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Experiments on Gamma-Ray Shielding Performance of Cracked Reinforced Concrete Wall

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1 ABSTRACT

This reports an experimental study on gamma-ray shielding performance of cracked reinforced concrete walls in nuclear related facilities. In some cases, a reinforced concrete structural wall is expected to be a shielding wall at the same time. In any case, a reinforced concrete shielding wall has possibilities to be cracked, for example, due to drying shrinkage of concrete, or due to earthquakes. The shielding performance of a cracked reinforced concrete wall against radioactive rays should be clarified.

The purpose of this study is not only for the engineering safety, but also for the mental security of people. Tests were carried out using six concrete plate specimens. Test parameters were crack shape (natural crack and pre-made slit), plate thicknesses (5, 10, and 15 cm), and crack width (0 to 10 mm). The gamma-ray radiation source used was Co-60. The useful data about the gamma-ray shielding performance of cracked concrete plates were accumulated.

2 INTRODUCTION

In nuclear related facilities, many reinforced concrete shielding plates against radioactive rays are used. Some shielding plates are simultaneously used as structural slabs or walls. Reinforced concrete shielding plates have possibilities to be cracked due to drying shrinkage of concrete, earthquakes, and so on.

Now, it has to be recognized that the mental security of people dose not always correspond with the physical safety of things. For the engineering safety, lack of knowledge might be ensured by conservative assumptions and large safety factors in the design process. On the other hand, mental security of people is heavily effected by inflammatory media report.

In order to avoid misunderstanding of media and to obtain the assurance of the society, scientific data should be accumulated. Experimental results are most fundamental. As for the shielding performance of cracked reinforced concrete plate, experimental data are not sufficient. Therefore, gamma-ray radiation tests to cracked concrete plates were carried out. An object of the tests is a reinforced concrete wall cracked by earthquakes. The tests reported here are at the first stage, and subsequent tests are planned and will be conducted.

3 EXPERIMENTAL PROGRAM

3.1 Outline

In this study, gamma-ray radiation tests to cracked reinforced concrete plates were carried out in order to measure gamma-ray shielding performance. Six concrete plate specimens were prepared and parameters of the test were crack shape those were natural crack and pre-made slit, plate thickness, and crack width. The natural crack was formed by splitting tensile stress, and the pre-made crack was straight slit which surface was made as plane intentionally. Concrete plates with 5, 10, and 15 cm of thickness were prepared. The crack width was controlled in the range from 0 mm to 10 mm. Radiation source was Co-60, and an ionization chamber was used as a detector. Numeric values displayed on a meter that was connected with ionization chamber, was recorded. The values on the condition that cracked concrete plate was placed in front of the chamber were compared with the values on the condition of no concrete plate.

3.2 Specimens

Fig. 1 shows detail of concrete plate specimen. Steel plates on side surfaces of concrete plate were used to control crack width. Four holes were used when the specimen was fixed in the radiation test. The specimens had notches at top and bottom to restrict cracking area, which detail was shown in right figure of Fig. 1. Table 1 and 2 show specifications of six specimens and mix proportion of concrete, respectively. Fig. 2 shows grading of fine and coarse aggregates.

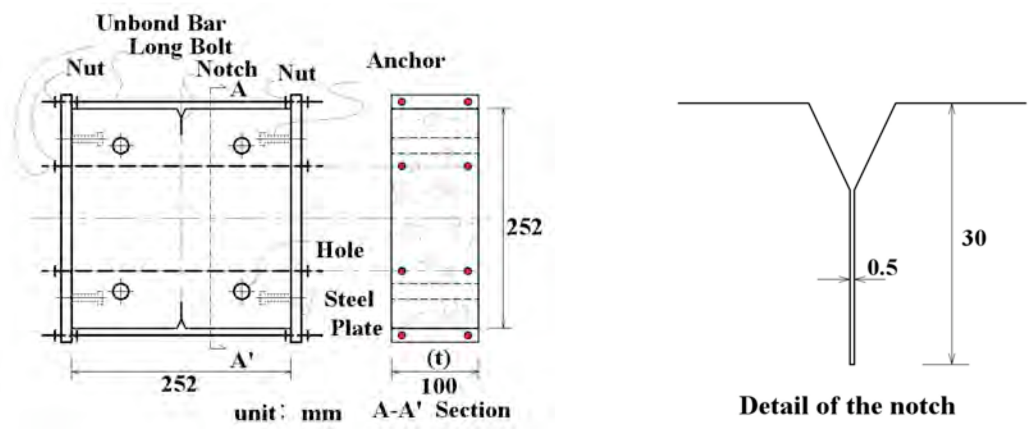

Figure 1. Detail of specimen

Table 1. List of specimens

Name of specimens	Thickness (mm)	Crack or Slit
50-C	50	Crack
100-C	100	Crack
150-C	150	Crack
50-S	50	Slit
100-S	100	Slit
150-S	150	Slit

Table 2. Mix proportion of concrete

Cement (kg/m^3)	Water (kg/m^3)	Fine agg. (kg/m^3)	Coarse agg. (kg/m^3)	Admixture; Vinsol (kg/m^3) (Yamaso Chemical Co., LTD)
277	180	810	990	0.138

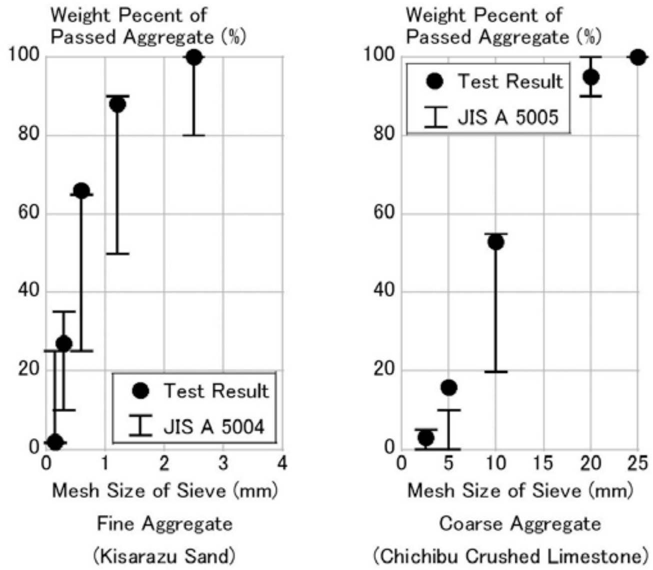

Figure 2. Grading of aggregate

3.3 Placing and curing of concrete

Three specimens with slit had placing joint in the middle of specimen as shown in Fig. 3. First half of concrete was placed that form of specimen was separated in the middle by a plate with smooth surface. After 8 days curing, the separating plate was removed and grease was laid on the concrete surface to make cold joint intentionally. And then the other half of concrete was placed. Fig. 4 shows concrete curing procedure of the specimens with and without slit in order. Fig. 5 shows compressive strength and relative density of concrete cylinders made at the same time as the specimens.

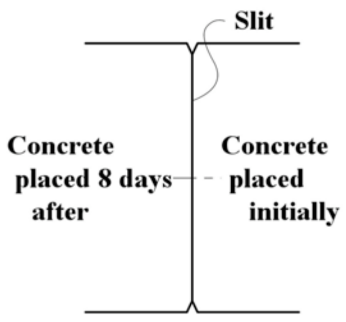

Figure 3. Process for specimen with slit

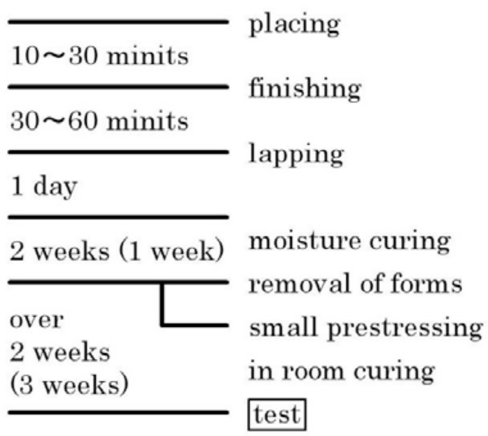

Figure 4. Concrete curing procedure of specimen

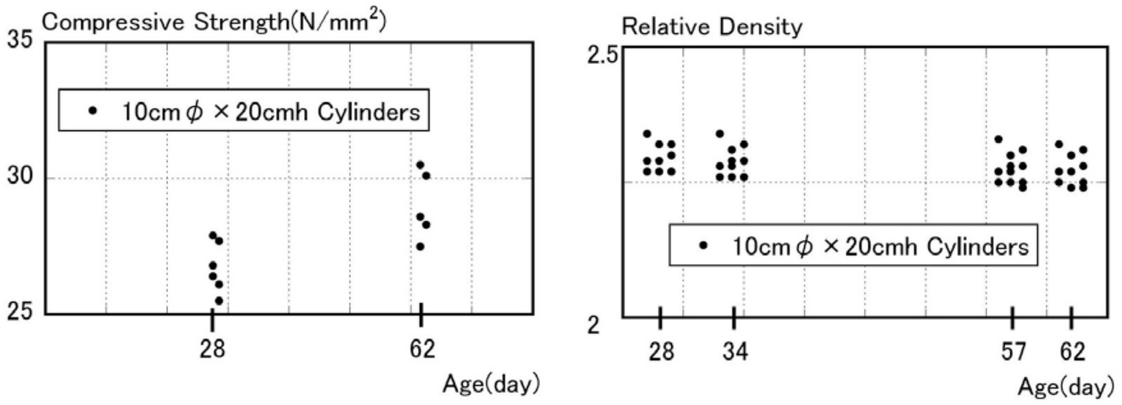

Figure 5. Compressive strength and relative density of concrete cylinder

3.4 Crack and slit of concrete

As shown in Fig. 6, two types of wedge were used to make a crack and to control the crack width, respectively. The wedges at the top and bottom of specimen were pushed into the specimen in order to make or widen a crack. Initial crack was formed by amsler testing machine. When crack width was narrowed or fixed, long bolts and nuts shown in Fig. 1 were used. As shown in Fig. 7, dial gages were used to control the crack width by measuring distance between two steel plates fixed on side surface of the specimen. In this paper, crack width was defined as an average of four values measured by the dial gages those were D1, D2, D3, and D4 shown in Fig. 7. The crack width was controlled as ratio of minimum value to maximum value measured by dial gages was in the range from 0.8 to 1.0, as follows.

$$0.8 \le \frac{D_{\min}}{D_{\max}} \le 1.0 \tag{1}$$

$$\textit{Crack Width} = \frac{D1 + D2 + D3 + D4}{4} \tag{2}$$

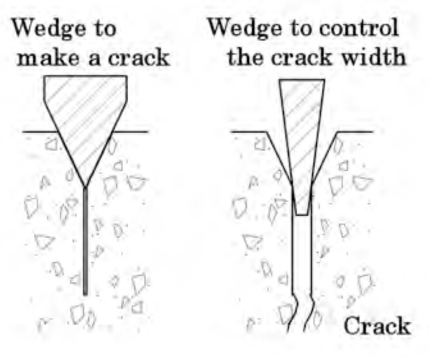

Figure 6. Wedges to make a crack and to control the width

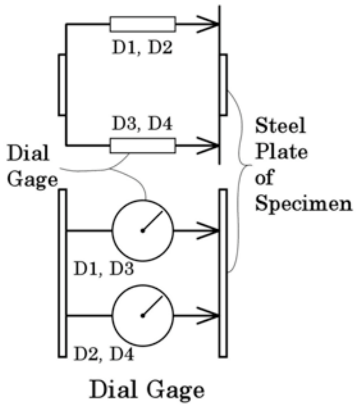

Figure 7. Control method of crack width

3.5 Measuring system

Fig. 8 shows gamma-ray radiation test system. Radiation source was Co-60, and an ionization chamber was used as a detector. The ionization chamber was at a distance *l* from centre of radiation source to effective centre of the chamber. The test was carried out by three methods those difference were surrounding condition of the ionization chamber. One was the chamber was bare, and numbered ¯,0 as shown in Fig. 8. Another was the chamber was covered with steel shield box in order to reduce influence of radiation except front of the chamber, and numbered 0. The other was a specimen was fixed in front of the chamber, and numbered 1.

Fig. 9 shows detail of gamma-ray radiation source. Co-60 pencils, 1 mm in diameter and 160 mm in length each, were arranged cylindrically. The cylindrical arrangement of Co-60 pencils had 104 mm in diameter. Details of ionization chamber and shield box were shown in Fig. 9 and 10, respectively. The ionization chamber (C-110, 60ml, Applied Engineering Inc., Japan) was connected with an electrometer (AE-1110a, Applied Engineering Inc., Japan). The shield box was consisted of steel walls of 96 mm in thickness, which the walls had four layers of steel plates of 24 mm in thickness.

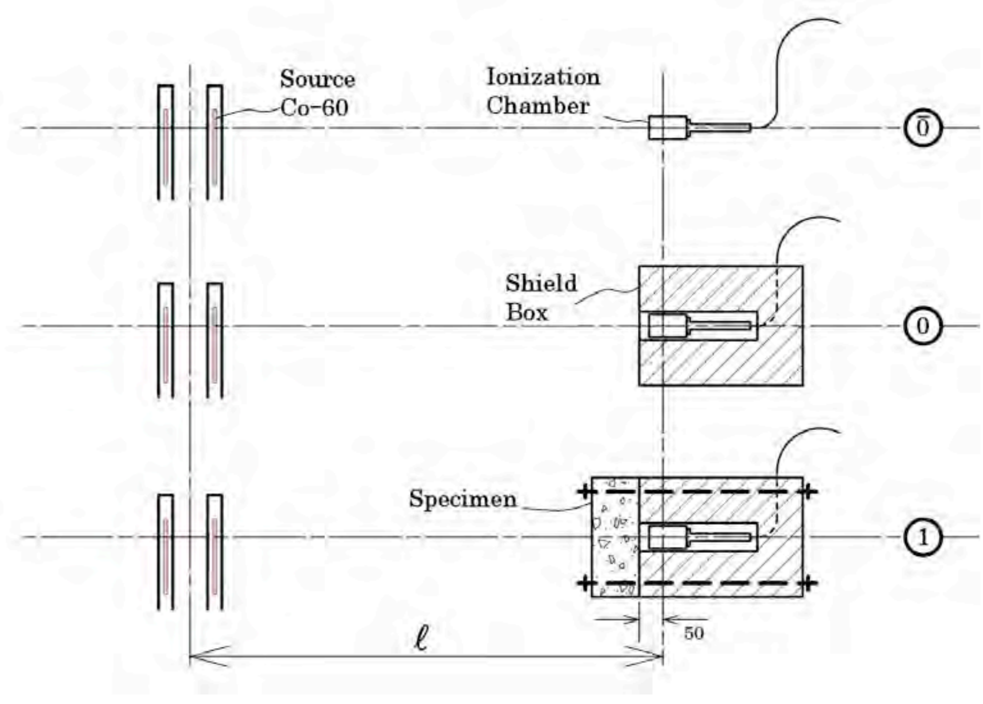

Figure 8. Gamma-ray radiation test system

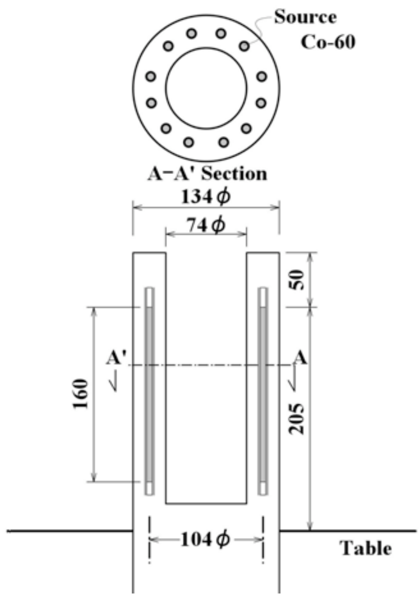

Figure 9. Gamma-ray radiation source (Co-60)

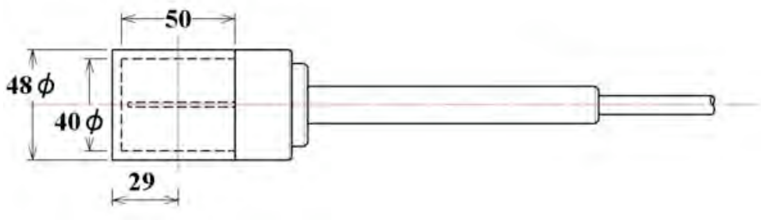

Figure 10. Ionization chamber

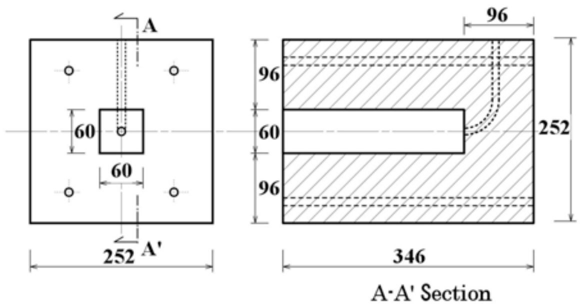

Figure 11. Shield box

4 TEST RESULTS

4.1 Results without specimens

The electrometer displays a numeric number when it detects gamma-ray. In this paper, Q is a numeric value multiplied the number displayed on the electrometer by measure range ($\times 10^2$ – $\times 10^5$). Q has the following relationship with dose rate, where I (Gy/h) is dose rate and k is equal to 3.7×10^{-3} Gy/h.

$$I = k \times Q \tag{3}$$

Fig. 12 shows relationship between Q and distance from radiation source to ionization chamber, shown in Fig. 8. (0) and (¯,0) those follow after Q are correspond to the numbers in Fig. 8. Therefore, Q(0) and Q(¯,0) are results with and without shield box, respectively. As shown in Fig. 12, Q with shield box was larger than Q without shield box. It was considered that scattering in the shield box influenced.

Fig. 13 shows relationship between date and Q with shield box and no specimen. The distance from radiation source to ionization chamber was 1000 mm, which was identical in all the results shown in Fig.13. The variance in Fig. 13 might be due to difference of environments those were temperature, humidity, and atmospheric pressure.

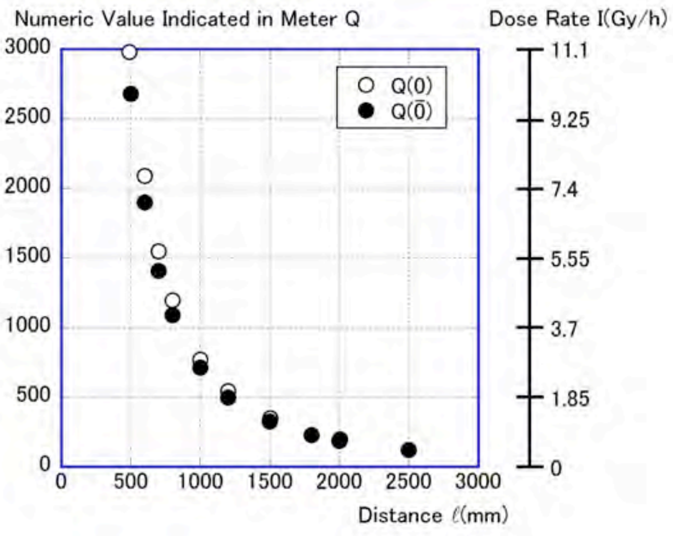

Figure 12. Relationship between distance from radiation source to ionization chamber and numeric values

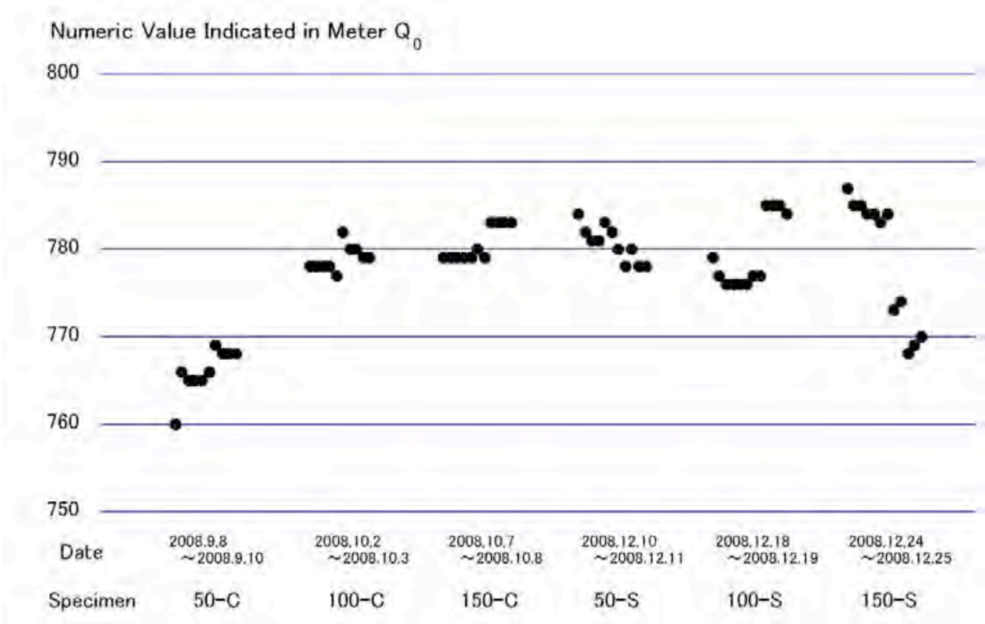

Figure 13. Numeric values by ionization chamber with shield box and no specimen (l=1000mm)

4.2 Results of specimens

Fig. 14 shows relationship between penetration rate and thickness of concrete plate without crack. The distance from radiation source to ionization chamber was 1000 mm. (0) and (1) those follow after I are correspond to the numbers in Fig. 8. The penetration rate is a ratio of $I(1)$ to $I(0)$, where $I(1)$ and $I(0)$ are dose rates with and without specimen, respectively. The penetration rate was used to eliminate environmental influence from the value. Three marks in Fig. 14 were results of 50-C, 100-C, and 150-C.

Fig. 15 shows relationship between penetration rate and crack width. The distance from radiation source to ionization chamber was 1000 mm, which was identical in all the specimens. The penetration rate is the same as Fig. 14. As shown in Fig. 15, the penetration rates of specimens with slit were larger than those with natural crack on every crack width.

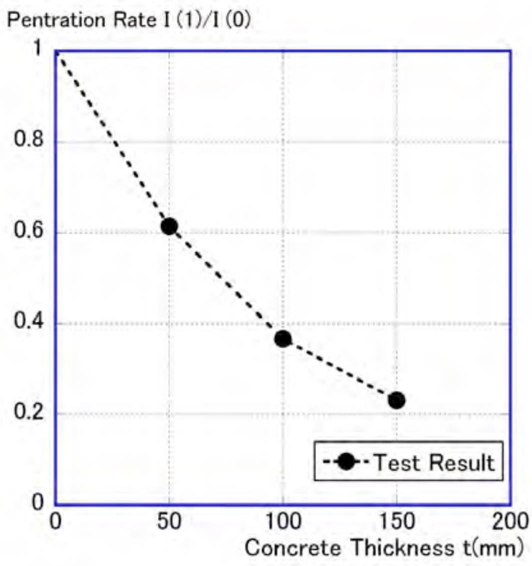

Figure 14. Penetration rate of concrete specimens without crack (*l*=1000mm)

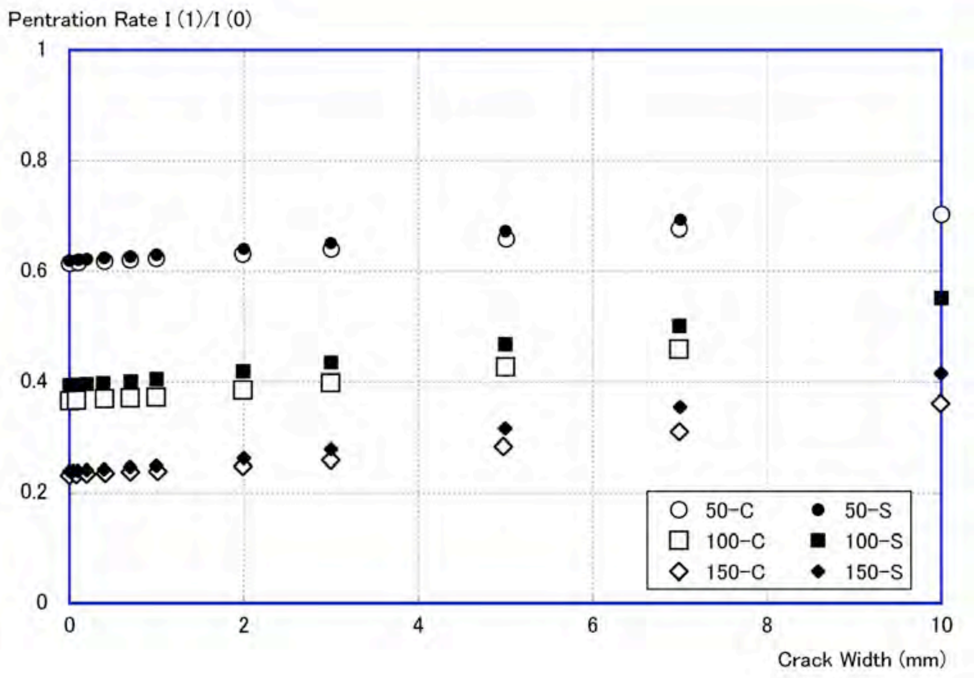

Figure 15. Penetration rate of all the specimens (*l*=1000mm)

5 CONCLUSION

Experimental results on gamma-ray shielding performance of a cracked reinforced concrete wall are reported. Subsequent tests will be conducted and test data will be generalized by analysis. To accumulate the fundamental data is important for physical safety of facilities and for mental security of people.

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