Research paper

Evaluation of the crater size in the reinforced concrete (RC) wall by small-scale blasting

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Abstract

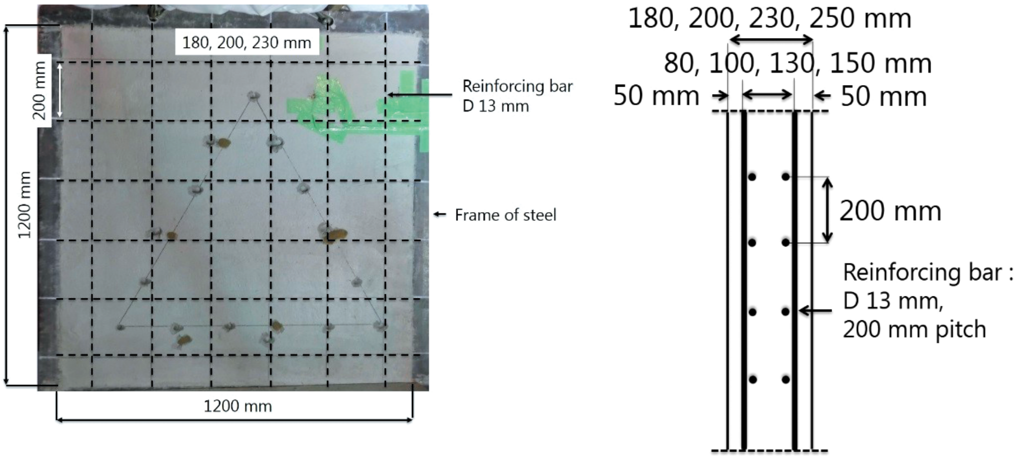
This study focuses on the depth of the crater size by small-scale blasting to determine suitable charge conditions for rescue work that requires creating a rescue route through various thicknesses of reinforced concrete (RC) wall. In this study, the amount of explosive and borehole depth as conditions for small-scale blasting experiments were varied depending on fixed diameter, angle of borehole, and stemming material. The fracture performance was defined as the ratio of generated crater depth to its borehole depth to estimate a fracture. The fracture performance was used to select the optimal borehole depths for each wall between 250 and 150 mm of thickness increasing by 5 mm. After the optimal borehole depths were obtained, the explosion tests were conducted to determine the adequate amount of explosive per hole. Based on the experiments, the proper conditions were obtained to control a fracture by selecting a suitable amount of explosive. Thus, the charge condition of small-scale blasting for rescue work was presented using sets of borehole depth and amount of explosive per hole.

Keywords: crater depth, charge condition, fracture performance, borehole depth, amount of explosive per hole

1. Introduction

The fracture manner is influenced by various factors. To establish the charge condition for small-scale blasting in rescue work, it is necessary to understand which factors determine the type of fracture, A or B. Type A fracture has a crater that occurs only on the borehole side and cracks develop on the back side. Type B fracture has a crater that is generated on both sides. In this study, the fracture was classified as well. Because the concrete wall has two free surfaces, four types of experimental results can be considered: no crater, a crater on the borehole side, a crater on the back side, and a crater on both sides. Our previous studies 1), 2) clarified a set of borehole depth, amount of explosive, and borehole angle to determine fracture manners required for rescue work when using a fixed borehole diameter of 16 mm3)−7) and clay as the stemming material8).

Several previous studies9)−12) have reported the evaluation of crater size on RC plates. McVay9) and Morishita et al.10) proposed formulae to predict the local damage of concrete plates subject to explosive load. Mcvay's formula9) was applicable for reinforced concrete slabs subjected to close-in explosion. Morishita et al.10) applied the prediction formula to contact explosion. Moreover, the crater depths left after their experiments were sorted by scaled concrete thickness11), which is calculated using Equation (1), and the damage to concrete was predicted.



(a) Front-sectional view (b) Cross-sectional view

Figure 1 Sample of reinforced concrete (RC) wall.

Scaled concrete thickness=$T/\sqrt[3]{W}$ (1)

where T is the thickness of the wall [cm], and W is the amount of explosive [g]. The scaled concrete thickness was used in the study of Tanaka and Morishita et al.12)−14) that confirmed the fracture mode in internal-explosion with respect to the experiments. The scaled concrete thickness was utilized to examine the influence of the concrete strength, type of reinforcing bar, and arrangement of reinforcing bars that were observed to have minimal effect on the fracture manner. As another example, Ohkubo et al.15) conducted experiments on the local destruction of concrete boards and the scale concrete thickness to predict the fracture manner with respect to detonation with C-4 explosives. Each type of explosives demonstrated different scales concrete thicknesses that resulted in penetration. The scaled concrete thickness enables to obtain penetration. However, to the best of our knowledge, the conditions that result in crater only on the borehole side or partial destruction, which is required in rescue work have not been clarified.

In this study, an optimal crater depth for rescue work was investigated through explosion tests. Based on the experimental results, the fracture performance was defined. The charge condition suitable for various thickness of the RC wall was identified.

2. Model experiments

2.1 RC wall sample

A sample of the RC wall is shown in Figure 1. The thicknesses of the RC walls were 180, 200, 230, and 250 mm. The width and height of the sample except 250 mm thickness were 1,200 mm as shown in Figure 1 (a), and those of 250 mm thickness were 750 mm. For all RC walls, the reinforcing bars were placed in a grid pattern at 50 mm from each surface of the wall as shown in Figure 1 (b). The reinforcing bar D13 was used. The concrete density was 2,300 kg·m^{-3}. The average concrete compressive strength of the wall was 27.1 MPa after 28 days.

2.2 Charge conditions

The borehole diameter was 16 mm, and the stemming material was clay. The prototype of the explosive device was constructed with C-4 explosive and a No. 6 electric detonator1). The boreholes for the single charge experiments were drilled at an angle of 45° into the wall2). The single-charge experiments with drilled a borehole were conducted as well as partial-charge experiments1). For partial-charge experiments, six or seven boreholes were drilled spaced at 180 mm. The explosives in each borehole were fired simultaneously.

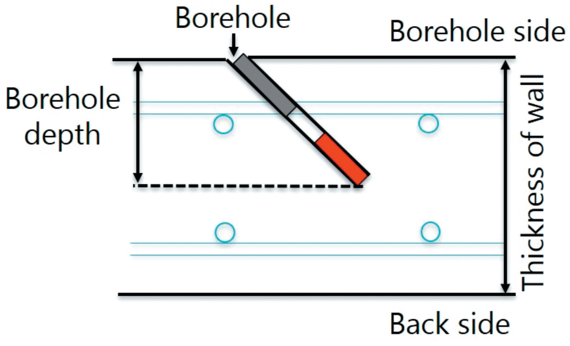


Figure 2 Borehole depth.

2.2.1 Design of borehole depth

In this study, the borehole depth refers to the vertical length from the bottom of the borehole to the surface on the borehole side of the wall as shown in Figure 2. To analyze the effect of borehole depth with respect to various wall thicknesses, the borehole depth, BD was represented as a ratio to the thickness of wall, TW. The ratio, BD / TW was varied from 0.32 to 0.70.

2.2.2 Design of amount of explosive

The amount of explosive was evidently an element to determine a suitable fracture manner2). Needless to say, it is ideal to load an optimal amount of explosive depending on the wall thickness. However, in the event of a chaos at disaster sites, it is difficult to adjust the adequate amounts of explosive for each wall thickness. To cope with such a disorder, an explosive device was prepared from 3.0 g to 8.0 g increasing by a one gram interval in advance. An appropriate device was selected for each wall thickness between 150 mm and 250 mm at 5 mm intervals.

2.3 Measurement

The blasting effects were expressed with crater depths. The crater depth was measured vertically from the surface of the wall to the vertex of the crater1). In our previous study1), two types of fracture manners were confirmed.

3. Results and discussion

3.1 Design of borehole depth

3.1.1 Type A fracture

Type A fracture limits the debris to the borehole side, which is suitable for rescuing a victim behind the wall. From the viewpoint of rapid removal of hindrance for rescue work, it is required that the concrete on the borehole side is removed as much as possible and only the cracks are generated on the back side. The fracture performance was used as an indicator to obtain the best fracture condition for Type A fracture.

3.1.1.1 Assessment of fracture performance using CD / BD

In our previous study2), the fracture efficiency was defined as the ratio of the generated crater depth to its burden. In this study, the fracture performance was defined as the ratio of the generated crater depth to its borehole depth to evaluate a fracture (Equation (2)). The ideal fracture performance is one, where the crater depth is equal to the borehole depth:

$$\text{The fracture performance} = \frac{\text{Crater depth}}{\text{Borehole depth}} \left(CD/BD \right) \quad (2)$$

Figure 3 is a schematic view indicating the fracture performances for Type A fracture.

The experimental results were plotted in Figure 4 with the ratio, BD / TW along x-axis and the fracture performance along y-axis. The fracture performance of 0.80 or more can be obtained when the ratio, BD / TW ranges from 0.50 to 0.60 and the proper amount of explosive was selected based on the previous study. When the ratio, BD / TW was 0.55, the fracture performance was indicated one or above. When the fracture performance exceeds 1, the bottom of a crater can reach the back side, which scrapes the concrete too much. To ensure safety and reduce uncertainty in rescue work the fracture performance is required to be less than 0.9. Therefore, the optimal ratio, BD / TW was determined to be 0.525 in this study to produce the best removal of concrete in Type A fracture, which produces 0.9 of fracture performance.

3.1.2 Type B fracture

For rapid operation, both sides of the wall should be fractured. Moreover, as Type B fractures occur on both sides of the wall, more concrete is removed compared with Type A. To obtain the knowledge to achieve an appropriate fracture manner as Type B, the borehole depth was normalized as well as Type A, and the crater depth were normalized (CD / TW) using the thickness of wall.

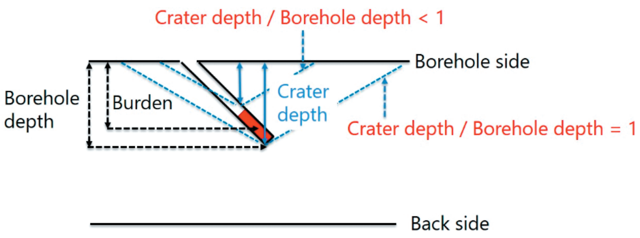


Figure 3 Schematic view indicating the fracture performances for Type A fracture.

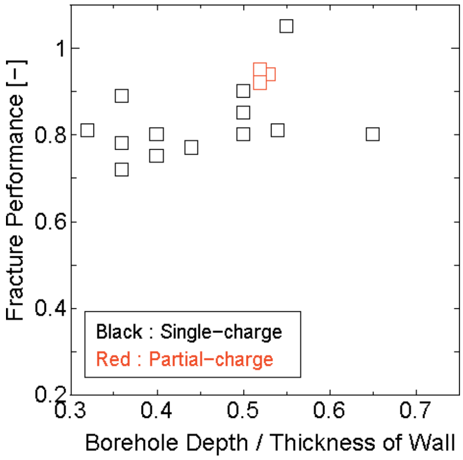


Figure 4 Variations of the fracture performance, CD / BD with BD / TW.

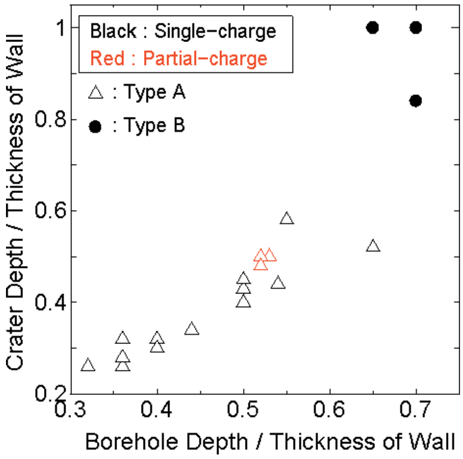


Figure 5 Relation between the ratio, BD / TW and the ratio, CD / TW.

3.1.2.1 Assessment of fracture performance using CD / TW

The borehole depth per thickness of wall and the crater depth per thickness of wall are plotted in Figure 5. The aforementioned experimental results of Type A were recalculated to obtain the ratio, CD / TW for comparison with Type B. The ratio, BD / TW of Type A fracture was from 0.32 to 0.65. In contrast, the ratio, BD / TW of Type B fracture ranged from 0.65 to 0.70. Figure 5 shows that the blasting resulting in 0.65 of BD / TW can be Type A or Type B. Therefore, the charge condition resulting in 0.65 of BD / TW does not guarantee the generation of craters on both the sides. Thus, these experiments indicated that the ratio, BD / TW should be more than 0.70 to accomplish Type B fracture.

3.2 Design of amount of explosive

3.2.1 Type A fracture

Table 1 shows the experimental results with respect to wall thickness of 250 mm and 230 mm. For a wall thickness of 250 mm, the ratio, CD / TW was 0.50, and the back side just cracked under the condition of 7.0 g of explosives per hole. In case of a wall thickness of 230 mm, the ratio, CD / TW was 0.48, and cracks were generated on the back side under either condition of 7.0 g or 6.0 g of explosives per hole. The condition did not cause debris. Because the same fracture manner was obtained for wall thickness of 250 mm and 230 mm for 7.0 g of explosives, it was considered that the same fracture manner can be obtained with 7.0 g of explosives for any thickness between 250 mm and 230 mm.

Table 2 shows the results obtained for a wall thickness of 200 mm and 180 mm. For a wall thickness of 200 mm, the ratio, CD / TW was 0.52, and the back side cracked when 5.0 g of explosives was used per hole. In case of a wall thickness 180 mm, the ratio, CD / TW was 0.50 and 0.49, respectively, and cracks were generated on the back side under either condition of 5.0 g or 4.0 g of explosives per hole. The condition did not cause debris. Because the same fracture manner was obtained for a wall thickness of 200 mm and 180 mm thickness with 5.0 g of explosives, it was considered that the same fracture manner can be obtained with 5.0 g of explosives for any thickness between 200 mm and 180 mm.

Table 1 Results for wall thicknesses of 250 mm and 230 mm.

Wall thickness [mm]	The ratio, CD / TW	Fracture manner on back side
250	0.50	Cracks, no debris
230	7.0 g of explosives per hole : 0.48	Cracks, no debris
	6.0 g of explosives per hole : 0.48	Cracks, no debris

Table 2 Results for wall thicknesses of 200 mm and 180 mm.

Wall thickness [mm]	The ratio, CD / TW	Fracture manner on back side
200	0.52	Cracks, no debris
180	5.0 g of explosives per hole : 0.48	Cracks, no debris
	4.0 g of explosives per hole : 0.48	Cracks, no debris

Table 3 Results for wall thicknesses of 200 mm and 180 mm.

Wall thickness [mm]	Fracture manner
200	Both sides fracture, almost penetration
180	6.0 g of explosives per hole : Both sides fracture, almost penetration
	5.0 g of explosives per hole : Both sides fracture, almost penetration

3.2.2 Type B fracture

Based on our previous study, Type B requires 1.0 g more explosives per hole than Type A for the same wall thickness. In case of a wall thickness of 250 mm, the craters were generated on both sides with 8.0 g of explosives[2]. Table 3 shows the results for a wall thickness of 200 mm and 180 mm. In case of a wall thickness of 200 mm, the craters were generated on both sides when using 6.0 g of explosives per hole, and the wall was almost penetrated. The fracture manner was Type B for a wall thickness of 180 mm when 6.0 or 5.0 g of explosives per hole. The same fracture manner was obtained for a wall thickness of 200 mm when using 6.0 g of explosives. Because the same fracture manner was obtained for wall thicknesses of 200 mm and 180 mm when using 6.0 g of explosives, it was considered that the same fracture manner can be obtained with 6.0 g of explosives for any thickness between 200 mm and 180 mm.

3.3 Establishment of charge condition

Figure 6 shows the proposed charge condition for rescue work. An operational condition of an explosive charge is determined by the borehole depth and amount of explosive. The charge condition is applied to RC wall thickness of 150 to 250 mm at 5 mm intervals. The borehole depth of Type A fracture is 0.525 of wall thickness and that of Type B fracture is 0.7 of wall thickness.

Meanwhile, the amount of explosive per hole was determined from the result for a wall thickness of 250 mm thickness. In case of Type A fracture, the amount of explosive per hole was 7.0 g. Type A fracture can be achieved with 7.0 g of explosives for a wall thickness of 230 mm. However, for the proposed charge condition, 6.0 g of explosives was selected to avoid excessive fracture of the RC wall. Therefore, 7.0 g of explosives per hole was recommended for a wall thickness varying between 250 to 235 mm and 6.0 g of explosives was recommended for a wall thickness varying between 230 to 210 mm. The amount of explosive is reduced by 1.0 g at each 20 mm decrease in wall thickness from 205 to 150 mm. In this regard, the amount of explosive for 200 mm thick wall and 180 mm thick wall were proved to be sufficient via

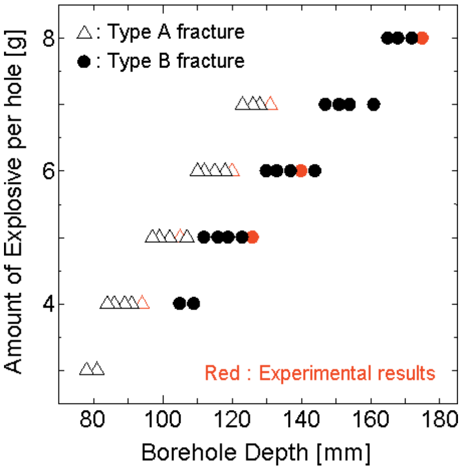


Figure 6 Charge condition for rescue work.

experiments. The amount of explosive per hole for Type B fracture increased by 1.0 g compared with that of Type A fracture.

4. Conclusion

The effect of borehole depth and amount of explosive on the fracture manner of small-scale blasting for rescue work was investigated while other parameters such as diameter and angle of borehole, and stemming material remained unchanged. To design the borehole depth, the fracture performance was defined, and experiments were conducted. Based on the ratio, BD / TW and the fracture performance obtained from experiments, the optimal ratio, BD / TW was selected. The ratio, BD / TW of Type A fracture was 0.525 and that of Type B fracture was 0.70.

Further, to design the amount of explosive per hole, the explosive device was prepared from 3.0 g to 8.0 g at intervals of 1.0 g. The optimum amount of explosive was proved by the explosion tests using 250, 230, 200, and 180 mm thickness of RC wall. In case of Type A fracture, 7.0 g of explosives per hole was recommended for walls with thickness ranging from 250 mm to 235 mm. And for a wall thickness of 230 mm or lower, the amount of explosive per hole should be reduced by 1.0 g at 20 mm intervals. The amount of explosive per hole of Type B fracture increased by 1.0 g compared to that of Type A fracture.

Acknowledgments

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