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Experimental Investigation of Brick Masonry Arches' (Vault and Rib cover) Behavior Unreinforced and Reinforced by C-FRP under vertical and Horizontal Load Simultaneously

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ABSTRACT

In this paper, two masonry structures including the arc and the beam in real dimensions under simultaneous vertical and lateral loading will be examined. Vertical load was applied on the spring and then lateral load applied at the arch to the base. In the first experiment, the sample was loaded without reinforcement, and according to the results, the second sample was reinforced with polymer fiber C-FRP and subjected to similar loading. According to the results in the first sample, the first cracks appeared at the site of force stretch to the structure. Therefore, carbon fiber was used to reinforce the vulnerable areas. The reinforced structure was able to show very high stability against lateral forces, with the displacement rate at various points of the structure being significantly reduced. Structural load capacity also increased 13KN.

Keywords:

Safety Risk, Construction Management, Risk Management, Construction Project.

1. Introduction

The masonry Buildings are one of the historic and traditional buildings that exist around the world. Due to the lack of modern building materials, these structures consist of materials of that era sun-dried brick and clay bricks and mud). Such structures are not resistant to seismic forces, and severely damaged or destroyed. These structures are less resistant than earthquakes, and compensate for this deficiency by small or large deformations.

Many researchers have tried to improve the seismic behavior of masonry structure in addition to evaluate the strength of structures to reduce the damage caused by increasing the strength of structures. For this purpose, fiber strips FRP and tie bars in the arch span under the various loads have been surveyed. By studying the mechanism of fracture and the sites of injury are reinforced that the results have been satisfactory. [1-5]

There are many structures in the world that need repairing and maintaining. These structures are being demolished under various forces, especially earthquakes. To increase the bearing capacity of these structures, their failure mechanism must first be analyzed and then reinforced. As mentioned above, several methods of reinforcement have been investigated, with the most common structures in the world being subjected to multiple in the laboratory and the modeling FEM. It was also reinforced by the polymer fiber FRP and the results were evaluated. CNR-DT200 / 2004 (Antonietta et al., 2013) [6] proposes the use of FRP polymer internal and external arc in simple curved structures (such as circular) to reduce the plastic joints that are destroyed the structure. Reinforced structures were analyzed under moments and shear forces and evaluated based on stress, shear and moment [7]. Installing FRP strips can also have a significant impact on increasing structural strength. The structure is subjected to compressive and tensile forces where the location of reinforcement as well as the thickness and length of these strips can affect the fracture mechanism, increase the load bearing rate of the structure and the strength of the structure [8-12]. The circular arc on the base, under the lateral force and the weight of the structure applied, also reinforcing with polymer strips FRP the internal and external span of arc, modifies the fracture mechanism with respect to the unreinforced structure such that in the unreinforced structure, initially creating three hinges: one in the key stone inside and two hinges in the interior by increasing the load on the other end of the pile, another hinge created which was destroyed by the four hinges in internal reinforced structure. The load of the external reinforced structure near 10 times [6, 13 and 14].

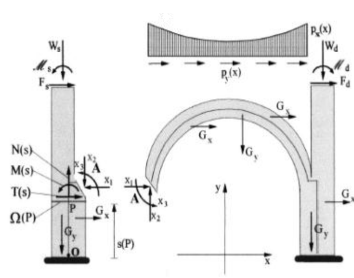
In this study, the behavior of masonry structure (vault and rib cover) under simultaneous vertical and horizontal loading will be investigated. Vertical loading is applied to the spring and horizontal loading is initiated after the vertical loading is completed. The first arc structure was loaded and their weaknesses were observed. Changes have been observed in the failure mechanism and the behavior of the structure will be analyzed. Unlike the arches used in the historical buildings of the world that have been studied, it is not of circular or Roman arch type, and its structure is common in the Middle East, especially in Iran. Including two arcs of springs and vaults in real dimensions on the base which were first subjected to simultaneous loading and the results were evaluated.

2. Analysis of the Arch Behavior

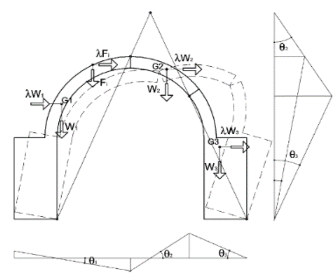
2.1. Simple Building Arch

The formation of plastic hinges and their distribution, as well as the mechanism of failure of the structures, can play an important role in the seismic design of the structure. The type of fracture mechanism affects the arch's sensitivity to its secondary effects, the amount of local and total ductility, the amount of energy absorbed, and the stability of the structure before damage, general instability and destruction. To maintain balance under stresses under loads applied to the structure, it can induce internal efforts in the elements of structure. Considering the no tension structure (NT), the principle of minimum complementary energy is discussed. The purpose of this method is to determine the permissible amount of internal and external reactions to the structure and determine its stability. Assuming equilibrium loads are applied to the structure, a hypothetical line within the structure can be assumed to represent the equilibrium of static forces. This line extends through the structure and there is the possibility of hinges during horizontal loading.

Due to the horizontal response supported in the arc, the small moment produces and increases its bearing tolerance. When the issue of forces exits the focal point of the arc. The deformation begins and as a result, the deformation of the plastic hinges is created at different locations in the arch and base. The arc buildings can withstand a slight bending moment. The dome and arches of the masonry materials are also incapable of withstanding the large bending moment and must inevitably be stabilized under compressive-axial forces. Accordingly, only horizontal and vertical component forces are examined. It should be noted, however, that the distribution of lateral load on the arch and base and the height base above ground can have a significant impact on the moment of the lateral force and drive the arch structure to destruction. In addition, one of the most common patterns of failure in the arch structure is the formation of four joints [4, 13 and 15].



(a)

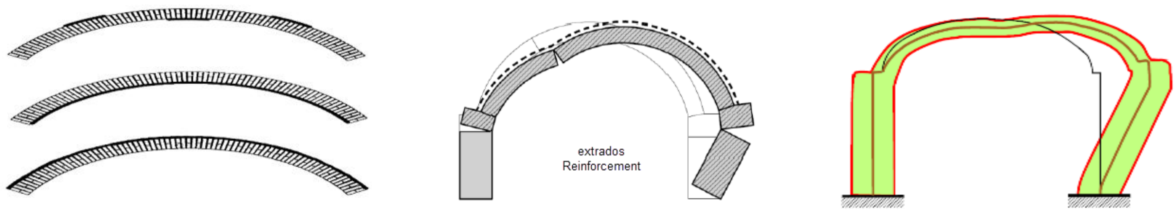


(b)

Figure 1. Position of forces in equilibrium stress and drawing of potential hinges: (a) pattern of loads and definition of equilibrium loads; (b) change of loading position according to base height; [15, 16].

2.2. Reinforced Masonry Arch

The polymer fiber strips FRP can be used in different sizes and at different locations in the structure. Depending on their location, the mechanism of deformation of the plastic hinges will be different. The applied forces, whether compressive stresses and moments or a combination of both, can affect the stability of the structure depending on the compressive strength of the building materials and the tensile strength of the polymer fiber. The external reinforcement of the arch causes four hinges: one at the key stone of the arch outside, two at the outside of the arch and one at the end of the column outside [4, 15 and 17].



(a) (b) (c)

Figure 2. (a) Types of FRP fiber layout; (c, b) hinges formation using FRP external arc [4, 6 and 18].

3. Test Model

3.1. Structure

The structure of this study consists of vault and rib cover on top of the base. The arch is of a six-part type. The diameter of the arc is 240 cm and 95 cm. vault and rib cover structure is located on the base with 100 cm high. To attach the base holder to the ground, the site was secured by a cement mortar and bolt, with 30 cm x 30 cm x 1 cm sheets, and welded on 4 rebar to prevent the structure from reacting to the applied force. For each structure, two bushings (lenge) are used for vaults and two smaller bushings for springs are used to attach bushings as well as arch joints. After fitting, brick and mortar were used to make springs and vaults. The specimen in the first experiment without reinforcement is subjected to vertical and horizontal simultaneous loading. Using the results of the first experiment, the second structure are reinforced with carbon fiber polymer strips and applied to the reinforced structure in the same way.

(a) (b)

Figure 3. The stages of construction structure: a) Structure view of arch and rib cover; b) Structural view after reinforcement.

4. Test Result

4.1. Survering of Crack Propagation and Failure Mode in Unreinforced Structure

Vertical load applied before horizontal loading after vertical loading was completed, lateral loading was applied gradually. The first cracks were created on the base below the 30 KN load. Then the load of the structure was reduced and the structure was able to withstand a load equal to KN 26. Under this load, the displacement was created beneath the force field, between the vault and the spring was appearing the longitudinal crack to have a slight opening, the cracks appearing at the base. The cracks created indicate the tensile forces at the sites that caused to open between the mortar and brick. The loading continued until the final load of 25 KN. Under this amount of force, more changes were observed in the structure, leading to the destruction of the structure as

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the load increased. The displacement was about 6.5 cm below the site of force, increased openings between the rob cover and the vault, the displacement of bricks and mortar in the vault, and more cracks at the base of the final load effects on the structure.

(a) *(b)* *(c)*

Figure 4. Cracks and openings in unreinforced structures under lateral loading;(a) Cracking beneath the force applied under 30 KN; (b)cracks inside base under horizontal load of 26 KN; (c) base movement dut to horizontal load under 25KN.

4.2. Survering of Crack Propagation and Failure Mode in Reinforced Structure

Lateral loading was performed by Jack after vertical loading. Under the horizontal load 25 KN appeared the crack in the spring between mortar and brick. When loading reached 41 KN, a great sound of failure was heard and after observation of the structure, cracks were observed along the rib cover and arc connection. At 43 KN loading, the cracks were observed beneath the brick-mortar loading location as well as under the brick-mortar loading location and decreased the structural tolerance. At the final loading 28 KN, cracking continued from the spring into the mortar and brick horizontally. Displacement was observed at the top of the fiber strip FRP. In the experiment, reinforced structures were observed the cracks on the rib cover and vault, but after loading all the cracks were moved to the base. Reinforced structures showed a 33% increase in bearing rate.

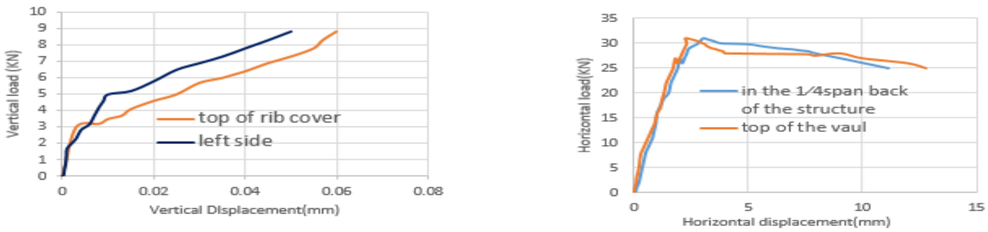
(a) *(b)* *(c)*

Figure 5. fracture changes in rib cover and vault structures under vertical and horizontal loading in reinforced structures: a) Cracks in the spring openings under load 43 KN; b) Detachment of FRP cement mortar under loading 29 KN; b) Cracks in the span of vault under load 43 KN.

5. Results and Analysis

5.1. Unreinforced Structure

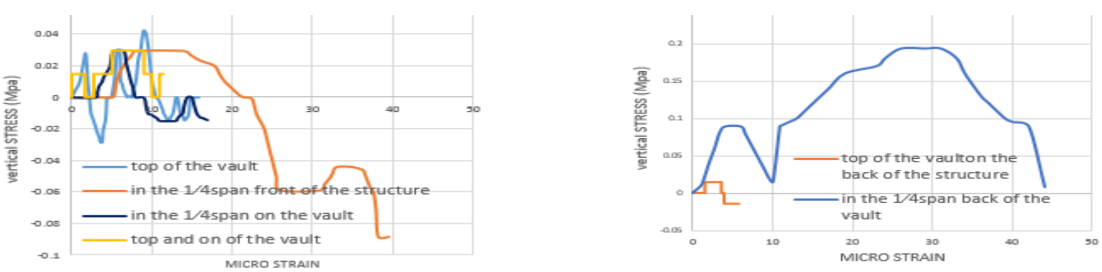
Force-displacement diagrams under lateral loading are shown in two directions perpendicular to the loading direction and to the loading direction. The highest amount of displacement is on the right side of the structure, which is about 11% more than the displacement on the other side of the structure. No displacement was observed under horizontal loading.



(a) *(b)*

Figure 6. Force-displacement diagram for an unreinforced structure: (a) vertical displacement; b) horizontal displacement.

According to the stress-strain diagrams in the structure without reinforcement, the recorded strains were very small and can be ignored. Some strains are lowered.



(a) *(b)*

Figure 7. Stress-strain curves in unreinforced structures: a, b) vertical stress.

5.2. Reinforced Structure

One of the most important graphs needed is the force-displacement graph. The reinforced structures mounted at critical locations reinforced by fiber strips C-FRP did not record spatial variations under vertical loading of displacement gauges. In horizontal loading the displacement of gauge perpendicular to the load axis have the highest value recorded on the ceiling and the displacement on the right and left sides of the structure is about 20% different.

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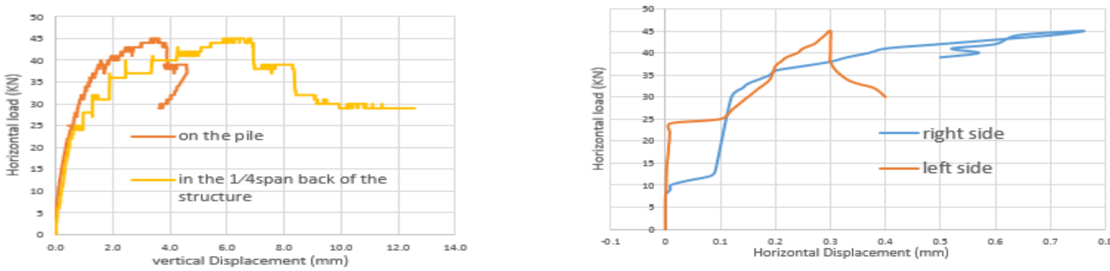
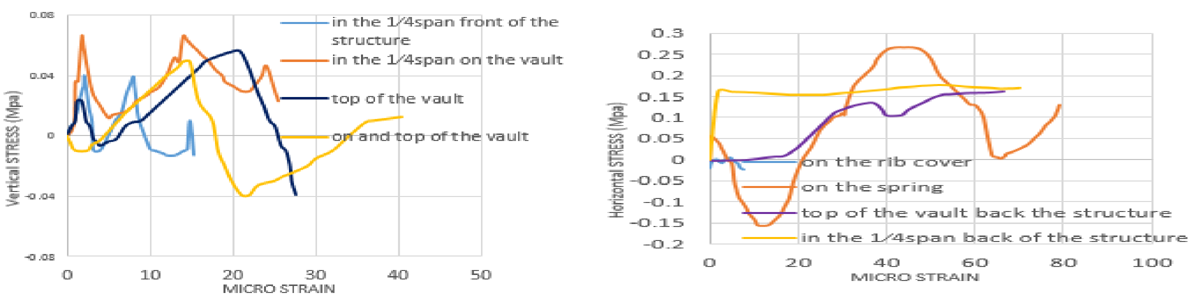


(a) *(b)*

Figure 8. Force-displacement diagram in reinforced structures: a) vertical displacement; b) Horizontal displacement.

As stated in the unreinforced structure, the strain rate in all parts of the structure was very small and less than the yield strain. The maximum strain recorded under the vertical loading was at the spring, which was about 122.22 micro strain. They did not show significant numerical strain, and because of the small amount of all strains, there is no room for discussion.



(a) *(b)*

Figure 9. Stress-strain diagrams in unreinforced structures: a) vertical stress, b) lateral stress.

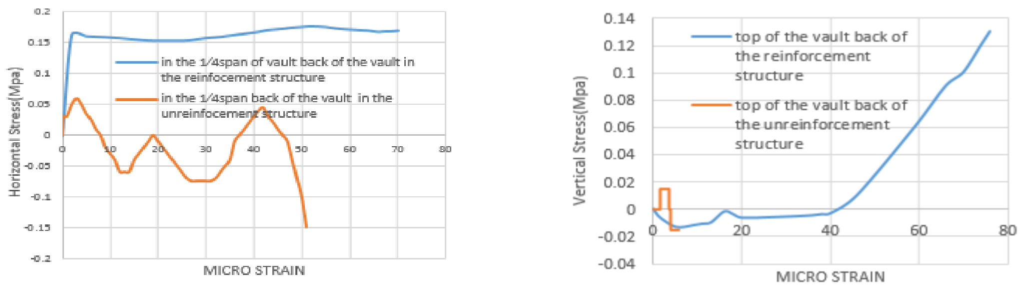
5.3. Comparison of Diagram in Two Structures Unreinforced and Reinforced Structure

Force-displacement in reinforced structures that sensitive and damage points were reinforced with C- polymer fiber strips C- FRP to compare with non-reinforced structures. Comparison of force-displacement diagrams under vertical loading due to low displacement rates was excluded, but under horizontal loading the displacement at the top of the front of the vault in the reinforced structure has increased about 5/5%.

(a) *(b)*

Figure 10. Comparison of the force-displacement diagram in reinforced and un reinforced structures: a) Horizontal displacement b) Vertical displacement.

Due to the amount of stresses obtained from the building charter and comparing it with the stresses in stress-strain diagrams in reinforced and unreinforced structures, none of the stresses yielded to stress. The stresses and strains were so small that they could not be compared. The following are some examples of a stress-strain diagram for view in.



(a) *(b)*

Figure 17. The stress-strain diagram in two unreinforced and reinforced structures: b) vertical load; a) lateral load.

6. Conclusion

This study was carried out on arch structures which is one of the most common historical structures in Iran. The structure consists of springs and vaults made of handmade brick, plaster mortar and water used in the past to build traditional structures. In this study, two unreinforced and reinforced structures with C-FRP fiber polymer strip were compared. The following points can be drawn from this study:

Unreinforced structure:

- In the structure, the crack was created at the site of applaing load, which eventually was observed the fracture and displacement. At the left spring, the cracks between the mortar and bricks extended to the rib cover and vault.
- According to the recorded strains, none of the strains showed a large number and can be ignored.
- The mechanism of the cracks, fractures and openings were investigated and the weaknesses in the structure were identified and reinforced with fiber strip C-FRP.

Reinforced structure:

- In reinforced structures before the peak of loading, the cracks were observed in rib cover and vault and springs. However, they were much smaller and scattered.
- Cracks were observed vertically on the base between mortar and brick but no shear-slip cracks were observed.
- Capacity of reinforced structures increased by about 13 KN of non-reinforced structures.

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