Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 30-31, 2025

Development of Air Leakage Prediction Model for Flexural Cracks in Reinforced Concrete Plates

Yousang Lee [a*] and Hong-gun Park [a]
[a] *Department of Architecture and Architectural Eng., Seoul National Univ., 1 Gwanak-ro, Gwanak-gu, Seoul 08826*
[*] *Corresponding author: y.lee@snu.ac.kr*

Keywords : leakage, reinforced concrete, airflow, permeability, crack

1. Introduction

This study addresses the critical issue of fluid and gas transport through cracks in reinforced concrete (RC) structures, which significantly impacts their durability and service life. While early research focused on cracks under uniaxial tension using simplified parallel plate models [1, 2], these approaches proved inadequate for real-world RC elements subjected to flexural loading. Existing models can overestimate flow rates by up to 85 times [3] because they fail to account for the nonuniform crack geometries that result from reinforcement and strain gradients—specifically, crack widths that vary linearly with depth and narrow near reinforcement due to bond resistance.

The research identifies two major limitations in current prediction models: the assumption of uniform crack profiles and the use of empirical coefficients derived from plain concrete rather than reinforced concrete. To address these gaps, the study develops a new flowrate estimation model incorporating experimentally validated nonuniform crack profiles and proposes a reduction factor calibrated at the meso-scale using RC specimens. This reduction factor accounts for surface roughness, tortuous crack paths, and crack width constriction near reinforcing bars, providing a more practical framework for assessing transport phenomena in cracked RC elements.

2. Methods and Results

2.1 Governing Equations

Airflow through nonuniform cracks in concrete is described using the Navier–Stokes equations for incompressible, Newtonian fluids:

$$(1)\quad \nabla \cdot \mathbf{u} = 0$$

$$(2)\quad \rho\left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u}\right) = -\nabla p + \mu \nabla^2 \mathbf{u} + \rho \mathbf{b}$$

Where ρ is the fluid density, $\mathbf{u}$ is the velocity, p is the pressure, μ is the dynamic viscosity, $\mathbf{b}$ is the body force.

For steady conditions at low Reynolds numbers, inertial and transient terms can be neglected, leaving a simplified pressure-driven flow between the crack faces. If the crack width is assumed to increase linearly along the flow path, $w(x)=w_i+(w_o-w_i)x/L$, the volumetric flowrate can be expressed as:

$$(3)\quad Q = \frac{b\Delta p}{6\,\mu L}\,\frac{w_i^2 w_o^2}{w_i + w_o}$$

Here, $\Delta p = p_i - p_o$ denotes the pressure difference, b is the crack breadth, and L is the flow channel depth or crack depth. Equation (3) demonstrates that the smallest inlet width w_i largely controls the hydraulic resistance, showing that flow through a nonuniform crack is governed by its narrowest section.

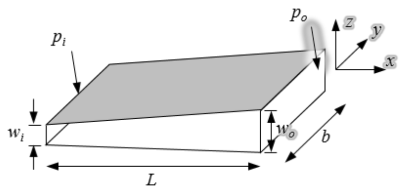

Fig. 1. Schematic of fracture domain and boundary conditions for a linearly expanding crack

2.2 Reduction Factor

To address the mismatch between idealized crack geometries and actual crack conditions, a reduction factor has been introduced in previous studies [4, 5]. This factor accounts for additional flow resistance caused by surface roughness, crack tortuosity, and local restrictions around reinforcement. With values less than 1.0, it is applied to theoretical formulations such as Equation (3) to avoid overestimating flowrates. While some researchers have suggested using a constant value for this factor [4, 5], others proposed expressions dependent on crack width [6].

In this study, the reduction factor was derived from experimental flowrate data of the U-series specimens, which were tested by the authors and are reported separately. By equating the theoretical and measured flowrate, reduction factors were calculated. Across most specimens, the reduction factors fell within 0.01–0.10. The only exception was specimen U4, which showed lower values, likely due to the use of smaller, more numerous rebars that produced finer and more distributed cracking.

To enhance the predictive capability of the reduction factor, a new model was proposed in this study. Prior research has indicated that the reduction factor decreases with higher reinforcement ratios and thicker covers, as both conditions tend to produce narrower internal cracks due to bond stress effects. Building on these findings, a power-law formulation was developed to quantitatively represent the influence of reinforcement ratio and cover thickness on flow resistance.

2.3 Validation

The proposed flowrate estimation formula, incorporating the reduction factor, was applied to the U-series specimens for benchmarking. Overall, the predicted flowrates showed reasonable agreement with the experimental results, generally within ±50% (indicated by the dashed lines). Given the uncertainty in crack width measurements and the strong sensitivity of flowrate to crack width, this level of accuracy can be regarded as acceptable. However, specimen U2 deviated markedly from the equality line, warranting further investigation to determine whether this represents an experimental anomaly or a systematic issue.

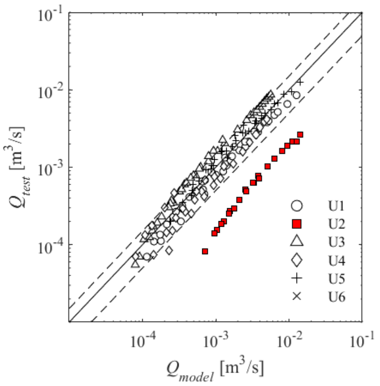

Fig. 2. Comparison between experimental and predicted flowrates for the U-series specimens

3. Conclusions

This study examined gas transport through flexural cracks in reinforced concrete plates, emphasizing the differences between nonuniform and uniform tension cracks. A theoretical model was developed by integrating the velocity profile across a linearly widening crack. To capture the effects of surface roughness and crack tortuosity, a reduction factor was introduced. A regression-based model showed strong predictive accuracy for the tested specimens.

REFERENCES

[1] S. H. Rizkalla, B. L. Lau, S. H. Simmonds, Air Leakage Characteristics in Reinforced Concrete, Journal of Structural Engineering, Vol.110, pp.1149-1162, 1984.

[2] T. Suzuki, K. Takiguchi, H. Hotta, N. Kojima, M. Fukuhara, K. Kimura, Experimental Study on the Leakage of Gas Through Cracked Concrete Walls, Proceedings of SMiRT-10, Session Q, pp.145-150, 1989.

[3] 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.

[4] E. Carola, Water Permeability and Autogenous Healing of Cracks in Concrete, ACI Materials Journal, Vol.96(4), pp.448-454, 1999.

[5] V. Picandet, A. Khelidj, H. Bellagou, Crack Effects on Gas and Water Permeability of Concretes, Cement and Concrete Research, Vol.39(6), pp.537-547, 2009.

[6] T. Suzuki, K. Takiguchi, H. Hotta, Leakage of Gas Through Concrete Cracks, Nuclear Engineering and Design, Vol.110(5), pp.121-130, 1992.