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Seismic performance evaluation of concrete shear wall in containment buildings with voids

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1. Introduction

Reinforced concrete structural walls are a common feature of major nuclear power plant structures, primarily due to their airtightness and structural integrity. The design of RC walls in nuclear power plant structures is such that they are intended to demonstrate elastic behavior in response to the design seismic load. Furthermore, the cross-section and reinforcement amount are typically larger than those typically seen in other structures. This renders experimental analysis of the extreme state of RC walls of nuclear power plant structures a challenging endeavor. Furthermore, there is a paucity of understanding regarding the inelastic behavior of structures under extreme conditions. Furthermore, the presence of voids, which have recently emerged as a concern in domestic nuclear power plants, can be regarded as a form of physical degradation that has the potential to impact shear wall performance. In order to gain insight into the potential changes in behavior and failure modes that may occur despite the relatively insignificant presence of voids within the overall volume of the containment building, this study fabricated a shear wall specimen with and without voids and conducted a series of repeated history experiments. Based on the experimental results, a finite element analytical model was constructed and the effect of void area and location on the shear strength of the wall was examined. Subsequently, the shear wall behavior with voids was extended to the containment building wall in order to evaluate the seismic performance of the containment building with voids.

2. Shear wall with voids

2.1 Test specimens

In order to evaluate the shear performance of the wall in consideration of voids, which has been a significant challenge in the context of domestic nuclear power plants, two shear wall test specimens were constructed in this study based on a scale model that can reflect the structural characteristics of nuclear power plant structures. The maximum shear strength of shear wall is approximately 1800kN according to the Barda's equation. The shape ratio is 0.8, and the diagonal shear failure is designed to occur. One of the two test specimens is a wall with a void, as illustrated in Figure 1. The void occupies 20% of the wall cross-section, has a height of 20mm, and is situated 2/3t deep (120mm) from the wall surface. Figure 2 depicts the experimental setup, which was subjected to a 1000kN axial force and repeatedly tested in the in-plane direction.

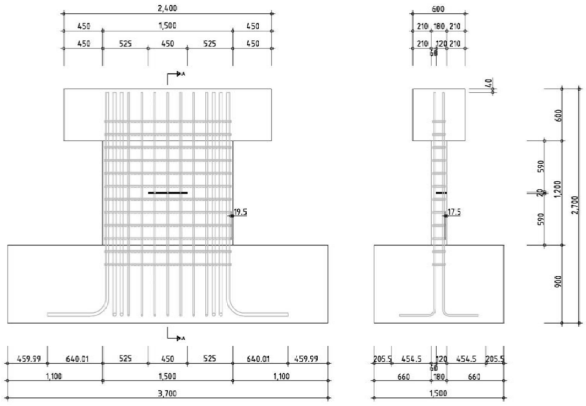

Fig.1. Details of shear wall specimen with void

Fig.2. Test set-up

2.2 Finite element model

To evaluate the performance of the shear wall in consideration of the size and location of the voids, a finite element analysis model was constructed based on the findings of the experimental investigation, as illustrated in Figure 3. ABAQUS 2023 was employed for this analysis, with the wall concrete modelled using the C3D8R element and the rebar represented by the T3D2 element. The Elastic Concrete material model was employed for the top beam and fixed end foundation, which were installed for load capacity purposes. In contrast, the CDP model was utilized for the shear wall section. The concrete stress-strain relationship was based on the provisions of Eurocode 2, as set forth by Mander et al. (1988), with a compressive recovery factor of 0.7 and a tensile recovery factor of 0.1. Isotropic hardening material was employed for the reinforcement, with the yield strength obtained from material testing utilized as the input value. The mesh size was determined to be 50 mm, with consideration given to the convergence of the analysis, and the void and loading force were simulated in a manner consistent with that of the experiment.

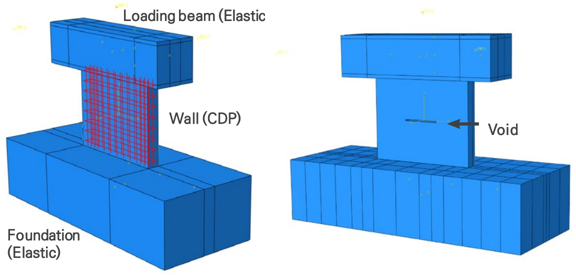

Fig.3. Finite element analysis model

2.3 Hysteresis behavior

Prior to undertaking an analysis of the variables, the shear wall analysis model was subjected to a comparison with the experimental results, with a view to ensuring the reliability of the model. Figure 4 illustrates the comparison between the experimental and analytical results of the basic shear wall without voids, while Figure 5 depicts the comparison between the experimental and analytical results of the shear wall with voids. The initial stiffness, ultimate strength, and overall hysteretic behavior are similar, indicating that the analytical model is properly constructed. Figure 6 illustrates a comparison of the failure of the shear wall with voids and the damage parameter contour in the analysis model, and the failure pattern around the voids is indicative of a similar mode of failure.

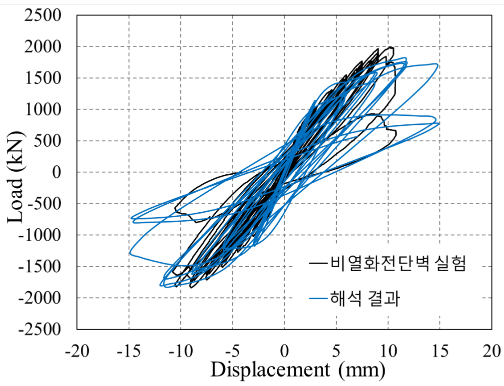

Fig.4. Force-displacement curve
of shear wall without void

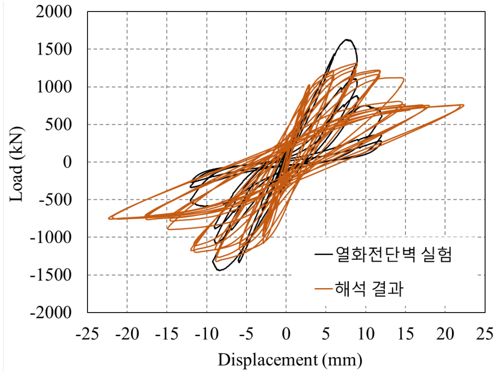

Fig.5. Force-displacement curve
of shear wall with void

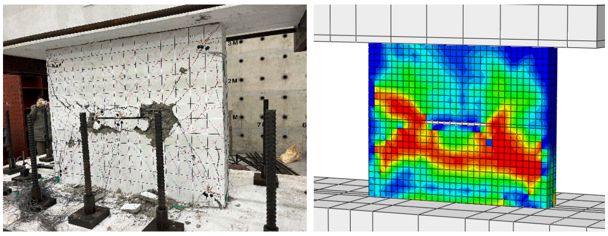
Fig.6. Crack pattern

3. Conclusions

In this study, the seismic performance of the containment building of a nuclear power plant was evaluated through a shear wall repeated history experiment and numerical analysis that considered voids, which represent one of the physical deterioration factors of the containment building. By employing the analytical model, it was feasible to ascertain the shear strength reduction contingent on the dimensions and position of the voids, and the material model of the wall with voids can be extrapolated to the entirety of the containment building for the purpose of evaluating the performance and behavior of the containment building in consideration of the effects of the actual investigated voids. While the percentage of voids identified is insufficient to impact the seismic performance of the containment building, it is crucial to assess the potential degradation that may arise when multiple aging factors are considered concurrently.

REFERENCES

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