

# Preliminary Assessment of Permeability in Large-Scale RC Structures with Cracks for NPP Containment Applications

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## 1. Introduction

Nuclear Power Plant (NPP) containment buildings are critical safety barriers designed to prevent the release of radioactive materials into the environment. The integrity of these structures, particularly their leak-tightness, is paramount. Reinforced concrete (RC) is the primary material for containment walls, and while designed to withstand significant loads, the formation of cracks under various operational and accidental scenarios is an unavoidable consideration. These cracks can potentially compromise the containment function by increasing permeability.

Existing research often focuses on scaled specimens or analytical models, which may not fully capture the complex behavior of full-size structures, especially concerning crack morphology and flow paths in very thick sections [1-3]. This study addresses this gap by presenting preliminary results from a pilot test on a full-size RC specimen, replicating the thickness of actual NPP containment walls. The objective of this pilot test was to experimentally assess the permeability characteristics of such structures under controlled tensile cracking conditions.

## 2. Experimental Program

### 2.1 Specimen Design and Fabrication

A full-size RC specimen was designed and fabricated to replicate the typical thickness of an NPP containment building wall. The specimen dimensions were 2400 mm long, 900 mm wide, and 1200 mm thick.

Reinforcement details include six No.18 (D57) reinforcing steel bars of ASTM Grade 60, placed in two layers with 300 mm spacing along the width direction. The top bars, corresponding to the outward layer of the containment wall, had a 50 mm concrete cover. The bottom bars, representing the inward layer where the containment liner plate, supporting channels, and angles are typically located, had a 343 mm concrete cover. Additionally, four D16 hoops were placed at the ends of the specimen to restrain local failure during testing.

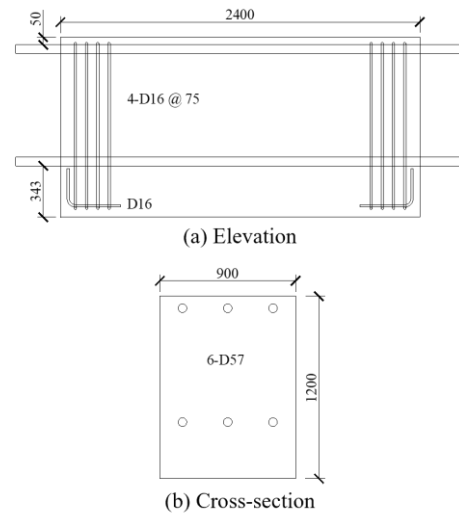


Fig. 1. Dimensions and reinforcing details of specimen (Unit: mm).

### 2.2 Test Setup and Loading Protocol

The specimen was subjected to controlled tensile loading to induce through-thickness cracks. The loading mechanism involved two 5000 kN hydraulic actuators. Foil type strain gauges were placed on reinforcing steel and four LVDTs were attached on side faces of the specimen to measure global deformation. In addition, fiber optic sensors (FOS) were embedded in the specimen to monitor crack initiation and propagation.

### 2.3 Permeability Measurement System

A specialized system was developed to measure the permeability of the cracked concrete. This system involved attaching a steel chamber to the top surface of the specimen, which served as a suction chamber. Air was drawn from the bottom surface of the specimen, through the induced cracks, and into this suction chamber. An ejector system was adopted to maintain a constant negative pressure within the chamber, thereby driving a controlled airflow through the cracked concrete. This suction method offered an advantage by not requiring a steel frame to rigidly tie down the chamber to the specimen, thereby simplifying the setup and minimizing the potential for parasitic leaks around the interface [4, 5]. To prevent leakage outside the steel

chamber, airtight sealing tape was applied to the four sides. Pressure sensors and flow meters were used to quantify the pressure difference and flow rate under various loading levels.

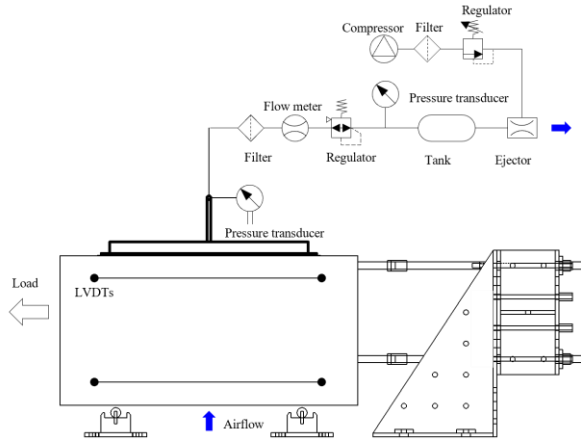


Fig. 2. Schematic of mechanical loading and permeability measurement system.

### 3. Results and Discussion

#### 3.1 Force and Deformation Characteristics

Tensile loading was applied to the specimen, and the sum of the applied force was continuously monitored. Approximately at 2800 kN, cracking was assumed to have occurred. This assumption was supported by two key observations: a noticeable change in the pressure value within the suction chamber, indicating the initiation of through-thickness flow paths, and a simultaneous sudden increase in the specimen's measured deformation as shown in Fig. 3.

Following this initial cracking, the load was increased incrementally by 100 kN per step. At each subsequent step, the specimen gradually accumulated further deformation, indicating the progressive opening and propagation of cracks.

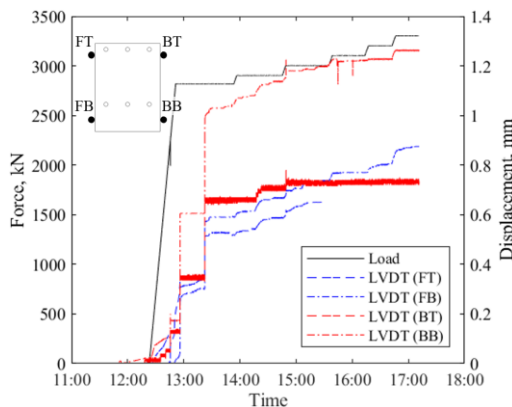


Fig. 3. Force and displacement measurements.

#### 3.2 Permeability Measurements

Prior to the application of tensile loading, suction was applied to the chamber, achieving a vacuum pressure of up to 16 kPa. This was done to check the airtightness of the intact specimen and the sealing system. This vacuum pressure was sufficiently maintained until the initiation of the first crack, at which point a distinct drop in pressure was observed, confirming the formation of through-thickness flow paths.

Fig. 4. illustrates the measurement history of differential pressure and flow rate during load step 2. As depicted, an increase in the differential pressure applied across the specimen led to a corresponding increase in the measured airflow rate through the cracks. This direct relationship qualitatively confirms the permeability of the cracked section. The precise quantitative relationship between differential pressure and flow rate, and its correlation with crack characteristics, requires further detailed analysis.

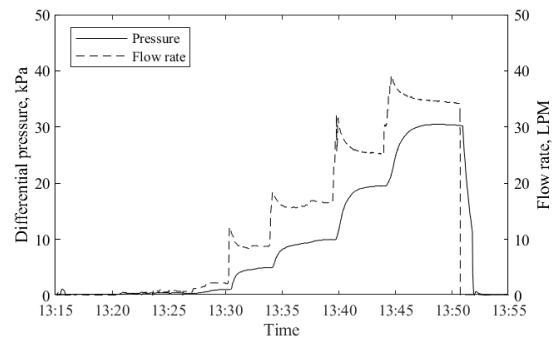


Fig. 4. Differential pressure and flow rate measurements during the second loading step.

### 4. Conclusions and Future Work

This pilot test provides valuable preliminary insights into the permeability of full-size RC structures with tension cracks, directly relevant to NPP containment applications. The ability to induce and characterize cracks in a full-scale specimen, coupled with direct permeability measurements, represents a significant step towards understanding the real-world behavior of these critical safety barriers.

Key findings include the identification of crack initiation at approximately 2800 kN tensile force, evidenced by simultaneous changes in chamber pressure and sudden increases in specimen deformation. The permeability measurement system demonstrated that increasing differential pressure across the cracked specimen directly correlated with an increased airflow rate. These observations highlight that even small crack widths can lead to measurable permeability in thick RC sections.

Future work will involve integrating data from FOSs to provide detailed insights into crack distribution and strain fields. A comparative study between these full-scale results and those obtained from small-scaled specimens will also be performed to assess scale effects

and validate extrapolation methodologies.

### **ACKNOWLEDGEMENTS**

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