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Detection of Underwater Blasting Using Electrical Noise

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ABSTRACT

We conducted a small-scale experiment on soil simulating underwater blasting and studied the shape of waves as well as properties of electrical noises generated during blasting. From these noise waves, we wanted to detect any failure in initiation of the charge or blasting conditions, etc. It was observed that the main source of noise is the residual electricity in the exploder; the shape of noise waves is typical of blasting conditions of the charge. It enables us to detect blasting failure, or blasting of detonator touching the water, or detonation of charge, etc. from these noise waveforms. It was also confirmed that this method of detection can also be applied in double-hole or multi-hole blasting which follows stage explosion.

1. Introduction

No method is available for the correct detection of underwater explosion or residual failure within the range of theoretical considerations. In this study we have tried to develop a method to detect underwater blasting or failure thereof using the electrical noises generated during blasting. Although the experiment was conducted on soil, we tried to simulate the underwater conditions as far as possible by an electrical system.

So far, a number of methods have been proposed to detect failure in blasting such as: (a) magnetic detection, (b) detection from color of sea water using pigments or a buoy, (c) detection with sound generator, and (d) detection using earth vibration or underwater sound waves generated during blasting, etc. However, none of these methods can be employed easily because of the intricate technology and high costs involved, particularly when the sea bed is very deep.

If we decide to use the proposed method, it is not necessary to use a special power supply, detectors, or other equipment. The method is equally easy for all depths, and all the above-mentioned problems faced in different methods can be resolved.

It is well known that some electrical noise is generated during blasting. This is the major hurdle while measuring the detonation velocity in a bore hole by a resistance wire method. Earlier efforts were directed at reducing this noise, whereas we have effectively turned the same noise to our own purpose.

2. Principle of Detection

It was observed that when a circuit is arranged as shown in Figure 1, a large electrical potential difference arises between grounds E_1 and E_2 as the cartridge explodes. This potential difference, when added to the input current of synchroscope, is seen in the form of noise waves changing with time. This waveform varies with the types of explosives and conditions of explosion. It is therefore quite useful, not only for the detection of failure in explosion, but also for the estimation of explosion conditions. This is the basic principle of this method.

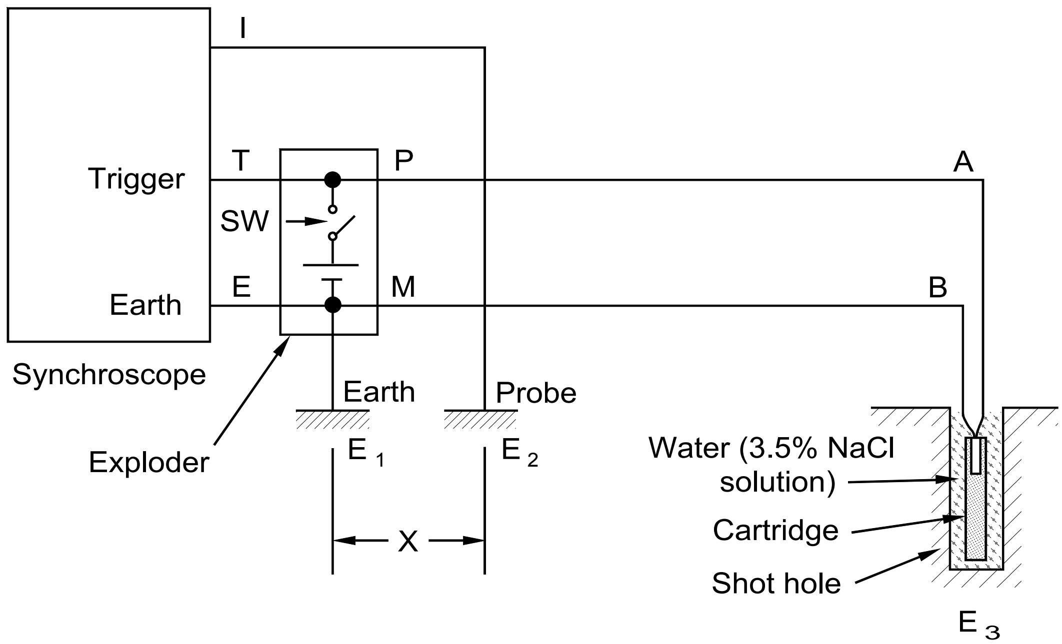

Figure 1. Circuit which produces a noise from one-hole blasting. I = input.

3. Apparatus, Material and Procedure (Figure 1)

1. *Synchroscope.* Iwasaki Tsushin Co.'s Junior II. Input impedance: 1 MΩ, 50 pF, parallel.
2. *Exploder.* Self-made, having a circuit diagram as shown in Figure 2.
3. *Grounds E_1, E_2.* Copper bar of 15 mm diameter and 345 mm length was buried into the soil to a depth of about 300 mm. The sum of individual contact resistance was 500–1,000 Ω. Hereafter, E_2 refers to the probe and X to length of ground wire.
4. *Blasting bore E_3.* A bore of 8 cm diameter and about 80 cm deep was drilled in the soil. It was filled by 3.5% salt solution to simulate sea water conditions. The soft loamy soil of the Kanto area had an eroded surface layer.
5. *Blasting cable PA-BM.* We used two types of PVC coated cables: I—copper wire diameter 0.6 mm, total resistance 5.22 Ω; II—copper wire diameter 1.6 mm, total resistance 1.77 Ω. Corresponding types were selected, depending on the object of the experiment.
6. *Input wire E_2-I.* Shielded wire (coaxial cable). For lengths above 30 m, we used one strand of five-stranded cable.
7. *Trigger wire P-T.* This was usually connected between pressure distribution point of exploder P_2 and trigger terminal T (Figure 2).
8. *Types of explosives.* Ignition charge: 0.85 ± 0.1 Ω; detonator: No. 6 industrial detonator; instantaneous electrical detonator: No. 6, 0.95 Ω. These last two are Nippon Yushi products.

Step blasting detonators were prepared using the above ignitor; delay element of minimum ferro silicate type; red explosive (potassium chlorate 65%, inert matter 35%, charge per detonator about 0.7 g); and a brass tube of diameter 6 mm, thickness 0.2 mm, and length 50 mm. A five-stage delay was obtained. The actual delay time was 4, 60, 200, 360 and 800 ms when about 5 A current was passed through it.

Explosive was potassium perchlorate 64%, aluminum flake 23%, sulphur 13%. This mixture was packed in 35 mm long, 20 mm ID, thick Kraft paper tube with a packing density of 0.85 g/cc. The above mentioned industrial or electrical detonator was fixed at the top or bottom depending on the object of the experiment.

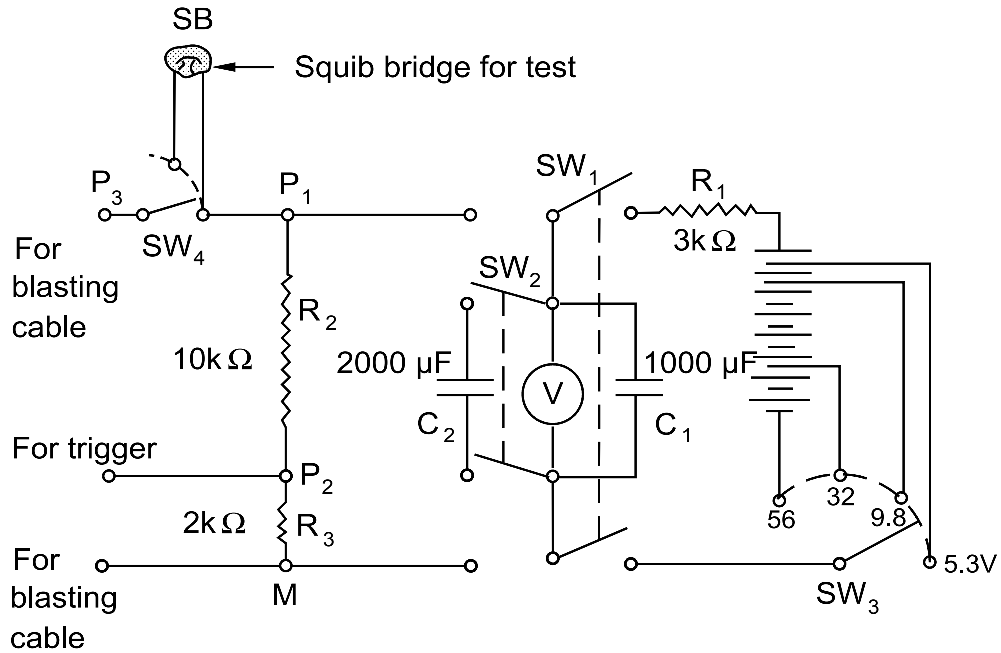

Figure 2. Circuit of exploder.

Then it was put into a thin polyethylene bag and sealed with vinyl tape to protect it from water. We used two types of cartridges. Short cartridge (explosive 177–190 g, length 220 mm) was used for simulation of half explosion, and long cartridge (charge 315–386 g, length 440–445 mm) for simulation of full explosion. Detonation velocity of this explosive was low, about 1,400 ms,[3] which is about 5/23 the detonation velocity of underwater explosions used in Honshu Shikoku Bridge Works.[5] However, it is convenient to simulate the actual explosive with the help of these small test cartridges. If we calculate the explosion time of charge using this detonation velocity, it comes to 0.16 ms for short cartridge and 0.32 ms for long cartridge.

A spherical capsule charge is made by adding some gum to the above explosive. The set material is made in the form of 4 mm ball wrapped in Kraft paper.[3] The quantity of charge was 30–50 g. This has about 1 ms of burning time and can be used to simulate a condition where the explosive burns without explosion. Also, it takes about 6–9 ms for explosion after switching on and, hence, can be used as a delay element in the experiment. For igniting this charge, the ignition tubes as used in concrete exploder (Asahi Chemical Co.'s CCR) were used.

4. Sources of Noise

There are two types of noise. One is due to the residual electricity in an exploder; the other is due to the explosion of charge. The latter is weaker than the former.

Figure 3a, “b” shows the experiment conducted with the electric detonator at comparatively low blasting voltage (9.8 V). If we insert detonator alone into the blasting hole E_3 and ignite it, then we get a noise pattern corresponding to input current, I, shown in “b”. The blasting voltage at the exploder terminal under this condition is shown in Figure 3a. Incidentally, if we use the squib SB, shown in Figure 2, in series (with detonator) and insert the detonator in blasting hole, then at blasting voltage above 50 V, the squib bridge would blow off before the detonator explodes,[4] and the blasting circuit will be disconnected. As a result, residual current from the exploder would stop flowing. The noise pattern under this situation appears as in Figure 3c. In this case, the length of ground wire was 1 m, and the distance between blasting hole E_3 and synchroscope earth E_1 was 77 m.

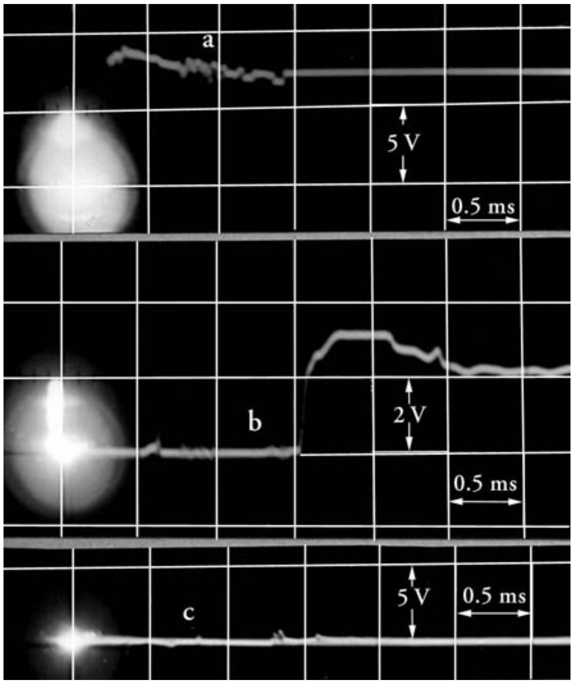

Figure 3. Noises from a detonator, a: blasting voltage for b; b: noise from a detonator; c: noise from a detonator under disconnection of blasting circuit.

The results of the explosion under a high explosion voltage (56 V) for a long cartridge are shown in Figure 4. The other conditions were the same as for Figure 3. Figure 4a indicates the blasting voltage at the exploder terminal, Figure 4b indicates noise from a charge, and Figure 4c indicates noise from a charge when residual electricity is disconnected.

In both the figures, the peak voltage in *b* is much higher than in *c.* Also, the voltage for *b* increases with the increase in ignition voltage, whereas voltage for *c* is independent of ignition voltage. This was also confirmed by another method described below.

Figure 5 shows the noise *(c_2),* when a short cartridge was exploded with industrial detonators or igniting wire without blasting electric detonator, and the noise (c_3), when a long cartridge is exploded with the blasting circuit totally made independent of measuring circuit and earth removed from the blasting circuit.

It can be seen that voltage of *c* wave-forms of Figures 3 and 4 and those of c_2 and c_3 (Figure 5) are around 0.5 V. (In case of c_3, switching

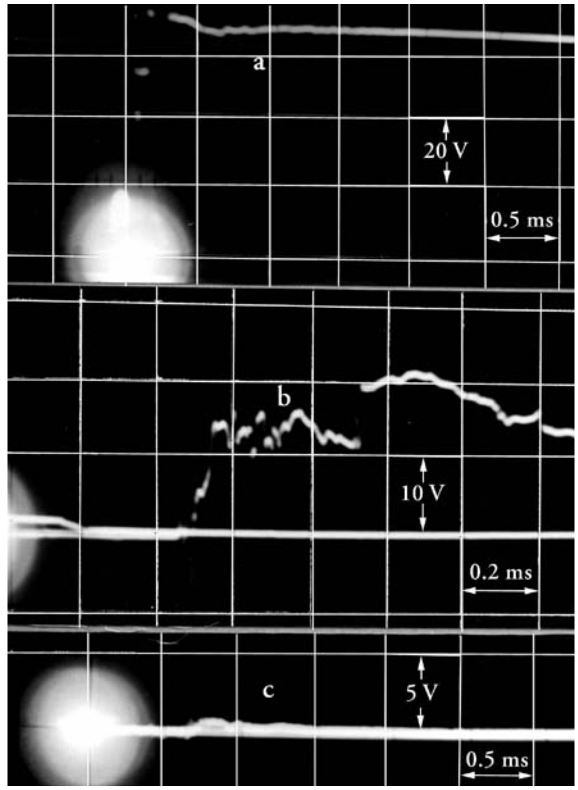

Figure 4. Noise from an explosive charge in a long cartridge (diameter: 35 mm, length: 440 mm, charge: 315–386 g, detonation velocity: 1400 m/s), a: blasting voltage; b: noise from a charge; c: noise from a charge under disconnection of blasting circuit.

voltage was 9.8 V.) The trigger signal of synchroscope was derived from c_2, c_3 voltage directly. However, as this voltage was small, the trigger was 2/5 effective.

It was thus confirmed that noise *b* is generated due to the residual electricity of exploder, whereas a completely different source (the origin of which lies in the explosion phenomenon of the explosive) is responsible for *c,* c_2 and c_3.. If the ion gap is used for trigger signal, the circuit remains the same as for the exploder. Hence, the power supply of the ion gap generates the same noise as *b.* In order to obtain noise due to residual electricity, it is necessary to use a common ground connection E_1 for the electric circuits of exploders and measuring circuit, but trigger wire *TP* is not that essential (Figure 1).

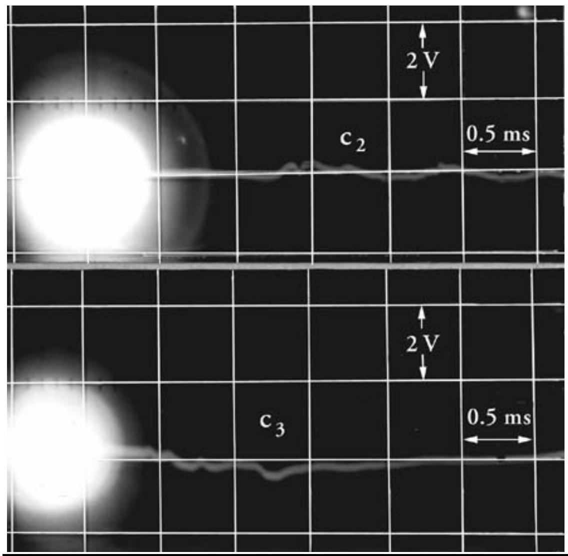

Figure 5 Noises from an explosive charge in a short cartridge (diameter: 35 mm, length: 220 mm, charge: 177–190 g, detonation velocity: 1,400 m/s), c_2: noise from a charge without electric initiation; C_3-noise from a charge with electric initiation, which is independent of the measuring circuit.

5. Location of Probe and Amplitude of Noise

Since the voltage of noise due to the residual electricity of the exploder is high, it can be used to detect the failure of explosion. We therefore discuss only this noise below.

During this study, we did not observe any correlation between the location of probe and amplitude of noise when the position of ground E_1 and shothole E_3 was constant. In other words, when an explosive is blasted off by electrical switching, the potential of the ground surface at certain points rises above (or goes below) E_1. This fluctuation does not have a fixed relation with the distance from the shothole. The relation is shown in Figure 6. In this figure, we have assumed the distance between E_1 and E_3 as 53 m. The probe position E_2 was changed point by point along the line joining E_1–E_3, and the noise at each position was measured. The explosive sample was the detonator. Detonation wire II was used. The switching voltage from exploder was 9.8 V. In this figure, we have also

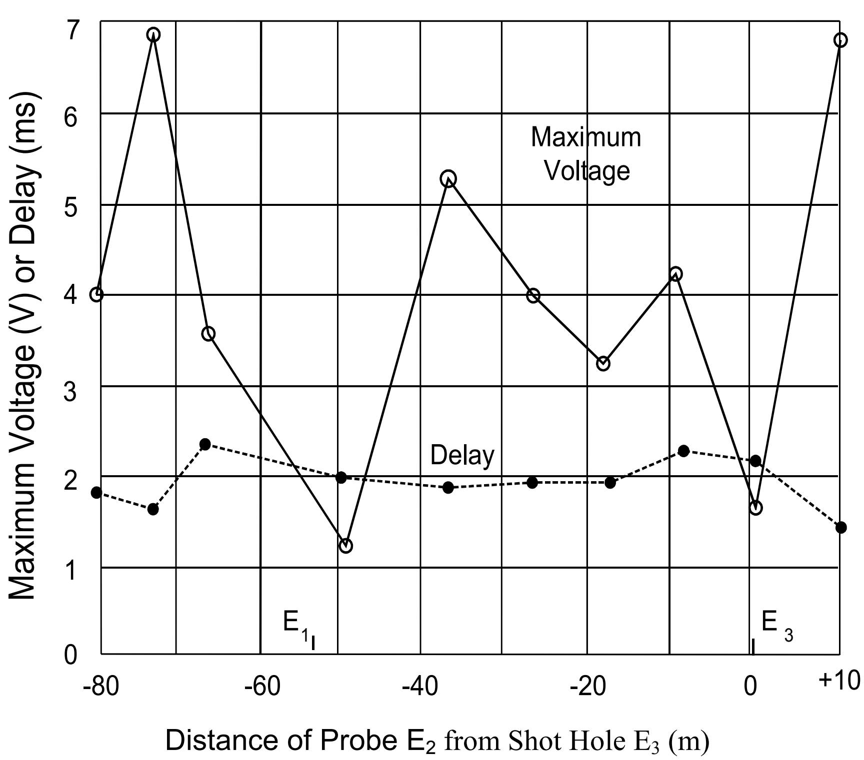

Figure 6. Influence of the position of the probe E_2 to the shot hole E_3 and to the ground of the exploder E_1 on the voltage of a noise. (Delay times from switching on to the initiation of a detonator are also shown.)

shown the time lag between the switching and rise of noise wave for the purpose of reference (dotted line).

From the above experiment, we can expect a high voltage noise even if ground E_1 and probe E_3 are placed very close to each other. The results of experiment were as follows. When the length of ground wire E_1E_2 at right angles with the direction of shothole E_3 was 1 m, the peak noise voltage was 4.3 V, 2.8 V. At 1 m in the direction of E_1, it was 3.6 V, 3.3 V. For 50 cm distance at right angles, it was 3.2 V, 2.8 V, and at 50 cm in the direction, 4.2 V and 3.0 V; at 10 cm at right angle, 4.2 V and at 10 cm in the direction, 2.2 V. Thus, even if E_1 and E_2 are placed close, at 10 cm, noise voltage is still of considerable amplitude. In this case, the positioning of ground wire is immaterial as far as noise voltage is concerned. (The experimental conditions in this case are the same as for Figure 6, except for the change in probe position.)

6. Noise Waveform

The shape of the time-dependent noise voltage curve has the following characteristics for electric detonator alone or with explosive. Both forms can be easily distinguished. Also, when the explosive is used, there is a clear difference in the noise pattern when the probe is directly inserted into shot hole or when the two are separated.

1. Blasting of electric detonator alone: The noise wave was as shown in Figure 7. When the switching current was high (3.3 A), we observed an overshoot pulse in the beginning, followed by the mountain wave with some time gap (a). When the current is low (1.6 A), the pulse is immediately followed by mountain wave (b), or the pulse can also be seen between the mountain waves (c). In another case, pulse and mountain wave start simultaneously (d).

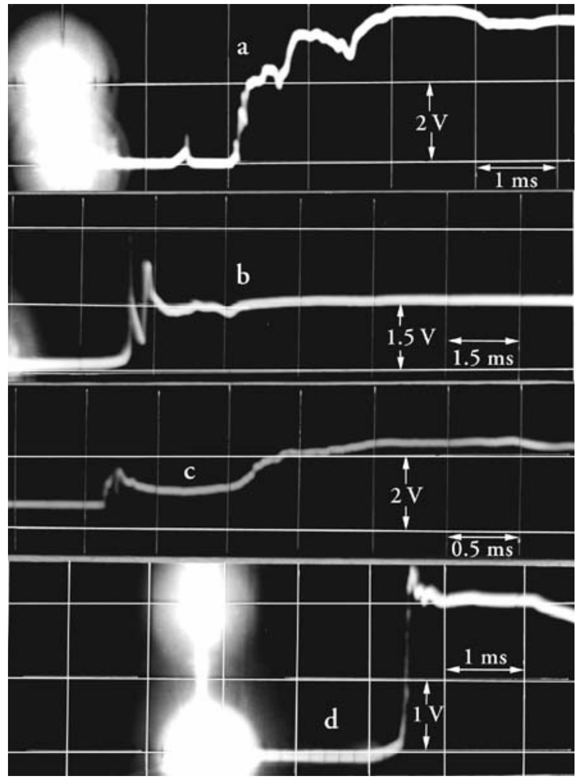

Figure 7. Noises from a detonator, blasting current: a = *3.3 A; and* b, c, d = *1.6 A.*

The pulse generation time is affected by the switching current and is probably due to blasting of ignitor bridge in the detonator.[4] As the detonator body is metallic, the electrical path at the time of bridge blasting becomes somehow electrically connected with the exterior; this may be the source of noise. No such overshoot was observed for the cartridge where the detonator is fully covered. The mountain wave is generated when the electrical contact is established between the circuit and the exterior as the detonator is exploded; as such, the rise time of pulse indicates instant blasting of the detonator.

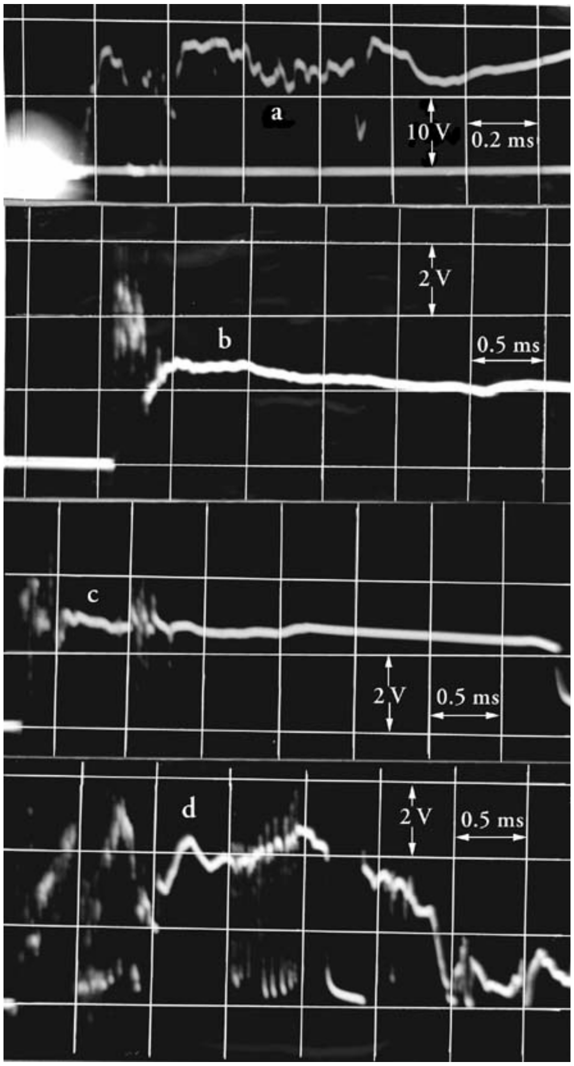

Figure 8. Noises from all explosive charge. The probe E_2 and the shothole E_3 are separated in the case of a*, and connected, in the case of* b, c, *and* d *(long cartridges, see Figures 4 and 5).*

2. *Blasting of cartridge*: This results in a representative noise waveform as shown in Figure 8. In Figure 8a, the length of ground wire X= E_1E_2 was taken as 1 m, distance between ground E_1 and shothole E_3 was 77 m, and a long cartridge with electrical detonator at top was used. Blasting voltage of the detonator was 56 V. Blasting starts 0.16 ms after switching on, and a comb-like waveform continues till 0.74 ms followed by mountain waves. The detonation time calculated from detonation velocity for long cartridge is 0.32 ms. This corresponds to the detonator termination point of falling pulse (Figure 8d). Figure 8b and following were obtained when a 2.5 mm dia. PVC-coated copper wire was inserted into the shothole and the lower half of the wire was used as a probe. The distance between E_1 and E_3 was taken as 52 m. If a noise wave is thus picked up directly from the shothole, it is possible to read the detonation time quite clearly. In other words, noise generally consists of a smooth mountain waveform at the background and a high amplitude, high frequency shock wave at the foreground (Figure 8b). Another wave, which is just a reflection of the above, is also seen in Figure 8c. The *b* and *c* waveforms are obtained when an electric detonator is connected at the tail end of the long cartridge. Compared to this, the waveform in Figure 8d is obtained when an electric detonator is connected at the front end of cartridge. In this case, a lot of reflected noise is clubbed together, and it is difficult to distinguish the point p corresponding to the end of detonation. Here, one method to detect p is to note the gaps in background noise.

We picked up the noise wave directly from the shothole and measured the detonation time of sample by the photographic method discussed above. A comparison of these values with the values calculated from detonation velocity is shown in the following table. An adequate number of experiments have not been conducted for a situation where E_2 and E_3 are separated. In this condition the last pulse is not very clear. Therefore, the above method of detection of detonation time is not valid.

Time of the So-called “Shock Noises” Compared with the Time of Detonation.

Cartridge	Time of detonation (calculated) (ms)	Time of shock noise measured (ms)	Difference (ms)
Short	0.16	0.17	–0.01
Short	0.16	0.11	0.05
Short	0.16	0.18	–0.02
Short	0.16	0.10	0.06
Long	0.32	0.32	0.00
Long	0.32	0.36	–0.04
Long	0.32	0.31	0.01
Long	0.32	0.30	0.02

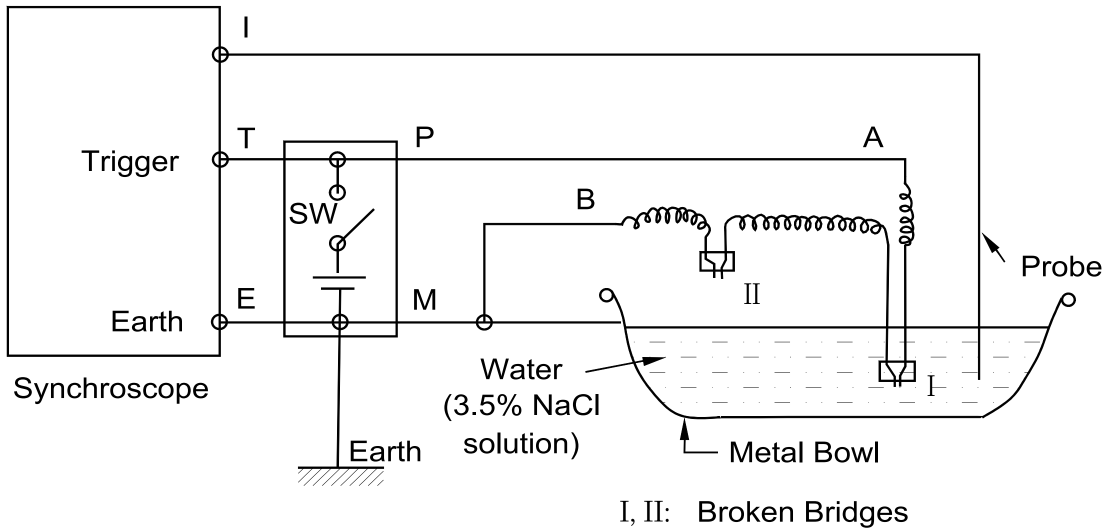

Figure 9. Circuit for imitation test of noises from double-hole blasting in a room. I = input, SW = switch *in exploder.*

3. Explosive burning: This used granular explosive in a spherical capsule. A condition was simulated in which the explosive burns instead of blasting. From the result of this experiment, we found that except for the rising instant, the noise wave does not have any overshoot.

7. Double-Hole and Multi-Hole Blasting

We first determined in a laboratory experiment the type of signals that are generated during double-hole blasting using the equipment and circuit diagrams shown in Figure 9.

A metallic bowl filled with a 3.5% salt solution can be considered as ground or sea water. I and II are the broken igniting bridges which can be freely submerged in the salt solution by moving up or down. If the synchroscope, exploder, ground, and probe are connected as shown above, and I and II are connected in series with the exploding circuit, we get a double-hole blasting circuit equivalent to Figure 1. In this condition, the resistance between *I* and *E* was 3,000 ohm. (There was no change in this value, even though probe position was varied.) The condenser of exploder has a capacitance of 3,000 μF and working voltage of 48 V. First, only bridge I on the right side of exploder wire was immersed in water, and the circuit was switched on by activating the exploder. It was then possible to simulate a condition where I breaks first and establishes an electrical contact with water. Subsequently, II can be immersed in water. Therefore, II cracks with some delay after I and makes contact with water. The input waveform from the probe in this case is shown in Figure 10a.

It can be seen from this figure that a pulse indicating a second explosion appears on the minus side. If the sequence is reversed (i.e., bridge II on the minus side of exploder is first immersed into water followed by I), we get waveform *b.* Here, the pulse indicating a second explosion appears on the plus side. From these experiments, it was quite clear that during stage explosion for a double-hole blasting the two explosions can be easily distinguished. The direction of blasting pulse in the corresponding noise waveforms is minus if the first blasting wire is connected to pulse terminal, and it is plus in the other case. Hereafter, we have indicated the line connecting the plus terminal of exploder for first blasting as the plus wire, and the other wire in the opposite mode as the minus wire.

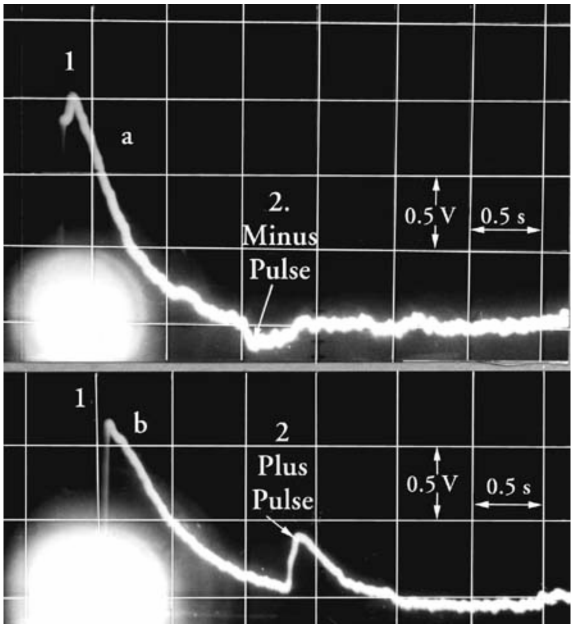

Figure 10. Noises from an imitation test, a: the plus terminal of the exploder is connected to the broken bridge, which is first put into the water, b: reverse of a.

Figure 11 shows the noise waveforms obtained when double-hole blasting was conducted in the field. Waveform *a* corresponds to the plus wire and *b* to the minus wire. For the first blasting, we used a detonator, whereas for the second blasting we used a spherical capsule which explodes with some delay. As this figure shows, in both *a* and *b*, an overshoot due to detonator is observed at 2.2 ms after the switching on; a mountain waveform rises at 2.4 ms, indicating where the detonator explodes (1). Subsequently, at about 10 ms, we observe another overshoot (2) which is on the minus side for *a* and on the plus side for *b*. Now, looking at the results of laboratory experiments, it is quite clear that in either case, this overshoot represents blasting of second stage explosive. The experimental conditions in this case were as follows: E_1E_2 =2 m, gap between blasting holes 2 m, distance between E_1 and blasting hole about 50 m, exploder wire II was used, blasting voltage, 9.8 V, exploder condenser had a capacity of 1,000 μF, and the series resistance between E_1E_2, was 800 ohm.

The basis for the generation of blasting pulses for a multi-hole blasting is exactly identical as in double-hole blasting. Figure 12 shows

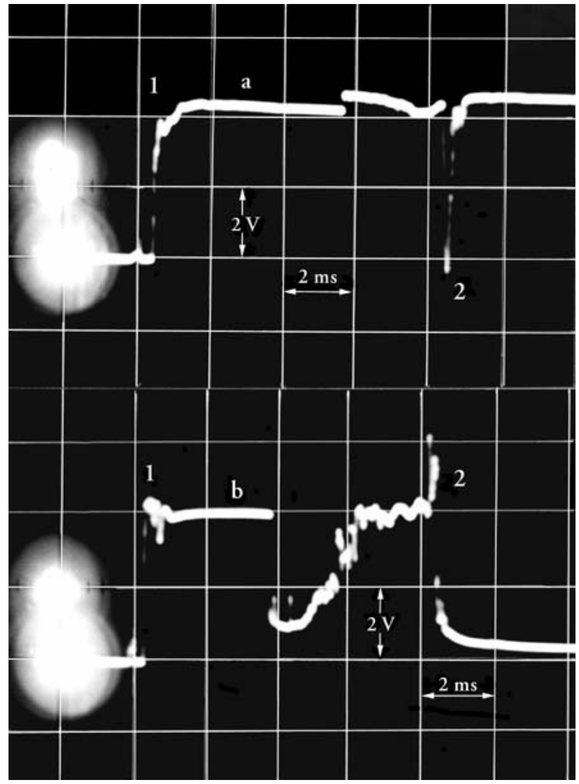

Figure 11. Noises from a double-hole blasting: a and b *correspond to those in Figure 10 respectively. 1: from a detonator; 2: from a small cartridge which explodes with a delay.*

the noise waves obtained when a multi-hole blasting was conducted in the field. Here, for step explosion, we used five self-made electrical detonators; they were connected to plus wire without the use of explosive cartridge. In this experiment, E_1E_2= 1 m. All five blasting holes

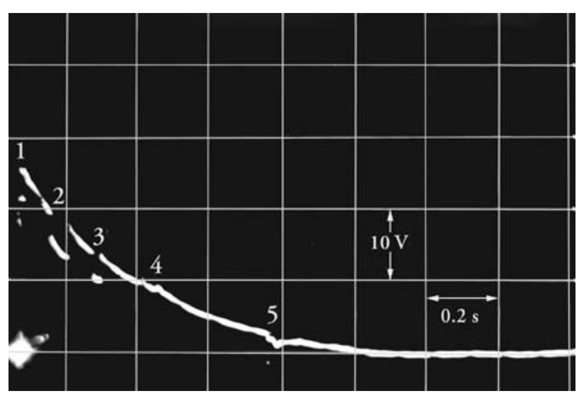

Figure 12. Noise from a five-step delay blasting using delay detonators.

were almost in a straight line having a gap of 2 m between two consecutive bores. Distance between E_1 and blasting hole group was about 75 m, exploder wire II was used, blasting voltage was 48 V, exploder condenser was of 3,000 μF capacity, and series resistance between E_1E_2 was 750 ohm.

8. Conclusion

We have discussed the noise waveforms under different explosion conditions. The noise was extremely clear when the probe was inserted directly into the blasting hole but, actually, it is much more economical to keep the probe near the exploder. Detection of failure of explosion is comparatively simple but a lot of data needs to be collected for detection of explosion conditions. The special feature of this circuit is that one terminal of the exploder is connected directly to the ground of measuring equipment. This method can be used for underwater wired and step explosions equally well. Whether this method can also be used for underwater wireless explosions, or explosions on land, needs to be studied in the future.[5]

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