

## EXPERIMENTAL STUDIES ON 1/5 SCALED REINFORCED CONCRETE FRAMES BY USING DIFFERENT STRENGTHENED METHODS

<sup>1</sup>Fatih Süleyman BALIK, <sup>2</sup>Fatih BAHADIR

<sup>1,2</sup>Necmettin Erbakan University, Konya Ereğli Kemal Akman Vocational School, Construction Department, Konya, TURKEY

<sup>1</sup>fsbalik@erbakan.edu.tr, <sup>2</sup>fatihbahadir24@gmail.com

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**ABSTRACT:** In this experimental study; five RC frames with a scale of 1/5, single spans and two storey were produced so as to reflect the characteristics of existing structures. Two RC frames were used as the reference specimens that without an infill wall and autoclaved aerated concrete blocks (AAC) infilled wall. Three of these RC frames were strengthened as CFS (Cold Formed Steel) drywall system, infill RC shear wall and both external RC shear wall and column jacketing. All specimens produced were tested under reverse cyclic lateral loading and constant vertical loading. Strength, stiffness and energy dissipation capacities of all test specimens are compared with each other. The lateral load carrying capacity and energy dissipation capacities of strengthened specimens have occurred higher than reference specimens. But initial stiffness and stiffness at the max lateral load of specimen strengthened with CFS drywall system have occurred lower than reference specimen with AACW.

**Key Words:** *Seismic behavior, Strengthening, Reversed cyclic lateral loading, Autoclaved aerated concrete block, Cold formed steel wall system*

### 1/5 Ölçekli Betonarme Çerçevelere Farklı Güçlendirme Metotları Uygulanması Üzerine Deneysel Çalışmalar

**ÖZ:** Bu deneysel çalışmada; mevcut yapıların özelliklerini yansıtacak şekilde 1/5 ölçekli, tek açıklıklı ve iki katlı 5 adet betonarme çerçeve üretilmiştir. Bu çerçevelerden 2 adedi referans numune olarak biri boş çerçeve diğeri gazbeton dolgu duvarlı olarak kullanılmıştır. Diğer üç adet betonarme çerçeve ise soğukta şekillendirilmiş çelik (CFS) duvar sistemi, betonarme dolgu duvarlı ve hem düzlem dışı betonarme duvarlı hem de betonarme kolon mantolu olarak güçlendirilmiştir. Üretilen tüm numuneler tersinir-tekrarlanır yatay yük ve sabit düşey yükleme altında test edilmiştir. Test numunelerine ait dayanım, rijitlik ve enerji tüketme kapasiteleri birbirleri ile karşılaştırılmıştır. Güçlendirilmiş numunelere ait yatay yük taşıma ve enerji tüketme kapasiteleri, referans numunelere göre daha yüksektir. Fakat soğukta şekillendirilmiş çelik (CFS) duvar sistemi ile güçlendirilen numunenin başlangıç ve maksimum yükteki rijitlik değerleri, gazbeton dolgu duvarlı (AACW) referans numuneninkinden daha düşük olmuştur.

**Anahtar Kelimeler:** *Deprem davranışı, Güçlendirme, Tersinir-tekrarlanır yatay yükleme, Gazbeton blok, Soğukta şekillendirilmiş çelik duvar sistemi*

## INTRODUCTION

Strengthening of existing structures due to possible earthquake in Turkey is an important issue. For this reason, it is necessary find to new strengthening methods and to develop existing methods. Many studies have been carried out on strengthening RC frames with different infill walls until today. These experimental studies have been carried out on strengthening RC infill wall.

In these studies, experiments with different parameters related to the infill walls have been carried out. Higashi et al. (1980) investigated that strengthened RC frames with full infill walls and partial infill walls. They obtained the result that the specimens with the partial infill wall made larger displacements than the specimens with full infill wall. Hayashi et al. (1980) investigated that two methods of strengthening. In the first method, RC frames were strengthened with infill RC shear walls, and the second method was strengthened the surroundings of the columns of RC frames with mortar and welded wire fabrics. These strengthening methods increased the strength and the ductility of RC frames. Altin et al. (1992) investigated that the behaviors of RC frames strengthened with RC infill walls were tested under reversed cyclic loading. The parameters in this study were the reinforcement detail of infill walls, the connection between the frame and the infill walls, and the flexural capacity of columns. The test results showed that, infill walls were increased strength, stiffness and rigidity of RC frames. Ozcebe et al. (2003) investigated that the infill wall thickness, the connection details between infill wall and RC frame and different the beam and column stiffnesses, as a parameter. This study showed that, the strengthening increases the RC frame's lateral load carrying capacity and initial rigidity. Until today, various strengthening methods have been carried out to improve the seismic behaviors of RC frames (Tankut et al., 2005; Baran, 2005; Erdem et al., 2006; Kara and Altin, 2006; Anil and Altin, 2007; Altin et al., 2008; Baran and Tankut, 2011; Baran et al., 2011; Korkmaz et al., 2011; Marius and Valeriu, 2012; Balik, et al, 2018).

It is important to know the behavior of RC frames with brick infill walls in order to clearly demonstrate the seismic contribution of strengthening works to RC frames. For this reason, many experimental works on RC frames with brick infill walls have been made up to this time. Mehrabi et al. (1996) investigated that the influence of masonry infill panels on the seismic performance of reinforced concrete RC frames. The test results showed that indicate that infill panels can significantly improve the performance of RC frames. Buonopane and White (1999) investigated that the earthquake behavior of the system by testing to 1/2 scaled, two-span and two-story brick-filled reinforced concrete frames under dynamic loading. In order to estimate the lateral stiffness and displacement capacity of the system using experimental results, different diagonal compressive member shapes were investigated analytically and the most suitable diagonal compressive member model for experimental results was investigated. Lee and Woo (2002) investigated that the effect of masonry infills on the seismic performance of 1/5 scaled RC frames with non-seismic detailing. The test results showed that, masonry infills were increased strength, stiffness and rigidity of RC frames. Zovkic et al. (2013) investigated that the seismic behaviors of RC frames with 1/2.5 scale the autoclaved aerated concrete blocks infills under constant vertical and cyclic lateral load. The test results showed that RC frames with had much higher stiffness and initial strength than the bare frame. Demirel et al. (2015) investigated that the effect of masonry infills and autoclaved aerated concrete blocks infills on seismic behavior in 1/2 scaled RC frames. They found that the masonry infills increased the base shear force by 43% but the capacity is quickly depleted, and the progressive drift values converge to the bare frame. Besides, the autoclaved aerated concrete blocks infills were increased seismic performance of RC frames. Adding RC infill wall to RC frames are widely used as structural strengthening method. Along with that, various strengthening methods are used at the strengthening of RC structures. Suzuki et al. (2017) investigated that the seismic behaviors of five RC frames with 1/4 scale the masonry infill walls under constant vertical and cyclic lateral load. They used horizontal and vertical stacking of the infill wall as parameters in their experiments. The experimental test results showed that the horizontally stacked infill formed a typical diagonal compressive strut and showed infill seismic performance than higher vertically stacked. Dautaj et al. (2018) investigated that the behaviour of masonry-infilled reinforced concrete (RC) frames under various lateral strength. They found that the type of masonry unit influenced to the failure mechanism of masonry-infilled RC frames.

In many studies, steel plates are often used in steel frames. Steel plates are rarely used for strengthening reinforced concrete frames. Some studies related to this are given below. Elgaaly (1998) investigated that the effect of thin steel plate infills on seismic behavior in 1/4 and 1/3 scaled RC frames. The steel plates of these specimens were joined to the RC frames by welding and bolting. All test results indicate that the behaviors of these specimens are stable in the post-buckling domain. Choi and Park (2011)

investigated that the cyclic behavior of walls that are composed of three-story RC frames and thin steel infill plates. The test results show that shear cracking and failure of the column-beam joints were prevented by using the steel infill plates. Pan and Shan (2011) investigated that the structural strength of cold-formed steel wall frames with sheathing under monotonic shear loading. They used three different sheathing material and two different thicknesses as thin steel plate in the test specimens. The test results show that the mechanical properties of the sheathing material affect not only the loading capacity of the specimens but also the structural behavior. Kamanli et al. (2011) investigated that 1/3 scaled the specimen of thin steel plate shear wall and other test strengthened specimens under cyclic loading were performed. Experimental results show that there is a significant increase in the horizontal load capacities of the strengthened specimens. In addition, the use and function of the construction is very little affected by such strengthening methods and the strengthening works can be carried out quickly. Akin et al. (2016) tested that 1/3 scaled, one-bay and two-story five RC frames of thin steel plate shear walls. The test results showed that the specimens with the steel plate increased horizontal load-carrying capacities and energy dissipation capacities. Aykaç et al. (2017) tested that 12 infill brick walls strengthened with perforated steel plates and a infill brick wall under reversed cyclic loading. Plate thickness, bolt spacing, and anchorages were test variables. According to the results, the strengthened specimens have increased ductility and strength compared to the reference specimen.

Generally, Cold Formed Steel (CFS) profiles are frequently applied in light steel building designs in 1-3 storey buildings. In addition, a lot of work has been done on wood, gypsum and steel plates, which are skeleton structures CFS profiles as sheaths of wall materials. Fülöp and Dubina (2004) investigated that the shear behaviour of six wall panel typologies. Different sheaths of wall material, door opening and skeleton types were used as test variable. They concluded that the shear-resistance of the test specimens is important both in terms of stiffness and load bearing capacity. Pan and Shan (2011) tested that 13 wall specimens under monotonic shear loading. Three different kinds of sheathing material were used in these wall specimens and these sheathing materials were calcium silicate board, oriented-strand board. In addition, the boards used in these specimens were produced in two different thicknesses. These experiments were shown that the mechanical properties of these sheathing materials affect not only the loading capacity of the specimens, but also the structural behavior. Baran and Alica (2012) tested that thirteen OSB-sheathed CFS wall panel specimens under static lateral load. Different OSB thickness, double-sided sheathing, diagonal struts, CFS section size, and screw spacing were used as test parameters. Test results showed that increased screw spacing reduced lateral load carrying and deformation capacity. In addition, diagonal struts added to the panels and increased OSB thickness were increased lateral load carrying capacity and initial stiffness. Ye et al. (2015) tested that the six full-scale walls specimens under cyclic loading. Different sheath materials, stud section and spacing were used as test parameters. The damages and the screw behaviors that occurred during these failure mechanisms were examined in detail. Wang and Ye (2015) investigated that test specimens of nine full-scale CFS shear walls with strengthened end studs under cyclic loading. Different sheathing material, stud type and openings were used as test parameters. They have developed a method for shear capacity as a result of their study. The experimental results were compared with the results of this method and the difference was found to be about 8%. Accorti et al. (2016) tested that the 21 CFS shear walls with different bracing systems under vertical and lateral loads. They investigated to the bare steel specimens, the use of trussed bracing, of a trussed frame and of diagonal bracing with flat straps. As result of their work, the performance of CFS walls with diagonal bracing was occurred the best under all aspects than the others specimens. In addition, CFS walls with trussed members are found to be moderate in wind and/or earthquake loads. Mohebbi et al. (2016) investigated that six steel sheathed wall specimens of various cladding configurations were tested under cyclic displacement-control loading. These boards of wall specimens were sheathed with the fiber cement and gypsum. As result of their experiments, the use of claddings on one side or both sides of the walls increased the stiffness of the specimens, the shear strength and the energy dissipation capacity. However, these kinds of works are not related strengthening with reinforced concrete frames.

In this study, five RC frames used in the experimental works have been produced with various structural defects, 1/5 scale, 2 storey and one span. Three of these RC frames were strengthened as CFS wall system, infill RC shear wall and both external RC shear wall and column jacketing. In order to determine the seismic contribution of these strengthening works, reference specimens were tested as bare frame and autoclaved aerated concrete block (AAC) infilled wall. All test specimens were tested under reverse cyclic lateral loading and constant vertical loading (Bahadir and Balik, 2017).

## MATERIAL AND METHOD

### Details of Test Specimens

The reinforced concrete frames of specimens were produced to reflect which these deficiencies were commonly observed in the existing reinforced concrete building stock in Turkey (Ozcebe et al., 2004; Yilmaz et al., 2010).

The stirrups of the columns and beams were used 2 mm diameter plain bars by 60 mm spacing and these stirrups placed by 90 degree hooks. In columns and beams, 5 mm diameter longitudinal reinforcement as deformed steel bars were used. In the production of reinforced concrete frames, the average cylinder compressive strength of the concrete was used 10.3 MPa on the 28th day of testing and the concrete of all the frames were cast at the same time. The dimensions and reinforcement details of the reinforced concrete frame of the produced specimens are given in Figure 1. These frames as two stories, 1/5 scaled and one bay were produced.

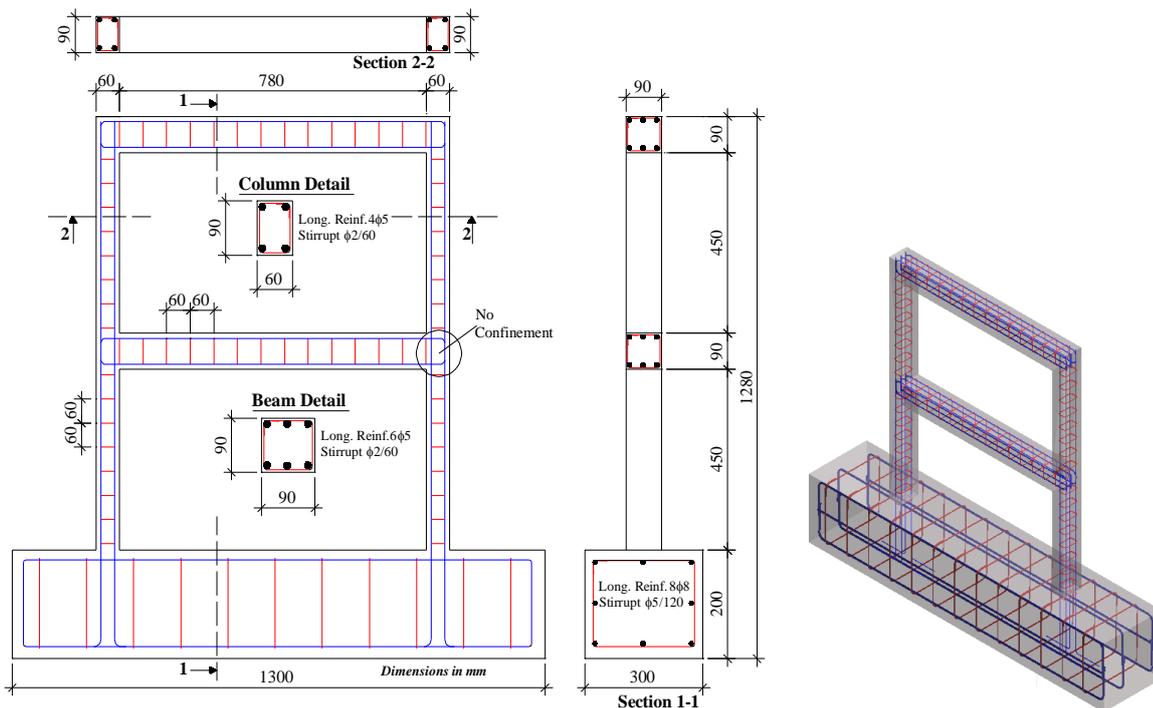
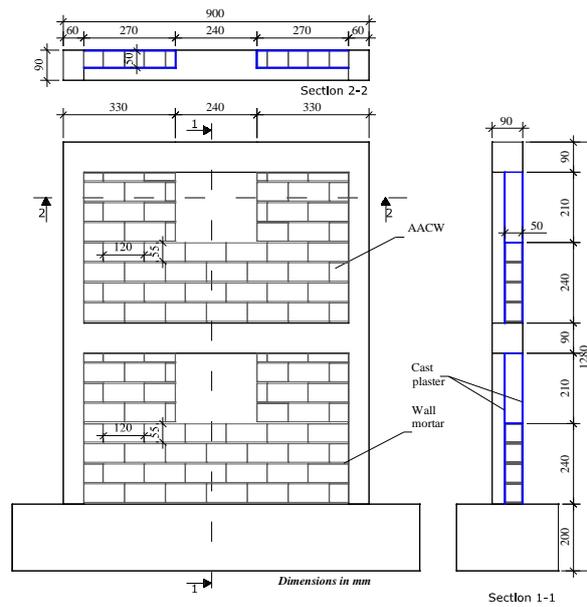


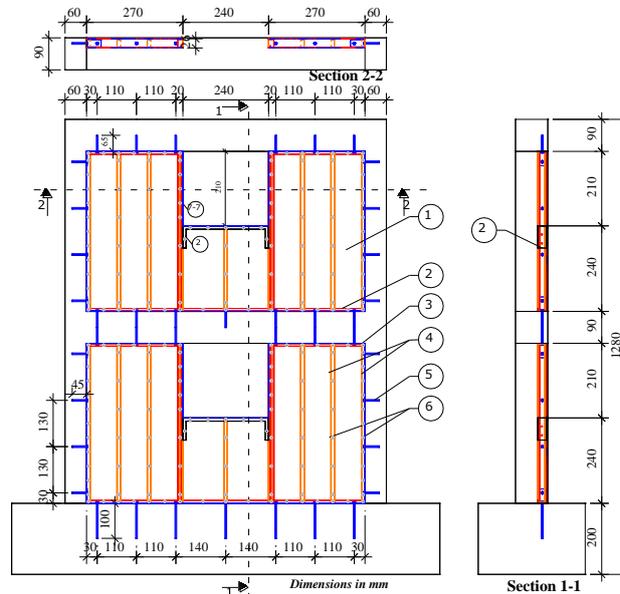
Figure 1. Dimensional and reinforcement details of the RC frames

Four of five reinforced concrete frames were produced different walls with window openings. These window openings were shifted to the mid-span at stories. The dimensions of window openings at these walls were 210x240 mm. Specimen 1 (RS) constructed was reference bare frame and not contained any infill wall and/or column jackets. Specimen 2 was constructed with autoclaved aerated concrete blocks (AAC) infilled RC frame. At Specimen 2, the dimensions of AAC blocks were used as 120x55x50 mm. The infill AAC walls were tested under diagonal compression. The average diagonal compressive strength of infill autoclaved aerated concrete walls is found as 0.28 MPa. Details of these specimens are given Figure 2.



**Figure 2.** Dimensions and reinforcements details of Specimen 2

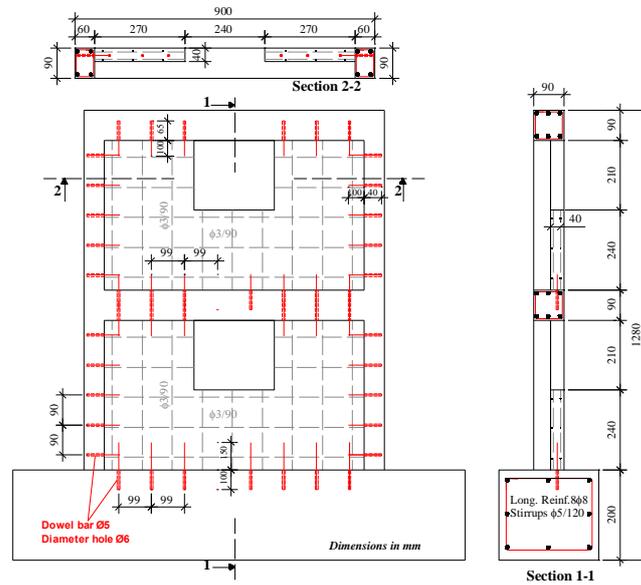
Specimen 3 (DW-SS) was strengthened with single skeleton drywall and 0.3 mm steel sheets. In this specimen, the thickness of the single skeleton drywall system was designed as 26 mm. The CFS profiles used in this wall were anchored to the columns and beams of the frame with M4 bolt bars. The spacing of the anchoring bars of single skeleton drywall system were used 120 mm in the beams, 130 mm in the columns and 120 mm in the base. The anchore holes with a diameter of 5 mm were drilled on the RC frame and these profiles were anchored with epoxy. 0.3 mm thick steel sheets were fixed on the front and back façades of the single skeleton drywall system. Dowel details and dimension details for the Specimen 3 are given in Figure 3.



**Figure 3.** Dimensions and reinforcements details of Specimen 3

Specimen 4 was strengthened with infill RC shear wall. In these specimens, the thickness of the infill RC shear wall was designed as 40 mm. At the two façades of the infill RC shear wall, plain bars with a diameter of 3 mm spaced at 90 mm were used as square reinforcing mesh. The square reinforcing mesh of infill RC shear wall ratios were  $\rho_v=0.0041$  in vertical direction and  $\rho_h=0.0039$  in horizontal direction. At the columns of Specimen 4, the dowel ratio was  $\rho_{column}=0.0055$ . At the beams of Specimen 4, the dowel ratios

were  $\rho_{\text{beam}}=0.0055$  and  $0.0050$ . Dowel details, reinforcing mesh and dimension details for Specimen 4 are given in Figure 4.



**Figure 4.** Dimensions and reinforcements details of Specimen 4

Specimen 5 was strengthened with external shear wall and RC column jacketing. The external shear walls were 40 mm in thickness and constructed at the one external façade of the frames. The connections between the frame and external shear wall were provided with 5 mm diameter deformed bars that were fixed with epoxy to the frame. At the two façades of the external RC shear wall, plain bars with a diameter of 3 mm spaced at 90 mm were used as square reinforcing mesh. The square reinforcing mesh of external RC shear wall ratios were  $\rho_v=0.004$  in vertical direction and  $\rho_h=0.0043$  in horizontal direction. The longitudinal reinforcements ratio of the RC column jackets was  $\rho_{\text{jacket}}=0.018$ . Dimension details and reinforcing meshes for Specimen 5 are given in Figure 5. Dowel details of Specimen 5 are given in Figure 6.

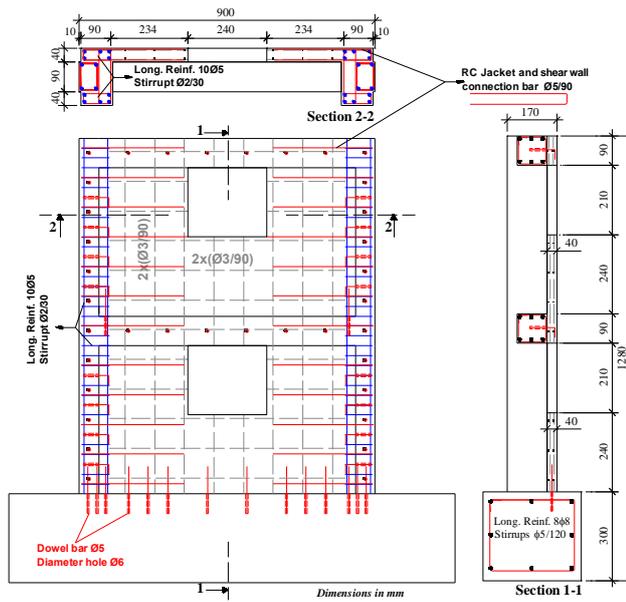


Figure 5. Dimensions and reinforcements details of Specimen 5

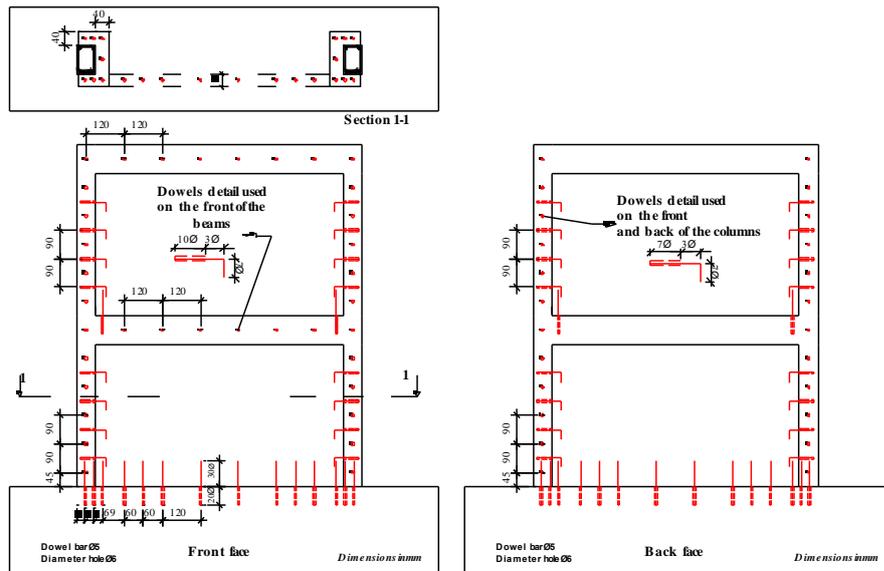


Figure 6. Dowel details of Specimen 5

### Test Setup

The experimental setup in which the test specimens are given in Figure 7. During the experiments, total 22 kN axial load was applied to the columns of the specimens. These loads were applied to the columns with a 100 kN capacity hydraulic jack. A special wheel system was used to allow the axial load system to move upper beam of the specimen. 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). The lateral loading was applied as reversed cyclic loading at the test specimens. This loading was applied by a 200 kN capacity hydraulic jack. During the experiments, 2/3 of the total lateral load to beam of the 2<sup>nd</sup> story and 1/3 of the total lateral load to the beam of the 1<sup>st</sup> story were applied to test specimens. Total lateral loads and axial load were measured by loadcells. Displacement data of the test specimens were measured by LVDTs at each storey level (Kaya et al., 2018). The values read from load cells and LVDTs were recorded.

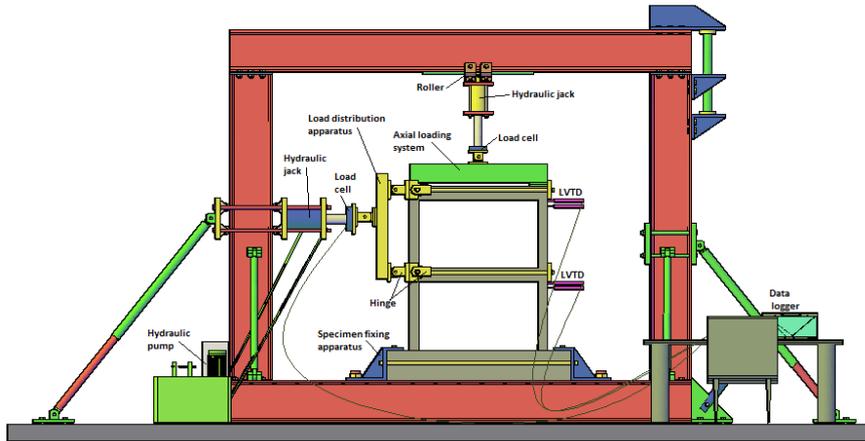


Figure 7. Test setup

**Materials**

The RC frames of test specimens were designed as low strength concrete to represent the strength of concrete in existing RC structures in Turkey (Kara, 2006). The average compressive strength of concrete used in the production of concrete of RC frames was 13 MPa. Concrete with average compressive strength of 27 MPa was used in the shear walls and column jacketing. Properties of reinforcements used in the test specimens are listed in Table 1. The members of infill walls used in the drywall system are given in Table 2.

**Table 1.** Properties of reinforcing bars used in the test specimens

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

**Table 2.** Properties of infill wall members at Specimen 3 with drywall system

Detail number	Member name	Geometry and picture	Thickness(mm)	Dimensions(mm)
1	Steel sheet		0.3	780x450
2	CFS-UW profile		0.5	11x26x11
3	Bracket		1	40x40x20
4	CFS-CW profile		0.5	9x25x9
5	M4 bolt bars		-	-
6	Screw with drill bit		-	3.9x13
7	CCW profile		0.5	9x24x14

## Experimental Study

### Specimen 1 (BF-Reference Specimen)

In the experimental program, Specimen 1 was the reference frame, which was tested to observe reference behaviour. It contained no infill wall. Until the end of the experiment, 11 hysteresis cycles were applied to Specimen 1 at both forward and backward. Specimen 1 reached to 9.42 kN max lateral load and +37.96 mm displacement at forward direction. It reached to -10.34 kN max lateral load and -31.05 mm displacement at backward direction. When it reached to lateral load carrying capacity, interstory drift value was 3.3% at forward direction and interstory drift value was 2.5% at backward direction. The hysteresis curves of Specimen 1 are shown in Figure 8.

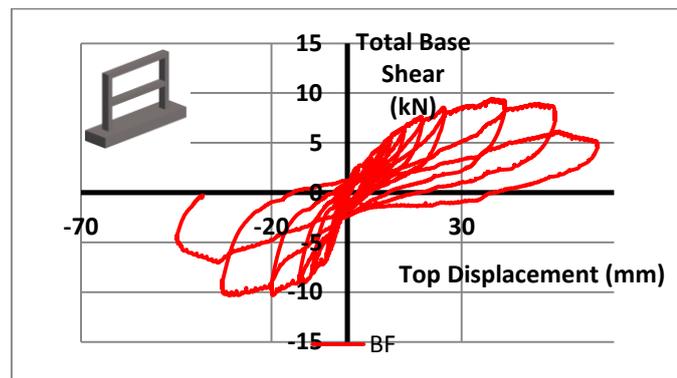


Figure 8. Hysteresis curves of Specimen 1

The plastic hinge formation occurred in the column-beam joints. Shear and bending cracks were observed on the frame of Specimen 1. The crack patterns of Specimen 1 at the end of the test can be seen in Figure 9.



Figure 9. Photos of Specimen 1 at end of the test (front and back façades)

### Specimen 2 (AACW- Reference Specimen)

Specimen 2 was produced with autoclaved aerated concrete blocks infilled RC frame. Until the end of the experiment, 9 hysteresis cycles were applied to Specimen 2 at forward direction and 8 hysteresis cycles were applied at backward direction. Specimen 2 reached to 15.52 kN max lateral load and +11.86 mm displacement at forward direction and to -18.07 kN max lateral load and -9.43 mm displacement at backward direction. When Specimen 2 reached to lateral load carrying capacity, interstory drift value was 0.9% at forward direction and interstory drift value was 1.3% at backward direction. The hysteresis curves of Specimen 2 are shown in Figure 10.

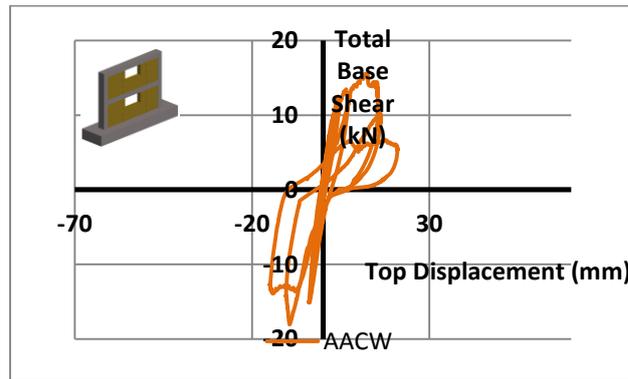


Figure 10. The hysteresis curves of Specimen 2

The diagonal cracks and damages occurred thoroughly from lower corner of window of 2<sup>nd</sup> story to beam of 1<sup>st</sup> story and from a beam of the 1<sup>st</sup> story to a column of 1<sup>st</sup> story. Further, the diagonal crack occurred thoroughly from lower corner of the window of the 1<sup>st</sup> story to a column-base. The short column behaviour observed at a column of 1<sup>st</sup> story. A plastic hinge formation was occurred at the lower and upper ends of the other column. The infill walls of 1<sup>st</sup> story collapsed partially at the end of the test. The sliding cracks occurred at the window opening level of 1<sup>st</sup> story. The plastic hinge formation also observed at a column-beam joint of the 2<sup>nd</sup> story. The crack pattern and damages of Specimen 2 at the end of the test can be seen Figure 11.

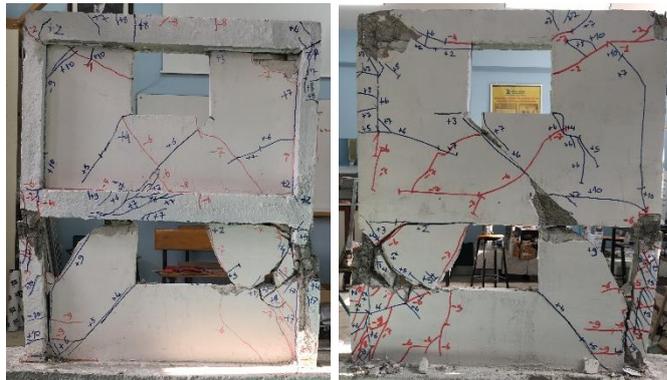
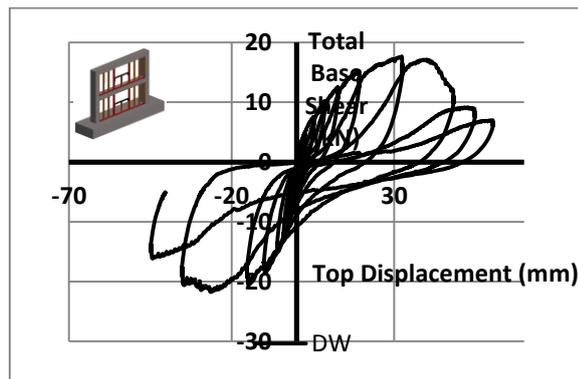


Figure 11. Photos of Specimen 2 at the end of the test (front and back façades)

### Specimen 3 (DW)

Specimen 3 was strengthened with single skeleton drywall and steel sheets. Until the end of the test, 10 hysteresis cycles were applied to Specimen 3 at both forward and backward directions. Specimen 3 reached to 17.70 kN max lateral load and +32.68 mm displacement at 7 hysteresis forward cycle and -21.76 kN max. lateral load and -26.36 mm displacement at 9 hysteresis backward cycle. When Specimen 3 reached to max lateral load carrying capacity, interstory drift value was 1.7% at forward direction and interstory drift value was 2.6% at backward direction. The hysteresis curves of this specimen are shown in Figure 12.



**Figure 12.** The hysteresis curves of Specimen 3

The plastic hinge formation observed at column-beam of 1<sup>st</sup> story and column-base joints. At the displacement of the cycles increased, damages at steel sheets corners of 1<sup>st</sup> story were observed. Furthermore, buckling of the steel sheets were observed more clearly at the 1<sup>st</sup> story. Moreover the corner anchorage bars of 1<sup>st</sup> story were separated from RC frame. The short column behaviour observed at a column of 1<sup>st</sup> story. The crack pattern and damages of Specimen 3 at the end of the test can be seen Figure 13.



**Figure 13.** Photos of Specimen 3 at the end of the test (front and back façades)

#### **Specimen 4 (ISW)**

Specimen 4 was strengthened with infill RC shear wall. Until the end of the experiment, 19 hysteresis cycles were applied to Specimen 4 at both forward and backward directions. Specimen 4 reached 53.08 kN lateral load and +17.65 mm displacement at 17 hysteresis forward cycle and -66.03 kN lateral load and -11.16 mm displacement at 17 hysteresis backward cycle. When Specimen 4 reached to max lateral load carrying capacity, interstory drift value was 1.3% at forward direction and interstory drift value was 1.2% at backward direction. The hysteresis curves of Specimen 4 are shown in Figure 14.

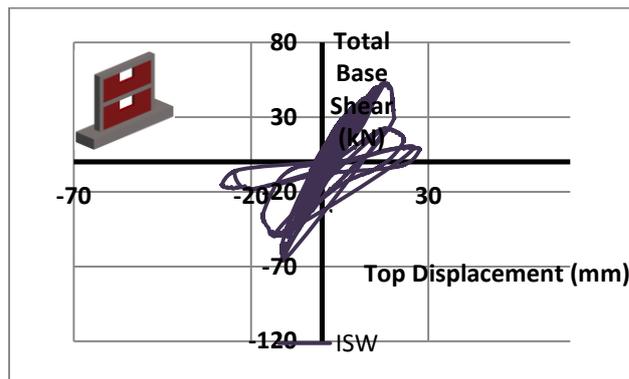


Figure 14. The hysteresis curves of Specimen 4

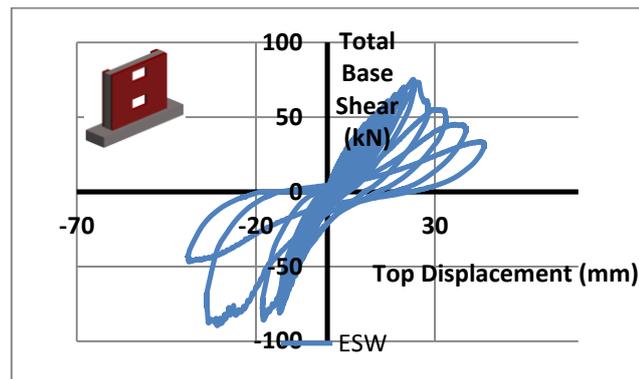
The diagonal cracks and damages occurred thoroughly from the beam-column joint of 1<sup>st</sup> story to base-other column joint on the parts without a window opening of 1<sup>st</sup> story. Further, diagonal cracks occurred thoroughly from the beam-column joint of 2<sup>nd</sup> story to a beam of 1<sup>st</sup> story. The short column behaviour observed in a column of 1<sup>st</sup> story. The plastic hinge formation observed at another column-base of 1<sup>st</sup> story. The crack pattern and damages of Specimen 4 at the end of the test can be seen Figure 15.



Figure 15. Photos of Specimen 4 at the end of the test (front and back façades)

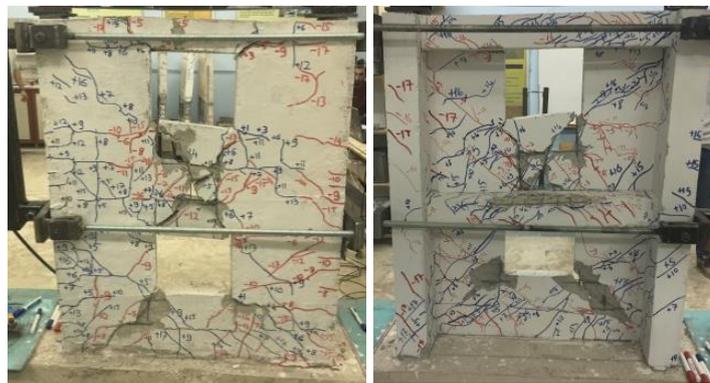
**Specimen 5 (ESW)**

Specimen 5 was strengthened with external RC shear wall and RC column jacket. Until the end of the experiment, 19 hysteresis cycles were applied to Specimen 5 at both forward and backward directions. Specimen 5 reached 75.34 kN lateral load and +24.23 mm displacement at 15 hysteresis forward cycle and -90 kN lateral load and -33.81 mm displacement at 18 hysteresis backward cycle. When Specimen 5 reached to max lateral load carrying capacity, interstory drift value was 3.9% at forward direction and interstory drift value was 2.2% at backward direction. The hysteresis curves of Specimen 5 are shown in Figure 16.



**Figure 16.** The hysteresis curves of Specimen 5

The main damage was occurred the cracks of X shape between the windows of the first and second story. In addition, shear cracks and damages were formed in the corner of the window of the first story. The cracks and damages of Specimen 5 were given in Figure 17 at the end of the test.



**Figure 17.** Photos of Specimen 5 at the end of the test (front and back façades)

## COMPARISON OF EXPERIMENTAL RESULTS

The comparison of the behavior of test specimens is prepared in terms of strength, stiffness and energy dissipation (Erdem et al., 2006).

### Strength

Total base shear-top displacement response envelope curves were constructed to evaluate and given in Figure 18. These envelope curves were drawn by connecting the peak points of each hysteretic curve for each specimen (Ha et al., 2018). The lateral load carrying capacities of test specimens are given Table 3.

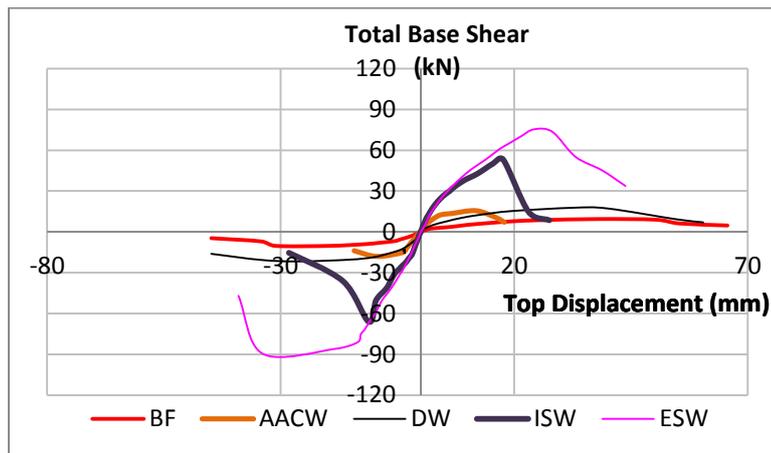


Figure 18. Total base shear-top displacement envelope curves of all specimens

Table 3. Summary of test results as the lateral loading capacity

Test Specimens		Top Displacement at Max. Lateral Load (mm)		Total Base Shear			
				Max Lateral Load (kN)		Ratio	
Test No	Window Opening Type	Forward	Backward	Forward	Backward	Forward	Backward
1	RS	38.0	-31.0	9.4	-10.3	1.0	1.0
2	AACW	11.9	-9.4	15.5	-18.1	1.7	1.8
3	DW	32.7	-26.4	17.7	-21.8	1.9	2.1
4	ISW	17.7	-11.2	53.1	-66.0	5.6	6.4
5	ESW	24.2	-33.8	75.3	-90.0	8.0	8.7

From the inspection of Figure 18 and Table 3, it can be seen that, the lateral load carrying capacities of all infilled frames were considerably greater than the lateral load capacity of Specimen 1. As expected, Specimen 5 strengthened with external shear wall and RC jacket had the highest lateral strength among the other specimens. Specimen 5 carried 8 times more at forward direction and 8.7 times more at backward direction than Specimen 1. The lateral loading capacity of Specimen 5 is increased by 42% at forward direction and 36% in the backward direction according to the Specimen 4. Although the lateral load carrying capacity of Specimen 2 and Specimen 3 were close values at both forward and backward directions, Specimen 3 was measured more displacement.

**Stiffness**

The stiffness values of test specimens are given in Table 4. In this table, the initial stiffness and stiffness at maximum load were listed for each of the specimens in forward and backward direction. The initial stiffness were calculated at the load level at which the first bending crack occurred in the experiment of the test specimens. Stiffness at maximum load level is calculated for the forward and backward directions applied to the test specimens. Stiffness in the arithmetic average of the maximum load level are used in the comparison with the Specimen 1 (RS). As expected, Specimen 4 strengthened with infill shear wall had the highest initial stiffness and stiffness of max lateral load among the other specimens. Although the lateral load carrying capacity of Specimen 2 and Specimen 3 were close values at both forward and backward directions, initial stiffness and stiffness of max lateral load of Specimen 3 was the lower than Specimen 2.

**Table 4.** Summary of test results as stiffness

Test Specimens		Initial Stiffness	Stiffness at Max. Lateral Load (kN/mm)			Ratio	
Test No	Window Opening Type		Forward	Backward	Average	Initial	Average at Max. Load
1	RS	1.53	0.34	0.33	0.34	1	1
2	AACW	4.76	1.31	1.92	1.61	3.11	4.81
3	DW	2.71	0.17	0.83	0.50	1.77	1.48
4	ISW	9.23	3.01	5.91	4.46	6.03	13.31
5	ESW	6.34	3.11	2.65	2.88	4.15	8.6

### Energy Dissipation

The different strengthening methods play an important role among the factors affecting energy dissipation capacity of RC frames. The energy dissipated was determined by summing the areas enclosed by hysteretic lateral load displacement curves for each cycle (Carrillo and Alcocer, 2013). The energy dissipation values of test specimens are given in Table 5. Among all strengthened specimens, Specimen 5 dissipated the largest amount of energy at both the forward and backward directions. Since the displacement value of Specimen 1 is greater than the displacement value of Specimen 2, Specimen 1 was dissipated more energy. The average energy dissipation values of Specimen 3 and Specimen 4 are close to each other. Although Specimen 2 was occurred higher stiffness value than Specimen 3, Specimen 3 was dissipated more energy.

**Table 5.** Summary of test results as energy dissipation

Test Specimens		Forward Cycles	Backward Cycles
Test No	Window Opening Type	Energy Dissipation	Energy Dissipation
1	RS	566.79	421.56
2	AACW	231.10	236.68
3	DW	886.86	1667.74
4	ISW	1171.92	1150.82
5	ESW	3785.00	3664.00

### CONCLUSION

In this study; five RC frames with a scale of 1/5, single spans and two storey were produced so as to reflect the characteristics of existing structures. Two RC frames were used as the reference specimens that without an infill wall and autoclaved aerated concrete blocks (AAC) infilled wall. Other three RC frames were strengthened with infill RC shear wall, single skeleton drywall system and external RC shear wall and column jacket. All specimens produced were tested under reverse cyclic lateral loading and constant vertical loading. Strength, stiffness and energy dissipation capacities of all test specimens are compared with each other.

The experimental test results are summarized below;

- Strength and stiffness of different strengthened specimens (Specimen 3, Specimen 4 and Specimen 5) and a specimen with AACW infill walls (Specimen 2) were significantly higher than those for reference specimen (Specimen 1).

- Energy dissipation capacities of different strengthened specimens were also significantly higher than those for reference specimen. But energy dissipation capacities of Specimen 2 was lower than as reference specimen. Since the displacement value of Specimen 1 was greater than the displacement value of Specimen 2, Specimen 1 was dissipated more energy.
- Although the load carrying capacity of Specimen 3 (DW) was lower than Specimen 4 (ISW), the average energy dissipation value was higher than the average energy dissipation value of Specimen 4. Because Specimen 3 exhibited a more ductile behavior than Specimen 4.
- The short column behavior was observed at the first storey of Specimen 3 (DW), Specimen 4 (ISW) and Specimen 2 (AACW). Thanks to RC column jackets, at Specimen 5 with the external RC shear wall were prevented to the short column behavior.
- The infill wall of Specimen 2 (AACW) was showed behavior out-of-plane at the test. This behavior observed at the infill wall of the Specimen 2 were increased the risk of occurring a soft story at the RC frame. Because the drywall system (Specimen 3) were anchored to RC frames, at this specimen has not been observed the out-of-plane behavior. Thus, the soft storey behaviour can be largely prevented by the dry wall strengthened method.
- Specimen 3 strengthened with drywall system has much lighter according to other strengthened specimens. Thanks to this strengthening method, seismic load acting on structures can be reduced. It is much easier and quicker to construct when this drywall system is used in the seismic strengthening of the existing building compared to the RC infill wall and external RC shear wall.

Different types of curtain wall systems are used to provide thermal insulation of RC structures. CFS drywall systems are one of these. The results of the study showed that CFS drywall systems have the positive contributions to the seismic behavior of RC structures. However, the seismic contribution to RC structures was limited according to other methods in the study.

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