Electromagnetic Phenomena Observed at Explosion Seismic Experiment

I. Tomizawa, M. Hayakawa and T. Yoshino
University of Electro-Communications, Chofu-shi, Tokyo, JAPAN
K. Ohta
Chubu University, Kasugai-shi, Aichi, JAPAN
T. Okada
Toyama Kenritsu University, Kosugi-cho, Toyama, JAPAN
and
H. Sakai
Toyama University, Toyama-shi, Toyama, JAPAN

人工地震に伴う電磁放射観測

冨澤一郎・早川正士・芳野赳夫（電気通信大学）
太田健次（中部大学）・岡田敏美（富山県立大学）・酒井英男（富山大学）

1. Introduction

Electromagnetic phenomena associated with the fracture of rock caused by the artificial deformation or the earth crustal deformation has been detected by many researchers in laboratories[1-5] or in the fields just before earthquakes[6-8]. However the generation and the propagation mechanisms of the electromagnetic phenomena has not been clearly explained. Underground explosion of a large amount of dynamite makes deformation around it by the high pressure. It is similar to the condition of the rock fracture caused by the tectonic pressure. Although the time derivatives of the pressure are quite different between two phenomena, the fractures of rock can be caused if the pressure is greater than the maximum stress of the consisting rocks. Therefore the electromagnetic generation can be expected at the time of underground explosion. In fact, such electromagnetic phenomena has been detected in the underground explosion[9-12]. Yamada[10,11] and Sakai et al.[12] only recorded the electric potential with the long-span electrode pairs at the explosion seismic experiments, and they revealed that the coincidental electric potential variation were observed prior to the arrival of the seismic wave in all of the explosions. It can be easily understood that the underground explosion generates the electric potential around the explosion point. However the electromagnetic characteristic of the generated source or the generation mechanism are not known. Our main objective of this measurement is the sensing of the electromagnetic characteristic of the generated underground source from the sensors arranged over the ground surface. Rocks and soil covered over the underground source are so conductive compared to the air that the electromagnetic field produced by the source are steeply attenuated by the covered media. So the produced electromagnetic field propagate through the lossy media that the radial dependency can be expected in the short range measurement.

2.Arrangement of observation system around the explosion point

The explosion seismic experiment was conducted at 01h22mJST (JST=UT+9) on October 17, 1991 in Ohyama-cho, Toyama Prefecture, to observe the crustal structure across the Cetral Tectonic Line by the seismic wave. The explosion point is shown as O in Figure 1. Dynamite of 450kg was placed at the bottom of the 75m metal casing pipe as shown in Figure 1(b). The geological structure at the explosion point is shown on the Figure 1(b). The ground surface is covered with the bank down to 4m, then the gravel continues down to 17m. The base rock at the explosion point is the granite. The sensor unit consists of two crossed loop antennas and two pairs of the 4m-span grounding electrodes. A pair of the sensor unit were used in this measurement to detect the radial dependency of the electromagnetic phenomena. The arrangement of the two units are shown in Figure 1(a). The near unit indicated as **R1** is 29m apart from the explosion point and the far unit as **R2** 97m apart on the same radial line. One pair of the consisting sensors are placed along the same radial line and the other in its orthogonal orientation as indicated in the square box in Figure 1(a). Grounding electrode is indicated as **G** and loop antenna as **L**. The orientation of the sensor is indicated by the suffix **r** for radial and by **a** for azimuthal. The electrode was a carbon-coated steel with 30cm in length and 1cm in diameter. The potential difference between the pair of electrodes were amplified by the high input impedance differential amplifier operated by the batteries and its output were transmitted to the recorder located about 150m from the explosion point via a coaxial cable. Magnetic field strength were detected by a ferrite-cored loop antenna with the dimension of 30cm in length and 1cm in diameter, and with 1000 turns of 0.5mm copper wire. The output of the loop antenna was amplified by the low input impedance amplifier and also transmitted to the recorder. The setup of the remote sensor unit at **R2** was all the same for that at **R1**. The output pairs of the same orientation but different in distance were recorded on the same DAT type recorder to eliminate the ambiguity in time difference. The alignment of the tape were made by using atmospheric waveforms. The ambiguity in time scale is approximately 200microsec among them. Frequency response of these measurement systems were almost flat between 10Hz and 2kHz. Additionally VLF crossed loop antennas were also placed 20m north of the **R2** point and the output of the loop antenna was also recorded on the DAT recorder. Recording was started 50 minutes before the explosion and stopped 20 minutes after it. Seven outputs of the sensor system were recorded in the proper level, however, the output of the azimuthal magnetic sensor at **R1** was not functioning properly during this period. The recorded digital data is transferred to the personal computer with a magneto-optical disk, and then is analyzed by software.

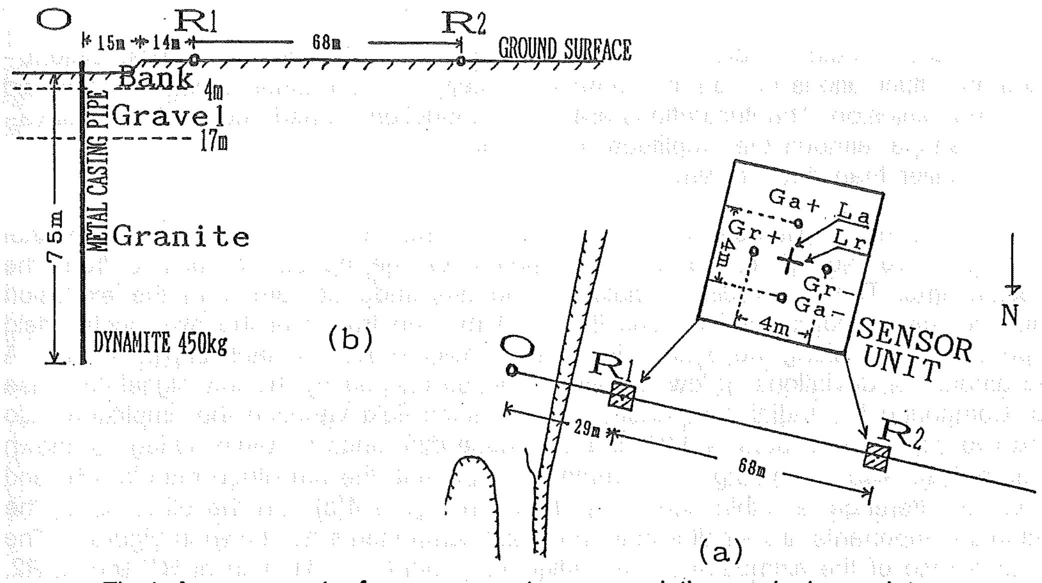

Fig.1 Arrangement of sensors system around the explosion point.

3.Observational results

The potential differences of the electrode pairs are converted to the electric field strength and are shown in Figure 2. The electric field strength of the same orientation are shown on the same panel to compare the time difference between two separate sensors. In the same manner the magnetic field strength are shown in Figure 3. It is very clear that the electric field variation starts just on the same timing of the explosion both at two distant positions and both on the two orientations. Amplitude of the waveform is smaller at the distant point **R2** than that at **R1**, however, phase is almost the same between two points. The acoustic and the seismic wave are detected after 8msec at **R1** and after 16msec at **R2**. Therefore the starting potential fluctuations can not be attributed to the arrival of the acoustic or the seismic wave. On the other hand the starting fluctuation can not be observed on the magnetic field as Figure 3. The magnetic field data are contaminated by the field induced by electric transmission lines close to the explosion point.

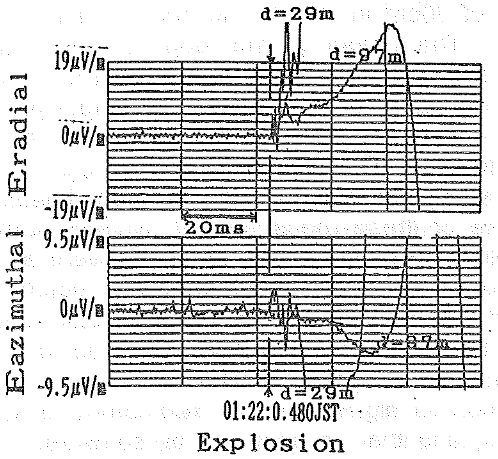

Fig.2 Surface Electric Fields. E-fields started their fluctuations just on the same time of the explosion. The fluctuations are similar in shape, althouh the amplitude at 97m is smaller than that at 29m.

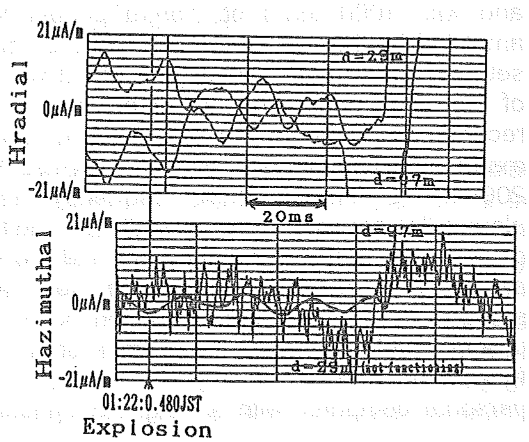

Fig.3 Surface Magnetic Fields. Unfortunately the azimuthal sensor at 29m did not function properly during this observation.

In Figure 4, the amplitudes of the two seprate points in the radial and the azimuthal components are plotted in the x-y coordinates for the period of 10msec from the explosion time. The x-coordinate indicates the amplitude at 29m from the explosion point, and the y-coordinate indicates that at 97m. The traces of the two electric field components move along the broken lines which indicate the constant amplitude ratio. A large amount of deviations at low amplitude can be caused by the low signal-to-noise ratio. Comparing the radial component of the electric field variation the amplitude ratio of the two separate sensors is 0.29 and the phase difference is within 30deg as shown in Figure 4(a). Also comparing the azimuthal component, the amplitude ratio is 0.50 and the phase difference is within 30deg as shown in Figure 4(b). On the other hand, the azimuthal components are smaller than the radial components as shown in Figure 2. The amplitude ratio of the azimuthal to the radial component is 0.31 both at **R1** and at **R2**, however, the phase difference is approximately 180deg. Since the phase reversal must be due to the order of the electrodes used in this observation, the two components can be considered to be within 30deg in phase.

Spectra of the initial 10msec fluctuations as shown in Figure 2 are displayed in Figure 5. All spectra show the broad peak at 750Hz. The gradual increase below 250Hz is due to the abrupt increase in amplitude at the explosion time. This characteristic frequency may be correlated with the time sequence of the explosion. The characteristic frequency of 750Hz is commonly detected in all of 4 potential records as can be expected by the similar shape of fluctuation of Figure 2.

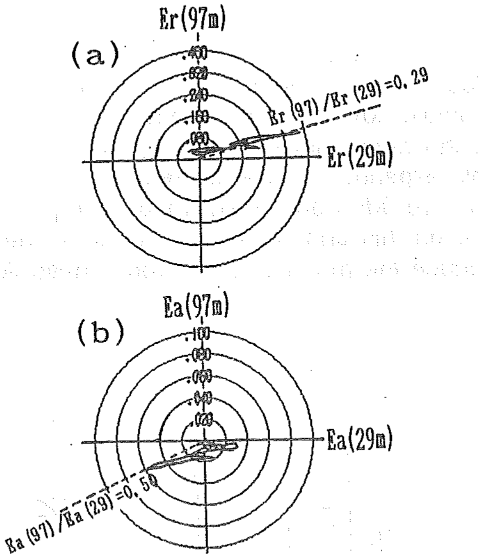

Fig.4 Amplitude traces of the two separate points (a)for the radial component and (b) for the arimuthal component. The traces seem along the broken lines which indicate the constant amplitude ratio. The ratio for the radial component is 0.29 and that for the azimuthal one is 0.50.

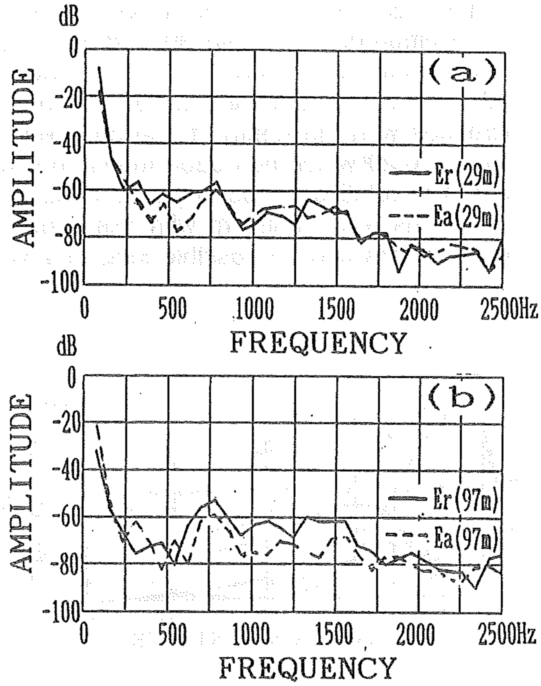

Fig.5 Spectral amplitude of the four elctric field fluctuations for 10msec after the explosion time.

4.Discussion

The radial decay of the amplitude of the electric field and the excess of the electric field relative to the magnetic field can be attributed to the source like an electric dipole. The assumed electric dipole must be placed on or under the ground surface where the measuring sensor units are allocated as in Figure 1(b). The ground conductivity around the explosion point is not known in detail but the apparent resistivity deduced by the VLF-MT technique was 10 to 100ohm•m[Sakai, personal communication]. Therefore we first assume that the ground conductivity as in a homogeneous half sphere is 0.01S/m and the relative permittivity is 10. The calculation is performed at the measured characteristic frequency of 750 Hz using the submerged dipole calculation described by Fraser-Smith et al.[13]. The calculation is made for the vertical and for the horizontal electric dipole placed under the ground.

At first the radial and the azimuthal electric field strength and the orthogonal magnetic field strength, and their relative phase angles are calculated along the radial line up to 200m in horizontal from the location of the dipole. Horizontal variation of the calculated field and their phase angle for the vertical dipole depth of 70m is shown in Figure 6. The calculated electric and magnetic field strengths are normalized to the dipole moment of p. No azimuthal field can be expected theoretically for the vertical dipole. Although the azimuthal component can be expected for the horizontal electric dipole, the expected magnetic field strength relative to the electric field must be much larger than the upper limit of this measurement. Thus the main source of the electromagnetic fields can be attributed to the vertical electric dipole.

Then calculation is made to explain the ratio of Er(97)/Er(29)= 0.29 and their relative phase difference is within 30 degrees. Figure 7(a) shows the ratio with respect to the dipole depth and Figure 7(b) shows their relative phase angle. It is interesting to note that the ratio is quite variable for the shallow dipole down to 10m–depth and it gradually increases with the depth. It can be seen that the ratio coincides at two depths with the value of 0.29 which has been measured by this experiment. The two depths are 8m and 68m. The relative phase angle at these depths are 0deg and 5deg, respectively. So the two depths are consistent with this experiment on this characteristic. Therefore the two dipole depths can be possible locations to produce the measured electromagnetic fields.

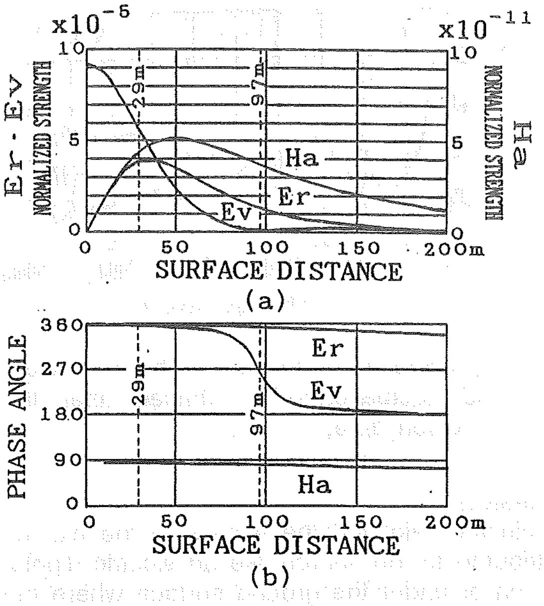

Fig.6 Horizontal variation of amplitudes and phases induced by an vertical electric dipole. The surface distances of 29m and 97m are indicated by the vertical broken lines.

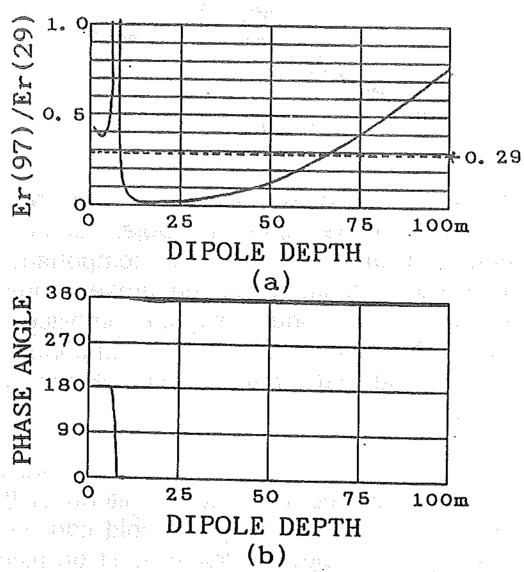

Fig.7 Vertical variation of the amplitude ratio and the relative phase of the radial components. The observed amplitude ratio of 0.29 is shown by the horizontal broken line. The curve of the amplitude ratio crosses at two depths.

The dipole moment p can be obtained by deviding the measured radial electric field strength by the calculated normalized one as shown in Figure 6 for the depth of 68m. The dipole moment is 0.26A•m. In the same way the dipole moment for the 8m depth is obtained and its value is 0.026A•m. The value of the dipole moment at the 8m depth is 1/10 to that at the 68m depth. By using these deduced dipole moment, the expected magnetic field strength can be calculated. The expected magnetic field strength are 1.7E-11A/m or 1.2E-11A/m for 8m or 68m depths, respectively. Both of the expected magnetic field strength are much smaller than the measurable strength of 1.0E-7A/m. It is, therefore, consistent with the fact that no magnetic field fluctuation observed coindident with the explosion.

5.Conclusion

Coincidental fluctuation of the electric fields were measured on the ground surface close to the underground explosion point. The fluctuation is coherent between two separate points and shows the radial decrease in amplitude. To explain these measured characteristic of the electromagnetic source generated by the underground explosion, model calculations for submerged vertical and horizontal electric dipoles are made. As the result of this calculation, a vertical electric dipole placed at 8m or 68m depth can be two possible sources of the explosion. Using the deduced dipole moment at two depths, it is concluded that the expected magnetic field strength must be much lower than the measurable strength. Although the typical characteristics can be explained by the simple vertical dipole model, it is required to proceed more calculations and to sofisticate the model, in order to explain other characteristics measured in this experiment.

Acknowledgements
The authors thank to Dr. K. Hattori, H. Sato and Y. Nakagawa for their help in this observation at Ohyama-cho, Toyama. One of the authors(I.T.) thaks to Dr. Yamada for helpful discussion and to Mr. Hara of Oh-Yoh Chishitsu Co. for his information on the experimental data.

References

[1]U. Nitsan, *Geophys. Res. Lett.*, **4**, 333-336, 1977
[2]J.W. Warwick, C. Stoker and T.R. Meyer, *J. Geophys. Res.*, **87**, 2851-2859, 1982
[3]I. Yamada and K. Masuda, *CA Kenkyukai, '85*, 129-135(in Japanese), 1985
[4]T. Ogawa, K. Oike and T. Miura, *J. Geophys. Res.*, **90**, 5245-6249, 1985
[5]G.O. Cress, B.T. Brady and G.A. Rowell, *Geophys. Res. Lett.*, **17**, 1465-1468, 1987
[6]M.B. Gokhberg, V.A. Morgounov, T. Yoshino and I. Tomizawa, *J. Geophys. Res.*, **87**, 7824-7828, 1982
[7]T. Yoshino, I. Tomizawa and T. Shibata, *Ann. Geophys.*, **3**, 727-730, 1985
[8]T. Yoshino and I. Tomizawa, *J. Geomag. Geoelectr.*, **22**, 225-235, 1990
[9]I. Yamada and H. Murakami, *Jishin*, **35**, 393-400 (in Japanese), 1982
[10]I. Yamada, Ph.D Thesis, Nagoya University, 1989
[11]I. Yamada, *CA Kenkyukai '90*, 39-48 (in Japanese), 1990
[12]H. Sakai, H. Oda, T. Nakayama and H. Doi, *J. Phys. Earth*, in press, 1992
[13]A.C.Fraser-Smith, D.M.Bubenik and O.G.Villard,Jr, *Radio Sci.*, **22**, 567-577, 1987