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Evaluating Fluid Leakage through Concrete Crack

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1. Introduction

The containment building serves as a final shield to minimize leakage of radioactive materials to outside world in an extreme event. If the containment building is destroyed by an internal explosion, as happened at the Fukushima Daiichi Nuclear Power Plant in 2011, radioactive materials can leak into the environment and cause an extremely serious accident. In the case of nuclear power plants in the Republic of Korea, the containment buildings are deteriorating due to long-term use. In 2016, corrosion on the backside of containment liner plate (CLP) due to concrete voids was confirmed at Hanbit Unit 2, and in 2017, voids up to 20 cm were found at Hanbit Unit 4 [1]. In this study, we aim to analyze the fluid characteristics due to cracks from concrete deterioration. The results will be used for developing an environmental leakage assessment model through cracks in containment buildings in the event of a major accident.

2. Methods and Results

The penetration behavior of fluid was evaluated for in-plane cracks. The fluid penetration characteristics with different crack widths were measured by experiments, and used to simulate fluid penetration along the through-crack using a general purpose finite element analysis using Abaqus [2].

2.1 Experiments to evaluate penetration behavior considering in-plane cracks

A three-point bending load was applied to the concrete specimen shown in Fig. 1 to produce a through-crack. An initial notch was introduced at the center of specimen so that the in-plane cracks were developed by applying three point bending load condition. To control the crack width of the specimen, anchors and turnbuckles were installed on the specimen as shown in Fig. 2. A turnbuckle is a device for adjusting length. It is coupled to the anchor via a nut to allow the crack width of the specimen to be controlled by adjusting the length of the turnbuckle. When the crack specimen was connected to the pressurizer cylinder, a waterproof coating was applied to the specimen sides using hot-melt adhesive (HMA) and epoxy resin. Water was poured into the notch of the through-crack specimen. The crack width was adjusted to 0.25, 0.50, 0.75, and 1.00 mm by the turnbuckle, and the time for 220 ml of water to be drained through the crack was measured for each crack width.

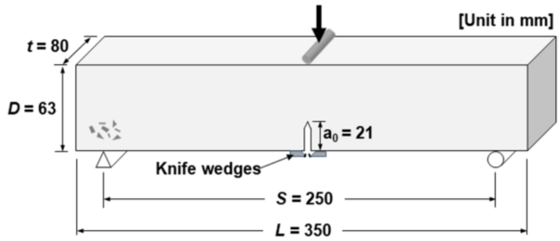

Fig. 1. Geometry and dimensions of concrete specimen for three-point bending to induce in-plane crack

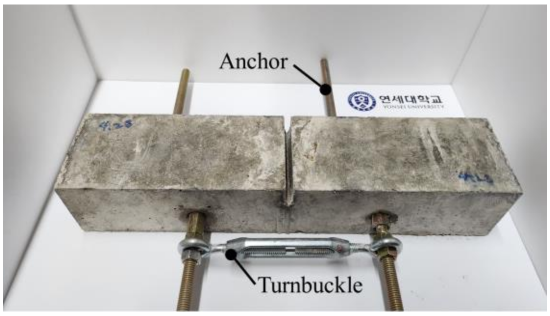

Fig. 2. Concrete through-crack specimen with controlled crack width

The results of the fluid penetration test with different crack widths are shown in Table I. The flow rate of water leaking through the cracks increased as the crack width increased as expected.

Table I: Fluid penetration results according to crack width

	Crack width (mm)			
	0.25	0.5	0.75	1.0
Time (sec)	512	242	34	11
Flow rate (ml/sec)	0.43	0.91	6.47	20.0

2.2 Fluid penetration evaluation model

The kinematic coefficient of water viscosity was used in the simulation [3], internal pressure was applied to analyze fluid penetration to mimic the condition in actual nuclear power plants. A pressure corresponding to a load of 220 ml of water was assigned to the top of the fluid and kept constant during simulations, as shown in Fig. 3. The fluid velocity is assumed to be zero along the boundaries of the crack planes.

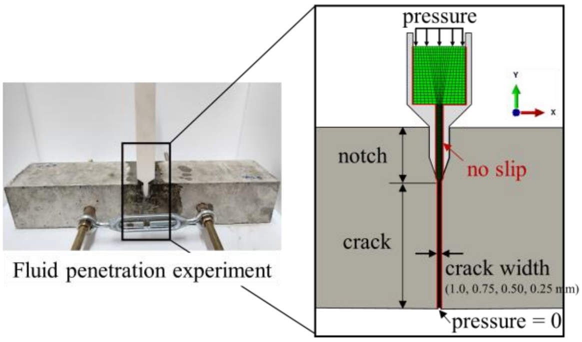

Fig. 3. Fluid penetration simulation model and boundary conditions according to crack width

The velocity distribution of the fluid penetration for a crack with of 1 mm is shown in Fig. 4. The calculated flow rates are presented in Table Ⅱ It is confirmed that, as the crack width increases, the flow velocity and the flow rate increases significantly.

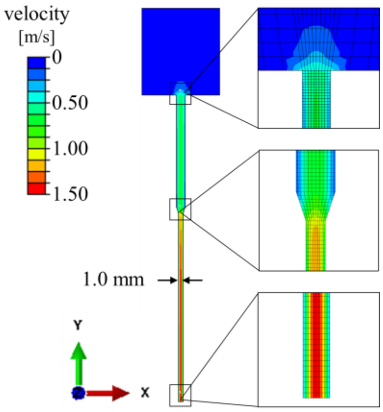

Fig. 4. Velocity distribution from the simulation

Table Ⅱ: Flow velocity and flow rate with different crack width

	Crack width (mm)			
	0.25	0.5	0.75	1.0
Flow velocity (mm/sec)	169	545	819	963
Flow rate (ml/sec)	3.4	21.8	49.1	77.0

3. Conclusions

This study shows the water penetration behavior depending on the width of cracks in concrete. The crack was assumed to be in-plane to investigate the effect of crack width alone among various variables that determine fluid flow. The fluid velocity and flow rate increased as the crack width both in the experiment and simulation results.increased. The flow rates obtained by the simulations were one order magnitude larger than those from the experiments, but it should be mainly due to the difference in the pressure loading condition between the actual experiment and the simulation. With further calibrations in the experimental and simulation setups, the results from experiment and simulation will be more comparable, and the simulation should be able to predict the experimental results within desired accuracy.

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