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GROUND-MOTION MEASUREMENTS NEAR SMALL CHEMICAL BLASTS ON THE GROUND SURFACE

by

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Abstract

The maximum amplitudes and corresponding frequencies of the ground movements were measured at recording distances 50 to 10 000 meters, using TNT explosions from 0.03 to 2 000 kg. A graph on logarithmic paper of the maximum amplitude of the ground displacement versus distance and mass of explosives is presented. The following equations fit quite well to the data of the curves.

Rayleigh wave	$\log A = 1.01 \log M - 1.43$ and
	$\log A = 0.56 \log M - 0.98$
Air wave	$\log A = 0.64 \log M - 0.12$
Rayleigh wave	$\log A = - 1.15 \log R + 1.89$
Air wave	$\log A = - 1.43 \log R + 4.09$

where A, M, and R are double amplitude in microns, mass of charge in kilograms and distance from the source in meters, respectively.

1. *Introduction*

This work was done at a test area in S. W. Finland in May 1968. The purpose of the measurements was to ascertain the seismic effect at different distances of blasts of considerable magnitude. The topography of the test

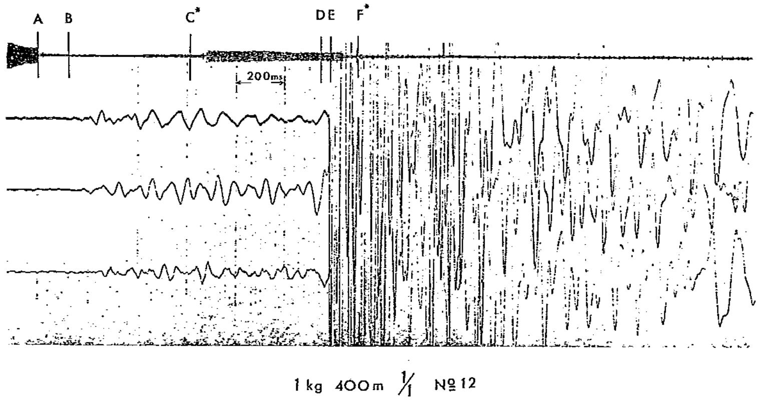

Fig. 1. An example of a seismogram recorded at a distance of 400 m from a 1 kg shot. Attenuation 1/1 = 0 dB. Paper speed 100 mm/sec. A = moment of explosion; B = arrival of body waves; C^x = measurement region of Rayleigh wave amplitude; D, E = arrival of ground-coupled air wave; F^x = amplitude measurement region of ground-coupled air wave.

area is flat. The surface layer consists of sand and is assumed to be virtually homogeneous along the profile. The seismic vibration was recorded at a constant site and the shot point was moved along the profile line. The charge masses and distances of the shot program were as follows: 0.03, 0.2, 1, 2, 3, 10, 17, 50, 100, 150, 500, 1000, 2000 kg; 50, 84, 100, 200, 400, 700, 1000, 2000, 5000, 10000 m.

The explosives were manufactured of pressed TNT (density 1.52 ± 0.04, sizes 0.03—2 kg) melted TNT (density 1.57 ± 0.03, sizes 1—50 kg) or groups of loose TNT blocks (average density approximately 0.75, sizes 100—2 000 kg). The weights of the charge masses were accurate to within 0.5 %. The distances from the geometrical center of the charge to the recording instrument were measured to the nearest 10—100 cm, depending on the size of the charge.

The amplitudes of the two maxima of ground motion (in this paper called Rayleigh wave and ground-coupled air wave) were measured on the seismogram at the points C and F (Fig. 1). The *P*-wave amplitudes at point B were too small to be measured. The maximum ground displacements were calculated by using magnification curves obtained with the permanent magnet and coil method (Fig. 2).

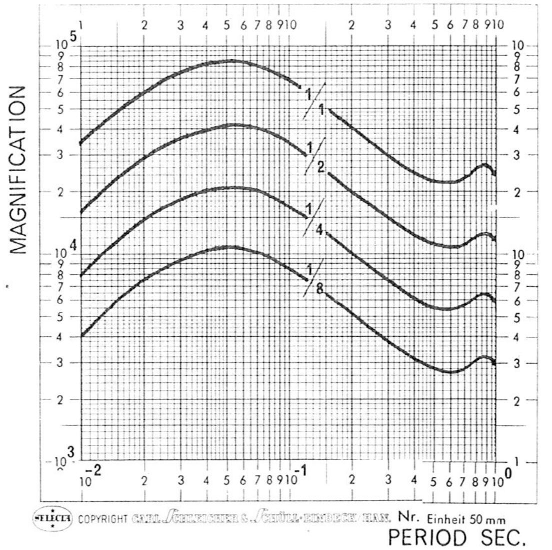

Fig. 2. A family of displacement magnification curves. Attenuation level marked with fractional numbers.

2. *Instrumentation*

The ground motion was detected with three Willmore Mark I seismometers. Coil resistance 500 ohms, free period 1.0 sec. and damping 22 % of critical. All the seismometers were sunk into the ground, at approximately 0.5 meters' depth, and covered.

Vertical, transverse and longitudinal components were recorded with the aid of a 12-channel ultraviolet galvanometer recorder type H 105 equipped with 20 Hz overdamped galvanometers. The paper speed selected for this recording was 100 mm/sec. The seismometers were connected to the galvanometers with an A 6 dB step attenuator. One internal time mark every 20 msec. and one additional time channel for recording the moment of the explosion were in use. To transfer the time mark from the shot area to the recorder a special blaster with two radiotelephones was used.

3. *Results*

Eleven explosions of unequal sizes were recorded at a distance of 1000 m in order to ascertain the variation of maximum ground displace-

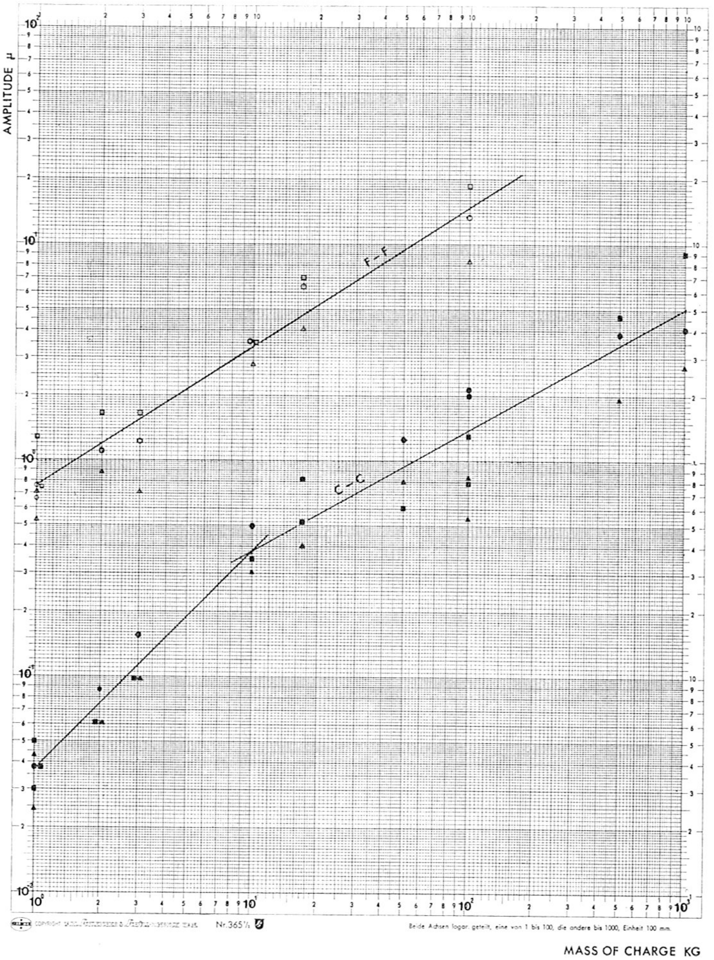

Fig. 3. The variation of the maximum double amplitude in microns versus the mass of charge yielded in kilograms. Lines C — C and F — F correspond to the Rayleigh and ground-coupled air wave, respectively. The amplitudes of vertical, radial and transverse components are plotted with circles, squares and triangles. The measuring distance is 1 000 m.

ment on increasing the charge yield. The masses of the charges were 1, 2, 3, 10, 17, 50, 100, 500 and 1000 kg. Fig. 3 shows two graphs of the maximum double ground displacements in microns versus the mass of charge in kilograms. The vertical, radial, and transverse components are marked with circles, squares and triangles. Solid and open dots represent amplitude values from the Rayleigh and ground-coupled air waves, respectively. The dots and mean values of the observation data have been drawn on logarithmic paper. The resulting line C — C representing Rayleigh wave is a broken line with slopes 1.01 and 0.56. The equations fitting the two parts of this line are:

$$\log A = 1.01 \log M - 1.43 \quad (1)$$

$$\log A = 0.56 \log M - 0.98 \quad (2)$$

where A is the maximum double amplitude of the ground movement in microns and M the mass of charge in kilograms.

The resulting line F—F represents the so-called ground-coupled air wave and is a straight line with a slope of 0.64. Its equation is

$$\log A = 0.64 \log M - 0.12 \quad (3)$$

The following two graphs in Fig. 4 show maximum double ground displacement in microns versus distance from the source in meters.

Ten blasts of 1 kg at distances of 50, 100, 200, 400, 700, 1000 m and four blasts of 50 kg at distances of 1000, 2000, 5000, 10000 m were recorded. The hand-drawn resulting lines C — C and F — F correspond to the amplitudes of the Rayleigh and ground-coupled air waves, respectively. The amplitudes recorded for the shots of 50 kg have been reduced to the level of 1 kg, using the data presented in Fig. 3. The dots of line C — C, except the observations at 5000 and 10000 meters, form a straight line with a slope of −1.15. The following equation fits the data of this line quite well:

$$\log A = -1.15 \log R + 1.89 \quad (4)$$

where A is the double amplitude of the ground displacement in microns and R the distance from the source in meters.

Line F — F, with a slope of − 1.43, is the resulting figure of the so-called ground-coupled air wave. Equation (5) fits to the data of this line

$$\log A = -1.43 \log R + 4.09 \quad (5)$$

The observations, especially at 10 000 meters, show that the curve becomes steeper as the measuring distance increases.

The frequency region obtained in the geological and instrumental circumstances described above seems to be from 5 to 70 cps. The most

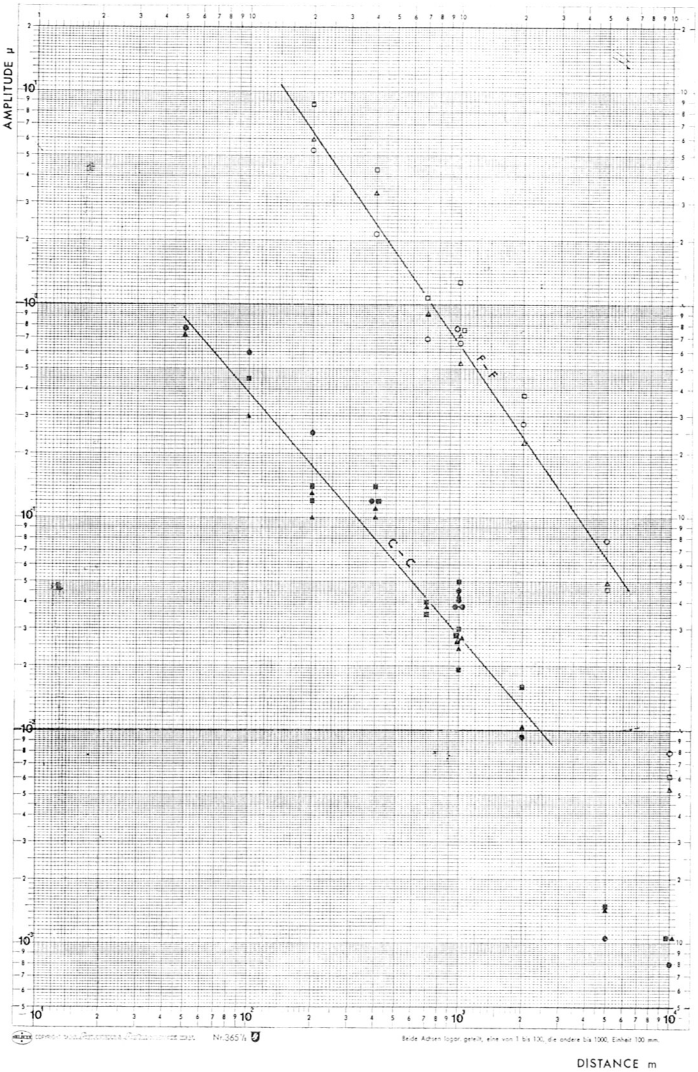

Fig. 4. The variation of the maximum double amplitude in microns versus distance from the source in meters. Lines C — C and F — F correspond to the Rayleigh and ground-coupled air waves, respectively. The amplitudes of the vertical, radial and transverse components are plotted with circles, squares and triangles. The mass of the charge is 1 kg.

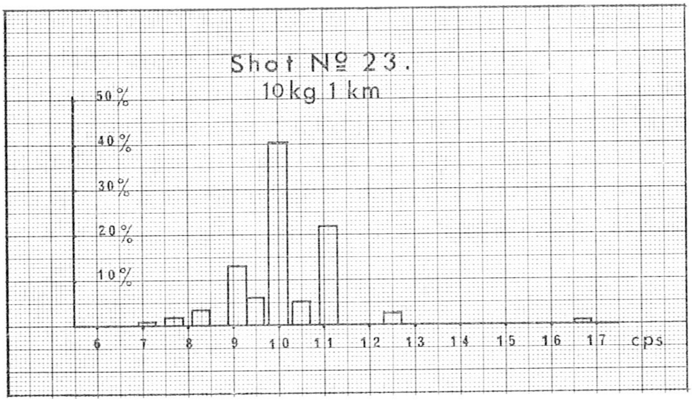

Fig. 5. Distribution of the frequencies (as percentages) in the recorded wave train.

common frequency is approximately 10 cps. Fig. 5 shows an example diagram of the frequency distribution of seismogram no. 23 (1 kg 400 m). This diagram is obtained by manually dividing the seismogram into separate waves and roughly calculating the distribution percentage.

4. *Conclusion*

From the work reported above, it is seen that the maximum amplitude values of the two horizontal components and the vertical component differ from each other reasonably. Which of these components is the biggest, varies, but the order vertical, radial, transverse is most common. With recording at short distances (R less than 10.000 m), the air wave exhibits amplitudes approximately 10 times as great as the Rayleigh wave; at longer distances the effect of the air wave gradually decreases. In all probability the occurrence of plants, in addition to the ground structure has a noticeable effect on the air wave amplitudes.

Berg and Cook [1] have given an amplitude distance graph using considerably bigger blasts — about a million kilograms. The slope of their resulting line is slightly steeper than that given in Fig. 4.

The well-known attenuation law for maximum amplitude with distance — given for instance by Medvedev [3] — is $1/R^n$ ($n = 1.5 - 3$ for body waves and $n < 1$ for surface waves). In the logarithmic equation (4) the coefficient $-$ 1.15 has the same meaning as n in the expression above. So the slope of the resulting line C — C in Fig. 4 seems to be a bit steeper than in the law given by Medvedev.

In the report by Dahlman, Axelsson and Edin [2], the Rayleigh wave amplitudes are proportional to the 0.59^{th} power of the yield (1 kg at the height of 1 m). The amplitudes from smaller blasts (0.05 kg) are proportional to the mass of the yield. The corresponding results for Fig. 3 are 0.56 and 1.01. The Rayleigh wave amplitudes as a function of the recording distance given by Dahlman and others is R^{-1}. The corresponding function in Fig. 4 was $R^{-1.15}$.

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