Research paper

Study of the blast wave ejected from the semi-sealed concrete structure

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Abstract

The explosion experiment was conducted in a semi-sealed concrete structure such as a magazine in order to investigate blast wave characteristics ejected from an exit of the structure. Composition C-4 was set in the center of the structure that has an opened surface on one side as the exit. Reflection pressure and impulse of the blast wave ejected from the exit were measured with piezo-electric pressure sensors. As a result of the experiment, it was found that distributions of the reflection pressure was such as "M-shaped function", and the impulse was such as "Inversed U-shaped function" using the center-line of the exit as a symmetry axis, respectively. Moreover, numerical simulations showed that multiplied shock wave was occurred by a shock wave induced from the explosion and a reflection wave from the ground surface. In addition, this shock was more enhanced by a reflection wave that occurred on the exit wall. This effect caused non-uniform distribution for the blast wave ejected from the exit of the structure.

Keywords: blast wave, magazine, reflection pressure, impulse

1. Introduction

Propagation of the blast wave, peak overpressure and impulse in air have been studied for many years[1)−3)]. However, there are few studies about the blast wave ejected from the magazine. Moreover, recent studies are focused on an underground magazine[4)−8)], and main attentions has been directed to the propagation of the blast wave in the magazines and intensity of the blast wave ejected from the magazine. The blast wave ejected from the magazine have been reported in several studies[9)−10)], but there are few reports for the blast wave characteristics near the exit of the magazine.

In this paper, in order to investigate the characteristic of the blast wave ejected from the magazine, the explosion experiment and the numerical simulation were conducted in a semi-sealed concrete structure such as the magazine.

2. Experimental and numerical simulation

2.1 Experimental set up

Figure 1 shows experimental set up. The explosive was set in the center of the concrete structure, and pressure sensors were set out of the structure exit. The inner size of the concrete structure were 7.5 m in length, 7.5 m in width and 6.0 m in height, and one side opened as the exit, which size were 1.6 m in length and 2.0 m in width and 2.5 m in height, respectively. Composition C-4 in 2.0 kg weight was set in air at 1.0 m in height from ground, and ignited by an electronic detonator. The ground under the explosive was sand and leveled. A piezo-electric pressure sensor (PCB model 113B24) was set in a 120 mm diameter sensor mount to measure reflection pressure. Five sensor mounts were set at 0.82 m in height from ground and at 6 m in distance from the explosive, and in five different points against the center-line, which were 0 m (i.e. on the center-line), 0.25 m, 0.50 m, 0.75 m, and 1.00 m from the center-line.

2.2 Numerical simulation

The propagation of the blast wave that interacted with the inner and the exit wall of the structure was investigated in a hydro-code AUTODYN 2-dimension and 3-dimension. Figure 2 shows schematics of 2-dimensional and 3-dimensional numerical simulations. CONC 140 MPA, SAND, C 4 and AIR, which are models of the AUTODYN data library, respectively, were set for structure, ground, explosive and air. These material properties were in

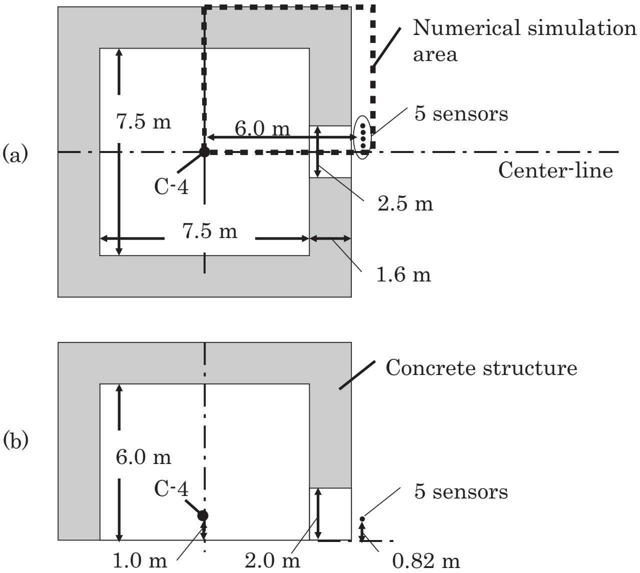

Figure 1 Experimental set up.
Composition C-4 was set in the center of the concrete structure, and 5 piezo-electronic pressure sensors were set out of the concrete structure. (a) Top view, and (b) Side view, respectively.

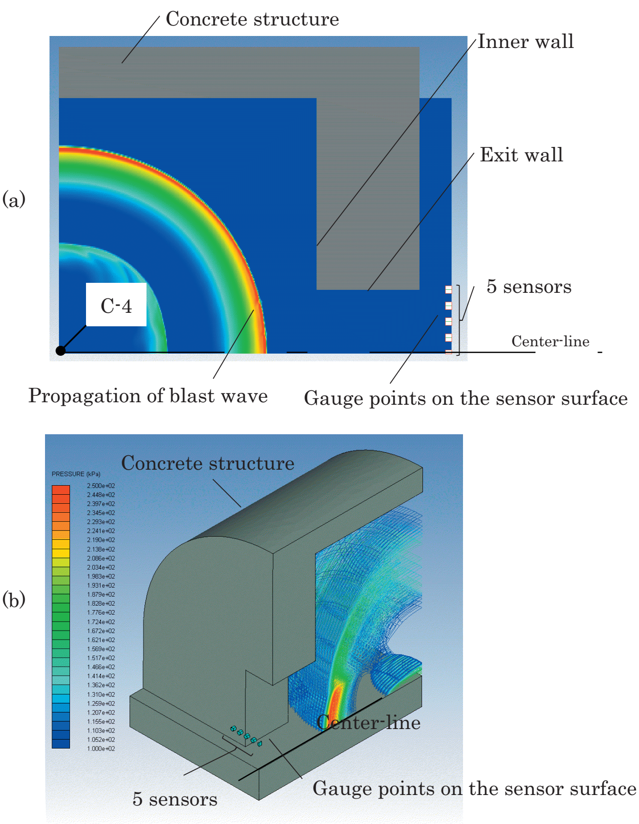

Figure 2 AUTODYN model.
(a) 2-dimensional model, and (b) 3-dimensional model, respectively. Gauge points are set on each sensor surface.

AUTODYN material library. To investigate the effect of structure shape simply, the structure and ground were set as rigid bodies, and the inner wall of structure was not set any terms. First, as shown in Figure 2 (a), 2-D numerical simulation was conducted to investigate basic tendency. Second, as shown in Figure 2 (b), 3-D numerical simulation was conducted to investigate the influence of reflection from ground surface. In each simulation, gauge points that

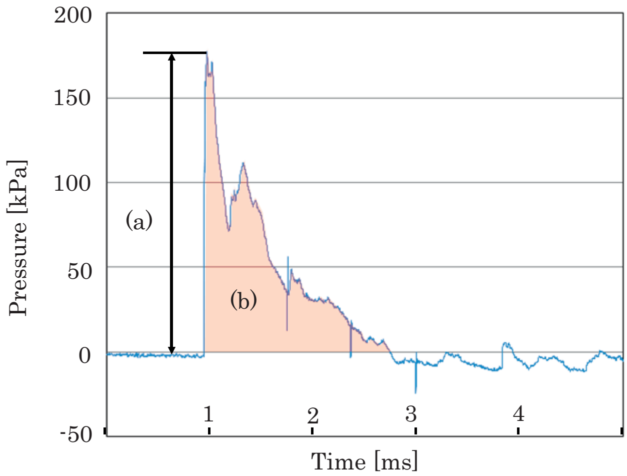

Figure 3 A pressure wave measured with sensor.
(a) Peak overpressure (P_{max}), (b) Impulse, and (c) Duration of positive phase, respectively.

Table 1 Experimental P_{max} and impulse.

Distance from center-line [mm]	P_{max} [kPa]	Impulse [Pa·s]
0	164	125
	182	136
	170	133
	160	128
	169	138
250	209	136
500	229	127
	220	123
	210	116
750	181	98
	170	91
	197	104
1000	140	75

get pressure profiles were set in front of each sensor parts.

3. Result and discussion

3.1 Experimental result

A shallow crater-like dent was found under the explosive point after ignition. A reflection pressure profile measured with sensor in experiment shows in Figure 3. As shown in Figure 3, Peak overpressure (P_{max}) is defined as a top value of pressure (a) in Figure 3, and impulse is defined as an integrated value of positive pressure area (b) in Figure 3. Duration is defined as a time of positive pressure phase (c) in Figure 3.

Table 1 shows the experimental results of the P_{max} and the impulse, and Figure 4 shows comparisons of each value for the distance from the center-line. In Figure 4, "0 mm" of side axis means "on the center-line" in Figure 2 (a), (b).

As a result of the experiment, it was found that the P_{max} at the point of 0.5 m in distance from the center-line was the biggest. The P_{max} showed the distribution such as "the

M-shaped function" using the center-line as a symmetry axis. On the other hand, the impulse at the point of 0 m (i.e. on the center-line) in distance from the center-line was the biggest. This showed the distribution such as "the U shaped function" using the center-line as a symmetry axis.

Generally, as the distance from the explosive increases, the pressure induced by explosion decreases[1), 2)]. However, as shown in Figure 3, the P_{max} distribution did not indicate this tendency. This was suggested that the effect of interaction with the structure was strong in P_{max}. On the other hand, as the distance from explosive increased, the impulse decreased. But, the impulse at the point of 0 m was not high compared with 0.25 mm and 0.50 mm in distance from the center-line. This was suggested that the effect of interaction with the structure was weak in impulse. The duration shown in Figure 3 (c) was not changed through from 0 mm to 1.00 m in distance from the center-line.

3.2 Analysis of numerical simulation

3.2.1 2-dimensional simulation

Figure 5 shows 2-dimensional simulation results. Figure 5 shows that the blast wave induced by the explosive initiation interacted with the inner and the exit of the wall. The blast wave propagated as below (1) ~ (3).

(1) As shown in Figure 5 (a), the reflection wave occurred on the wall, when the blast wave propagating with a curved shock front interacted with the inner wall of the structure[1), 2)]. For the same reason, the reflection wave occurred on the exit wall. In particular, on the exit wall, a triple point occurred by interference between the incident blast wave and a Mach stem induced by the reflection wave[3)], and the high-pressure region is following the Mach reflection.

(2) As shown in Figure 5 (b), when the incident blast wave reached the outside through the exit, the triple point and the Mach stem established the reflection wave on the exit wall disappeared. However, the high-pressure region following the Mach reflection remained, and it caused non-uniform distribution for the blast wave.

(3) As shown in Figure 5 (c), when the propagating blast wave reached at the sensors surface, the reflection region occurred on the sensors surface. As is evident from Figure 5 (c), the high-pressure region is not the sensor at 0 m but at 0.5 m in distance from the center-line.

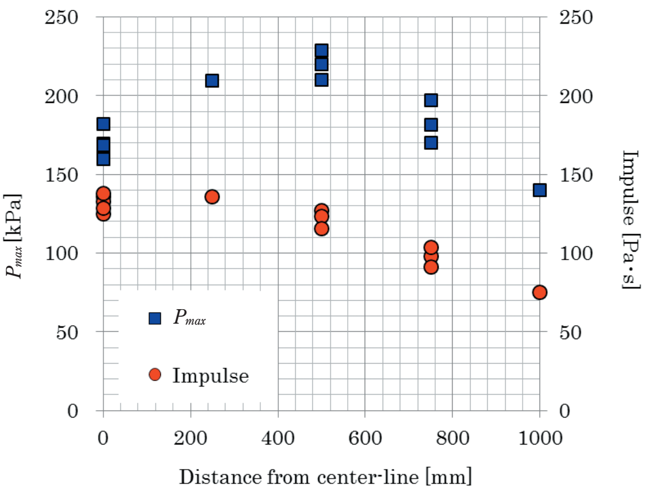

Figure 4 P_{max} and impulse in distance from the center-line.

3.2.2 3-dimensional simulation

Figure 6 shows 3-Dimensional simulation results. Figure 6 (a) shows that the blast wave was enhanced by the reflection from ground surface. Figure 6 (b) shows that the blast wave was enhanced by the exit wall from bottom to top of the exit wall.

Table 2 shows each P_{max} for experimental result, 2-dimensional and 3-dimensional simulation. Figure 7 shows comparison of each P_{max} for distance from center-line. As shown in Figure 7, the 2-dimensional simulation did not agree with the experimental result. But, the 3-dimensional simulation agreed with the experimental result. This differ shows the effect of the reflection of ground surface[3)].

Table 3 shows each impulse for experimental results, 2-dimensional and 3-dimensional simulation. Figure 8 shows comparison of each impulse for distance from the center-line. As shown in Figure 8, the 2-dimensional and the 3-dimensional simulations agreed with the experimental result, since the each duration in Figure 3 (c) were same. This was suggested that the effect of the reflection of the exit wall and ground surface is not in the duration of positive pressure phase in Figure 3 (c) but in the peak overpressure in Figure 3 (a).

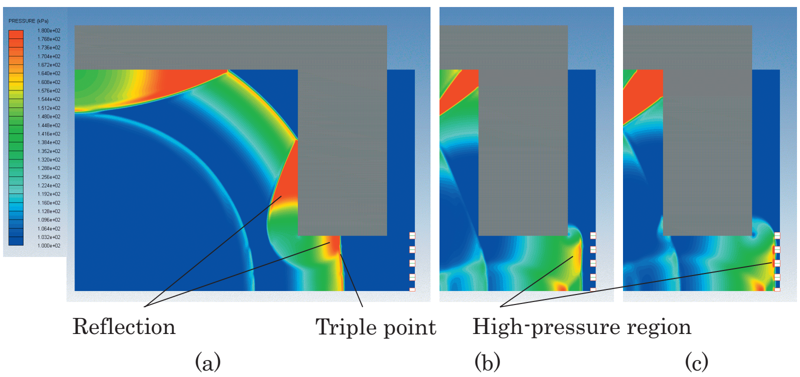

Figure 5 Propagation of blast wave reflected by concrete structure.
(a) Reflection and triple point occurred due to interference between the incident shock wave and the inner and the exit wall of the structure, (b) High pressure region propagating along the exit wall, and (c) High pressure region on the sensor surface, respectively.

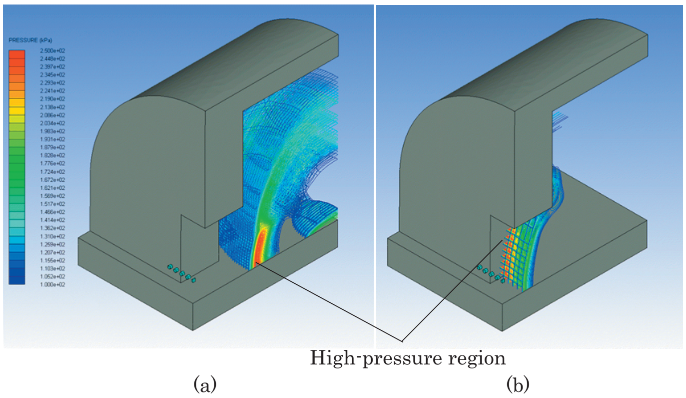

Figure 6 Reflection of ground surface and exit wall. (a) Reflection by ground surface, and (b) Reflection by the exit wall, respectively.

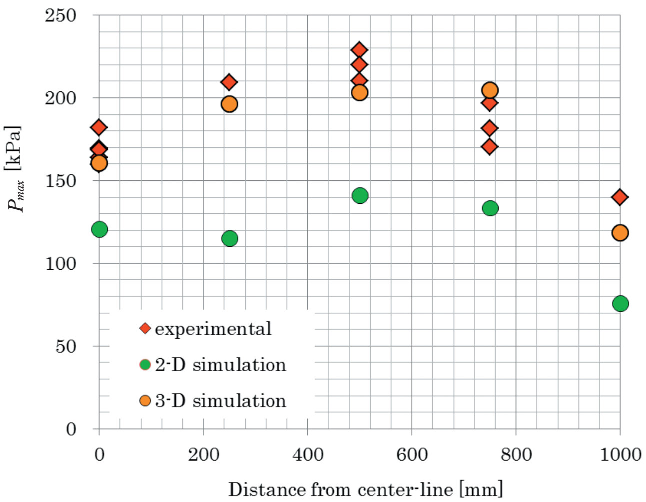

Figure 7 Comparison of P_{max} for experimental, AUTODYN 2-D and 3-D, respectively.

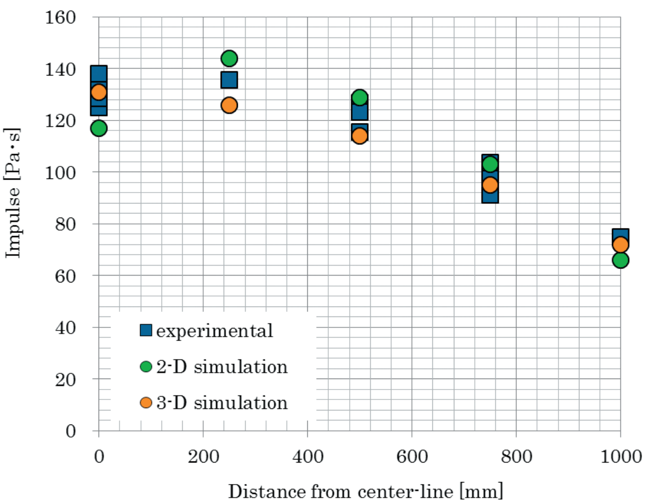

Figure 8 Comparison of impulse for experimental, AUTODYN 2-D and 3-D, respectively.

4. Conclusion

In this paper, the characteristic of the blast wave ejected from the exit of the concrete structure such as a magazine is revealed. It was found that the high-pressure region occurs on the exit wall and propagate outside, when the blast wave with curved shock front interacted with the exit wall. It caused non-uniform distribution for the blast wave, and the distribution of the reflection pressure showed "M-shaped function", and the impulse showed "Inversed U-shaped function" using the center of the exit as a symmetry axis, respectively. The ground deformation was not take into account in the numerical simulation. However, the numerical simulation agreed with the experimental result due to the reflection of the exit wall and ground surface. Thus, it considered that the distribution of pressure is influenced by the shape of structure mainly.

Table 2 P_{max} for experimental, AUTODYN 2-D and 3-D.

Distance from center-line [mm]	P_{max} [kPa]		
	Experimental average	Simulation 2-D	Simulation 3-D
0	169	121	160
250	209	115	196
500	220	141	203
750	183	133	205
1000	140	76	118

Table 3 Impulse for experimental, AUTODYN 2-D and 3-D.

Distance from center-line [mm]	Impulse [Pa·s]		
	Experimental average	Simulation 2-D	Simulation 3-D
0	132	117	131
250	136	144	126
500	122	129	114
750	98	103	95
1000	75	66	72

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