

Experimental investigation of the use of ferrocement laminates for repairing masonry in filled RC frames

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Abstract

An experimental study was carried out to investigate the in-plane strength of masonry infilled reinforced concrete portal frame rehabilitated with ferrocement. A model of a portal frame having masonry infill panel was constructed and tested in the laboratory for this purpose. The load was applied monotonically at the top of the frame till the ultimate capacity was reached accompanied by substantial formation and propagation of cracks. Then both the infill and the frame were repaired by ferrocement coating. After rehabilitation, the frame was tested in the laboratory following the same procedure as for the original frame. The masonry infill frame repaired with ferrocement showed significant improvement in performance and more than original strength was achieved. This reveals the potential use of ferrocement as a retrofitting and strengthening material of the existing infilled frame.

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1. Introduction

Masonry infill panels have been used in reinforced concrete (RC) frame structures as exterior and interior partition walls for a long time. It is well established and reported that infill panel increases the stiffness of bare frame 4 to 20 times (Comite Euro-International Du Beton 1996). Recent earthquakes in several parts of Bangladesh repeatedly indicated that older RC frames suffered extensive damage. Typical damage was related to cracking of columns, beams and infill panels. The distressed structures

require immediate attention, inquiry into the cause of distress and suitable remedial measure so as to bring the structures into its service.

A study on seismic vulnerability of buildings of five major cities of Bangladesh was conducted by the Department of Civil Engineering of Bangladesh University of Engineering and Technology (BUET 2002) sponsored by CARE. In this study the seismic damage prediction was made according to macro-seismic intensity scale. This assessment gives a vivid idea of how many buildings are susceptible to earthquake hazard and also the level of damage they are going to suffer. The evaluation showed that under an earthquake of intensity VIII (MMI), more than 60% of the buildings would be moderately or partially damaged and needs to be retrofitted. Therefore, the development of effective and affordable retrofitting techniques for masonry elements is an urgent need in this region.

Many investigations were undertaken for strengthening and repairing of slabs, beams, columns, but a few research works are available for strengthening of infills. Because of its easy application and low cost, especially in developing countries, ferrocement has been used for many years as a repair material for reinforced concrete and masonry elements as an alternative to other expensive ones. It allows rapid construction with no heavy machineries or high-level skilled workers, imposes small additional weight and the cost of construction is low. These unique qualities make the ferrocement as an ideal material for rehabilitation.

The restoration of masonry constructions has been systematically studied since 1960's. But very few of them dealt with retrofitting of masonry infilled frames using ferrocement laminates to enhance its in-plane behavior. Reinhorn et al (1985) tested a series of brick masonry walls strengthened with ferrocement layers. The 12.7 mm thick ferrocement coatings, applied to both faces, were reinforced using different mesh arrangements. The strength, ductility and stiffness of the coated walls were nearly double than those of the uncoated walls. The strength enhancement, however, was little affected by mesh spacing. Experimental investigations conducted by Irimies and Crainic (1993), Jabarov et al. (1985), Kahn (1984), Alcocer et al. (1996), Mander and Nair (1994), Oliveria (2001) showed that mortar overlays with some sort of reinforcement can be a powerful rehabilitation technique to strengthen masonry infills.

This paper presents an experimental investigation (Alam 2003) of ferrocement overlay as a repairing material for distressed masonry infilled RC frame under lateral loading condition. The study gives an idea of how much load carrying capacity can be regained after distressed condition. A comparative study of the behavior of masonry infilled RC frame and that of distressed masonry infilled RC frame repaired by ferrocement overlay is given.

2. Experimental program

The test arrangement is shown in Fig.1. The test specimen was chosen as a scaled down model of an infilled portal. The design details of the frame are shown in Fig.2 and Fig.3. Masonry infilled reinforced concrete frame were constructed monolithically with the reaction frame as shown in Fig.2 and Fig.3. For the experimental purpose, column and beam dimensions were taken as 150 mm by 150 mm in cross-section and a height 1.5 m was chosen for the infill. Each beam-to-column joint had horizontal stirrups to prohibit brittle shear failure. The concrete base of the specimen was cast one week before the frame. The concrete was made with Ordinary Portland cement conforming to the ACI

code, crushed stone aggregate (maximum size of 10mm) and natural river sand as fine aggregate. Finally, curing of the RC frame was done by covering it with hessian in moist condition.

The reaction frame consists of a base beam and two columns. The base is stiff enough to withstand any bending failure during testing of the infilled frame. The lateral load was applied by means of 267 kN hydraulic jacks as shown in Fig.2. These jacks were mounted at the top of column, which is supported by a cantilever element projected from top of the column. Detail design of the reaction frame is shown in Fig.3. The bending strength of the column is not sufficient to withstand the reaction of the hydraulic jack. Therefore, a pair of tie rods on each side of the frame was used to tie the column top to the farthest point of the base as shown in Fig.2.

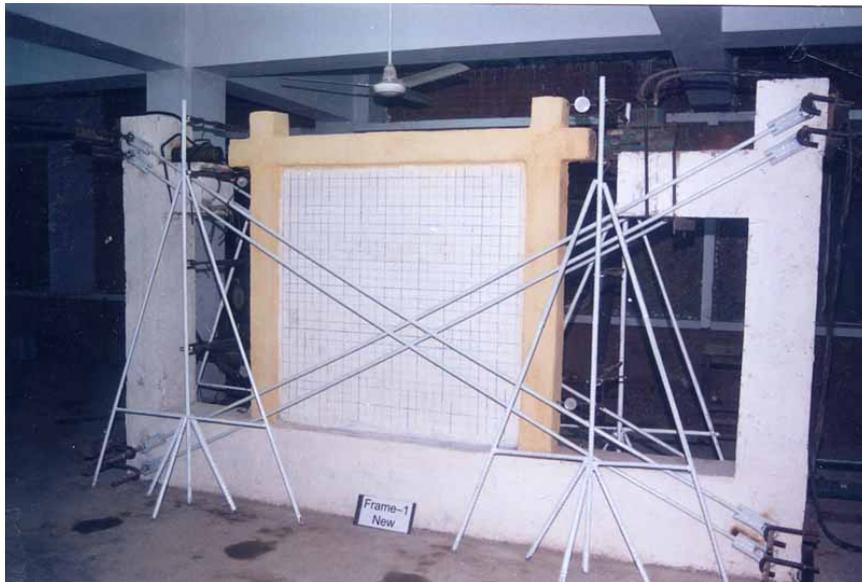


Fig.1. General test setup

Four deflectometers were used to measure the deflection of the infilled frame. Two were towards the loaded side and the other two were on the leeward side. These are used to measure the top and the bottom deflection from both sides, as shown in Fig.2. While measuring the dial reading, it was ensured that movement of the test frame does not affect the reading and that all dial readings are taken with respect to a stationary reference, which is, in this case, the floor of the lab. To accomplish this, two sets of mounting frame made of 25 mm diameter rods were constructed, which can be seen in Fig.1. Four dial gauges were attached to the mounting frame.

For the model, scaled down masonry units were used for the infill panel. Masonry specimens were obtained by slicing a normal size brick (250 mm x 125 mm x 75 mm) using a diamond saw. For the infill panel, 125 mm x 75 mm x 35 mm solid clay bricks were used in the specimen. Its configuration is shown in Fig. 4. The infill was constructed by a professional mason after the frame had been completed. The clay bricks had mortar applied onto the entire bed joint. The head joints were filled partially with mortar as practice. The bed and head joints were 9.5 mm thick. The specimen was tested at least 28 days after the construction of the infill. Then the distressed infill panel as well

as the frame was rehabilitated with ferrocement overlay. The rehabilitated infilled frame was tested again at least 28 days after repairing.

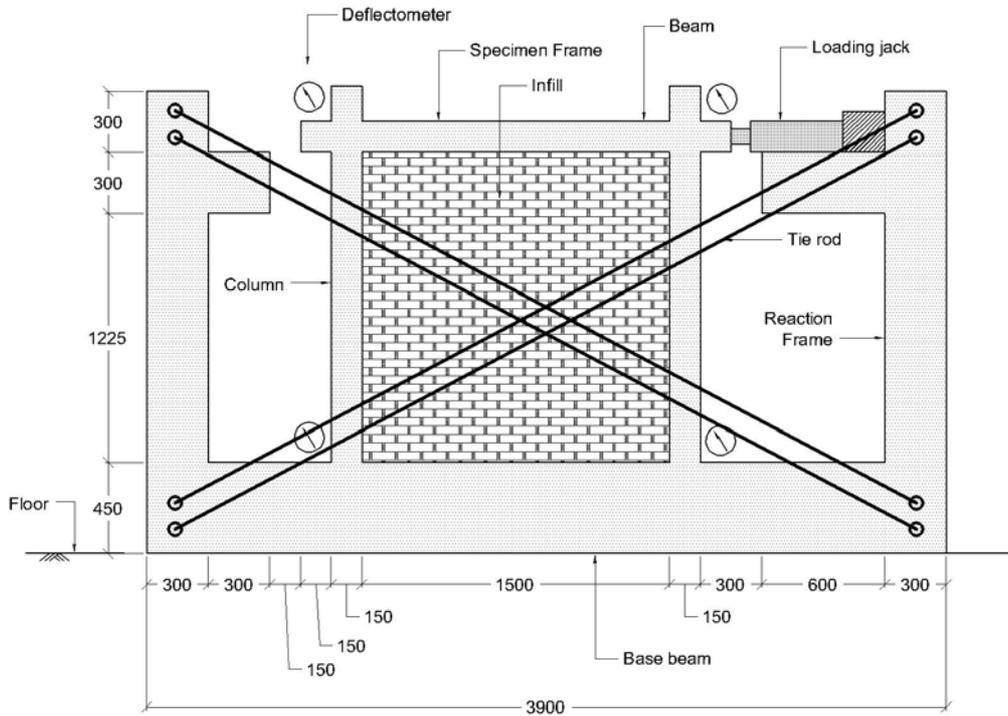


Fig. 2. Schematic diagram showing test setup details

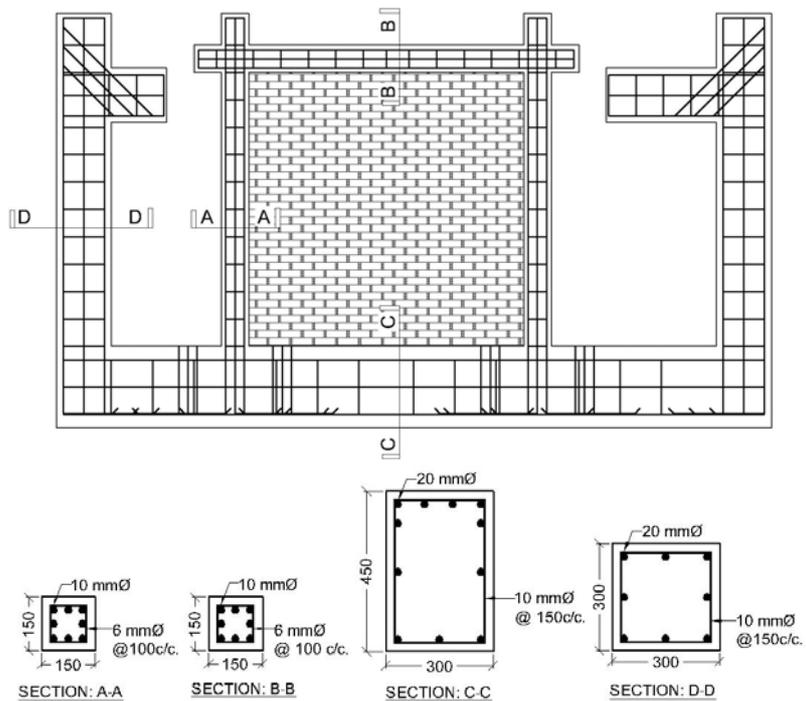


Fig. 3. Reinforcement details of frames



Fig. 4. Scaled down brick specimens sliced out from full sized brick

2.1 Material properties

Material tests were conducted on the reinforcing steel and on concrete and masonry samples for the specimen. The specimen beam and columns were cast with crushed stone coarse aggregates having maximum aggregate size of 10mm. The mix ratio was 1:2:4 and the 7 day cylinder compressive strength was found to be 16.4 MPa. The yield strengths of reinforcement were tested to be 689 MPa, 318 MPa and 441 MPa for 6mm, 10mm and 20mm bars respectively. The compressive strength of stack bonded prism specimens made of scaled down bricks were 18 MPa and 14 MPa for load perpendicular and parallel to joints respectively. The compressive strength of mortar used in ferrocement was tested to be 34 MPa at 7 days.

2.2 Testing procedure and load pattern

The masonry infilled RC frame was tested by applying monotonic lateral load at the top of the RC column up to initiation of failure. The surface of masonry infill (both sides) and all sides of column were colored white and yellow to facilitate the viewing of cracks. Load was increased stepwise at the rate of 1 ton per step until the failure occurred. Applied loads were recorded from machine dial gauges. The test was terminated when severe damage was observed in the specimen. Fig.5 shows the failed infilled frame with a prominent diagonal crack.

2.3 Rehabilitation of distressed infilled frame

Ferrocement technique was adopted to repair the distressed RC frame and masonry infill wall. At first the mortar cover was chipped off. The chipping process continued from either side of the crack. Fig.6 shows the distressed masonry infill panel after chipping off the mortar layer. After chipping, the surface was cleaned thoroughly and washed with a water jet to remove dust and loose debris. In order to ensure proper bond between crack surfaces, cement slurry was sprayed over the crack. Thereafter a thin layer of mortar was

applied all over the surface of the column and masonry. Afterwards, two layers of wire mesh were placed on columns and one layer mesh was placed on the infill on both sides, which were held in place by the previously affixed nails. Thereafter, the final layer of mortar was applied on the wire mesh. This mortar penetrated through the openings of the mesh and came in contact with the previously applied mortar thus securing the mesh in place with proper bonding. Finally, curing of the repaired frame was done by covering the rehabilitated region with hessian in moist condition.

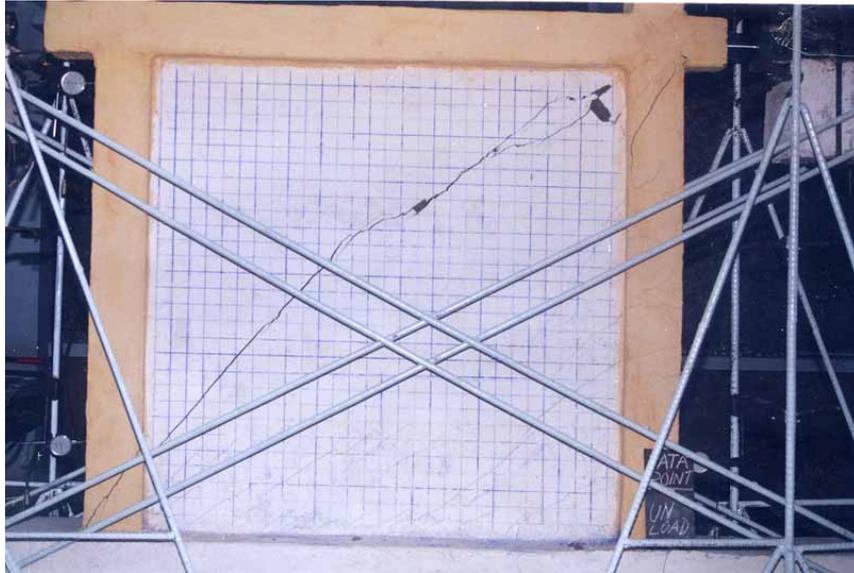


Fig.5. Failed infilled frame with a prominent diagonal crack.

2.4 Testing the rehabilitated frame

After repairing of the distressed masonry infilled RC frame, the surface of masonry infill and all sides of columns were painted white and yellow respectively to facilitate the viewing of cracks. The repaired frame was again tested using hydraulic jack in the laboratory with the previous test setup. One point loading was applied over the top of the frame by the hydraulic jack and was recorded using machine dial gauge and the deflections were measured using dial gauges placed at the same locations as discussed earlier.

3. Experimental results

3.1 Results from the original infilled frame

The load was applied monotonically with the hydraulic jack at the top of the frame with an increment of 1 ton. At one stage of loading, approximately at 12 ton, first crack appeared along bottom right corner of masonry infill. The crack propagated diagonally upward as load was gradually increased and the number of cracks was also increased with the increase of load. All the cracks propagated through infill towards upward direction. Both faces of the infilled RC frame showed similar crack pattern. At a load of 19 ton, the infill frame was failed with a major diagonal crack. The diagonal cracks were also observed at the top of the column at loaded side and at bottom of leeward side. The

crack went through the masonry (Fig.6), which means that brick failure occurred. After the full failure of the frame and infill, the loading was stopped and frame was kept for repairing. The load deflection curve of the original frame is shown in Fig.7 with a continuous line.



Fig. 6. Close up view of the crack after the plaster is chipped off.

3.2 Crack growth in original infilled frame

When load was gradually applied to the original frame, the frame deflected at the top, thereby causing shear deformation in the infill panel. The first visible crack appeared near the bottom of infill at the loading side at a load of 12 ton. The corresponding top deflection was approximately 4mm. The cracks were diagonal in nature. The corresponding shear strain can be calculated as 0.00262 radian. Thus it is possible to get an idea of the maximum shear strain that may be developed in infill to produce visible cracks. This first diagonal crack appeared at the furthest corner from the loaded compression diagonal. This indicates that the infill was substantially bonded with the base as well as with the column. When load was increased to 15 ton, several cracks parallel to the first one were observed. However, at this stage, horizontal cracks were developed in the column at the loading side. These cracks are developed due to the tension developed in the column. Development of such crack continued till 18 ton load. When the load reached 19 ton the frame with infill failed with a major diagonal crack as seen in Fig.5. Diagonal cracks were also observed at the top of the column on the loading side and bottom of the column on the leeward side. This indicates that the columns were weaker in shear. Observing the major diagonal cracks, it can be said that the infill failed basically due to diagonal tension. Also, the more or less straight nature of the crack reveals that the crack passed through brick infills. This is visible in Fig.6, which shows the damaged infill after the plaster is removed. The reasons behind failure

of bricks may be attributed to the fact that the mortar was probably stronger than the bricks.

3.3 Results from the repaired frame

The repaired frame was tested in a similar fashion as the original frame. The first crack in the infill was formed at the bottom of the leeward side at a load of 16 ton. The corresponding deflections at the top and bottom were 5.99 mm and 1.87 mm, which are less than those of original frame (6.38 mm and 3.63 mm respectively). These cracks propagated vertically upward as the load was gradually increased. At a stage of loading of 23 ton, the repaired frame was failed as shown in Fig.8. Again, the diagonal cracks were observed at the top of the column at loaded side and at bottom of column at leeward side also, which can be seen in Fig.8. Load deflection curves of the rehabilitated infilled frame are shown in Fig.7 with the dashed line. It is also found that, for comparable loads, the deflections of rehabilitated frame are less than those of the original frame.

3.4 Crack growth in repaired infilled frame

When the frame was repaired, the dimension of the sections of infill and the beam and columns were slightly changed due to the addition of ferrocement coating. In the original frame, the plaster was about 12.5 mm thick everywhere. In the repaired frame this thickness was about 19 mm. When the repaired frame was subjected to loading, cracks started appearing at 16 ton load, which is higher than the corresponding load of the original frame. These cracks propagated vertically upward as the load was gradually increased. At a stage of loading of 23 ton, the repaired frame failed with the occurrence of a major diagonal crack at the same location as was in the original frame. This is due to the fact that the cracks in the original frame were not repaired; instead, the whole frame was coated with ferrocement. This left the crack zones weaker than other parts of the frame and infill. As a result, cracks in the repaired frame occurred at the same location, as the cracks appeared in the original frame. It was, however, observed that the amount of crack opening (width of crack opening) was significantly smaller than those of the original frame. This reveals the superior capability of the ferrocement in protecting the damaged structure from environment. Fig.8 shows the repaired frame after failure in which the smaller width of cracks is visible when it is compared with Fig. 5.

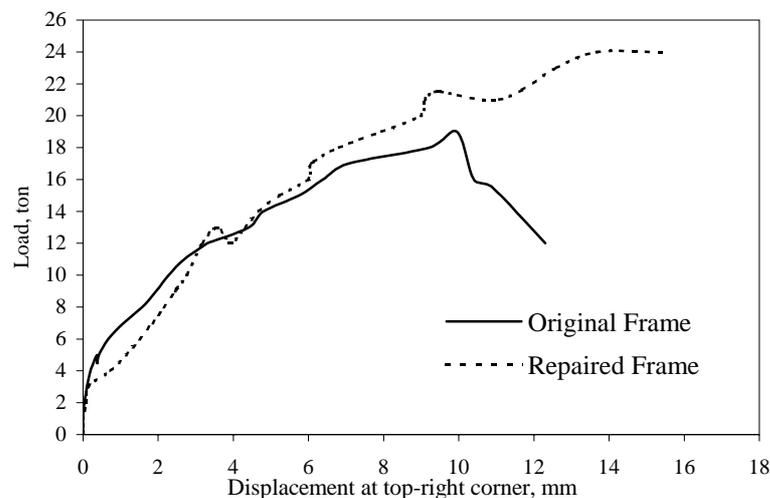


Fig.7 Load vs. displacement diagram of original and repaired frame

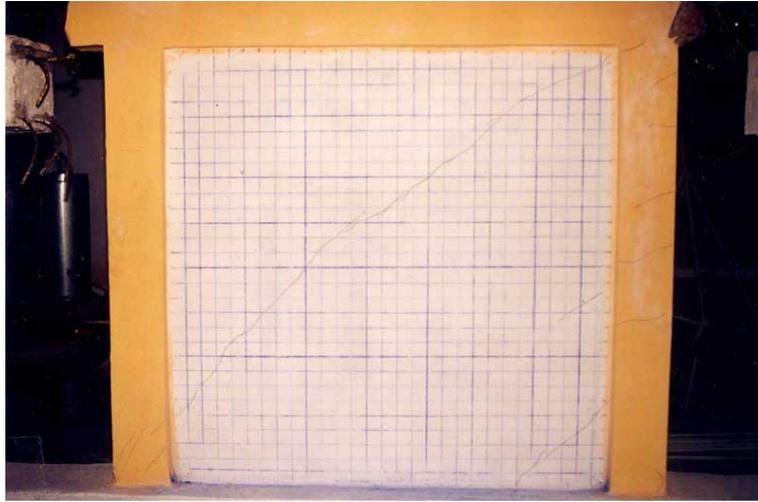


Fig.8. Cracks in the repaired frame

4. Performance of ferrocement coating

After the frame was repaired using ferrocement overlay, the tested capacity was even higher (23 ton). Comparison of the load vs. displacement characteristics of the original frame and repaired frame can easily be observed in Fig.7. This figure clearly demonstrates the effectiveness of the repair methodology using ferrocement overlay. Since the failure of the repaired frame was diagonal tensile failure, it can be inferred that the capacity of repaired frame depended on the tensile strength of the ferrocement. In the repaired frame, the cracks were not repaired. It can be thus said that the combined capacity of the two layers of ferrocement was higher than the masonry. If before applying ferrocement coating, the cracked masonry and column were repaired using epoxy grouting then these components could contribute to the load carrying capacity of the ferrocement. That would have resulted in even higher load capacity. It can, thus be said that, if ferrocement overlay is applied to any existing undistressed infill then the capacity of the infilled frame will be significantly higher.

5. Conclusions

An experimental investigation is presented in which a portal frame with infill was subjected to monotonic loading till failure. The failed frame was then repaired using ferrocement coating and was tested again to failure. The failure load of the repaired frame was higher than that of the original frame. Thus it can be concluded that ferrocement overlay is a highly effective method of strengthening/repairing distressed reinforced concrete frame with masonry infill. Since the tested capacity of the repaired frame was more than the capacity of the original frame, it is quite logical to say that if ferrocement overlay is applied to any existing undistressed infill, the lateral load capacity of the frame would significantly be increased. From the experiment it is also observed that the width of cracks developed in the repaired frame were smaller than those of the original frame. This establishes the superior capability of ferrocement in protecting the repaired frame from environment. It should be kept in mind that due to limited scope, only a single frame was tested. In order to generalize the findings, more

tests are required to be done. Therefore, the findings of the present study should be interpreted with due considerations given to the limited nature of the investigation.

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