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Farklı Güçlendirme Yöntemleri Kullanılarak 1/5 Ölçekli Betonarme Çerçevelerde Kısa Kolon Davranışlarının İncelenmesi

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ÖZET: Bu deneysel çalışmadaki amaç, iki güçlendirme methodunda pencere boşluğunun kısa kolon davranışına etkilerini araştırmaktır. Bu çalışmada, iki katlı, 1/5 ölçekli ve tek açıklıklı yedi betonarme çerçeve üretilmiştir. Numuneler, Türkiye'de konut binalarında yaygın olarak görülen çeşitli eksiklikleri içermektedir. Bu numuneler, sabit düşey yük ve yatay yükleme altında test edilmiştir. Birinci numune referans boş çerçeve olarak üretilmiştir. İkinci ve üçüncü numuneler gaz beton bloklu dolgu duvarlı olarak üretilmiştir. Dördüncü ve beşinci numuneler betonarme dolgu duvarları ile güçlendirilmiştir. Altıncı ve yedinci numuneler ise dıştan betonarme duvarlı ve betonarme kolon mantolu olarak güçlendirilmiştir. Tüm numunelerin duvarları, kısa kolon davranışının etkilerini araştırmak için iki farklı pencere boşluğu ile üretilmiştir. Test sonuçları göstermiştir ki, uygulanan güçlendirme yöntemleri, betonarme çerçevenin, yatay yük taşıma kapasitesini, enerji tüketme kapasitesini ve başlangıç rijitliğini önemli derecede artırmıştır. Betonarme kolon mantosu sayesinde dıştan betonarme duvarlı numunelerde kısa kolon davranışı önlenmiştir.

Anahtar kelimeler: Betonarme çerçeveler, tersinir tekrarlanır yatay yükleme, güçlendirme, pencere açıklıkları.

Investigation of Short Column Behaviors at 1/5 Scaled Reinforced Concrete Frames Using Different Strengthening Methods

ABSTRACT: The purpose of in this experimental study is to investigate the effects of short column behavior due to window opening at two strengthening methods. At this study, seven reinforced concrete frames as two stories, 1/5 scaled and one bay were produced. The specimens contained several deficiencies that were commonly observed in residential buildings in Turkey. These specimens were tested under lateral loading and constant vertical loading. First specimen was produced as the reference bare frame. Second and third specimens were produced with infill autoclaved aerated concrete blocks wall. Fourth and fifth specimens were strengthened with infill RC shear wall. Sixth and seventh specimens were strengthened with external RC shear wall and RC column jackets. The walls of all specimens were manufactured with two different windows opening to investigate the effects of short column behavior. The test results showed that these applied strengthening methods have significantly increased the lateral load carrying and energy dissipation capacities, initial stiffness of the RC frame. Thanks to RC column jackets, at specimens with the external RC shear wall was prevented to the short column behavior.

Keywords: RC frames, reversed cyclic lateral loading, strengthening, window openings.

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INTRODUCTION

Turkey is located on an active seismic region of world (Kaltakcı et al., 2011). Thus, most of the regions of Turkey are threatened by the possibility of a major earthquake. Lastly, more than 30 000 buildings were damaged during the Van-Ercis earthquake. At this earthquake, many columns were observed short column effect due to the band windows of infill walls where these columns were located (Erdik et al., 2012, Korkmaz, 2013). Besides, researches had shown that, a big majority of the existing reinforced concrete (RC) buildings in Van-Ercis earthquake are seismically deficient (EERC, 2011). These deficiencies were low-strength materials, no column stirrups at the beam-column joints, strong beam-weak column formation, no confinement zones at the end of the columns beams, and wide spacing of beam and column stirrups (EERC, 2011; Bahadır and Balık, 2017). Because of these deficiencies, these buildings had an insufficient lateral load carrying capacity, lateral stiffness, energy dissipation capacity and ductility. Also, many RC buildings in Turkey are known to have this deficiency (Sezen et al., 2003; Canbay et al. 2003, Erdem et al., 2006).Thus, these buildings must be rehabilitated with effective strengthening methods as economical, rapid and feasible (Altin et al., 2008; Bahadir et al., 2013). Large amount of experimental studies has been undertaken in the past to investigate the behavior of RC frames with structural deficiencies under reversed cyclic loads (Ersoy and Uzsoy, 1971; Lee and Woo, 2002; Kara and Altin, 2006; Surendran and Kaushik, 2012; Soltanzadeh et al., 2018). These studies are showed that the location and size of the openings in the infill walls significantly affect the formation of short column behavior in the frame. Especially, band window opening in the infill walls is known to cause short column problem. In most of the strengthening studies, filling the RC frame completely with RC shear wall is widely applied in our country. However, in terms of architecture, it may sometimes be desirable to preserve the existing window openings of the buildings to be strengthened. For this reason, in this study, it is aimed to investigate the effect of window opening adjacent to the column on short column behavior at the strengthening application.

In this experimental study, seven reinforced concrete frames with a scale of 1/5, one bay and two stories were produced to reflect the seismically deficiencies of existing structures. Four of the RC frames were strengthened with external RC shear wall, RC column jackets and with infill RC shear wall. The other three RC frames were used as reference which one is bare frame and the others as autoclaved aerated concrete blocks walls. The walls of all specimens were manufactured with two different windows opening to investigate the effects of short column behavior. At the walls of these specimens, dimensions of the window openings were determined to reflect the window properties applied to existing structures. Therefore, strengthening method and the size of the window opening were determined as parameter in this study.

MATERIALS AND METHODS

Test Specimens

In the experimental study, seven reinforced concrete frames as two stories, 1/5 geometric scaled and one bay were produced. The RC frames were manufactured with the deficiencies observed in RC buildings. At these RC frames, the columns were 60x90 mm and the beams were 90x90 mm. While determining the dimensions of columns and beams in reinforced concrete frames, size details of 1/3 scale specimens in the literature were taken into consideration (Altin et al., 2008; Anil and Altin, 2007; Unal et al., 2014). The maximum size of aggregates used in the production of concrete of

RC frames was 6 mm. While determining the maximum aggregate diameter, the produced concrete could be easily placed in the formwork and geometric scaled of specimens were taken into account. Moreover, Water/Cement ratio of in the production of concrete was about 0.65. The average compressive strength of concrete of frames was evaluated from concrete samples cylinders and found as 13 MPa. According to the minimum longitudinal reinforcement ratio of TEC-2007, the longitudinal reinforcement ratios of column and beam were determined. Thus, in the columns four 5 mm diameter deformed bars and in the beams six 5 mm diameter deformed bars were used as longitudinal reinforcement. For the beams and columns dimensions selected the diameter of the steel bars had to be smaller than that of standard rebars, so steel wires with the stirrups diameter of 2 mm were used (Ruiz et al., 1998). Dimensional and reinforcement details of the RC frames are given Figure 1.

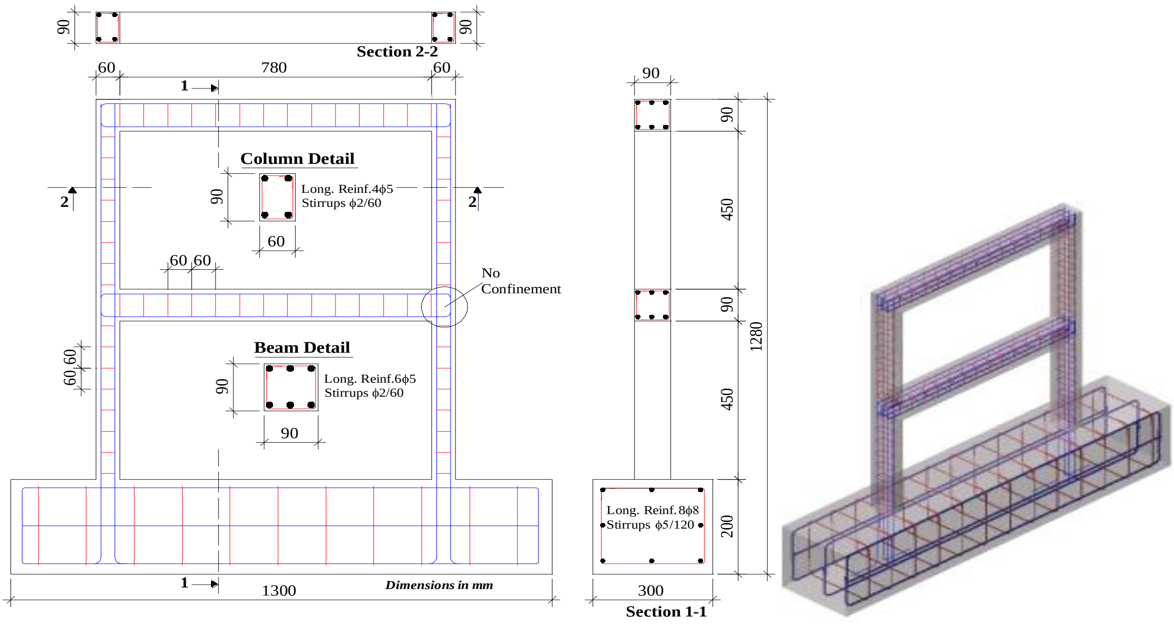
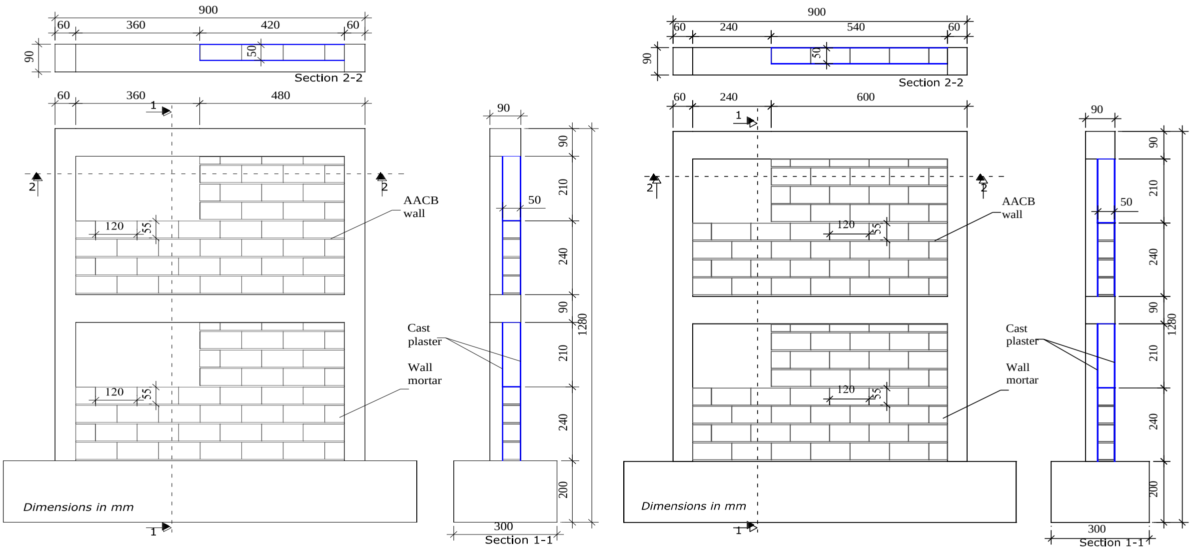


Figure 1. Details of the RC frames

Specimen 1 (RS) was reference bare frame. Specimen 2 and Specimen 3 were constructed with autoclaved aerated concrete blocks (AAC) infilled RC frame. These specimens were produced to represent existing RC structures with autoclaved aerated concrete blocks (AAC) walls. Details of these specimens are given Figure 2. In infill walls which AAC blocks of specimens were tested under diagonal compression (Figure 3). The average diagonal compressive strength of infill autoclaved aerated concrete blocks walls is found as 0.28 MPa.



a) AACW-BW b) AACW-SW

Figure 2. Details of Specimen 2 and Specimen 3

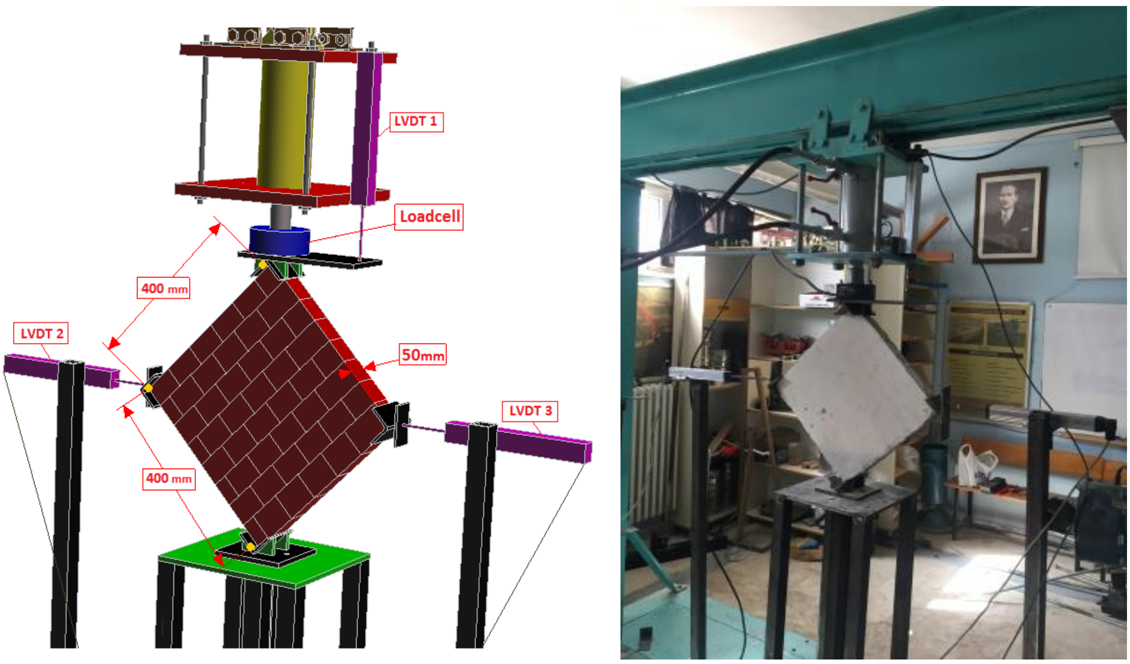
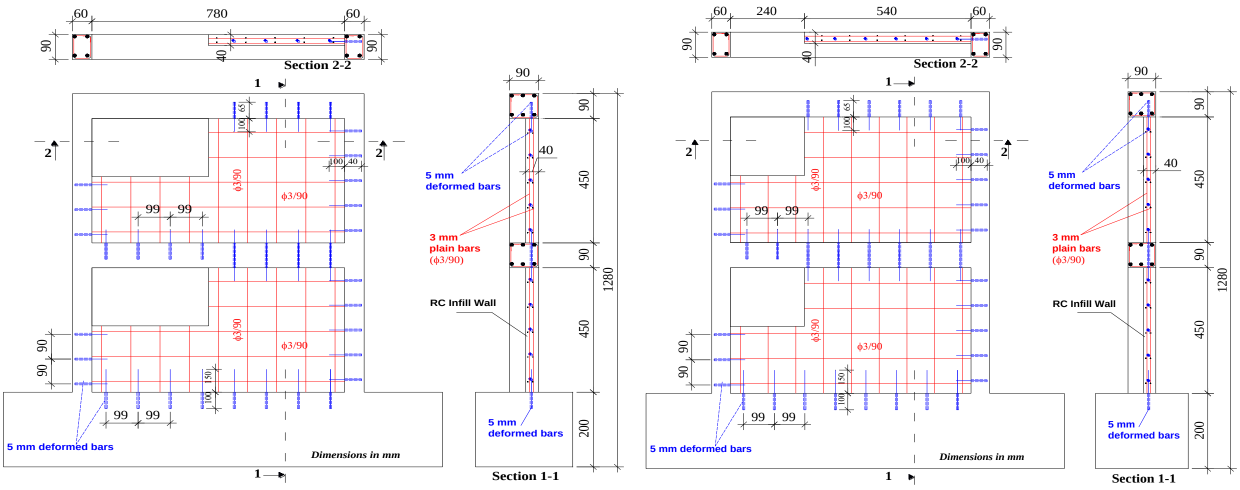


Figure 3. The test setup of the AAC wall

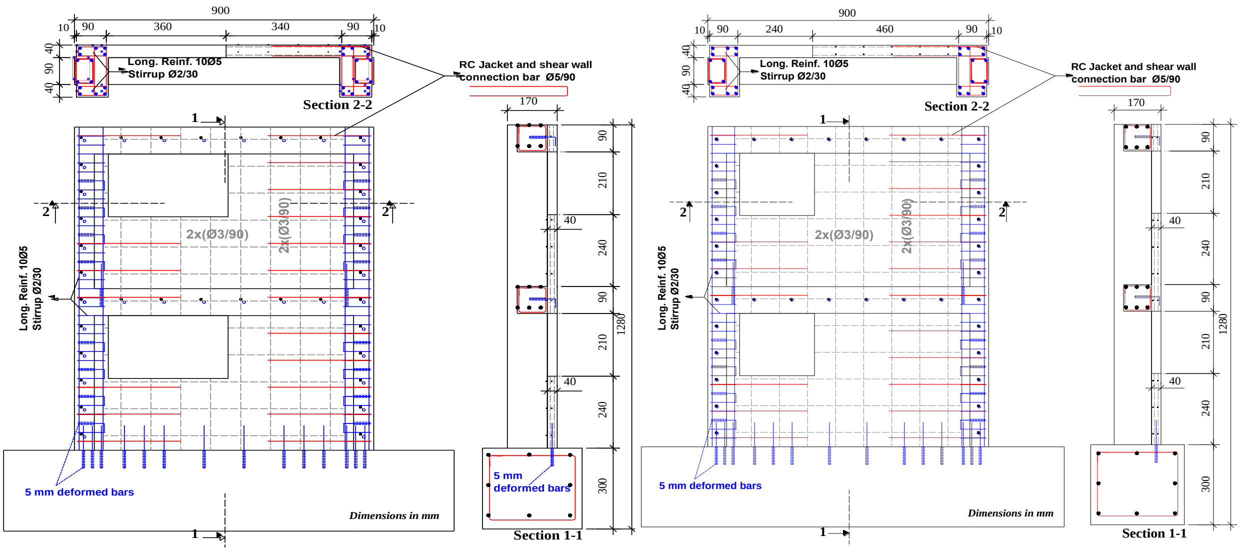
Specimen 4 and Specimen 5 were strengthened with infill RC shear wall. According to TEC-2007, the minimum compression strength of concrete should be 20 MPa. The target concrete compression strength of RC shear wall is aimed as 25 MPa (Kaltakcı et al., 2010). In the infill reinforced concrete (RC) shear wall, the average cylinder compressive strength of the concrete was measured as 26.7 MPa on the 28th day of testing. The maximum size of aggregates used in the production of concrete was 6 mm. Moreover, Water/Cement ratio of in the production of concrete was about 0.45. Dowel details, reinforcing mesh and dimension details for Specimen 4 and Specimen 5 are given in Figure 4.



a) ISW-BW b) ISW-SW

Figure 4. Details of Specimen 4 and Specimen 5

Specimen 6 and Specimen 7 were strengthened with external shear wall and RC column jacketing. In order to compare the Specimen 4 and Specimen 5, no brick infill wall had been applied in these specimens. Besides, the RC column jackets were added to provide the load-transfer of from the external shear wall to the columns. Dimension details and reinforcing meshs for Specimen 6 and Specimen 7 are given in Figure 5. The average compressive strength of concrete of shear walls and RC jackets was found to be as 22 MPa. The maximum size of aggregates used in the production of concrete was 6 mm. Moreover, Water/Cement ratio of in the production of concrete was about 0.5.



a) ESW-BW b) ESW-SW

Figure 5. Details of Specimen 6 and Specimen 7

The reinforcements used in the test specimens were subjected to tensile testing and the reinforcement properties are given in Table 1.

Table 1. Properties of reinforcing bars

Bar diameter (mm)	f_{sy} (MPa)	f_{su} (MPa)	Type
2	981	1242	Plain
3	760	962	Plain
5	639	809	Deformed

Test Setup

The tests of specimens were tested under lateral loading and constant vertical loading (Bahadır and Balık, 2017). The applied lateral loading was reversed cyclic loading that simulates the earthquake executions (Bahadir et al., 2013). The reversed cyclic loading was applied at both storey levels by a load distribution apparatus which was used to the disturbed lateral load such that to 2/3 of it was applied to second floor and 1/3 of it was applied to the first floor. The lateral loading was continued as load controlled until the yield point. After the lateral loading was reached the yield point, it was continued the experiment as displacement controlled (Unal et al., 2014). The experiments were terminated by applying a load cycle at both directions, after the maximum load level decreased by 20% ($0.8xV_{max}$). According to TEC-2007, at least 10% axial load of design compressive load should be applied for bearing system members that will be dimensioned as a column (Unal et al., 2014). Furthermore, according to TEC-2007, the maximum axial load level for the columns is limited to 50%. In this study, a special vertical loading system was designed to apply vertical axial forces to the columns. The steel roller wheels were used between the top beam of the test setup and the hydraulic jack in this system. Thus, this system was able to perform the same displacement as the displacements in the specimens. Additionaly, vertical load of 22 kN was applied on the top of each second story column prior to testing the specimen. This axial load corresponded to 20% of the axial load capacity of the column. The axial load was kept constant before lateral loading began for all test specimens. During the testing, story displacements and applied loadings were measured and recorded. The test setup and instrumentation was given Figure 6.

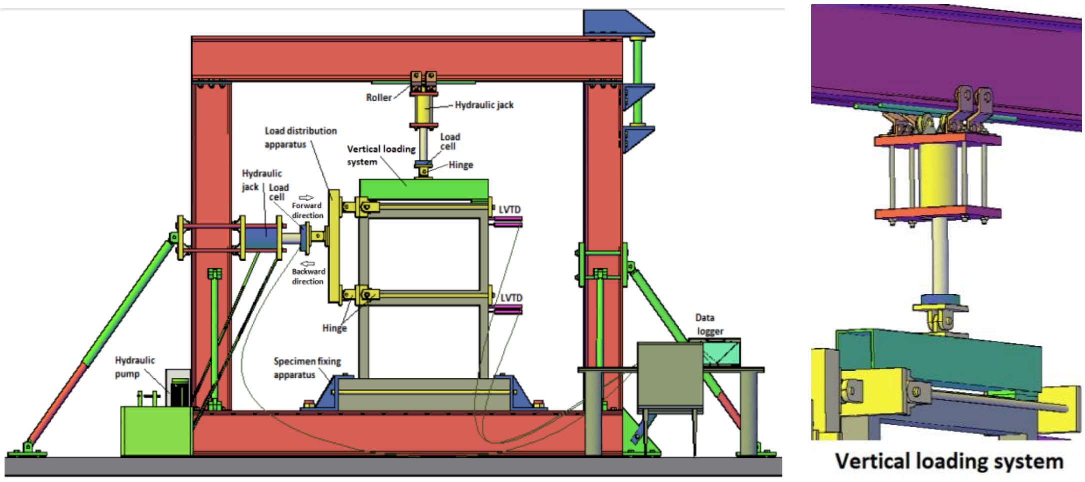


Figure 6. Test setup

RESULTS AND DISCUSSION

Experimental Results

Hysteretic curves for each test specimen were given in Figure 7. These hysteretic curves were used to expound the lateral strength, the stiffness, energy dissipation and general behaviors of specimens. After the shear cracks were occurred on the bottom corners of the windows at the experiments, there was more displacement at the forward direction of the test specimens (except Specimen 1). At the backward directions (-x directions) of these experiments, because of the close of these cracks, the displacements of the specimens were occurred smaller. The cracks and damages of the test specimens were given in Figure 8 at the end of the test.

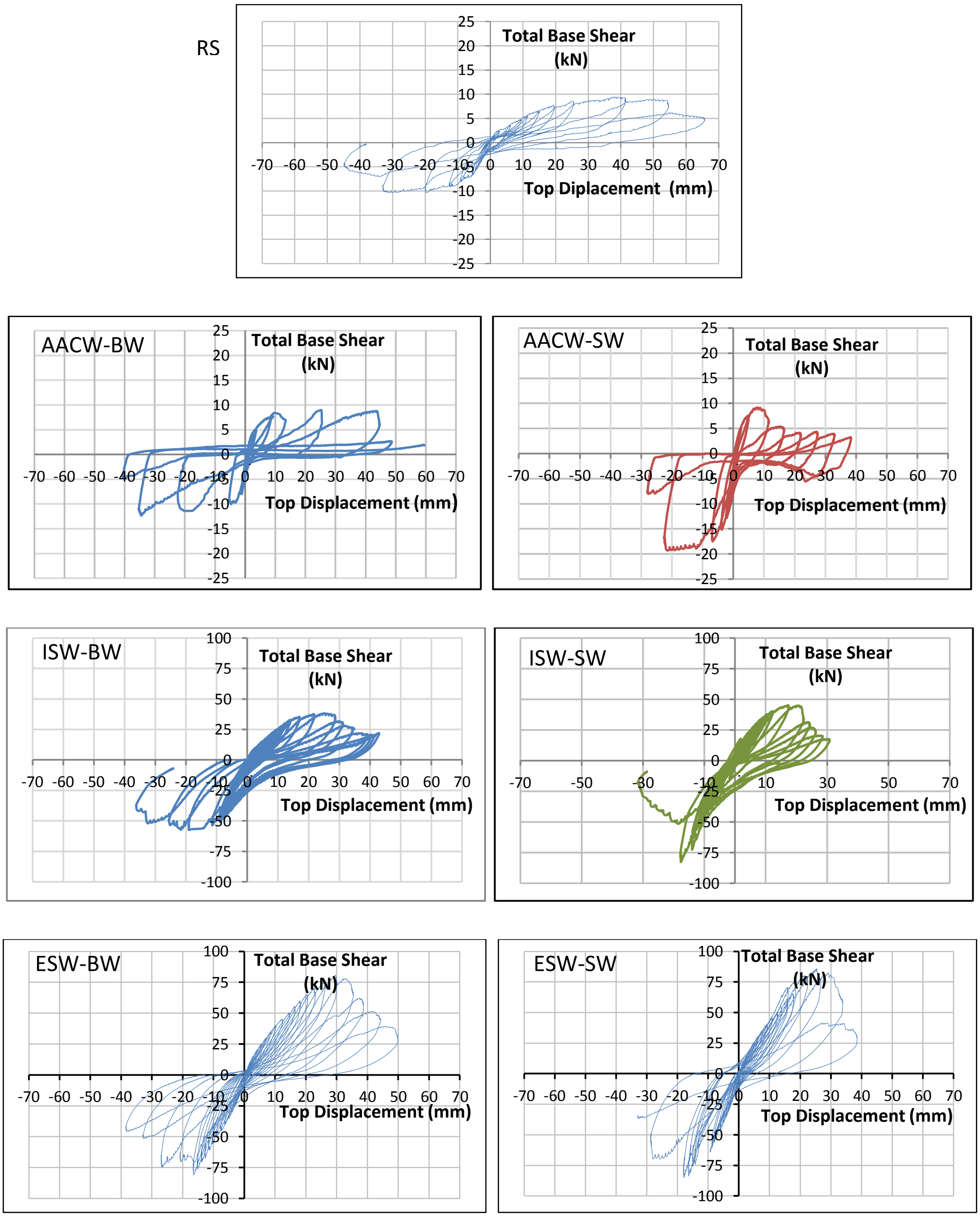


Figure 7. Base shear versus-second story displacement hysteresis curves of test specimens

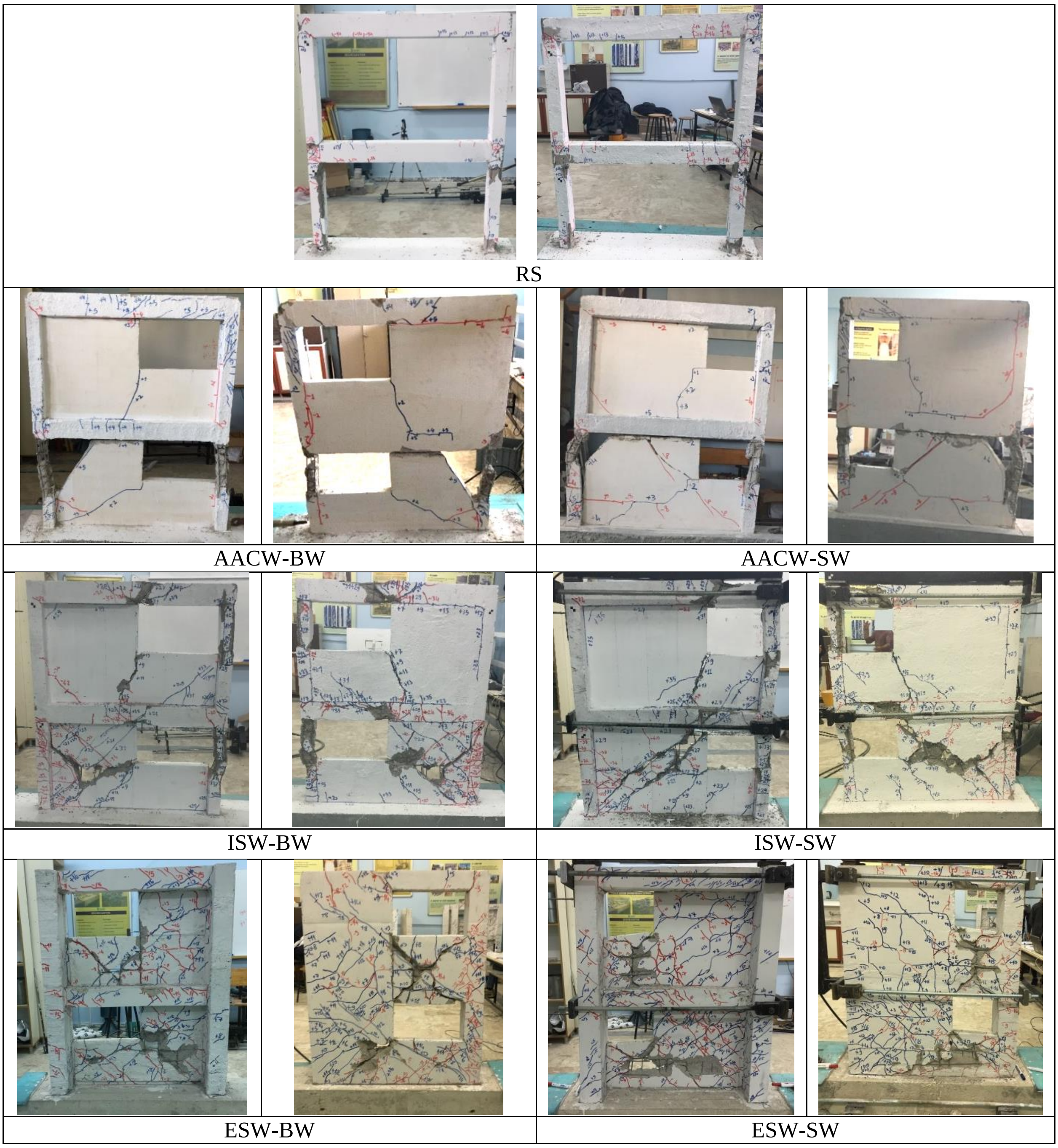


Figure 8. Photos of test specimens at the end of the test (front and back facades)

Specimen 1 (RS) tested was reference bare frame. Shear and bending cracks were observed on column-beam and column-base joints of Specimen 1. The plastic hinge formations occurred in the column-beam joints. Specimen 2 (AACW-BW) was constructed with AAC infilled RC frame and infill walls of Specimen 2 were produced as the big windows opening. *The short column effect* was clearly observed at the columns of 1st story. At the load and displacement increases, the AAC walls separating from the base and beams tries to rotate in a plane because of a rigid body and eventually partially damaged at the corner region. In addition, the shear cracks were observed intensely on the column located next to the window opening at the 2nd story of Specimen 2. Specimen 3 (AACW-SW) was constructed with AAC infilled RC frame and infill walls of Specimen 3 were produced as the small windows opening. *The short column effect* was observed at the columns of 1st story. Damage and behavior observed on AAC walls of Specimen 2 were also observed on the walls of Specimen 3. In addition, the shear cracks were intensely observed on a column located next to the window opening at the 2nd story of Specimen 3. Specimen 4 (ISW-BW) was strengthened with infill RC shear wall and the big window opening was located to the side of the one column. In the Specimen 4, the cracks were occurred intensely and these cracks were occurred as shear cracks at corners of the window opening of 1st and 2nd stories. The shear cracks were formed intensely on the part without a window opening of 1st story. *The short column effect* was observed in the columns where the window openings of 1st and 2nd storey were found. Shear cracks were also occurring intensely at the beams of Specimen 4. It has been observed that the beam of 2nd story contacts the vertical loading system in the forward cycles due to increased damage on the beam of 2nd story of this specimen. Therefore, the test was continued only in the backward cycle so that this specimen could reach its failure load. Specimen 5 (ISW-SW) was strengthened with infill RC shear wall and the small window opening was located to the side of the one column. At Specimen 5, *the short column effect* was occurred in the columns where the window openings of 1st and 2nd storey were found. The shear cracks were formed intensely on the part without a window opening of 1st story. Specimen 6 (ESW-BW) and Specimen 7 (ESW-SW) were strengthened with external RC shear wall and RC jackets. The main damages at shear walls of Specimen 6 and Specimen 7 were occurred the cracks of X shape between the windows of the 1st and 2nd storey. In addition, shear cracks and other damages were formed in the corner of the window of the 1st story. *The short column effect* was not occurred at columns of these specimens.

Comparison of Strength

Response envelope curves were drawn to compare general behaviors of specimens. These envelope curves were drawn by connecting the peak points of each hysteretic curve for each specimen (Ha et al., 2018). Total base shear-top displacement response envelope curves were constructed to evaluate (Wasti and Özcebe, 2012) and given in Figure 9. In order to compare the effect of the applied strengthening technique on max lateral load calculated results are summarized in Table 2.

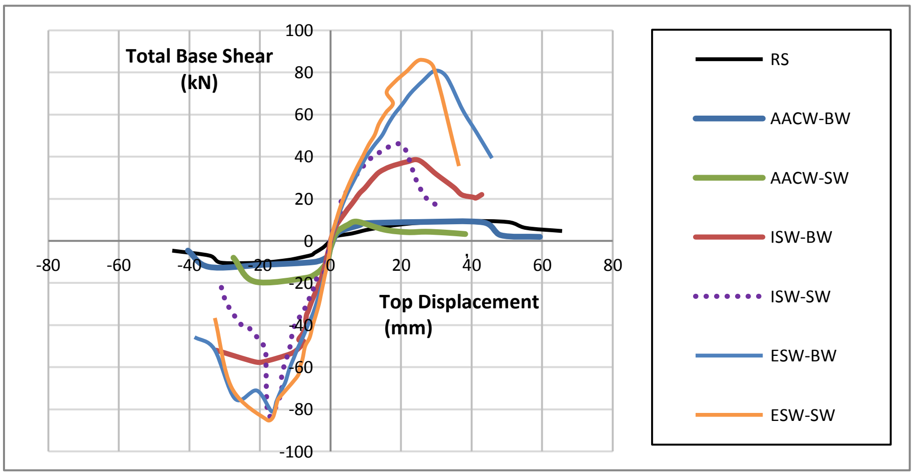


Figure 9. Total base shear-top displacement envelope curves of all specimens

Table 2. The lateral load carrying capacities of test specimens

Test Specimens		Top Displacement at Max. Lateral Load (mm)		Max. Lateral Load (kN)		Ratio*		Interstory Drift %	
		Forward	Backward	Forward	Backward	Forward	Backward	Forward	Backward
1	RS	38	-31	9	-10	1	1	3.3	2.5
2	AACW-BW	25.2	-34.5	9	-12.4	1	1.24	3	2.1
3	AACW-SW	7.56	-21.5	9.1	-19.3	1.02	1.93	0.7	3
4	ISW-BW	25.1	-19.1	38.3	-57.4	4.25	5.74	2.3	2.2
5	ISW-SW	17.3	-17.7	45.2	-82.7	5.02	4.52	1.5	1.5
6	ESW-BW	30	-17	81	-81	8.58	7.84	2.5	1.6
7	ESW-SW	25	-18	86	-85	9.12	8.23	2.1	1.6

*Ratio of maximum loads of infilled frames to Specimen 1 maximum load

In Figure 9, there was a sharp drop in total base shear carried by the strengthened specimens after reaching the max lateral load at both loading directions. From the inspection of Figure 9 and Table 2, it can be seen that, the lateral load carrying capacities of all strengthened frames were considerably greater than the lateral load carrying capacity of the bare frame. As expected, Specimen 7 (ESW-BW) was strengthened with external RC shear wall and RC column jacket had the highest lateral strength among all the other specimens. The lateral load carrying capacity of Specimen 6 and Specimen 7 were about between 8 and 9 times higher than the capacities of reference specimen at both forward and backward directions. Specimen 4 (ISW-BW) and Specimen 5 (ISW-SW) were strengthened with infill shear walls were about between 4 and 5 times higher than the capacities of reference specimen at both forward and backward directions. The lateral load carrying capacities of Specimen 2 and Specimen 3 were very close to the lateral load carrying capacity of Specimen 1 (RS) at both forward and backward directions. The lateral load carrying capacities of Specimen 2 and Specimen 3 are normally expected to be higher than Specimen 1. Because of the brittle behavior of the infill wall and the crushing of the wall, the strength of Specimen 2 and Specimen 3 were lower than expected due to the lack of load transfer from the frame to the infill wall. The test results showed that the size of the window opening has no significant effect on the lateral load carrying capacities of the test specimens (Balik et al., 2013).

Comparison of Stiffness

Initial stiffness were measured as the initial slope of the load-displacement curves of test specimens (Anil et al., 2018). The stiffness values at initial and max lateral load of the test specimens were listed in Table 3. The highest initial stiffness was achieved at the Specimen 5. The initial stiffness and at max lateral load stiffness of Specimen 2 was very close to Specimen 1 (RS). Stiffness values of specimens infilled with AAC walls are normally expected to be higher than Specimen 1. However, the stiffness values of Specimen 2 were decreased due to the big window openings on the AAC wall. The initial stiffness of the strengthened specimens were about between 2.5 and 5 times higher than reference specimen. At max lateral load, the stiffness of these specimens was also found to be about between 6.7 to 11 times greater than the stiffness of the Specimen 1. The stiffness of Specimen 6 (ESW-BW) and of Specimen 7 (ESW-SW) were measured very close values at both forward and backward directions. The stiffness reductions of specimens infilled with AAC and RC shear walls were consisted due to the damages on the walls and columns of the 1st story. The most stiffness reduction was occurred at Specimen 2. The stiffness reductions of Specimen 6 and Specimen 7 were consisted due to damages on the walls of the 1st story. From the inspection of Table 3, the specimens of the small windows were had higher than stiffness ratio of the average at max lateral load compared to the specimens of the big windows.

Table 3. Stiffness values of test specimens at initial and max lateral load

Test Specimens		Initial Stiffness	Stiffness at Max. Lateral Load (kN/mm)			Ratio*	
			Forward	Backward	Average	Initial	Average at Max. Lateral Load
1	RS	1.53	0.34	0.33	0.34	1	1
2	AACW-BW	1.75	0.36	0.36	0.36	1.14	1.07
3	AACW-SW	2.15	1.21	0.90	1.05	1.41	3.09
4	ISW-BW	4.44	1.52	3.01	2.27	2.90	6.76
5	ISW-SW	7.08	2.61	4.68	3.65	4.63	10.88
6	ESW-BW	6.34	2.61	2.65	2.63	4.15	7.85
7	ESW-SW	3.93	2.74	2.82	2.78	2.57	8.29

*Ratio of stiffness values of infilled frames to Specimen 1 stiffness values

Comparison of the Energy Dissipation Capacities

The energy dissipation capacities values were determined by summing the areas enclosed by hysteretic lateral load displacement curves for each cycle (Anil and Altin, 2007). In order to compare the cumulative energy dissipation values of all specimens, these values at the failure load ($0.8xV_{max}$) of all specimens are given in Table 4. The energy dissipations of strengthened specimens were occurred quite higher than other specimens. Because Specimen 2 and Specimen 3 were reached to maximum load carrying capacity without more displacement than from Specimen 1, the energy dissipation values of these specimens at the forward cycle were occurred lower than from Specimen 1.

Table 4. Energy dissipation values of test specimens

Test Specimens		Forward Cycles	Backward Cycles
		Cumulative Energy Dissipation (J)	Cumulative Energy Dissipation (J)
1	RS	567	422
2	AACW-BW	369	430
3	AACW-SW	97	680
4	ISW-BW	1511	3718
5	ISW-SW	1333	2252
6	ESW-BW	2627	4180
7	ESW-SW	3005	4666

CONCLUSION

In the experimental study, seven reinforced concrete frames as two stories, 1/5 scaled and one bay were produced. These specimens tested under reversed cyclic lateral loading and constant vertical loading. The test results are summarized below:

The applied strengthening methods have significantly increased the strength, initial stiffness and energy dissipation capacity of the RC frame. However, the short column behavior could not be prevented especially at the first storey of the strengthened specimens with RC infill walls. The RC column jackets were increased both the load carrying capacity of Specimen 6 and Specimen 7 and prevented the formation of short columns. Therefore, the external RC shear wall and RC jackets application could be limited the structural damages and prevent the collapse of the entire structure of seismically deficient due to short column effect during earthquake. Further, the external RC shear wall and RC jackets application has several advantages from cost, construction time and owner-user satisfaction point of views. Since the added RC shear wall is intended to be constructed at the outer facades of the building, the destruction of existing infill walls are not required. Therefore, the buildings will not be affected negatively from heat insulation. Additionally, during the strengthening period, the evacuation of the building may not be required or evacuation period is shortened. Loss of function of the facility and corresponding economical loss may be limited. This advantage is more important for hospital or dormitory type, daily used public facilities.

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