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Behaviour of Ferrocement Panels Subjected to Inplane Lateral Load

KEYWORDS: Ferrocement, Ultimate load, Ductility and Modulus of elasticity.

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ABSTRACT *Ferrocement (FC) is defined as wire mesh reinforcement impregnated with cement mortar to produce elements of small thickness. Ferrocement offers several advantages such as light weight, ductility, resilience, toughness and crack resistance. Observing that studies on cantilever FC elements subjected to lateral load are limited, present study is aimed at determining the behaviour of FC panel elements under lateral load.*

1000 mm X 2000 mm X 30 mm size FC elements for lateral load test containing single, two, three and four layers of hexagonal chicken mesh and skeletal reinforcement were cast using cement mortar 1:3 (w/c= 0.5) and cured for 28 days. The elements fixed at base were progressively tested under in-plane lateral load applied at top up to failure and their behaviors are compared.

Introduction

It is known that Ferrocement (FC) is a blend of rich cement mortar and uniformly spaced chicken mesh layers with or without skeletal reinforcement and can be used to prepare thin structural elements. It is known for its light weight, crack resistance, energy absorption capacity, architectural flexibility, etc.

Many studies on ferrocement panels horizontally placed, acting as simply supported slabs are available in recent times. Hossain and Sohji (2003) dealt with comparison of young's modulus and bearing strength of thin plates with geogrid and hexagonal meshes and found the latter to be better. Shoheen. et.al.(2012) examined the behaviour of simply supported ferrocement slabs with two types of meshes of different numbers under pure bending. Howlader (2013) studied the flexural performance of ferrocement panels exposed to saline water and found it to reduce the performance. Shaheen. et.al.(2013) investigated the possibility of the use of ferrocement concrete in construction of water supply pipe. This work presents the comparison between the performance of ferrocement pipe and reinforced concrete pipe under static load. Bedoya-Ruiz (2014) conducted tests on thin ferrocement walls subjected to cyclic loading and compared the behaviour with an analytical study using structural dynamics. Randhir.et.al.(2014) described the results of testing flat ferrocement panels reinforced with different number of wire mesh layers and fibers. Test results showed that panels with more number of layers (with fibers) exhibited greater flexural strength and less deflection as that compared with panels having less number of layers of mesh.

Most of the above studies consider the ferrocement panels as slabs simply supported at ends and spanning horizontally, load being applied normal to the plane of the slab. Hence the present study is concerned with testing ferrocement panels fixed at base and subjected to in plane lateral load applied at the top free end of the panel.

2. Experimental Investigation

Test specimens considered were Ferrocement panels with different volume fractions of reinforcement consisting of varying number of layers of chicken mesh and constant amount of skeletal steel. The specimens were fixed at base and tested till failure under progressive in-plane concentrated lateral load applied at the top free end of the specimen, behaving as a cantilever. From the measurement of lateral deformations made during each increment of load, the behaviour of the panels is studied by presenting the results in the form of load deformation behaviour, modulus of elasticity and ductility. The crack patterns are also discussed.

3. Details of test specimens

Test specimens were Ferrocement panels of width 1000 mm, height 2000 mm and 30 mm thick consisting of one, two, three and four layers of hexagonal chicken mesh and single layer of skeletal steel resulting in V_f of 0.44, 0.52, 0.59 and 0.67% respectively. Fig .1 shows the plan and sectional elevation of a typical upright specimen. Each specimen was provided with an integral foundation beam of size 1500 x 150x100 mm which could be used to obtain fixed condition at base for the upright Ferrocement panel specimens during test.

4. Materials Used

The materials used for preparation of Ferrocement Elements for each test, namely, cement, chemical Admixture, fine aggregate, water and wire mesh were tested in the laboratory as per relevant IS codes.

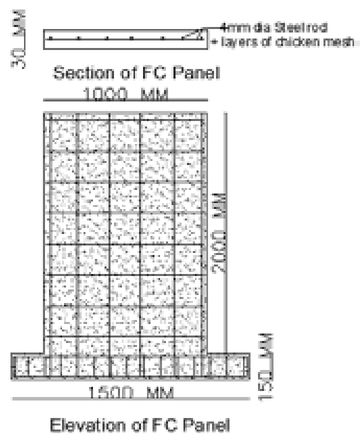

Fig.1 Details of lateral load test specimen

4.1 Cement

Ordinary Portland cement of 43 Grade conforming to the requirements of IS 12269-1987 is used in the experimental work. The quantity of cement required for the experiments was collected from single source. Tests were conducted to obtain specific gravity, normal consistency, initial & final setting time and compressive strength are reported in Table 1.

Table 1. Test result of ordinary Portland cement

Sl. No	Properties	Test Results	As per IS 12269-1987
1	Normal Consistency (in %)	31.00	28 -35
2	Specific Gravity	3.076	
3	Setting Time (in Minutes) a)Initial Setting Time b)Final Setting time	85 Min 490 Min	Not less than 30 minits Not more than 600 minits
4	Compressive Strength(MPa) (70.6*70.6*70.6mm Cubes) 3 days strength 7 days strength 28 days strength	24.5 MPa 36.5 MPa 47.45 MPa	Not less than 22Mpa Not less than 33Mpa Not less than 43Mpa
5	Fineness of cement	3.56 percent	Not more than 10 %
6	Soundness	4.5 mm	Not more than 10 mm

4.2Chemical Admixtures

Commercially available Poly- carboxylic ether based Super plasticizer (Glenium 6100) having specific gravity of 1.06 was used in this study.

Typical Properties as per manufacturer's specifications are as follows

Light brown liquid
Relative Density : 1.09 ± 0.01 at 25°C
pH : >6
Chloride ion content : < 0.2%
Dosage:

Optimum dosage of Glenium 6100 should be determined with trial mixes. As a guide, a dosage range of 500 ml to 1500 ml per 100kg of cementitious material is normally recommended from the manufacturer. Because of variations in concrete materials, job site conditions, and/or applications, dosages outside of the recommended range may be required. In the present study an optimum dosage of 10 ml per kg is used.

4.3 Aggregate

Locally available natural river sand was used as fine aggregate in the mix. The tests on fine aggregate were conducted in accordance with IS 383 -1970 to determine physical properties. The Sand had Specific Gravity of 2.63, fineness Modulus of 3.74 and belonged to Zone-II.

4.4 Water

Potable water was used for conduction of experimental work.

4.5 Reinforcing Materials

The core portion of Ferrocement elements are chicken mesh of hexagonal shape and reinforcement bar (Fe-415) as skeletal steel.

4.5.1 Wire Mesh

Wire mesh was tested as per IS 1604-2012, the results are tabulated in table 2.

4.5.2 Reinforcement Bars

HYSD bars of 4mm, 6mm, and 10 mm diameter used for FC elements as skeletal reinforcement (Fe-415) were tested as per IS 1786-2008, the results are tabulated in table 2.

Table 2. Properties of reinforcing materials

Sl No	Type of Material	Properties	Values		
1	Chicken (Hexagonal) mesh	Average diameter	0.45 mm		
		Opening size of mesh	13 mm x 15 mm		
		Yield strength	290 Mpa		
2	Fe-415 Steel (IS-1786-2008)	Diameter	4mm	6mm	10 mm
		Yield strength	490 N/mm^2		
		Ultimate strength	525 N/mm^2		
		% elongation	14.25 %		

5. Casting of Ferrocement Panels

Ferrocement panels of dimension 1000 mm x 2000 mm and 30 mm thick (fig.1) were cast in moulds prepared using ply wood sheets. Moulds were placed horizontally on a clean and level surface after cleaning and oiling. The skeletal reinforcement mesh was prepared by fabricating 4 mm diameter mild steel rods at 247 mm c/c spacing in both directions, provided to avoid any folds of the chicken mesh. The chicken mesh was spread over the steel mat (fig. 2). The reinforcement in the foundation beam at bottom of the wall panel consisted of two bars of 10 mm diameter at top and bottom, with 2 legged stirrups of 6 mm diameter placed at 150 mm c/c.

The mortar mix was prepared with cement and sand in proportion 1:3 with w/c 0.5 and super plasticizer to get good workability. The cement mortar was then spread over the bottom surface of the panel mould up to a thickness of about 10 to 13 mm by evenly leveling and then compacted well. The reinforcement mat with steel rods and chicken mesh was then placed over the bottom mortar layer carefully and the leveling was checked. Another 10 to 13 mm thick cement mortar layer was placed over this layer and compacted well such that the mat was totally impregnated in to the mortar. The thickness of mortar layer was adjusted evenly so as to accommodate the required number of layers of chicken mesh depending on the specimen being cast. It was then leveled to obtain a smooth finished surface. At bottom of wall panel, the reinforced concrete foundation beam was cast by using M20 concrete. The reinforcement in the panel was anchored well with that of foundation beam so as to obtain an integral specimen. M20 Grade concrete was used to cast the beam. The specimen so prepared was allowed to set for 24 hours and the panel was de-molded. The specimens were water cured up to 28 days. A typical specimen as obtained is shown in fig.3.

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Fig 2. Mould and reinforcement details of panel


Fig 3. Ferrocement panel element

6. Testing of Ferrocement Panels

The ferrocement panel anchored to RC foundation beam at bottom was placed in the loading frame. The RC beam was anchored to the loading frame with bolts and steel plates to obtain fixed condition at the base, taking care to see that the panel was oriented vertically without any other support. Provision was made to apply the horizontal load through hydraulic jack at top of the wall panel at 2000 mm height from bottom of panel as shown in fig. 5. The loading was continuously applied from zero to the failure of specimen. The lateral displacement at top of the panel at every 1.0 kN load was recorded using dial gauges, simultaneously observing the appearance of cracks and their extensions (fig .5). The loading was continued till the panel failed. Typical crack patterns at failure are shown in fig.6. The measurements made for three specimens with V_f = 0.52% and the average displacement for the panels tested are presented in table 3.


Fig. 4 Loading arrangement of lateral load test


Fig. 5 Specimen under lateral load test

Table 3. Ferrocement panel lateral load test result of two layer mesh (V_f= 0.52%)

Sl No.	Load (kN)	Displacement (mm)			Avg	Remarks
1	0.0	0.0	0.0	0.0	0.00	
2	1.0	0.46	0.56	0.61	0.54	
3	2.0	1.07	1.06	1.11	1.08	
4	3.0	1.74	1.56	1.58	1.63	
5	4.0	2.21	2.05	2.26	2.17	
6	5.0	3.34	3.26	3.43	3.343	
7	6.0	5.19	5.06	5.12	5.123	
8	7.0	8.43	8.22	9.42	8.173	Avg. first crack load
9	8.0	10.64	10.59	10.63	10.620	
10	9.0	13.87	13.36	13.46	13.563	
11	10.0	15.98	16.03	15.86	15.957	
12	11.0	18.67	18.32	18.41	18.467	
13	12.0	20.78	20.54	20.33	21.093	
14	13.0	22.33	22.14	21.96	22.143	
15	14.0	25.58	26.32	26.56	26.153	


a. Single layer mesh b.Two layer mesh c.Three layer mesh d.Four layer mesh

7. Presentation and Discussion of Results

From the measurements made during the lateral load test of the upright panel fixed at base,_lateral load- lateral displacement behaviour , modulus of elasticity and ductility of panels are determined. Also discussed are the failure patterns of the tested specimens.

It is to be expected that as the volume fraction of (V_f) increases , all quantites such as ultimate load, ultimate displacement , modulus of elasticity, ductility etc. also increase. i.e performance of the FC elements enhances. Hence to quantify this, Performance Enhacement Factor (PEF) for each quantity indicating increase in the quantity considered for higher V_f (2, 3& 4 number of meshes) in terms of the same quantity for minimum V_f adopted (single mesh) is defined as follows.

PEF for any quantity

For example PEF for ultimate load for specimen with V_f = 0.52

PEF for ultimate load

7.1 Load –Displacement behaviour

From the recordings of lateral load and corresponding top lateral displacement (maximum displacement) throughout the loading range ,the load verses displacement plots are obtained for the four categories of the specimen considered.

Fig.7a-d shows the lateral load- lateral displacement behaviour of ferrocement panel specimens with different percentage volume fractions of reinforcement 0.44, 0.52, 0.59 and 0.67%. These figures show that the behaviour for a particular volume fraction and the overall behaviour for the different V_f considered (fig .7e) have similar trends. The behaviour consists essentially of three zones, initial straight portion, second straight or slightly curved portion indicating initial yield and the last portion with reduced slope up to failure wherein for any small increment in load larger displacement are encountered indicating yielding of steel meshes. No drooping down of the curves is observed.

Table 4 reports the values of load at first crack, ultimate load and ultimate displacement for the specimens with different V_f tested. The table also reports the PEF for ultimate load and PEF for ultimate displacement.

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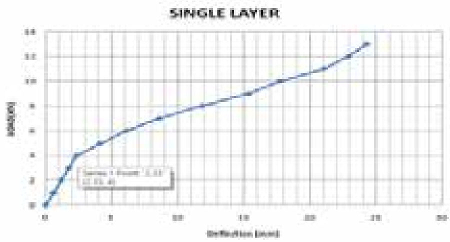
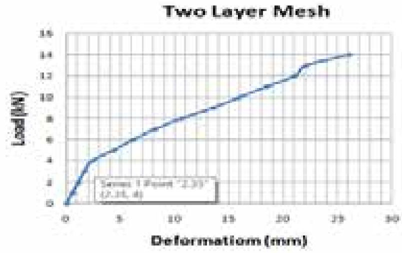
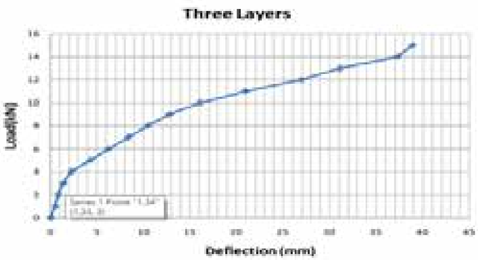


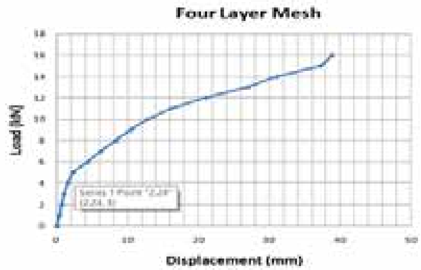
a. Volume Fraction 0.44



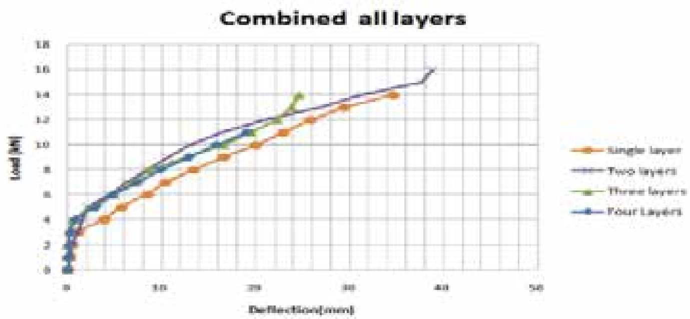
b. Volume Fraction 0.52



c. Volume Fraction 0.59



d. Volume Fraction 0.67



e. Combined behaviour of different V_f

Fig 7. Load- Displacement behaviour under lateral load of F.C elements with different volume fraction

Table 4. Ultimate load and their PEF of FC elements for lateral load

Sl No	No of Mesh Layers	Volume fraction (%)	Load at First Crack (kN)	Ultimate Load (kN)	Ultimate Displacement (mm)	Performance Evaluation Factor (PEF) for	
						Ultimate Load	Displacement
1	Single	0.44	7.0	13.00	24.29	1.00	1.00
2	Double	0.52	7.0	14.00	26.15	1.07	1.08
3	Three	0.59	8.0	15.00	33.98	1.15	1.40
4	Four	0.67	9.0	16.00	38.91	1.23	1.60

Table 5. Modulus of elasticity and their PEF of FC elements for lateral load

Sl No	No of Mesh Layers	Volume fraction (%)	Load at First Crack (kN)	Modulus of Elasticity (E)N/mm^2	Performance Evaluation Factor (PEF) for
					E_{lt}
1	Single	0.44	7.0	18312.45	1.00
2	Double	0.52	7.0	19689.89	1.08
3	Three	0.59	8.0	21858.61	1.19
4	Four	0.67	9.0	24133.48	1.32

As can be expected, as the number of mesh layers or V_f increases, there is a small enhancement in ultimate load and considerable increase in displacement. The ultimate load varies from 13 kN to 16 kN and ultimate displacement varies from 24.29 mm to 38.91 mm as V_f varies from 0.44% to 0.67%. The PEF for ultimate load (i.e increase in ultimate load of FC panels with (higher V_f) in comparison to that of specimen with least V_f provided) of specimens is found to be 1.07, 1.15 and 1.23 for Vf of 0.52, 0.59 and 0.67% respectively. Similarly PEF for Ultimate displacements are found to be 1.08, 1.4 and 1.60 respectively for V_f of 0.52%, 0.59% and 0.67%.

It is seen that the small increase in PEF of ultimate load is mainly because the variation in V_f values is not considerable. However, even a small increase in V_f is found to considerably increase the ultimate deformation showing the effectiveness of chicken mesh present.

7.2 Modulus of Elasticity

For a verrtical cantilever member, subjected to concentrated horizantal load applied at the top of the specimen of hight "h" (fig.8) the maximum horizantal displacement δ is given by.

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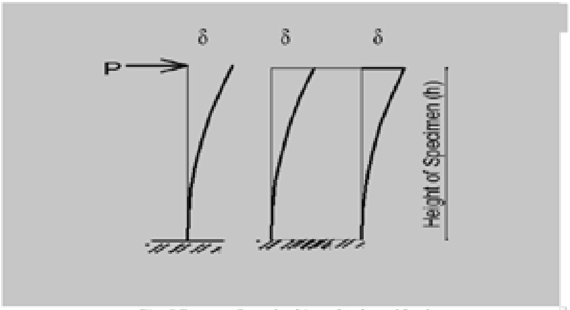


Fig .8 Pattern of panel subjected to lateral load

$$\partial = \frac{Ph^3}{3EI} \quad (1)$$

Where P= ultimate load ,N
E = Modulus of elasticity, N/mm^2
I = moment of inertia, mm^4
measured , mm

From equation.1 Modulus of elasticity

$$E = \frac{1000\,h^3}{3I}(P/\partial) \quad (2)$$

Where, (P/) in kN/mm is obtained from the initial straight line portion of load- displacement curves (fig. 7).

E_{lt} (Modulus of elasticity under lateral load) values obtained for panel elements with different volume fraction of reinforcement are listed in table 5 and the variation of E_{lt} with volume fraction is shown in fig .9a. Table 5 also lists PEF for E_{lt} of FC elements for lateral load. It is seen that E_{lt} of specimen increases from 18312.45 to 24133.48 N/mm^2 as V_f varies from 0.44 to 0.67%. The PEF for E_{lt}, for V_f = 0.52, 0.59 and 0.67% are found to be 1.08, 1.19 and 1.32 respectively, showing considerable increase in stiffness of elements for small increase in V_f the variation being almost linear .

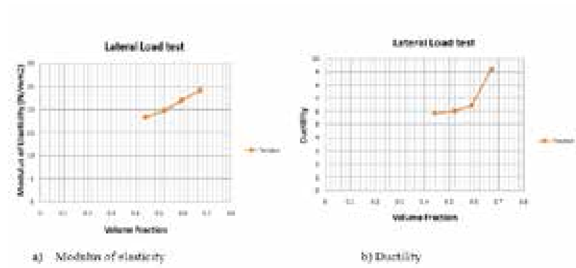
7.3 Ductility of Panel Elements
From the load- displacement behaviour (Sec 7.1) it is clear that the slab elements exhibit good ductility imparted by the steel. The ratio of ultimate displacement to displacement at yield is calculated as the displacement ductility of different specimens and indicated in table 6 and the variation of ductility with V_f is shown in fig.9b .

From table 6 and fig 9b, it is seen that the ferrocement panel specimens exhibit maximum ductility for the largest V_f adopted.

The PEF for ductility are found to be 1.03, 1.10 and 1.52 for panel with V_f = 0.52, 0.59 and 0.67% respectively.

Table 6. Ductility of FC elements under lateral load

Sl No	No of Mesh Layers	Vol. Fraction (%)	Displacement at Yield	Ultimate Displacement	Ductility	PEF for Ductility
1	Single	0.44	4.14	24.29	5.87	1.00
2	Double	0.52	4.34	26.153	6.03	1.03
3	Three	0.59	5.25	33.983	6.47	1.10
4	Four	0.67	4.36	38.913	8.93	1.52



a) Modulus of elasticity b) Ductility
Fig. 9 Variation of modulus of elasticity and ductility of laterally loaded cantilever FC panels

7.4 Failure Patterns
The initail cracks appear at the bottom fixed end of the panel on tension face i.e the loading face at an average load of 14.5 kN. On further application of load the cracks propagated along the depth of the section, and the specimens collopsed with major cracks at bottom widening and reaching three fourth the depth of the cross-section. Number of cracks, closely spaced, reducing in depth towards top, spread over half the height of the panel also formed a part of the crack pattern at failure.

8. Conclusions
Ferrocement panel specimens with varying V_f, in their upright position and fixed at base were subjected to lateral load at the top free end of the specoimen. From the measurements made, the behaviour of the panels is studied considering the load-deformation behaviour, modulus of elasticity and ductility. From the limited tests conducted , the following conclusions are drawn.

The load-deformation behaviour of Ferrocement panel acting as cantilever can be idealised to consist of three zones , Elastic zone, elesto plastic zone and plastic zone.

The ultimate load, ultimate lateral displacement , modulus of elasticity and ductility of ferrocement panels subjected to inplane lateral load increases with increase in volume fraction.

As V_f increases by 1.52 times, the ultimate load and ultimate displacement increase by 1.23 and 1.64 times respectively.

The modulus of elasticity of FC panels acting as cantilever increase 1.32 times with increase in volume fraction of 1.52 times.

The ductiliy of FC panels subjected to lateral loads increase 1.52 times with increase in volume fraction of 1.52 times.

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