Using Ferrocement in Repair and Strengthening of Corner Beam-Column Joints subjected to Displacement Cyclic Loading

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ABSTRACT (extended)

Beam-column joints are more liable to damage compared to other structural elements, when the structure is subjected to earthquakes excitations or cyclic loading. Joints in typical buildings, constructed before issuing the current Egyptian Code of Practice (ECP 95), lack adequate steel reinforcement detailing to resist dynamic excitations without suffering excessive damage. In these joints, the confining reinforcement such as column stirrups does not extend in the joint region. The pattern of joint damage in building subjected to the October earthquake in 1992 showed that the lack of joint confinement was one of the major reasons for joint damage. Hence, the need for an adequate cheap and environment friendly method for joint confinement either in strengthening or repair would be indispensable especially for probable future earthquakes. Several methods are available for joint strengthening, however, the use of steel wire mesh (or Ferrocement overlays) gives a promising method for which all the used materials are locally produced with no materials with harmful effect on human health. The challenge in the tested models in the current study is the repair of 3D-joints with the existence of a secondary beam perpendicular to the plan of loading. This secondary beam represents an obstacle for easily wrapping of steel-wire mesh and that resembles the joint in real structures. The study consists of testing 3D beam-column joints under cyclic displacement-controlled cyclic loading. Five Full-scale specimens with various study parameters are tested. The models tested are for corner joints. Test measurements include applied displacements, applied loading and induced deflection. Test comparisons are based on energy dissipation, stiffness and strength degradation with loading cycle till joint collapse initiation.

KEYWORDS: Beam-column joints; energy; ferrocement

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INTRODUCTION

The building damage vulnerability in Egypt, due to earthquake excitation, has been increased in the last decade. After the major earthquake in 1995, great effort was devoted to enhance the building capacity to resist earthquake excitations without major damage. Special concern was devoted to the beam-column joints, where most of building damage seems to be located. One of the major reasons for joint damage was the inadequate reinforcement that provides joint confinement. Unfortunately, and after inspection of existing buildings, it was observed that most of the beam-column joints need strengthening or repair to withstand similar earthquakes. The need for a cheap, reliable method of repair and strengthening becomes indispensable.

One of the promising strengthening methods is the use of ferrocement overlays. Ferrocement is a form of reinforced concrete using closely spaced multiple layers of mesh and/or small diameter rods completely encapsulated in mortar[1]. Previous researches were performed on the application of ferrocement technology in strengthening of masonry structures[2,3,4], reinforced concrete beams[5,6], slabs[7,8], domes and arches[9] and columns[10]. On the other hand, and concerning the applications in repair, ferrocement was used in relining of sewers or tunnels[11], repair of steel structures[12].

Irrespective of strength, ferrocement has several advantages compared to other strengthening methods such as: ductility, crack control[11]. Moreover, for developing countries like Egypt, other characteristics such as ease of application, cheapness, local production, non-toxic effects and light in weight will be of important concern.

Research Objectives

The paper reports the effectiveness of ferrocement in either strengthening or repair of corner beam-column joints, and showing its merits and demerits. Full-scale joint models are tested. The joints are subjected to displacement control cyclic loading at the tip of the beam end. Moreover the existence of out-of plan beam, perpendicular to the plan of loading, provides another challenge for wrapping ferrocement overlays, due to the discontinuity of steel wire mesh for ferrocement layers.

EXPRIMENTAL PROGRAM

Specimen dimension and concrete mix

The current study is performed on a full-scale corner beam-column joints. As shown in Fig. 1, corner joint is a four-legged specimen. The column section is 20 x 30 cm^2. The main beam which is subjected to cyclic loading is 20 x 40 cm^2 and have a length 150 cm. Another secondary beam of section 30 x 40 cm^2 is confining the joint from one side while the other side is left unconfined. The joint is cast monolithically to act as one unit with no surface of separation. The average concrete characteristic compressive strength is 250 kg/cm^2.

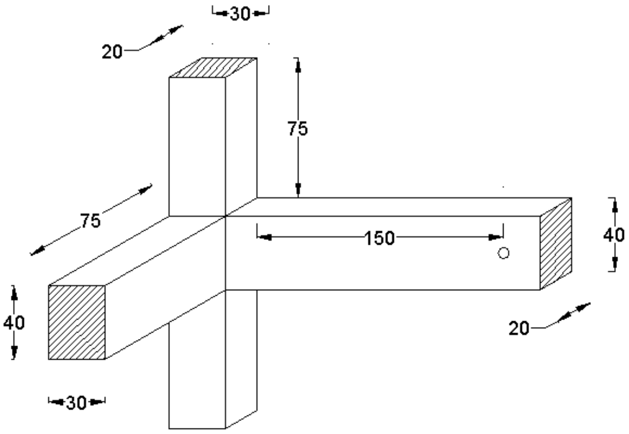
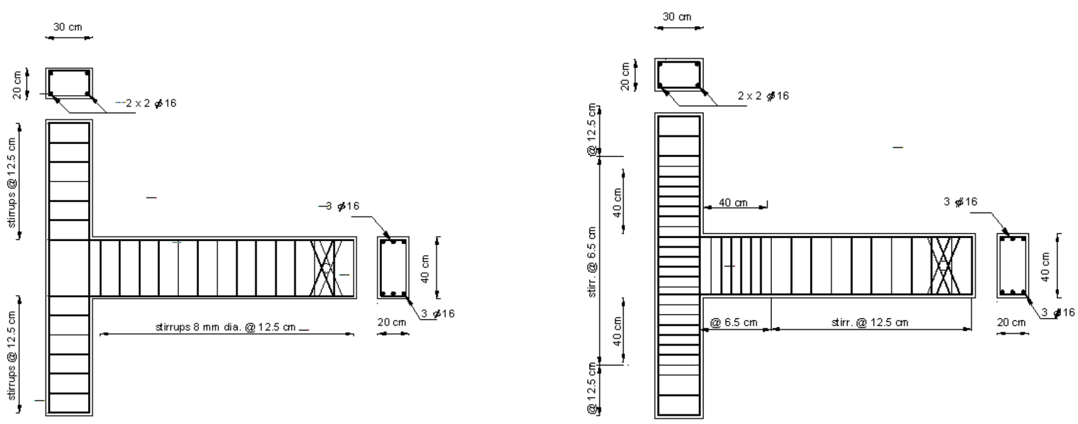


Fig. 1 Specimen Dimensions

Specimen Reinforcement

Fig. 2 shows the reinforcement arrangements of the specimens. The average yield strengths of the used reinforcing steel for longitudinal and stirrups are 3600 and 2800 kg/cm^2, respectively. To account for stress concentration at the tip of beam, cross steel reinforcing bars are provided. The first reference specimen RCJ1, shown in Fig 2a, is not provided with stirrups in the joint region. The specimen RCJ1 resembles the usual joint in traditional buildings which is designed, only, to resist vertical loads. On the other hand, the reference specimen RCJ2, shown in Fig. 2b, is designed according to the ACI regulations for joints to resist cyclic loading. Stirrups are provided in the joint region with closer spacing distance.



(a) **(b)**

Fig. 2 Specimen reinforcement details.
a) without reinforcement in joint, specimens RCJ1, CJ2, CJ3, CJANG
b) with additional reinforcement in joint, specimen RCJ2

Two other specimens, having the same reinforcement as that of reference specimen RCJ1, i.e. without stirrups in joint region, are tested. These specimens are wrapped with wire mesh sheets in multiple layers. These specimens, named CJ2 and CJ3, are strengthened with two or three ferrocement layers before testing.

After specimen RCJ1 had been tested, the damaged concrete was removed and the cracks were filled with epoxy mortar. Three ferrocement layers were also added. The repaired specimen is named CJANG. A steel angle is provided to ensure the fixation of the ferrocement layers to the specimen. The reinforcement and the number of ferrocement layers are described in Table 1.

Table 1. Specimens' description and no. of ferrocement layers

Name	Description	No. of ferrocement layers
RCJ1	Residential Building joint (Lower bound)	
RCJ2	Seismic resistant (upper bound)	
CJ2	Strengthened (ferrocement layers)	Two
CJ3	Strengthened (ferrocement layers)	Three
CJANG	Repaired (ferrocement + steel angle)	Two + angle

Specimen wrapping with ferrocement layers

Ferrocement layers are applied to specimens for strengthening or repair. Special care was devoted to assure contact between the ferrocement and the concrete throughout the test duration and avoid early separation. The concrete cover is removed; hence the surface roughness is increased. Threaded dowels are drilled into the concrete with sufficient embedded length. Steel wire mesh pieces are wrapped around the specimen and cement mortar is applied to the layer. The cast layer is cured until complete setting is assured. The process is repeated for every ferrocement layer. Finally a washer is tied to the threaded dowels combining all the ferrocement layers. Schematic details of the steel wire meshes and the arrangement of dowels are shown in Fig. 3

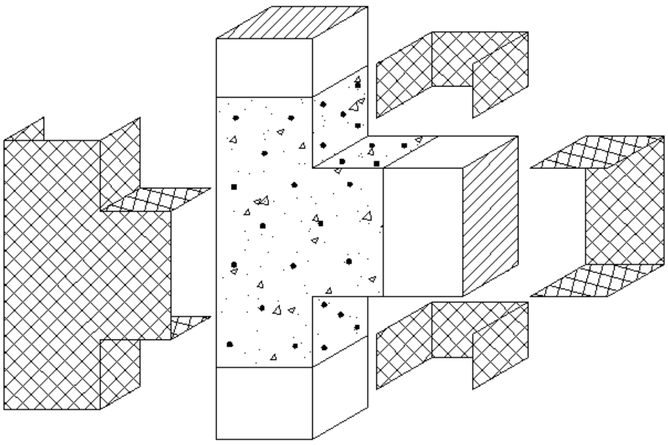


Fig. 3 Specimen wrapping with expanded wire mesh and ferrocement overlays

Test setup

Specimens are tested under symmetrically reversed cyclic displacement-controlled loading. The setup of specimen is shown in Fig. 4. Constant vertical load equals 20 tons is applied to the column by a hydraulic jack, indicated in figure as jack no. (1). The vertical load is applied manually by means of hydraulic pump. On the other hand, the dynamic load is applied by means of computerized data acquisition system to ensure accurate and immediate load and displacement monitoring. Displacement magnitude versus load cycle is stored as input data into the computer of the system. The displacement history, shown in Fig. 5, is applied to the beam end by means of a reversed hydraulic jack, indicated in figure as jack no. (2). The computer is measuring the applied load to the beam by means of loading cell mounted to the reversible hydraulic jack. Moreover, the induced deflection is measured by an LVDT under the beam end. After reaching the displacement level, the load is remained till balancing occurs between the loading and the specimen deformations. After recording the deflection, the next loading step is applied.

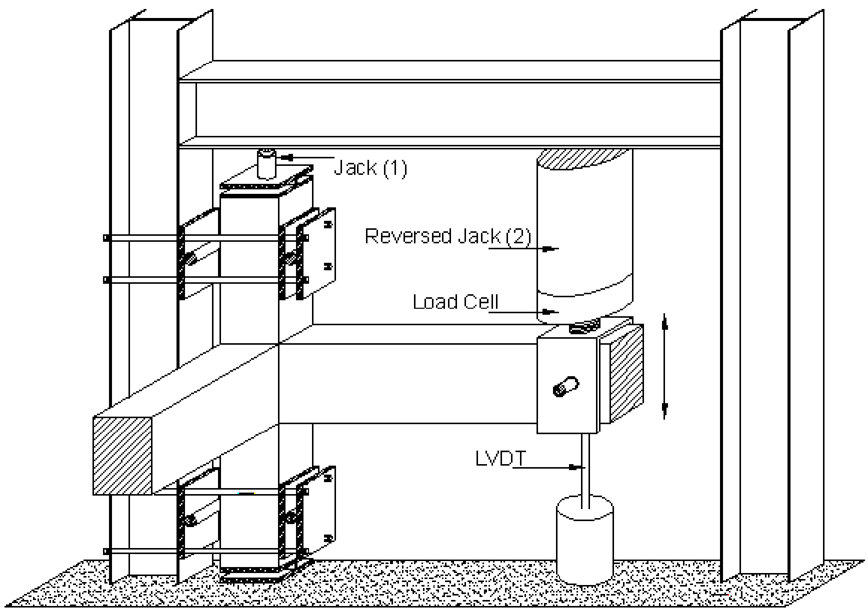


Fig. 4 Test Setup

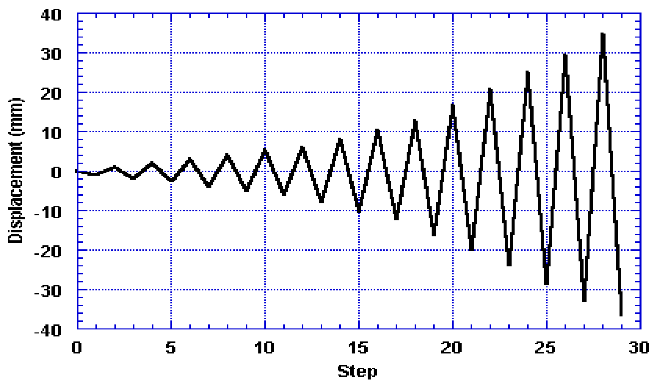
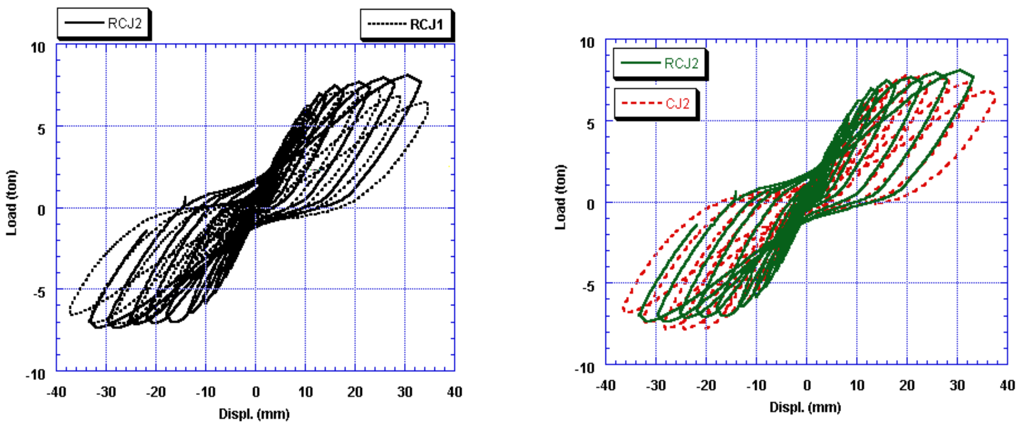


Fig. 5 Displacement load history applied at beam end

RESULTS AND DISCUSION

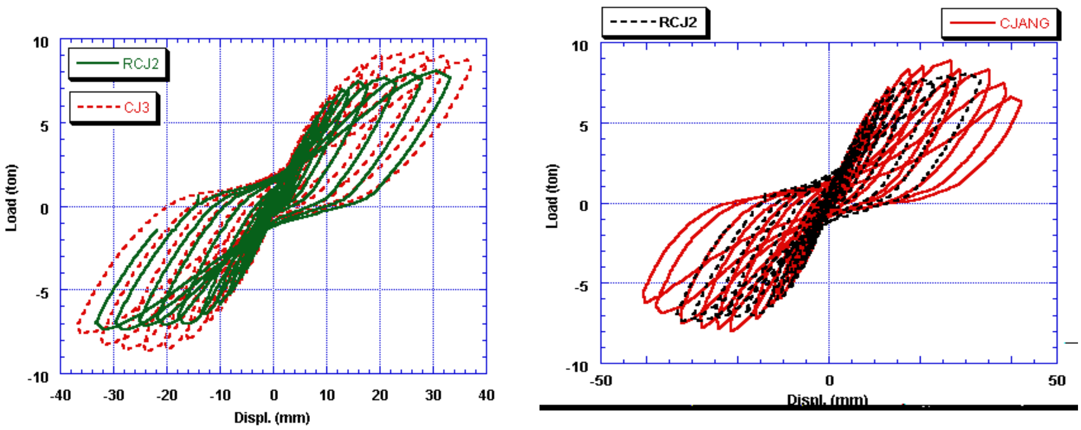
Load-displacement hysteresis loops

Fig. 6 shows load-displacement hysteretic loops for the tested specimens. The main comparison viewpoints are the symmetry of the loops, the yield load level, and the number of cycles in yield, before decrease in load. Symmetry of the loops assures the proper setting of specimen and load setup (i.e. no eccentricity in load). In general, all the tested specimens have shown excellent loop symmetry. Fig. 6.a shows a comparison between specimens RCJ1 and RCJ2. It can be easily seen that the level of yield load for specimen RCJ2 is 8.5 tons is greater than that for specimen RCJ1 that is 7.0 tons. Moreover, Specimen RCJ1 exhibits three complete cycles before the strength decreased below the yield load. On the other hand, specimen RCJ2 strength still constant in the same three displacement cycles. Although both specimens have the same flexure steel reinforcement, it is easily concluded that the difference in behavior is due to the effect of the increased in joint confinement due to the addition of transverse reinforcement. Referring to specimens strengthened before testing, a comparison is shown in Fig. 6.b for hysteresis loops of specimens RCJ2 and the specimen strengthened with two ferrocement layers CJ2. The yield load is almost the same for RCJ2; however, the load cycles at yield load are less. A comparison is shown in Fig. 6.c for hysteresis loops of specimens RCJ2 and the specimen strengthened with three ferrocement layers CJ3. Although specimen RCJ2 may be considered as an upper bound for the joints, as it is a joint designed to resist cyclic loading according to ACI provisions, the behavior of CJ3 shows better performance with greater yield load of 9.5 tons. Also, the yield load remains constant along the five loading cycles. Better performance of specimen CJ3 compared to specimen CJ2 is due to increase of layers. The efficiency of ferrocement layers application in repair is also tested. The results for specimen CJANG with three layers of ferrocement and a steel angle are shown in Fig. 6.d. The yield load is almost the same for RCJ2. The load cycles are almost the same before the strength starts to decrease.



(a) (b)

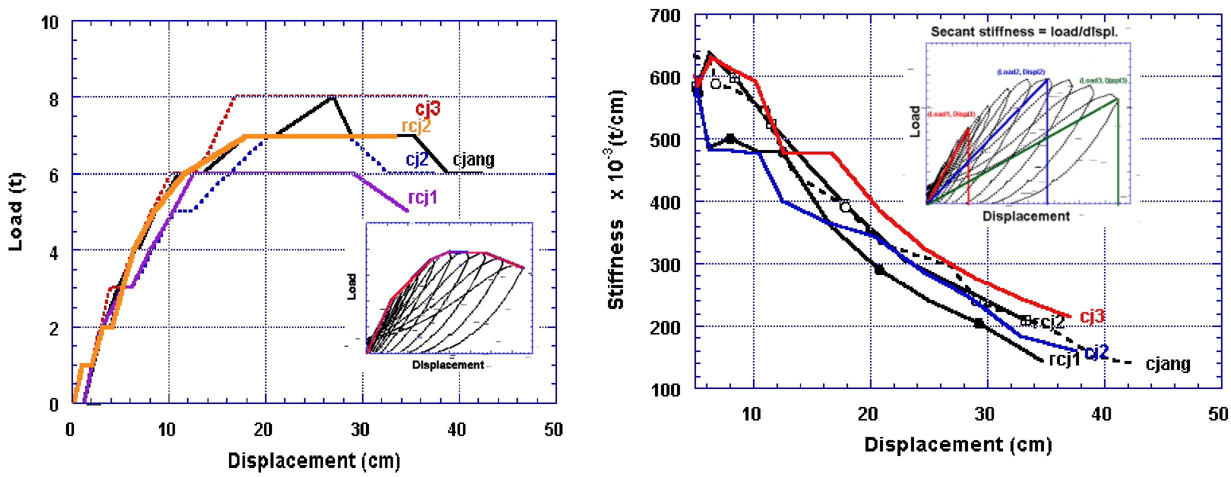
Fig. 6 Load-displacement hysteresis loops: a) RCJ1 and RCJ2 , b) RCJ2 and CJ2



(c) (d)

Fig. 6 Load-displacement hysteresis loops: c)RCJ2 and CJ3 and d) RCJ2 and CJANG

Envelops for load-displacement in the positive load and displacement directions are compared in Fig. 7.a. It can be noticed that specimens CJ3 and CJANG show better performance over the other specimens, even over the reference specimen RCJ2. Due to the repair effect, specimen CJANG shows lower stability of strength compared to CJ3. This notice is shown in Fig. 7.b, where comparison for the cycle secant stiffness degradation is compared for the specimens. Cycle secant stiffness is calculated as the maximum attained load in the specified cycle divided by the maximum attained displacement in the cycle. It can be noticed that CJ3 showed the best stability for stiffness degradation.



(a) (b)

Fig. 7 Specimen comparison: a) strength envelopes , b) secant stiffness degradation

From the previous discussion about load-displacement behavior for the tested specimens, it can be concluded that the addition of ferrocement layers enhances the capacity of joints to resist higher loads. In addition, the rate of strength and stiffness degradation, with respect to loading cycle is decreased.

Hysteretic energy dissipation
The energy dissipated at the beam-column joint through plastic deformations was the sum of the area in the force-displacement hysteresis loops as shown in Fig. 8. The capacity of tested joints to dissipate energy during the loading cycles is compared. Referring to Fig. 8, the cumulated hysteretic energy dissipated is bigger for the joints either repaired or strengthened compared to the reference joints (RCJ1, RCJ2). It can be concluded that due to the addition of ferrocement layers, the capacity of the joint to dissipate energy increased.

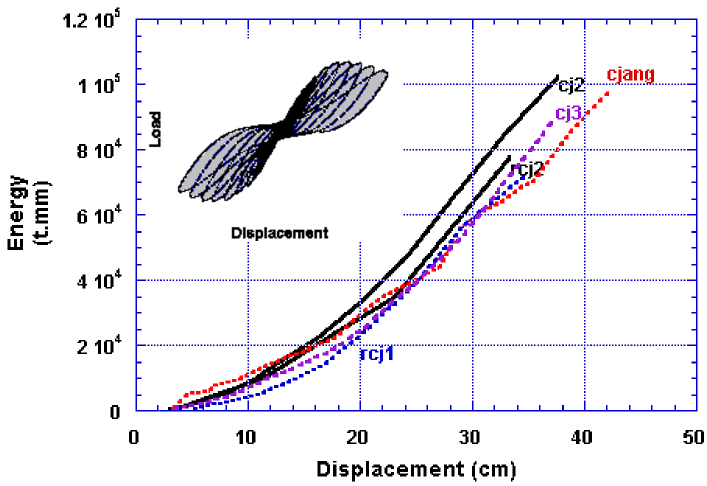


Fig. 8 Specimen comparison (cumulative hysteretic energy)

CONCLUSIONS

The efficiency of ferrocement overlays in strengthening and repair of reinforced concrete corner joints, subjected to displacement control symmetric cyclic loading, is revealed in this study. It was shown that strengthening with ferrocement would enhance greatly the load carrying capacity as well as the energy absorbing capacity of the joint. The ferrocement layers will substitute as shear reinforcement in the joint region. Hence the use of ferrocement layers in strengthening joints without shear reinforcement will enhance the behavior of these joints and will reduce the vulnerability of these joints to be excessively damaged when subjected to seismic loading. For the repaired tested joint by ferrocement, the joint is well restored and both energy dissipation and load carrying capacity is increased. Special care should be devoted to assure contact between the ferrocement and the concrete surface, and to avoid early separation. This can be achieved by roughness of the surface, adding dowels and steel angels.

REFERENCES

1. ACI Committee 549, "State-of-The-Art Report on Ferrocement", ACI, Detroit, 1988
2. Reinhorn A.M., Prawel S.P. and Jia Z.H., 'Experimental Study of Ferrocement as a

Seismic Retrofit Material for Masonry Walls", Journal of Ferrocement (Bangkok), Vol 15, No.3, July 1985, pp 247-260

3. Singh K.K., Kaushik S.K. and Prakash A, "Strengthening of Brick Masonry Columns by Ferrocement", Proceedings of The Third International Symposium on Ferrocement Roorkee 1988, pp 306-313
4. Walker P.J. and Damo M, "Shear Reinforcement for Brickwork Beams using Ferrocement", Journal of ferrocement, Vol. 27, No. 1, Jan. 1997, pp 33-45
5. Anwar A.W., "Rehabilitation of Structural Elements Using Ferrocement", M. Engg. Thesis, Asian Institute of Technology, Bangkok, 1989
6. Fahmy E.H., Shaheen Y.B. and Korany Y.S., "Repairing Reinforced Concrete Beams by Ferrocement", Journal of Ferrocement, Vol. 27, No. 1, Jan. 1997, pp 19-32
7. Shabaan I.G., "Behavior of Thin Plates Reinforced with Wire Fabric", Ain Shams University, Scientific Bulletin, Vol. 32, No. 4, Egypt 1997
8. Shabaan I.G., "Behavior of Small Concrete Elements reinforced or Repaired with Expanded Steel Mesh", Journal of the Egyptian Society of Engineers, Vol. 37, No. 2, Jan. 1998, pp 28-35
9. Shabaan I.G. and Ibrahim I.M., "Analysis of Ferrocement Roof Structures: New Construction and Utilization in Repair Procedures", The 4th International Conference on Concrete Engineering and Technology", Malaysia 1995
10. Fahmy E.H., Shaheen Y.B. and Korany Y.S., "Application of Ferrocement Laminates in repairing Reinforced Concrete Columns", Proceedings of the Arab conference for Repair and Rehabilitation of Structures, Vol. 1, 1998, pp. 411-422
11. Romualdi J.P., "Ferrocement for Infrastructure Rehabilitation", Concrete International, Vol. 9, No. 9, Sept. 1987, pp. 24-28
12. Trikha D.N., Sharma P.C. and Johnson S., "Rehabilitation of Corrosion-Damaged Steel Tanks by Ferrocement Treatment at University of Roorkee", Proceedings of the 3rd International Conference on Ferrocement, Roorkee 1988, pp. 207-215