Leakage Tests of the Wall Segments of a Prestressed Concrete Containment Building

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1. Introduction

Containment buildings have to maintain their air tightness under extreme loading conditions such as earthquakes, missile impact, and severe accidents to maintain their functional integrity. For evaluating the functional failure of containment buildings, it is important to predict the leakage level through cracked concrete walls.

The leakage through concrete cracks has been studied since 1972. Buss [1] examined the flow rate of air through a pre-existing crack in a slab under air pressure. Rizkalla el al. [2] initiated an experimental study for the leakage of prestressed concrete building segments under uniaxial and biaxial loadings to simulate the loading condition of containment buildings under an internal pressure. Recently, Salmon el al. [3] initiated an experimental program for determining the leak rates in typical reinforced concrete shear walls subjected to beyond design basis earthquakes.

This study determined the leak rate for the wall segments of a prestressed concrete containment building through leakage tests.

2. Mathematical Formulation of the Leak Rate

For reinforced concrete elements, a cracked section is extremely complex. However, assuming that the width of any given crack is reasonably uniform through out the thickness, the crack may be idealized as a gap between two parallel plates. Rizkalla el al. [4] derived the leakage flow equations for a gap between parallel plates as

$$\frac{P_1^2 - P_2^2}{L} = \left(\frac{k^n}{2}\right)\left(\frac{\mu}{2}\right)^n (RT)^{n-1} \left|\frac{P_2 Q_2}{B}\right|^{2-n} \frac{1}{\sum_{i=1}^{j} W_i^3} \qquad (1)$$

where the subscripts *1* and *2* represent the conditions at the beginning and at the end of the crack, respectively. P and Q are the absolute air pressure and the total flow rate respectively; L is the length of the crack in the direction of the flow; B is the extent of the crack; k is the wall roughness; μ is the dynamic viscosity; R and T are the gas constant and the absolute temperature respectively; W_i is the width of the ith crack which must be determined from measurements; n is the flow coefficient, which can be determined experimentally.

Equation (1) can be simplified as equation. (2), where $P'' = (P_1^2 - P_2^2)/L$, modified pressure gradient; $C = (k^n/2)(\mu/2)^n (RT)^{n-1} / \sum W_i^3$, a constant; $m = 2-n$; and $P_2 Q_2 / B$, rate of the flow per unit extent of a crack.

$$P'' = C\left|\frac{P_2 Q_2}{B}\right|^m \qquad (2)$$

Equation (2) implies a linear relationship between the modified pressure gradient, P'' and the rate of the flow of air per unit extent of a crack using a log-log scale, as in equation (3).

$$\log P'' = \log C + m \log\left|\frac{P_2 Q_2}{B}\right| \qquad (3)$$

3. Leakage Test for the Wall Segments

3.1 Test Specimen

The leakage test was carried out to predict the leak rate through cracked reinforced concrete containment wall elements [5]. The overall dimensions of a test specimen and air chamber are shown in Figure 1. The test specimen represented the containment wall segment with a thickness of 1.2m and width of 0.2m. The concrete had a nominal design strength of 400kgf/cm^2 and the rebar had a yield strength of 4,000kgf/cm^2 (SD40). Three rebars of D29 were embedded into the specimen for a reinforcement in one direction spaced at 0.45m center-to-center. Three steel plates with a dimension of 200x75x6mm were embedded into the specimen to simulate the stiffeners of the liner spaced at 0.375m center-to-center.

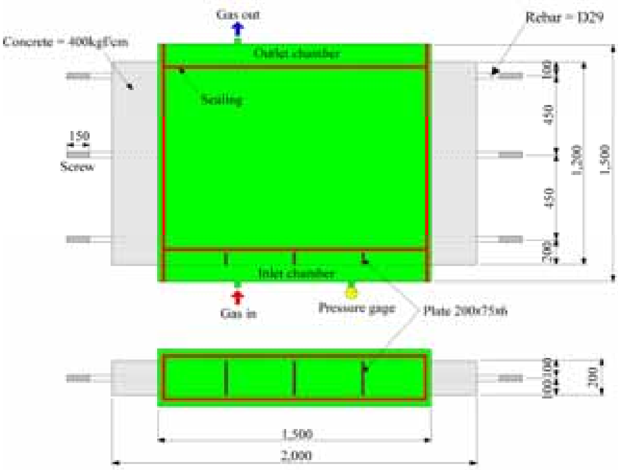

Figure 1. Leakage test specimen and air chamber.

An air chamber with a gas inlet, outlet, and pressure gage was provided. To provide air-proofing between the inlet and outlet chambers, a rubber liner was provided along the edges of the specimen and the chamber for a sealing.

3.2 Test Procedure

The test procedure was divided into two steps. At the first step, tension loads were imposed through the reinforcements to cause the cracks of the test specimen by using hydraulic actuators in a displacement control mode. At this step, the total crack width was measured with vernier calipers. At the second step, by holding the constant displacement state, the air chamber blocks were assembled with a test specimen, and then the air leakage tests were performed. Nitrogen gas was used for increasing the air pressure. At this step, input and output pressures, and the flow rate at the outlet were measured. Leak rate was measured at each load or displacement increment after investigating the crack patterns of the concrete.

4. Leak Rate through Cracks of Reinforced Concrete

Figure 14 shows the pressure-flow rate relationship according the crack width. It was observed that the wider the cracks, the larger the flow rate. It was also found that the flow rate was affected by the total crack width.

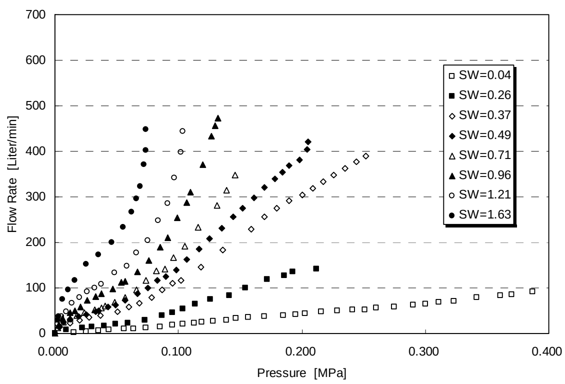

Figure 2. Pressure-flow rate curve

Based on the experimental results, a graphical representation of the relationship is shown in Figure 3. This relationship could be utilized as a criterion for the leakage of a containment wall. The slope of each regression line represents the exponent value of *m* from which the turbulent coefficient *n* can be determined. Similarly, *k* can be calculated from the intersection point on the y-axis. These results are listed in Table 1.

5. Conclusion

The leakage rate characteristics for a cracked reinforced concrete are investigated. Through the uniaxial tension test and leakage test for the wall segment of a prestressed concrete containment building, the leak rates were determined for different crack widths and air pressures. The results suggested in this study can be used not only for the analysis of the functional integrity of prestressed concrete containment buildings, but also for the determination of the failure criteria of containment buildings.

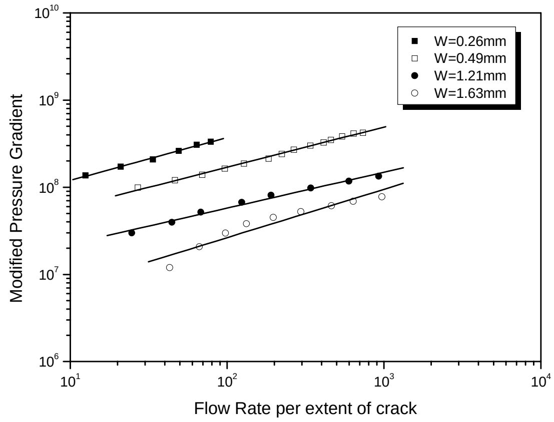

Figure 3. Modified pressure gradient-flow rate

Table 1. Flow coefficient and wall roughness according to crack width

ΣW_i [mm]	k	n
0.26	30.926	1.5080
0.49	65.749	1.5391
1.21	187.642	1.5882
1.63	210.220	1.4457

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