On the Relationship between Seismic Ground Amplitude and the Quantity of Explosives in Blasting

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Introduction

The problem of the ground tremor concurrent with blasting is mostly studied in connection with the quarry blasting for the purpose of reducing damages on the buildings and other structures located near the mines. Although the complaint on damage on buildings seldom exists in our country at the quarry blasting, it is necessary to study the peculiarity of the vibrations in the ground and/or rocks near blasting area, not only for the purpose of preventing damages to structures but also for the safety of mines.

In the present investigation, the relationship between the seismic ground amplitude and the quantity of explosives charged in the blasting operations is studied.

Assuming that, under ideal circumstances, the amplitude of the ground movement is proportional to the square root of energy released in the explosion and the energy released is in direct proportion to the quantity of explosives charged, the relation

$$\text{Quantity of explosives} \propto \text{amplitude squared}$$

is conceivable[1].

However, in the actual blasting operation, certain portion of the energy developed will be consumed in breaking and throwing off the broken rocks in which the explosives are charged and in some other complicated forms of energy, it is quite impossible to expect such an ideal relation in the actual operation as mentioned above.

This problem has recently been studied by some investigators and the results obtained by them are as shown in the following Table 1.

Considering these results, it appears to be quite impossible to show the relationship between the ground amplitude and the quantity of explosives used

Table 1

Names of investigators	Formula of the relation obtained	Category of the ground or rocks	References to be referred
Rixmann*	$A=0.00854\,C^{0.9124}$, $A=0.10163\,C^{0.6079}$, where A=amplitude in micron, C=charge in grams.	In dry sands. In moist sands.	(2)
Thoenen and Windes	$A=0.027\,C^{0.5}/d$, provided $20\text{ lb}<C<200\text{ lb}$, $300\text{ ft}<d<1{,}500\text{ ft}$, where A=maximum amplitude in inches, C=weight of charge in pounds, d=distance in feet.	In mine rocks.	(3)
Thoenen and Windes	$A=Ke^{0.371C}$, where K=a constant, A and C are the same units as above.	The conditions are similar to those of Rixmann.	(3)
Thoenen and Windes	$A=PC^{2/3}\,(0.07e^{-0.00143d}+0.001)/100$, where P=a site factor, A=maximum amplitude in inches, C=weight of charge in pounds, d=distance in feet.	In quarry blasting.	(3)
Habberjam and Whetton	$A=0.583\,C^{0.805}$, where A=amplitude in ten thousandth of an inch, C=weight of charge in pounds.	In quarry blasting.	(1)

* The formulas shown in the table are obtained by the computing Rixmann's research work.

in the blasting by a simple formula because it affected by many factors, such as the category of the ground in which the vibrations are diffused, the amount of charges, and the distance between the observation point and blast points.

Research Experiments

The following experiments were carried out on the top of a hill near the blasting laboratory of the Taketoyo Factory of the Nihon Oil and Fats Co., Ltd.

This area is covered by a few meters of red clay mixed with small amount of sands and geologically this layer of red clay is classified in the age of neogene.

The summit of the hill is comparatively plain and a measuring line of approximately 150 meters long was set up in about north-south direction. Four measuring points were selected on this line at the distances of 10, 20, 30 and 50 meters from the shot point and a seismograph was set up at each of these measuring points. As the ground was soft and the shot hole could not be used again, both the shot hole and the measuring points were moved about 5 meters at every blasting performed.

The seismographs used in this investigation were the ones designed by Prof. Sasa of the Institute of Geophysics, Kyoto University, to measure the components of vertical vibrations and had their natural vibration period of about 1/15 seconds. All the records were taken by the electromagnetic oscillograph, Yokokawa Electric Works Model N-6, which were connected directly to the seismographs. The vibrator installed in the oscillograph was the type D which had a vibration period of 1/150 seconds. With this measuring arrangements, the magnification of 800 to 900 is obtained for the simple harmonic motion of the period of 1/30 seconds.

The observation point was set in a building at a distance of about 200 meters from the shot point.

The explosive used throughout this investigation was an ammonia gelatin dynamite, known as "Shinkiri", the properties of which are listed in Table 2.

Table 2

Items	Units	Results
Lead block test	cc	410
Ballistic pendulum test	mm	84.2
Explosion temperature	°C	2,540
Explosion heat	kcal/kg	985
Gas-volume of explosion product	L/kg	875
"Force" of explosive	L-kg/cm^2	9,294
Velocity of detonation	m/sec	5,500
Oxygen balance	g/100 g	+3.10

The shot holes were about 34 mm in diameter and about 2 meters deep and the amount of charges per each hole selected for their respective records were 200, 500, 1,000 and 1,500 grams. All the blastings were done by using ordinary electric detonators fired by dry batteries.

Results of Experiments and their Considerations

Sixteen records were taken at this experiments. The typical form of the seismogram is as shown in Fig. 1 which was obtained from a blast of 1,500 grams explosion. The seismograms obtained, on the whole, however, are of simple type as shown in Fig. 2. This record shows that the vibrations are simple and similar to damped harmonic wave.

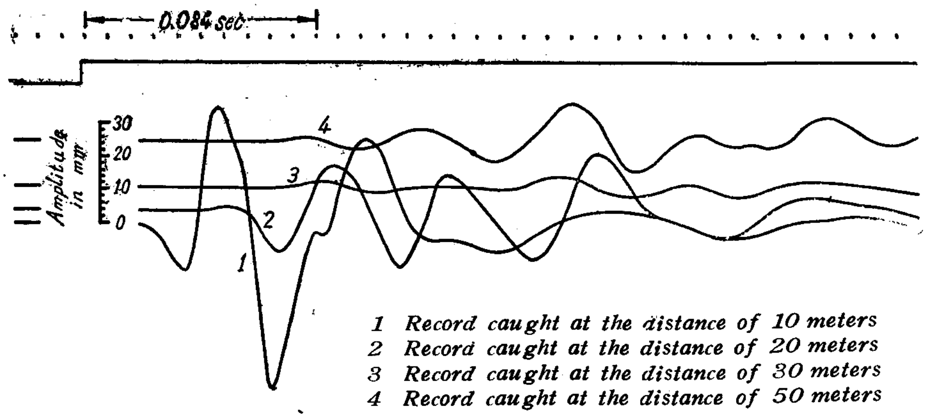

Fig. 1 Seismograms of 1,500 gram blast.
Record No. 13

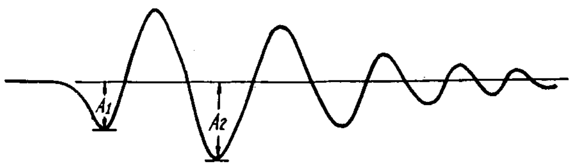

Fig. 2 General wave form of the seismogram.

Upon a close scrutiny of the seismogram, the following characteristics of the vibration at this area are obtained: the propagation velocity of seismic longitudinal wave was 640 m/sec and the frequency of vibration of the ground was about 30 cycles per second.

The maximum amplitudes are generally associated with the second peak amplitude, but in this experiment, I gave attention to the first and second peak amplitudes, as shown A_1 and A_2 in Fig. 2, and the relation between the amplitude of vibration and the quantity of charge was considered.

The results obtained are as shown in Table 3. In this table, amplitudes measured from the center line are shown in the third and fourth columns and the ground amplitudes calculated from these recorded amplitudes taking into consideration of the magnification of seismograph, are shown in the fifth and sixth columns.

The ground amplitudes given in Table 3, when shown on logarithmic scale per each quantity of explosives charged, will become Fig. 3. According to these

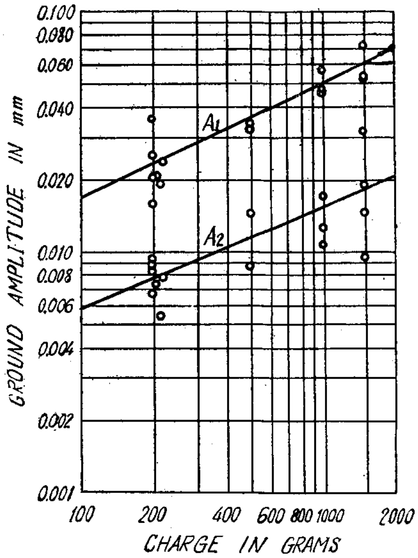

Fig. 3 (a) Relationship of charge and amplitude.
Records caught at the distance of 10 meters.

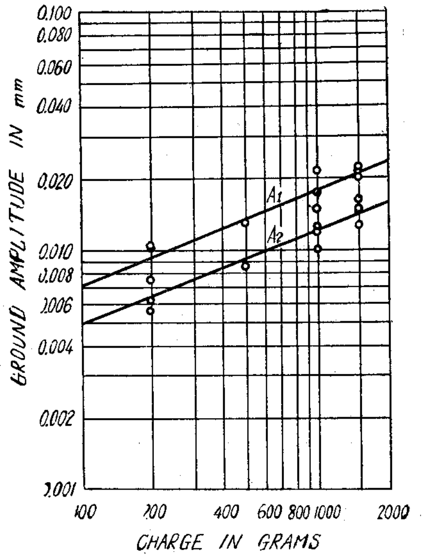

Fig. 3 (b) Relationship of charge and amplitude.
Records caught at the distance of 20 meters.

results, it is evident that there exists a simple power relationship among them. The specific relations among them for each case are as follows:

a) records caught at the distance of 10 meters,

amplitude A_1 : $C=1.65A^{2.03}$,

amplitude A_2 : $C=0.29A^{2.14}$,

b) records caught at the distance of 20 meters,

amplitude A_1 : $C=1.82A^{2.52}$,

amplitude A_2 : $C=0.80A^{2.51}$.

Note: C is the quantity in grams of explosives charged and A is the ground amplitude in units of one thousandth of a millimeter.

Table 3

(A) Records caught at the distance 10 meters from the blast point.

Record No.	Charge in grams	Amplitude recorded in mm		Ground amplitude in mm	
		A_1	A_2	A_1	A_2
1	200	6.24	15.00	0.00664	0.01595
2	200	7.78	24.00	0.00828	0.02553
3	200	8.20	19.19	0.00872	0.02041
4	200	8.80	34.00	0.00936	0.03617
5	210	6.70	19.70	0.00713	0.02096
6	215	5.00	18.00	0.00532	0.01915
7	220	7.23	22.60	0.00769	0.02404
average	200	7.14	21.78	0.00760	0.02317
8	500	8.20	32.00	0.00872	0.03404
9	500	13.60	30.00	0.01447	0.03191
average	500	10.88	31.00	0.01157	0.03298
10	1,000	16.20	54.20	0.01723	0.05766
11	1,000	10.30	45.30	0.01096	0.04819
12	1,000	12.14	44.10	0.01291	0.04691
average	1,000	13.13	47.87	0.01397	0.05093
13	1,500	14.00	51.00	0.01489	0.05425
14	1,500	9.00	49.50	0.00957	0.05266
15	1,500	17.82	67.80	0.01896	0.07212
16	1,500	29.79		0.03169	
average	1,500	17.65	56.10	0.01878	0.05968

(B) Records caught at the distance 20 meters from the blast point.

Record No.	Charge in grams	Amplitude recorded in mm		Ground amplitude in mm	
		A_1	A_2	A_1	A_2
2	200	5.20	8.50	0.00619	0.01012
3	200	4.70	6.20	0.00560	0.00738
4	200	6.20	8.60	0.00738	0.01024
average	200	5.37	7.77	0.00639	0.00925
9	500	7.20	11.00	0.00857	0.01310
10	1,000	10.20	14.80	0.01214	0.01762
11	1,000	10.60	18.00	0.01262	0.02143
12	1,000	8.50	12.60	0.01012	0.01500
average	1,000	9.77	15.13	0.01163	0.01801
13	1,500	12.10	17.20	0.01440	0.02048
14	1,500	10.80	17.90	0.01286	0.02136
15	1,500	12.50	17.40	0.01488	0.02071
16	1,500	14.00	18.80	0.01667	0.02238
average	1,500	12.35	17.82	0.01470	0.02121

Transforming these formulas respectively, we obtain the following relations:

a) records caught at the distance of 10 meters,

amplitude A_1 : $A=0.782C^{0.492}$,

amplitude A_2 : $A=1.786C^{0.468}$,

b) records caught at the distance of 20 meters,

amplitude A_1 : $A=0.789C^{0.397}$,

amplitude A_2 : $A=1.093C^{0.398}$.

These relations are somewhat different from the results obtained by the previous investigators listed in Table 1. However, the present results obtained in the records taken at the distance of 10 meters from the shot point are somewhat similar to those obtained by Thoenen and Windes in the rocks of a mine. It is conceivable that these differences are caused by the difference in the properties of the ground investigated and in the method of blasting and conditions under which the experiments were conducted. In this case, as previously mentioned, all the shot holes were about 2 meters deep but no craters were observed after every blasting even in the explosion of 1,500 gram charge. From this fact, in my experiments, it may be construed that the greater part of the energy released in the explosion was consumed in propagating the seismic waves throughout the ground.

Although the distribution of the amplitude values above shows a considerable spread, it may justifiably be conceived from the present investigation that the following formulas represent the relationship between the ground amplitude and the quantity of charge of explosive as:

$$C = Q_1 A^{2.0} \quad \text{or} \quad C = Q_1 A^{2.1}$$

and

$$C = Q_2 A^{2.5}.$$

Note: Q_1 and Q_2 are the factors which vary within a certain limit.

Now, we will contemplate on how much divergent these results from an amplitude squared relation, which appears to be more reasonable from a theoretical standpoint.

In practical blasting the energy developed by an explosion is generally consumed in breaking and throwing off the rocks and as heat and possibly in some other ways; but only a small portion of the total energy is propagated as seismic waves.

According to Habberjam and Whetton[1)], the effective quantity of charge that produces vibrations is decreased by an amount " E " which is proportional to the total charge C (or $E=nC$), and the factor n is also a function of the charge C and can be represented by the following expression:

$$n = pe^{-rC},$$

where r is a constant and is positive and p is another constant which is not greater than 1.

Then the modified relation of the squares of amplitude can be expressed as follows,

$$C(1-n) = GA^2$$

or

$$C = GA^2/(1-pe^{-rC}),$$

G is also a constant in this case.

In this experiment the above modified relationship is examined with respect to the ground amplitude A_1 obtained in the records taken at the distance 10 meters from the shot point.

The relation between the squares of the ground amplitude and the charge of explosive is as shown in Fig. 4. In this chart, if one particularly low value obtained at 1,500 grams is ignored, the curves 1 and 2 written in full lines show the maximum and minimum expansion of the squares of amplitude and the dotted lines show the results of calculation which are obtained by the last formula with particular values given to G, p and r. The dotted curve 1 refers to the relation obtained when $p=2/3$ and $r=0.0047$, and dotted curve 2 to that when $p=1$ and $r=0.0002$; and in both instances the value of G used is 161. In other words, both curves shown correspond to variations produced in the same amplitude squared relation. If C is the charge of explosive in grams and A is the ground amplitude in units of one thousandth of a millimeter, then the dotted curves correspond approximately to the limits of the spread of the amplitude squared values obtained in Fig. 4.

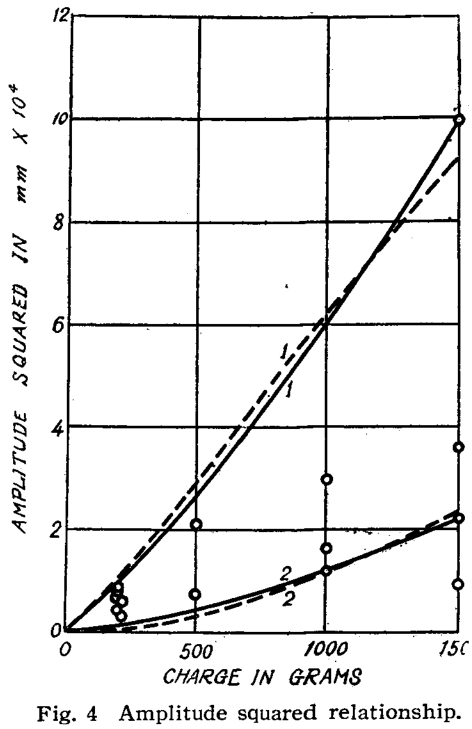

Fig. 4 Amplitude squared relationship.

In both particular cases, the variation in the value of n with respect to the amount of charge of explosive is shown in Table 4.

Table 4

When $p=2/3$, $r=0.0047$		When $p=1$, $r=0.0002$	
C in grams	n	C in grams	n
200	0.2604	200	0.9608
500	0.0636	500	0.9048
1,000	0.0064	1,000	0.8187
1,500	0.0006	1,500	0.7408

Assuming all the conditions of blasting are equal, it is obvious from the above table that the effective charge producing the vibrations is increased as the amount of charge of explosive is increased.

However, it should also be added that the relation shown above is established on condition that the assumed relation of square of amplitude is considered right.

Summary

I have described here the relationship between seismic ground amplitude and the quantity of charge of explosives obtained from my experiment. It is conceivable that these results could be shown with a simple power relationship. However, it must be necessarily noted that the characteristics of the seismic waves are influenced by the properties of the medium through which they propagate. Consequently it is expected that different results will be obtained in case of blasting operations in the hard rocks.

I am preparing to continue the similar investigations in order to account for the relationships in question in other types of rocks.

Acknowledgment

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