Article

Experimental study on the attenuation of blast waves by a water layer

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The present paper describes the relationship between the thickness of a water layer and its attenuation effect on blast waves. The blast waves passing through the water layer were measured using piezoelectric sensors. The results show that peak overpressures and scaled impulses were reduced by approximately 97% and 87%, respectively at a scaled depth of $11.3\ \mathrm{m \cdot kg^{-1/3}}$. The water layer is confirmed to be extremely effective in attenuating blast waves.

The impedance mismatch method was employed in order to estimate the blast wave pressure. It was found that the blast wave pressure could be estimated by the impedance mismatch method for scaled depths deeper than $4\ \mathrm{m \cdot kg^{-1/3}}$.

1. Introduction

In recent years, due to the housing situation and the high rate of industrial development, the instances in which high energetic materials are stored, transported and consumed near residential districts have been increasing in Japan. If an accident occurs in such an area, the blast wave resulting from an explosion of energetic materials could cause serious damage to structures as well as loss of human life. Thus, a higher degree of safety is required when using energetic materials, as is a more effective method for attenuating blast waves in the event of an explosion.

The present study focuses on the application of a water obstacle as a potential attenuator. Several studies have examined on the attenuation of blast waves using water obstacles, for example, via water spray[1)2)] or aqueous foams[3)4)]. However, these techniques are estimated to attenuate the overpressure by less than 20 %. There have also been a number of studies on the utilization of water curtain[5)6)] and water enclosed in an elastic shell[7)], which have been shown to reduce overpressure by more than 50 %. Based on these previous studies, it is thought that as the density of the water obstacle increases the attenuation effect also increases. Thus, the present study focuses on the use of a water layer in order to prevent blast wave damage. The density of the water layer is $1000\ \mathrm{kg \cdot m^{-3}}$ which is the highest density possible for a water obstacle. In the present study, in order to investigate the attenuation effect of the water layer, underwater explosions were performed. However, very little information[8)] is available on air blasts from underwater explosions. In order to predict the effects of water as an attenuator, more data is required on air blast effects under various conditions. The present study is performed in an attempt to investigate the relationship between the water depth and the attenuation effect on the blast wave.

2. Experiments

2. 1 Blast wave pressure in free air

The first test was performed in free air in order to obtain standard data. Figure 1 shows the experimental setup in free air. The explosive ($\rho_0 = 1300\ \mathrm{kg \cdot m^{-3}}$) used in this study was comprised of 70 wt% pentaerythritol tetranitrate (PETN) and 30 wt% silicon rubber (KE10, Shin-Etsu Chemical Co. Ltd.); the latter served as a binder to control the shape of the explosives. The weight of explosives ranged from 0.01 kg to 0.12 kg. The explosives and the sensors were both located 1 m from a net shaped floor surface. The explosives were initiated by a wire-explosion type detonator (RP-501, Reynolds Industries Inc.).

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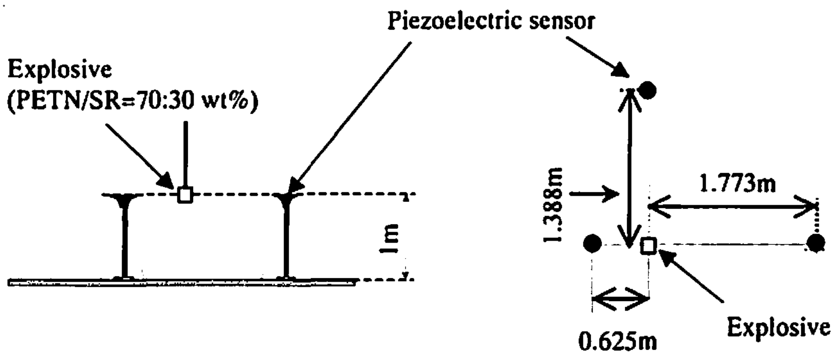

(a) Side view (b) Upper view

Fig.1 Experimental setup in free air

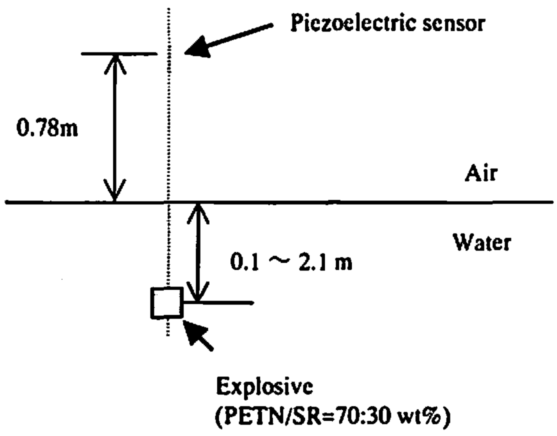

Fig.2 Experimental setup with a water layer

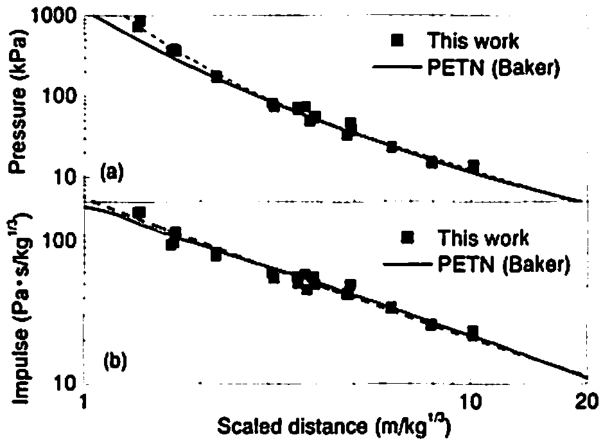

Fig.3 DTA and TG thermograms

The blast pressure was measured by three piezoelectric sensors (PCB 102A12), which were located 0.6, 1.2 and 1.8 m from the explosive, respectively. The blast wave pressure versus time was recorded using a digital waveform recorder (Sony Textronix, RTD 710A).

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2. 2 Blast wave pressure from an underwater explosion

The second test was performed with a water layer. Figure 2 shows the experimental setup of the underwater explosion. The explosives were located 0.1, 0.2, 0.3, 0.6, 0.8, 0.9, 1.4 and 2.1 m below the water surface. The charge weight was constant at 0.0095 kg. The air blast pressures resulting from the underwater explosion was measured by a sensor (PCB 102A12) located 0.78 m above the water surface. The blast wave pressure versus time was recorded using a digital waveform recorder (Gage, CS1610).

In order to investigate the relationship between the thickness of the water layer and its attenuation effect on the blast wave, the positions of the sensor and the water surface were fixed; only the charge depth was varied.

3. Results and discussion

3. 1 Blast wave pressures in free air

Figure 3 shows that the PETN data of Baker in free air (We used the detonation energy of PETN to get the PETN data with Nondimensional blast parameters of Baker[9]) and the experimental results of peak overpressures and scaled impulses versus the scaled distance. Although the peak overpressure was slightly greater than Baker's data for scaled distances of less than 3 m·kg$^{-1/3}$, the experimental results of the present study generally agreed well with the data reported by Baker. Thus, the present experiment was confirmed to provide reproducible, valid data.

3. 2 Air blast pressures with the water layer

Figure 4 shows the blast wave histories recorded with and without a water layer, at a charge depth of 0.1 m and a sensor-to-explosive charge distance of 0.88 m. The blast intensity is clearly attenuated as a result of the water layer. In Fig. 4, it was also found that the time duration of blast wave is much longer in the presence of a water layer. The decay shape of the blast wave pressures passing through a water layer differs from that of blast wave pressures passing through the air only. There are two possible explanations for this. One possibility is that this is due to the influence of the reflection wave[10]. When the primary shock wave reaches the water surface, the reflected wave is always a rarefaction wave. When the rarefaction wave reaches the gas bubble, the reflected wave is a compression wave. The compression wave also goes through the water surface, and propagates in the air. The compression wave must eventually be combined into the blast wave passing through the water layer by the primary shock wave. The other possibility is that the effect is due to the gas bubble energy released into the atmosphere. At a scaled depth of 0.5 $m \cdot kg^{-1/3}$, a gas bubble caused by a charge of this size would reach the water surface before its contraction begins[11]. The measurements of shock wave pressures taken underwater confirmed that the gas bubble pulse disappeared.

Figure 5 shows the peak overpressures and the scaled impulses versus the scaled distance. Comparison of the free air data with the water layer data revealed that the peak overpressure and the scaled impulse were greatly reduced by the presence of the water layer. It was confirmed that a water layer was extremely effective for attenuating blast waves.

Figure 6 shows the pressure attenuation ratio $(P_0-P_w)/P_0$ and the impulse attenuation ratio $(I_0-I_w)/I_0$ as a function of the scaled depth, where P_w and P_0 are the peak overpressure with and without the water layer, respectively, and I_w and I_0 are the scaled impulse with and without the water layer, respectively. The scaled depth is the distance from the explosives to the water surface. The attenuation effects were found to increase with the scaled depth. Comparison of the attenuation ratios of pressure and impulse revealed that the attenuation effect on the peak overpressure was greater than that on the scaled impulse.

4. Theoretical analysis using the impedance mismatch method

Figure 7 shows the pressure (P_s) as a function of particle velocity (u_p) for water and air. The Hugoniot of water and air were obtained from the experimental data[12][13]. When the primary shock wave reaches the water surface with a pressure P_1, its pressure is released, and drop down to a pressure P_2. The pressure P_2 would be found on the mirror-reflected P-u_p curve of water. It is believed that the pressure P_2 can be

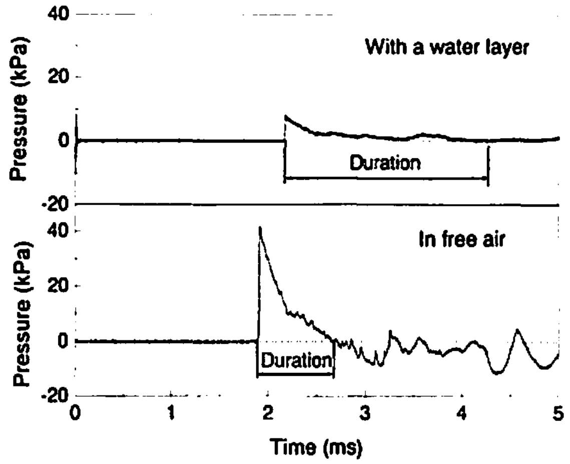

Fig.4 Comparison of the overpressure-time histories (at 4.7 $m \cdot kg^{-3}$)

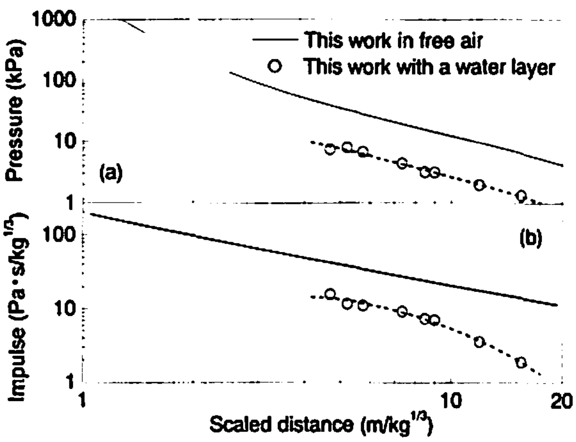

Fig.5 Peak overpressure (a) and scaled impulse (b) with a water layer

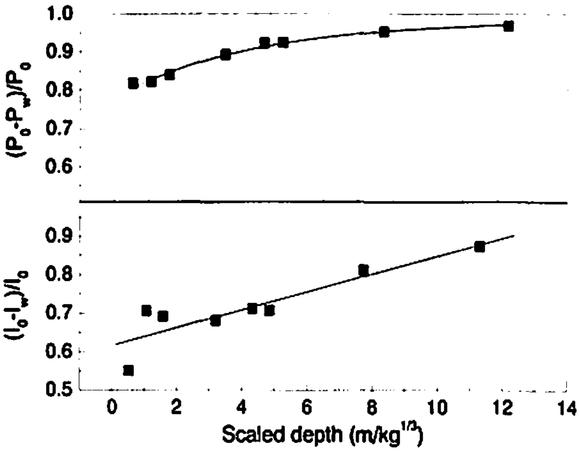

Fig.6 Attenuation ratios of peak overpressure and scaled impulse

determined by the impedance mismatch method.

When the primary shock wave arrives at the water surface, P_1 can be estimated by the distance from the explosive charge to the water surface and the weight of the explosive charge. Then, the air blast pressure of P_2 can be estimated using the impedance mismatch method. Finally, the pressure at the sensor located 0.78 m above the water surface can be estimated by the scaled distance. In the present study, the PETN data of Baker were used to estimate the pressures.

Figure 8 shows the theoretical value based on the impedance mismatch method and the experimental data. The agreement between the two was found to improve with increasing scaled depth. However, near the water surface, the experimental data deviates greatly from the theoretical data.

The result of the present study shows that the attenuation effect of the peak overpressure can be estimated by the impedance mismatch method for the case of a deep underwater explosion. In a further study, more detailed measurements will be performed for a shallow explosion.

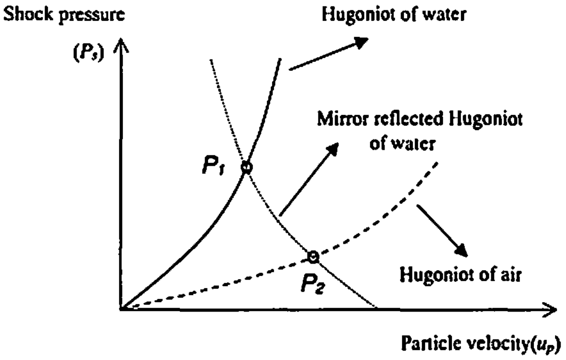

Fig.7 Illustration of the impedance mismatch method

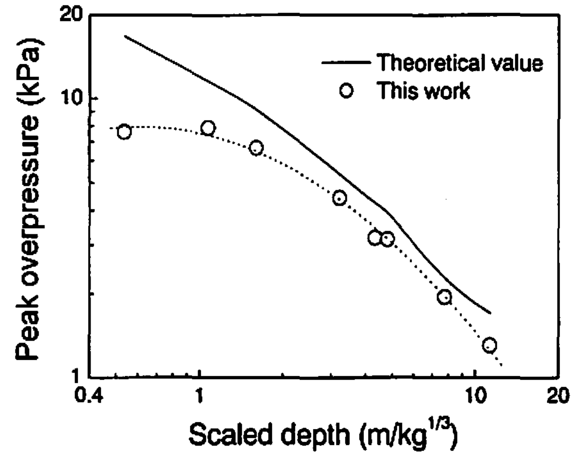

Fig.8 Comparison of the theoretical value and the experimental data

5. Conclusions

The present paper describes the effects of a water layer on the attenuation of blast waves;

- The peak overpressure and the scaled impulse were reduced greatly by the presence of the water layer. It is confirmed that a water layer is highly effective in attenuating blast waves.
- Comparing the attenuation ratios of pressure and impulse, the attenuation effect on the peak overpressure was found to be greater than that on the scaled impulse.
- The decay shape of blast wave pressures passing through a water layer differs from that of blast wave pressures passing through the air only.
- By using the impedance mismatch method in the case of a deep underwater explosion, the attenuation effect on the peak overpressure can be estimated.

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