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ON THE SEISMIC WAVE ENERGY AND THE EFFICIENCY OBSERVED IN THE FIRST KURAYOSHI EXPLOSION

By

Michio HASHIZUME and Masao NAKAMURA

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Abstract

On discussing the earthquake energy, we must take into consideration the following problems:

1) the ratio of wave energy emitted from the origin to total energy of an earthquake,
2) how to get the wave energy exactly from seismogram,
3) the mechanism of generation, and transmission of wave energy.

For this purpose we analysed the seismogram of the lst Kurayoshi Explosion using our newly constructed square analogue computer. The results are as follows: the efficiency of the explosion was about 8%, the wave energy was estimated to correspond to M=2.3, and large part of energy was received as direct wave at the distance of about 150 km, and a few proportion of energy was radiated as S wave.

1. Introduction

Estimation of the energy of earthquake is, needless to say, a fundamental problem in seismology. It is a pretty difficult task, however, to determine the exact value of energy of natural earthquake, because, we have no exact knowledge about its origin. First, we can not precisely determine its location of hypocenter. But the most serious problem is that the natural earthquake generally has respective complicated mechanism at its origin, and so we shall be requested to get the exact observations at as many stations as possible, in order to determine how the seismic wave energy was emitted from its origin. On the other hand, these conditions seem to be pretty simplified in case of the explosion. We can know beforehand the location of origin, the pattern of emission of seismic waves at the origin, and moreover the amount of the explosives, so that, in case of the artificial explosion, we shall be able to estimate in pretty good approximation the seismic wave energy radiated from the origin and its proportion to the total energy of explosives. This result regarding the artificial explosion will give a powerful clue to resolve the some problem in natural earthquakes.

For such purposes as described above, we constructed a trial square analogue computer and applied it to seismograms obtained in the Kurayoshi Explosion to estimate the seismic wave energy. The results will be given in some detail in the followings.

2. Square analogue computer

The "Silistor", which consists of SiC, was used to construct a square analogue computer. This material has some particular characteristics of symmetric and non-linear resistance, and of no phase shift. Namely, the behavior of the silistor is expressed as follows:

$$E_i = CI_0^{\beta}, \qquad (1)$$

where E_i: input voltage,
I_0: output voltage,
β: const. which varies from 0.2 to 0.4,
C: const.

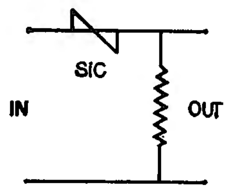


Fig. 1a. An element of square circuit.

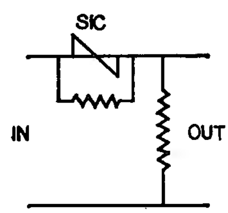


Fig. 1b. An improved circuit.

We shall first consider a simplest circuit shown in Fig. 1a, in order to show the principle of the square analogue computer used in the present study. In this figure the following equations are easily derived,

$$E_i = CI^{\beta} + RI, \qquad (2)$$

$$E_0 = RI. \qquad (3)$$

From the equations (2) and (3), we get

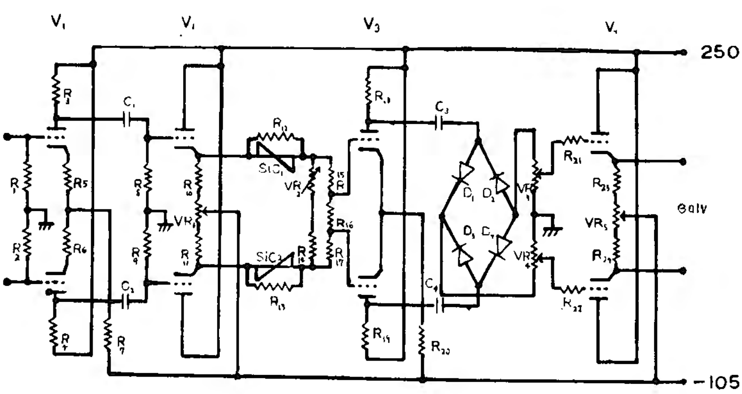


Fig. 2. Circuit of square analogue computer.

$R_1, R_2 = 1\text{M}\Omega$	$R_{10}, R_{11} = 60\text{K}\Omega$	$R_{18}, R_{19} = 50\text{K}\Omega$	$VR_2 = 250\text{K}\Omega$
$R_3, R_4 = 50\text{K}\Omega$	$R_{12}, R_{13} = 2\text{M}\Omega$	$R_{20} = 60\text{K}\Omega$	$VR_3, VR_4 = 1\text{M}\Omega$
$R_5, R_6 = 100\Omega$	$R_{14} = 50\text{K}\Omega$	$R_{21}, R_{22} = 2\text{M}\Omega$	$VR_5 = 5\text{K}\Omega$
$R_7 = 40\text{K}\Omega$	$R_{15}, R_{17} = 30\text{K}\Omega$	$R_{23}, R_{24} = 50\text{K}\Omega$	$C_1, C_2 = 1\mu\text{F}$
$R_8, R_9 = 1\text{M}\Omega$	$R_{16} = 25\text{K}\Omega$	$VR_1 = 20\text{K}\Omega$	$C_3, C_4 = 30\mu\text{F}$
$SiC_1, SiC_2 = $ C605	$D_1, D_2, D_3, D_4 = $ 1S315	$V_1, V_2, V_3, V_4 = $ 12AX7	

$$E_i = \frac{CE_0^{\beta}}{R^{\beta}} + E_0 . \tag{4}$$

It is possible to find out such a suitable range of voltage, E, that three constants, C, β and R take some proper values in order to get the following approximate relation:

$$E_0 \approx KE_i^{-z} , \tag{5}$$

where K is a constant. To do this, better approximation can be gotten in such a way shown in Fig. 1b. The final circuit used in the present analysis is shown in Fig. 2. The quality of this circuit is shown in Fig. 3.

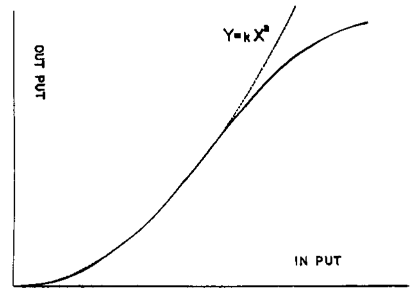


Fig. 3 Quality of square analogue circuit.
Solid line : aquality of this circuit
Dotted line: ideal case

For example, if we put an input function of $\cos \omega t$, response must be $(\cos 2\omega t + 1)/2$. This example was fairly well completed as can be seen in Fig. 4.

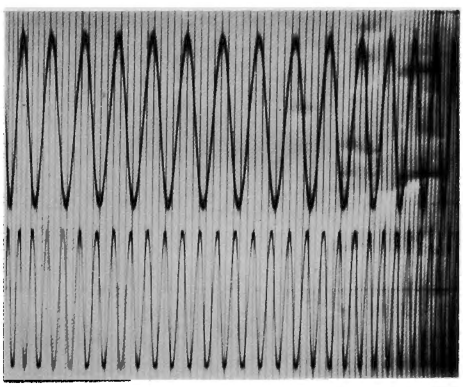


Fig. 4 Example of computation.
Uppe: : input function $\cos \omega t$
Lower: output function $\cos (2\omega t + 1)/2$

3. The first Kurayoshi Explosion

The first Kurayoshi Explosion was detonated in November 1963 by the Research

Group for Explosion Seismology (R.G.E.S.). The Explosive of 2 ton-dynamite (T.N.T.) was set in a shaft of an abandoned mine, at Kurayoshi, Tottori Pref., in such a manner as shown in Fig. 5. The seismic waves generated by this explosion were well observed at as far distance as 300 km. The seismograms used in the following analysis were observed at Nadasho, Fukui Pref., 158.5 km distant from the shot point. The geological formation at the observation point is the Tanba Palaeozoic Strata. The seismic waves were recorded on the magnetic tape, with a transistor amplifier, frequency response of which was nearly constant in a range of 0.2c/s to 20c/s. Three components of seismometer used were of electro-magnetic type, and their constants are as follows:

	Z	Radial	Transversal
Tn (sec)	1.02	0.99	1.01
G (volt/kine)	2.00	2.41	1.86
h	0.7	0.7	0.7

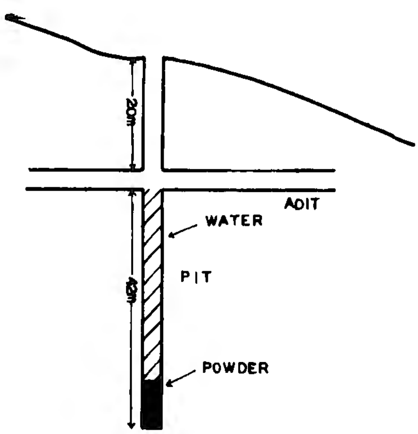


Fig. 5 Picture of shot point.

4. Estimation of wave energy

In order to estimate the energy of seismic body waves, the following equation was used:

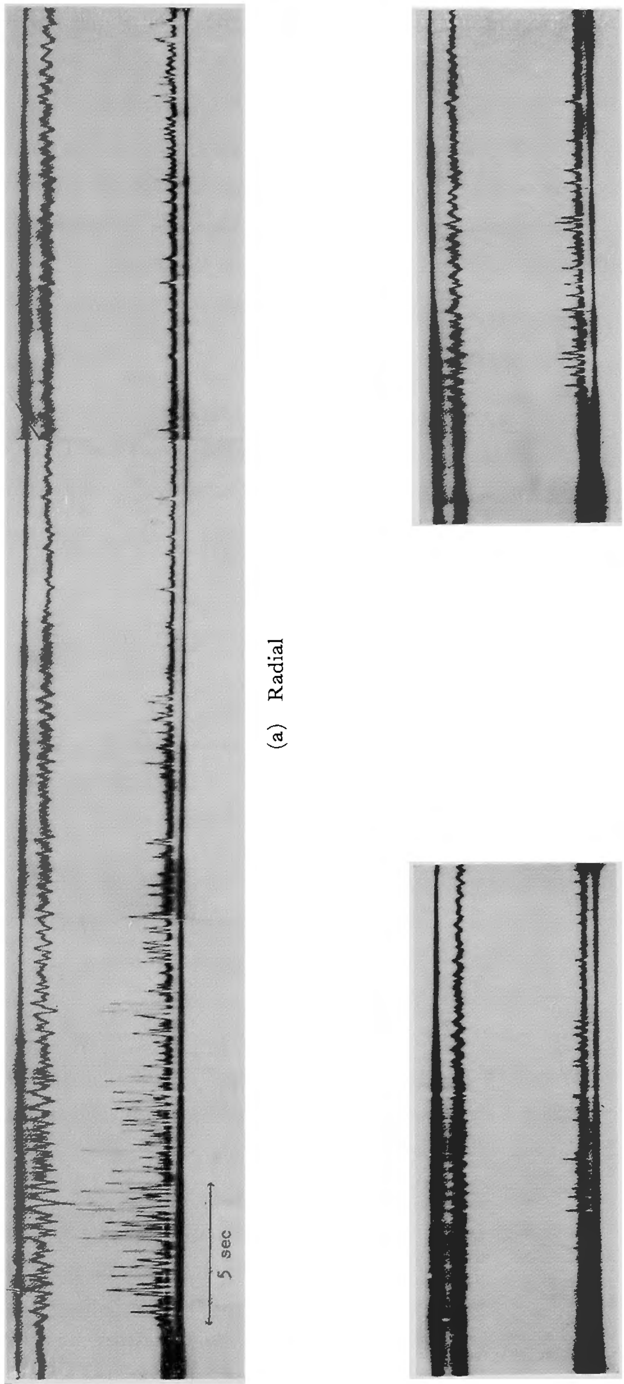
$$E = 2\int_0^\infty 4\pi \Delta^2 V \cdot e^{\frac{2\Delta}{Vc}} \cdot \frac{1}{2} \varrho(\varphi_i v_i)^2 dt\,, \qquad (6)$$

where E: the total seismic wave energy emitted in all directions equally in the lower half space from a surface focus,

Δ: epicentral distance,

V: phase velocity,

ϱ : density,



(a) Radial

(b) Transversal

(c) Vertical

Fig. 6 Square seismogram. Uppermost line is the original seismogram.

φ_i: correction factor to the effect of reflection at the surface,

v_i: particle velocity on the surface. (The suffix denotes respective component), and

$\exp(2\Delta/r_c)$: attenuation factor.

The last, $\exp(2\Delta/r_c)$, was originally proposed by Muramatsu [in press] in his study on microearthquakes. According to him, the relationships between r_c, magnitude and energy are expressed as follows:

$$3.7 \log r_c - 4.8 = M\ , \tag{7}$$

$$\log E = 11.8 + 1.5 M\ . \tag{8}$$

v_i was obtained by use of our square analogue computer above-described. The results are shown in Figs. 6a, b and c, for the radial, transversal and vertical components, respectively. In each figure, a uppermost line is the original seismogram. $\int_0^\infty v_i^2 dt$ calculated for respective cases shown in Figs. 6a, b and c is shown in Fig. 7.

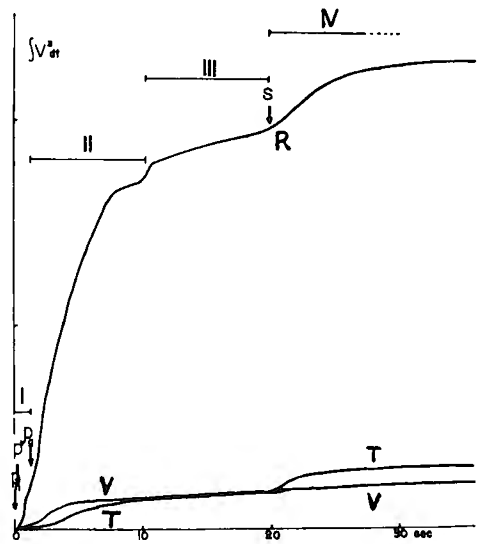


Fig. 7. Picture of $\int_0^\infty v_i^2 dt$, each phases are refer ed to the result of Miboro Explosion.
R: radial T: transversal V: vertical

The density, ϱ, was taken as 2.7 g/cm, and r_c was assumed as 85 by the trial and error method. V and φ_i should be estimated from the time-distance curves of respective seismic waves. Referring to the crustal structure derived from the Miboro Explosion (Mikumo et al., [1961]), each seismogram is to be divided into 4 parts from the initial motion of P wave up to S wave as follows:

I. P*. The seismic velocity, Vp*, was taken as 6.0 km/sec, referring to the Miboro Explosion. φ_i was tentatively assumed to be equal to that of II.

II. Pg. Vp = 5.5 km/sec was adopted in the same manner. In order to determine the value of ϕ_i in this phase, the particle motion of the surface was examined as shown in Fig. 8. The angle of incidence seems to lie in a range of 70° to 80°. If we assume $i=75°$, φ_V and φ_R are 1/1.67 for vertical and 1/2.54 for radial component, respectively. The seismic energy seems to mostly belong to this part, as seen in Fig. 7.

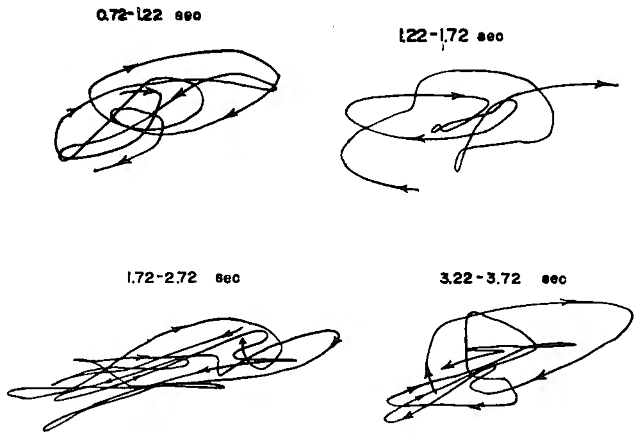


Fig. 8. Orbital motion of part II.

III. It is difficult to determine what wave group this part belongs to. We provisionally assume that V = 4.0 km/sec and ϕ_i is the same that in group II. The amount of energy in this part, however, does not seem so large, seen in Fig. 7, and so that the above assumption does not seem to give a large error to the final result.

IV. S wave and surface wave. Angle of incidence of refracted S wave is estimated to be near 38° from the result of the Miboro Explosion (Knopoff, [1957]). Since the observational error of SV phase is pretty large, we shall assume, in the followings, that the total energy of S wave is as twice as that of SH wave. φ_T for SH wave is 1/2. The energy of surface wave is safely neglected in this analysis.

The calculation being made for respective groups, the results are listed in Table 1.

Table 1

Unit of each quantities are expressed as follows:

v_i: μkine, t: sec, V: km/sec.

	Z	52	192	32	
					400
	H	946	6085	980	
Total		998	6277	1012	400
V		5990	34800	4050	1280

5. Discussion

(a) As can be seen from seismograms shown in Fig. 6, the wave energy of radial component is considerably large. This does not seem to be explainable by the observational errors, but may be explained by the local characteristics at the observation station.

(b) The energy generated from the "Shingiri" dynamite (T.N.T.) used in the Kurayoshi Explosion is estimated as 10650 l-kg/cm/kg, namely, 1.04×10^{13} erg/kg. As mentioned above, the total energy radiated from the origin as the seismic waves was estimated as 2.1×10^{16} erg, corresponding to 8% of the total energy of the dynamite. This means that the "efficiency" of the dynamite was 8% in the present explosion.

(c) Magnitude of this explosion can be calculated using Gutenberg-Richter's equation [1956].

$$\log E = 1.5M + 11.8 \qquad (9)$$

From this formula, the magnitude of this explosion is estimated as

$$M = 2.3$$

(d) Energy of S wave (whithout converted S wave) is considered to be about 3% of the total wave energy.

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