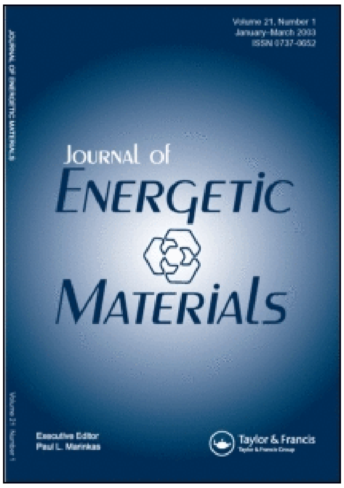

Journal of Energetic Materials
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713770432

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To cite this Article Wada, Yuji , Yabashi, Hideo , Tamura, Masamitsu , Yoshida, Tadao , Matsuzawa, Toshio and Hosoya, Fumio(1991) 'Shock sensitivity of blasting explosive cartridges', Journal of Energetic Materials, 9: 1, 105 — 132
To link to this Article: DOI: 10.1080/07370659108019860
URL: http://dx.doi.org/10.1080/07370659108019860

SHOCK SENSITIVITY OF BLASTING EXPLOSIVE CARTRIDGES

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ABSTRACT

The undersand variable gap-initiator test was applied to most Japanese blasting explosive cartridges and found useful as the sensitivity test for the cartridges. The recent Japanese watergel and emulsion explosives were shown to be more shock-sensitive than previous ones. The blast noise in the undersand explosion was shown to decrease when the depth of sand cover the cartridge was increased. For 100g of explosive, a sand layer 20cm deep was effective in reducing the blast noise, when the depth of the sand layer was increased, there was no additional effect. All blasting explosives excluding Kuro Carlit were not ignited by a small gas flame. A cartridge of 100g Kuro Carlit was ignited undersand but did not show the phenomenon of deflagration to detonation

Journal of Energetic Materials vol. 9, 105-132 (1991)
Published in 1991 by Dowden, Brodman & Devine, Inc.

transition, and this deflagration did not communicate with another cartridge 10cm away from the doner cartridge.

1. INTRODUCTION

Modern explosives have experienced several changes since Alfred Nobel invented dynamite in 1866. Recently, the so called "insensitive explosives" such as ammonium nitrate / fuel oil (ANFO)[1] and watergel explosives have been used in large quantities.

Regarding the use of blasting explosive cartridges, initiation sensitivity, detonation propagation, explosive power, and gap sensitivity, are important properties. On the other hand, from the viewpoint of accident prevention for an explosive cartridge, it is best when the explosive is not too sensitive to impact and shock, is safe to naked fire, static and friction sparks etc., and stable during storage.

In Japan, the air gap and ballistic pendulum tests have been used as the performance tests for blasting explosive cartridges[2]. The performance tests for blasting explosives itself are, heat resistance (stability), drop hammer, BAM friction (sensitivity), Dautriche detonation velocity, and ballistic mortar (explosion power) tests.

However, after the watergel explosives were invented, it was recognized that the conventional tests are insufficient for evaluating less-sensitive watergel explosives. The technical committee of the Japan Industrial Explosives Association for watergel explosives proposed that the following tests should be added to the above mentioned tests :

The drop hammer with sand paper, weak detonator, card gap, rifle bullet, ignition, safety fuse, growing steel rod, and pressure vessel tests[3].

The NORDTEST for nordic countries published 8 tests for slurry and watergel explosives which are, drop hammer, Koenen, rifle bullet, DTA, critical diameter, minimum booster, air gap and DDT tests[4,5,6].

We have examined testing methods for self-reactive materials including powders and explosives[7,8]. One of the tests we have used is the combination of the variable initiator[9] and the small card gap tests[10] for shock sensitivity of blasting explosives. We believe that these testing methods are excellent among most modern tests today. But we have still found several problems with them.

An example is the variable initiator test[9]. This test is applied to relatively low-sensitivity materials. The shock sensitivity by this method is judged by the amount of initiator which can completely explode a 5g sample. However, there are cases in which an initiator cannot propagate detonation through out the length of a larger sample though the 5g sample detonates completely. This case was shown in the study of detonation propagation of composite rocket propellants containing HMX[11,12].

Blasting explosive cartridges are known to be initiated and propagate detonation by the detonation of a No.6 detonator. Therefore, by applying the weaker detonator than a No.6 detonator, the sensitivity of blasting explosive cartridges can be examined. The problem is how to determine whether the cartridge detonated completely or not. In order to determine the fraction of explosion quantitatively, the underwater explosion method is superior to other methods. However, the recovery of explosive remains without complete explosion is difficult in the case of underwater explosions. The ballistic pendulum test may be used but it is not suitable because of the loud noise.

Here we chose the undersand explosion method. The method is easy to carry out, less-noisy, easy to estimate explosion fraction (though less-accurate), and easy to recover the remains of the explosives[13].

2. EXPERIMENTAL

2.1 Samples

The following blasting cartridges were used in the experiments : No.3 Shin-Kiri dynamite (a dynamite containing NH_4NO_3), No.2 Enoki dynamite (a dynamite containing NH_4NO_3 and $NaNO_3$), No.3 Toku-Shiraume dynamite for coal mines (made by "A" firm), emulsion explosive, ammonium nitrate explosive for coal mines, ANFO explosive (B firm), watergel explosive A (C firm), Kuro Carlit (NH_4ClO_4-FeSi-Oil explosive), Akatsuki Carlit (D firm), watergel explosive B (E firm), Kozumite (TNT-NH_4NO_3 powdery explosive), (F firm) and Ammon explosive (containing NH_4NO_3, wood meal, starch, Al and TNT), (G firm).

A fuse head manufactured by Hosoya Kako Co., Ltd. and grain gun powder made in Taiwan were used for igniting the Kuro Carlit cartridge in the undersand communication test.

2.2 Experimental Field

The undersand explosion experiments were conducted in a sandwell in the Technology Development Center of Hosoya Kako Co., Ltd. An outline of the sandwell is shown in Fig.1. The sand layer is 3m in diameter, 1.5m deep and surrounded by reinforced concrete blocks 15cm thick.

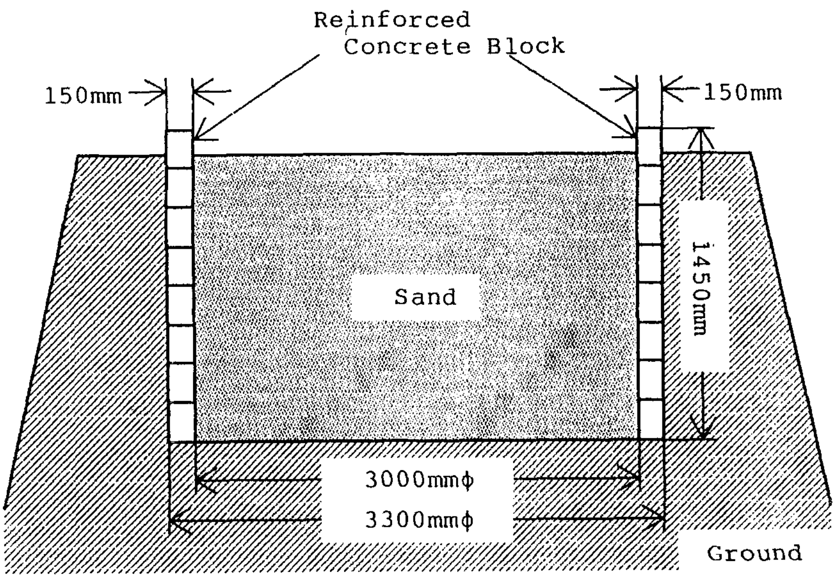


FIGURE 1
Outline of the experimental sand well.

The sand surface is about 2m higher than the ground level and is useful for draining water naturally. No hazardous fragments were expected in the experiments, so no measures were taken to prevent flying objects from escaping the area.

2.3 Undersand Variable Gap-Initiator Test

Blasting explosive cartridges 30mm in diameter and 100g in weight were used in the experiments. In order to get desirable conical craters, the position of the cartridges were chosen to be 30cm under sand. ANFO 30mm in diameter is known not to propagate detonation. Therefore, in the case of ANFO, we chose a 200g explosive, 50mm in diameter, and accordingly buried the cartridge 50cm under sand.

The test procedure is as follows :

(1) Peel one side of the cartridge and make a hole with a rod for inserting a detonator.

(2) Insert the detonator into the hole until the whole detonator no longer can be seen, wind the leg wires round the cartridge in order to prevent the detonator from slipping out of the cartridge (Fig.2 (a)).

(3) Make a hole in the sand 31.5cm deep, place the cartridge horizontally in the sand in the hole, cover the hole with sand (Fig.3 (a)).

(4) Connect the blasting circuit and initiate the detonator with a blasting machine (Fig.3 (b)).

(5) Determine the minor (a) and major (b) axes, and the depth (h) of the formed crater (Fig.3 (c)).

(6) Calculate the crater's volume (V) by using the equation $V = \pi abh/12$ and record the results along with the shape of the crater.

(7) Dig out the sand and examine the sample remains.

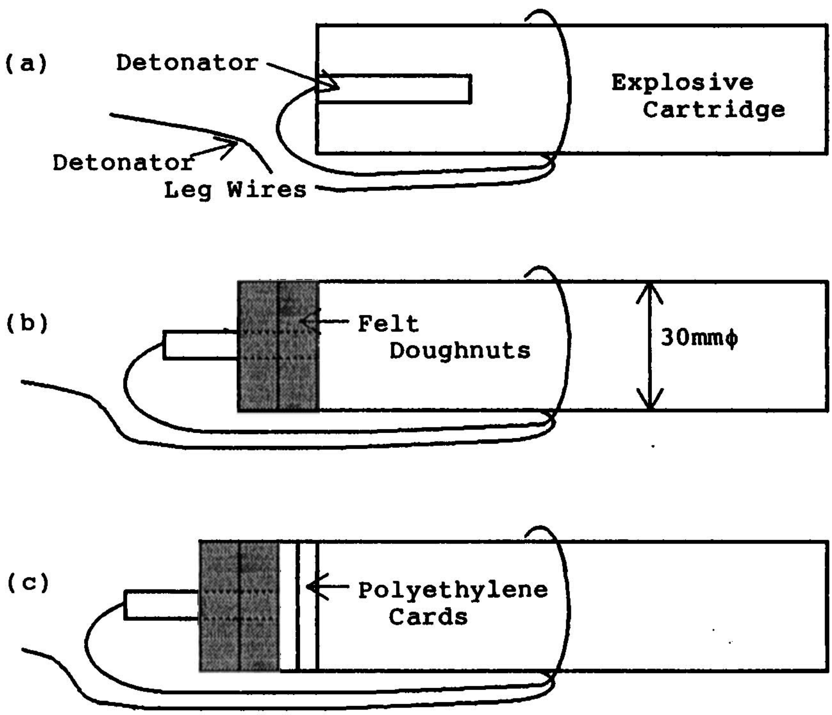


FIGURE 2
Sample assemblies for the variable gap-initiator test using the undersand explosion.

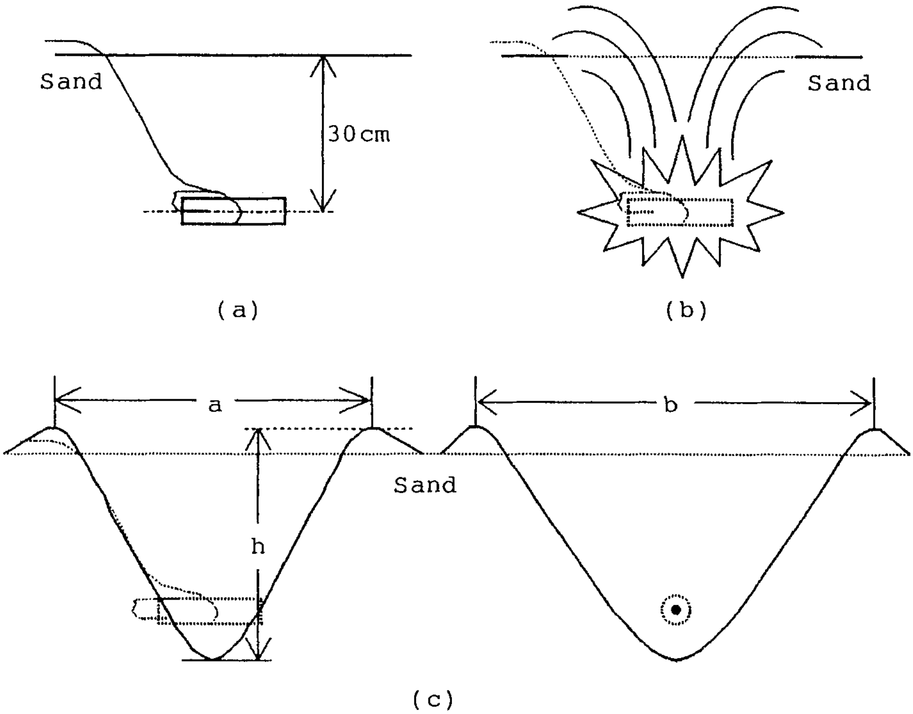


FIGURE 3
Sequence of the undersand explosion.

When the sample detonates when using an inserted No.0 detonator, the procedure is changed as follows :

(1a) Open one end of cartridge and insert the doughnut shaped felt and vinyl tape.

(2a) Put the No.0 detonator in the felt and be sure the detonator is in contact with the exposed explosive. Then close the cartridge.

(3a) Wind the leg wires around the cartridge to prevent the detonator from falling out (Fig.2 (b)).

When the sample detonates by a contacted No.0 detonator, change the procedure as follows :

(1b) Peel one side of the cartridge, insert polyethylene cards between the No.0 detonator and the explosive, and fixed them like (1a, 2a, 3a) (Fig.2 (c)).

2.4 Experiments Correlating the Depth of Cartridges Under Sand and Blast Noise

A condenser microphone (RION Co., Ltd., UC-29) and a precision level meter (RION Co., Ltd., NA-80) were used for determining blast noise. The position of the microphone was 30m from the blast point and 1.0m lower than the surface of the sandwell. The experimental area is shown in Fig.4.

The blast noise is determined with A-fast characteristics.

The blasting explosive cartridges used were the No.3 Shin-Kiri dynamites 25mm in diameter and 100g in weight. The position of the cartridges were placed 0 to 30cm deep under sand, at 5cm increments.

The experimental procedure is as follows :

(1) Prepare a sample assembly according to procedure 2.3 (1).

(2) Make a hole in the sand, place the sample cartridge horizontally in the sand hole at the arranged level, and cover the hole tp the level ground with sand.

(3) Connect the blasting circuit and prepare for determining the blast noise.

(4) Initiate the detonator with a blasting machine.

(5) Determine the minor and major axes, and the depth of the formed crater.

(6) Calculate and record the crater's volume and record the blast noise.

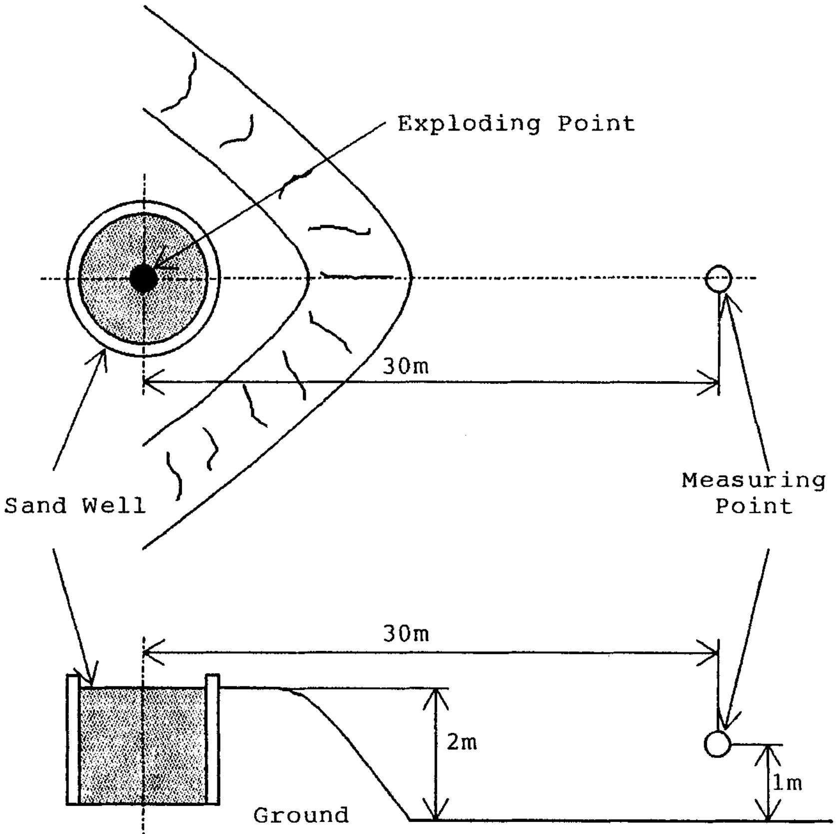


FIGURE 4
Outline of the experimental field
for the measurement of the explosion noise.

2.5 Undersand Communication Test for Ignited Kuro Carlit

The Carlit cartridges used were 30cm in diameter and 100g in weight. The cartridge container was a single package container made of poly vinyl chloride.

The experimental procedure is as follows :

(1) Wrap 10g of grain gun powder with Parafilm M (American Can Co.) and insert a fuse head into the gun powder.

(2) Peel one side of a Kuro Carlit cartridge and contact the wrapped gun powder to it.

(3) Put the igniter assembly and a Kuro Carlit cartridge into a container. This is the donor assembly. The accepter assembly is the container containing a Carlit cartridge only (Fig.5).

(4) Dig a hole in the sand 32.5cm deep and place the donor and accepter assemblies in the hole horizontally. The distance between the centers of two cartridges are 15cm. Cover the assemblies with sand.

(5) Connect the blasting circuit and ignite the donor with a blasting machine.

(6) Determine the crater's volume and observe the appearance of the two cartridges.

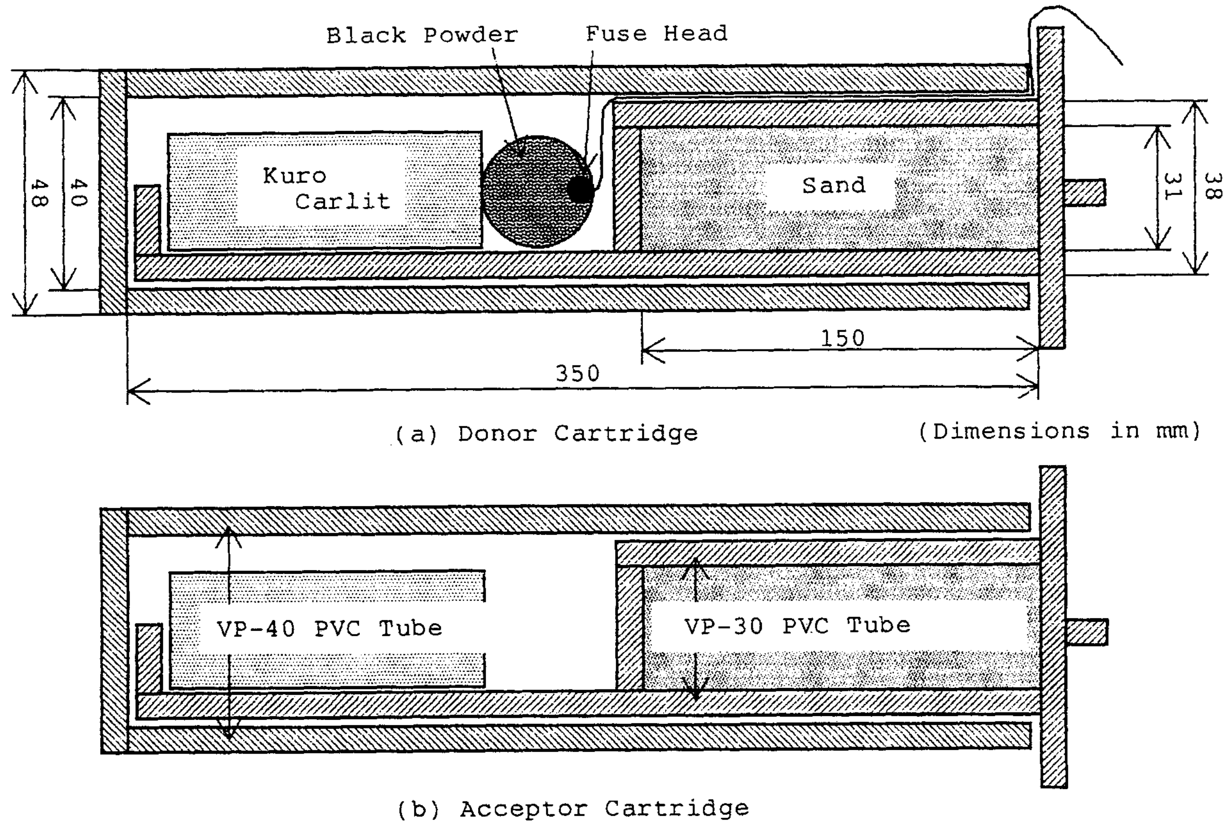


FIGURE 5
Sample assemblies for the undersand communication test.

2.6 Ignitability Test of Blasting Explosives

The small gas flame test was carried out according to the classification test method for the Class 2 hazardous materials by Japanese Fire Law. We ran a trial test once instead of three times. As the ignition source, a modified Bunsen burner was used. The ignition was remote-controlled.

A blasting explosive sample of about $3cm^3$ was placed on a mineral heat insulating plate 15cm x 12cm x 10mm thick. The sample was placed on the 7cm long flame of liquefied petroleum gas and was removed from the flame 10 seconds later. It was observed whether the sample continues to combust.

3. RESULTS AND DISCUSSION

3.1 Results of the Undersand Variable Gap-Initiator Test for Blasting Explosives

The results of the undersand variable gap-initiator test are listed in Table 1. The graphs of crater volume vs. detonator No. or gap length for No.0 detonator are shown in Fig.6-8. The figures are a measure of shock which are given to the blasting explosives.

The crater volume in Fig.6-8 rises up from the critical point where no crater is formed and plateaus out from the critical point of complete detonation. The critical points of complete detonation are also compiled in Table 2.

TABLE 1

Results of the Undersand Variable Gap-Initiator Test of Explosive Cartridges.
Cartridge Mass = 100g, Cartridge Diameter = 30mm,
Depth of Explosion Point Under Sand = 30cm.

No.	Sample	Initiator	Gap Length	Crater a [cm]	Crater b [cm]	Crater h [cm]	Crater V [l]	Note
1	No.3 Kiri D.	No.0 Det.	4mm	---	---	---	---	Not exploded
2	No.3 Kiri D.	No.0 Det.	2mm	130	131	41	183	
3	No.3 Kiri D.	No.0 Det.	1mm	121	127	40	161	
4	No.3 Kiri D.	No.0 Det.	Touch	122	129	36	148	
5	No.3 Kiri D.	No.0 Det.	Insert	132	135	41	191	
6	No.3 Kiri D.	No.1 Det.	Insert	130	138	43	202	
7	No.3 Kiri D.	No.2 Det.	Insert	126	135	43	191	
8	No.3 Kiri D.	No.3 Det.	Insert	125	131	42	180	
9	No.3 Kiri D.	No.6 Det.	Insert	127	136	41	185	
10	No.2 Enoki D.	No.0 Det.	8mm	---	---	---	---	Not exploded
11	No.2 Enoki D.	No.0 Det.	4mm	123	138	40	178	
12	No.2 Enoki D.	No.0 Det.	2mm	126	139	42	193	
13	No.2 Enoki D.	No.0 Det.	1mm	126	131	42	181	
14	No.2 Enoki D.	No.0 Det.	Touch	130	131	45	201	
15	No.2 Enoki D.	No.0 Det.	Insert	126	136	39	175	
16	No.2 Enoki D.	No.1 Det.	Insert	121	133	38	160	
17	No.2 Enoki D.	No.2 Det.	Insert	127	133	39	172	
18	No.2 Enoki D.	No.3 Det.	Insert	131	131	40	180	
19	No.2 Enoki D.	No.6 Det.	Insert	126	135	38	169	
20	No.3 Shiraume D.	No.0 Det.	8mm	---	---	---	---	Not exploded
21	No.3 Shiraume D.	No.0 Det.	4mm	127	129	40	172	
22	No.3 Shiraume D.	No.0 Det.	2mm	124	129	40	168	
23	No.3 Shiraume D.	No.0 Det.	1mm	119	125	40	156	
24	No.3 Shiraume D.	No.0 Det.	Touch	118	121	36	135	
25	No.3 Shiraume D.	No.0 Det.	Insert	117	123	32	121	
26	No.3 Shiraume D.	No.1 Det.	Insert	117	126	36	139	
27	No.3 Shiraume D.	No.2 Det.	Insert	119	126	34	133	
28	No.3 Shiraume D.	No.3 Det.	Insert	113	125	34	126	
29	No.3 Shiraume D.	No.6 Det.	Insert	114	118	27	95	
30	Emulsion Expl.	No.0 Det.	1mm	---	---	---	---	Not exploded
31	Emulsion Expl.	No.0 Det.	Touch	120	125	38	149	
32	Emulsion Expl.	No.0 Det.	Insert	122	128	36	147	
33	Emulsion Expl.	No.1 Det.	Insert	120	124	36	140	
34	Emulsion Expl.	No.2 Det.	Insert	120	123	36	139	
35	Emulsion Expl.	No.3 Det.	Insert	115	118	31	110	
36	Emulsion Expl.	No.6 Det.	Insert	111	122	26	92	

a : Minor Axis, b : Major Axis, h : Depth, V : Volume.
D. : Dynamite, Det. : Detonator, Expl. : Explosion.

TABLE 1 continued.

No.	Sample	Initiator	Gap Length	Crater a [cm]	b [cm]	h [cm]	V [l]	Note
37	Watergel Expl. A	No.0 Det.	2mm	---	---	---	---	Not exploded
38	Watergel Expl. A	No.0 Det.	1mm	122	134	42	180	
39	Watergel Expl. A	No.0 Det.	Touch	122	130	44	183	
40	Watergel Expl. A	No.0 Det.	Insert	120	125	35	137	
41	Watergel Expl. A	No.1 Det.	Insert	126	126	41	170	
42	Watergel Expl. A	No.2 Det.	Insert	121	123	35	136	
43	Watergel Expl. A	No.3 Det.	Insert	119	121	35	132	
44	Watergel Expl. A	No.6 Det.	Insert	116	126	35	134	
45	Watergel Expl. B	No.0 Det.	8mm	---	---	---	---	Not exploded
46	Watergel Expl. B	No.0 Det.	6mm	---	---	---	---	Not exploded
47	Watergel Expl. B	No.0 Det.	4mm	125	127	38	158	
48	Watergel Expl. B	No.0 Det.	2mm	120	122	40	153	
49	Watergel Expl. B	No.0 Det.	Touch	122	130	37	154	
50	Watergel Expl. B	No.0 Det.	Insert	120	127	37	148	
51	Watergel Expl. B	No.1 Det.	Insert	123	126	37	150	
52	Watergel Expl. B	No.2 Det.	Insert	120	130	36	147	
53	Watergel Expl. B	No.3 Det.	Insert	125	131	37	159	
54	Watergel Expl. B	No.6 Det.	Insert	123	124	38	152	
55	Kuro Carlit	No.0 Det.	8mm	---	---	---	---	Not exploded (Burnt)
56	Kuro Carlit	No.0 Det.	6mm	---	---	---	---	Not exploded (Burnt)
57	Kuro Carlit	No.0 Det.	4mm	---	---	---	---	Not exploded (Burnt)
58	Kuro Carlit	No.0 Det.	2mm	128	130	44	192	
59	Kuro Carlit	No.0 Det.	1mm	133	138	45	216	
60	Kuro Carlit	No.0 Det.	Touch	125	132	47	203	
61	Kuro Carlit	No.0 Det.	Insert	123	126	35	142	
62	Kuro Carlit	No.1 Det.	Insert	120	128	40	161	
63	Kuro Carlit	No.2 Det.	Insert	125	127	38	158	
64	Kuro Carlit	No.3 Det.	Insert	125	127	37	154	
65	Kuro Carlit	No.6 Det.	Insert	122	132	40	169	
66	Akatsuki Carlit	No.0 Det.	2mm	---	---	---	---	Not exploded
67	Akatsuki Carlit	No.0 Det.	Touch	120	132	40	166	
68	Akatsuki Carlit	No.0 Det.	Insert	105	121	24	80	
69	Akatsuki Carlit	No.1 Det.	Insert	121	125	37	147	
70	Akatsuki Carlit	No.2 Det.	Insert	125	125	39	160	
71	Akatsuki Carlit	No.3 Det.	Insert	116	134	35	142	
72	Akatsuki Carlit	No.6 Det.	Insert	122	129	37	152	

a : Minor Axis, b : Major Axis, h : Depth, V : Volume.
Expl. : Explosive, Det. : Detonator.

TABLE 1 continued.

No.	Sample	Initiator	Gap Length	Crater a [cm]	b [cm]	h [cm]	V [l]	Note
73	Kozumite	No.0 Det.	2mm	---	---	---	---	Not exploded
74	Kozumite	No.0 Det.	Touch	130	132	43	193	
75	Kozumite	No.0 Det.	Insert	125	125	38	155	
76	Kozumite	No.1 Det.	Insert	125	128	39	163	
77	Kozumite	No.2 Det.	Insert	127	138	40	184	
78	Kozumite	No.3 Det.	Insert	130	130	42	186	
79	Kozumite	No.6 Det.	Insert	127	132	42	184	
80	AN Expl.	No.0 Det.	Touch	---	---	---	---	Not exploded
81	AN Expl.	No.0 Det.	Insert	---	---	---	---	Half exploded
82	AN Expl.	No.1 Det.	Insert	114	120	34	122	Half exploded ?
83	AN Expl.	No.2 Det.	Insert	121	123	36	140	
84	AN Expl.	No.3 Det.	Insert	122	125	38	152	
85	AN Expl.	No.6 Det.	Insert	114	124	35	130	
86	Ammon Expl.	No.0 Det.	2mm	---	---	---	---	Not exploded
87	Ammon Expl.	No.0 Det.	1mm	---	---	---	---	Not exploded
88	Ammon Expl.	No.0 Det.	Touch	127	134	36	160	
89	Ammon Expl.	No.0 Det.	Insert	128	132	34	150	
90	Ammon Expl.	No.1 Det.	Insert	137	142	42	214	
91	Ammon Expl.	No.2 Det.	Insert	141	143	40	211	
92	Ammon Expl.	No.3 Det.	Insert	133	140	40	195	
93	Ammon Expl.	No.6 Det.	Insert	139	144	43	225	
94	ANFO*	No.6 Det.	Insert	22	25	7	1	Crack (45cm × 50cm)
95	ANFO*	No.8 Det.	Insert	100	100	9	24	Caldera
96	ANFO*	No.6 Det. + 5g No.3 Kiri D.	Insert	69	69	9	11	Sinking
97	ANFO**	No.6 Det. + 5g No.3 Kiri D.	Insert	104	110	30	90	

* : Cartridge Mass = 200g, Cartridge Diameter = 50mm, Depth of Explosion Point Under Sand = 50cm.
** : Cartridge Mass = 200g, Cartridge Diameter = 50mm, Depth of Explosion Point Under Sand=30cm.
a : Minor Axis, b : Major Axis, h : Depth, V : Volume.
Expl. : Explosive, Det. : Detonator, AN : Ammonium Nitrate, FO : Fuel Oil, D. : Dynamite.

3.1.1 Shock sensitivity and blast power of dynamite cartridges

Fig.6 shows the crater volume vs. shock data of for dynamites. All dynamite cartridges detonated completely by a No.0 detonator blasted a 100-200 liter crater. Judging from crater volumes, blasting powers of No.3 Shin-Kiri and No.2 Enoki dynamites were similar, and the No.3 Toku-Shiraume dynamite is weaker by about 25%. This may be from the inclusion of about 30% sodium chloride as a cooling agent.

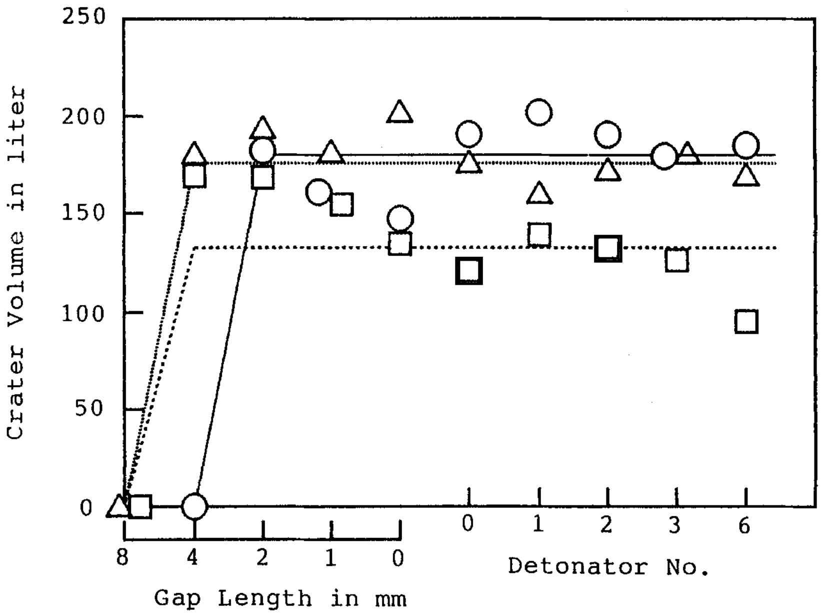


FIGURE 6
Plot of crater volume *vs.* gap length or detonator number for dynamites.
○ : No.3 Kiri Dynamite
△ : No.2 Enoki Dynamite
□ : No.3 Shiraume Dynamite

Regarding the sensitivity of dynamites, the No.2 Enoki and No.3 Toku-Shiraume dynamites were not initiated by a No.0 detonator with a 8mm card gap but were initiated by the same detonator with a 4mm card gap. On the other hand, the No.3 Shin-Kiri dynamite was initiated by a No.0 detonator with a 2mm card gap and not with a 4mm card gap.

3.1.2 Shock sensitivity of watergel explosive cartridges

Fig.7 shows the data on watergels. Genarally, watergels are said to be less sensitive than dynamites. The emulsion explosive and watergel A were not initiated by a No.0 detonator with 1mm and 2mm card gaps respectively, therefore they are less sensitive than dynamites. However, watergel B was initiated with a 4mm card gap and is more sensitive than No.3 Shin-Kiri dynamite.

Based on the previous experiments, some watergels and emulsion explosives were not initiated by a No.0 detonator. Results of this experiment suggest that the recent watergels and emulsion explosives are more sensitive than previous ones.

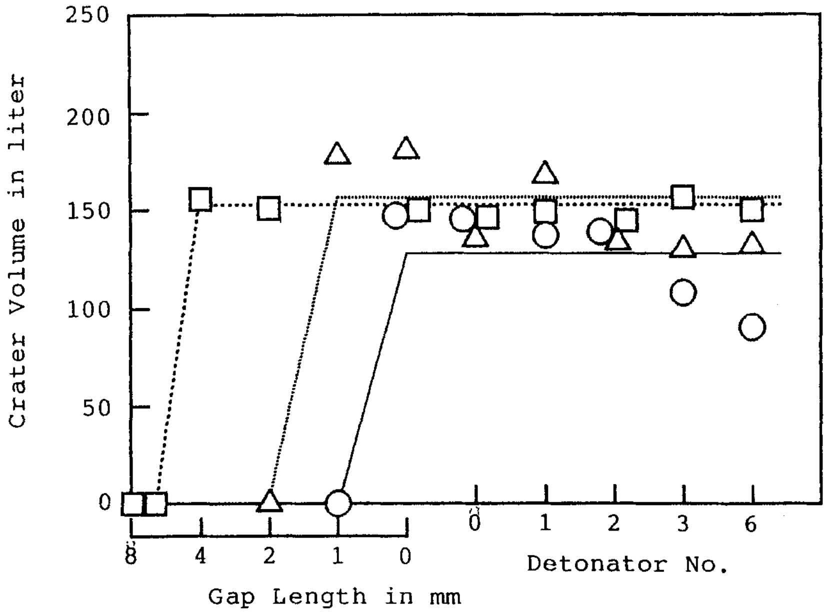


FIGURE 7
Plot of crater volume *vs.* gap length or detonator number for slurry explosives.
○ : Emulsion Explosive
△ : Watergel Explosive A
□ : Watergel Explosive B

3.1.3 Shock sensitivity of other explosive cartridges

Fig.8 shows the data on powdery explosive cartridges including Carlits, Kozumite, and ammonium nitrate explosives. The ammonium nitrate explosive for coal mines was not initiated by the inserted No.0 detonator and the residual explosive was recovered. The ammonium nitrate explosive for general use was not initiated by a No.0 detonator with a 1mm card gap, and Akatsuki Carlit and Kozumite were not initiated with a 2mm card gap.

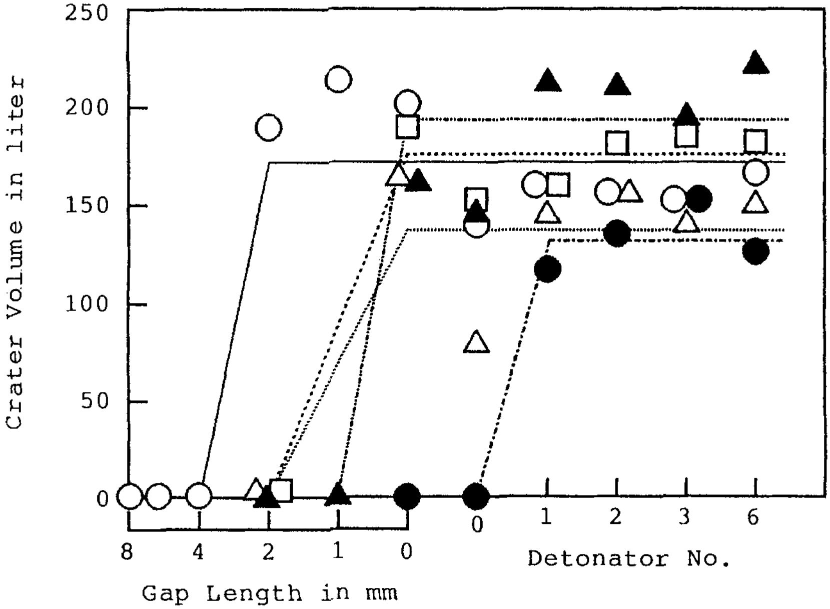


FIGURE 8
Plot of crater volume *vs.* gap length or detonator number for other explosives.
○ : Kuro Carlit
△ : Akatsuki Carlit
□ : Kozumite
● : Ammonium Nitrate Explosive
▲ : Ammon Explosive

Kuro Carlit was initiated and completely detonated with a 2mm card gap and made a crater. This explosive was not initiated with 4mm, 6mm and 8mm gap cards and did not produce a crater. However, in all cases of no detonation, explosives burnt with a red flame under the sand.

The test of ANFO was carried out by using a polyethylene tube cartridge 50mm in diameter and 200g in weight. The initiation was made

50cm deep under sand. The initiations by a No.6 detonator and a No.8 detonator failed. 5g of No.3 Shin-Kiri dynamite with a No.6 detonator was also unable to initiate the ANFO cartridge. In all of the above cases, the remains of ANFO were recovered.

In a previous experiments, ANFO which was put in a PVC tube 50mm in diameter was initiated by a 50g RDX booster and propagated a detonation. Therefore, in this experiment, ANFO might fail to propagate a detonation when an insufficient amount of booster is used.

TABLE 2
Shock Initiation Limit of Explosive Cartridges.

Sample	Limit of Initiation Not Initiated	Initiated
No.3 Kiri Dynamite	No.0 Det. - 4mm Gap	No.0 Det. - 2mm Gap
No.2 Enoki Dynamite	No.0 Det. - 8mm Gap	No.0 Det. - 4mm Gap
No.3 Shiraume Dynamite	No.0 Det. - 8mm Gap	No.0 Det. - 4mm Gap
Emulsion Explosive	No.0 Det. - 1mm Gap	No.0 Det. - Touch
Watergel Explosive A	No.0 Det. - 2mm Gap	No.0 Det. - 1mm Gap
Watergel Explosive B	No.0 Det. - 6mm Gap	No.0 Det. - 4mm Gap
Kuro Carlit	No.0 Det. - 4mm Gap	No.0 Det. - 2mm Gap
Akatsuki Carlit	No.0 Det. - 2mm Gap	No.0 Det. - Touch
Kozumite	No.0 Det. - 2mm Gap	No.0 Det. - Touch
AN Explosive	No.0 Det. - Insert	No.1 Det. - Insert
Ammon Explosive	No.0 Det. - 1mm Gap	No.0 Det. - Touch
ANFO	No.6 Det. + No.3 Kiri Dynamite 5g	---

Det. : Detonator, TNT : Trinitrotoluene,
AN : Ammonium Nitrate, FO : Fuel Oil

3.2 Relationship Between Blast Noise and Depth of a Cartridge Under Sand

Table 3 lists the observed results of blast noise in undersand explosions at different depths. Fig.9 shows the plot of blast noise vs. depth of the No.3 Shin-Kiri dynamite cartridges 25mm in diameter and 100g in weight. The plot of crater volume against the depth is shown in Fig.10.

TABLE 3
Blast Noise Level Produced by Undersand Explosion.
Sample : No.3 Kiri Dynamite, Mass = 100g, Diameter = 25mm.
Initiator : No.6 Detonator.

No.	Sand Thickness [cm]	Crater Major axis [cm]	Crater Minor axis [cm]	Crater Depth [cm]	Crater Volume [l]	Noise Level [dB(A-fast)]
1	30	130	119	37	150	81.1
2	25	148	132	46	235	84.4
3	20	148	135	45	235	89.9
4	15	147	136	39	204	104.0
5	10	132	121	34	142	119.8
6	5	109	98	25	70	131.3
7	0	72	70	19	25	132.5

The blast noise is shown to be reduced with depth of the cartridge under sand. In more detail, the blast noise is nearly equal between explosions on the sand and 5cm deep under sand. The crater volumes in both these cases were rather small, showing that the energies released by the explosions were not absorbed by the sand but released into the air as noise. The noise changed little when the depth was changed more than 20cm. From these results, a depth of 20cm under sand may be enough to reduce the blast noise of a 100g explosive cartridge.

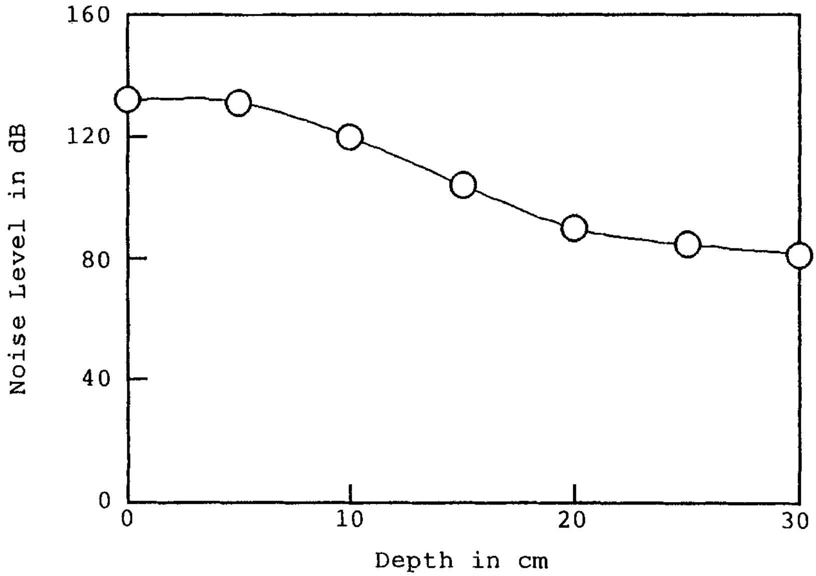


FIGURE 9
Plot of noise level in dB(A-fast) *vs.* depth of explosion.

The crater volumes did not change between 20cm and 25cm depths. However, at a depth of 30cm, the volume was smaller than with 20cm and 25cm. This is a general trend for the undersand explosion[12].

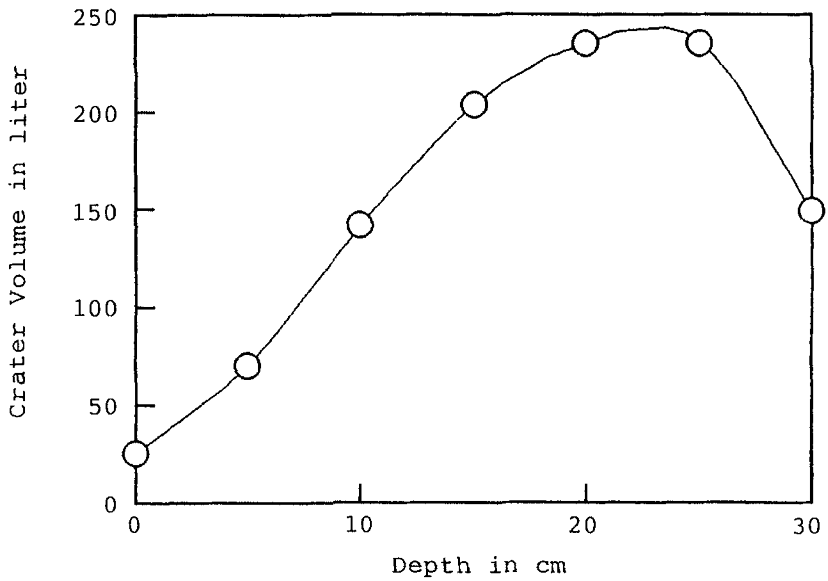
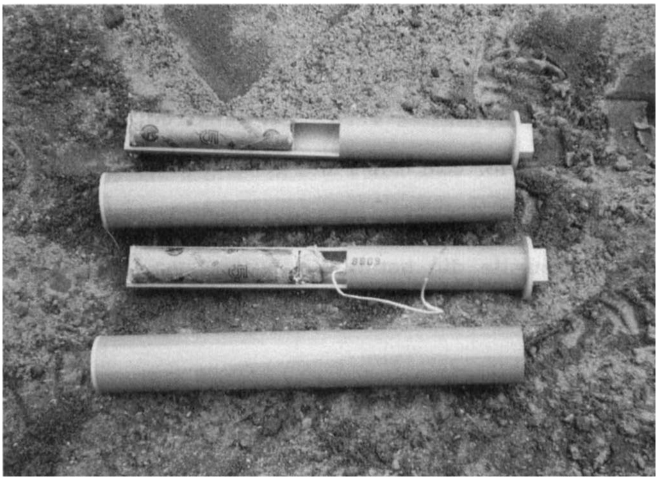


FIGURE 10
Plot of crater volume *vs.* depth of explosion.

3.3 Results of Undersand Communication Test of Kuro Carlit by Ignition

The results of the undersand communication test of Kuro Carlit showed that the single cartridge container for the donor charge was charred, and the inside and outside PVC tubes moved by about 13cm each to the opposite side. This shows that the doner Carlit deflagrated but did not detonate because the PVC tube did not fragment. The container with the acceptor Carlit cartridge did not show any change in appearance outside and inside, and no sympathetic detonation took place. Photo 1 shows the photographs of the single cartridge containers before and after the undersand communication test.



(a) Before the test.

(b) After the test.

PHOTO 1
Photographs of the undersand communication test
for cartridges of Kuro Carlit.

3.4 Results of Ignitability Tests for Blasting Explosives

Results of the small gas flame test are listed in Table 4. Only Kuro Carlit was ignited in one second by the small gas flame and showed to be sensitive to the flame. No.3 Shin-Kiri dynamite was ignited after 8 seconds but self-extinguished after removing the flame. No.2 Enoki and No.3 Toku-Shiraume dynamites were partly charred, but not ignited. Ammonium explosives for coal mines and general use, and ANFO were only partially melted and not burnt. Akatsuki Carlit, watergels, an emulsion explosive and Kozumite did not ignite. Japanese blasting explosives excluding Kuro Carlit are not sensitive to the small gas flame.

TABLE 4
Results of Small Gas Flame Sensitivity Test of Blasting Explosives.

No.	Sample	Result	Note
1	ANFO	Not burnt	Burnt partially
2	No.3 Kiri Dynamite	8 seconds	Gone out itself
3	No.3 Shiraume Dynamite	Not burnt	Burnt partially
4	AN Explosive	Not burnt	Melted a little part
5	Emulsion Explosive	Not burnt	
6	Watergel Explosive A	Not burnt	
7	No.2 Enoki Dynamite	Not burnt	Burnt a little part
8	Kuro Carlit	1 second	
9	Akatsuki Carlit	Not burnt	
10	Watergel Explosive B	Not burnt	Sparked at 5 seconds
11	Kozumite	Not burnt	
12	Ammon Explosive	Not burnt	Melted partially

AN : Ammonium Nitrate, FO : Fuel Oil.

ACKNOWLEDGEMENTS

The authors are grateful to the explosive producers for supplying us with explosive samples and especially grateful to Nippon Oil & Fats Co., Ltd. for giving us all the detonators used in this study. Financial assistance from All Japan Association for Retailers of Explosives and Guns was of great help.

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