Attenuation of blast waves by a water column

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This paper describes the attenuation of a blast wave by a water column. After a water column had been generated by a previous underwater explosion, a blast wave was caused by the detonation of a high explosive. The blast pressures passing through the water column were measured using piezoelectric gauges. The result showed that peak overpressure and scaled impulse were reduced by about 90% and 80%, respectively. It was concluded that the water column effectively attenuated the blast waves.

1. Introduction

One way to reduce blast pressure is to place obstacles between the explosive source and structures that require protection. Several studies have been conducted on the attenuation of blast waves using water obstacles, such as water curtains [1], aqueous foams [2][3] and liquid sheets [4]. However, the attenuation effects using these techniques are estimated to reduce overpressure by relatively less than 20% or more.

This paper focuses on the use of a water column as an attenuator to prevent blast wave damage. To reduce the intensity of the blast wave, it is necessary to increase the density of water sprayed into the space through which the blast wave passes. A water column generated by an underwater explosion was selected. This technique can create high water density around the main explosives within several hundred microseconds. The present study aims to investigate the relationship between the behavior of the water column and the attenuation effect on the blast wave.

2. Experimental

2.1 The behavior of the water column

Figure 1 illustrates the experimental arrangement for measuring the height and width of the water column. A small charge (1 g) of explosive which comprised of 70 wt% pentaerythritol tetranitrate (PETN) and 30 wt% of silicon rubber (KE10, Shin-Etsu Chemical Co. Ltd.), was used for generating the water column. The average density of the charges was about 1300 kg · m^{-3}. The explosive for generating the water column was settled in a plastic tank (ϕ570 mm×H450 mm) filled with water, and was situated at a depth of 130 mm from the water surface; the axis of symmetry was the center of the tank. The explosive was initiated by a detonator of the EBW (exploding bridge wire, RP-501, Reynolds Industries Inc.) type. The behavior of the water column was analyzed using a high-speed video camera (Redlake MotionScope PCI Model 2000).

2.2 Measurement of the blast wave

The measurement system for the blast wave is also shown in Fig. 1. The 9 g of main charge that is the same charge for generating the water column, was set directly above the water tank. The main explosive for the blast generation must be detonated after detonation of the water column explosive. In

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this work, the delay time (t_d) is controlled by a digital pulse generator (DG-535, Stanford Research Systems, Inc.). The pressure of the blast wave was measured using two piezoelectric gauges (H102A12, 102A12, PCB Piezotronics, Inc.), which were located at the same distance of 0.6 m from the main explosive. The blast wave history versus time was recorded using a digital waveform recorder (Sony Textronix RTD 710A).

The effect of the delay time on attenuation of the blast pressure was investigated. It is considered that changing the delay time would also change the water density around the main explosive and therefore, would influence the attenuation of the blast pressure. In this study, the delay time was set to 10, 50, 100, 150 and 500 ms.

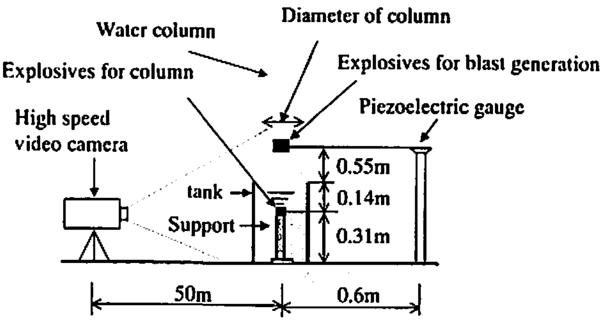
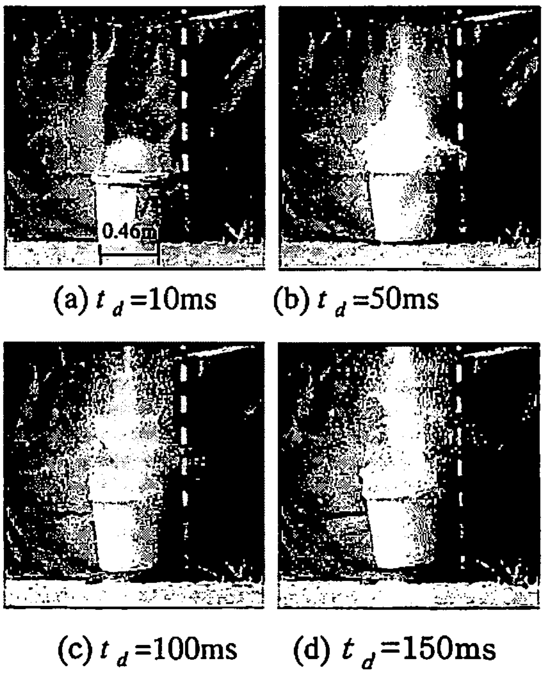


Fig.1 Experimental setup of water surface rise and for blast wave measurement

3. Results and discussion

3. 1 The behavior of the water column

Figure 2 shows the photographic records of the water column taken by the high-speed camera. It is found that the water surface has a hemispherical shape at t_d=10 ms. The growth of the dome may be considered to be caused by the reflection of the shock wave at the surface [5]. The gas bubble then makes the hemispherical shape change into a water column. Figure 3 illustrates the heights and diameters of the water columns obtained for each delay time. It is found that the diameter of the water column is the widest when the time delay is about 100 ms. The behavior of the water column is supposed to be controlled by the opposing forces of gravity and air resistance.



(a) t_d=10ms (b) t_d=50ms

(c) t_d=100ms (d) t_d=150ms

Fig.2 Photographic record for water surface rise at (a) t_d=10 ms, (b) t_d=50 ms, (c) t_d=100 ms, (d) t_d=150 ms.

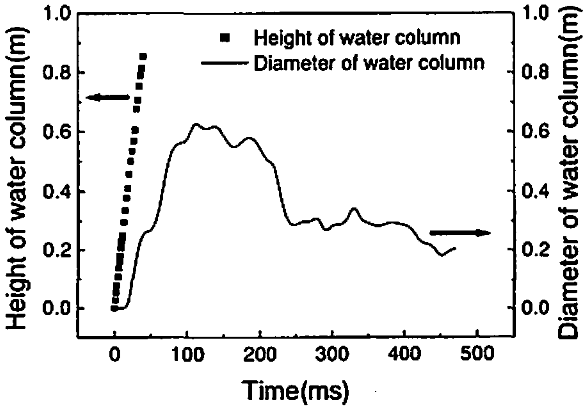


Fig.3 Height and diameter of water column versus time

3. 2 Attenuation of pressure and impulse

Figure 4 shows the blast wave histories versus time recorded with and without the water column. It is found that the blast intensity is attenuated when the main explosive is detonated with a water column.

The time-histories were interpolated by smooth cubic natural spline functions to obtain peak static overpressure and impulse (the time-integral of the overpressure during the positive pressure phase). Figure 5 shows the non-dimensional peak overpressure ratio (P_w / P_0) and the non-dimensional scaled

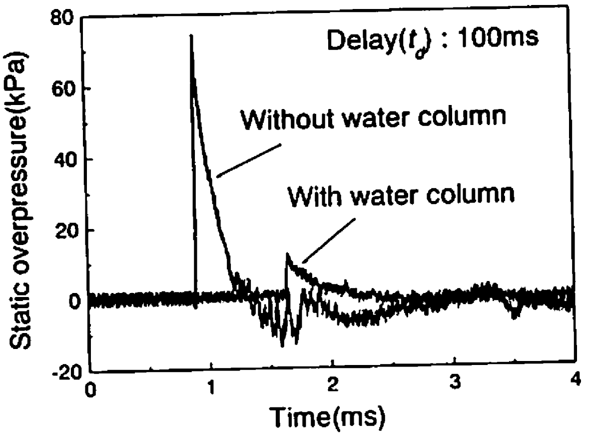


Fig.4 Comparison of the overpressure-time histories (Weight of explosive = 0.009 kg)

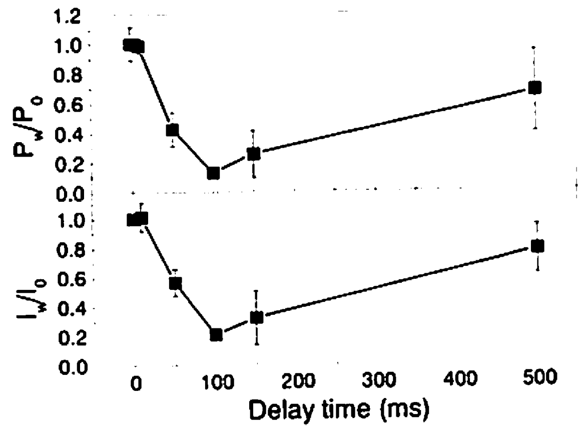


Fig.5 Non-dimensional peak overpressure and non-dimensional scaled impulse versus delay time (Weight of explosive = 0.009 kg)

impulse ratio (I_w/I_0) versus the delay time, where P_w and P_0 are the peak overpressure with the water column and without the water column, and I_w and I_0 are the scaled impulse (the impulse which is proportional to the cube root of the explosive weight) with and without the water column. When the delay time is 100 ms, the non-dimensional peak overpressure and the non-dimensional scaled impulse are 0.12 and 0.21. It is found that when the diameter of the water column is at its greatest, i.e. at t_d =100 ms, the attenuation effects are also the most significant. At the delay times of 50 and 150 ms, the peak overpressure and the scaled impulse are also lower. However, these results contain a degree of error. It is assumed that the water column did not remain uniform, even if it had been uniform at the beginning. It is found that the water tank expands and shrinks as shown in Fig. 3. This lack of uniformity of the water column may have been due to the deformation of the tank. When the delay time is 10 ms, the attenuation effects are less evident. This is probably because the water column was not created in time to block the blast wave from the main explosive. After the delay time becomes 150 ms, i.e. t_d =500 ms, the attenuation effects become less. This is probably because the high-density part of the water column passes through the point of the main explosive.

As a result, it is found that the set of the delay time is deeply connected with the attenuation effects. It is considered that the water column density has a strong influence on the degree of attenuation of the blast wave.

4. Conclusions

This paper describes the effects of a water column on the attenuation of blast waves created by the detonation of a high explosive. The peak overpressure and the scaled impulse are found to be reduced by about 90% and 80%, respectively when the delay time is 100 ms. It is confirmed that a water column is one of the most effective attenuators of blast waves.

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