Experimental Study of the Leakage Rate through Cracked Reinforced Concrete Wall Elements for Defining the Functional Failure Criteria of Containment Buildings

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1. Introduction

Containment buildings in nuclear power plants should maintain their structural safety as well as their functional integrity during an operation period. To maintain the functional integrity, the wall and dome of the containment buildings have to maintain their air tightness under extreme loading conditions such as earthquakes, missile impact, and severe accidents. For evaluating the functional failure of containments, it is important to predict the leak amount 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 investigates the cracking behavior of reinforced concrete containment wall elements under a uniaxial tension and addresses the outline of the leakage test for unlined containment wall elements.

2. Mathematical Formulation of the Leak Rate

For reinforced concrete elements, in general, it is impossible to model accurately the crack path because the geometric configuration of a crack extending through a cracked section is extremely complex. However, in the case 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.

3. Behavior of the Reinforced Concrete Wall Elements under a Uniaxial Tension

In a typical reinforced concrete containment wall element, the crack pattern is influenced by the stiffeners that are welded to the liner [5]. The crack pattern in concrete under a uniaxial tension, which is applied through the rebars and liner, is shown in figure 1. The first crack, which is perpendicular to the rebar, occurs in the middle of the specimen, and the second and third cracks occur at both sides of the first crack with an equal spacing. The distances between the first and second cracks and between the first and third cracks are

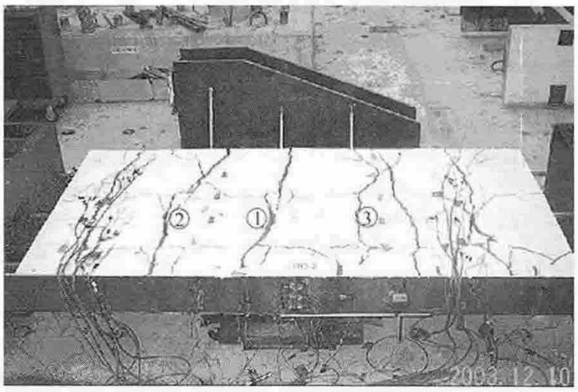

Figure 1. Crack patterns in a lined wall element under uniaxial tension.

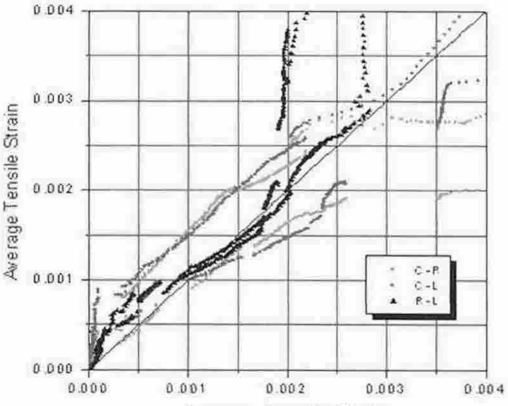

Figure 2. Relative comparisons of strains in concrete(C), rebar(R), and liner(L).

almost the same as the distance between the stiffeners. After the perpendicular cracks, parallel cracks occur along the rebars. Finally, concrete is totally damaged and separated from the rebars and liner. The liner does not reach a failure until the concrete is totally collapsed. Figure 2 shows the relative comparisons of the average tensile strain in the concrete, rebar, and liner for two specimens. In figure 2, C-R represents the relative strain of the concrete to the rebar. Similarly, C-L and R-L represent the relative strains of the concrete and rebar to the liner respectively. The horizontal and vertical axes represent the strains for the first and second materials in the C-R, C-L, and R-L, respectively.

Roughly speaking, the average tensile strains in the concrete, rebar, and liner are almost the same although there are big differences for one specimen. It can be found that the liner does not affect significantly the behaviors of the concrete and rebar. Therefore the liner will be excluded in the specimen for the leakage test.

4. Leakage Test for the Reinforced Concrete Wall Elements

The leakage test will be carried out to predict the leak rate through cracked reinforced concrete containment wall elements. The overall dimensions of a test specimen and air chamber are shown in figure 3. The test specimen represents the containment wall segment with a thickness of 1.2m and width of 0.2m. The concrete has a nominal design strength of 400kgf/cm^2 and rebar has a yield strength of 4,000kgf/cm^2 (SD40). Three rebars of D29 are embedded into the specimen for reinforcement in one direction spaced at 0.45m center-to-center. Three steel plates with a dimension of 200x75x6mm are embedded into the specimen to simulate the stiffeners of the liner spaced at 0.375m center-to-center.

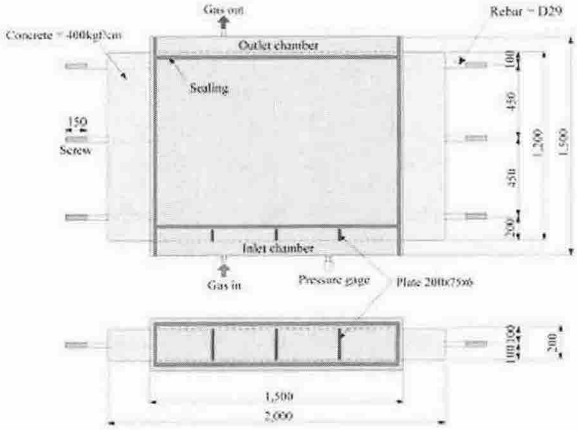

Figure 3. Leakage test specimen and air chamber.

An air chamber with a gas inlet, outlet, and pressure gage is provided. To provide air-proofing between the inlet and outlet chambers, rubber liner is provided along the edges of the specimen and chamber for sealing. Nitrogen gas is used and its pressure is increased up to 2.0MPa. Leak rate will be measured at each load or displacement increment after investigating the crack patterns of the concrete. Testing will be terminated when the rebars will reach yielding point.

5. Conclusion

The outline of the leakage rate through the cracked reinforced concrete is introduced. Also, the behaviors of the reinforced concrete containment wall elements under a uniaxial tension are addressed. It is found that the stiffeners of the liner affect the crack patterns of the concrete significantly, while the liner does not affect the behaviors of the concrete and rebars. The liner may be excluded in the specimen for the leakage test. The specimen and air chamber for the leakage test are designed and the test procedure is decided.

Acknowledgement

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