Research paper

Blast pressure distribution around a wall

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Abstract

Blast pressure distribution around a wall for protection is evaluated. The relation between the azimuth angle, distance, and blast parameters, such as peak pressure and positive impulse, was examined. A cylindrical pentaerythritol tetranitrate (PETN) pellet of 1.4 g was put on a paper box, whose height was 15 mm, was detonated on a steel plate. A model wall, whose height, width and thickness was 63 mm, 104 mm, and 6.0 mm, respectively, was placed at 60 mm from the charge. The distance measured in scaled distance from 5.4 m・kg$^{-1/3}$ to 21.7 m・kg$^{-1/3}$. The direction measured in angles from 0° to 180°, where 0° was defined as a vertical from the PETN pellet to the wall plane. The peak pressure was extremely mitigated at the direction of 30°, while it was slightly enlarged at the direction of ranging from 120° to 150°. The impulse was mitigated at direction of less than 90°, especially at 40° and 50°, while it was enlarged at direction of more than 90°. The area enclosed by the isobaric line of scaled impulse moved to the direction of 180°.

Keywords : explosive, blast pressure, wall, mitigation, distribution.

1. Introduction

A wall is often used to protect people and valuables from the blast wave and fragments caused by an unexpected explosion. The blast pressure distribution around the wall must be evaluated for the purpose of protection from the blast wave. Sudo reported the blast pressure distribution around a full−scale wall[1]. However, the precise result and the blast data are not described in the report. Although Mizushima also reported the mitigation effect of a full−scale wall[2], the pressure measurement in the report did not have time resolution. Authors have been reported[3] the distribution of blast parameters around a full scale concrete wall with TNT of 80 kg. As the scale of the experiments was large, the number of experiments and the arrangement of pressure transducers were strictly limited.

This study concerns the precise distribution of the blast pressure around the wall. The full scale concrete wall was similarly reduced as the weight of the explosive was the order of 1 g and the experiments were carried out in an indoor pit. The reflection of the blast wave by the wall was also examined, which was not evaluated in the full scale experiment[3].

2. Experimental

2.1 Test explosives

A pressed pellet made of pentaerythritol tetranitrate (PETN) and carbon powder was used as an explosive. The pellet consists of 95 weight % of PETN and 5 % of carbon powder. The pellet was cylindrical with diameter of 10.7 mm and the length of 10.9 mm. The weight and the density of the pellet were 1.4 g and 1.55 Mg・m^{-3}, respectively. Specially designed electric detonator, whose main primary explosive was tricinate of 100 mg, was used. The detonator was glued on the top of the pellet. The supplier of the explosives and detonators is Showa Kinzoku Kogyo Co., Ltd. A spacer was used so as to the height of the center of the explosive was 0.18 m・kg$^{-1/3}$. The spacer was made of pasteboard and was cubic with the edge of 15 mm. The bottom of the cylindrical pellet was glued on the spacer using epoxy resin adhesive. The spacer was held on the center of a steel disk, whose diameter was 400 mm, using

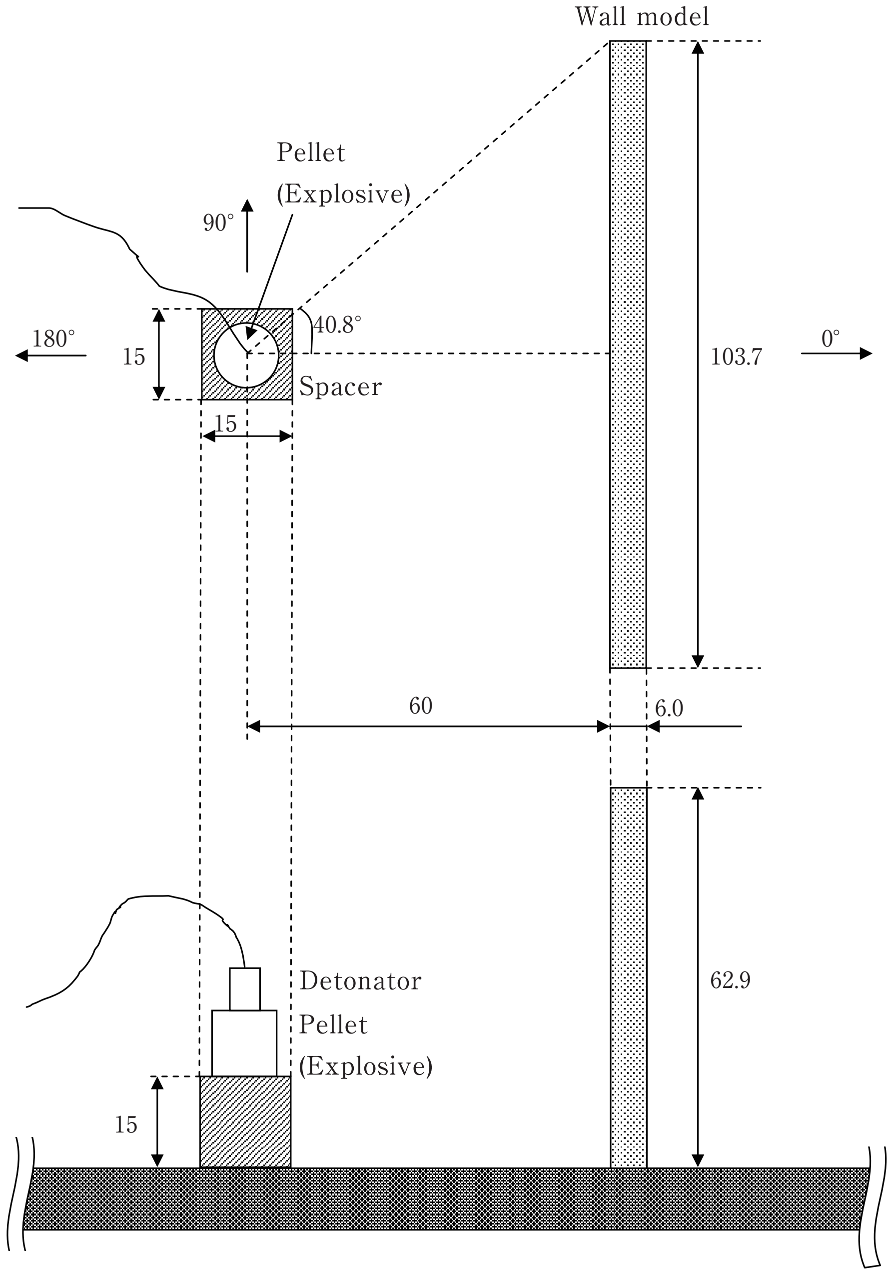

Fig. 1 Setup of the wall model and the explosive.

adhesive tape. This steel disk was fitted into the ground surface model, described later. The profile of the blast wave around the symmetry axis of the cylindrical explosive has been reported to be complicated[4]. To avoid this complication, the line of blast measurement was set to be perpendicular to the direction of initiation, which is on the symmetry axis of the cylindrical pellet.

2.2 Wall model

The wall model was made of JIS SS400 steel. The height, width, and thickness were 62.9 mm, 103.7 mm, and 6.0 mm, respectively. The wall model was screwed to the disk as the distance from the center of the explosive to inside surface of the wall was 60 mm. It is noticeable that many walls for protection actually constructed are made of concrete and are brittle, while this model is regarded as rigid body. Figure 1 represents the arrangement of the model wall and the explosive.

2.3 Ground surface model

A steel plate, whose length, width and thickness were 3200 mm, 2000 mm and 10 mm, respectively, was fixed on a table. This plate was regarded as a ground surface model. The ground surface model is represented in Fig. 2. A part of the plate was cut circularly so as the steel disk was flush with the ground surface model. To measure the pressure history around the wall, five pressure transducers described later were fixed. Instead, the disk with the wall model was rotated and the pellet was initiated for every 10 degrees. The azimuth angle of 0° was defined as a vertical from the pellet to the wall plane (Fig. 1). The pressure history was measured at ranging from 0° to 180°.

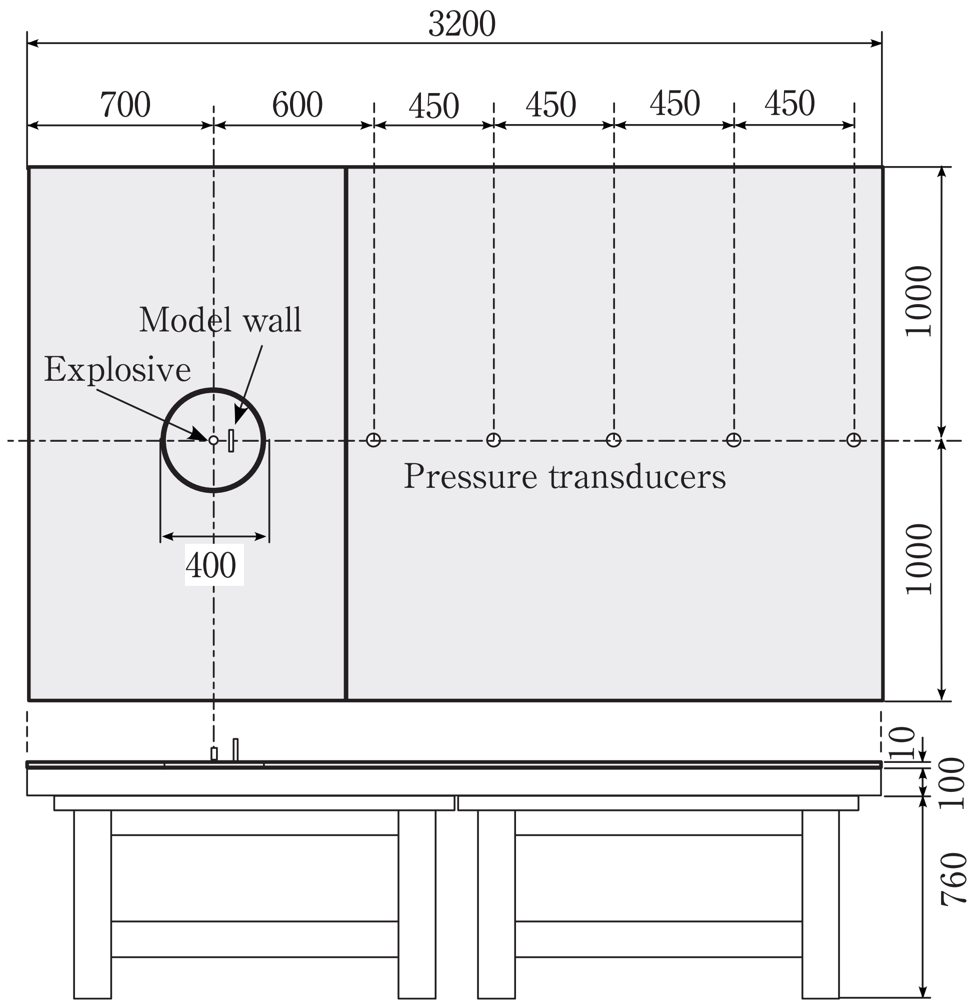

Fig. 2 Ground surface model.

2.4 Blast measurement

Five pressure transducers (102M256, PCB Piezotronics, Inc.) were used to measure the blast pressure. The pressure transducers were set with the vibration isolator (GEL Tape, Taica Corporation) as the diaphragm of the transducer was flush with the ground surface model. The distance from the center of the disk was 600 mm, 1050 mm, 1500 mm, 1950 mm, and 2400 mm, respectively. The corresponded Hopkinson scaled distance was from $5.4\,\mathrm{m \cdot kg^{-1/3}}$ to $21.7\,\mathrm{m \cdot kg^{-1/3}}$. The Hopkinson scaled distance was obtained the distance divided by 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, Labortechnik Tasler GmbH ; sampling rate of 1.04 MHz and resolution of 16 bits in this study) through an amplifier system (30510 and 30622, H−Tech Laboratories, Inc.).

2.5 Confirmation of measurement system and standard data

As the weight of the pellet is relatively small, the large dispersion due to the degree of the detonation of the pellet is possible. Experiments without the wall model were carried out for four times to confirm the reliability of the system and to discuss the effect of the wall. The result demonstrates that the dispersion of the peak overpressure was less than 10%. These experiments are referred to herein as the “standard experiment”. The other obtained data was compared with the averaged data of the standard experiment.

3. Results and discussion

Figure 3 shows the typical pressure history obtained in this study. The characteristics of these profiles are similar to those of full scale experiments, previously reported[3]. That is, split peaks of the overpressure and bumps on the decay process were observed, depending on the angle and the scaled distance. For example, the second peak immediately after the main peak was observed at angle of 20° in Fig. 3. A ramp wave was observed during the decay of the main peak at angle of 30°. The diffraction of the blast wave from an edge of the wall should cause the mitigation and delay of the peak overpressure, but should not cause the split peaks. The blast wave was diffracted at three edges of the wall in addition to the direct wave. The difference of the distance related to the route should cause the time difference of arrival.

The obtained blast wave profiles were fitted using a spline function. The peak overpressure and positive impulse (referred to as impulse, hereinafter) were then determined from the fitted curve. The Hopkinson scaled impulse, which is calculated using equation (1), are used

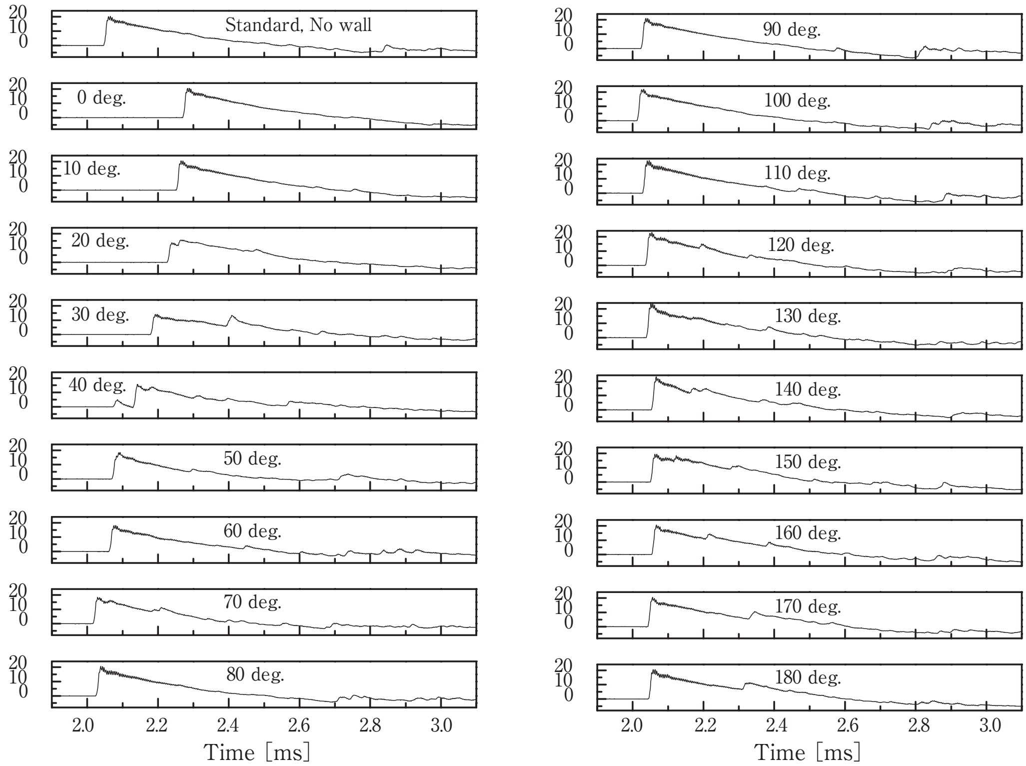

Fig. 3 Pressure history at the scaled distance of 9.5 m・kg$^{-1/3}$. The unit of the vertical axis is kPa.

for evaluation.

$$\overline{I} = \frac{I}{W^{\frac{1}{3}}} \quad (1),$$

where $\overline{I}$ is the scaled impulse, I is the impulse, and W is the weight of PETN.

The dependence of the peak overpressure and the scaled impulse on the azimuth angle is represented in Fig. 4. The vertical axes of Fig. 4 correspond to the obtained peak overpressure or scaled impulse divided by those of standard experiment. This value is referred to as "normalized peak overpressure" and "normalized scaled impulse". Figure 4 demonstrates that the wall does not reduce the peak overpressure at azimuth angle of 0°, reduces it at 30°, intensify it at ranging from 120° to 150°, and does not intensify it at ranging from 150° to 180°. The distribution of the scaled impulse moves to the direction of 180° on the whole. The impulse is remarkably reduced at 40° and 50°, whereas the impulse is relatively large at more than 90°. The maximum impulse is observed at 180°.

The relationship between the peak overpressure P (kPa) or scaled impulse $\overline{I}$(Pa・s・kg$^{-1/3}$) and scaled distance $\overline{r}$(m・kg$^{-1/3}$) of each azimuth angle were fitted using quadratics as a log–log plot using equations (2), (3), and (4).

$$\log P = az^2 + bz + c \quad (2)$$

$$\log \overline{I} = lz^2 + mz + n \quad (3)$$

$$z = \log \overline{r} \quad (4),$$

where a, b, c, l, m, and n are fitting parameters for each azimuth angle and z is a transformation parameter for the log-log plot. The obtained fitting parameters are tabulated in Table 1. Quadratics fitting was utilized as it adequately represents the data as the coefficients of determination were more than 0.992, and are also shown in Table 1.

Explosives control law in Japan requires the safety distance from an outside wall of a magazine to a object as the scaled distance of 5 m・kg$^{-1/3}$, 8 m・kg$^{-1/3}$, 14 m・kg$^{-1/3}$, and 16 m・kg$^{-1/3}$ for four levels of the objects. Thus, isobaric lines of the peak overpressure and the scaled impulse were constructed. The lines of the standard experiments and that of the experiments with the wall were compared to examine the effect of the wall. First, the peak overpressure and the scaled impulse of the standard experiment at 5 m・kg$^{-1/3}$, 8 m・kg$^{-1/3}$, 14 m・kg$^{-1/3}$, and 16 m・kg$^{-1/3}$ were calculated using fitting parameters shown in Table 1. Second, the scaled distance, where the peak over pressure or the scaled impulse corresponds to that of the standard experiments at 5 m・kg$^{-1/3}$, 8 m・kg$^{-1/3}$, 14 m・kg$^{-1/3}$, and 16 m・kg$^{-1/3}$, at every azimuth angles was calculated. The determined scaled distances were illustrated as isobaric lines as shown in Fig. 5. The origin of the circle represents the point of explosion. The lines of ranging from 190° to 350° are just mirror images of the lines of 10° to 170°. The dotted lines signify the lines of the standard experiments. The radius of the dotted lines reasonably corresponds to each levels of safety distance.

Figure 5 demonstrates that the wall affects the blast wave even at the relatively far points. The area enclosed by the isobaric line is not distinctly affected with respect to the peak overpressure on the whole. The lines significantly near the wall at around 30° and the direction is relatively safe. On the other hand, the area enclosed by the isobaric line of scaled impulse moved to the direction of 180°, compared with the standard experiment. Especially, the lines remarkably recede from the wall at

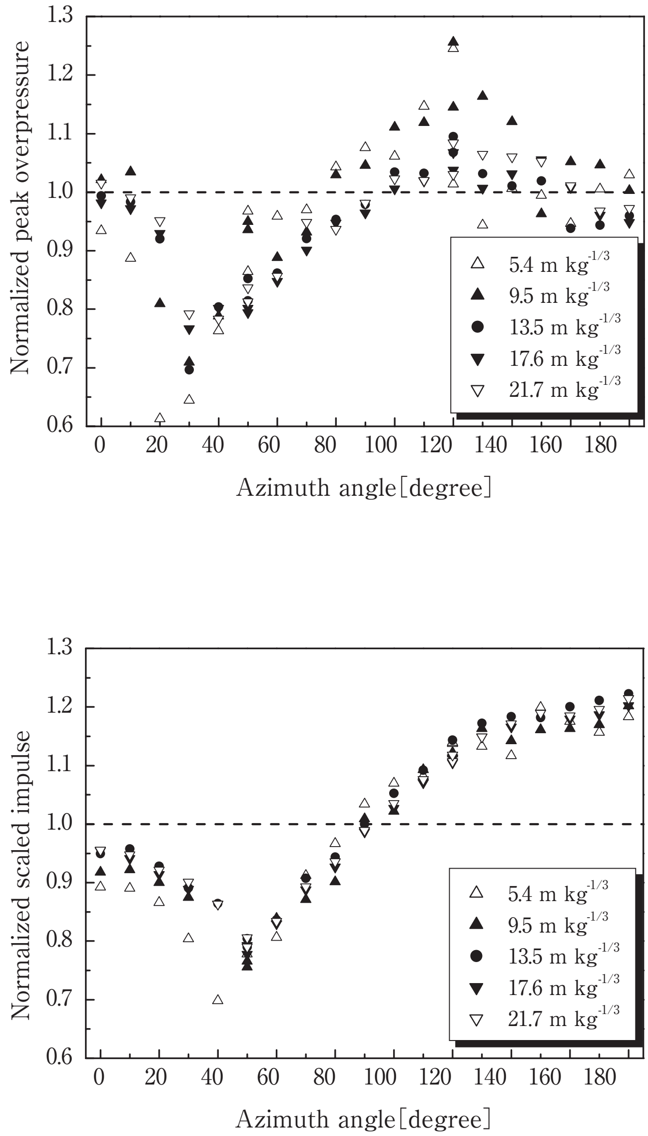

Fig. 4 (a) Dependence of the peak overpressure on the azimuth angle. (b) Dependence of the scaled impulse on the azimuth angle. The vertical axes correspond to the obtained peak overpressure or scaled impulse divided by those of standard experiment, which is carried out without the wall model.

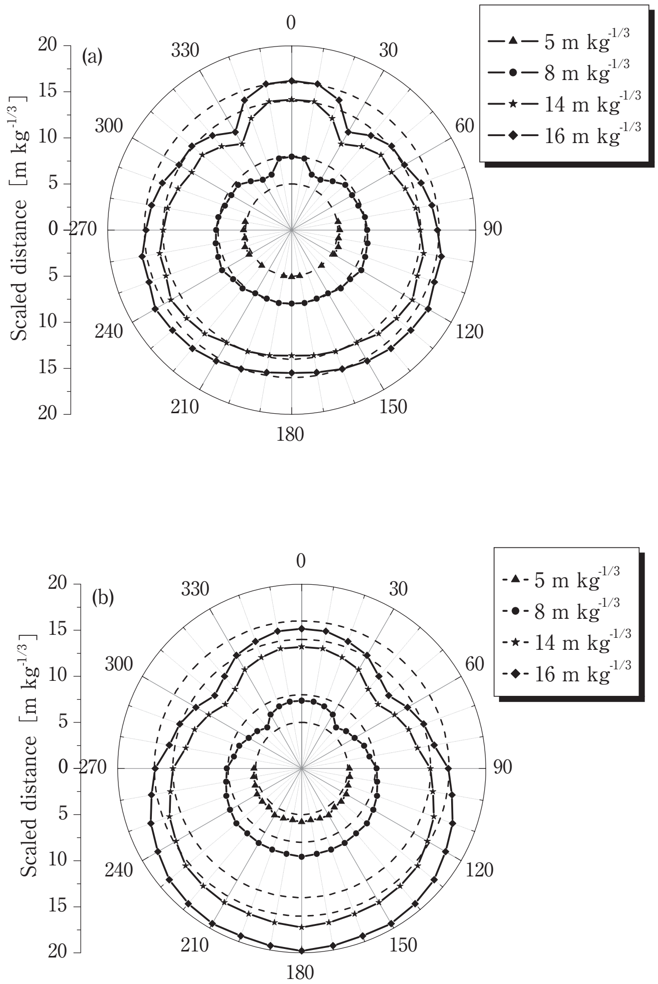

Fig. 5 (a) Isobaric line of the peak overpressure. (b) Isobaric line of the scaled impulse. Dotted line represents the case without wall. The symbols of 5 m・kg$^{-1/3}$ is partly absent, because it was beyond the measured range.

around 180°. The peak over pressure is comparable but the duration is long at around 180°, compared with the other directions. The long duration should be due to the reflected wave from the wall model in addition to the direct blast wave. The travel distance of the reflected wave was 120 mm longer than that of the direct blast wave, which was double of the distance between the explosive and the wall. The reflected wave should arrive at the pressure transducer with the delay of approximately 0.3 ms, if the reflected wave traveled extra 120 mm with the sound velocity of approximately 340 m・s^{-1}. Small peaks were observed at approximately 0.3 ms after the arrival of the blast wave at angles of 170° and 180° in Fig. 3. These small peaks should be the result of the reflected wave. Thus, the reflected wave caused the long duration and large impulse at around 180°. Fig. 5(b) suggests that the examination of the impulse at opposite side to the wall is required.

Acknowledgments

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Table 1 Fitting parameters of relationship between blast parameters and scaled distance in log-log plot.

Angle	Peak overpressure				Scaled impulse			
	a	b	c	R^2 for a, b, and c	l	m	n	R^2 for l, m, and n
Standard	0.72848	−3.08156	3.52826	0.99851	0.21539	−1.43764	2.72274	0.99933
0	0.62152	−2.69268	3.31003	0.99822	0.17179	−1.29334	2.59149	0.99992
10	0.42044	−2.26120	3.07889	0.99747	0.11497	−1.18333	2.53964	0.99962
20	0.24080	−1.62907	2.54591	0.99866	0.11310	−1.18142	2.52770	0.99956
30	0.89237	−3.15245	3.33735	0.99865	0.04423	−1.00674	2.40453	0.99902
40	0.64761	−2.76261	3.25267	0.99982	0.06337	−0.96119	2.29738	1.00000
50	0.65287	−2.90820	3.44574	0.99519	0.28347	−1.55461	2.66224	0.99879
60	0.95432	−3.50736	3.73465	0.99955	0.11030	−1.20100	2.51298	0.99918
70	0.97079	−3.48568	3.71740	0.99876	0.30133	−1.62416	2.77235	0.99964
80	0.74843	−3.07988	3.56703	0.99925	0.37782	−1.78671	2.87237	0.99955
90	0.85059	−3.28865	3.68378	0.99895	0.24544	−1.53320	2.79222	0.99960
100	0.63026	−2.79888	3.43643	0.99818	0.29453	−1.62121	2.84271	0.99968
110	0.79484	−3.18936	3.66704	0.99905	0.15217	−1.31437	2.70074	0.99940
120	0.54059	−2.63464	3.39012	0.99280	0.21547	−1.45459	2.79106	0.99955
130	0.32973	−2.09015	3.03199	0.99253	0.10093	−1.19250	2.65858	0.99951
140	0.62533	−2.73176	3.37038	0.99648	0.14518	−1.25551	2.67476	0.99972
150	0.97214	−3.40380	3.66350	0.99971	0.31692	−1.64789	2.90115	0.99997
160	0.69335	−2.85398	3.39518	0.99651	0.21724	−1.43232	2.78684	0.99976
170	0.72848	−3.00163	3.50976	0.99796	0.16585	−1.30947	2.71759	0.99965
180	0.87657	−3.31052	3.66121	0.99907	0.16448	−1.31362	2.73022	0.99955

防爆壁周囲の爆風圧分布

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防爆壁周辺の爆風圧分布，すなわち，角度，距離と爆風パラメータ（ピーク圧力，インパルス）の関係を縮小モデルを用いて評価した。1.4gの円柱形ペンスリットペレットを防爆壁モデル（高さ63mm，幅104mm，厚さ6.0mm）から60mm離して高さ15mmの紙製装薬台に置き，鋼板製の地表面モデル上で起爆した。ペンスリットペレットから防爆壁モデルに向かう方向を０度と定義し，０度から180度の間で10度ごと，換算距離5.4m・$kg^{-1/3}$から21.7m・$kg^{-1/3}$の５点で圧力計測を行った。ピーク圧力は30度方向で著しく低減化された。一方，120度から150度では，やや大きくなった。インパルスは，90度以下で低減化され，特に40度から50度で著しく低減化された。一方，90度よりも大きい領域では，大きくなった。等インパルス線で囲まれる領域は，一枚の壁により，180度方向へ移動することがわかった。

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