Blast Pressure Mitigation by Surface Explosion Using Water in a Walled Container

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Abstract: Mitigation of blast pressure using water in a walled container was evaluated. A PETN (pentaerythritol tetranitrate) pellet of 1.4 g near the model wall was detonated on a steel plate. A water-filled container was placed between the explosive and the wall. The pressure histories at six points, which corresponded to Hopkinson scaled distance of from $3.6 \text{ m}\cdot\text{kg}^{-1/3}$ to $21.7 \text{ m}\cdot\text{kg}^{-1/3}$ were evaluated along with dependence of mitigation effects on the amount of water and the position of the container. The presence of the water and the wall mitigated the peak overpressure near the explosion points and the positive impulse along all points. The mitigation effect was equivalent to 20-30% reduction of explosive weight based on discussion of the equivalent ratio. The presence of the water along the wall (not very close to the explosive) also mitigated the blast pressure.

Key words: Blast pressure, mitigation, water, wall, equivalent ratio.

1. Introduction

Damage caused by the unexpected sudden explosion of explosives is generally caused by a fire ball, a blast wave, and high- and low-velocity fragments. Damage caused by the fire ball occurs only near the explosion. However, the blast wave and the fragments can damage people and property even at distant points. Consequently, the damage and means to mitigate the damage should be studied.

The authors have studied damage mitigation methods for blast waves such as explosives covered by water gel [1], sand [2], and biodegradable foam [3]. The effects of a wall have also been evaluated [4, 5]. But although field experiments have examined the mitigation effects of water in containers stacked along a full scale wall made of concrete blocks, the water effects have not been confirmed [6]. Moreover,

mitigation effects have been evaluated only insufficiently in earlier experiments because the experiments and pressure transducers were few. This study used surface explosion experiments and small models to examine the mitigation effects of blast pressure using water with a walled container.

2. Experiment

2.1 Test Explosives

A pressed pellet made of PETN (pentaerythritol tetranitrate) and carbon powder was used as a test explosive. The pellet consists of 95 wt.% of PETN and 5% carbon powder. The cylindrical pellet was of 10.7 mm diameter and 10.9 mm length. The pellet weight and the density were 1.4 g and $1.55 \text{ Mg}\cdot\text{m}^{-3}$, respectively. A specially designed electric detonator containing 100 mg lead azide was used. The detonator was glued onto the top of the pellet. Showa Kinzoku Kogyo Co. Ltd. supplied the explosives and detonators. A spacer was used to adjust the height of the explosive center to $0.18 \text{ m}\cdot\text{kg}^{-1/3}$. The cubic pasteboard spacer

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was 15 mm wide. The bottom of the cylindrical pellet was glued on the spacer using epoxy resin adhesive. The spacer was held on the 400 mm diameter steel disk center using adhesive tape. This steel disk was fitted into the ground surface model, as described later. The direction of initiation was perpendicular to the surface, from top to bottom. Then 4 kV was applied to the detonator to initiate the detonator using a firing system (FS-43; Teledyne RISI, Inc.).

2.2 Container

Water in a rectangular block container was put near the explosive to evaluate the water mitigation effect on the blast wave. The paper container was destroyed, becoming lightweight fragments. The container was $110 \times 50 \times h \text{ mm}^3$, where h is the container height. The container was filled entirely with tap water. Its top was left open. The standard height of the container was 15 mm, which was equal to that of the spacer. For comparison, the height was varied from 6 mm to 30 mm. For an experiment to assess the container position effects, a $110 \times 25 \times 30 \text{ mm}^3$ container was put along the wall model. The water amount was equal to that of the standard height container.

2.3 Wall Model

The wall model was made of JIS SS400 steel. The

respective height, width, and thickness were 62.9 mm, 103.7 mm, and 6.0 mm. The wall model was screwed to the disk; the distance from the center of the explosive to the inside surface of the wall was 60 mm. Fig. 1 depicts the mutual arrangement of the model wall and the explosive.

2.4 Ground Surface Model

A steel plate with respective length, width, and thickness of 3,200 mm, 2,000 mm, and 10 mm was fixed on a table. This plate was regarded as a ground surface model. A part of the plate was cut circularly so that the steel disk, on which the wall model was fixed, was flush with the ground surface model.

2.5 Blast Pressure Measurement

Six pressure transducers (102M256; PCB Piezotronics, Inc.) were used to measure the blast pressure. The distances from the point of the explosion were, respectively, 400 mm, 600 mm, 900 mm, 1,350 mm, 1,800 mm, and 2,400 mm. The corresponding Hopkinson-scaled distance (scaled distance hereinafter) [7] was $3.6 \text{ m} \cdot \text{kg}^{-1/3}$ to $21.7 \text{ m} \cdot \text{kg}^{-1/3}$. The scaled distance was obtained as the distance divided by the cube root of the net weight of PETN, 95% of the measured weight of the pellets. The output signals were recorded using a transient recorder (LTT184/8,

Fig. 1 Setup of explosive, water in container, and wall.

sampling rate of 1.04 MHz and resolution of 16 bits in this study; Labortechnik Tasler GmbH) through an amplifier system (30510 and 30622; H-Tech Laboratories, Inc.).

2.6 Standard Experiments—Surface Explosion

Experiments without water in the container and the wall model were conducted three times to confirm the system reliability and to discuss the effects of the water and the wall. The result demonstrates that the dispersion of the peak overpressure and scaled positive impulse were less than 10% and 5%, respectively. The averaged data are referred to herein as the “standard data”. The other obtained data were compared with the standard data.

3. Results and Discussions

After the explosion, water was spattered along the wall, but it did not pass over the wall. The obtained pressure histories were fitted by spline functions, and blast pressure (blast parameters), which were the peak overpressure (peak pressure hereinafter) and the positive scaled impulse, were determined.

Figs. 2a and 2b show the relation between the scaled distance and the peak pressure or the positive scaled impulse of the experiments, in which the container height was varied. The positive scaled impulse [7] (scaled impulse or impulse hereinafter) was defined as the positive impulse divided by the cube root of the net weight of PETN, 95% of the measured weight of the pellets. The solid curves in the figures show the standard data fitted by quadratics on the log-log plane as the standards. The peak pressure was mitigated at near points to less than $5.4 \text{ m} \cdot \text{kg}^{-1/3}$ (Fig. 2a). It was not obviously mitigated at further points because the symbols are almost on the curve. It is difficult to discuss the mitigation effects by water based on this graph. However, the symbols of impulse are apparently lower than those of the solid curve (Fig. 2b). The mitigation effect seems to depend on the container height.

Figs. 3a and 3b portray the results of the experiments for which the container was placed along the wall. The peak pressure was not mitigated clearly by presence of water at all measured points in Fig. 3a. However, the impulse was mitigated, even though the container was placed as separated from the explosive (Fig. 3b). The mitigation effect was much less than when it was placed close to the explosive.

The mitigation of blast pressure by water was evaluated quantitatively using the equivalent ratio [8] because it is difficult to discuss the mitigation effect of water solely from the information in Figs. 2 and 3. The equivalent ratio is defined as the ratio of the explosive weight (surface explosion without wall and water, standard data/experimental condition) that provides the same blast parameter at the same radial distance from each of the explosives. An experimental condition with a large equivalent ratio can generate the same blast parameters but with small amounts of explosive and is therefore more powerful and dangerous. The equivalent ratio of 1 implies that the blast parameter of the experimental condition is equal to that of the surface explosion. The equivalent ratio can therefore be calculated independently using the specific blast parameter, such as the peak overpressure and the impulse. The equivalent ratio also depends on the scaled distance. The relation between these blast parameters and the scaled distance was fitted using quadratics as a log-log plot. Comparing a curve of each experimental condition with that of the standard data, the equivalent ratio was calculated.

The obtained relation between the equivalent ratio and the scaled distance is shown in Figs. 4a and 4b. The peak pressure was mitigated at points close to the point of the explosion (Fig. 4a). Mitigation corresponded to 20-30% reduction of the explosive weight. The mitigation effect was slight at distant points, probably because of the diffraction of the blast wave after passing through the wall [5]. For a wall without water (solid line), the equivalent ratio at further points was greater than 1. All lines

Fig. 2 Relation between the scaled distance and (a) the peak overpressure and (b) the positive scaled impulse. The amount of the water was examined.

Fig. 3 Relation between the scaled distance and (a) the peak overpressure and (b) the positive scaled impulse. The place of the water container was examined.

Fig. 4 Relation between the scaled distance and the equivalent ratio based on (a) peak overpressure and (b) positive scaled impulse.

corresponding to the data with water are below the solid line. Therefore, the mitigation effect of water itself to the peak pressure is confirmed. In fact, the mitigation effect depends on the water amount.

The scaled impulse was independent of the scaled distance (Fig. 3b). All equivalent ratios in the range of this study were less than 1. The mitigation corresponded to 20-30% reduction of explosive weight. The blast profile shows that the peak pressure was not mitigated compared with the standard data, but the duration was short and the pressure decay was sharp at points that were distant from the point of explosion. Thereby, the impulse was small. Much water possessed greater mitigation effects to both blast parameters, similar to the peak pressure.

The chain double-dashed lines in Figs. 4a and 4b show the equivalent ratio of the case in which the container was placed along the wall. Even in such a condition, the mitigation effect was observed clearly. Compared with the result of same volume of water ($h = 15$ mm), the mitigation effect was small. However, in practice, it might be difficult to place water near explosives in a magazine. Consequently, this finding is important for application.

The origin of mitigation is expected to be the following: conversion from the energy of blast wave to kinetic energy of water, then absorption by evaporation of water. In addition, reflection of the blast wave at the water surface is expected to be reduced to a greater degree than by a solid surface such as steel or soil. The mitigation mechanism is not known; it remains as a subject for future investigation.

4. Conclusions

The mitigation effects of water and a wall on blast pressure were evaluated experimentally. The presence of water and a wall mitigated the peak pressure near the explosion points and the positive impulse along all

points. The mitigation effect was equivalent to 20-30% reduction of explosive weight based on discussion of the equivalent ratio. The blast wave diffraction by the wall affected the mitigation effect. Thereby, the mitigation effect on the peak pressure was slight at distant points. The finding that even the presence of water along the wall (not close to the explosive) can mitigate the blast pressure is important from the perspective of application. The exact nature of the mitigation remains uncertain. It shall be the subject of future research.

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References

- [1] Homae, T., Wakabayashi, K., Matsumura, T., and Nakayama, Y. 2008. "Dependence of Blast Attenuation on Weight of Barrier Materials." *Materials Science Forum* 566: 179-84.
- [2] Homae, T., Wakabayashi, K., Matsumura, T., and Nakayama, Y. 2007. "Attenuation of Blast Wave Using Sand around a Spherical Pentolite." *Sci. Tech. Energetic Materials* 68: 90-3.
- [3] Homae, T., Saburi, T., Matsumura, T., Wakabayashi, K., and Nakayama, Y. 2009. "Attenuation of Blast Wave Using Biodegradable Foam Material around a Spherical Charge of Composition C-4." *Sci. Tech. Energetic Materials* 70: 76-9.
- [4] Homae, T., Matsumura, T., Wakabayashi, K., and Nakayama, Y. 2008. "Blast Mitigation by a Full-Scale Concrete Wall." *Sci. Tech. Energetic Materials* 69: 92-7.
- [5] Homae, T., Matsumura, T., Wakabayashi, K., and Nakayama, Y. 2011. "Blast Pressure Distribution around a Wall." *Sci. Tech. Energetic Materials* 72: 155-60.
- [6] Zenkoku Kayakurui Hoankyokai. 2007. Hoansetsubi Kyoudotou Hyouka Iinkai Houkokusyo. (in Japanese)
- [7] Baker, W. E. 1973. *Explosion in Air*. Austin: University of Texas Press.
- [8] Esparza, E. D. 1986. "Blast Measurements and Equivalency for Spherical Charges at Small Scaled Distances." *Int. J. Impact Eng.* 4: 23-40.