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Displacement of Reinforced Concrete Space Shear Walls as a Result Of Earthquake Effect

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Abstract

In reinforced concrete buildings, gaps are formed in certain parts of the curtains. There are displacements in reinforced concrete shears under the effect that simulates an earthquake. Accordingly, in this study, the change between force-displacement relations was examined. The curtains that are the subject of the study are slender curtains with a height/height (Hw/ℓw) ratio higher than 2.5-3.0 according to TBDY 2018, and slender curtains with a combined shear-bending behavior with aspect ratios between two limits. are given as medium-delicate curtains. The effect on the behavior according to the void ratios left at the midpoint of the reinforced concrete curtains was investigated. For this, a total of 4 pieces with ½ scale; Reinforced concrete shears, one of which is a reference and the others with a void ratio of 20%, 35% and 50%, respectively, were produced and the results were compared under the effect of earthquakes. The size effect was tried to be avoided, but since the actual dimensions of the sample were too large, it was produced in 1/2 scale. In the study, a built-in support condition should be created in the laboratory environment in order to represent the curtains structurally close to the real behavior.

Key Words

"Reinforced Concrete Shear, Displacement, Space Ratio, Earthquake Effect, Ductility"

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1. Introduction

Although the design and production of structural elements by scaling in experimental studies does not pose a problem for elastic behavior, it creates problems in capturing real behavior in terms of inelastic behavior. For this reason, it is of great importance that the samples of reinforced concrete walls to be produced within the scope of the experimental study are produced in 1/1 scale in terms of convergence of the inelastic behavior of the building element. However, when evaluated in terms of economy and installation, scaled studies are carried out. Materials that will not deform during concrete pouring should be used in order to create the geometry of the opening in the hollow samples. Within the scope of this study, some studies in the literature related to porous curtains and the difficulties experienced in experimental studies are presented. *Liauw (1979-1980)* in one of the studies, single-span, four-storey steel frame and reinforced concrete filled test elements were used. The ratio of the height of the frame to the width, the void ratio in the infill and the connection detail between the infill and the frame are the variables used in the research. It was determined that the gap negatively affects the stiffness and strength of the system. *Daniel et al., (1986)* for the behavior of hollow reinforced concrete shear walls under the effect of horizontal loads simulated to earthquake loads, 1/3 scale and two samples were produced according to ACI and UBC standards. It was observed that the samples could not resist the shearing effect. *Kato vd., (1999)* in addition to the size and location of the void space in the reinforced concrete walls produced as a cast, the change in the amount of reinforcement placed on the side of the walls on the cavity side was investigated. It has been observed that the shear force carried by the hollow shear wall is carried only by the part under the pressure effect, and the bending strength and displacement capacity of the elements do not change much compared to the hollow shear walls. *Ono & Ezaki (2000)* they produced seven 1/3 scale, single span, single storey samples. Three of the samples they produced were tested under the effect of reversible-repeatable horizontal loading and vertical load. In addition, four of the samples they produced were tested under the effect of dynamic loading in order to determine the effects of loading speed on the behavior of hollow reinforced concrete walls. The second variable in the samples are the loading speeds. It was made as 0.01-0.1 cm/sec for static loading and 1 cm/sec for dynamic loading. After reaching the maximum strength, the lateral load-displacement relationship dropped steeply when the void ratio was less than 0.4. The lateral load-displacement relationship showed a gradual decrease in strength when the void ratio was greater than 0.4. Two types of crack formation were observed. It first occurred at the gap corners due to diagonal stress. Later, bending cracks occurred at the wall edges due to shear force. *Kara & Altın (2006)* in the study of strengthening non-ductile reinforced concrete frames with partial reinforced concrete infill walls, 7 single-span, 2-storey 1/3 scale test elements were tested under reversible and repeated horizontal loads. It has been demonstrated that partially filled non-ductile reinforced concrete frames exhibit significantly higher strength and higher stiffness than unfilled frames. As the aspect ratio of the infill wall increased, the lateral strength and stiffness increased significantly. The strength and ductility deficiencies of the frame members affected the lateral performance of the frame reinforced with partial fills. The most successful behavior was obtained from specimens with partially infilled walls attached to both the columns and beams of the frame. *Anıl & Altın (2007)* in a study, the ratio of the partial infill wall length to height and the arrangement of the partial infill wall in the frame were considered as the variables of this study. It has been determined that when the dimensions of the inner shear wall are increased, the rigidity of the system and the lateral load carrying capacity increase very significantly, and the junction and type of the inner shear wall and the frame also affect the lateral load carrying capacity of the system significantly. It has been observed that the inner shear wall, which is connected to the columns and beams together, works much more effectively than the others. *Sakurai vd., (2008)* in the study, in which the behavior of shear walls with more than one cavity was examined, the results were compared by keeping the position and shape of the cavity different, although the same type of frame and the same amount of space were used. The shear strength, failure mode, and deformability of reinforced concrete shear walls with openings were significantly affected by the difference in the number and arrangement of openings. Axial deformation and stress distribution at the base of hollow shear walls are different from non-void shear walls, where the end columns contribute to the foundation moment to the shear body. *Öztürk (2010)* in the study of 1 of the frames is empty, 2 of them are reinforced with the addition of reinforced concrete outer shear wall, and 1 of them is reinforced with the addition of a non-beamed reinforced concrete outer shear wall and compared under the effect of earthquake load. For this purpose, a horizontal load of 2 units on the upper floor and 1 unit on the lower floor was applied to the samples, and an equivalent static horizontal loading system was prepared to realize the triangular load distribution in the earthquake, and the samples were tested under reversible-repetitive horizontal loading. In the case where the outer shearing is directly attached to the frame without making a tie beam, a significant increase has been achieved in terms of horizontal load carrying capacity; However, it has been observed that the system may collapse in a brittle manner, with heavy damage to the side columns and column-beam junctions where the wall meets. *Kebeli (2018)* in a study, the first bending crack (in the foundation-curtain junction area) occurred in fully filled shear walls, while the first shear crack (in the window corners) occurred in shear walls with window spaces. This shows that the fully filled curtain wall collapsed over the foundation acting more rigid than itself, and the curtain wall with window openings collapsed due to the shear effect from the lower part of the window, which is more rigid than itself. The curtain walls with window openings have collapsed from the lower corners of the windows, which are their weakest points. When the reinforced concrete parts on both sides of the window space are considered as short curtains, the curtain wall under the window shows a more rigid behavior like the foundation. As in short curtains, the sliding effect dominates the bending effect and the system collapsed at an angle of 45° due to the shear effect.

2. Material and Method

Reinforced concrete wall samples were manufactured in 1/2 scale considering **TS500 (2000)** and **TBDY (2018)** conditions. Experiments of a total of 4 reinforced concrete wall systems, which were created by defining different wall void ratios, were carried out in Erciyes University Earthquake Research Laboratory. There is no curtain gap in the system produced as a reference to the study. In addition, other samples whose effects on bending behavior were investigated are models with 20%, 35% and 50% voids, respectively.

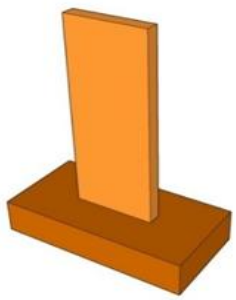
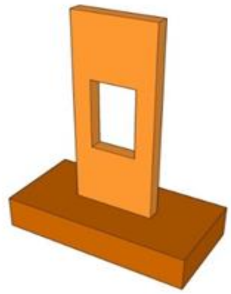
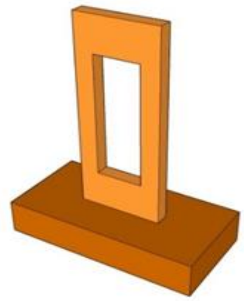
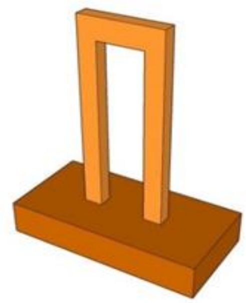
Experiment 1	Experiment 2	Experiment 3	Experiment 4
			
Referance-without space	%20 Space	%35 Space	%50 Space

Figure 1. Experimental Models

The design concrete class of the experimental models was determined as C30 and the reinforcement was determined as B420C. 3 different types of reinforcement with Ø4, Ø6 and Ø8 mm diameters were used in the manufacture of the reinforced concrete curtain. The dimensions of the 1/2 scale reinforced concrete wall are 150 x 900 mm and the height is 2250 mm.

In each experiment, the sample to be tested was carefully transported with a crane to the front of the loading wall, which is the area to be tested. Then, it is connected to the rigid flooring with the help of rods in such a way that it is recessed into the floor. Then, in each test, the necessary mechanism, hydraulic jack, the construction where the jack is connected to the loading wall, traverse, connection and bridge cables and displacement gauges were connected to give the sample horizontal and vertical (axial) loads.

First, a reference model without gaps in the bulkheads was placed in front of the loading wall. Necessary security measures have been taken by pulling a security strip around. Then, the connections of the horizontal and vertical loading devices were made. Before starting the experiments, 3D drawings of the experimental setup elements were made. In all experiments performed, the required load and displacement readings were made and recorded using a computer aided data reading system.

Before starting the installation process of the experimental setup with the transport of the samples to the experiment area, first of all, the optimum solution was thought to ensure the use of the existing vertical loading setup in the laboratory in a way that would fit all of the samples, and the setup was revised and the necessary cutting and welding processes were performed. Each specimen brought to the test area was connected to the rigid platform, which was opened at 50 cm intervals, by means of eight threaded shafts with a diameter of 36 mm. These threaded shaft slots are placed during the formation of the rigid platform and there is no risk of dislodgement during any force applied to the shafts. Secondly, the horizontal loading mechanism was mounted on the loading wall for the test samples. The loading wall is 50 cm thick and 6 meters wide, with slots 50 cm apart and 70 mm in diameter to connect the wall. Horizontal loading mechanism consists of hydraulic jack, joint at two ends and a load cell and parts that connect these parts to each other. The connection between the two plates placed on both the pushing and pulling faces of the test specimen was created using 4 transmission shafts with a diameter of Ø24 mm. In the experiments, lateral loading was carried out with a two-piece hydraulic jack with a capacity of 1000 kN, capable of pushing and pulling. The first part of the jack is the hydraulic piston, which is the load output point, and the second part is the manual loading arm that provides oil to the piston. A load cell with a capacity of +500/-500 kN was used to measure the horizontal loading values from the hydraulic jack and transfer the load data to the computer environment.

Before starting the experimental studies, the necessary threaded parts for the connections of the jacks with the joints and load cells were produced and their connections were made. The load cell is externally calibrated and mounted using steel tie plates. The connection of the hinges, which can move perpendicular to the horizontal loading direction, with the loading wall and the test sample is provided by bolting the plate at the end of the joint to plates of special dimensions. The mobility of the joints during horizontal loading is important in terms of maintaining the horizontal position of the device during the test.

The jack to be used in the vertical loading mechanism has a capacity of 600 kN, and the load cell has a capacity of 500 kN. The axial load value is the equivalent of 0.1Acfck for each sample and will be kept constant throughout the test.

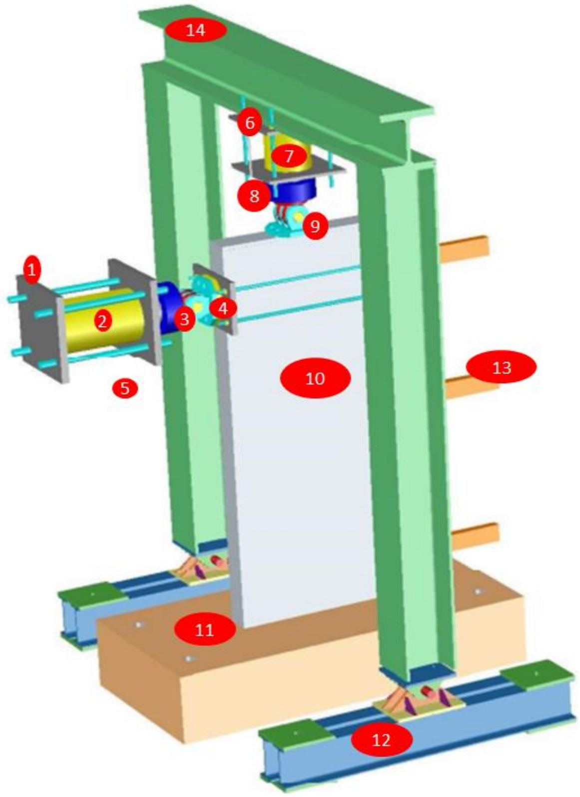


Figure 2. Experiment Setup

Table 1. Experimental Rig Components

No	Device	No	Device
1	Roller Bearing	8	Load cell
2	Hydraulic Jack	9	Roller Bearing
3	Load cell	10	Concrete Shear Wall
4	Roller Bearing	11	Foundation Anchorage
5	Horizontal Loading Setup	12	Traverse
6	Roller Bearing	13	LVDT
7	Hydraulic Jack	14	Axial Loading Frame

For all samples, the height that will provide the ratio of $H_w/\ell_w=2.5$ was chosen for the horizontal load application point. In order not to crush the concrete along the slab placed at the application point, horizontal reinforcement was arranged (5 cm intervals) by tightening the transverse reinforcement intervals in these regions in each sample.

In order to apply the lateral load to the samples, a 600 kN compression and 420 kN pulling capacity hydraulic jack attached to the rigid wall at one end and a 500 kN compression capacity load cell at the other end were used. These two ends consisted of joints to avoid additional effects other than axial load during lateral loading. A load cell was used to obtain the load data. Three displacement meters were used to measure the displacements. A data logger was used to transfer the data taken from the displacement meters and the load cell to the computer. The positions of the displacement gauges on the test setup are shown in Figure 3.

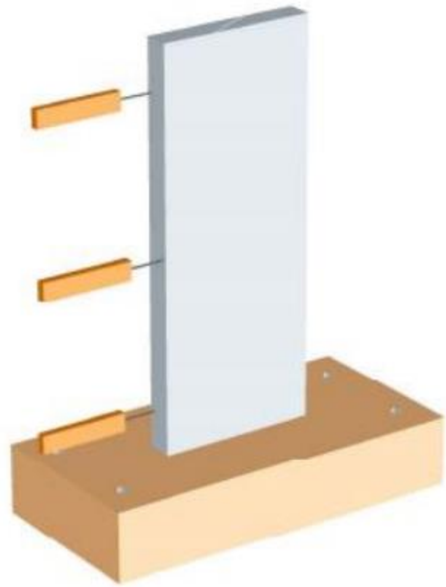
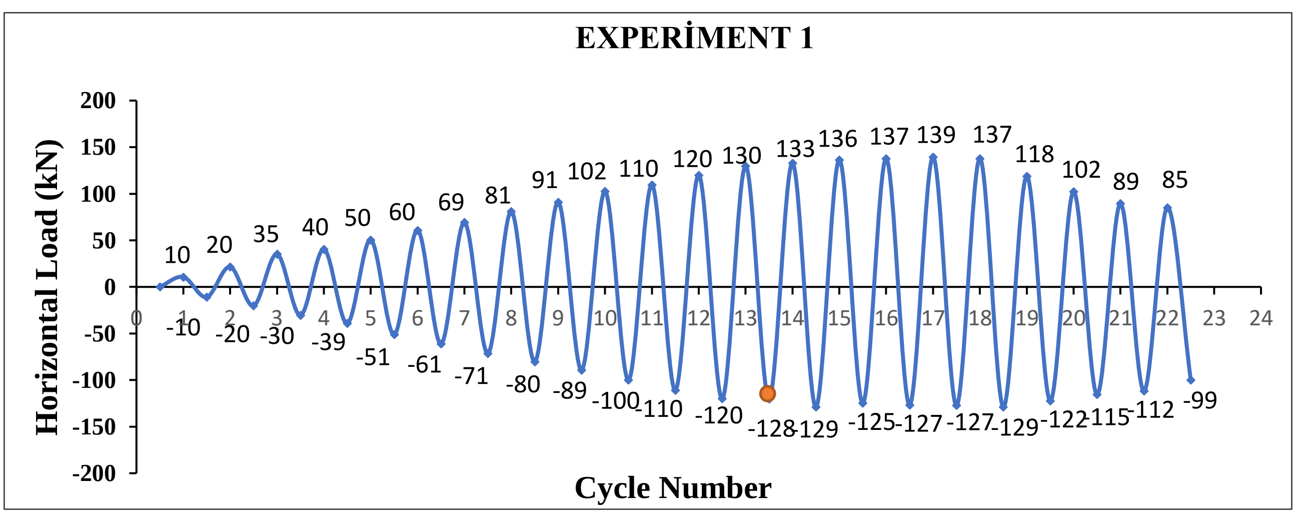


Figure 3. Positions of Displacement Gauges in the Experimental Setup

During the experimental studies, the hysteresis curves showing the horizontal load-displacement relationship of the test element were drawn in real time with the data recording taken at 125 ms (1/8) intervals. As a result of the graphics and values obtained as a result of the loading to be made on the reinforced concrete walls and the tests of the other samples; crack development will be observed, displacement effect, energy consumption, bearing capacity, and stiffness will be examined. All experiments were started with load control and continued in this way until the lateral load level where yielding occurred in the longitudinal reinforcement. In each cycle, one push and one pull were made. The first cycle started with a horizontal load of 10 kN and continued in increments of 10 kN until yielding occurred. After yielding, loading was continued with displacement control. After switching to displacement controlled loading, loading was continued with an increase of 5 mm. Crack development was investigated by stopping the test after each push and pull motion in all cycles. Cracks in the push cycle are drawn in red, and those in the pull cycle are drawn in blue. Experiment reports were prepared and the developments of the experiments were recorded step by step. The pre-experimental view of the reinforced concrete reference wall is shown in Figure 4.

3. Results and Discussion

The frames of the reinforced concrete carrier system used in all the experiments are identical in terms of material size and geometrical aspects. The parameters that vary between experiments are the curtain void ratio. It is assumed that the reference experiment will show bending behavior. Thus, as the curtain void ratio increases, the differences between the first test, which we can accept as a reference, and the other tests, in terms of bending behavior, were examined.



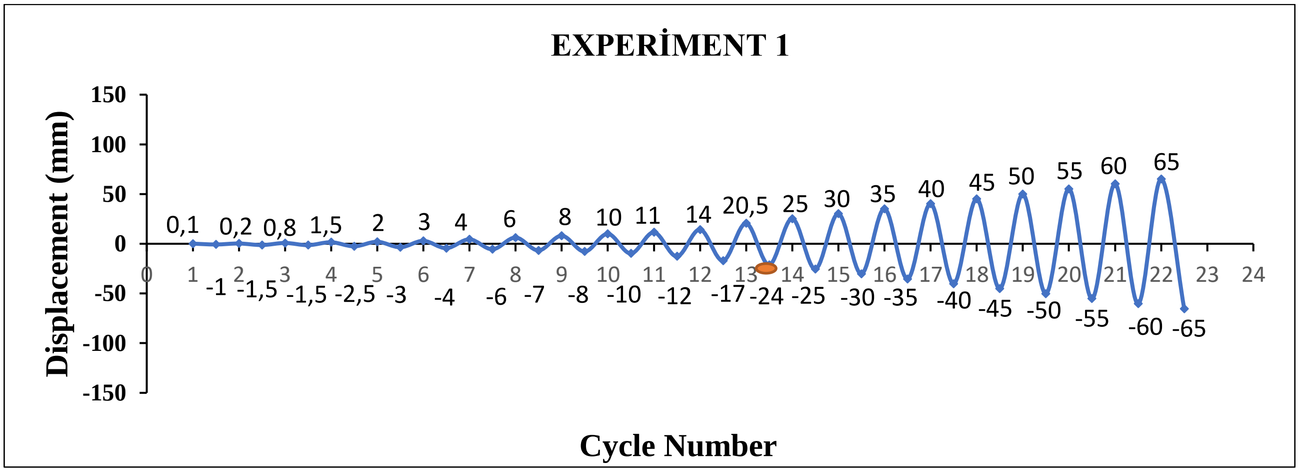
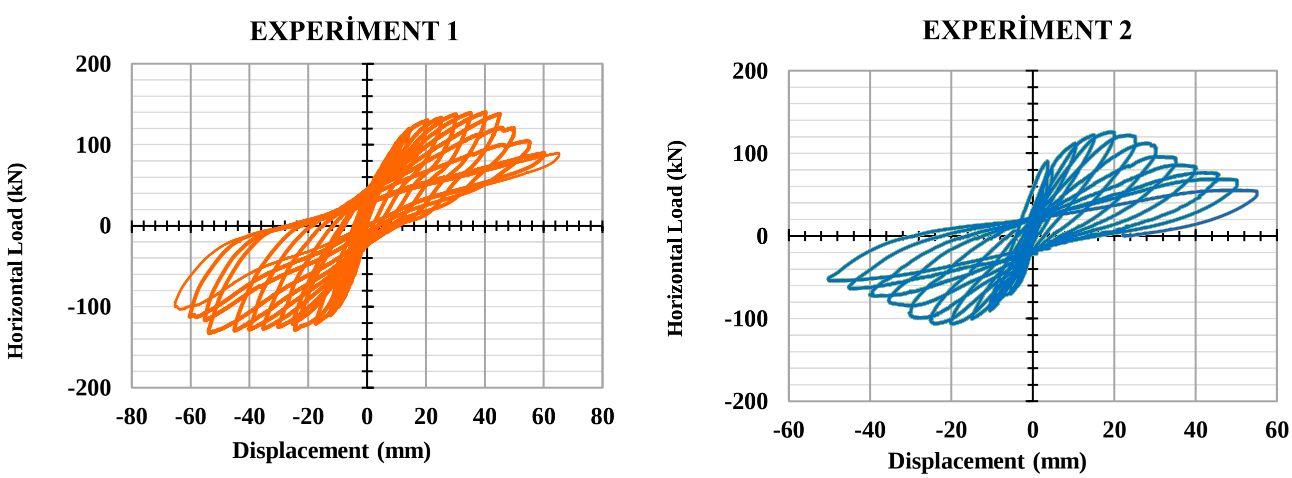


Figure 5. Loading Procedure of the First Experiment

In the reference sample, which is the 1st test, yielding occurred in the 13th drawing cycle. The yield load is about -128,749 kN, and the yield displacement is about -24,563 mm. After yielding, load-controlled loading was switched to displacement-controlled loading in the 14th pressure cycle. At the end of 22 cycles in total, 65,202 mm displacement in the pushing cycle and 65,285 mm in the tension cycle was made in the reinforced concrete carrier system. Accordingly, the total δ/H ratio was found to be 0.029 and the experiment was completed at this point.

In the second experiment, the 20% void sample test, yielding occurred in the 9th tensile cycle. The yield load is about -83.896 kN, and the yield displacement is about -10,148 mm. After yielding, in the 10th cycle, load-controlled loading was switched to displacement-controlled loading. At the end of 18 cycles in total, the reinforced concrete carrier system has a displacement of -50,195 mm in the pushing cycle and -50,195 mm in the pulling cycle. Accordingly, the total δ/H ratio was found to be 0.022 and the experiment was completed at this point.

In the 3rd experiment, the sample with 35% voids, yielding occurred in the 6th drawing cycle. The yield load is about -35.402 kN, and the yield displacement is about -15 mm. After yielding, load-controlled loading was switched to displacement-controlled loading in the 7th cycle. At the end of a total of 15 cycles, the reinforced concrete carrier system has a displacement of 0,085 mm in the pushing cycle and -46.474 mm in the tension cycle. Accordingly, the total δ/H ratio was found to be 0.021 and the experiment was completed at this point.



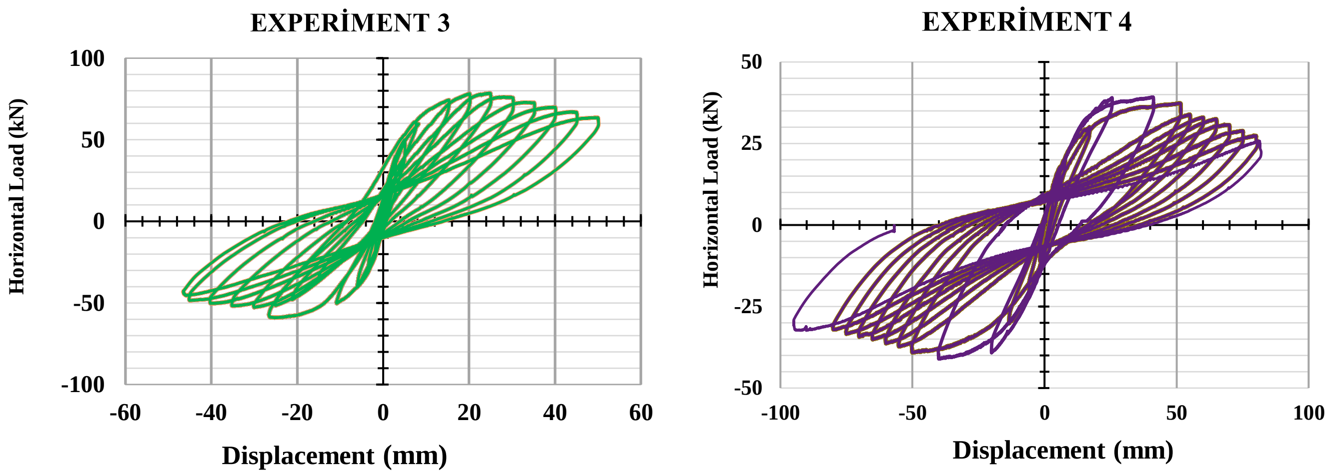


Figure 6. Lateral Load–Lateral Displacement Responses of the Experiments.

In the 4th experiment, the 50% void sample, yielding occurred in the 5th thrust cycle. The yield load is about 39,065 kN, and the yield displacement is about 39,726 mm. After yielding, load-controlled loading was switched to displacement-controlled loading in the 5th tensile cycle. At the end of 13 cycles in total, the reinforced concrete carrier system has a displacement of -81.589 mm in the pushing cycle and -94,912 mm in the pulling cycle. Accordingly, the total δ/H ratio was found to be 0.039 and the experiment was completed at this point.

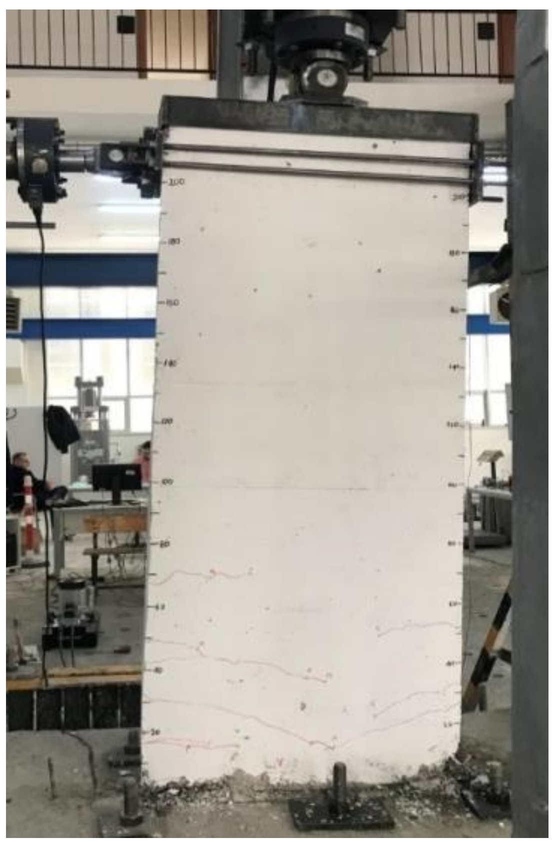


Figure 7. Post-Experiment View of the Reference Reinforced Concrete Shear.

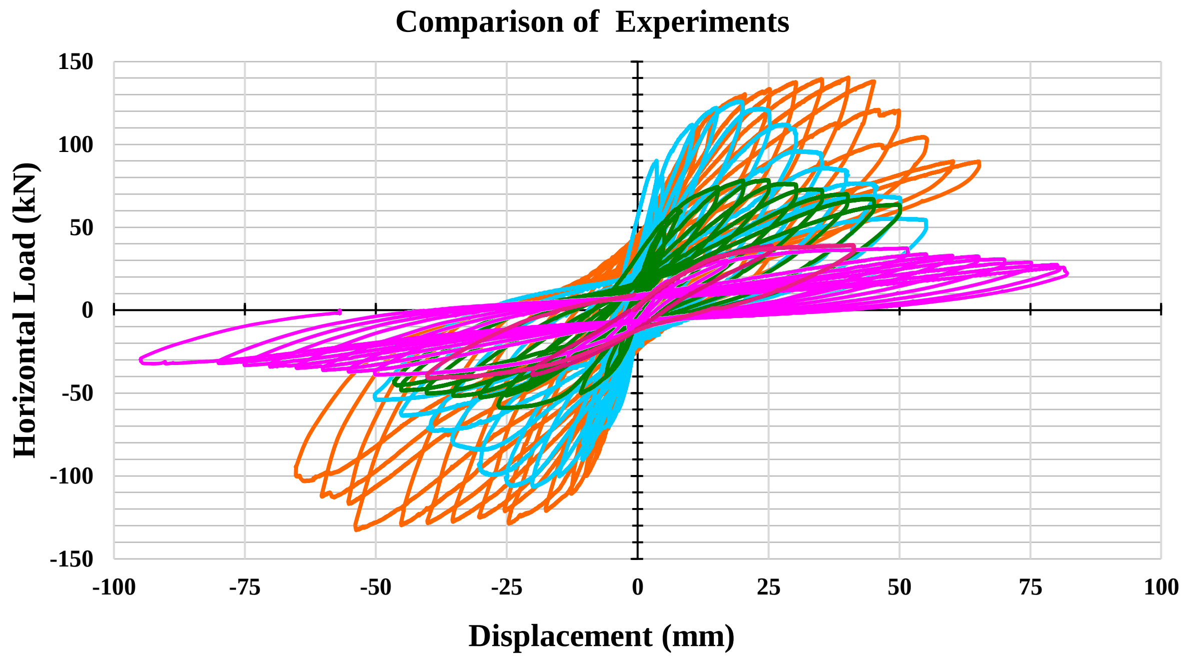


Figure 8. Comparison of the Horizontal Load-Displacement Plots of the Experiments

Table 2. Horizantal Loads and Displacements

Test Sample	Cycle Number	Load Type	Load (kN)	Displacement (mm)
Experiment 1	5	Push	50,50	1,20
Experiment 2	5	Push	50,63	1,74
Experiment 3	5	Push	50,06	4,99
Experiment 4	5	Push	39,55	39,73

The values showing the displacements according to the 5th thrust cycle, which is the yield cycle of the 4th test sample, are given in Table 2. Thus, it was possible to compare displacements in the same cycle. In Table 3, it is presented that the yield loads and displacements start as a result of different cycles and their displacements with the current yield loads.

Table 3. Post-Yield Loads and Displacements

Test Sample	Cycle Number	Load Type	Post-yield Load (kN)	Displacement (mm)
Experiment 1	13	Pull	129	24,56
Experiment 2	9	Pull	84	10,15
Experiment 3	6	Pull	35	15,00
Experiment 4	5	Push	39	39,73

4. Conclusions and Recommendations

In case there is no gap in the wall, the horizontal loads acting on the building allow the building to fully utilize its horizontal displacement capacity. As the wall void ratio increases, the shear force distribution to the columns becomes uneven, and the limit state of the bearing capacity is reached early. This caused the structure to have less displacement as a result of some power exhaustion while the reinforced concrete curtain still had capacity.

As the void ratio increases according to the yield load, the amount of displacement of the carrier systems decreases. As the void ratio according to the maximum horizontal load increases, the amount of displacement made by the carrier systems increases.
During high ton capacity loading, the sample should be placed in the system fully symmetrically against the possibility of rotation of the loading apparatus.

As a result of the study, if the wall void ratio is 20% compared to the reference sample, the displacement value decreases by 23% and the horizontal load carrying capacity is reduced by 13%. If the curtain gap ratio is 35%, the displacement value is reduced by 29% and the horizontal load carrying capacity is reduced by 45%. If the curtain gap ratio is 50%, the displacement value increases by 45% and the horizontal load carrying capacity decreases by 73%.

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