# Preliminary Study on Leakage Rate Estimation of Cracked Concrete Walls

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*

## 1. Introduction

Reactor containment buildings function as final defense line to prevent the release of radiation into the environment during a severe accident. Therefore, it is important to ensure the structural integrity of these buildings for the required duration after the accident. However, in the event of a failure of the containment buildings, it is crucial to assess the amount of radiation that could potentially leak into the environment. In this study, a preliminary numerical analysis was carried out to review the available leakage rate estimation formulae.

## 2. Literature Review

In this section some of the available leak rate evaluation formulae are reviewed. Rizkalla et al. [1] performed air leakage tests of reinforced concrete panels subjected to uniaxial, monotonic tension. Based on the tests, the authors proposed an empirical leakage rate estimation formula as a function of crack geometry, which relates structural behavior and leakage rate.

Nagano et al. [2] measured air leakage through reinforced concrete panels cracked by three-point test. The authors compared the measured volume rates with those estimated by theoretical equation of Poiseuille's flow.

Suzuki et al. [3, 4] performed similar tests with variables of aggregate size and existence of reinforcing bar. The authors also suggested an estimation formula which overestimated the leakage rate for the reinforced concrete specimens.

Greiner and Ramm [5] conducted two sets of leakage tests, one with a defined single crack and the other with a typical crack pattern. The authors varied concrete grading curve, crack length, crack width and pressure. The authors suggested a new leakage formula including the wall shearing stress term based on the experiment data. Aforementioned estimation formulae are presented in Table I.

Table I: Leakage Formulae

| Ref. | Formula |
|---|---|
| Rizkalla et al. [1] | $\frac{p_1^2 - p_2^2}{t} = \left(\frac{k^n}{2}\right)\left(\frac{\mu}{2}\right)^n (RT)^{n-1} \left\lvert\frac{p_2 Q}{b}\right\rvert^{2-n} \frac{1}{1.42Nw^3}$ <br> $N = n\ cracks$ <br> $n = \frac{0.195}{\left(Nw^3\right)^{0.063}}$ <br> $k = 8.702\times10^6 \left(Nw^3\right)^{0.367}$ |
| Nagano et al. [2] | $Q = bw^3 \frac{p_1 - p_2}{12\mu t}$ |
| Suzuki et al. [3] | $Q^2 = \frac{w^3\left(p_1^2 - p_2^2\right)}{2\rho_0 p_0 t\left[\bar{a}(w)\frac{12\mu}{\rho_0 Q} + b(w)\right]}$ <br> $\bar{a}(w) = 6.5\times10^{-4} / W + 1$ <br> $b(w) = 9.2\times10^{-5} / W$ |
| Suzuki et al. [4] | As Suzuki et al. [3] <br> $\bar{a}(w) = 4.33\times10^{-5} / W^{1.5} + 1$ <br> $b(w) = 3.41\times10^{-4} / W$ |
| Greiner and Ramm [5] | $Q = \sqrt{\left(p_1^2 - p_2^2\right) b^2 w^2 \frac{RT}{p_2^2} \frac{2w}{ft}}$ <br> $f = \left(\frac{0.105k^{0.409}}{w}\right)^{[1/1.739ln(k/0.414]}$ <br> $+0.20k^{0.3043} - 0.024$ |

$Q$: volume rate through the wall; $b$: crack length; $w$: crack width; $t$: wall thickness; $p_1$: upstream pressure; $p_2$: downstream prssure; $\mu$: dynamic viscosity; $\rho$: density; $f$: friction coefficient; $T$: absolute temperature; $R$: gas constant; $k$: maximum aggregate size

## 3. Method and Results

In order to compare the leak rate formulae, a specimen described in Riva et al. [6] was adopted. Nonlinear finite element analysis was carried out to investigate load, displacement and cracks relations. A commercial software ATENA was used for this purpose. The obtained crack widths were used to estimate the corresponding leakage rate at given pressure differences.

In addition, 2D air flow study was carrided out via computational fluid dynamics (CFD). FLUENT was used to calculate mass flow rate for given crack widths. As a preliminary study, the penetrating cracks were modelled as rectangular conduits and no frction was considered. Fig. 1 shows the results of analytical equations and the CFD. It is notable that the Poiseuille's flow equation overestimates compared to the other equations. This is because the effect reinforcing bars and wall shearing stress are not accounted for. As the same conditions were applied to the CFD, the result of Nagano et al. [2] and that of the CFD agree.

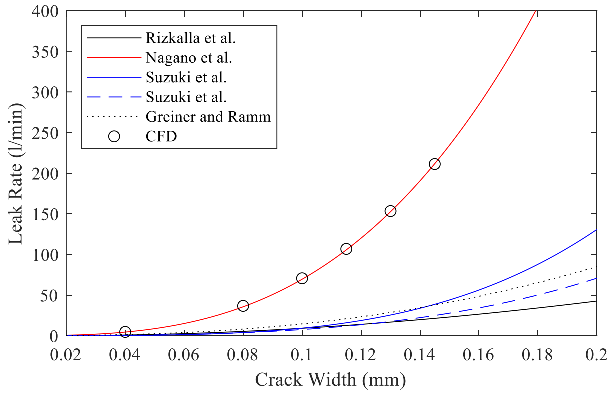


Fig. 1. Comparison of the leakage rate estimation formulae and CFD results.

## 4. Conclusions

In this study, some of the available leakage rate estimation formulae were reviewed. The formula by Nagano et al. [2] overestimates the leak rate compared to the other equations. In the future study, more realistic boundary conditions will be applied to the CFD and its result will be compared to the other formulae.

## ACKNOWLEDGEMENTS

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