Acta Polytechnica CTU Proceedings **33**:85–91, 2022
https://doi.org/10.14311/APP.2022.33.0085

FEASIBILITY EXPERIMENTS OF SEISMIC CONCRETE BLOCK WALLS WITHOUT JOINT MORTAR

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Abstract. The authors developed two types of block systems consisting only of main block and key block without joint mortar in consideration of seismic performance and workability. Two types of block systems have different key block shapes: One is the peanuts shape and the other is the dumbbell shape. In this study, the proposed two types of block walls as well as a typical block wall were experimentally investigated to evaluate the seismic performance. In the tests, full-scale, single-story specimens were tested under static cyclic in-plane loading, and failure patterns and cracks were carefully observed. In this paper, the loading bearing capacity, energy dissipation capacity and reuse ratio of block walls are discussed in detail. As a result, the deformability, energy absorption capacity and reuse ratio of the proposed block systems were considerably higher than those of typical block system.

Keywords: In-plane, key block, main block, out-of-plane, unreinforced masonry.

1. Introduction

In some regions of Asia, Europe, and Latin America where earthquakes frequently occur, serious earthquake damage is commonly found resulting from catastrophic building collapse. Such damaged buildings often have unreinforced masonry (URM) walls, as shown in Figure 1(a). Since the seismic performance of the URM wall buildings and infill walls are relatively poor compared to the other structural types, these buildings and walls always damaged when an earthquake occurs. Furthermore, in Japan which is an earthquake-prone country, the use of URM walls is prohibited by the Building Standards, but concrete block fences with reinforcing bars are often used. However, the damage of the fences always occurred when the earthquake occurs, as shown in Figure 1(b).

Under these backgrounds, the authors developed two types of block systems consisting only of main block and key block without joint mortar in consideration of seismic performance and workability. Two types of block systems have different key block shapes: One is the peanuts shape and the other is the dumbbell shape.

In this study, the proposed two types of concrete block walls as well as a typical concrete block wall were experimentally investigated to evaluate the seismic performance. In the tests, full-scale, single-story specimens were tested under static cyclic in-plane loading, and failure patterns and cracks were carefully observed.

In this paper, the loading bearing capacity, energy dissipation capacity and reuse ratio of block walls are discussed in detail.

2. Experimental program

2.1. Developed block systems

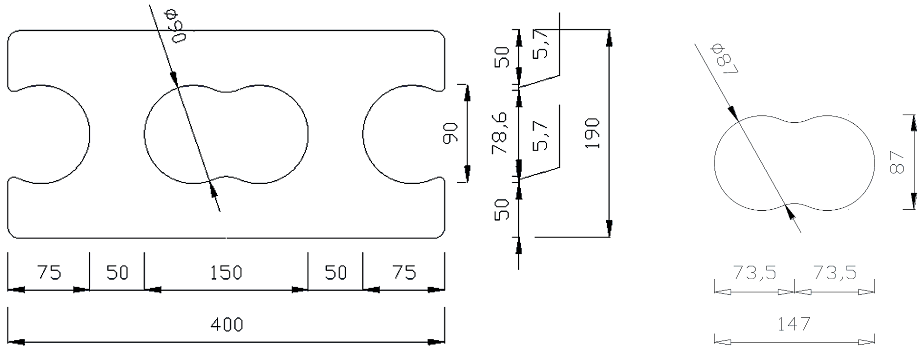
The authors developed two types of concrete blocks to improve the seismic performance of both in- and out-of-plane directions and to enhance the workability without the joint mortar [1]. The two types of concrete blocks only consist of main blocks and key blocks, and they have different key block shapes: One is the peanuts shape and the other is the dumbbell shape, as shown in Figure 2.

As shown Figures 2, the gap between the main block and the key block was designed to be 1.5 mm on all sides in consideration of workability and manufacturing accuracy. As can be found in Figure 3, the proposed block systems have half-height difference between the main block and the key block. Therefore, the seismic performances in the out-of-plane direction as well as the in-plane direction of the proposed block systems are expected to be much higher than that of typical masonry walls.

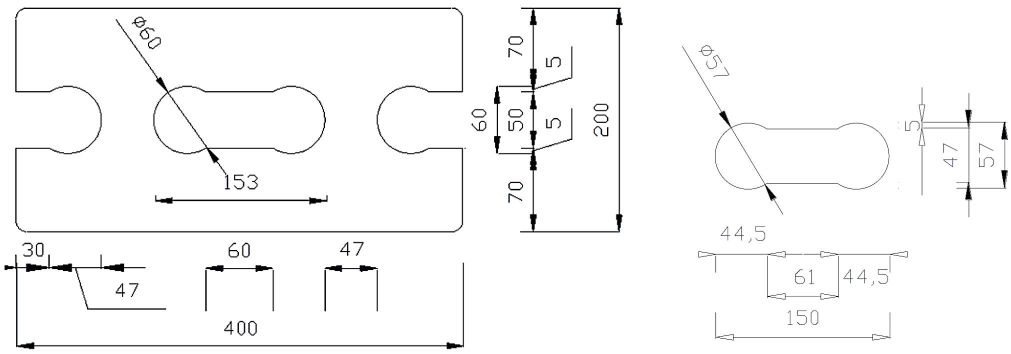
Each concrete block material test results are shown in Table 1 (the average values of three samples are shown in the table). The typical concrete block and peanut shape concrete block were made by the normal cement-to-sand ratio of 1 : 3.5 used in Korea. Since the dumbbell shape concrete block was, however, used higher cement ratio, the compressive strength is the highest value among three concrete blocks, as shown in Table 1. The compressive strength of the peanut shape concrete block is higher than that of the typical concrete block, because the peanut shape

(a) L'Aquila earthquake, Italy (2009) (b) Northern Osaka earthquake, Japan (2018)

Figure 1. Masonry wall damage.



(a) Peanuts shape concrete block



(b) Dumbbell shape concrete block

Figure 2. Two types of concrete block systems (unit: mm).

	Compressive strength [N/mm²][1]		
	Typical concrete block	Peanut shape concrete block	Dumbbell shape concrete block[2]
Block unit	8.8	14.9	22.0
Block prism[3]	5.8	7.7	18.1

[1] to whole area [2] with key blocks [3] a layered specimen

Table 1. Mechanical properties of each concrete block.

concrete block has the key blocks in hollow parts of the main block.

2.2. Test specimens

In this study, three full-scale, single-story specimens were designed and fabricated supposing the single-story storage building, as shown in Figure 4(a) typical concrete block wall specimen with joint mortar (Specimen CB); (b) seismic block wall with peanuts shape key block without joint mortar (Specimen PS); (c) seismic block wall with dumbbell shape key block without joint mortar (Specimen DS). The specimen size is 2.0 m by 1.4 m, as shown in Figure 4.

The typical concrete block wall can resist only friction force to the horizontal load after losing the adhesive force between concrete block and joint mortar. On the other hand, the proposed concrete block wall systems are expected higher deformability due to the shear key mechanism between the main block and the key block.

2.3. Test methods

A loading system for the static cyclic in-plane tests is shown in Figure 5. Lateral loads in the positive and negative directions were applied to the left end of the upper beam with hydraulic actuators. As mentioned above, since the reference building of this study is a single-story storage building, the axial load was considered as the weight of the upper beam (13.7 kN, axial stress, $\sigma_0 = 0.04\text{N/mm}^2$). Figure 6 shows a lateral loading protocol that was controlled by a drift angle R, defined as a lateral drift Δ at the top-center of specimen divided by the height from the bottom of the specimen, H, as shown in Figure 5.

The measurement system is shown in Figure 7. The relative lateral displacement, the lateral displacement at each layer of wall, the vertical displacement of both ends of specimen, and diagonal deformation of wall were measured, respectively. Furthermore, the maximum crack widths at peak loads and residual crack widths at unloaded stages were carefully measured.

3. Experimental results

3.1. Failure patterns and lateral force-drift angle relationships

Figure 8 and 9 show the damage patterns after final loading and the lateral force-drift angle relationships of all specimens, respectively. The behavior of each specimen to failure is summarized below.

3.1.1. Specimen CB

During the first loading drift, R, of 0.05 % rad., the cracks were observed in the entire bed joint (horizontal joint) causing slippage between second and third joint interface. Since the shear crack in the bottom of compression side was occurred during $R = 0.67\,\%$ rad., the test was terminated at $R = 1.0\,\%$ rad. Until the final loading, this specimen showed the rocking behavior between second and third layers. The maximum strength of 14.7 kN was recorded at $R = 0.67\,\%$ rad. and no remarkable strength deterioration is found until $R = 1.0\,\%$ rad.

3.1.2. Specimen PS

The small width crack was occurred on the main block of the right-bottom end at $R = 0.25\,\%$ rad. This specimen also showed the rocking behavior until final loading because of low axial force according to the single-story storage building. Since the crushing and spalling off of the main block where is the rightmost side of the second layer was occurred at $R = 5.0\,\%$, the experiment was terminated after $R = 5.0\,\%$. The maximum strength of -17.5 kN was recorded at $R = -2.0\,\%$ rad. and no remarkable strength deterioration is found until the final loading.

3.2. Comparison of in-plane seismic performance of each specimen

3.2.1. Lateral force-drift angle relationships

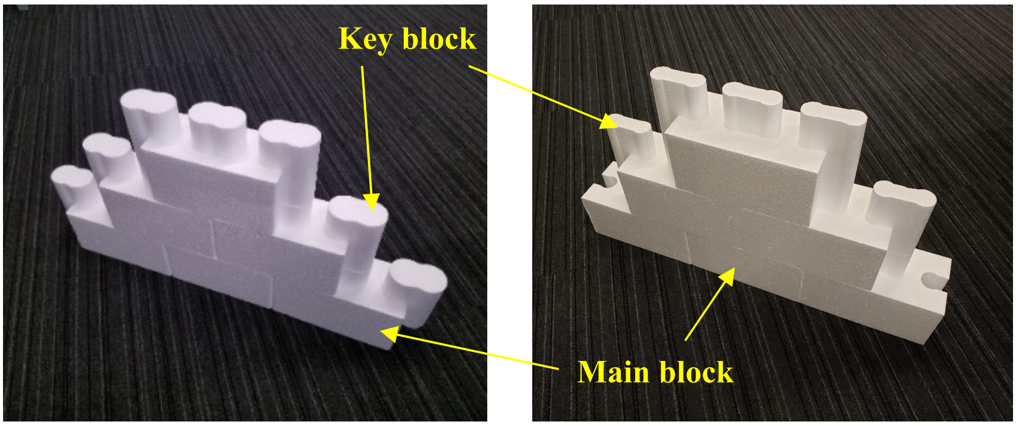
Figure 10 shows the skeleton curves of each specimen. As shown in the figure, the in-plane seismic performances of Specimens PS and DS were much higher than that of Specimen CB. In particular, the deformability of the proposed system has improved remarkably due to the shear key mechanism between the main blocks and the key blocks. Since all specimens show the rocking behavior, as mentioned above, the lateral loads of each specimen were calculated considering the simple rocking mechanism, as shown in Figure 11. As shown in the figure, the axial loads were considered as the sum of the weight of the upper beam ($N_1 = 13.7$ kN) and the self-weight of the specimen ($N_2 = 6.0$ kN, 9.0 kN and 10.8 kN of Specimens CB, ,PS, DS, respectively). The calculated lateral loads were shown in Figure 9. As can be found in the figure, the calculated lateral loads agreed well with the experimental results.

3.2.2. Equivalent viscous damping ratios

In order to compare the energy dissipation capacities of all specimens, the equivalent viscous damping ratios were calculated, as shown in Figure 12. The results of the proposed systems considerably had higher values than that of Specimen CB. Furthermore, the remarkable deterioration of the ratios of the proposed systems were not found until the final loading.

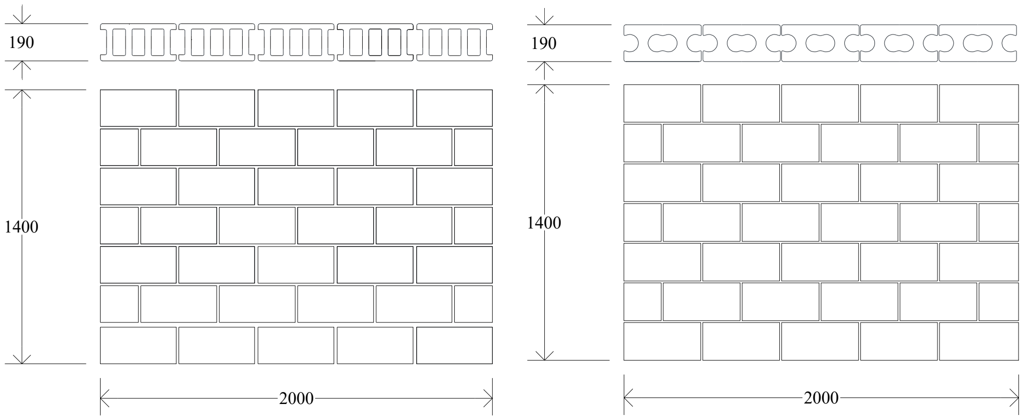
3.2.3. Reuse ratios of Specimens PS and DS

The typical concrete block and brick may not commonly reuse because of the using of the joint mortar. On the other hand, the proposed systems consisted of only main and key blocks without joint mortar can reuse. In this study, the reuse ratio is defined as the ratio of no damage main blocks to all main blocks. Figure 13 shows the reuse ratio of Specimens PS and



(a) Peanuts shape (b) Dumbbell shape

Figure 3. Construction of the proposed block walls.



(a) Specimen CB (b) Specimen PS

Figure 4. Details of typical and proposed concrete block wall specimens (unit: mm).

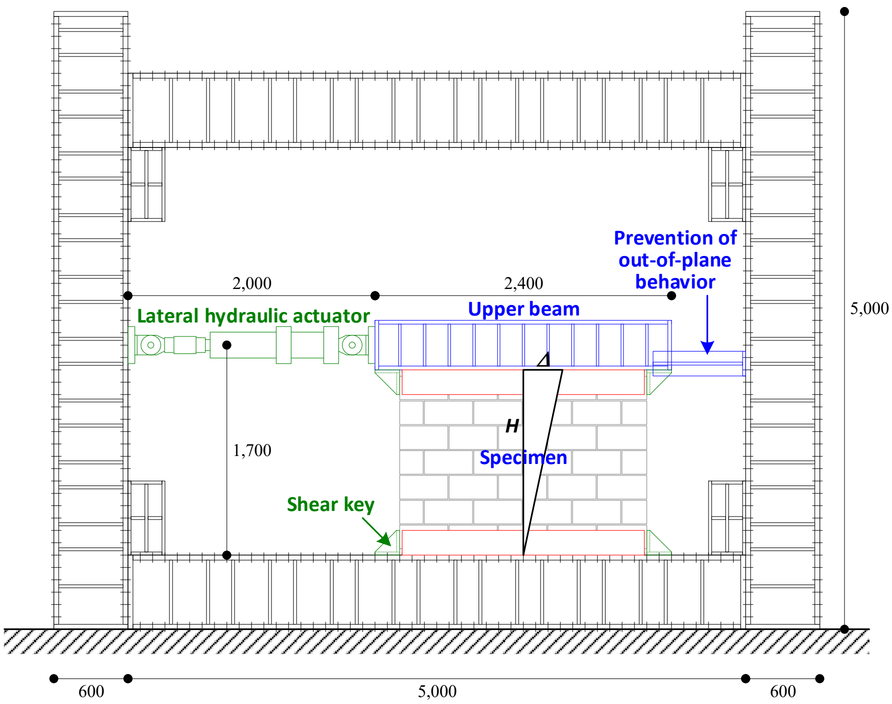


Figure 5. Loading system (unit: mm).

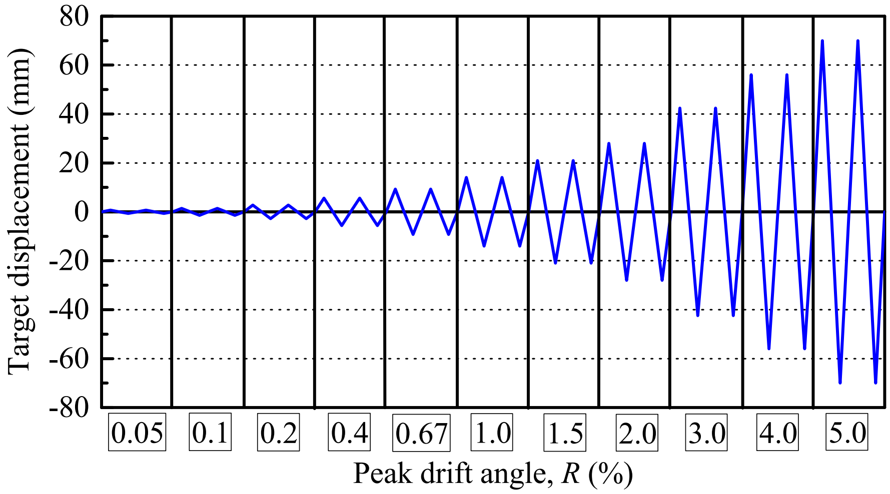


Figure 6. Lateral loading protocol.

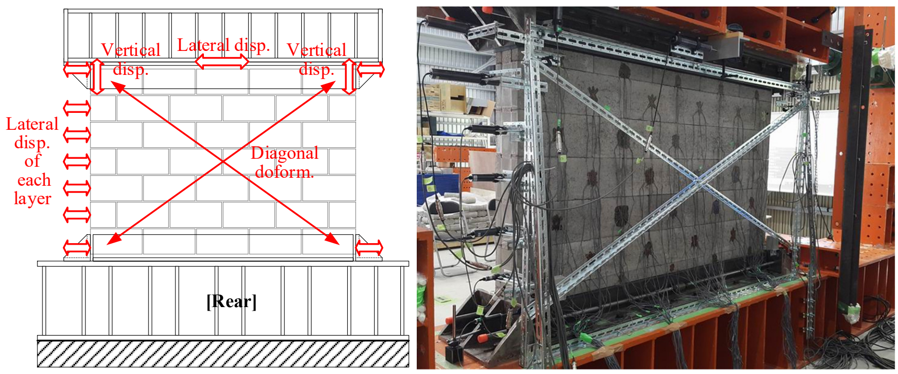
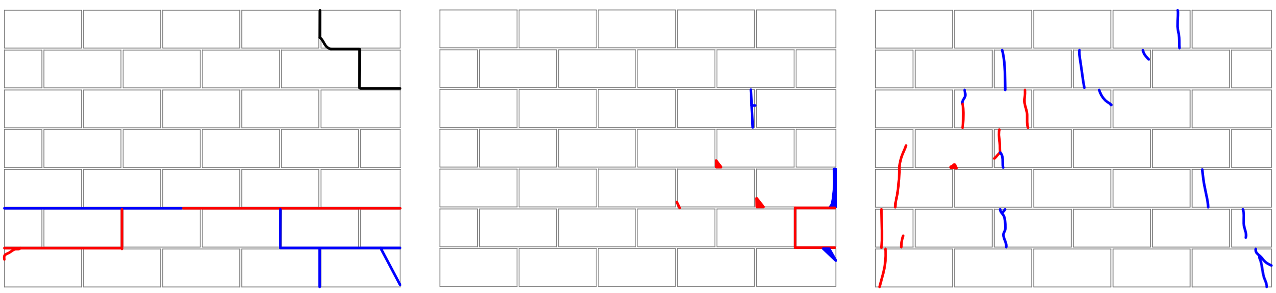


Figure 7. Measurement system.



(a) Specimen CB (b) Specimen PS (c) Specimen DS

Figure 8. Final crack patterns (Blue: Positive dir., Red: Negative dir., Black: Initial cracks).

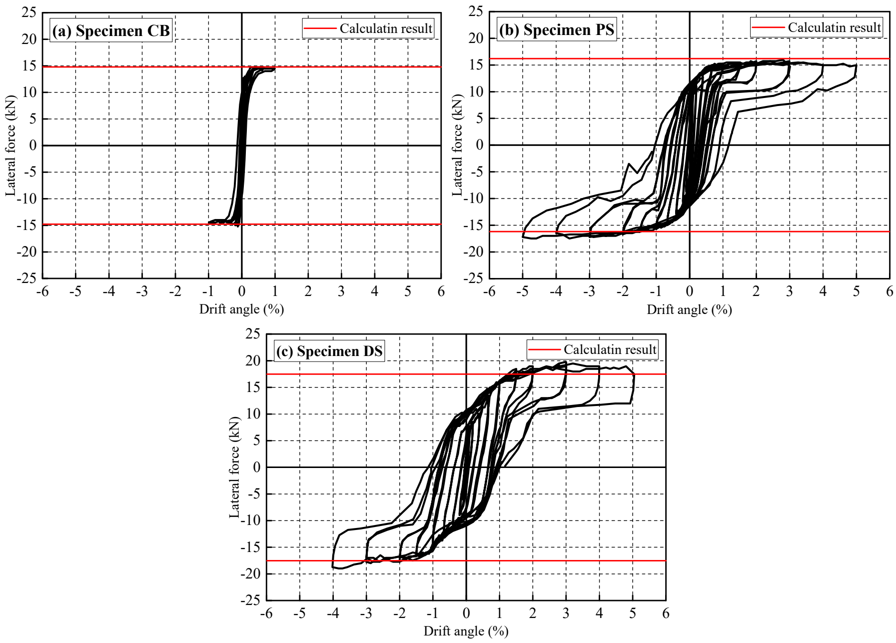


Figure 9. Lateral force-drift angle relationships of each specimen.

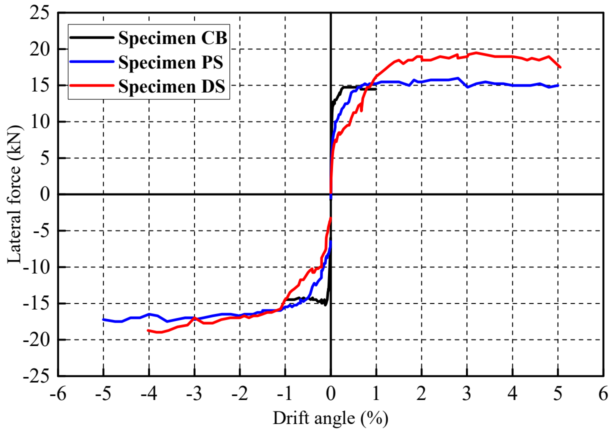


Figure 10. Skeleton curves of each specimen.

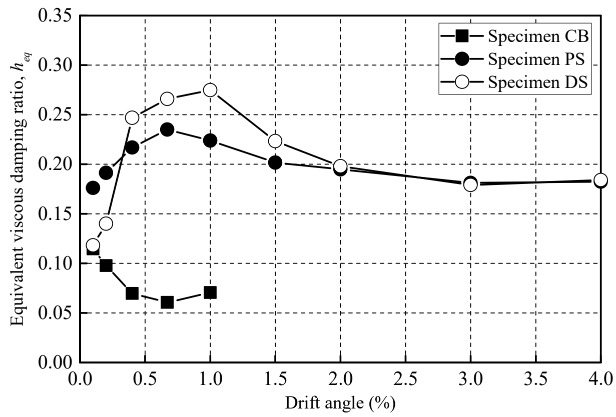


Figure 12. Equivalent viscous damping ratios.

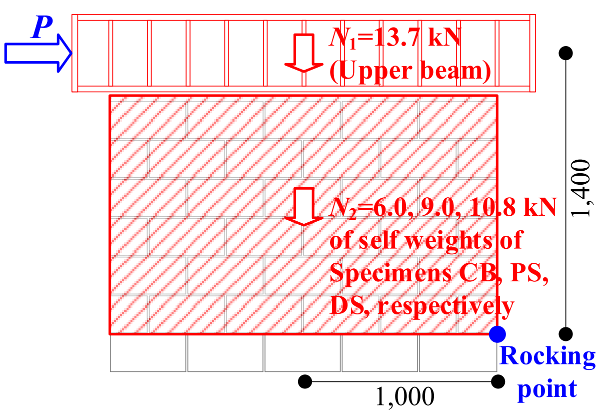


Figure 11. Lateral load P due to rocking mechanism.

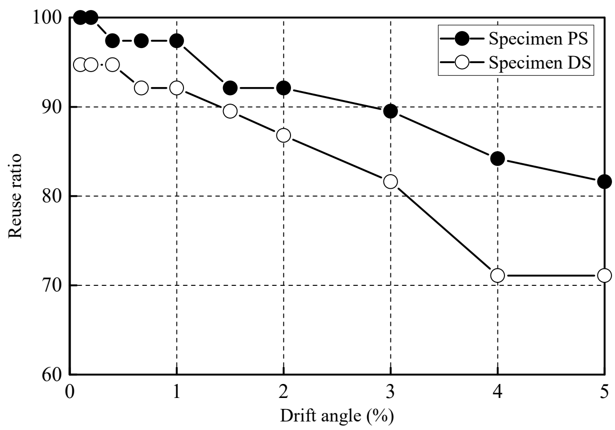


Figure 13. Reuse ratios of the main blocks of Specimens PS and DS.

DS. As can be found in the figure, the proposed seismic block systems can reuse more than 70 % after $R = 5.0\,\%$ rad. This result imply that the proposed concrete block wall systems are economical and eco-friendly.

4. Concluding remarks

The current paper presented the experimental tests of the two types of new concrete block walls as well as a typical block wall and investigated the in-plane behaviour, the loading bearing capacity, energy dissipation capacity and reuse ratio. The following major findings were obtained:

1. The in-plane seismic performances of Specimens PS and DS were much higher than that of Specimen CB. In particular, the deformability of the proposed system has improved remarkably due to the shear key mechanism between the main blocks and the key blocks.
2. The calculated lateral loads based on the simple rocking mechanism agreed well with the experimental results.
3. The energy dissipation capacities of the proposed systems considerably had higher values than that of Specimen CB. Furthermore, the remarkable deterioration of the ratios of the proposed systems were not found until the final loading.
4. The proposed seismic block systems can reuse more than 70 % after final loading. This result imply that the proposed concrete block wall systems are economical and eco-friendly.

The current paper focused only on the in-plane experimental behavior. The experimental data should be investigated from numerical perspectives, and the out-of-plane experimental and numerical behaviours should be carried out, in future studies.

Acknowledgements

The project was funded by the JSPS Grant-in-Aid for Scientific Research (Category (c), Grant No. 18K04425, Principal Investigator: Ho Choi) and the Joint Research with Nara & Tech Co. Ltd. The authors are thankful to both agency and company for their financial support.

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