Research paper

Card gap tests of plastic high explosive by using mortar, light weight concrete and sand as gap materials

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Abstract

The series of card gap test like experiments were carried out to examine the relation between gap length and sympathetic detonation of plastic high explosive, and the scale effect of shock initiation sensitivity of the explosive. Composition C-4 explosive charges (1400 $kg \cdot m^{-3}$ in density) of cylindrical shape and with same weight, were used as donor and accepter charges. The ratio of charge length to diameter (L/D) was set to be one. The experiments have been conducted with five explosive weights ; 10 g, 40 g, 320 g, 2.5 kg, and 20 kg. Three kinds of gap materials, i.e., mortar, light weight concrete and sand with various thicknesses, were used. The sand layer was sandwiched by two thin mortar disks. Detonation or no−detonation of accepter charge was determined by observing the situation of a mild steel witness plate after the experiment. It became clear that, even in the case for 20 kg charge, the critical gap length of detonation and no−detonation can be evaluated in the range of 20 mm or so. Furthermore, in log−log coordinate system of gap length as a function of explosive weight, it was found that all three gap materials showed good linear relationship, and those inclinations were larger than the value of the scale factor of explosive weight (= 0.333). It was obtained a tendency that the material with higher density showed higher obstruction effects to prevent the sympathetic detonation.

Keywords : shock sensitivity, sympathetic detonation, gap test, scale effects, composition C-4

1. Introduction

In the assessment of the safety of storage facilities for explosives, it is necessary to investigate the blocking effects of sympathetic detonation by obstacle, such as a partition wall. If the sympathetic detonation of the adjoining storage bay can be obstructed by the partition wall, the safety distance can be decreased because the explosive amount is considered to be a half of the net total amount. A composite structure which consists of sand fills in between two concrete or mortar walls can contribute to the strength of the concrete or mortar and the sand itself can reduce the shock pressure[1, 2].

In case of breakup and dispersion of debris from the partition wall caused by the explosion accident of the adjacent storage bay, it is important to consider the selection of the partition wall material. That is, when thinking about the influence by the collision of the secondary fragments, the wall must be covered by energy absorbing material, relatively low−strength and porous in comparison with normal weight concrete, to reduce the impulse loading of the acceptor charge and to prevent the scenario of sympathetic detonation.

In this study, a composition C-4 plastic high explosive with high shock sensitivity, was chosen from among the commercial explosives currently being used and based on the scale rules for the gap tests with mortar, light weight concrete and sand were conducted. In order to clarify the scale effects in the shock sensitivity, laboratory scale experiments with 10 g, 40 g, and 320 g of composition C-4 explosive for the donor and accepter charges and medium scale explosion experiments with 2.5 kg and 20 kg of composition C-4 explosive for the donor and accepter charges were carried out.

2. Experiment

2.1 Explosives and assembly

The composition C-4 (hereafter, abbreviated as Comp. C-4) explosive (Nippon Koki Co., Ltd.) was used for the donor and acceptor charges. Schematic drawings of the gap test assembly are shown in Figure 1, and sizes of the devices are listed in Table 1. According to the amount of charge, two types of assembly were used for the sand gap experiments. The donor and acceptor charges were set respectively at the top and bottom of the gap material, and the lower side of the acceptor charge was set on the two−ply mild steel witness plates that could touch it.

The Comp. C-4 stuffed into PMMA tube was used and its density was adjusted to 1400 kg·m^{-3}. The ratio of the charge length to the diameter (L/D) was set to one. A booster holder made of polyethylene with Comp. C-4 booster explosive, 2 wt. % exclude of charge amount, was set on the donor charge[3]. In the laboratory scale experiments, the donor charge was detonated by one electric detonator. In the field explosion experiments, the donor charge was detonated by two electric detonators.

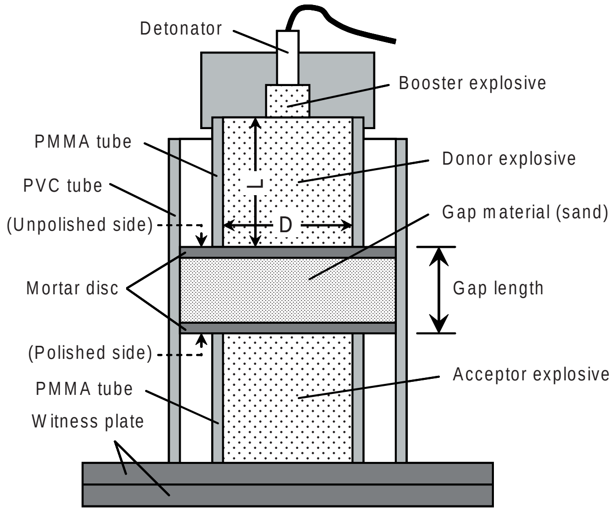
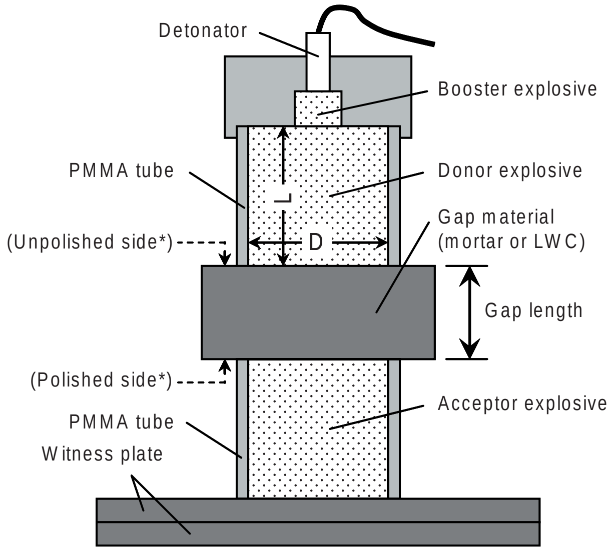


Fig. 1 (b) Experimental setup for sand gap (explosive weight up to 2.5 kg).



* LWC gap was used upside down.

Fig. 1 (a) Experimental setup for mortar or light weight concrete gap.

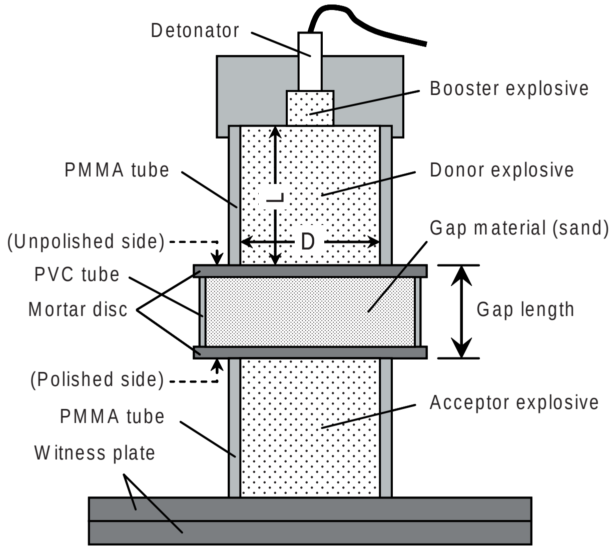


Fig. 1 (c) Experimental setup for sand gap (explosive weight of 20 kg).

Table 1 Sizes of each part of test devices.

Explosive weight	PMMA tube for donor / acceptor charge		Mortar / LWC gap	PVC tube for sand gap	Mortar disk for sand gap		Witness plate (mm)
	Inner diameter (mm)	Length (mm)	Diameter (mm)	Inner diameter (mm)	Diameter (mm)	Thickness (mm)	
10 g + 10 g	20	20	33	35	33	3.5	60×60×2.3
40 g + 40 g	32	32	53	67	53	5.5	100×100×4.5
320 g + 320 g	65	65	108	125	108	11.5	200×200×8
2.5 kg + 2.5 kg	126	126	208	240	208	23	400×400×16
20 kg + 20 kg	260	260	442	395	442	45	800×800×32

Table 2 Specification of gap materials.

Gap material	Mortar	Light weight concrete	Sand
Composition	Water, Cement, Aggregate	Water, Cement, Coarse aggregate, EPS	Soma sand
Mixing ratio	0.4 : 1.0 : 2.0	0.45 : 1.0 : 1.19 : 0.1	1.0
Apparent density ($kg \cdot m^{-3}$)	2200	1400	1520
Compressive strength ($N \cdot mm^{-2}$)	35.0	16.4	–
Grain size (mm)	0.15—2.5	<3	0.425—1.7
Remarks	–	EPS : Expandable polystyrene	Natural silica sand. Standard sample of strength test etc. on cement.

2.2 Gap material

The specifications of each gap material are tabulated in Table 2. Three kinds of gap materials, mortar, light weight concrete (hereafter, abbreviated as LWC) and sand were used in this study. It was decided to make the diameter of the gap materials 1.66 times that of the explosive charge in accordance with the Japan Explosives Society standard[4].

The sand gap was produced by loading the sand in between two mortar disks with same thickness. The loading density of the sand was adjusted to $1600 kg \cdot m^{-3}$.The side surface of sand gap was supported by using a polyvinyl chloride (PVC) tube. As mentioned in the previous section, two types of assembly were used for the sand gap experiments. In case that charge weight of less than or equal to 2.5 kg, the thickness of sand layer was adjusted by changing the location of two mortar disks set inside the PVC tube. And in case that charge weight of 20 kg, the thickness of sand layer was adjusted by using the PVC tubes of various lengths. The total gap length was therefore defined by adding the thickness of two mortar discs to the length of sand layer.

There was a difference in surface roughness on the front side and the back side of the mortar and LWC gaps. One side of the gap was polished to fine−tune the thickness and to smooth its surface, and the aggregate section was exposed. On the other hand, small holes due to bubbles were apparent, but hardly any aggregate was visible on the other side (unpolished). In this study, the polished side was made the back side of mortar gap which contacted with the top surface of the accepter charge, and the other side was made the front side of mortar gap which contacted with the bottom surface of the donor charge. In case of LWC gap, however, unpolished side was rougher than polished side ; the gap material was used upside down.

Natural silica sand was used as sand gap material. The particle size of the sand has been adjusted by sifting out to 0.425−1.7 mm though it was considerably all of a size at this point. The foreign object such as clay was removed from the mined original sand by washing in clear water.

3. Results and discussion

3.1 Damage states of the witness plates

After the explosion experiments, three types of reaction phenomena of the accepter charge were obtained from the damage states of the witness plates as following. 1) Sympathetic detonation of the accepter charge ; the witness plates were greatly distorted, and the hole were opened on both plates. In addition, no remaining unexploded explosive was discovered on the witness plate or in its vicinity. 2) No−detonation of the accepter charge ; neither of the two witness plates was distorted. In addition, remaining unexploded explosives were discovered on the witness plate and in its vicinity. 3) Incomplete detonation of the accepter charge ; distortion of the witness plates was obviously less than in case of sympathetic detonation, and no hole was opened to either witness plate. However, no remaining unexploded explosives were discovered on the witness plate and in its vicinity. The reaction appears to be an incomplete detonation, though the acceptor charge reacted in this case. It was difficult to categorize the damage to the witness plates either sympathetic detonation or no−detonation, and the result was judged to be incomplete detonation. In that sense, the gap length in the result judged to be incomplete detonation is thought to be very close to the critical gap length.

If the shortest gap length judged to be no−detonation is shown to be L_n, and the longest gap length judged to be sympathetic detonation is shown to be L_d, the critical gap length (L_c) is expressed as

$$L_c = \sqrt{L_n \times L_d}$$

In addition, the length judged to be incomplete detonation is assumed to be the critical gap length in this study.

3.2 Effect of the weight of explosive on shock sensibility

The scale effects on the shock sensitivity of Comp. C-4 explosive are indicated in Table 3. When pay attention to the longest gap length of sympathetic or incomplete detonation (L_d), the scale effect of the explosive could realize for all three gap materials. In case of the LWC gap for example, the L_d of 320 g (39.9 mm) is longer than 2 times of the L_d of 40 g (17.5×2=35 mm), the L_d of 2.5 kg (110.3 mm) is longer

Table 3 Scale effect on the shock sensitivity of the Comp. C-4 explosive.

Explosive weight	Gap material	Gap length (mm) and Judge※
10g + 10g	Mortar	10.2 (○) −12.0 (×)
	Light weight concrete	10.1 (○) −12.0 (×)
	Sand	9.4 (○) −10.4 (△) −12.0 (×)
40g + 40g	Mortar	14.9 (○) −19.8 (△) −24.8 (×)
	Light weight concrete	15.1 (○) −17.5 (△) −20.2 (×)
	Sand	17.8 (○) −20.7 (×)
320g + 320g	Mortar	40.3 (○) −50.0 (×)
	Light weight concrete	39.9 (○) −50.3 (×)
	Sand	40.0 (○) −50.0 (×)
2.5kg + 2.5kg	Mortar	110.0 (○) −118.7 (×)
	Light weight concrete	110.3 (○) −119.0 (×)
	Sand	107.7 (○) −126.4 (×)
20kg + 20kg	Mortar	240.5 (○) −257.8 (×)
	Light weight concrete	299.1 (○) −320.0 (×)
	Sand	260.6 (○) −279.6 (×)

※○ : detonation, × : no−detonation, △ : incomplete detonation

than 2 times of the L_d of 320 g (39.9×2=79.8 mm), and the L_d of 20 kg (299.1 mm) is longer than 2 times of the L_d of 2.5 kg (110.3×2=220.6 mm) also. Same trend can realize the result for other two gap materials.

And, when pay attention to the shortest gap length of no−detonation (L_n), the scale effect of the explosive could also realize for all three gap materials. In case of the sand gap for example, the L_n of 320 g (50 mm) is longer than 2 times of the L_n of 40 g (20.7×2=41.4 mm), the L_n of 2.5 kg (126.4 mm) is longer than 2 times of the L_n of 320 g (50×2= 100 mm), and the L_n of 20 kg (279.6 mm) is longer than 2 times of the L_n of 2.5 kg (126.4×2=252.8 mm) also. Same trend can realize the result for other two gap materials.

The peculiar effect of the scale on the explosion phenomena of explosives is enumerated as a reason for the results obtained in these experiments. It was possible to delimit the boundary between sympathetic or incomplete detonation and no−detonation for three kinds of gap materials within the range of 1.6 mm − 20.9 mm through experiments with 10 g − 20 kg Comp. C-4 explosive. Even in the case of the charge amount of 20 kg, it was possible to determine the boundary of each sympathetic or incomplete detonation and no−detonation within the range of 17.3 mm (for mortar gap), 20.9 mm (for LWC gap), and 19 mm (for sand gap) respectively. Moreover, the relationship between the weight of explosive and the critical gap length exhibited straight lines in the log − log plane, as shown in Figs. 2 through 4. The power law between the gap length and the weight of explosive was approved.

If L is gap length (in mm) and W is weight of explosive ($0.01\,\mathrm{kg} \leqq W \leqq 20\,\mathrm{kg}$), the approximation is expressed as

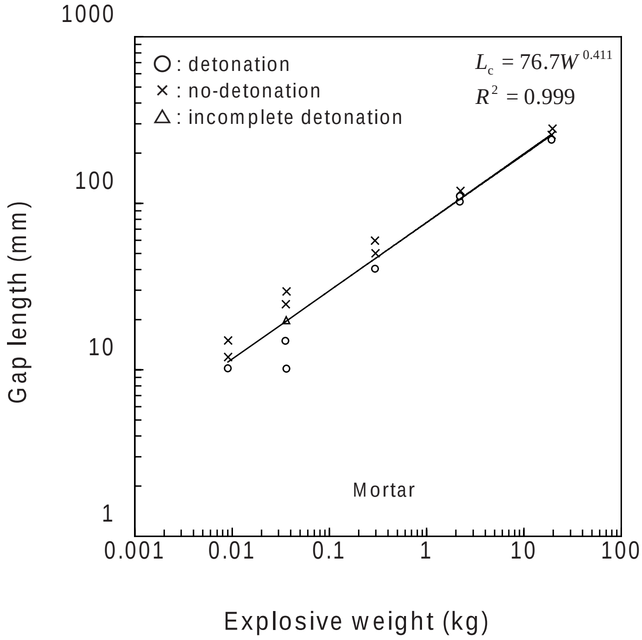


Fig. 2 Relation of explosive weight and gap length for mortar.

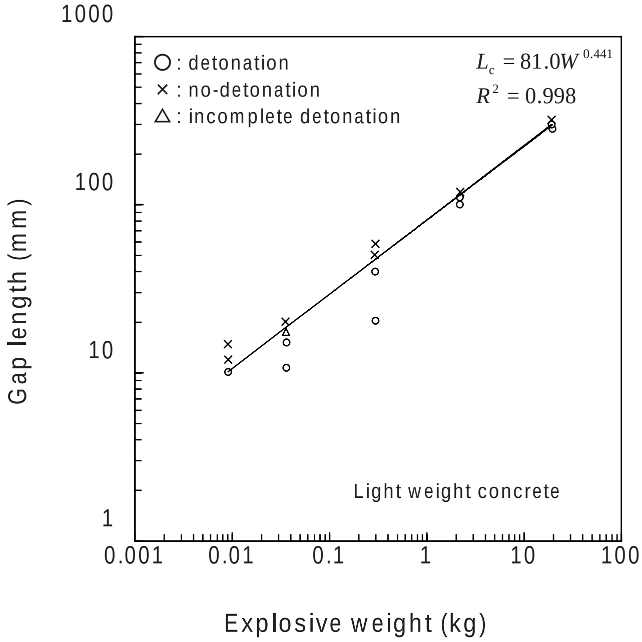


Fig. 3 Relation of explosive weight and gap length for light weight concrete.

$$L = Aw^{b},$$

and the formulas of L_c for all three gap materials are expressed as

$L_{c,\mathrm{mortar}} = 76.7W^{0.411}$, $R^2 = 0.999$ for mortar,

$L_{c,\mathrm{LWC}} = 81.0W^{0.441}$, $R^2 = 0.998$ for light weight concrete, and

$L_{c,\mathrm{sand}} = 78.3W^{0.427}$, $R^2 = 0.999$ for sand.

It was clear that those inclinations were larger than the value of the scale factor of explosive weight (= 0.333). Duration time of the shock wave becomes long and the impulse grows though the incident shock pressure to the gap material doesn't change so much as the amount of the explosive increases. Because the destruction situation of the

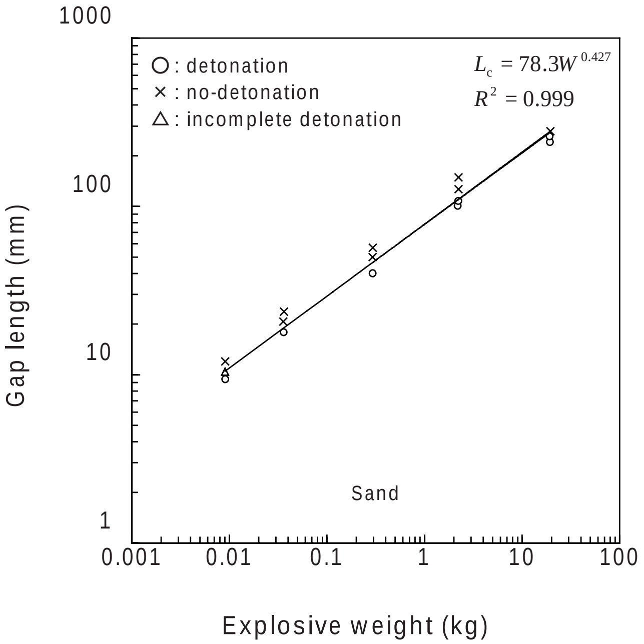


Fig. 4 Relation of explosive weight and gap length for sand.

gap material is different depending on the amount of the explosive, it is thought that different results besides the scale factor were obtained. It seems that the scale effects of shock initiation sensitivity of the explosive were shown. The coefficient of determination (R^2) shows the accuracy of the predictive value to the actual data by an approximate curve, and the accuracy of the approximated curve rises as this value approaches to one[5)]. It is suggested that this scale rule enabled the extrapolation for much larger amount of explosive presumed from these experiments.

In case of the charge weight of 20 kg, the critical gap lengths are 262.7 mm (mortar), 303.6 mm (LWC), and 281.4 mm (sand), respectively. It seems that the material with higher density shows higher obstruction effects to prevent the sympathetic detonation. When thinking about the influence by the collision of the secondary fragments, the LWC seems to be effective to reduce the impulse loading of the acceptor charge and to prevent the scenario of sympathetic detonation, however, the different results were obtained by the gap tests. That is, the LWC showed the longest critical gap length. Therefore, to design or evaluate the optimum length for each materials of the composite partition wall structure, further investigation should be encouraged.

4. Conclusions

A series of card gap tests like experiments with five amounts of plastic high explosives and by using three kinds of gap materials were carried out. The Comp. C-4 explosive was used for the donor and accepter charges, to clarify the relationship between gap length and sympathetic detonation and the effects of the amount of the explosive on shock sensitivity. The results obtained are as follows :

1) Even in the case of the charge amount of 20 kg, it was possible to determine the boundary of each sympathetic or incomplete detonation and no−detonation within the range of 17.3 mm (for mortar gap), 20.9 mm (for light weight concrete gap) and 19 mm (for sand gap), respectively.

2) It was found to have a linear relationship between the amount of explosive and the critical gap length for all three gap materials in the log − log plane and those inclinations were larger than the value of the scale factor of explosive weight (= 0.333). It seems that the scale effects of shock initiation sensitivity of the explosive were shown.

3) In the range of the amount of explosives used in the present study, it was obtained the tendency that the material with higher density showed higher obstruction effects to prevent the sympathetic detonation.

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モルタル，軽量コンクリート，砂をギャップ材に用いた可塑性爆薬のカードギャップ試験

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可塑性爆薬のギャップ長と殉爆の関係，また，当該爆薬の衝撃起爆感度の規模効果を調べる目的で，カードギャップ試験に類似したシリーズ実験を行った。励爆薬と受爆薬には，同薬量の円柱形コンポジションC４爆薬（密度1400kg・m^{-3}）を使用した。爆薬長さと直径の比（L/D）は１とした。５水準の薬量（10g，40g，320g，2.5kg，および20kg）で実験を行った。様々な厚さの３種類のギャップ材（モルタル，軽量コンクリート，砂）を使用した。砂の層は２枚の薄いモルタル板でサンドイッチにした。受爆薬の爆・不爆は，軟鋼製の証拠板を観測することで判定した。本実験により，薬量20kgの場合でも，爆・不爆の限界ギャップ長を20mm程度の範囲で評価できることが分かった。加えて，３種類のギャップ材全てについて，爆薬量と限界ギャップ長は両対数座標系で良好な直線関係を示すこと，それらの傾きは爆薬のスケール則の値（1/3＝0.333）より大きいことが分かった。また，本実験で用いた薬量の範囲では，密度の高い材料ほど，殉爆阻止効果が大きくなる傾向が得られた。

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