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Experimental Study on Residual Seismic Capacity of RC Squat Walls

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Abstract— **Following minor cracking damage to squat RC walls in the Onagawa Nuclear Power Plant buildings during the 2011 Tohoku Earthquake, concerns were raised regarding the performance of these walls in future earthquake events. To assess the residual capacity of squat RC walls, ¼ scale RC walls were tested using pseudo-static cyclic loading. The tests were divided into three series (four walls per series) with the parameters investigated between series being two levels of wall reinforcement ratio and boundary element geometry and the parameters investigated within each series being the four levels of initial damage. The results showed that no significant deterioration was observed in ultimate strength and maximum deformation capacity due to previous damage. RC walls having boundary elements as flange walls had relatively greater stiffness degradation due to prior damage.**

I. Introduction

The Great East Japan Earthquake occurred on March 11, 2011 with magnitude of Mw 9, caused different levels of damage throughout the Tohoku region. The seismic response for the Nuclear Reactor Building of Unit 2 of the Onagawa NPP remained within elastic range, although hairline cracks were observed in shear walls. The slightly damaged walls in the reactors are thought not to affect the safety due to the high safety factors used in the design of RC walls of nuclear power plants. However, the degradation of seismic capacity of shear walls due to previous slight damage is still unclear. The objective of this study is to clearly quantify the degradation of seismic capacity at each of the classified damage state based on experimental results of static cyclic loading tests of RC walls.

In other words, the RC walls were first loaded until it experienced a certain damage level, then reloaded again until its failure. 3 Series of tests were conducted with each series represents a certain parameter. Each series have 4 specimens of 1\4 scale reinforced concrete (RC) shear wall.

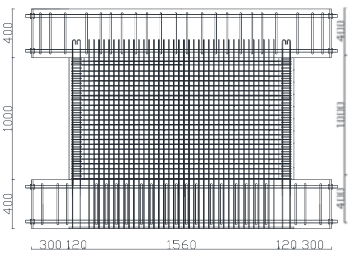
II. Experimental Plan

A. Outline of Experiment

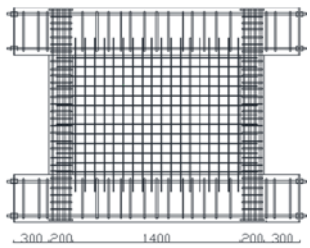
Three different series of tests were conducted (SC-13, SC-06, SF-13); each one comprised of four identical specimens of reinforced concrete shear walls. The parameters taken into consideration were damage level (before conducting the main test), reinforcement ratio in the shear wall, and the boundary elements of the shear walls. More specifically, SC13 represents walls with lateral reinforcement ratio of 1.3% and with columns as boundary elements (S represent shear wall, C indicates that columns are boundary elements of the wall and the number 13 represent lateral reinforcement ratio of 1.3%). Series SC-06 are shear walls with lateral reinforcement ratio of 0.6% and columns as boundary elements. Series SF-13 have shear walls with the same amount of reinforcement as SC-13 Series, but with flange walls as boundary elements. In other words, SC-13 Series and SC-06 Series have exactly the same boundary elements which are columns but with different reinforcement ratio, whereas in SF-13 Series flange walls were used as boundary elements. Details of the three experimental series is shown in Figure 1 and Table 1.

Table 1 Specimens details

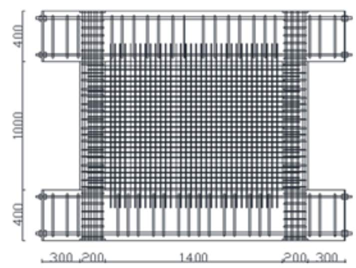
	Name of specimen	SC-13 Series	SC-06 Series	SF-13 Series
	Damage class	0~IV (None～Severe)	0~IV (None～Severe)	0~IV (None～Severe)
Shear wall	Height(mm)	1000		
	Length (mm)	1800		
	Thickness (mm)	120		
	Arrangement of reinforcement	D6@40(SD295) Double	D6@80(SD295) Double	D6@40(SD295) Double
	Reinforcement ratio (%)	1.32	0.66	1.32
	Shear span to depth ratio	0.31		



a) Series SC-13

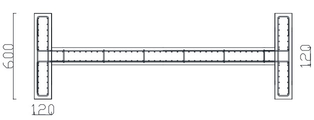


b) Series SC-06



c) Series SF-13

series SC (boundary columns)



series SF (boundary flange)

c) Top view

Figure 1 Dimension and reinforcing details of specimens: (units in mm)

B. Loading plan

Loading setup is shown in Figure 2. Cyclic horizontal load is applied using two hydraulic jacks fixed at the mid-height of the wall, in order to make the inflection point at the mid-height of the specimen with a shear span ratio to depth of the wall of 0.31. Loading procedures for all series, except for specimen D0, as illustrated in Figure 3, comprise of two main phases, the first is application of the pre-loading until the specimens reach a certain damage level similar to that observed after an earthquake. The D0 tests only the main loading was applied (no prior loading). Then, the second phase, main loading is applied to all specimens until failure of specimens. In this paper, damage classes in the shear walls (SC-13-D0, SC-06-D0 and SF-13-D0) are judged based on the Post-Earthquake Damage Evaluation Guideline JBDPA [1]. Using these criteria and by comparison with the observed damage in specimens D0, it was determined that a drift of less than 0.1% corresponds to damage class I (slight damage), 0.1%~0.3% drift corresponds to damage class II; 0.3%~0.5% drift corresponds to damage class III (moderate damage), and the drift larger 0.5% drift at ultimate shear strength corresponds to damage class IV (severe damage).

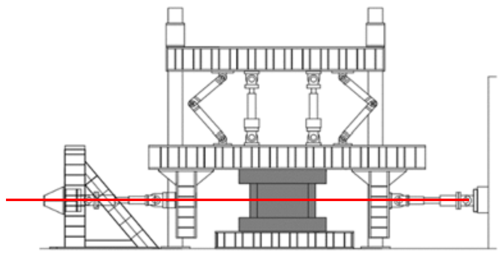


Figure 2 Loading test setup

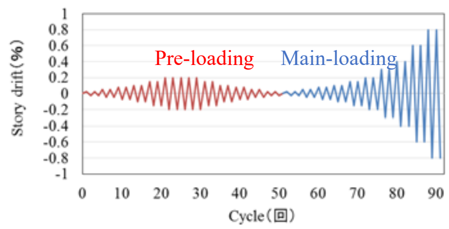


Figure 3 Loading history

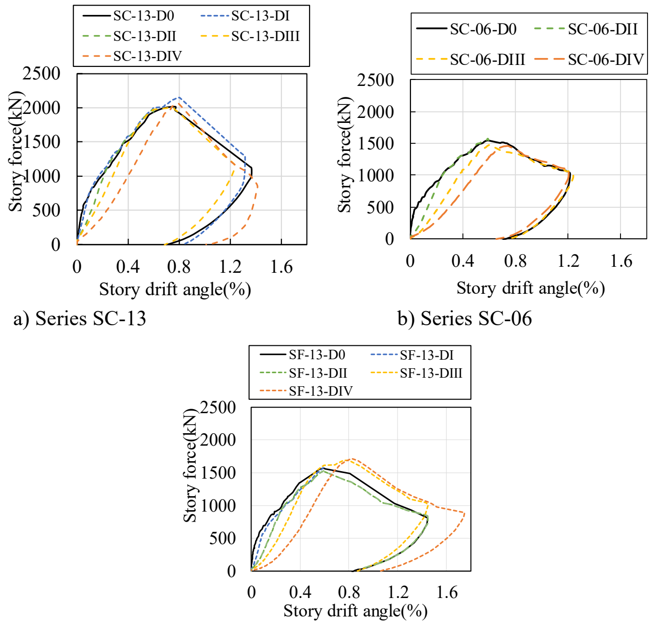
III. Results and Discussion

A. *Comparison of shear strength and deformation capacity*

Envelopes of the shear force and story drift for all the specimens in each series are demonstrated in Figure 4. For test series SC-13 and SF-13 (walls with relatively high reinforcement ratio), beyond the target story drift for each pre-damage state, there is no significant difference in force capacity and deformation as compared to the specimen with prior D0 tests, as shown in Figure 4. On the other hand, in S-06 series, the maximum shear force of the specimens with damage level III or IV at their main loadings showed a slight reduction value of about 10% but this observation is not conclusive since the number of specimens is limited.

B. *Comparison of shear strength and deformation capacity*

The relationship between story drift and stiffness degradation is illustrated in Figure 5. It is noticed that even for damage class I that experienced limited damage during the pre-damage phase, the initial stiffness decreased to by approximately a factor of two compared to the D0 wall tests. On the other hand, beyond experienced deformation in the pre-loading phase almost no difference is noticed in stiffness compared to the undamaged specimen D0. SC-06 with a lower reinforcement ratio (0.6%) experience relatively greater stiffness degradation compared to the walls in series SC-13 (reinforcement ratio of 1.3%).

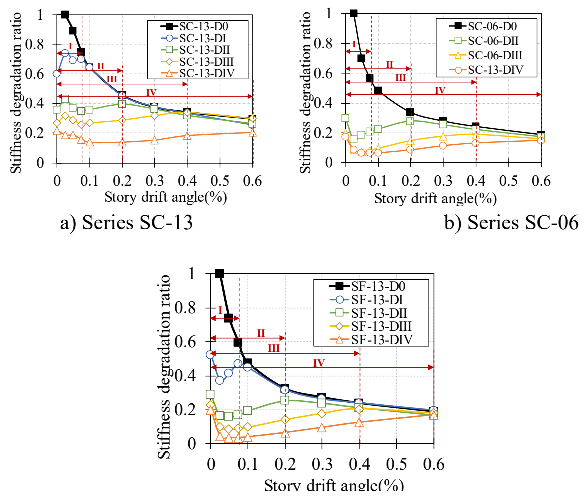


a) Series SC-13

b) Series SC-06

c) Series SF-13

Figure 4 shear force – story drift curves for different damage level



a) Series SC-13

b) Series SC-06

c) Series SF-13

Figure 5 stiffness degrading ratio

IV. Conclusion

Three series of tests of 1\4 scale reinforced concrete (RC) shear wall using static cyclic loading were conducted. The investigated parameters are: two levels of wall reinforcement ratio, column and flanged boundary of shear walls and four levels of initial damage. The following are the main findings:

1- The results showed that no significant deterioration was observed in ultimate strength and maximum deformation capacity due to previous damage.
2- Specimens with flange boundaries have relatively greater stiffness degradation and smaller energy dissipation. The specimens with walls of less reinforcing ratios showed a slight degradation of strength of less than 10 % when subjected to prior damage level IV (Severe damage), but those results are inconclusive due to limited number of specimens.

References

[1] Japan Building Disaster Prevention Association (JBDPA). (2001). “Standard for Post-Earthquake Damage Level Classification of Reinforced Concrete Building”