Experimental Study on Strengthening of Load Bearing Structures by Ferrocement Lamination

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Abstract— **Ferrocement can be used as a retrofitting material due to its property of quick application on a damaged element without requirement of special bonding material with less skilled labours. The aim of this research is to provide ferrocement lamination to preexisting brick masonry structures as well as pre-damaged brick masonry structures and observe the increase in load bearing capacity of the structure. In recent years, repairs of damaged and unstrengthened members by external repair technique of bonding such as ferrocement lamination is increasing which demands needs of research work on behaviour of ferrocement confinement of column with ferrocement laminates considering the change in parameters. Brick is perhaps the oldest manmade material used in the building construction. The strength of brick masonry work depends upon the compressive strength of the bricks and mortar used. Brick masonry is primarily used as load bearing walls to carry out vertical loads. In these work, an attempt has been made to identify the increase in load carrying capacity under the application of point load on damaged walls after providing lamination with ferrocement. This paper aims to study the work carried out for strengthening of load bearing structures by ferrocement lamination on existing brick masonry as well as predamaged structures before collapse.**

Keywords—Ferrocemnt, lamination, retrofitting, brickwork.

I. INTRODUCTION

As compared to the present era, brick work are the oldest housing systems that humans have created. Compressive strength of the brick and the type of mortar used are the two factors on which strength of masonry wall depends. The primary use of brick masonry walls is that it is used as load bearing walls to carry vertical loads. The setup of reinforced mortar or plaster over layers of chicken mesh or metal wire mesh or fibers and possibly closely spaced small diameter steel rod such as rebar is called as ferrocement or ferrocrete. It is a flexible material which contributes much less to pollution and does not requires skilled labours and can be constructed with locally available materials that eventually reduces the cost of construction.

Wire mesh used can be available in different forms such as square, hexagonal, diamond shape which may be either steel or galvanized in nature. The alignment or aspect of reinforcement which is the angle in degree between reinforcement mesh provided and particular direction of applied stress has also a specific importance or consideration related to compressive strength of ferrocement. Ferrocement applications in water tightening structures like swimming pool, retaining wall, water tank, etc. have been in need of this concept. In ferrocrete, cement mortar mix does not crack as these forces that contribute to the cracking are taken by the steel wire mesh provided immediately below the surface. The overhaul of the particular damaged structural component or element is one of the best remedial measures instead of replacing it. The overhaul of the structure can be done basically in two ways i.e. global or local. In local method only the part damaged or to be repaired is provided with retrofitting whereas in case of global method the whole structure has to be retrofitted. Lamination construction around the structure is a preferred method of retrofitting. One of the best advantage of ferrocement is that it can be casted into any shape having higher degree of complexity without making it costlier in case of formwork. Strength enhancement and retrofitting are the two major areas where engineers are finding issues. Many of the individuals have recommended ferrocement as the enveloping material for strengthening of various structural components.

II. LITERATURE REVIEW

There has been a lot of research work about uprising trend of ferrocement applications in repairs and retrofitting of damaged structures in the construction era. The following are the 10 literature reviews done for this research:

Enea, Mustafaraj; Yavuz, Yardim, [1] worked on usage of ferrocement jacketing for strengthening of damaged unreinforced masonry walls by testing the specimen under diagonal compression to compare it in terms of increase in shear strength, drift and mode of failure which brought them to conclusion on bases of their observation that there was a considerable increase in shear strength and deformation capacity of repaired and reinforced masonry panels. The mode of failure observed was diagonal cracking. Very brittle behavior and low shear strength was observed in unreinforced walls whereas reinforced panels demonstrated much ductile behavior, high shear strength and huge deformation capacity.
Medhat, Enas; Elsayed, Mahmoud; Elsayed, Alaa, [2] carried out investigation of efficiency of using ferrocement lamination for rehabilitation of concrete brick masonry walls was done by performing non-linear 3D numerical analyses. The specimen used for testing were built using concrete bricks which were tested under uniform axial vertical load and lateral load using square wire mesh. The numerical results indicated that the strength, energy absorption, ultimate carrying capacity and stiffness of masonry walls can be successfully increased using ferrocement confinements. There was an increase in ultimate lateral load of about 180% and 310% in that of uncracked stiffness of strengthened models of u retrofitted wall. Mechanical characteristics had a marked improvement that ensured effectiveness of rehabilitation of walls using ferrocement technique. Also the ferrocement thickness and characteristic strength of mortar has significant importance in enhancement of lateral load capacity and to improve wall characteristics.
A. Garg, [3] carried out study which shows that ferrocement is highly effective in restoring strength of damaged brick masonry columns and damaged structures can be repaired using ferrocement as long as it has not collapsed. Observations show that the time duration between the appearance of first visible crack and ultimate failure of plain brick wall is very less while that in case of ferrocement encasing ultimate failure occurs much after first visible crack which concluded that ferrocement jacketing takes the initial axial compressive load and failure in it is observed before the failure of the core. Also high variation in value of elastic modulus of brick masonry is seen.
Wail N. Al-Rifaie; , Khaled Mohammad [4] carried out study which aimed in investigating the behavior and ultimate strength of ferrocement clay brick composite walls which were subjected to axial compressive loads. Construction and testing was done on three ferrocement brick composite walls and compared to the results obtained from clay brick wall built and coated with cement mortar. Number of wire mesh was the main parameter considered. The study showed that addition of wire mesh has small effect on the ultimate load carrying capacity of the structure.
S.V. Venkatesh [5] in this study made an attempt to determine the increase in load carrying capacity of cracked brick masonry walls by encasing with ferrocement. The investigation deals with test on brick masonry walls with different shapes, bonds and method of fixing mesh for ferrocement. The crack width, crack pattern,first crack and ultimate load were noted. Two methods were adopted for fixing of mesh which were using 6mm M. S. Rod and nails; and other was by using nails only. Walls in which 6mm M. S. Rods were used along with nails showed better characteristics. The crack pattern observed before encasement was isolated loops and that after encasement were observed to be straight and vertical.
V.Nandakumar; , K.Revathi; , M.P.Revathi [6] carried out work which focuses on the fact that as bricks cannot withstand large amount of lateral loads, provision of ferrocement casing gives additional strength to structure. The testing was done on column without mesh and on 1mm, 0.707mm and 0.354mm thick ferrocement casing which showed 1.05, 1.04 and 1.42 times higher compressive strength in comparison to column without mesh. So the study concluded that encased specimen showed consistently higher compressive strength and hence ferrocement jacketing improves the compressive strength of brick masonry columns.
V.Bhatewara, Varsha; , Dhananjay G. Ahire; , Nikita G. Agrawal [7] evaluated the capability of ferrocement for strengthening of un-reinforced brick. Also to see whether this process is effective, economical and easy to practice. The test were performed on short columns which were subjected to compressive load after 7 dats and 28 days of curing. The failure load of encased columns was twice to that of un-reinforced masonry. Uncollapsed columns which have been loaded close to failure can be strengthened by ferrocement casing and the average crack spacing is directly proportional to the spacing is wire.
Iffat Hussain Shah; , Mohammad Zakir [8] In various parts of the world, Reinforced Concrete (RC) structures are still being designed only for gravity loads even in seismic zones. Even though showing good performance under conventional gravity load case, such structures could lead to a questionable structural performance under seismic or wind load. Those structures are highly vulnerable to any moderate or a major earthquake in most cases. Therefore, in the design of the reinforced concrete beam-column joints subjected to seismic load, it is desirable to limit joint strength degradation until the ductility capacity of the beam reaches the designed capacity. The repair and retrofit materials can be classified into three categories: 1. Grouts: (i) Injection grout 2. Bonding Agents.

3. Replacement and Jacketing Material: (i) Steel plate bonding (ii) Ferrocement.

The load carrying capacity of retrofitted specimen joints for both types of retrofitting techniques increases significantly as compared to control beam-column joint. Specimens with mesh wire wrapped diagonally showed maximum improvement in the ultimate load carrying capacity.There was observed substantial increase in the yield load also in both types of retrofitting. There was a decrease in the deflection in case of retrofitted specimens as compared to control specimen.The ductility ratio of control specimen was more than the ductility ratio of retrofitted specimen. The ductility ratio of those specimens in which mesh wire was wrapped in the shape of L was observed to be less than specimens in which mesh wire was wrapped diagonally.
V.Anandan; , S.Senthamilkumar; , S.Gunaselvi; , V.Sundararajulu; , M.Jeganathan, [9] presented a paper on results of an experimental study on the increase in the load carrying capacity of conventional ferrocement wrapped columns and modified ferrocement columns shows that the

ferrocement wrapping reinforced with two layers of welded steel meshes when used to test six short RCC square columns including four strengthened columns (Two with convensional ferrocement and two with modified ferrocement), subjected to axial compressive load till failure the results indicated that the increase in load carrying capacity of column was about 79.60% which were wrapped with conventional ferrocement over control specimen that of column wrapped with modified ferrocement observed to be 89.80% over control specimen.Hence it is concluded that modified ferrocement jackets can be effectively used for strengthening of RCC columns. This phenomenon should also be studied in case of brick masonry.

Reza Amiraslanzadeh; , Toshikazu Ikemoto; , Masakatsu Miyajima, [10] in this paper made comparison and discussion on seismic retrofitting methods of masonry brick walls, advantages, drawbacks and limitations. Also most suitable methods for both historical and conventional masonry brick walls considering efficiency and financial problems were presented. The result showed that the center core technique and surface treatment methods were the most appropriate methods with high level of improvement in both in-plane and out-of-plane behavior for historical and conventional masonry brick walls respectively. The main benefit of the Center Core technique is the least disturbance and no disfiguring of the historical building structures. Surface treatment methods for conventional building structures were recommended because of its low cost and no requirement for high technical workers as well. Low cost or low technology cannot provide suitable efficiency, however relatively appropriate performance were shown by some methods like Bamboo-band retrofitting technique.Due to low quality of mortar and brick in rural regions, application of post tensioning methods is not recommended even for historical buildings. High mass of URM structures is one of the most important problems that must be taken into consideration, and hence point retrofitting methods with low additional mass are preferably used.

Hima Shrestha, Suman Pradhan, Ramesh Guragain [11] Past devastating earthquakes have proven the destructibility of most low strength masonry buildings and the need for seismic strengthening through existing remedial measures that are inexpensive and not beyond the skills of local building industries. The study in this paper focuses on the collective experiences in retrofitting of school buildings and residences of low-strength masonry through different retrofitting techniques. Out of the various retrofit methods employ wall jacketing and splint and bandage, using steel bars or galvanized wire mesh, have proven to be the most appropriate, both technically and economically viable whilst sufficiently enhancing the overall performance of the building to a level of life safety. The cost of these methods varies from $3 to $6 per square feet area of the building. It also includes experience of implementing an alternate retrofit approach using Polypropylene mesh to case masonry walls, a low-cost option for upgrading of low strength masonry buildings.

Jorge Miguel Proença, António Sousa Gago & Ana V. Costa [12] in this paper presented the results of a sequence of experimental testing stages devised to determine the strengthening effects and to identify the most effective detailing procedures for this solution. The initial testing focused on the behaviour of composite mortar-mesh specimens, subjected to tensile tests. Later a group of eight nearly full scale masonry wall models, unreinforced and reinforced with steel or fibreglass meshes, were subjected to in-plane and out-of-plane imposed displacements. The details of the implementation of this strengthening solution in a school in the Algarve are also reviewed.

M Gohnert, Z Mahamed and Y Nadasen [13] in this paper proposes a method of reinforcing masonry referred to as wire stitching. The technique is applicable to cracked or damaged masonry walls to restore strength, or applied to high stressed areas to prevent cracking. As the name of the method implies, a crack is “stitched up” with binding wire
to restore strength. A bending moment equation is derived, and severaltests performed to determine the viability of the method. Tests indicate that the equations adequately predict the bendingcapacity of masonry strengthened with wire stitching.

Subhamoy Bhattacharya, Sanket Nayak, Sekhar Chandra Dutta [14] Unreinforced masonry (URM) buildings are common throughout Latin America, the Himalayan region, Eastern Europe, Indian subcontinent and other parts of Asia. It has been observed that these buildings cannot withstand the lateral loads imposed by an earthquake and often fails, in a brittle manner. Methods for retrofitting URM buildings to increase the time required for collapse and also to improve the overall strength widely vary. This review has collated information on various types of retrofitting methods either under research or early implementation. Furthermore, these methods are categorized and critically analyzed to help further understand which methods are most suitable for future research or application in developing countries. The comparison of the different methods is based on economy, sustainability and buildability and provides a useful insight. The study may provide useful guidance to policy makers, planners, designers, architects and engineers in choosing a suitable retrofitting-methodology.

M. ElGawady, P. Lestuzzi, M. Badoux [15] In many seismically active regions of the world there are large numbers of masonry buildings. Most of these buildings have not been designed for seismic loads. Recent earthquakes have shown that many such buildings are seismically vulnerable and should be considered for retrofitting. Different conventional retrofitting techniques are available to increase the strength and/or ductility of unreinforced masonry walls. This paper reviews and discuses the state-ofthe-art on seismic retrofitting of masonry walls with emphasis on the conventional techniques. The paper reviews retrofitting procedures, advantages, disadvantages, limitations, effect of each retrofitting technique.

Piyush Sharma [16] in ths paper investigated the possibility of using ferrocement concrete in different types of advanced construction. The current work presents the comparison between the performance of ferrocement and reinforced concrete under static load. The goal of the current research is studying the feasibility of ferrocement concrete in design and construction of structures. This study has brought out that ferrocement construction is an innovative and advanced technique, its readily available materials and ease of construction make it suitable in developing countries for housing, water and food storage structures. Ferrocement is

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found to be a suitable material for repairing or reshaping the defective RCC structural elements and enhancing its performance.

III. METHODOLOGY

*A. **Material Used***

Bricks

Standard bricks of size 190mm x 90mm x 90mm were used.

Mud Mortar

Mud mortar was used for the reason that in rural areas, were more load bearing structures are to be found, traditionally the locally available mud is used as the binding material to reduce the cost of construction. The ratio of mud to sand is taken as 1:5.

Wire Mesh

Two types of wire mesh were used:

(a) Welded wire mesh
(b) Chicken mesh

The welded wire mesh was sandwiched between chicken mesh. The mesh used for repairing was galvanized welded wire woven mesh, having square openings of 9.35mm x 9.35mm. The diameter of the mesh wire was approximately 0.5 mm.

Cement Mortar

Cement mortar used for plastering during ferrocement lamination was of ratio 1:2. Cement of grade 53 was used.

*B. **Specimens Details***

Once the materials to be used (soil, wire mesh, concrete) were made ready, the next significant step was the casting of the brick wall samples.

6 specimens 600mm x 500mm x 100mm were casted using mud mortar as binding material.

*C. **Experimental Programme***

<u>Testing of unreinforced brick masonry wall samples</u> Point load was applied at the centre of the four wall specimen vertically and load at first crack was observed and noted. Lateral point load application was considered as our focus is on the load bearing structures in rural areas which are subjected to point load due to the roof truss.

Fig. 1: First Crack Experimental Setup

Ferrocement Jacketing

- Sandwiched Welded Wire Mesh between Chicken Mesh was prepared using metal wires.
- Mesh was fitted on wall samples with help of metal washers and screws at a suitable distance to hold the mesh in place.
- Cement Mortar used for plastering was of the ratio 2:1.

Fig. 3: Ferrocement- Application of Cement Mortar

IV.

RESULTS AND DISCUSSION

Fig. 2: Preparing Mesh

- The peak load of two sample walls was observed to be 7.96 kN.

Results of Vertical Point Load Application

The results obtained after the application of point load on the sample walls are as follows:

Wall Sample No.	Peak load (kN)	Cross Head Travel at Peak (mm)	Failure Pattern
1	07.96	4.00	Vertical cracks through bricks
2	10.00	5.20	Vertical cracks through bricks
3	07.96	4.90	Vertical cracks through bricks
4	03.64	8.40	Cracks through mortar joints

- Other two samples showed the reading 10 kN and 3.64 kN.
- The average peak load here is considered to be 7.96 kN.

Ferrocement Jacketing

Fig. 4: Load vs Deflection Graph-Wall Sample 1

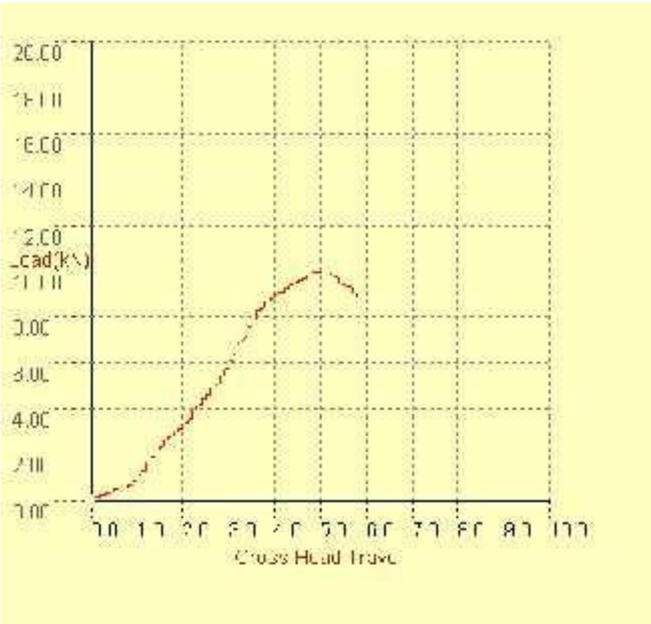

Fig. 5: Load vs Deflection Graph-Wall Sample 2

- Load vs Cross head travel graph were plotted where xaxis indicated the cross head travel in mm and y-axis indicated the load in kN.
  - ➢ Sample 1-
  - There was a gradual increase in load upto cross head travel of 4 mm.
  - After this point the load started decreasing.
  - The peak load noted at 4mm cross head travel was 7.96 kN
  - The failure pattern was observed to be vertical cracking through bricks.
  - ➢ Sample 2-
  - There was a gradual increase in load upto cross head travel of 5.2 mm.
  - After this point the load started decreasing.

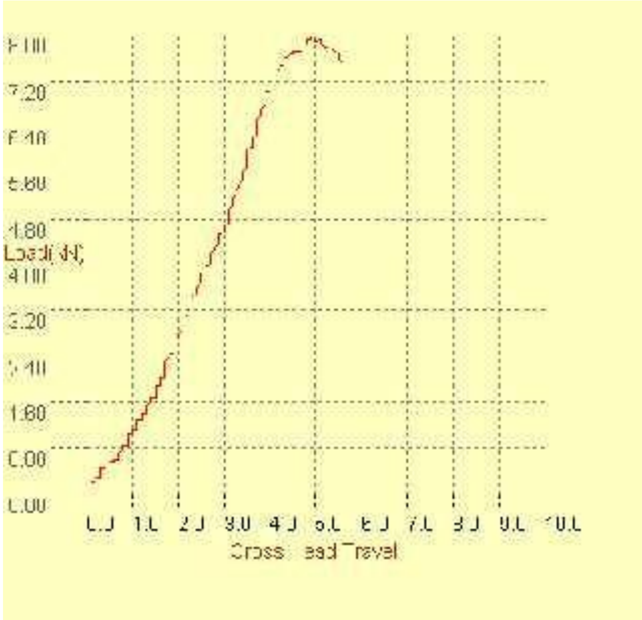

Fig.6: Load vs Deflection Graph-Wall Sample 3

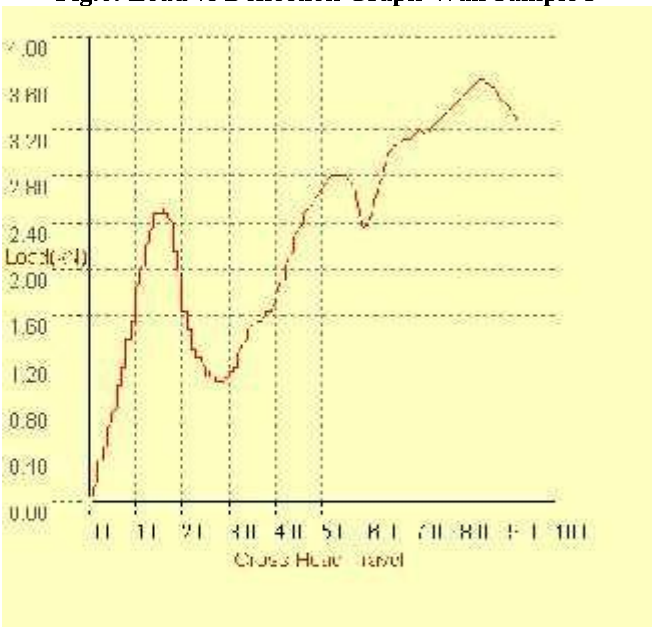

Fig. 7: Load vs Deflection Graph-Wall Sample 4

- The peak load noted at 5.2 mm cross head travel was
  10.00 kN
- The failure pattern was observed to be vertical cracking through bricks.
- ➢ Sample 3-
- There was a gradual increase in load upto cross head travel of 4.9 mm.
- After this point the load started decreasing.
- The peak load noted at 4.9 mm cross head travel was
  7.96 kN.
- The failure pattern was observed to be vertical cracking through bricks.
- ➢ Sample 4-

- For this sample different beviour of graph was observed.
- There were multiple dips in the load before the first crack appeared.
- The 1st dip was noted at 1.6 mm and the load started increasing again at cross head travel of 2.8 mm.
- The 2nd dip was noted at 5.3 mm and the load started increasing again at cross head travel of 5.9 mm.
- The peak load of 3.64 kN was noted at 8.4 mm cross head travel where the first crack was observed.
- The failure pattern was observed to be cracks through mortar joints.

- Variation in peak load was observed that indicated the error during construction as the bricks used for all the wall samples and the method of application of load were identical.
- As 2 samples here showed peak load as 7.96 kN, the average peak load was considered to be 7.96 kN.

Failure Load.

As mentioned earlier, a total of 4 unreinforced brick masonry walls were tested in this experimental program. All walls were tested using universal testing machine of capacity 400,000 lbs. The vertical point load was applied to the top of the specimen. Point load was applied at the centre of the four wall specimen and load at first crack was observed and noted. Lateral point load application was considered as our focus is on the load bearing structures in rural areas which are subjected to point load due to the roof truss. The load was applied incrementally until the first crack developed.

Variation in peak load was observed.

The bricks used for construction of all the samples were identical.

Hence it can be said that the variation in peak load shown is due to the error occurred during construction, i.e., due to labour error or improper mortar mix. Such errors also result in need of damage repairs in near future.

Crack Initiation and Propagation

In this investigation load was applied incrementally and at every load increment the surfaces of the specimens were checked very carefully to observe the cracks. The crack was initiated at the point of application as shown in Figure 3.6 For three wall samples whose the peak load was 7.96 kN, 10.00kN & 7.96 kN; the failure pattern was observed to be vertical cracking through bricks. For wall sample whose the peak load was 3.64 kN the failure pattern was observed to be cracking through mortar joints. This indicated the error in mortar mix.

Limitations

- Structures made of it can be punctured by collision with pointed objects.
- Corrosion of the reinforcing materials due to the in complete coverage of metal by mortar.
- It is difficult to fasten Ferrocement with bolts, screws, welding and nail, etc. Large no. of laborers required.
- Tying rod sand mesh together is especially tedious and time consuming.

V. FINAL COMMENT

After performing the test in the laboratory on unreinforced brick masonry walls using the Universal Testing Machine (UTM) for application of vertical point load it was observed that there were some variations in the peak load obtained for the wall samples. As the bricks used for the preparation of all the wall samples were identical, variations observed were due to the errors occurred during construction of the samples which lead to the need of repairs in near future. The literature study suggested that there are various other methods of repairs and retrofittings like sand/cement mortar, crack stitching, epoxy injections, etc.; but ferrocement proves to be easy and cost effective providing strength to the damaged masonry before collapse or pre-existing undamaged masonry construction, requiring unskilled labourers.

VI. FUTURE SCOPE

- After the initial cracking of wall samples, ferrocement jacketing was done on all the wall samples.
- The samples were to be cured for 28 days but due to the worldwide pandemic of COVID-19 and the lockdown announced by the Indian Government in this repercussions, the samples could not be cured and tested further.
- Application of ferrocement jacketing provided strength to the masonry wall samples.

Further study can be carried out on the extra load it can carry after the application of ferrocement jackting as it is yet to be determined

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