Performance Analysis of Ferrocement Retrofitted Masonry Wall Units under Cyclic Loading

Raquib Ahsan, Md. Mahir Asif, Md. Zahidul Alam

***Abstract*—**A huge portion of old masonry buildings in Bangladesh are vulnerable to earthquake. In most of the cases these buildings contain unreinforced masonry wall which are most likely to be subjected to earthquake damages. Due to deterioration of mortar joint and aging, shear resistance of these unreinforced masonry walls dwindle. So, retrofitting of these old buildings has become an important issue. Among many researched and experimented techniques, ferrocement retrofitting can be a low cost technique in context of the economic condition of Bangladesh. This study aims at investigating the behavior of ferrocement retrofitted unconfined URM walls under different types of cyclic loading. Four 725 mm × 725 mm masonry wall units were prepared with bricks jointed by stretcher bond with 12.5 mm mortar between two adjacent layers of bricks. To compare the effectiveness of ferrocement retrofitting a particular type wire mesh was used in this experiment which is 20 gauge woven wire mesh with 12.5 mm × 12.5 mm square opening. After retrofitting with ferrocement these wall units were tested by applying cyclic deformation along the diagonals of the specimens. Then a comparative study was performed between the retrofitted specimens and control specimens for both partially reversed cyclic load condition and cyclic compression load condition. The experiment results show that ultimate load carrying capacities of ferrocement retrofitted specimens are 35% and 27% greater than the control specimen under partially reversed cyclic loading and cyclic compression respectively. And before failure the deformations of ferrocement retrofitted specimens are 43% and 33% greater than the control specimen under reversed cyclic loading and cyclic compression respectively. Therefore, the test results show that the ultimate load carrying capacity and ductility of ferrocement retrofitted specimens have improved.

***Keywords*—**Cyclic compression, ferrocement, masonry wall, partially reversed cyclic load, retrofitting.

I. Introduction

EARTHQUAKE is one of the most horrific natural calamities in Bangladesh. Even though Bangladesh has not experienced any major earthquake yet, recent occurrences of earthquake in neighboring countries have caused ground shaking in this country. A considerable amount of masonry structures are located in Bangladesh. From the previous studies, it has been found that masonry structures performed very poorly during previously occurred earthquakes in Turkey [1]. These heavy masonry structures are primarily designed to resist axial load which make them more vulnerable to in-plane or out-of-plane shear force resulting from lateral loads such as earthquake. So, retrofitting of these earthquake affected masonry structures has become necessary in the recent years. Though several seismic retrofitting techniques are available for masonry structures, ferrocement technique proves itself as both advantageous and cost-effective [2].

Ferrocement is a thin retrofitting construction element. Rich cement mortar is used in it without any existence of coarse aggregates and one or more layers of continuous/small diameter steel wire/weld mesh netting are used as reinforcement. Ferrocement has become very popular because of its availability of raw materials, cost-effective process and flexibility in construction [3]. Resistance of structures to fire, corrosion and earthquake can be increased by using ferrocement coating [4]. Again, in plane and out of plane strength and ductility of an unreinforced masonry wall can be enhanced by using thin ferrocement coating [5]. Strengthening of brick masonry columns using ferrocement was also found effective [6]. Moreover, lateral load capacity of interior beam column joint retrofitted with ferrocement was found satisfactory [7].

The primary objective of the present study is to investigate the performance of ferrocement retrofitted masonry wall units under both partially reversed cyclic loading and cyclic compression in terms of load carrying capacity and corresponding deformations. Investigation of the failure pattern of the specimens is also included in this study.

II. Experimental Program

A. Identification and Preparation of Specimens

Four masonry wall specimens were investigated. Two of them were control specimens (bare masonry wall) denoted as URM (for partially reversed cyclic loading) and URMC (for cyclic compression) whose final section size stood 725 mm × 725 mm × 138 mm as shown in Fig. 1. The other two were ferrocement retrofitted specimens denoted as FRS-20 (for partially reversed cyclic loading) and FRSC-20 (for cyclic compression) whose final section size stood 725 mm × 725 mm × 163 mm as shown in Fig. 2. All the bricks were connected by stretcher bond. 12.5 mm mortar was used between two adjacent layers of bricks. Between ferrocement layer and brick wall 37.5 mm standard nails were placed at a spacing of 150 mm c/c at alternate brick layers and embedded to 25 mm into the wall.

Proper preparation of specimens is one of the important conditions for obtaining accurate results from structural tests. Four walls were prepared with bricks and mortar. Mortar preparation is the first stage which is necessary for brick bonding. For brick jointing the ratio 1:4 (cement: sand) was used in mortar. After preparation of mortar, the brick walls

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were built as shown in Fig. 3.

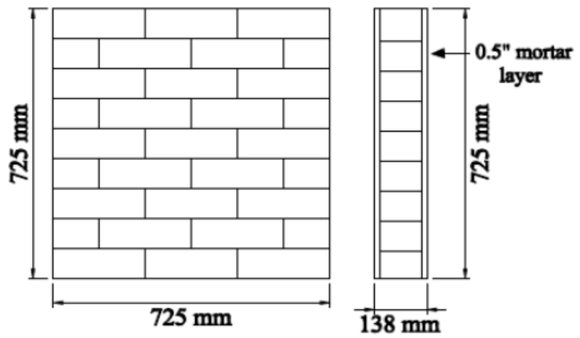

Fig. 1 Control Specimens

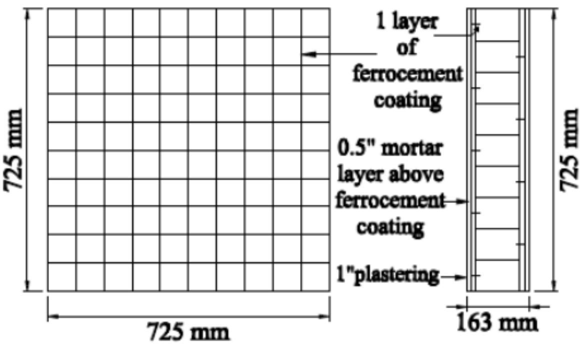

Fig. 2 Ferrocement Retrofitted Specimens

Fig. 3 Construction Process of Brick Wall

Plasterwork refers to construction or ornamentation done with plaster, such as a layer of plaster on both faces of walls. In our study, mortar was used as plaster. So, at next stage mortar was prepared for plaster work. The ratio 1:2 (Cement: sand) was used in mortar for plasterwork as well as for ferrocement work. The section size and mortar mix proportion of four brick wall specimens are shown in Table I.

TABLE I
SUMMARY OF SECTION SIZE AND MORTAR MIX PROPORTION OF SPECIMENS

Specimens	Dimension	Masonry Mortar Mix Proportion	Ferrocement Mortar Mix proportion
URM	725mm×725mm×138mm	1:4	-
URMC	725mm×725mm×138mm	1:4	-
FRS-20	725mm×725mm×163mm	1:4	1:2
FRSC-20	725mm×725mm×163mm	1:4	1:2

It may be noted that the water-cement ratio was maintained at 0.45 in all types of mortar [8]. All four masonry walls were plastered with 12.5 mm mortar on both faces. Now 20 gauge woven wire meshes were wrapped on two walls (FRS-20 and FRSC- 20) on both faces. 12.5 mm mortar was again applied on these wrapped wire meshes to complete the ferrocement work. Fig. 4 represents the state of a wall after the completion of applying ferrocement coating.

Fig. 4 Brick Wall After Applying of Ferrocement Coating

Ferrocement containing particular types of properties was mainly used in this study. Especially gauge type, wire mesh sizes, applied ferrocement layer no. were clearly specified. Detail ferocement properties used in this study are represented in Table II.

TABLE II
PROPERTIES OF FERROCEMENT

Specimens	Wire Size (Gauge)	Wire Mesh Size	No of Layer
URM	-	-	-
URMC	-	-	-
FRS-20	20	12.5mm×12.5mm	1
FRSC-20	20	12.5mm×12.5mm	1

After applying ferrocement coating, curing was done for 28 days allowing the walls to gain sufficient strength. Gunny bags were used for homogeneous curing. Moreover, the opposite corners of each wall were grinded by grinding machine for developing full interlocking to fit it into the testing machine. Eventually, each wall was painted on both sides for observing the cracks on specimen during testing.

B. Experimental Setup

After completion of preparation, the walls were ready to be tested by testing machine. A hydraulic jack was used to apply cyclic load to the specimens as showed in Fig. 5. The hydraulic jack was pressure operated and its maximum capacity was 150 Mpa. Two M-shaped steel frames were also used in this experiment. One steel frame was attached with the hydraulic jack.

Another M-shaped steel frame was attached with reaction beam. Pure epoxy binder was applied at the interface of brick wall and steel frame allowing the application of tensile force. A dial gauge was used in this experiment to measure the deflection of the specimen along both directions with the precision of 0.01 mm. Schematic diagram of full experimental setup of our experiment is pictured in Fig. 6.

Fig. 5 Hydraulic Jack

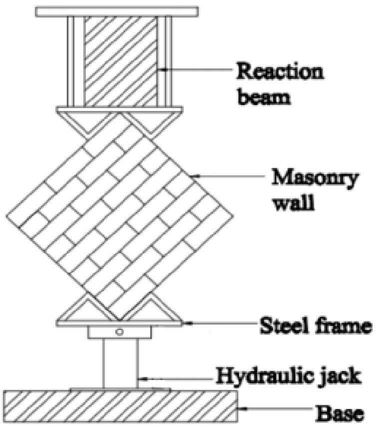

Fig. 6 Schematic Diagram of Experimental Setup
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It should be noted that, two M-shaped steel frames were used to hold the specimen diagonally. So the dimension of each of this steel frame should be such that it can properly hold the specimen. Fig. 7 represents its dimension.

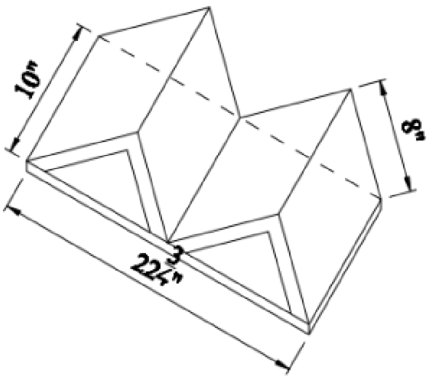


Fig. 7 M-Shaped Steel Frame

C. Cyclic Loading

During testing, cyclic load was applied gradually by hydraulic jack and corresponding deformation was recorded from dial gauge. Applied load was increased with the increment of cycle number. Two types of loading history were used in this experiment. They were partially reversed cyclic loading and cyclic compression.

Partially reversed cyclic loading i.e. a complete loading cycle consists of both compression half cycle and tension half cycle was applied on specimen URM and FRS-20 as shown in Fig. 8. Applied tensile force was 15% of the compressive force for each cycle.

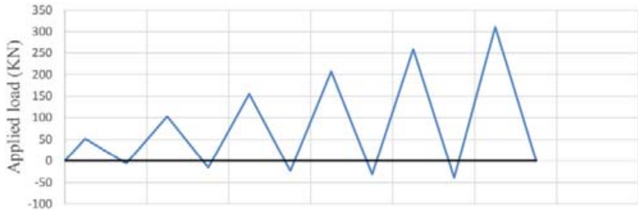


Fig. 8 Load History of Specimen URM and FRS-20

Cyclic compression i.e. loading cycle only consists of compressive force was applied on URMC and FRSC-20 maintaining 51.5 KN of residual compression as showed in Fig. 9. Maximum value of compressive force per cycle was increased with the increment of cycle number.

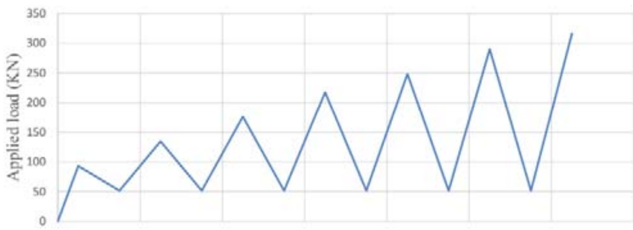


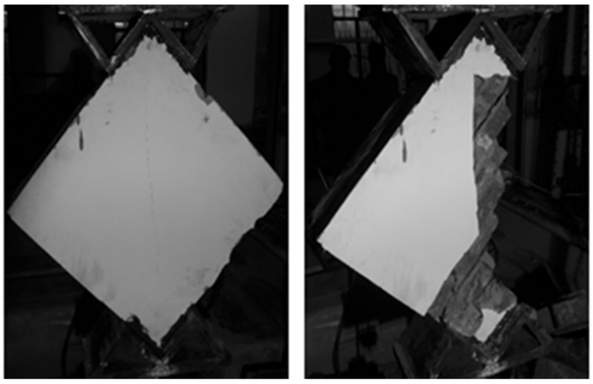
Fig. 9 Load History of Specimen URMC and FRSC-20

III. Experimental Results

Load was applied diagonally on the all four walls one by one during testing.

After applying partially reversed cyclic load on URM, first crack appeared on the surface along the diagonal of the specimen as shown in Fig. 10 (a) at the load of 155.15 KN during 3rd cycle under compression and corresponding deformation was 2.05 mm. Crack started to extend along the diagonal with the increment of load. Finally failure occurred by diagonal splitting of the specimen as shown in Fig. 10 (b) at the load of 206.97 KN and corresponding deformation was 4.1 mm. Failure occurred along the mortar joint.

After applying partially reversed cyclic load on FRS-20, First crack on the surface occurred on the surface along the diagonal as shown in Fig. 11 (a) at the load of 258.79 KN during 5th cycle under compression and corresponding deformation was 5.7 mm. Gradually this crack extended further along the diagonal and was accompanied by a series of small cracks. Finally complete failure of the specimen occurred along the diagonal as shown in Fig. 11 (b) at the load of 280.59 KN and corresponding deformation was 5.9 mm. Failure occurred due to both mortar joint failure and brick failure under compression.

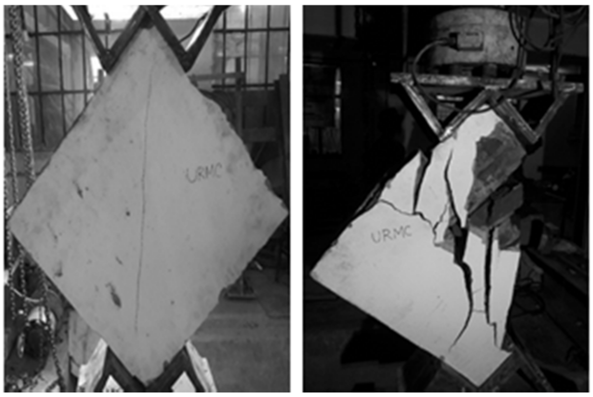


(a) (b)

Fig. 10 (a) First Crack Pattern and (b) After Failure State of URM

(a) (b)

Fig. 11 (a) First Crack Pattern and (b) After Failure State of FRS-20

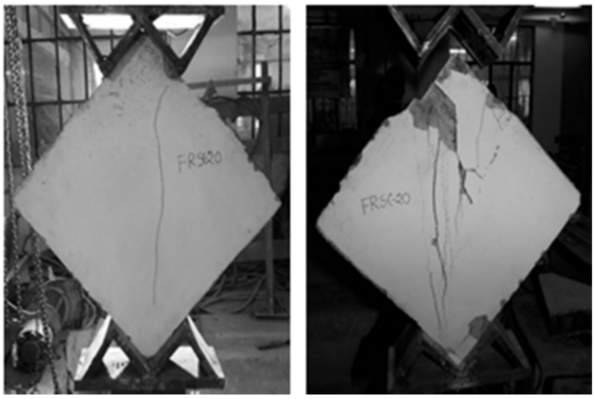


(a) (b)

Fig. 12 (a) First Crack Pattern and (b) After Failure State of URMC

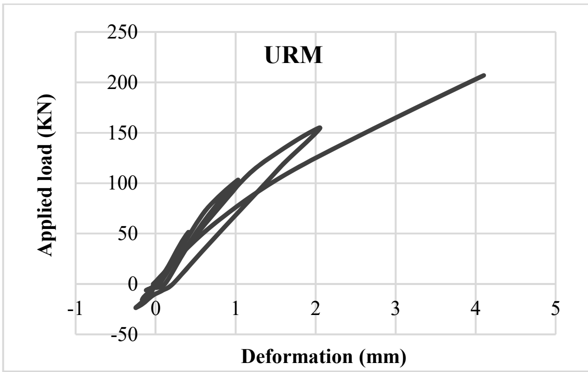
After applying cyclic compression on URMC, first crack appeared on the surface along the diagonal of the specimen as shown in Fig. 12 (a) at the load of 217.49 KN during 4th cycle under compression and corresponding deformation was 4.69 mm. Crack started to extend along the diagonal with the increment of load. Finally failure occurred by diagonal splitting of the specimen as shown in Fig. 12 (b) at the load of 248.61 KN and corresponding deformation was 4.93 mm. Failure occurred along the mortar joint.

After applying cyclic compression on URMC, first crack on the surface occurred on the surface along the diagonal as shown in Fig. 13(a) at the load of 290.11 KN during 5th cycle under compression and corresponding deformation was 5.97 mm. Gradually this crack extend further along the diagonal and was accompanied by a series of cracks. Finally complete failure of the specimen occurred along the diagonal as illustrated in Fig. 13 (b) at the load of 316.62 KN and corresponding deformation was 6.56 mm. Failure occurred due to both mortar joint failure and brick failure under compression.

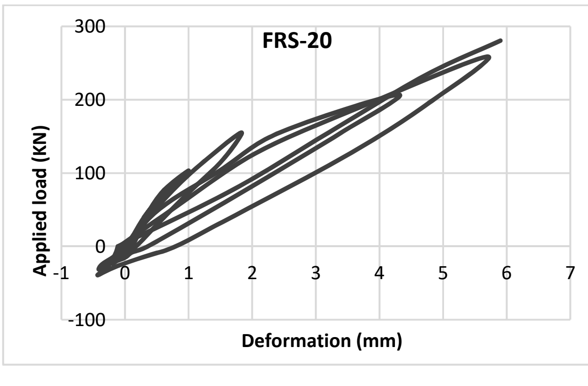


(a) (b)

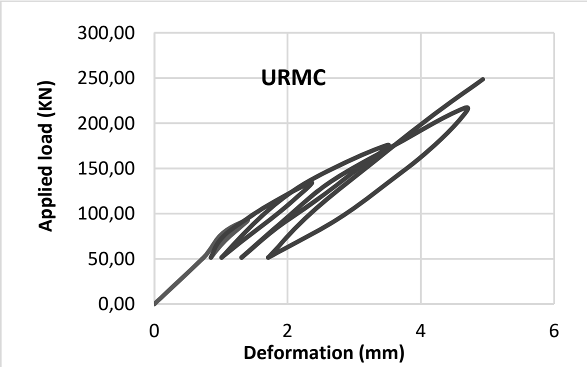
Fig. 13 (a) First Crack Pattern and (b) After Failure State of FRSC-20



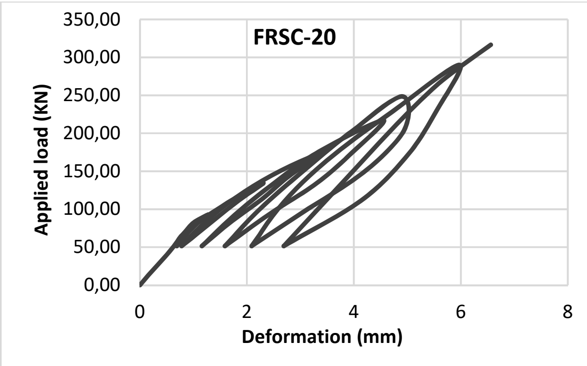
(a)



(b)



(c)



(d)

Fig. 14 Load-Deformation graph of (a) URM (b) FRS-20 (c) URMC (d) FRSC-20

TABLE III
SUMMARY OF OBTAINED EXPERIMENTAL RESULTS IN COMPRESSION

Specimens	Compressive Load at Cracking (KN)	Ultimate Load Carrying Capacity (KN)	Maximum Deformation (mm)
URM	155.15	206.97	4.1
FRS-20	258.79	280.59	5.9
URMC	217.49	248.61	4.93
FRSC-20	290.11	316.62	6.56

TABLE IV
SUMMARY OF OBTAINED EXPERIMENTAL RESULTS IN TENSION

Specimens	Maximum tensile load applied (KN)	Maximum deformation under tension (mm)
URM	23.69	0.25
FRS-20	39.25	0.43
URMC	-	-
FRSC-20	-	-

The load-deformation curves of all specimens are expressed in Fig. 14.

It is obtained from the graph that stiffness of the ferrocement retrofitted specimens is greater than the control specimens. The ferrocement retrofitted specimens also showed greater ductility. Stiffness of both retrofitted specimens and control specimens decreases with the increment of each cycle.

Summary of compressive load at cracking, ultimate load carrying capacity and maximum deformation of all specimens are arranged in Table III.

Summary of maximum tensile load applied and maximum deformation under tension of all specimens are represented in Table IV.

IV. CONCLUSION

The behavior of ferrocement retrofitted unreinforced masonry wall units and bare masonry wall units were carefully investigated under cyclic loading. The behavior difference of the specimens under partially reversed cyclic load and cyclic compression were also observed.

Before showing first crack the ferrocement retrofitted specimens carried 67% and 33% greater load than bare specimens under partially reversed cyclic load and cyclic compression respectively. The ultimate load carrying capacities of the ferrocement retrofitted specimens were 35% and 27% greater than the unretrofitted specimens under partially reversed cyclic loading and cyclic compression respectively. The tensile load carrying capacity of the ferrocement retrofitted specimen was found 66% greater than bare specimen.

Before failure, the ferrocement retrofitted specimens experienced 43% and 33% greater deformation than the unretrofitted specimens under partially reversed cyclic loading and cyclic compression respectively. Also, 72% deformation increment of ferrocement retrofitted specimen in tensile force was found over control specimen. This indicates that ductility of the masonry wall was enhanced due to the ferrocement overlay. Moreover, the improvement of stiffness of the specimens for using ferrocement coating was also clear from load-deformation graphs.

By comparing the experimental results under both loading conditions, it is found that capacity of masonry wall decreased when it was subjected to partially reversed cyclic loading. In case of unreinforced masonry wall, it decreased by 17% but in case of ferrocement retrofitted wall, the decreasing value was 11%.

Eventually, by carefully investigating the overall performance of ferrocement retrofitted specimens it can be stated that seismic retrofitting of unreinforced masonry walls with ferrocement can be a trustworthy and effective strengthening method.

ACKNOWLEDGMENT

Financial support for the present study was provided under "Higher Education Quality Enhancement Project (HEQEP)" by University Grant Commission (UGC). The authors would also like to acknowledge the technical support of Bangladesh University of Engineering & Technology (BUET).

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