Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 22-23, 2025

Experimental Investigation of Airflow and Crack Behavior in Reinforced Concrete Plates

Yousang Lee [a*] and Hong-gun Park [a]
[a]*Department of Architecture and Architectural Engineering, Seoul National University*
[*]*Corresponding author: y.lee@snu.ac.kr*

Keywords : reinforced concrete, permeability, airflow test, crack behavior, strain analysis

1. Introduction

Understanding the permeability of cracked reinforced concrete (RC) structures is crucial in assessing their durability and performance in nuclear and other infrastructure applications [1]. The purpose of this study is to better understand the phenomenon of airflow through cracks in RC elements. This study follows a pilot study [2] which was limited by a maximum pressure difference of 200 kPa. Containment buildings in nuclear power plants require reliable permeability assessments, particularly under high-pressure conditions. In the present study, these limitations were addressed through improved testing conditions and analysis.

2. Experimental Setup

The experimental setup, illustrated in Figure 1, consists of a reinforced concrete specimen subjected to four-point bending to induce controlled cracking. A chamber was embedded within the specimen to introduce airflow, and pressure transducers were used to monitor differential pressure. Linear variable differential transformers (LVDTs) were placed at specific locations to measure displacement. The airflow system included a compressor, regulator, filter, flow meter, and pressure transducers to record the volumetric flowrate and gauge pressure.

In the pilot test, initial leakage was observed before loading due to construction joints, which were necessary for creating the air chamber. This "baseline leakage" was later subtracted from the total leakage, assuming it was the sum of baseline leakage and additional crack leakage. In the present study, the air chamber was covered with a steel casing, eliminating leakage through construction joints. This ensures that the measured inlet flowrate equals the leakage rate, as no other leak paths exist.

The test procedure involved a monotonic four-point bending test under displacement control. Loading was applied incrementally, with initial loading continued until the first surface crack was identified by elongation measurements from a DEMEC gauge and stiffness degradation in the load–deflection curve. After crack initiation, deflection was increased in 1–2 mm steps. At each loading step, crack widths were measured and a series of airflow tests were performed. For airflow tests, steady-state flowrate was measured at selected gauge pressure levels (20–200 kPa) while maintaining constant deflection. Due to pressure-induced cracking observed in one specimen at over 200 kPa, most tests were limited to 200 kPa, except for the final step where pressure was increased up to 400 kPa. Steady-state conditions were defined by less than 2% variation in flowrate and pressure over a 60-second interval.

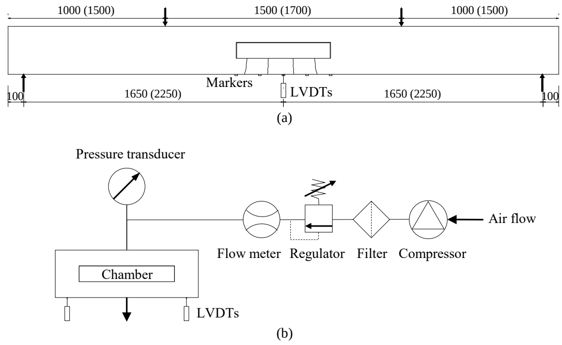

Fig. 1. Schematic of the experimental setup, showing: (a) the reinforced concrete specimen, airflow chamber; (b) pressure transducers, and measurement devices.

3. Results and Discussion

3.1 Flowrate – Differential Pressure

Figure 2 presents the relationship between the flowrate and the differential pressure across the cracked region. In the pilot study [2], linear flow behavior was observed up to 200 kPa. Similarly, in the present study, a linear relationship between flowrate and differential pressure was observed, even at pressures exceeding 200 kPa.

At higher pressures, increased flow velocity could cause non-linear flow behavior, which motivated testing beyond 200 kPa. A maximum pressure of 400 kPa was chosen as it aligns with the design pressure of nuclear power plant (NPP) containment buildings, ensuring the study's relevance for high-pressure structural assessments [3].

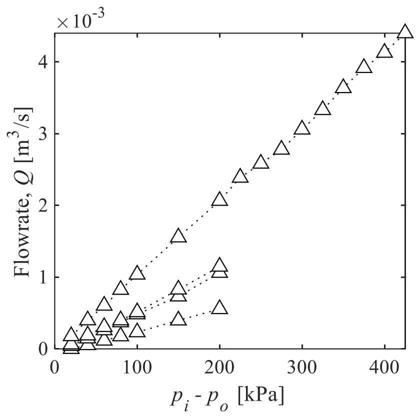

Fig. 2. Flowrate - differential pressure relationships of U3 specimen

3.2 Steel Strain Response to Internal Pressure

Table 1 presents the ratio of steel strain at 200 kPa internal pressure to the strain without internal pressure $\varepsilon_{sm,p}/\varepsilon_{sm}$. The results indicate an increase in mean steel strain by approximately 3%, implying that the cracks might have widened due to the internal pressure. Although 3% crack width may seem trivial, flowrate is known to be proportional to the cube of the crack width, meaning a 3% crack width increase could result in roughly a 10% increase in flowrate. However, despite this increase in strain, the flowrate did not exhibit a corresponding increase, contradicting the expectation that a larger crack width should result in increased permeability.

Table 1: Ratio of steel strain under 200 kPa internal pressure of U3 specimen

	Median	Mean	C.o.V
$\varepsilon_{sm,p}/\varepsilon_{sm}$	1.028	1.025	0.010

3.3 Discrepancy Between Strain Increase and Flowrate Stability

The applied internal pressure could induce additional bending moments in the plate, leading to a strain gradient across its section. This bending effect could cause crack closure at the top of the plate, while the steel strain increases. Pressure gradient applied at the crack surface may attribute to the steel strain increase. However, a significant increase in flowrate could be prevented as the narrowest crack width tends to govern the overall permeability, and the cracks at the top of the plate may experience closure due to bending.

Moreover, increased pressure could lead to turbulence effects within the cracks, stabilizing the permeability response.

4. Conclusions

This study analyzed the relationship between steel strain and airflow permeability in cracked RC plates under internal pressure. While the increase in steel strain suggested a widening of cracks, the flowrate remained largely unchanged, indicating a complex interaction between crack geometry, stress distribution, and flow resistance. Future work will focus on numerical modeling to refine the understanding of permeability changes under varying internal pressure conditions.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea Government (MSIT) (No. RS-2022-00144409).

REFERENCES

[1] S.H. Rizkalla, B.L. Lau, S.H. Simmonds, Air Leakage Characteristics in Reinforced Concrete, Journal of Structural Engineering, Vol.110(5), pp. 1149-1162, 1984.
[2] Y. Lee, H.-G. Park, Experimental Study of Air Leakage of Reinforced Concrete Panel with Cracks, Nuclear Engineering and Technology, Vol.56(11), pp. 4755-4769, 2024.
[3] Y.-S. Choun, H.-K. Park, Containment Performance Evaluation of Prestressed Concrete Containment Vessels with Fiber Reinforcement, Nuclear Engineering and Technology, Vol.47(7), pp. 884-894, 2015.