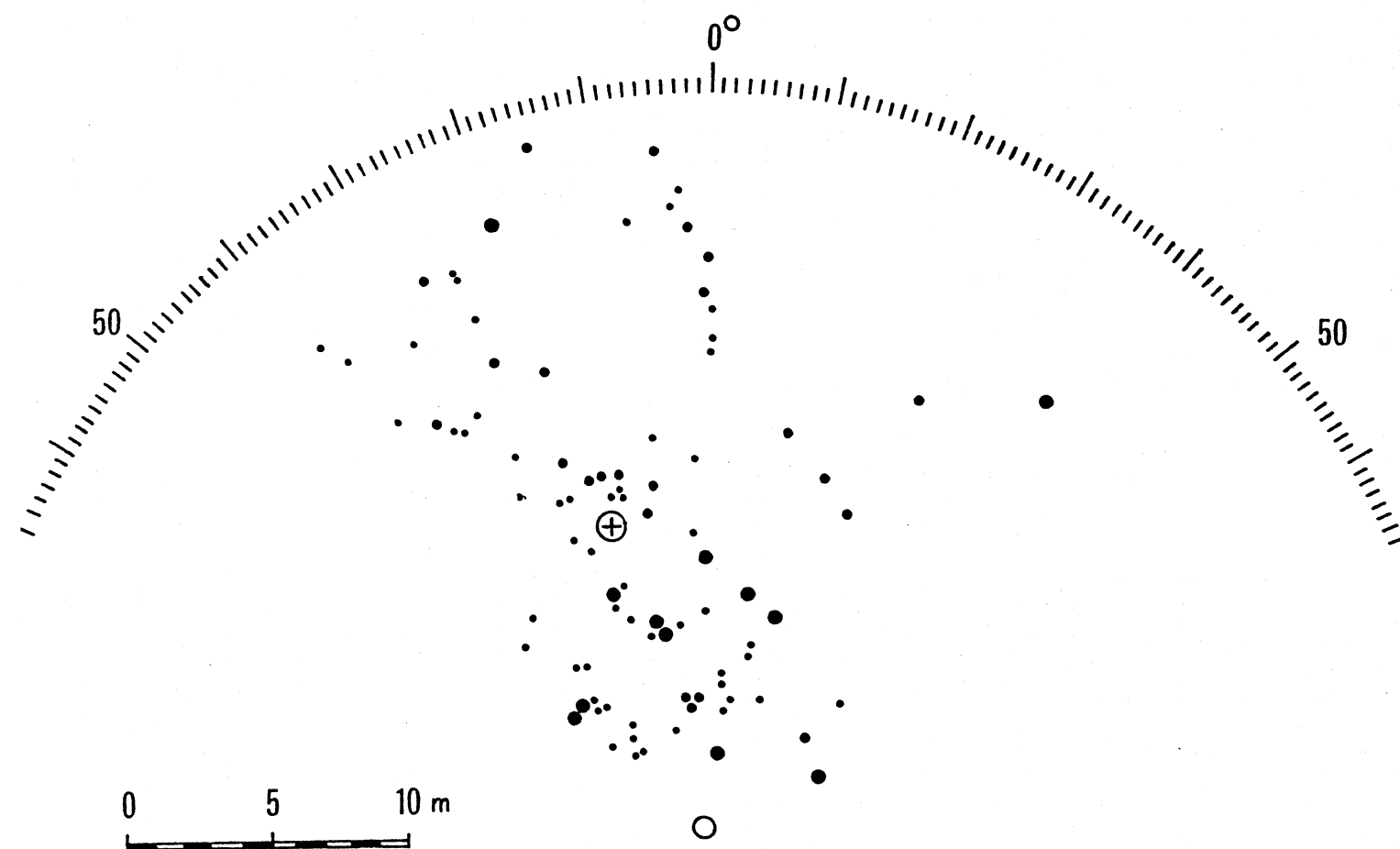


Fig. 5. The throw and scatter resulting from a blast according to fig. 4.

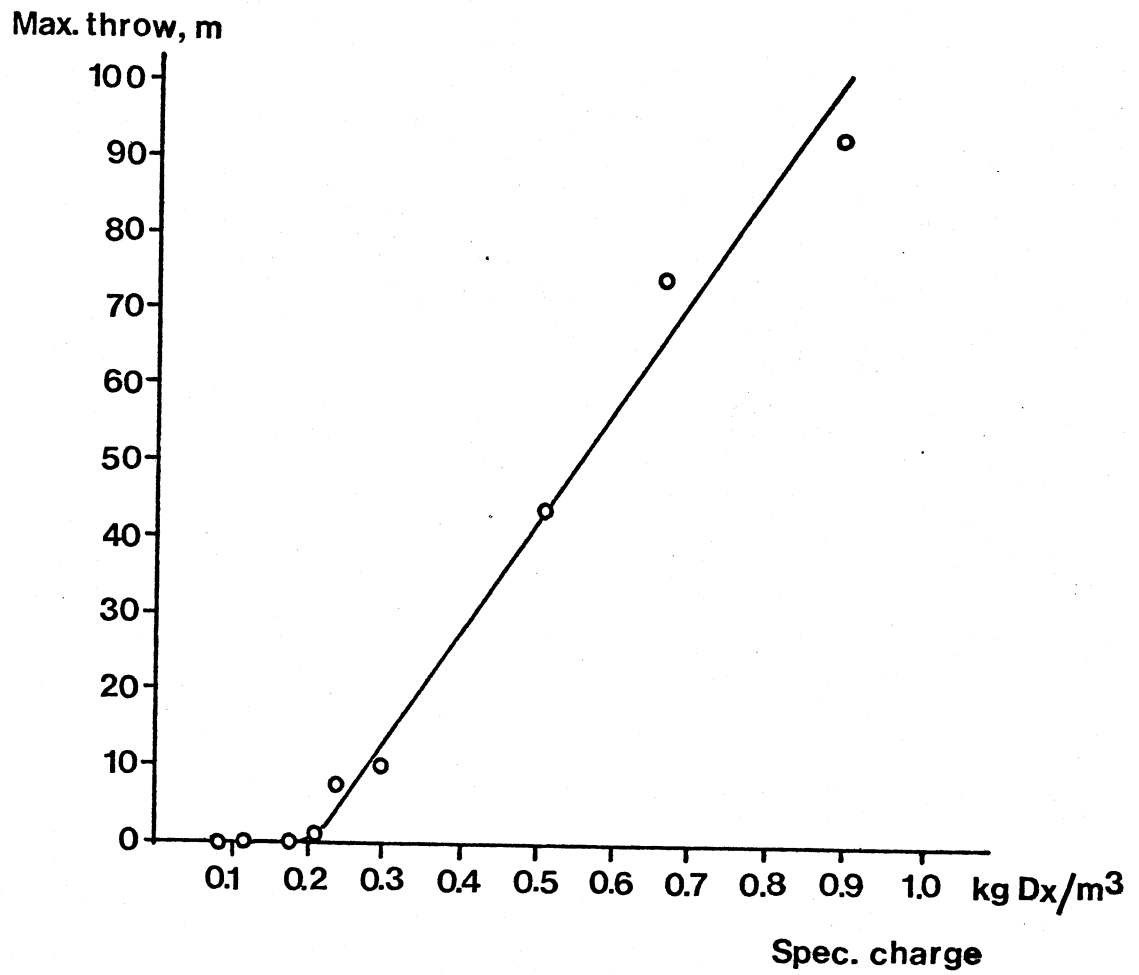


Fig. 6. Maximum throw at bench blasting versus specific charge.

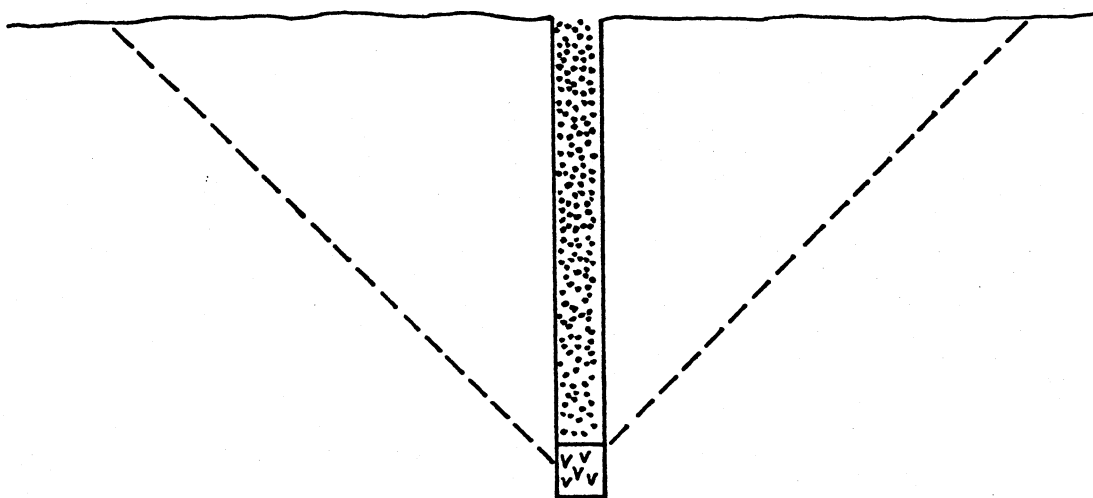


Fig. 7. The geometry of crater blasting.

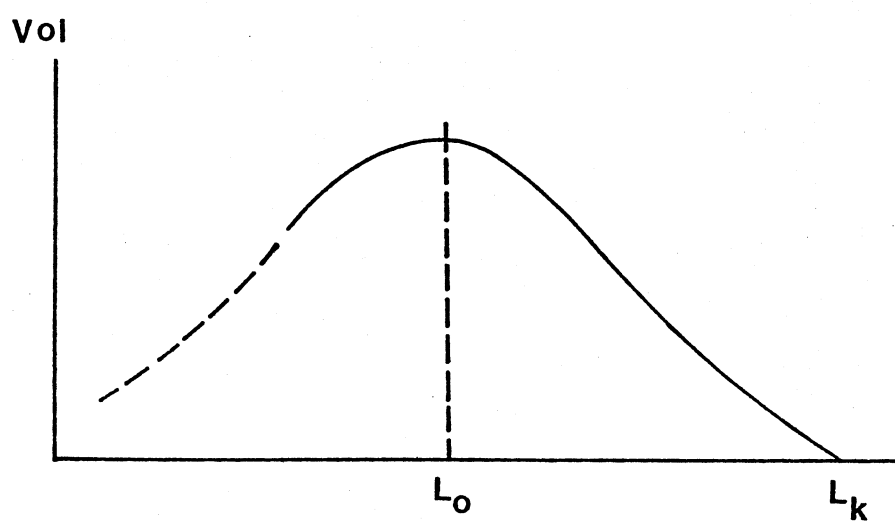


Fig. 8. Volume removed by a charge at different depths.

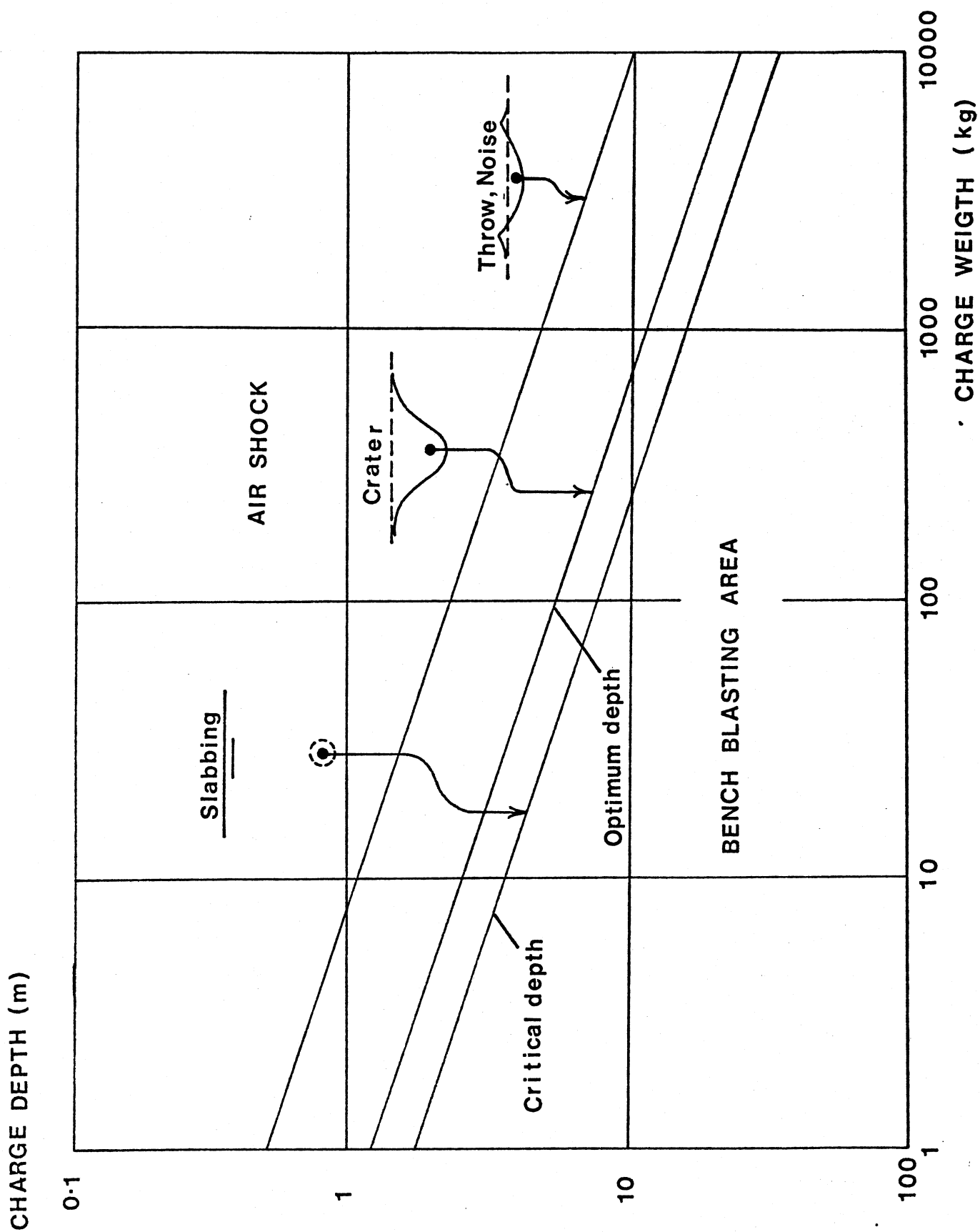


Fig. 9. Charge depth versus charge weight at different parameters.

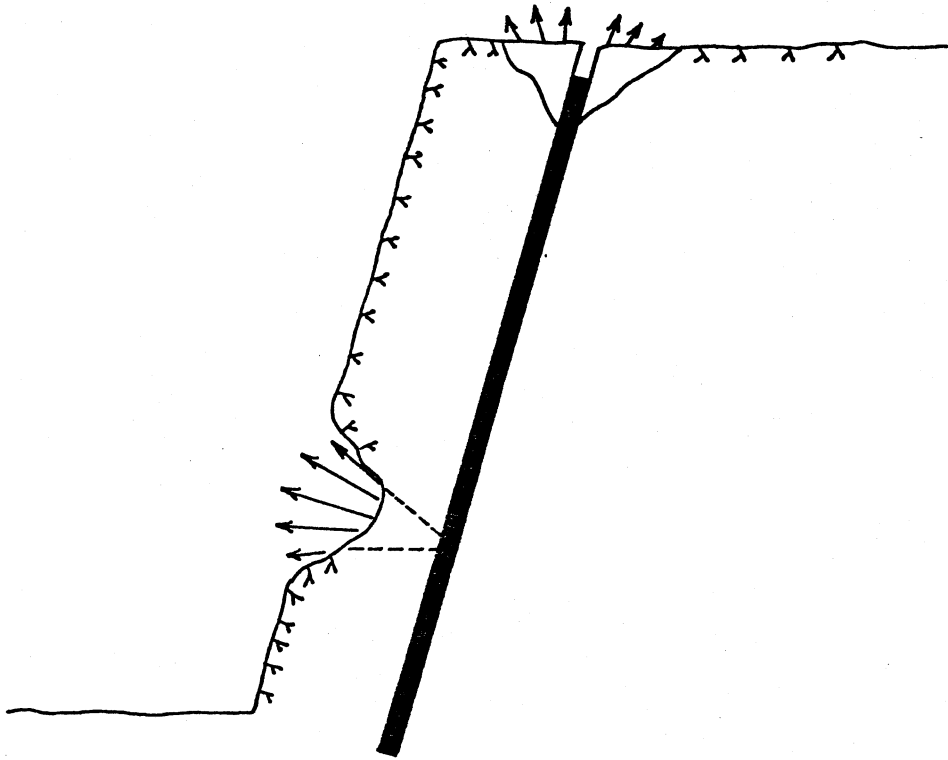


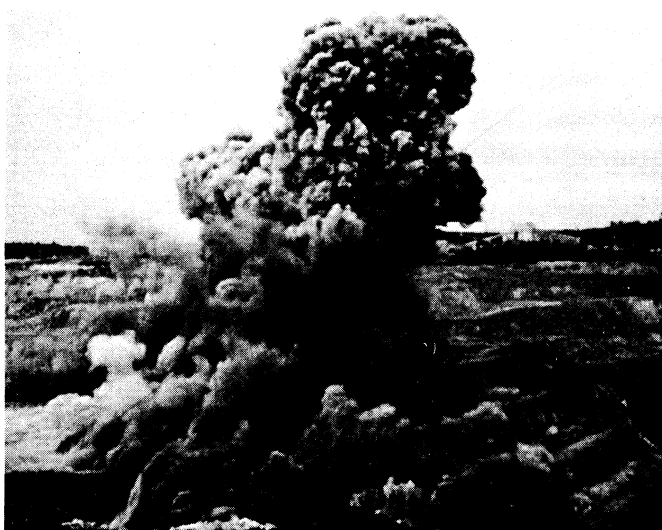
Fig. 10. Crater effects in bench blasting.



a/



b/



c/

Fig. 11. Blasting round with 10 metres bench height and 41 7.5" holes containing 16.000 kgs slurry explosives.

- a) 0.05 s after initiation
- b) 0.75 s after initiation
- c) 4.05 s after initiation

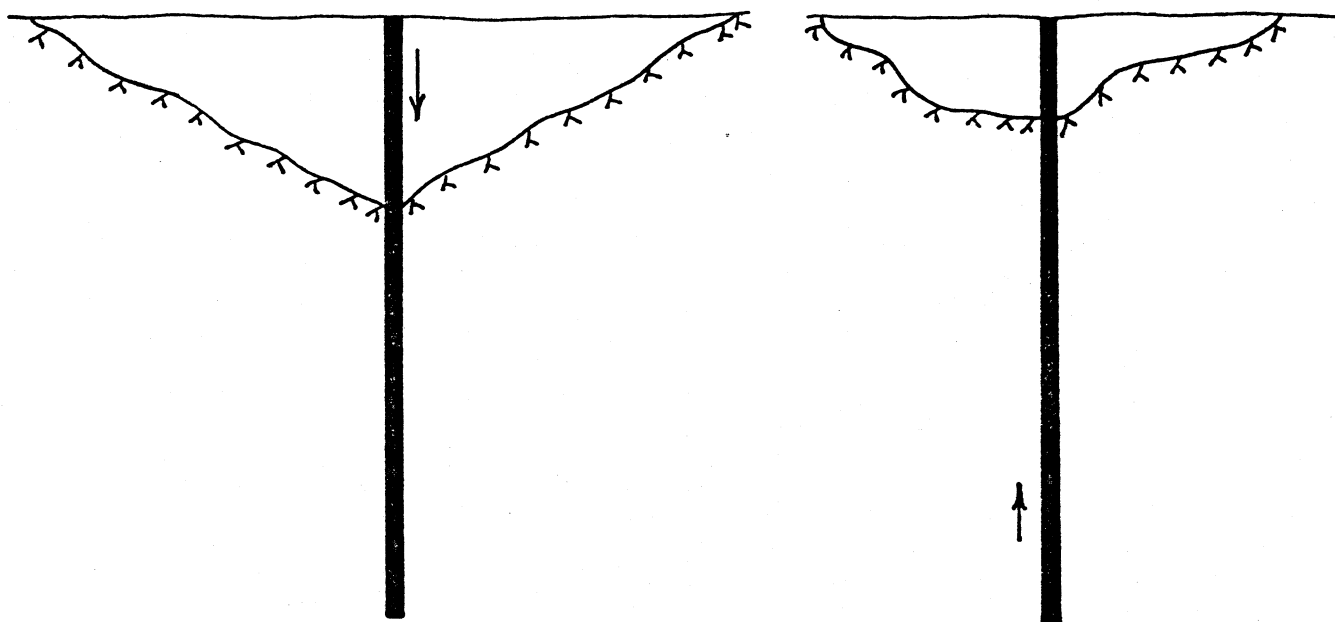


Fig. 12. Crater effects in fully loaded 1" boreholes with top- and bottom initiation respectively.

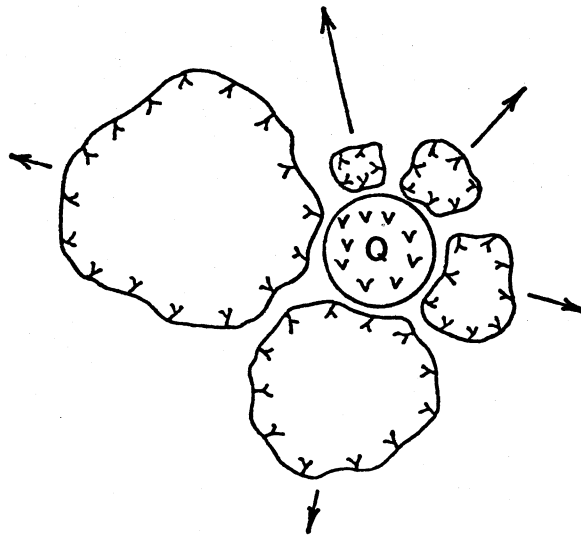


Fig. 13. Spherical charge, Q surrounded by stones of varying size.

$$\frac{\rho}{2600} \phi v_0 \text{ (m}^2\text{/s)}$$

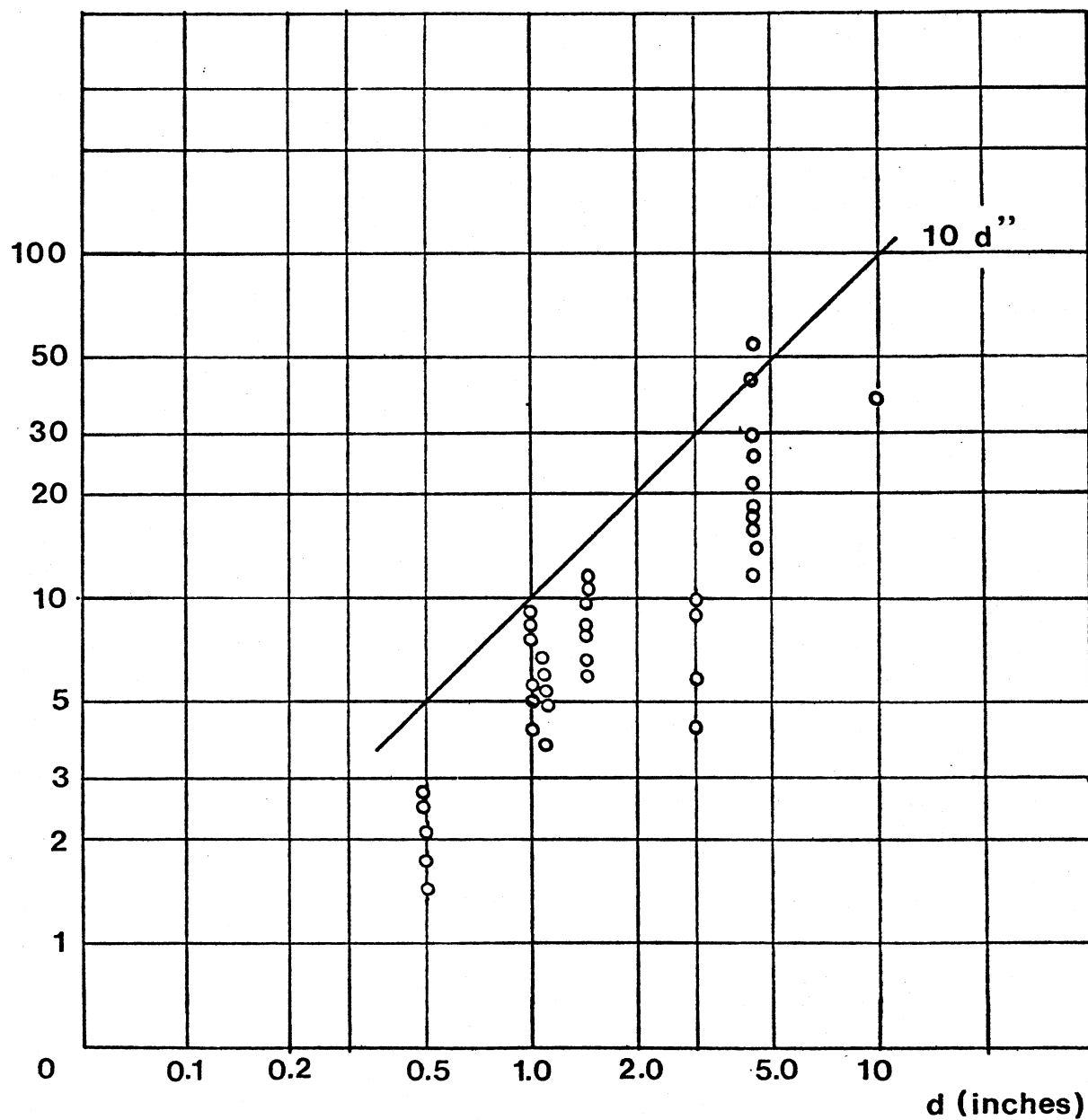


Fig. 14. $\frac{\rho}{2600} \phi v$ versus borehole diameter.

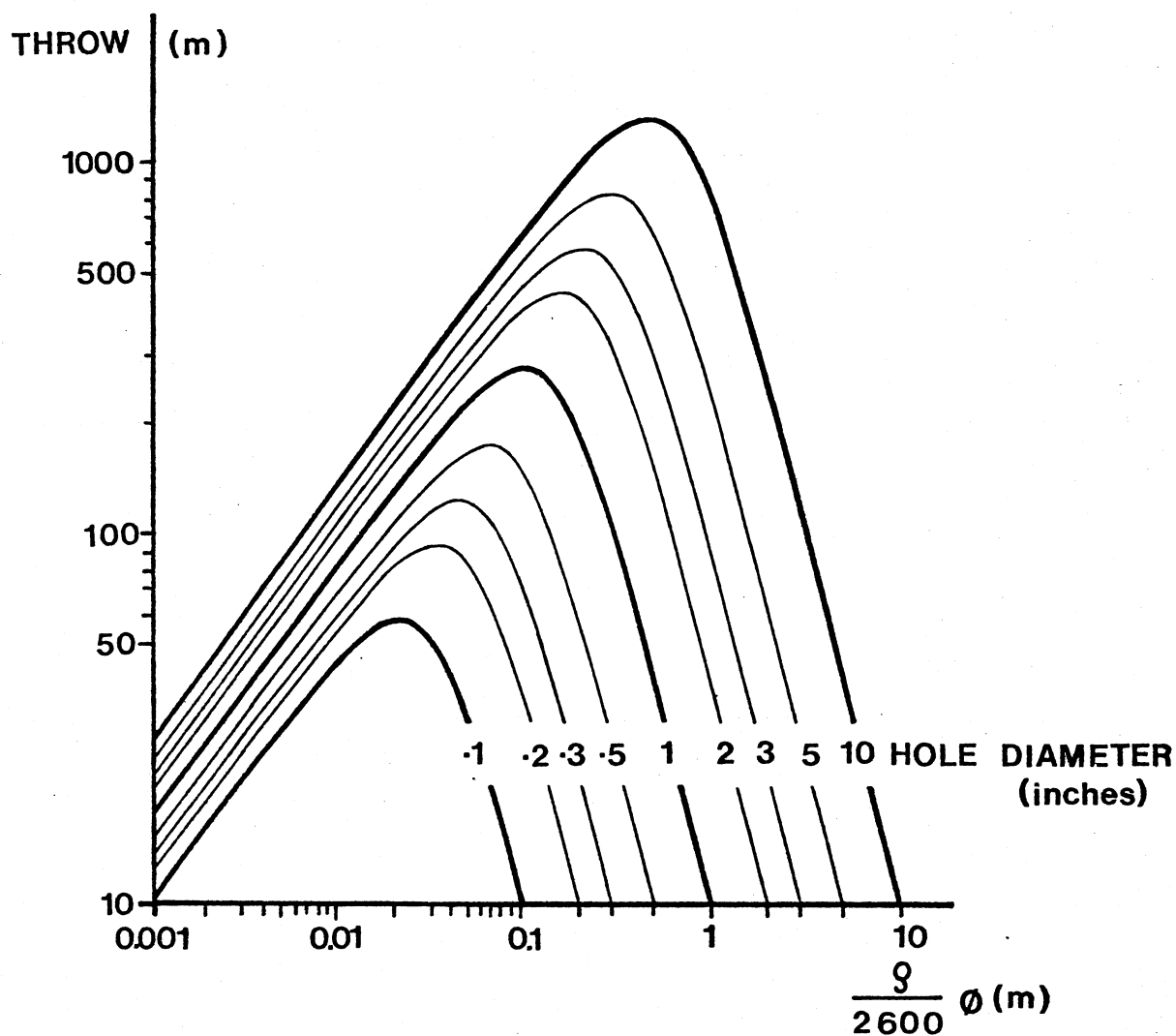


Fig. 15. Calculated maximum throw versus boulder size and borehole diameter as a parameter.