Behavior and Strength of Bearing Wall Strengthening by CFRP

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***Abstract*—Collapse of load bearing wall is the cause of many casualties during extreme loading events. The objective of this current research was to investigate effective and practical approaches for strengthening load bearing walls with openings to resist extreme loads. This paper presents the results of investigation on structural behavior of the load bearing walls of interlocking bricks system. Six specimens were prepared with the same height (1.2m) and width (0.8m). Two walls were plain and considered references specimens, one was made from brick with thickness 0.24m and the other was made from concrete block with thickness 0.2m. Two walls were constructed with rectangular opening, and two walls were opening and strengthened with carbon fiber reinforced polymer (CFRP) strips. The test results clearly demonstrate the efficiency of using CFRP strips as a repair and strengthening technique for unreinforced load-bearing walls to increase the stiffness and ultimate bearing load.**

Keywords*—Bearing wall, Opening, Strengthening, CFRP.

1. INTRODUCTION

Load bearing wall is a composite material made of units, e.g., clay bricks or concrete blocks, and mortar. The large number of influence factors, such as anisotropy of units, dimension of units, joint width, material properties of the units and mortar arrangement of bed as well as head joints and quality of work-man ship. Common wall often need to be opened in order to meet the requirements for using function and vertical layout in building structures. On the one hand, strength and stiffness of the wall will be reduced due to the decrease of concrete area and discontinuity around the opening, moreover stress concentration can be easy to appear at the corners of opening, which will cause cracks at an earlier stage of loading process and affect using functions [1].

Walls are commonly used as a load bearing structural elements. Uniaxial action walls are defined as laterally supported and restrained against deflection along top and bottom supports. It is designed to resist in-plane vertical loads acting downward from the top of the wall and it, also transfers loads in one direction to supports at the top and bottom. The wall often undergoes accidental eccentric loads due to the imperfections in construction. Because of the low tensile strength of masonry, this situation is further complicated by tension cracking, which leads to variations of effective sectional properties over the member height. Because the reduction in the load-carrying capacity of walls can be significant, the design of slender walls must include the secondary moment effects in a rational way [2].

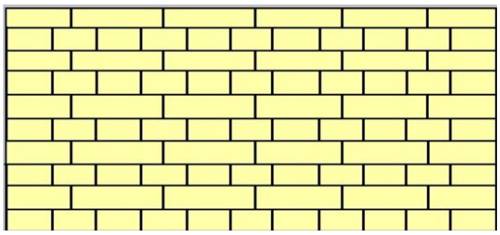
Fiber reinforced polymer (FRP) is a new kind of civil engineering structure materials after steel and concrete, which possesses the advantage of light weight, high strength and corrosion resistance property and excellent designable property. FRP can significantly enhance the performance of structure and extend the service life. FRP strengthening technique originated in the 1980s, which was first applied in the rehabilitation of reinforced concrete structures with remarkable effect. Recently, this technique has been paid attention in the masonry structure’s experimental and theoretical study gradually. Many researchers have verified the effectiveness of this kind of strengthening technique [3-7]. In lightly reinforced and unreinforced masonry walls, such as concrete masonry units and brick, fiber-reinforced polymer (FRP) material systems have demonstrated several benefits by adding flexural resistance and by improving the ductility of the walls [8].

The walls with openings the static system may be altered when a considerable amount of concrete and reinforcing steels have to be removed. This leads to a decreased ability of the structure to resist the imposed loads [9]. The presence of the openings in the panels determines the load paths and creates stress concentrations around the opening, which encourages cracks to occur first at the corners of the opening [10 and 11]. Therefore, the openings in the wall panels need to be strengthened.

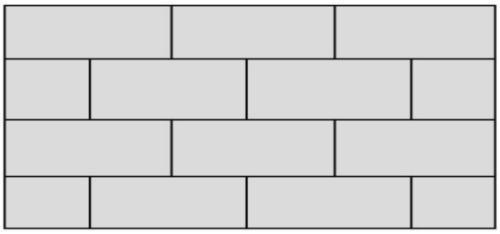
2. EXPERIMENTAL PROGRAM

2.1 TEST SPECIMENS

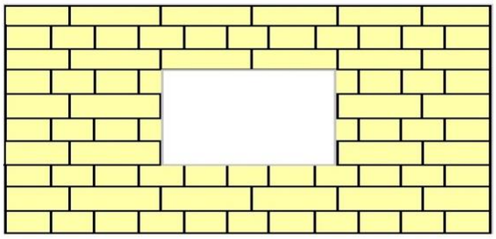
A total of six load bearing wall comprising two identical series of three specimens each are tested. Table(1) shows the dimensions of all tested load bearing wall. All the test panels are 1200 mm width and 800 mm height. Series one designated WS1-WO1 and WC1 are used with brick dimension (24 ×10×8) cm. While series two designated WS2-WO2 and WC2 are used with concrete block dimension (40×40×20)cm. WO1in series 1 and WO2 in series 2 are tested with opening to study the effect of opening on the behavior of bearing wall. WC1 and WC2 are tested with CFRP strips strengthened to wall containing openings. Configuration of load bearing walls for laboratory tests is presented in Figure (1).



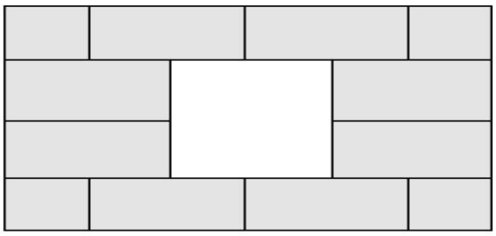
(a) WS1



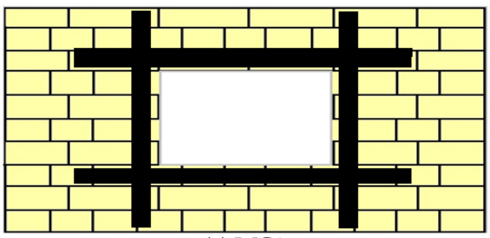
(b) WS2



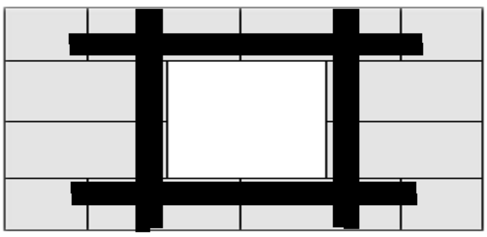
(c) WO1



(d) WO2



(e) WC1



(e) WC2

Figure (1) Configuration of load bearing walls for laboratory tests

Table (1) Dimensions of load bearing walls

Series	Wall	Wall Size (mm)			Type	Opening dim. (mm)
		H	L	T		
1	WS1	800	1200	240	Plain	-
	WO1	800	1200	240	Opening	400 400×
	WC1	800	1200	240	Opening +Strengthened	400 400×
2	WS2	800	1200	200	Plain	-
	WO2	800	1200	200	Opening	400 400×
	WC2	800	1200	200	Opening +Strengthened	400 400×

2.2 MATERIALS

The concrete used for all the specimens in this research were having the mixture proportions of (cement: fine aggregate: water) 1:3:0.5. Ordinary Portland Cement (OPC) Type I which conforms to the requirement of Iraq specification No. (5)-1984 was used in the concrete mix. It has been stored in airtight plastic containers to avoid exposure to atmospheric conditions. The fine aggregate has been used after it has been sieved by sieve size (4.75 mm).Average concrete slumps for the concrete is approximately 75 mm which is medium slump. An average Compressive strength of 50 mm cubes at the age of testing the wall panels is 27MPa. Compressive test is conducted just before the wall panels are tested. Average concrete tensile strength taken from splitting tensile strength test of concrete cylinder is 1.64MPa. The concrete compressive and splitting strengths are the mean values of three test cubes and cylinders respectively.

2.3 EXPERIMENTAL SETUP

The testing arrangement for all load bearing walls specimens are shown in Figure (2). All specimens with rectangular cross sections and rectangular openings occupying 16.67% of the wall area were constructed and tested in the Structural Laboratory of the College of Engineering / Diyala University. The load bearing walls were tested by using a 2000kN capacity hydraulic jack and was measured with a 1000kN capacity load cell .The hydraulic jack transmitted a uniformly distributed load across the top of the load bearing wall. The load was increased gradually at increments of (10kN) up to failure. Carbon fiber reinforced polymers (CFRP) strips were used to strengthening the WC1 and WC2 specimens. The CFRP strips used in the strengthening application was Sika CarboDurS512 unidirectional flexible strip. The structural adhesive paste used for bonding the Sika CarboDur strips to the concrete substrate was (Sikadur-30) which is high-modulus high-strength two component (A and B) product, see Figure (3). CFRP strips width was 50mm. Uniaxial CFRP strips are placed as a single layer for strengthening and two component epoxy adhesive is used for bonding. Application of the CFRP took place after the curing of the brick walls for at least 28 days under laboratory conditions as shown in Figure (4). The application of the CFRP strips material was a simple and rapid operation. First, the desired surface was smoothed by grinding and was cleaned with high air pressure. Second, a strong cementitious filler layer was applied to the surface to give a flat surface .Third; the surface was coated with a thin layer of two component epoxy. Fourth, one layer of the carbon fiber fabric was laid into the epoxy dry, worked into the underlying layer of epoxy by hand pressure .The temperature during application was 20 $\pm$ 2 ċ in all cases. After bonding operations was completed, specimens were cured for 7 days under laboratory conditions before testing. Properties of CFRP strips and epoxy, which are suggested by the manufacturer, are presented in Tables (2) and (3).To measure crack widths, an optical micrometer with an accuracy of (0.02mm), as shown in Figure (5), was used for all walls specimens. The wall surfaces were painted with white color to make it easy to see the crack and measured it, as shown in Figure (6).

Figure (2) Test setup, cont,d

Figure (2) Test setup

Figure (3) Manufactured forms of CFRP materials

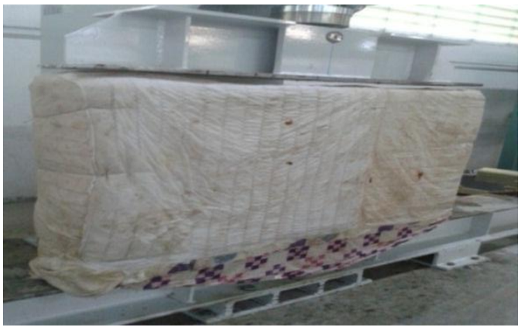


Figure (4) sample curing

Figure (5) Optical micro-meter

Figure (6) Painted the wall with white color

Table (2) Properties of CFRP strip (Sika CarboDurS512)*

Fiber type	High strength carbon fibers			
Base	Carbon fiber reinforced polymer with an epoxy resin matrix			
Shelf Life	Unlimited (no exposure to direct sunlight)			
Color	Black			
Tensile Strength	Mean Value 3100 MPa Design Value 2800 MPa			
Modulus of Elasticity	Mean Value 165000 MPa Design Value 160000 MPa			
Elongation at Break	1.69%			
Design Strain	0.85%			
Thickness	1.2 mm			
Temperature Resistance	>150°C			
Fiber Volumetric Content	>68%			
Density	1.60 g/cm3			
Physical Properties				
Product	Thickness	Width	Cross Sectional Area	Tensile Force
Type S512	1.2 mm	50 mm	60 mm^2	168 kN

* Provided by the manufacturer

Table (3) Properties of Sikadur-30 (Impregnating Resin)*

Color	Light gray
Storage Conditions	Store dry at (4°-35°C). Condition material to (18°- 29°C) before using
Consistency	Non-sag paste
Pot Life	Approximately 70 minutes @ 23°C (1 qt.)
Mixing Ratio	Component 'A': Component 'B' = 3:1 by volume
Density	1.65 kg/l (mixed)
Tensile Properties (ASTM D-638) 7 day	Tensile Strength (24.8 MPa) Elongation at Break 1% Modulus of Elasticity (4482 MPa)
Flexural Properties (ASTM D-790)14 day	Flexural Strength (Modulus of Rupture) (46.8 MPa) Tangent Modulus of Elasticity in Bending (11721 MPa)
Shear Strength (ASTM D-732) 14 day	Shear Strength (24.8 MPa)

* Provided by the manufacturer

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 FAILURE LOAD OF WALLS

Figure (7) and Table (4) show the experimental failure loads for all tested specimens. It is clear from thisFigure that the presents of opening in the load bearing walls will cause decrease in the ultimate load capacity where the load failure in WO1and WO2 decreases about 31.14%and 31.25% compared with WS1and WS2 respectively.The load carrying capacity of walls has been greatly increased by strengthening using CFRP strips. This increase was 130% and 127% for WC1 and WC2 compared with WO1and WO2 respectively. This meansthat the strengthening with CFRP strips gives good results and may be adequate for most cases.

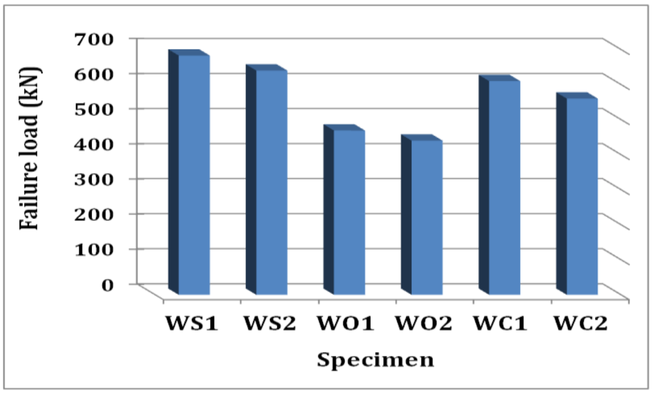


Figure (7) Failure load of tested specimens

Table (4) Ultimate load capacity of specimens

Specimen	Ultimate load, P_u (kN)	% $P_u/P_{u\ Reference}$	% Decreasing in P_u
WS1	683	Reference	Reference
WS2	640	Reference	Reference
WO1	469	68.86	31.14
WO2	440	68.75	31.25
WC1	610	89.31	10.69
WC2	560	87.50	12.50

3.2 FIRST CRACK

Figure (8) shows the loads at which the first crack occurs. From this Figure can be seen that the first crack in the wall WS1 appear at load of 291kN and at load 241kN for wall WS2 that mean the size of unit brick will effect on the behavior of load bearing wall. As well as the delay in the appearance of cracks in the specimens WC1 and WC2 because of Carbon fiber reinforced polymer will be work as reinforcement therefore the crack will be delayed.

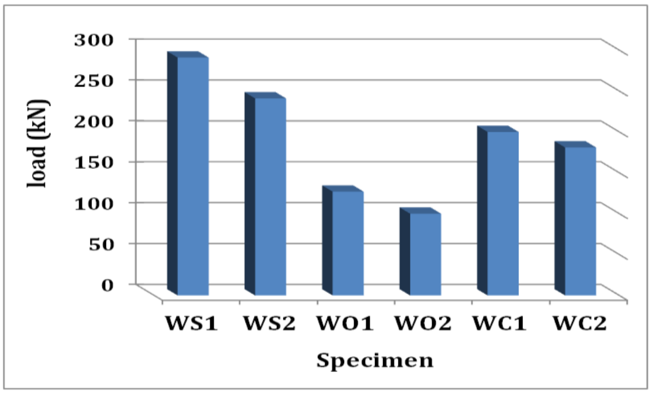


Figure (8) Load at the first crack of tested specimens

3.3 LOAD-CRACK WIDTH

Crack width calculation is one of the serviceability requirements in the structural elements. The occurrence of cracks in structure is expected under service loads, due to the low tensile strength of concrete. Control of cracking is important for obtaining acceptable appearance and for long-term durability of wall structures, especially those subjected to aggressive environments. Excessive crack width may reduce the service life of the structure by permitting more rapid penetration of corrosive factors. In addition, cracking in structures has an effect on structural performance including stiffness, energy absorption, capacity, and ductility. Consequently, there is an increased interest in the control of cracking by building codes and scientific organizations. Figure (9) shows the load crack -width curves for all load bearing walls. At low loads, crack-widths at the surface of the wall were very small or no cracks occur and therefore not displayed.

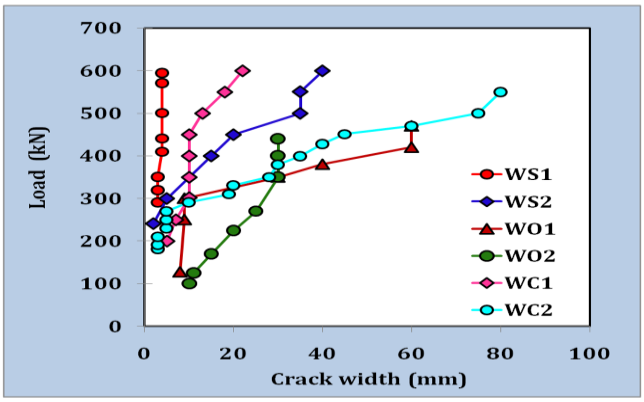


Figure (9) Load-crack width curves of tested specimens

3.4 CRACKS PATTERN AND FAILUREMODE

Crack patterns for the tested walls were observed and demonstrated in Figures (10 to 15). The crack patterns shown in Figures (14) and (15) for specimens (WC1) and (WC2) respectively indicated shift of location of cracks as the CFRP strips in the piers significantly increased the strength and stiffness of the weak piers. Therefore, diagonal shear cracks concentrated in the spandrels at the top and bottom of the opening.

Figure (10) Failure modes of specimen WS1

Figure (11) Failure modes ofspecimen WS2

Figure (12) Failure modes ofspecimen WO1

Figure (13) Failure modes ofspecimen WO2

Figure (14) Failure modes ofspecimen WC1

Figure (15) Failure modes ofspecimen WC2

4. CONCLUSIONS

1. In general, the test results show that modes of failure for load bearing walls are significantly affected by the present of the opening and strengthening. For both strengthening walls, it has been found that CFRP strips increase the load capacity.
2. Results of tests on plain walls show that the behavior and the load carrying capacity of the brick walls are highly sensitive to presence of opening. Opening dramatically decreases the strength and stiffness of the wall. Failure of wall without opening started by splitting and local crushing at loading zones followed by sliding over the whole length of the wall. For walls with opening failure started by splitting along the vertical axis from the opening corner towards the loading points.
3. It has been found that the CFRP strip is an efficient strengthening technique for brick walls. It was found that the load carrying capacity of WC1 and WC2 about 130% and 127% compared with WO1 and WO2 respectively. This means that CFRP strengthening technique is more efficient in case of openings.
4. Strengthening load bearing wall with CFRP significantly decreased the diagonal cracks ofbrick walls.

5. REFERENCES

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