EXPERIMENTAL BEHAVIOR OF BRICK-INFILLED CONCRETE FRAMES STRENTHED BY CFRP WITH IMPROVED ATTACHIG TECHNIQUE

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ABSTRACT :

Due to various deficiencies and inadequate lateral stiffness many reinforced concrete buildings are highly damaged or collapsed in Iran and throughout the world during the last major earthquakes. In this study, retrofitting of undamaged infilled reinforced concrete frames using Carbon fibre-reinforced polymer (CFRP) is discussed in detail. The main objective of the extensive experimental program is to reinforce the masonry infilled concrete frames, which are known to contribute to the seismic performance of the reinforced concrete structures significantly and to improve the behavior of such buildings to prevent total collapse. CFRP sheets are wrapped around the column to prevent the shear failure. CFRP sheets are attached to the masonry wall faces and anchor to the concrete frame to carry diagonal tension. The frame of the specimens is designed and detailed in accordance to the old codes. Four 1/2 scaled 1-story, 1-bay brick infilled concrete frame are tested; namely, a control specimen and three rehabilitated specimens. The specimens are tested under reversed cyclic quasi-dynamic load to the failure. Strength, stiffness, and story drifts of the test specimens are determined. The control specimen showed combined brittle column shear and corner crushing infill failure modes while the rehabilitated specimens showed a more ductile failure mode. This paper is to discuses specific design, test setup, analytical and theoretical background as well as improved results obtained during testing. Finally a series of recommendations is proposed for the actual use of CFRP's in the industry.

KEYWORDS: Concrete, Infilled Frame, CFRP, Masonry, retrofitting

1. INTRODUCTION

Many infilled frames can be found as interior and exterior walls in reinforced concrete and steel framed structure. There is often ignored by structural engineers because of they are normally considered as architectural elements. However, even thought they are considered nonstructural, they tend to interact with the bounding frame when the structure is subjected to earthquake loads; the resulting system is referred to as an infilled frame. Masonry infilleds have weak behavior in moderate earthquake. This behavior is brittle with small plastic range or without it.

To improve the behavior of such buildings and to prevent total collapse, necessary amount of strengthening must be provided. Strengthening of RC frames by reinforced concrete infills was first suggested by Ersoy and Uzsoy [1] after performing tests on one-story, one-bay infilled RC frames. The authors observed significant improvement in lateral strength and stiffness by introducing RC infills. The authors also carried out analytical studies to verify test results. Canbay et al. [2] investigated the effects of introducing RC infill on a pre-damaged 1/3-scaled, two-story, three-bay RC frame. To evaluate the contribution of the RC infills, the authors used two special force transducers at the base of the exterior columns. The authors stated the importance of steel anchors and the effect of possible slip of longitudinal bars in columns. Most of these methods are expensive, not practical and seem to be not feasible. On the other hands some of them can only be used in special building.

The application of fiber reinforced polymers, FRP, to upgrade different elements in structure such as bridge girders, piers, beam and columns of structures and masonry walls is very effective [3]. Different studies show that strength and ductility of columns increase when they are warped with CFRP. Bending capacity of beams

increase by use of CFRP sheets [4]. Seismic rehabilitation of beam–column joints using FRP materials are investigated in several experimental studies. It has been observed that shear capacity of joints are increased in different upgrading methods [5].
In this study overall behavior of masonry infilled concrete frame which upgrade with CFRP sheets are presented. CFRP sheets are wrapped around the top or bottom of columns. CFRP sheets are attached to the masonry wall faces and anchor to the concrete frame. The specimens are tested under reversed cyclic quasi-dynamic load to the failure.

2.EXPERIMENTAL PROGRAM

2.1.General

In this experimental study a total of four specimens were tested under reversed cyclic loading. All specimens consisted of one-bay-one-story reinforced concrete frames with brick infills. Three of these specimens were strengthened by using CFRP sheets prior to testing. The reinforced concrete frame was designed to reflect the common deficiencies observed in many RC buildings. Some of these deficiencies are: poor lateral strength, splices made above floor levels with inadequate lap length, insufficient lateral reinforcement at member ends. The frames consist of two column and one beam and one foundation beam. The foundation beam was heavily reinforced to prevent local failures.
After the reinforcement of the specimen was prepared, the concrete was cast in the horizontal position. When the concrete gained adequate strength, the specimen was placed in a vertical position in the laboratory. The bricks were laid while the specimen was in a vertical position and then the masonry infills were completed.

2.2.Detail of concrete frames

The RC frame was cast horizontally by use of special formwork. All the columns were 200×200 mm and the top beam was 250×200 mm and the foundation beam was 300×250 mm. The schematic view of the RC frame and Specimen Test Setup are shown in Figure 1. Four 14 mm bars and four 12 mm bars were used in the columns and beam respectively. In columns and beam 6 mm plain bars spaced at 150 mm were used as ties. Six 16 mm bars were used in the beam foundation and 6 mm plain bars spaced at 100 mm were used as ties.

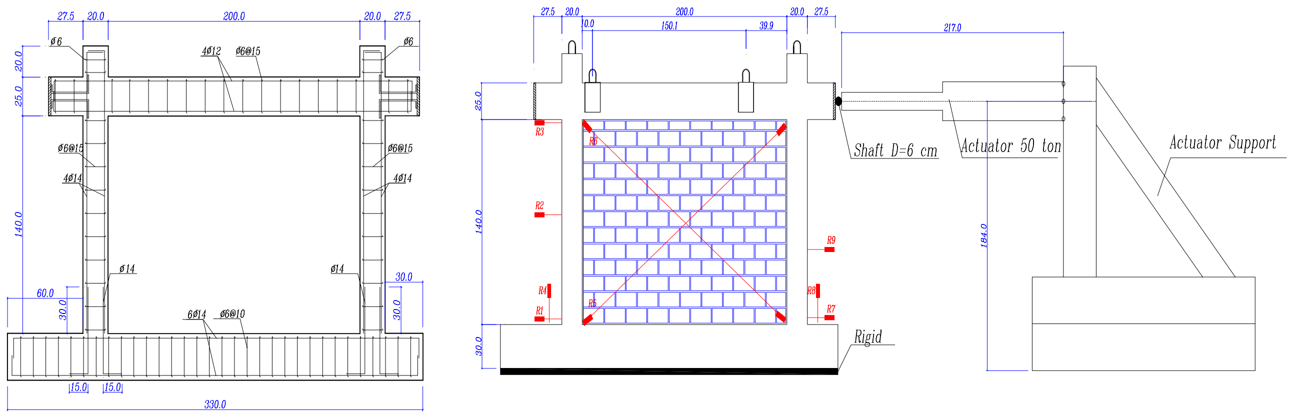

Figure1 Dimensions(Dimensions are in cm), Reinforcement Details and Specimen Test Setup

Longitudinal bars of the columns were lapped spliced at the bottom of the columns. Lap length was equal to 30 centimeters that is less than one suggested by ACI code. Typical 200×100×50 mm solid brick was used as the infill material.

The specimens were tested in an vertical position similar to the existing position in a RC structure, as shown in Fig. 2. All the holes in beam foundation were placed in direction of holes at floor of laboratory and the specimens were bolted to rigid floor by means of 20 bolts. The actuator was positioned to load the end of the overhang beam of the specimens. Once the full axial load had been applied, earthquake lateral loads were simulated by applying an alternating force to the end of the beam through an idealized pin. This force was applied in a reversed cyclic quasi-dynamic load pattern using a horizontally positioned servo-controlled hydraulic actuator with a 500 kN and a stroke of ±150 mm. Data from the load cell and the actuator's displacement transducer were recorded using a computer controlled data acquisition system.
An important point during testing was the transfer of the force from the actuator to the beam. This was achieved through a combination of a 250×200×15 mm rigid metallic plate cap, which confined the beam's free end, and a 60-mm diameter metallic cylinder. The specimens were laterally braced to eliminate out-of-plane movements. Strain gages and transducers were employed to measure strain, displacement, frame joint rotation, and shear stress. Predictive finite element analysis provided critical guidance for the instrumentation placement, as shown in Fig. 1. In each test, a maximum stroke of approximately 70 mm was reached in the course of 15 min. Pre- and postcracking behavior was tracked, including crack onset in the RC frames, crack propagation in the infill, delamination of CFRP sheets and operation of dowel anchors.

2.3.Control Specimen (SC)

The first one of the four identical specimens was an unstrengthened specimen with masonry brick infill. This specimen was intended to serve as a reference specimen. The infill was made by an ordinary construction worker and the thickness of it was 10 centimeters. The mortar between the brick was made by mixing sand, cement and water. The bricks were laid when the specimen was placed in a vertical position. On side of masonry brick infill was plastered by small thickness of gypsum.

2.4.Test Specimen 1 (S1)

The S1 was strengthened by two orthogonal layers of CFRP applied on the two exterior face of the infill. CFRP reinforcement was applied to the brick infill wall and was anchored to the four corners of reinforced concrete frame by use of dowel anchors. Since the bond between CFRP to brick infill is very weak, the CFRP sheets were anchored to the brick infill to provide better connectivity between them.
Local strengthening was made at the spliced regions of the columns at the bottom of them by wrapping this region by two layers of CFRP sheets. The height of wrapped region was 40 centimeters and the width of each CFRP strap applied was 300 mm. Also two shear and two flexural CFRP sheets were laid at the beam foundation-column joints. For better adhesive between surfaces and CFRP sheets, surfaces were compeletly cleaned and the dust on the surfaces was removed using pressurized air and then the Concresive coat was applied to the surface on which CFRP sheets would be applied.

Figure 2 Preparation of Anchor Dowels

The last phase of the fabrication of specimens was the preparation of the anchor dowels. First, the holes of specified length and diameter were drilled in the specified locations. These locations were in four corners in two sides of frame and five point on masonry infill. The dust in the holes was removed using pressurized air. To make the anchor dowels, CFRP was cut into pieces of specified length and then the pieces were rolled and tied at three locations (middle and two ends). Preparation of anchor dowels is shown in Figure 2.

2.5.Test Specimen 2 (S2)

The characteristic of concrete, Reinforcement and the procedure of strengthen by CFRP for the test specimen 2 were as the same as the specimen 1. Because of observed delamination in CFRP sheets at some points in specimen S1, the number of anchor dowels was increased from five to nine on the infill for specimen 2. Thus, distance between two successive anchor dowels was limited to 40 centimeters. The bottom of the columns was wrapped by two layers of CFRP sheets similar to specimen S1. The height of wrapped region was 40 centimeters and the width of each CFRP strap applied, was 300 mm. Also two shear and two flexural CFRP sheets were laid at the beam foundation-column joints completely similar to specimen S1.

2.6.Test Specimen 3 (S3)

Because of shear failure at the top of the columns in test specimens S1 and S2, local strengthening was made at the top of the columns by using CFRP sheets which was similar to bottom of the columns. That is two shear and two flexural CFRP sheets were laid and the columns were wrapped by two layers of CFRP sheets from beam-column joints to 40 centimeters. The number of anchor dowels was similar to specimen 2.

Figure 3 Retrofitting Schemes for Specimen S3

2.7.Material Properties

The achieved average compressive strengths of the concrete used in the specimens which are obtained from standard cylindrical test, are given in Table 1.1. Average compressive strength of the mortar used in the construction of the masonry infills of Specimens were found to be 4.5 MPa. The properties of the reinforcing steels are given in Table 1.2.

Table 1.1 Compressive strengths of the concrete

Specimen	mean compressive strength (Mpa)
SC	255.95
S1	266.37
S2	295.06
S3	297.26

Table 1.2 Properties of Reinforcing Bars

Type	Diameter	$f_y\,(MPa)$	$f_u\,(MPa)$	Property
Beam Longitudinal	12 mm	355	560	
Column & beam foundation Longitudinal	14 mm	360	565	
Tie	6 mm	320	500	Plain

The common mix design for the mortar used in the construction of the brick infills was selected. tttttttttttttttttttttt CFRP sheets were composed of an epoxy-based matrix and carbon fiber reinforcement. The carbon fiber used in this study was unidirectional. The following properties (average values) were provided by the manufactures for the composite materials: elastic modulus and failure strain of carbon sheets=230 GPa and 0.015, respectively;

3.EXPERIMENTAL RESULTS

3.1.*Control Specimen (SC)*

The maximum bearing load for specimen SC was 12 ton. Because of loading style, this value was small different in tension and compression. The stiffness was reduced from beginning of the test and the strength gradually decreased after 2 centimeters displacement. Because of shear frailer in the bottom of the columns and infill fracture, reduction of stiffness and strength were less than beginning of the test. After 6 centimeters displacement the strength was fixed on 2.5 KN since sever damages were happened in the frame and masonry infill. The initial stiffness was 49 KN/mm which are 7 to 9 times larger than RC frame without masonry infill.

By load increase at the beginning of the test, bound cracks in the positions of the frame and infill connection were happened. Diagonal cracks were occurred in the masonry infill when the load was achieved to 6 ton. After infill cracks were increased, small cracks were happened in the bottom of the column in 45 degree direction. Finally, the masonry infill was failed in diagonal cracking mode at the end of the test as shown figure 4.

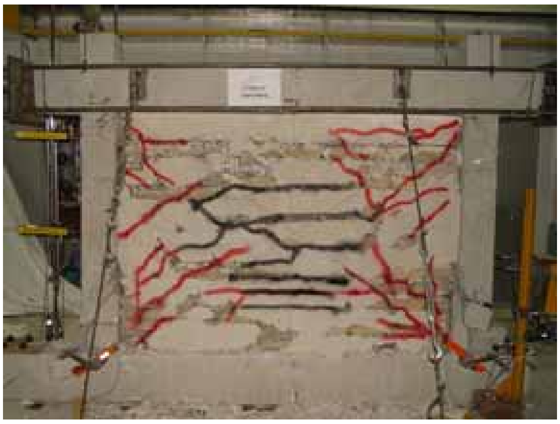

Figure 4 Failure pattern of specimen SC

3.2. *Test Specimen 1 (S1)*

The maximum bearing load for specimen SC was 22.3 ton which is 2.5 times larger than the maximum bearing load of control specimen. Because of CFRP sheets delamination from compression corners of the masonry infill, the strength was decreased after 9 millimeters displacement. Since at the high displacements the top of the columns were severe damaged and infill cracked, reduction of stiffness and strength were less than beginning of the test. The test was stopped in 4.2 centimeters displacement for prevention of actuator destruction. The initial stiffness of specimen S1 was about 50 KN/mm which are similar to control specimen. In the 3% drift ratio the stiffness was reduced to 2.5 KN/mm. The first delamination of CFRP sheets were happened between the top compression corner of the infill and the first anchor dowel in the infill at 18.5 ton lateral load.

3.3. *Test Specimen 2 (S2)*

The behavior of specimen S2 was similar to specimen S1. But delamination of CFRP sheets was happened in higher displacement since the number of dowel anchors was increased in specimen S2. The maximum lateral load level was 18.5 ton. Values of cumulative energy dissipated by specimen S1 and S2 were 31000 and 38000 N.m respectively. This shows that the ductility of specimen S2 was increased in comparison with specimen S1. Figure 5 shows the specimen S2 after the test.

Figure 5 Crack Pattern, CFRP Delamination and Failure Mode of Specimen S2

3.3. *Test Specimen 3 (S3)*

The maximum lateral load level was 23.2 ton for specimen S3 and the strength was gradually decreased after 30 millimeters displacement corresponding to partially delamination of CFRP sheets from infill surface. Figure 6 shows the specimen S3 after the test.

Figure 6 Crack Pattern and CFRP Delamination of Specimen S3

The decrease of strength and stiffness was stopped after 60 millimeters displacement duo to crushing in the loaded corner of infill at 10 ton load level. The maximum value of cumulative energy dissipated by specimen S3 was 80000 N.m which is two times the cumulative energy dissipated by control specimen.
The first delamination of CFRP sheets were happened in the 2.5% drift ratio between the top compression corner of the infill and the first anchor dowel. No main crack was seen in the frame or masonry infill until this moment. A small bending crack was appeared at the middle of the column and the loaded infill corner damaged when the displacement was increased largely. By continuation of the test and increase the number of loading cycle, a crack began to form near the bottom of the infill corner with angle of 60^o respect to horizontal line and developed to the center of infill. Hysteric loops and envelope of load displacement curves for all specimens were shown in figure 7.

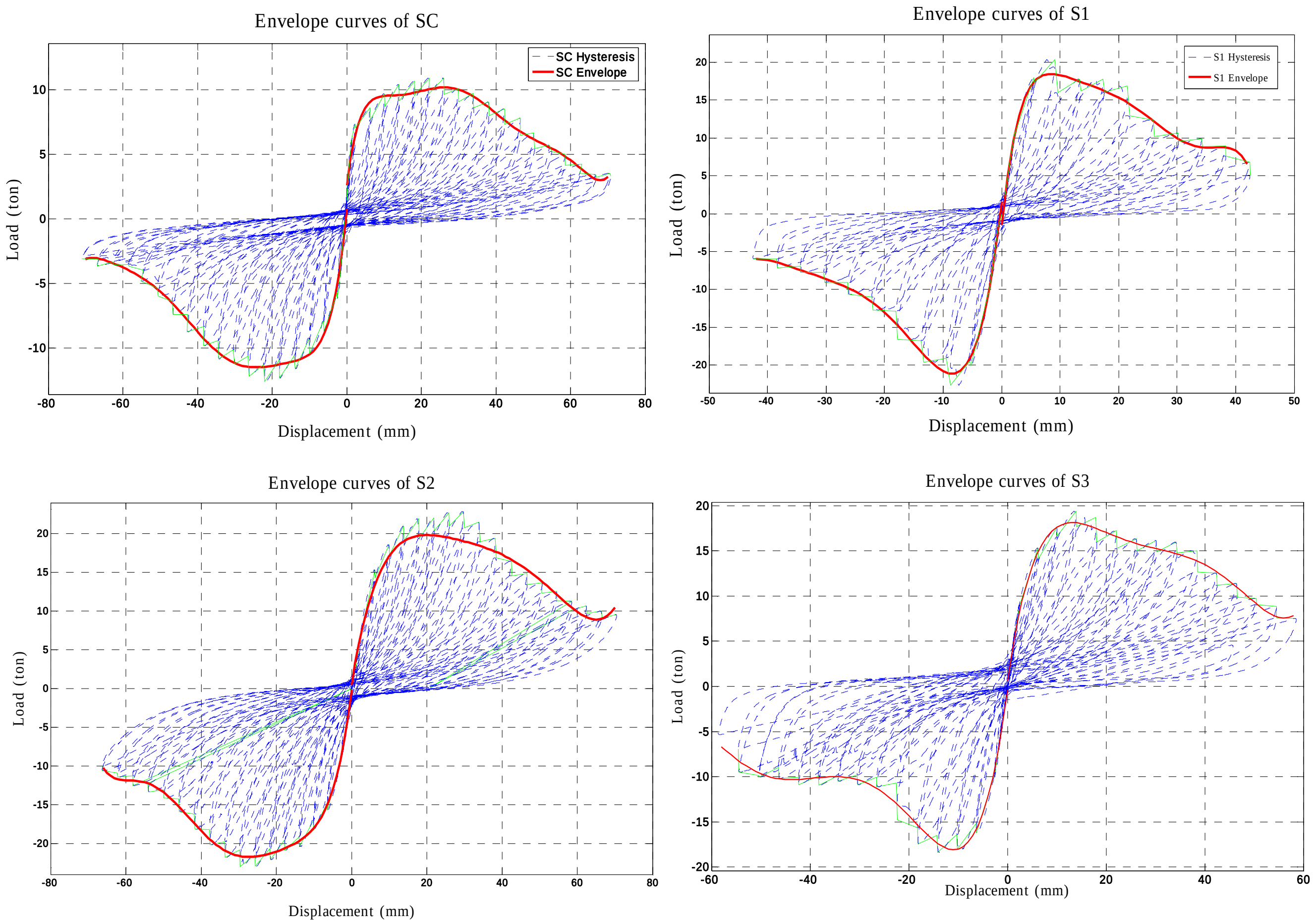

Figure 7 Hysteric Loops for Control Specimen and CFRP strengthen specimens

4. CONCLUSION

- The control specimen with masonry brick infill showed a brittle mode failure. The bottoms of the columns were severe damaged and widely shear cracks occurred and then infill cracked suddenly.
- Comparison between the control and the rehabilitated specimens S1 and S2 emphasized the effectiveness of the rehabilitation schemes. These two tests clearly showed that CFRP strengthening would not be effective unless CFRP is properly anchored to the infill and to the frame members. Special anchor dowels made by rolling CFRP sheets and inserting them into holes in drilled in frame members and the masonry brick infills were very effective in anchoring the CFRP sheets and strips. So strengthening made by using properly anchored CFRP significantly improved the strength and held the infill intact.

- CFRP strengthening did not increase the lateral stiffness significantly. The maximum increase in initial lateral stiffness due to strengthening was about 10%. But If the lateral stiffness of the structure, considering the contribution of the infills is adequate to control the drift, a small increase in stiffness due to CFRP strengthening can be considered as an advantage since the strength demand will not increase significantly.
- Confining the bottom of the column by wrapping with CFRP, eliminated the local failure in this region and improved the behavior. Local strengthening made in specimen S1 and S2 by confining the base of the column at the foundation level by wrapping with CFRP changed the failure mechanism and resulted in brittle shear failure at the top of the columns. In the specimen S3 where this local strengthening was applied at the bottom and top of the columns (specimen S3), the failure mode was flexure and therefore the behavior was more ductile.
- The CFRP laminated maintain the full-scale infilled structural integrity and prevented collapse and debris fallout, contain and localize the damage of the unreinforced masonry (URM) walls even after ultimate failure. No signs of distress were evident throughout the wall except at the vicinity of the corners. This keeps the masonry infill, thus reducing the possibility of the external walls or partitions spalling, which, in itself, a major source of hazard during earthquakes even if the whole structure remains safe and functioning.

- It was observed that the energy dissipation capacity was increased in specimens strengthened by CFRP especially at specimen S3.

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