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Analysis and Design of Ferrocement Panels an Experimental Study

Nagesh M. Kulkarni, D.G.Gaidhankar

Abstract-Ferrocement is a form of reinforced concrete that differs from conventional reinforced or prestressed concrete primarily by the manner in which the reinforcing elements are dispersed and arranged. It consists of closely spaced, multiple layers of mesh or fine rods completely embedded in cement mortar. This paper describes the various experiments conducted on ferrocement panels in literature review and the conclusions and remarks drawn by the authors. The results obtained are going to help in the project work to investigate the behavior of ferrocement panels for various parameters and loading. This is useful to find solutions by searching new design techniques and method of constructions.

Keywords:- Cement mortar, Ferrocement, Mesh, Panels

I. INTRODUCTION

Ferrocement is a highly versatile form of reinforced concrete made up of wire mesh, sand, water, and cement, which possesses unique qualities of strength and serviceability. It can be constructed with a minimum of skilled labor and utilizes readily available materials. There are several applications of Ferro cement which include building industry, irrigation sector, water supply and sanitation areas. Studies indicate that it appears to be an excellent composite in the case of seismic resistant structures.

Ferrocement is a building material composed of a relatively thin layer of concrete, covering such reinforcing material as steel wire mesh. Because the building techniques are simple enough to be done by unskilled labor, ferrocement is an attractive construction method in areas where labor costs are low. There is no need for the complicated formwork of reinforced cement concrete (RCC) construction, or for the welding needed for steel construction, everything can be done by hand, and no expensive machinery is needed.

The main difference between ferrocement and reinforced concrete is ferrocement is a thin composite made of cement matrix reinforced with closely spaced small diameter wire meshes instead of larger diameter rods and large size aggregates. The thickness of ferrocement generally ranges from 25 - 50 mm. The latest ACI Code encourages the use of non - metallic reinforcement and fibres.

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Ferrocement is an environment friendly sound technology and possesses excellent unique properties such as good tensile strength, improved toughness, water tightness, liglitness, fire resistance, resistance to cracking and cost, time and material effective construction technology.

The following definition was adopted by the ACI Committee: "Ferrocement is a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh. The mesh may be made of metallic or other suitable materials."

A. Durability of Ferrocement

According to the ACI Committee, 'durability' is defined as 'ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration', that is, durable concrete will retain its original form, quality and serviceability, when exposed to its environment. The various measures required ensuring 'durability' in conventional reinforced concrete is also applicable to ferrocement, since, ferrocement has almost the same type of ingredients/constituents**,** except, coarse aggregates and the use of smaller fine aggregates, than conventional concrete and a thin cross section. However, other unique factors, which affect durability, especially, the susceptibility to corrosion of ferrocement are:

1. The cover to the mesh reinforcement is very small;
2**.** The cross sectional area of the mesh reinforcement wires is very low;
3**.** The surface area of the reinforcement is high because of small wires being used
4. Mesh reinforcement are galvanized to prevent corrosion, but the zinc coating can cause and produce hydrogen gas bubbles during hydration.

B. History of Ferrocement

Ferrocement is the name given by Italian Professor Pier Luigi Nervi to a thin slab of mortar reinforced with superimposed layers of wire mesh and small diameter bars. The result is a product with a high degree of elasticity and resistance to cracking which can be cast without the use of formwork. Nervi successfully proved on many jobs the remarkable strength and lightness of this method of construction and its great adaptability to any shape. The end result of Nervi's experiments was a medium in which the thickness of a finished slab was only a very little greater than that of the assembled layers of mesh, the difference being only as much as was necessary to provide adequate cover for the steel. This ferro-cement was found on testing to have very little in common with normal reinforced concrete, however, since it possesses the mechanical characteristics of a completely homogeneous material. ACI Committee 549, Ferrocement and Other Thin Reinforced Products, was organized in 1974 and was given the mission to study and report on the engineering properties, construction practices, and practical applications of ferrocement and to develop guidelines for ferrocement construction.

II. LITERATURE REVIEW

A. FERROCEMENT FLOOR AND ROOF SYSTEM FOR BUILDINGS By Dr.T.S.Thandavamoorty and S.Durairaj Professor at Adhiparasakti Engineering college Melmaaruvathur

A hollow cored ferrocement floor panel of size 900 mm X 600 mm was precast with cement mortar 1:2 and cured for 7 days. Then it was arranged in a loading frame and tested under gradually increasing static loading till failure. The ultimate load sustained by the panel was 85 kN.

Experimental Program

A welded mesh was prepared with two layers of chicken mesh. The specimen was casted with cement mortar 1:2 and reinforcement mesh as prescribed. The finished specimen was cured for 7 days. The specimen was arranged on a loading frame. Load was applied in increment and dial reading for each in increment was recorded. Load was increased till failure of the panel.

Results

The ultimate load observed was 85 kN. This load was distributed on the panel with the intensity of 78.7 kN/m2. As per IS 875 part 2 the live load recommended on floor is only 2 kN/m2. Going by this consideration ferrocement floor panel is suitable, realistic and feasible.

B. FLEXURAL BEHAVIOR OF FLAT AND FOLDED FERROCEMENT PANELS by Mohamad Mahmood Civil Engineering department Mosul University Iraq

The paper describes the results of testing folded and flat ferrocement panels reinforced with different number of wire mesh layers. The main objective of these experimental tests is to study the effect of using different numbers of wire mesh layers on the flexural strength of folded and flat ferrocement panels and to compare the effect of varying the number of wire mesh layers on the ductility and the ultimate strength of these types of

ferrocement structure. Seven ferrocement elements were constructed and tested each having (600x380mm) horizontal projection and 20mm thick, consisting of four flat panels and three folded panels. The used number of wire mesh layers is one, two and three layers. The experimental results show that flexural strength of the folded panels increased by 37% and 90% for panels having 2 and 3 wire mesh layers respectively, compared with that having single layer, while for flat panel the increase in flexural strength compared with panel of plan mortar is 4.5%, 65% and 68% for panels having 1, 2 and 3 wire mesh layers respectively. The strength capacity of the folded panels, having the particular geometry used in the present study, is in the order of 3.5 to 5 times that of the corresponding flat panels having the same number of wire mesh layers.

Experimental Program

Geometry of the specimens:

The tested ferrocement elements consist of three folded panels and four flat panels. The dimensions of the folded and flat panels are shown in Fig. (1) which depicts that the horizontal projection of the folded panel is equal to (380x600mm) which is equal to the dimensions of the flat panel. The thickness of all the elements is equal to 20mm. The number and designation of the tested elements are given in Table (1). In handling the folded panel without wire mesh, it failed along the longitudinal folds after removing it from the mold so it has been excluded for the test results. The panels are constructed using the conventional ferrocement materials, which is composed of cement mortar and square wire meshes.

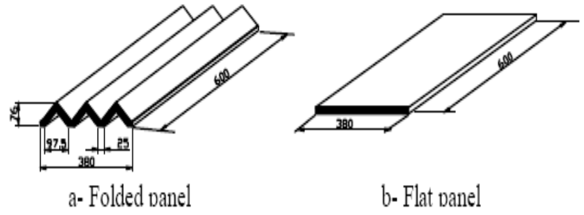

Fig. (1) Dimensions of the folded and flat panels (dimensions are in mm).

Table (1) Details of the tested panels.

Panels number	panel type	Number of mesh layers
A1	Folded panels	1
A2		2
A3		3
B1	Flat panels	0
B2		1
B3		2
B4		3

Wire mesh:

The wire mesh used in the work is mild steel galvanized welded wires of square grid having wire spacing equal to 12.5mm with a wire diameter equal to (0.65mm). Several wires were tested under tension The average values of yield stress (fy), ultimate stress and modulus of elasticity are given in Table (2). The yield stress is determined corresponding to a 0.2% offset according to ASTM standard A370.

Table (2) properties of the constituent materials.

Mortar	
Cement : sand : water (by weight)	1 :2 : 0.45
Cube strength (7 days)	22.5MPa
Cube strength (28 days)	37.4MPa
Modulus of rupture (28 days)	6.3MPa
Wire mesh	
Grid size	12.5x12.5mm
Diameter of wire	0.65mm
Yield stress (0.2% offset)	400MPa
Ultimate tensile strength	500MPa
Modulus of elasticity	63490MPa

Preparation and testing:

A simple rectangular mold having 20mm depth with 600x380mm dimensions is made for the flat panels; while a special mold for the folded panels is made to match the required geometry of the folded panel shown in Fig. (1). Each sample is molded after fixing the required wire mesh (or meshes) in its proper position through the thickness of the sample. Although it is not easy, particularly for the folded panels, special care and effort has been taken to maintain a uniform distribution of the wire meshes throughout the thickness of the panels, this was achieved by using small stone spacer. For the panels with single wire mesh, the mesh was placed at mid depth of the panels. The samples are removed from the mold 24 hours after casting and the elements are cured in water for 28 days at temperature ranges 20° - 25°C. Six samples of standard cubes (50x50x50mm) as per the ASTM C 109 specification, are molded to determine the compressive strength of the mortar, three are tested at the age of 7 days and 3 at the age of 28 days. Also three standard prisms for testing the modulus of rupture of the mortar, as per the ASTM C348-02 [12] specification, are also prepared to measure the modulus of rupture of the used mortar. Properties of the mortar and wire mesh are summarized in Table (2). All the panels are tested under two line loads located at the third points of the 500mm supported span. The setup of the tested folded and flat panels is shown in Fig. (2). Load is applied in small increments and simultaneously the deflection at the center of the panel was recorded during the loading process up to failure. The deflection at midspan is measured by a dial gage having accuracy equal to 0.01mm. Cracking was carefully checked throughout the loading process and the corresponding cracking load is also noted.

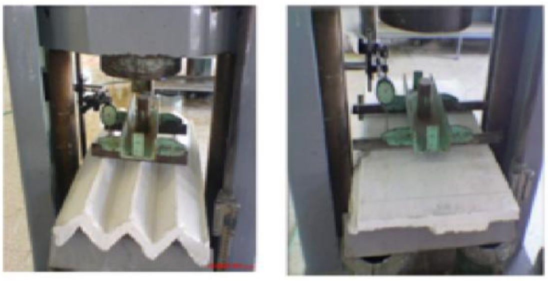

Fig. 2 Setup of the tested folded and flat panels.

Concluding Remarks

Based upon the experimental test results of the folded and flat panels the following can be stated:

The cracking load was not significantly affected by the number of the wire mesh particularly for the folded panels.

The flexural strength of the folded panel increased by 37 and 90 percent for panels having 2 and 3 wire mesh layers compared with that of single layer; while for the flat panel the percentage increase in the flexural strength using 2 and 3 layers is 65% and 68% compared with that of plain mortar panel. The gain in the flexural strength of the flat panel with single layer, located at mid depth of the section, compared with that of plain mortar is only marginal. But using single layer helps in increasing the ductility of the flat panel.

The experimental and numerical results show the superiority of the folded to the flat panel in terms of ultimate strength and initiation of cracking.

Finally increasing the number of layers of wire mesh from 1 to 3 layers significantly increases the ductility and capability to absorb energy of both types of the panel.

C. STRUCTURAL BEHAVIOR OF FERROCEMENT SYSTEM FOR ROOFING By Wail N. Al-Rifaie and Muyasser M. Joma'ah

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(2) Civil Engineering Dept, Eng. College, University of Tikrit

It has become necessary to seek for structural building elements, which have the structural phenomena of prefabricated elements in terms of ease of handling, light, minimum Maintenance and low cost. It is with these in mind, elements of a structural system are made from ferrocement. Ferrocement has been developed mainly during the past twenty five years and yet has reached a very advanced stage in technique and design. A considerable amount of laboratory testing research and prototype constructions have been completed at the Building and Construction Engineering Department of University of Technology, Iraq for the production of ferrocement members that would be used in the roof /floor/wall of building/housing. By using the unique properties of ferrocement with a relatively low Amount of reinforcement, be composite floor and wall panels can assembled into an effective multi-purpose panel system. The major advantages of this system over current construction methods are mainly due to the reduction in structural dead load and the use of fewer building elements, which are much easier to handle. In the present investigation, four ferrocement plates are cast and tested due to flexural loading. The Structural behavior was monitored by reading the deflection and by observing the crack Patterns. The measured values of deflections and the observations made indicated that ferrocement can be used in construction of buildings.

Experimental work: -

Slab specimens S1 to S4, are square having overall dimensions of 500x500 mm. Specimens S1 and S2 are 20 mm thick, whereas S3 and S4 are 30 mm thick. Specimens S1 and S3 have two mesh layers while specimens S2 and S4 have four mesh layers. Hexagonal wire mesh with diameter of 0.7mm is used for both slab specimens and beam models. The moulds of slab specimens consists of a flat steel plate of which angle iron pieces having out-standing leg of 20 mm or 30 mm have been bolted to get square inside dimensions of 500x500 mm. Ink markings have been made all-round the inside periphery of the mould to indicate location of the mesh layers. The top surface has been leveled off by a trowel.

Ordinary Portland cement and sand passing through BS Sieve No.7 and conforming to Building Code Recommendations for ferrocement (IFS 10-01)1 were used throughout. The mix proportion of sand: cement used in casting the ferrocement slab specimens and beam models was 2:1 by weight with water: cement ratio of 0.45. All the materials required were weighed carefully, and then mixed in a mechanical mixer. Sand and cement were first mixed for 1 min, then water was added and mixed for 2 min. The mortar was forced into the mesh reinforcement with trowels. No mechanical vibrators have been used during casting. The slab specimens and beam models have been air dried for 24 hours, then in a water tank 28 days at room temperature of about 30oC and finally taken out of the water tank and kept in the open at room temperature before testing them.

Testing program

Test program was carried out by applying central patch loads to the ferrocement slab specimens. Each slab specimen has been tested with its two edges simply supported over a span of 300 mm as shown in Figure 2. Ferrocement beams which are rotated by 180 degrees are used as simply supports. The load from a universal testing machine has been applied over patch load of square size 100 mm. The central dial gauge was fixed and the initial reading of dial gauge was recorded at the beginning of the test. The load was applied in increment of 10 N and central slab deflections were measured. The applying load was continued until failure occurred.

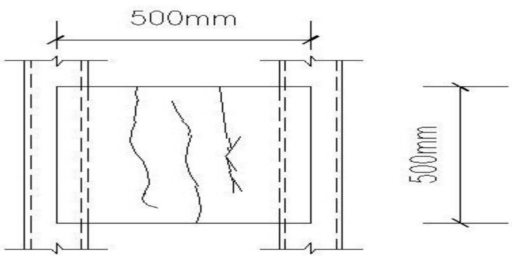

Fig.(5):The crack pattern (S2).

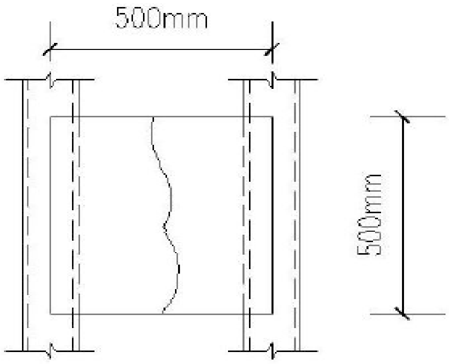

Fig.(6): The crack pattern (S_3).

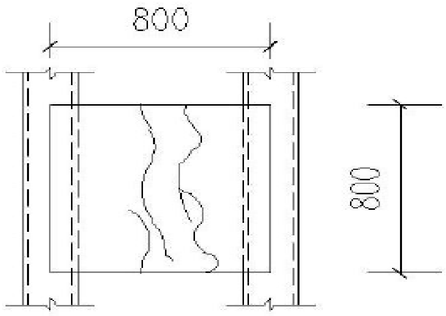

Fig.(7): The crack pattern (S_4).

RESULTS

For slab specimens, in general, all slabs were cracked at the middle along the width (one way action):

Slab specimen having 20 mm thick with 4 layers of wire mesh (S2), the failure occurred on the slab specimen with a total load of 30 N. The crack pattern is shown in Figure 5. It was noticed before testing, cracks were exist for slab S1 (20 mm thick, with two layers of wire mesh), So that, the test was neglected. Slab specimen S3, the ultimate load was 20 N. The crack pattern is shown in Figure 6. Slab specimen 30 mm thick with 4 layers of wire mesh (S4), the failure occurred on the beams along the span (beam action). The failure load was 64 N with fine cracks at slab specimen as shown in Figure 7.

Conclusion

This investigation has shown that, for low cost housing, the proposed ferrocement flooring and roofing system can be satisfactorily used as housing components.

D. FERROCEMENT BOX SECTIONS-VIABLE OPTION FOR FLOORS AND ROOF OF MULTI-STOREYED BUILDINGS By A. Kumar Structural Engineering Division, Central Building Research Institute, Roorkee

A 5m x 9m size interior panel of a framed structure has been designed as beam-slab construction, flat slab construction and using ferrocement box sections for 5 kN/m2 live load. The self-weight, floor/ roof height and cost of these options have been compared. It is found that the flat slab option is comparable in weight to the beam-slab option, about 58.2% less in floor height and 17.7% costlier than the conventional beam and slab construction. The ferrocement box section alternative is found to be 56.2% less in weight, comparable in floor height and 15.6% cheaper than the beam - slab construction. The ferrocement box sections being light in weight need less strong supporting structures. Being a precast product, they also increase speed of construction and can be used in bad weather conditions.

Comparison of Design

On the basis of costs for all the three options it is found that the flat slab option and the ferrocement box section option are costlier and cheaper than the beam-slab construction by 17.7% and 15.6% respectively. It also shows the dead weight of the three options. A comparison of weights shows the relative values are to be 100%, 101.1% and 43.8% for the beam-slab option, flat slab and ferrocement box sections option respectively. A comparison also shows the depth of the beam-slab and ferrocement box section options have comparable floor depths (910mm), while the flat slab option is thinner than the previous two options (380mm). In beam-slab type construction and flat slab type option, the cost of formwork varies from 12 to 18 percent of the material cost while very nominal formwork is required for ferrocement precast box sections. Also repeated use of the formwork reduces the cost of the formwork. The small cost of formwork, makes the adoption of ferrocement box sections a financially attractive option. This has been included in the cost comparison. In conventional reinforced concrete construction, the dead weight of a floor varies from 80 to 100% of the live loads on the floors. In case of ferrocement box sections the weight varies from 35 to 50% of the conventional floor weight. Hence the use of ferrocement box sections lead to an economy in the supporting structures also.

Cracking of the RCC and ferrocement elements is necessary for effective use of the reinforcement provided. The cracking depends on the distribution of the reinforcement in the tension zone. Closer placement of reinforcement reduces the distance between the cracks. Cracking is also related with the cover provided to the reinforcement. An increase in the cover thickness leads to an increase in the spacing of the cracks and also the crack-widths. In case of cyclic and sustained loading, the time effect further increases the crack-widths but does not change the spacing between the cracks. The time dependent deformations are mainly due to creep and to a much smaller extent shrinkage. At service loads, the ferrocement products display a higher number of cracks of smaller crack-width compared to few wider cracks in reinforced concrete construction. Ferrocement box sections are precast products and have a better finish and quality. Also the material is used efficiently and economically. Mostly, the material is used in the flanges to resist the bending stresses, making the product efficient. Precast products save money and time. Prefabrication technology is better than cast-in-situ option at places with adverse climatic and weather conditions like sub-zero temperatures, inclement weather in rainy season and hot and dry condition as obtained in the deserts.

Conclusion

1. The ferrocement box sections supported on R.C.C. beams are found to be 15.6% cheaper than the beam and slab construction, while the flat slab option is 17.7% costlier.
2. The ferrocement box section is found to be 56.2% lighter than the beam and slab construction, while the two reinforced concrete options are comparable in weight. The use of ferrocement box sections will economize on the supporting structure also due to their lower self weight.
3. The ferrocement box sections supported on R.C.C. beams and the beam – slab construction have

comparable floor depths (910mm), while the flat slab option is smallest in floor depth (380mm).

4. At service loads, ferrocement shows a large number of cracks of smaller crack-width compared to few wide cracks in reinforced concrete.
5. Being a precast product, use of ferrocement box section will increase the speed of construction and also make the construction of buildings feasible in bad weather conditions.
6. The use of ferrocement box sections with higher ductility will make the structure less prone to seismic damage.

E. EFFECT OF WIRE MESH ORIENTATION ON FERROCEMENT ELEMENT by Dr. S.K. Kaushik Professor and Head, Department of Civil Engineering, Indian Institute of Technology, Roorkee

The experiment investigated the efficiency of mesh overlaps of ferrocement elements by varying the length of overlap in square woven meshes with different wire diameter and mesh openings. The number of mesh layers has also been varied and tested under flexure. Cement-sand mortar mixes of 1: 1.5 and 1:2 were used for the above investigations. They developed an analytical expression for the lap length (Lp) based on the concept that the mesh overlap must be suficient to develop full bond strength around **t**he surface w that there is no slippage while taking the stress allowed to it. They cast 350 test specimens having 400x200 mm dimensions, with 5 mm cover on all the four sides, with w/c-0.4. All the specimens were tested under central point loading on a simply supported span of 300 mm. Based on the above, they concluded that (i) the mortar strength, diameter of reinforcing wire and mesh opening influence the overlap length; (ii) bond failure occurs due to slippage at overlap. when length of mesh overlap is insufficient, with the cracking load much lower than that of a continuous mesh reinforcement; (iii) a minimum overlap of 100 mm to be provided.

F. PERFORMANCE OF PRECAST FERROCEMENT PANEL FOR COMPOSITE MASONRY SLAB SYSTEM BY Y. Yardim, Universiti Putra Malaysia

This study investigates the performance of inverted two-way ribs precast ferrocement thin panel. The two-way inverted ribs in the ferrocement panel enhanced its flexural stiffness, as well as providing link between the precast layer and the in situ elements. Flexural behaviors of two precast panels and two composite slabs are investigated under two line load and distributed load. Test results indicate that the thin panel with suitable ribs layout and support distance can be used as permanent formwork. Typical load from construction worker and in situ elements could be sustained by the panel. The panel also acts as good composite component with in situ brick and concrete. Composite full slab can sustain typical design loads for residential buildings and until ultimate load and no separation or any horizontal cracks between the layers were observed.

Test Setup

Ordinary Portland cement and natural sand were used for concrete in the ratio 1:3 with water/cement ratio of 0.5. The mortar mix was designed to give 28-day cube strength of 30 N/mm². The ferrocement reinforcement used in all slabs consisted of high tensile steel bars and galvanized welded square wire mesh of 0.9 mm diameter and 12 mm openings. The tensile strength of the mesh was found 321 N/mm².

Schematic view set-up of test, Two line load test (actual picture)

Precast layer test set-up for uniformly distributed load

Summary of Theoretical and Experimental results

Spec.	First Crack Load (kNm^2)		Ultimate load (P_{ULT}) (kN/m^2)	
	Theor.	Exper.	Theor.	Exper.
CS1	4.6	6.4	16.05	18.6
CS2	4.6	6.35	16.05	17.93
FP1	2.2	2.9	5.4	6.5
FP2	5.8	7.5	10.8	13.7

This study introduces a new invert ribbed precast ferrocement slab system for composite slab. Tests were complied for precast layer of composite slab system and composite slab system under two line loads and uniformly distributed loads. System shows excellent connection between two layers of slab until ultimate load. Integrity of structure was sustained until ultimate load and no separation observed. The results show that integrity of slab is well established with interlocking mechanism. Precast layer achieves its required tasks which are working as formwork, forming interlocking connection and carrying temporary loads such as toping and construction loads. System was carried out the load which was more then theoretical estimation. Test results shows that the precast layer is able to carry temporary loads and light enough to handle with simple crane. Ferrocement layer creates high modulus of rupture so that first crack load was observed at 40% of ultimate loading, provides strong protection against spalling and most of others surface distress and Eliminate cost of formwork.

G. APPLICATIONS OF FERROCEMENT IN STRENGTHENING OF UNREINFORCED MASONRY COLUMNS BY Abid A. Shah

The load carrying capacity, ductility and serviceability of unreinforced masonry columns can substantially be improved if encased by ferrocement. The parameters such as cement mortar thickness, gage-wire spacing and bond at the interface of ferrocement and brick columns have effects on overall behavior. In the present experimental study, it was found that the first crack load and ultimate load of a ferrocement encased masonry column was increased by 119% and 121% respectively. Cracks developed in ferrocement encased column were finer and well distributed as compared to plain specimen. However, premature failure is possible when bond at the interface of brick masonry column and ferrocement is poor. At higher reinforcement ratio, severe spalling and delamination is expected.
Brick masonry columns are commonly used in rural and urban areas. Because of improper structural design and no maintenance over a period of time, they have lost a major portion of strength and stiffness. Many masonry columns require strengthening due to increase in their share of building loads. Severe cracks due to repeated earthquakes are also very common in these masonry elements. These factors make brick masonry columns unsafe and they require economical, safe and easy remedial measures.
Experimental study was made on burnt clay brick column specimens. Locally available burnt clay bricks of 221 mm x 110 mm x 55 mm were used. Ordinary Portland cement and alkaline free sand were mixed together to cast cement mortar joint of 4.6 mm. In addition, locally available 24 gage steel wire having tensile strength of 276 MPa was used in the ferrocement. Masonry columns of 221 mm x 221 mm x 784 mm, were prepared (see Fig. 1).

Fig. 1 Plain (unreinforced) brick masonry column

After a period of one week of wet curing, steel wire was manually wrapped around column in both directions. Cement mortar was then applied and cured for minimum of 10 days before testing in compression. The type of mortar for brick masonry joint was same for all specimens. Specimens without ferrocement application were also constructed for comparison. All specimens were tested under axial compression using a Structural Testing Frame at the structural concrete laboratory End conditions for each of the test specimen were kept similar. For the uniform distribution of load, rubber pads of 245 mm x 245 mm x 6.125 mm in size were placed at both ends of specimen and were covered with steel plates of dimensions 392 mm x 392 mm x 6.125 mm. Ferrocement encased specimen was instrumented with electrical resistance strain gages at mid height of the specimens. Strain gage (or gages) was attached in a direction parallel to loading as shown in Fig. 2.

Fig. 2 Plastered specimen with a strain gage at mid-height

This experimental study was made on burnt clay brick column specimens. Locally available burnt clay bricks of 221 mm x 110 mm x 55 mm were used. Ordinary Portland cement and alkaline free sand were mixed together to cast cement mortar joint of 4.6 mm. In addition, locally available 24 gage steel wire having tensile strength of 276 MPa was used in the ferrocement. Masonry columns of 221 mm x 221 mm x 784 mm, were prepared. The test results analysis led to the following conclusions.

1. Encasement of unreinforced brick masonry columns by ferrocement doubles the failure load.
2. Average crack spacing reduces with reduction in spacing of wire.
3. Premature failure is possible if mesh is not properly wrapped and plaster does not fully penetrate into it.
4. Mortar strength has comparatively smaller influence on failure load.

H. UTILIZATION OF FERROCEMENT AS FLEXURAL BUILDING MEMBER (Applied as a Hollow Box Joist) By R Abasolo, C Bandivs, Civil Engineering department College of Engineering Xavier University-Philippines

This study focuses on the fabrication and the Maximum Moment Capacity of a Ferrocement beam. There were three batches with 3 specimens each. The beams were casted vertically by plastering. This study used a cement to sand ratio of 1:3 by volume, and a water to cement ratio of 0.5:1 by weight. It also used two layers of # 16 gage wire mesh kept constant on each batch. Tension bars of 8 mm dia. were used, the number of which increases by one on each batch. Nine specimens of 200mm x 200mm x 3000mm hollow box beam with a 25 mm thickness were casted. The Standards and Procedure for each of the beams were based on the ASTM Standards and on the article by J.P. Hartog. The testing of the beam was done after the 28th curing day period, and was conducted to failure in order to determine the Actual Moment Capacity of the design beam. The results show that Maximum Moment Capacity or Flexural Strength of the fabricated Ferrocement beams did not go below the calculated ultimate moment capacity for office occupancy of 5.3792 KN-m. This means that the beams are safe for use as floor joist beams in residential and commercial structures.

Beam Set up

A. For Calibration

1. Set the beam as simply supported beam.
2. Measure the unsupported length and set the dial gauge at its midspan for deflection reading.
3. Prepare sand bags weighing 25 kg/bag.
4. Gradually load the bags into the beam at 50 kg per batch at 5 batches.
5. Record reading to compare result with UTM Reading.

B. Data collecting procedure

1. Record time of testing.
2. Set and install the dial gauge on innovative compression machine.
3. Set the beam into the compression testing machine to be loaded at the midspan.
4. Gradually load the beam at every 1mm deflection and record gauge reading.
5. Check for micro cracks and record gauge reading.
6. Continue loading until complete failure is achieved.
7. Record the force and its corresponding deflection
8. Record finishing/ending time of testing
9. Set another sample beam for another deflection testing.

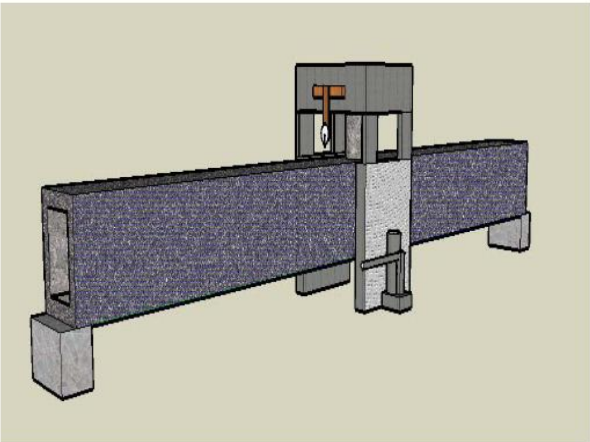

Figure 2. Beam Setup

The study was successful in fabricating and determining the flexural strength of the Ferrocement box beam. Even though the Ferrocement beam was supposedly designed for sustainable housing, the results showed that the calculated actual moment of the Ferrocement Beams is good for use as floor joist beams for residential, office and commercial occupancy. The Ferrocement box joist can be applied on residential and commercial occupancy with a one meter spacing base on the minimum live load for residential and commercial occupancy as stated in the National Structural Building Code of the Philippines.The Ferrocement box joist has an average of 11 kgs, which is lighter compared to the designed reinforced concrete beam. The strength to weight ratio of the Ferrocement box joist is greater compared to that of the conventional beam.

Based on the material cost comparison between the Ferrocement box joist and the designed conventional beam, the Ferrocement is less expensive. Its use can save on gravel and scaffolding costs. Using Ferrocement materials adds an economic advantage in saving general costs in construction. Its light weight feature would mean an increase in workability and transportation, resulting in a fast-paced construction. The researchers acknowledge the possibility of incurring errors such as machine errors since the machine used for testing has not been calibrated for a long time and it's dial reading available is 500 pounds per tread. Such machine error may affect the reading of the actual moment capacity or flexural strength of the Ferrocement beam. However, the researchers can check the accuracy of the machine through calibration using the point loading at the midspan with the corresponding deflection of the Ferrocement beam.

I. DESIGN OF COLLEGE BUILDING WITH FERROCEMENT ELEMENTS By Arun Purandare, Structural Consultant, Pune

A simple system of precasting with ferrocement elements was developed for the construction of Engineering college at Talegaon. Three elements namely column boxes, channel beams, and a deck slab were used for the entire section. The aim was to crate light weight elements for lifting, eliminate formwork totally and reduce member propping during construction to an absolute minimum. All the three aims have been fulfilled.

An engineering college building was under construction for D.Y. Patil Engineering college at Ambi village, Talegaon. The G+4 structure has been constructed by the conventional method of in situ R.C. construction. The column spacing are 7m X 7.5 m. Each floor is about 3000 sq.m. built up area. The foundation and columns were designed for G+8 upper floor building. At this stage of construction it was decided to add the balance 4 floors with member element made with Ferrocement.The structural frame had to be the same as that used on lower floor. The principal idea was to eliminate formwork and the slab and beam units shall be able to carry all dead loads. The slab and beam had to span between supports without propping. The members therefore eliminated formwork and propping at site. The design of members was also done with ease of construction and lifting to its position as primary consideration. Slab elements span between channel beams. The panels are 3m X 1m wide. The design of panels is done as suggested by ACI.

The project has been saving in material cost and significant saving in time. The main advantages seen in the system are:-

1. No formwork and minimal scaffolding.
2. Elements casted on ground at site or yard
3. Very fast erection and reduction in time of construction.
4. Saving in overall cost compared to R.C. system.

III. EXPERIMENTAL STUDY

After studying the literatures the various results and conclusions obtained are going to help in the project work to investigate the behavior of ferrocement panels for various parameters and loading**.** The study is primarily aimed at investigating experimentally and analytically

1. The behavior of ferrocement panels under flexure with following parameters.
   - Change in wire mesh size
   - Change in wire mesh orientation
   - Change in panel size
   - Providing ribs
2. The yield line pattern for ferrocement panels.

The results obtained will aid the designer and manufacturer the design procedure, method of construction for slabs that is consistent with the level of risk specified or intended.

As newer applications of ferrocement are introduced in market, many interesting problems will be posed so we will have to find solutions to these problems by searching new design techniques and method of constructions.

IV. ACKNOWLEDGMENT

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REFERENCES

[1] Ferrocement floor and roof system for buildings By Dr.T.S.Thandavamoorty Adhiparasakti Engineering college Melmaaruvathur
[2] Flexural Behavior of Flat and Folded Ferrocement Panels by Mohamad Mahmood Civil Engineering department Mosul University Iraq
[3] Structural behavior of ferrocement system for roofing By Wail N. Al-Rifaie University of Nottingham
[4] Research Needs in Ferrocement Technology by Dr.P.N.Divekar, President, Ferrocement society, Pune
[5] Effect Of Wire Mesh Orientation On Ferrocement element by Dr. S.K. Kaushik Professor and Head, Department of Civil Engineering, Indian Institute of Technology, Roorkee
[6] Performance of Precast Ferrocement Panel for Composite Masonry Slab System by Y. Yardim, Universiti Putra Malaysia
[7] Applications of Ferrocement in Strengthening of Unreinforced Masonry Columns By Abid A. Shah
[8] Utilization of Ferrocement as Flexural Building Member (Applied as a Hollow Box Joist)By R Abasolo, C Bandivs, Civil Engineering department College of Engineering Xavier University-Philippines
[9] Design of College Building with Ferrocement Element By Arun Purandare, Structural Consultant, Pune
[10] ACI Committee 549, “State-of-the-art report on ferrocement”, ACI549-R97, in Manual of Concrete Practice, ACI, Detroit, 1997, 26 pp
[11] ACI committee 549-1R-88, “Guide for design construction and repair of ferrocement,” ACI 549-1R-88 and 1R-93, in Manual of Concrete Practice, ACI, Detroit, 1993, 27 pp.
[12]. Association of Structural Engineers of the Philippines,Inc. (2001). National structural code of the Philippines (NSCP) 2001, Volume1.Structural Concrete. Philippines.