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Evaluation of Shear Performance and Load-Carrying Capacity of RC Shear Walls with Concrete Voids via Cyclic Loading Tests

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1. Introduction

Reinforced concrete (RC) shear walls are critical lateral force-resisting systems in nuclear power plants, designed with high reinforcement ratios to maintain structural integrity under extreme seismic loads. However, internal concrete voids caused by construction imperfections or aging have been reported, raising concerns about potential reductions in seismic safety and load-carrying capacity. These voids can reduce the effective cross-sectional area and induce localized stress concentrations, yet experimental data quantifying their direct impact on shear performance remain limited. Therefore, this study aims to evaluate the influence of void size and location on the shear performance of low-aspect-ratio RC shear walls.

2. Numerical Analysis of Shear Walls

In this section, prior to experimental testing, several numerical models were constructed, and the shear performance of each model was compared. Based on these models, test specimens were fabricated, and a trend analysis was performed on the numerical models.

As previously performed, the location of the voids was considered to be a diagonal shear crack in the shear wall based on the parametric studies. The variables considered here are the effective shear area reduction based on the equation of Ogaki et al. (1981), the thickness-wise location (surface or center of wall), and the void thickness (t/3, 2t/3 mm). According to the equation presented by Ogaki et al., shear strength decreases proportionally with the rate of decrease in effective shear area. The effects of void thickness and location were analyzed. Considering these variables, 5 condition void analysis models were constructed, and the results were compared. In the case of the void area, an analysis model was constructed considering the reduction rates of 5 and 20%, and no clear trend was found in the shear strength reduction rate according to the 5% reduction of effective cross-sectional area. It was confirmed that the failure mode of each wall was in the form of a diagonal shear crack.

3. Cyclic Load Test of Shear Wall

To analyze the trend of results compared to previously performed numerical analysis, a non-degradation/degradation shear wall was constructed and cyclic loading tests were performed. The experimental setup is shown in Fig. 1. The lateral cyclic loading is applied by dynamic actuator installed horizontally at the top slab of shear wall. To promote an even distribution of lateral forces and suppress undesirable torsional responses, the actuator was coupled to the loading beam during the test. A constant axial load of 1,000 kN, representing the concrete compressive capacity, was applied throughout the test to simulate the gravity loads. The cyclic lateral loading was applied under displacement control with progressively increasing drift ratios, following the protocols of ATC-24 and ACTI 374.2R-13. For each drift level, three fully reversed cycles were performed to capture the cyclic degradation characteristics and hysteretic response.

4. Test Results and Discussion

The experimental results indicated that all specimens primarily exhibited shear-dominated failure, characterized by the development of diagonal cracks and subsequent concrete spalling. The non-degradation specimen reached a maximum later shear strength of 2,040.22 kN. In contrast, specimens containing voids showed a reduction in peak strength and accelerated post-peak degradation. Specifically, for the specimens with a 20% reduction in effective cross-sectional area, a decrease in shear strength was confirmed at a rate similar to the reduction in effective cross-sectional area, similar to the results of the numerical analysis.

The failure patterns were highly dependent on void location; center-void specimens showed relatively symmetric damage, whereas side-void specimens displayed pronounced damage concentration and asymmetric failure near the void regions. Strain measurements indicated that while vertical reinforcement generally remained below yielding, horizontal reinforcement exhibited localized strain concentrations near the voids. This confirms that the internal voids disturb the shear load transfer mechanism and accelerate the degradation of structural performance.

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