FLEXURAL BEHAVIOUR OF FERROCEMENT SLAB PANELS USING WELDED SQUARE MESH BY INCORPORATING STEEL FIBERS

Randhir J. Phalke[1], Darshan G. Gaidhankar[2]

[1]*PG Scholar, Department of Applied Mechanics and Structural Engineering), MAEER 'S, MIT–Pune, Maharashtra, INDIA*

[2]*Associate Professor, (Department of Applied Mechanics and Structural Engineering) MAEER 'S, MIT–Pune, Maharashtra, INDIA*

Abstract

*The present study describes the results of testing flat ferrocement panels reinforced with different number of wire mesh layers. The main objective of this work is to study the effect of using different no of wire mesh layers on the flexural strength of flat ferrocement panels and to compare the effect of varying the no of wire mesh layers and use of steel fibers on the ultimate strength and ductility of ferrocement slab panels. The no of layers used are two, three and four. Slab panels of size (550*200) with thickness 25 mm are reinforced with welded square mesh with varying no of layers of mesh. Panels were casted with mortar of mix proportion (1:1.75) and water cement ratio (0.38) including super plasticizer (Perma PC-202) with dosage of 1% of total weight of cement. Some panels were casted with steel fibers (0.5%) of total volume of composite and aspect ratio (l/d) =57. Panels were tested under two point loading system in UTM machine after curing period of 28 days. Test result shows that panels with more no of layers exhibits greater flexural strength and less deflection as that compared with panels having less no of layers of mesh.*

***Keywords**: Ferrocement; Wire Mesh, effect, Flexural Strength, Ductility, Ultimate Strength, Layers, panels, plasticizer and steel fibers*

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1. INTRODUCTION

A large number of civil infrastructures around the world are in a state of serious deterioration today due to carbonation, chloride attack, etc. Moreover many civil structures are no longer considered safe due to increase load specifications in the design codes or due to overloading or due to under design of existing structures or due to lack of quality control. In order to maintain efficient serviceability, older structures must be repaired or strengthened so that they meet the same requirements demanded of the structures built today and in future. Ferrocement over the years have gained respect in terms of its superior performance and versatility. Ferrocement is a form of reinforced concrete using closely spaced multiple layers of mesh and/or small diameter rods completely infiltrated with, or encapsulated in, mortar. In 1940 Pier Luigi Nervy, an Italian engineer, architect and contractor, used ferrocement first for the construction of aircraft hangars, boats and buildings and a variety of other structures. It is a very durable, cheap and versatile material**.**

Definition-

"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 and suitable materials. In the words of Nervi who first used the term ferrocement its notable characteristics is "Greater elasticity and resistance to cracking given to the cement mortar by the extreme subdivision and distribution of the reinforcement"

1.1 Constituents of Ferrocement

The constituents of ferrocement include the hydraulic cement mortar which should be designed according to the standard mix design procedures for mortar and concrete which includes Portland cement, water, sand, wire mesh and admixtures.

Cement: The cement should be fresh of uniform consistency and free of lumps and foreign matter and of the type or grade depending on the application.

Water: Potable water is fit for use as mixing water as well as for curing ferrocement.

Fine Aggregates: Normal weight fine aggregate clean, hard, and strong free of organic impurities and deleterious substances and relatively free of silt and clay.

Wire mesh: Steel meshes for ferrocement includes square woven or square welded mesh and chicken wire mesh of hexagonal shape and expanded metal mesh. Some mesh filaments are galvanized. Properties of the resulting ferrocement product can be expected to be affected by mesh size, ductility, manufacture and treatment.

Admixtures: In numerous admixtures available, chemical admixtures is best suitable for ferrocement because it reduces the reaction between matrix and galvanised reinforcement. Chemical admixtures used in ferrocement cement serve one of the following purposes like water reduction, improvement in impermeablity, air entrainment, which increases resistance to freezing and thawing.

1.2 Properties of Ferrocement Composites

- Wire diameter 0.5 to 1.5 millimeters
- Size of mesh opening 6 to 35 millimeters
- Maximum use of 12 layers of mesh per inch of thickness
- Maximum 8% volume fraction in both directions
- Maximum 10 square inches per cubic inch in both directions.
- Thickness 6 to 50 millimeters
- Steel cover 1.5 to 5 millimeters
- Ultimate tensile strength up to 34 MPa
- Allowable tensile stress up to 10 MPa
- Modulus of rupture up to 55MPa
- Compressive strength up to 28 to 69Mpa

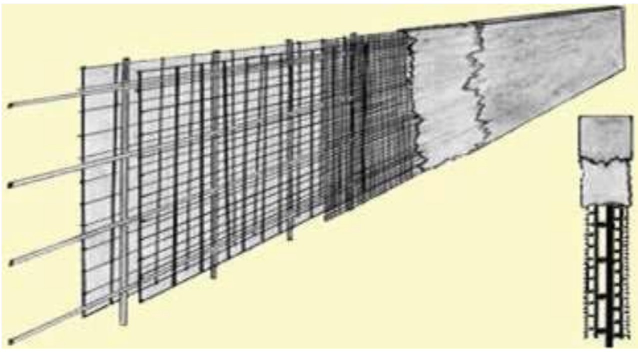


Fig-1: A typical cross-section of ferrocement structure

1.3 History of Ferrocement

Joseph Louis Lambot a horticulturist experimented with plant pots, seats and tubs made of meshes and plastered with sand and cement mortar replaced his rotting rowing boat. He called this material as “Ferciment” in a patent which he took in 1852. There was very little application of true ferrocement construction between 1888 &1942 when Pier Luigi Nervi began a series of experiments on ferrocement. He observed that reinforcing concrete with layers of wire mesh produced a material possessing the mechanical characteristics of an approximately homogeneous material capable of resisting high impact. In 1945 Nervi built the 165 ton Motor Yatch “Prune”on a supporting frame of 6.35mm diameter rods spaced 106mm apart with 4 layers of wire mesh on each side of rods with total thickness of 35mm.It weighed 5% less than a comparable wooden hull &cost 40% less at that time. In 1948 Nervi used ferrocement in first public structure the Tutrin Exhibition building, the central hall of the building which spans 91.4m was built of prefabricated elements connected by reinforced concrete arches at the top &bottom of the undulations. In1974 the American Concrete Institute formed committee 549 on ferrocement.ACI Committee 549 first codified the definition of ferrocement in 1980 which was subsequently revised in 1988,1993 and 1997(AE Naaman2000)

2. LITERATURE REVIEW

S. Deepa Shri and R. Thenmozhi[2] carried out an experimental work on ferrocement panels for studying their flexural behaviour by using polypropylene fibers. Silica fume is added to reduce the dosage of chemical admixtures needed to get required slump. It is well known that addition of fibers will generally improve the ductility, toughness, flexural strength and reduce the deflection of cementitious materials. In the present study, polypropylene fibers is added to the matrix and the dosage of fibers is taken as 0.3% by weight of cementitious materials. Weld mesh is arranged in different layers in ferrocement slab instead of reinforcement. Weld mesh of size 590 mm X 290 mm with grid size 20 mm X 20 mm and 1.2 mm dia. skeleton reinforcement is used for casting of ferrocement slabs. The slab panel size was 700mm X 300mm X 25mm and 30mm. The authors conclude that the load carrying capacity of SCC ferrocement slab panel with 0.3% fibers is larger compared to without fibers, delayed the first crack load, yield load and ultimate load compared to without and there is an increase in strength with the increase of slab thickness. Hybrid reinforced ferrocement specimens could sustain the larger deflections both at yield and ultimate loads compared to the SCC ferrocement specimens without . Many micro cracks are formed before failure of the specimens, indicating more energy absorption and ductility, the stiffness of the specimens with 2-layers bundled weld mesh is lower than that of the specimens with 3 layers bundled.

Mohamad N. Mahmood Sura A. Majeed[1] carried out an experimental work on flat and folded ferrocement panels for studying their flexural behaviour. The panels tested for flexure are of size 380mm X 600mm with 20mm thickness for both flat as well as folded slab panels. The wire mesh used was mild steel galvanized welded wire mesh of 0.65 mm diameter and 12.5 mm square grid size. From his experimental work the author concludes that the cracking load was not significantly affected by the number of the wire mesh particularly for the folded panels. The also concludes that 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.

M.N. Soutsos, T.T. Le, A.P. Lampropoulos[3] carried out an experimental project involved casting and testing 66 prisms of size 150*150*550 mm and cubes of size 100 and 150 mm. Cubes were tested for compressive strength using a Tonipact compression testing machine with maximum capacity of 3000 KN. Concrete was mixed in batch sizes of either 73 or 95 l which was sufficient for casting six 100 mm cubes for testing at 3 and 7-days, three 150 mm cubes for testing at 28-days, and six 150*150*550 mm prisms .Load–deflection curves were determined by loading the 28-day prism specimen using a Denison Avery 100 KN test machine in order to load the specimens at a constant deflection rate rather than constant load rate. Materials include CEM I Portland Cement 42.5 N, natural sand and 20–5 mm gravel. The mix proportions used were: 267 kg/m3 of Portland cement, 805 kg/m3 of sand, 1190 kg/m3 of gravel and 189 kg/m3 of water. The total water–cement ratio was 0.71. It appears that the incorporation of steel fibres increased the compressive strength by about 4 and 5 N/mm2 for fibre dosage rates of 30 kg/m3 and 50 kg/m3. The increases in the compressive strength of synthetic fibres is lower, about 2–3 N/mm2 for dosage rates of 4.5–5.3 kg/m3. Incorporation of steel fibres also appeared to increase only slightly the flexural strength, i.e. by about 0.4–0.6 N/mm2 for the plain concrete value of 4.2 N/mm2. The most important parameters for the design of ground supported slabs are the flexural toughness and the equivalent flexural strength ratio. The flexural toughness of concrete increases considerably when steel and synthetic fibres are used.

3. OBJECTIVE OF EXPERIMENTAL STUDY

The main objective of this experimental work is to study the behaviour of ferrocement panels under flexural loading in which welded square mesh has been used as a reinforcement .The various parameters considered in this study are as follows -:

a). Effect of number of mesh layers on the flexural strength of slab panels.

b) Effect of steel fibers on the flexural strength of slab panels.

c) Effect of volume fraction on the flexural strength of panels.

3.1 Experimental Work

The experimental program includes preparing and testing of flat ferrocement slab panels under two-point loading. The primary variables were the number of layers of meshes in panels and the use of steel fibers.

MATERIALS-Cement Ordinary Portland Cement (Grade 43), Sand -:Passing through 2.36 mm I. S. Sieve, Admixture (Perma PC-202) Water – Ordinary Drinking Water, Mesh Used – Welded Square Mesh of 1.6 mm Diameter. Steel fibers of corrugated type with aspect ratio (l/d=57).

3.2 Mix Proportion

Cement sand ratio (1:1.75).Water cement ratio (0.38). A total of 9 cubes of size (70*70) of above proportion were casted with and without steel .Compressive strength obtained is tabulated below

Table-1: Comp strength of cubes at 28 days

S.NO	SIZE	Load at failure (kg)	Comp strength (N/mm²)	Average comp strength
Without steel fibers				
1	70*70	20,000	40.04	
2	70*70	20,000	40.04	40.84
3	70*70	21,200	42.44	
With steel fibers				
4	70*70	18,800	37.63	
5	70*70	24,300	48.64	43.43
6	70*70	22,000	44.04	

Table-2: Details of panels to be casted

WITHOUT STEEL FIBERS

NO	SIZE OF PANEL	LAYERS	NO OF PANELS
1	550*200*25	2	3
2	550*200*25	3	3
3	550*200*25	4	3

WITH STEEL FIBERS

NO	SIZE OF PANEL	LAYERS	NO OF PANELS
1	550*200*25	2	3
2	550*200*25	3	3
3	550*200*25	4	3

Preparation of mortar-Mortar was prepared by calculating the exact amount of cement sand and water. At first the cement and sand were mixed dry. Admixture with dosage of 1% of wt of cement was mixed thoroughly with water and then added to dry mix. Steel fibers with dosage of 0.5% of total volume of composite were added.50% of steel fibers were added in dry mortar and remaining 50% after mixing of water.

Fig-2: Mixing of steel fibers in mortar

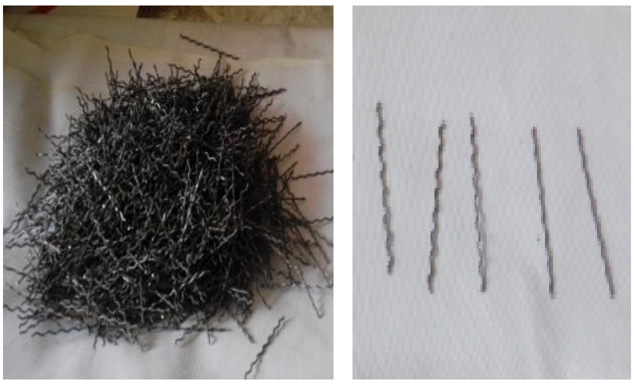


Fig-3: Corrugated type steel fibers

Fig-4: Admixture (Perma PC-202) after mixing with water was used in mix

Casting-The steel mould prepared were properly oiled before casting .At bottom a layer of mortar was applied of thickness 3 mm followed by layer of welded square mesh and again followed by layer of mortar. The procedure continues for placing layers of mesh in panel**.**

Fig-5: Steel mould oiled before casting of thickness 25 mm

The mesh pieces were cut down according to the size of panel leaving a cover of 3 mm on both side of mesh (544*194).

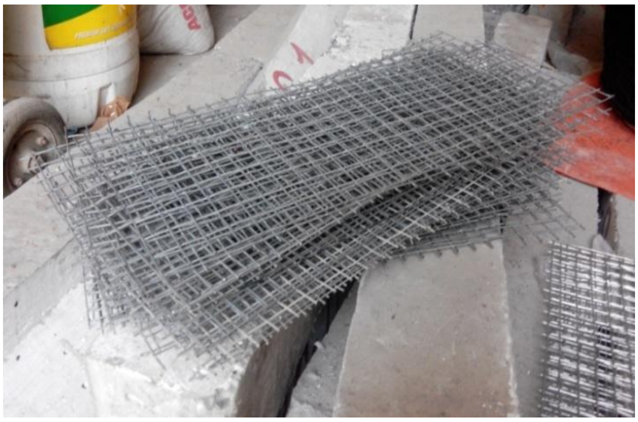


Fig-6: Pieces of Welded Square Mesh (Spacing 20*20 mm, 1.6mm Diameter)

Fig-7: Placing of layers in mortar

Curing-After casting of panels they were removed from mould after a period of 24 hours. After removal the panels were cured in normal water tank for a period of 28 days.

Testing-The panels were removed from the curing tank after a period of 28 days. White wash was applied to the panels to get clear indication of the cracks due to bending under service load. Panels were tested for flexure test under Universal testing machine. The panels were placed on support leaving a space of 50 mm from both ends. Dial gauge was placed below the panel to record the deflection in mm at each stage of loading.

Fig-8: (25 mm-2 layers) panel under testing set-up

After testing to calculate the flexural strength the panels were loaded under two point loading and load and deflections were noted down

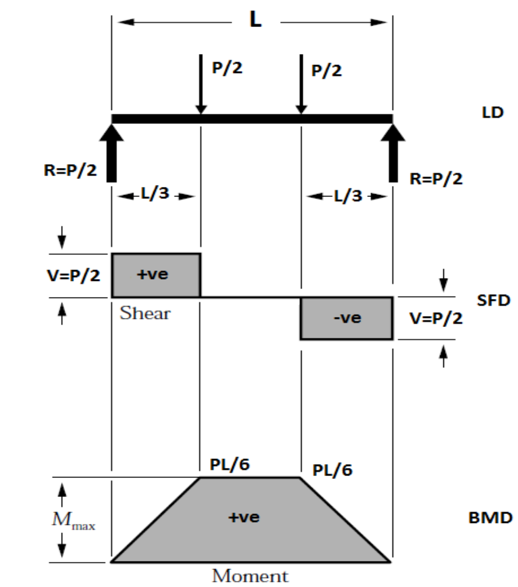


Fig-9: SFD and BMD distribution

The bending strength was calculated using the following formula

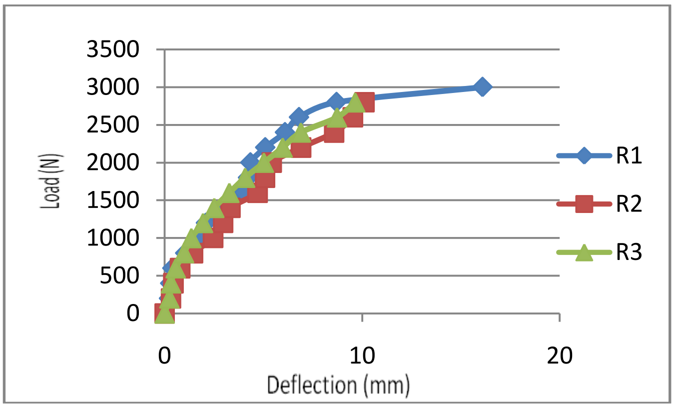
$$M/I=\sigma/y \text{ thus } \sigma=M/I * y$$

Where:
M: Bending Moment, (N.mm)
y= D/2, (mm)
I: Moment of Inertia=$bd^3/12$.

4. TEST RESULTS

Table-3: Panel thickness-25mm, Layers-2 (Without steel fibers)

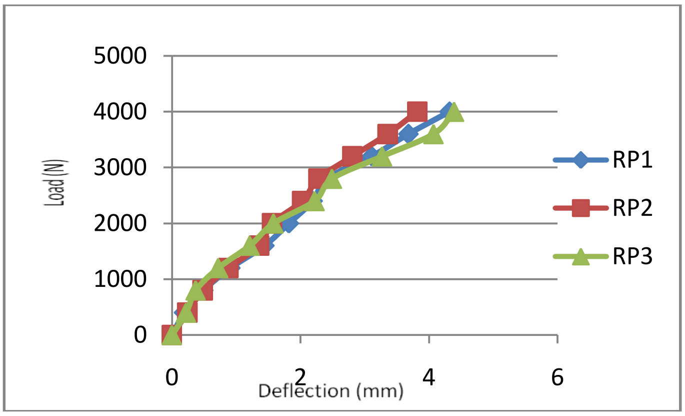
Load (N)	Deflection (mm)		
	R1	**R2**	**R3**
0	0	0	0
200	0.22	0.32	0.24
400	0.28	0.44	0.32
600	0.39	0.78	0.56
800	1.04	1.44	0.98
1000	1.75	2.45	1.35
1200	2.09	2.96	1.94
1400	3.02	3.33	2.51
1600	4	4.7	3.27
1800	4.22	5.08	4.07
2000	4.34	5.42	5.02
2200	5.09	6.9	5.97
2400	6.09	8.58	6.89
2600	6.8	9.52	8.72
2800	8.7	10.11	9.64
3000	16.09		10.75
1st Crack	6.09	6.9	5.97
Max.Load	3000	2800	3000



Graph-1: Showing load vs deflection (25mm-2layers)

Table-4: Panel thickness-25mm,Layers-2 (with steel fibers)

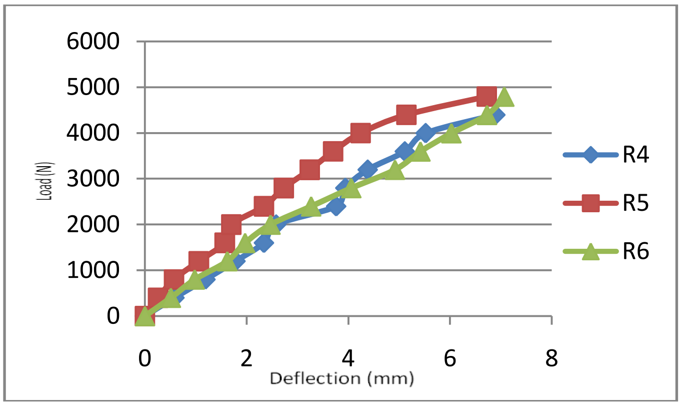
Load (N)	Deflection (mm)		
	RP1	**RP2**	**RP3**
0	0	0	0
400	0.19	0.24	0.22
800	0.49	0.48	0.37
1200	0.91	0.88	0.72
1600	1.44	1.36	1.21
2000	1.82	1.56	1.58
2400	2.19	2.03	2.22
2800	2.41	2.28	2.49
3200	3.11	2.81	3.27
3600	3.68	3.36	4.07
4000	4.32	3.82	4.39
1st Crack	4.32	3.58	4.39
Max.Load	4200	4000	4200



Graph-2: Load vs deflection (25 mm-2 layers) with steel fibers

Table-5: Panel thickness-25mm, Layers-3 (without steel fibers)

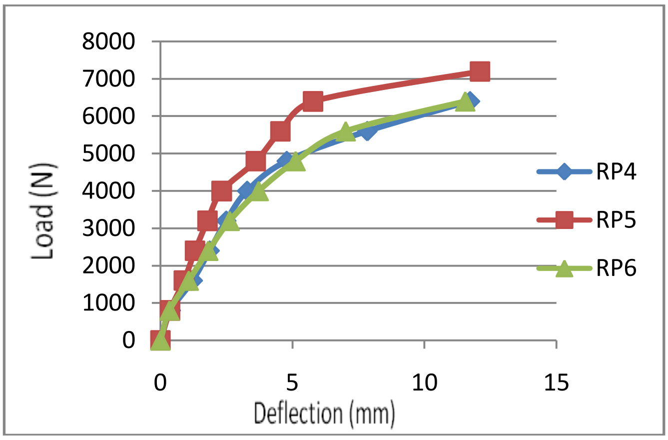
Load (N)	Deflection (mm)		
	R4	**R5**	**R6**
0	0	0	0
400	0.58	0.26	0.51
800	1.19	0.57	0.98
1200	1.78	1.06	1.62
1600	2.34	1.57	1.97
2000	2.58	1.7	2.47
2400	3.76	2.34	3.27
2800	3.94	2.73	4.06
3200	4.38	3.24	4.92
3600	5.11	3.7	5.42
4000	5.52	4.24	6.03
4400	6.89	5.14	6.73
4800		6.72	7.07
1st Crack	5.52	6.12	6.03
Max.Load	4400	4800	4800



Graph-3: Load vs deflection (25 mm-3 layers) without steel fibers

Table-6: Panel thickness-25mm,Layers-3 (with steel fibers)

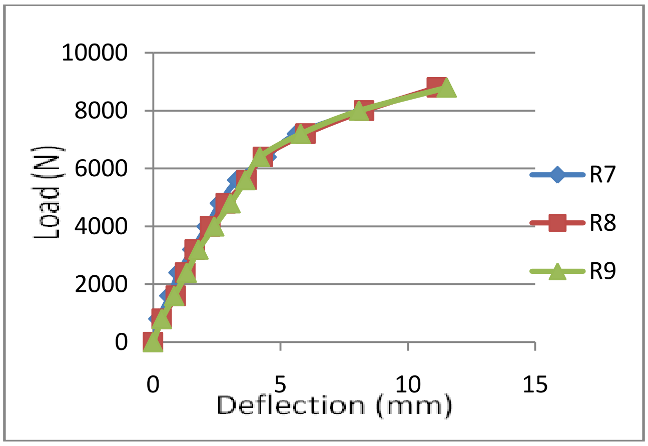
Load (N)	Deflection (mm)		
	RP4	**RP5**	**RP6**
0	0	0	0
800	0.39	0.36	0.34
1600	1.22	0.89	1.07
2400	1.86	1.31	1.81
3200	2.49	1.78	2.62
4000	3.28	2.32	3.72
4800	4.78	3.61	5.12
5600	7.83	4.54	7.02
6400	11.72	5.78	11.55
7200		12.1	
1st Crack	5.81	5.04	5.55
Max.Load	6400	7200	6400



Graph-4: Load vs deflection (25 mm-3 layers) with steel fibers

Table-7: Panel thickness-25mm, Layers-4 (without steel fibers)

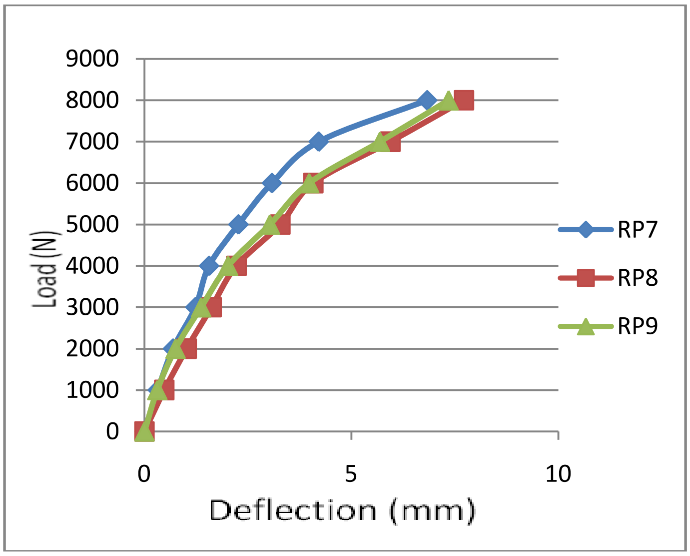
Load (N)	Deflection (mm)		
	R7	**R8**	**R9**
0	0	0	0
800	0.21	0.34	0.34
1600	0.64	0.89	0.83
2400	1	1.26	1.32
3200	1.54	1.64	1.78
4000	2.1	2.24	2.4
4800	2.62	2.85	3.04
5600	3.3	3.67	3.62
6400	4.45	4.31	4.19
7200	5.64	5.98	5.79
8000	8.21	8.28	8.08
8800		11.13	11.52
1st Crack	3.86	4.99	4.89
Max.Load	8000	8800	8800



Graph-5: Load vs deflection (25 mm-4 layers) without steel fibers

Table-8: Panel thickness-25mm, Layers-4 (with steel fibers)

Load (N)	Deflection (mm)		
	RP7	**RP8**	**RP9**
0	0	0	0
1000	0.32	0.48	0.31
2000	0.69	1.02	0.75
3000	1.23	1.62	1.37
4000	1.56	2.22	2.02
5000	2.27	3.28	3.03
6000	3.08	4.08	3.98
7000	4.21	5.94	5.69
8000	6.83	7.72	7.35
1st Crack	5.8	5.94	6.12
Max.Load	8000	8000	8000



Graph-6: Load vs deflection (25 mm-4 layers) with steel fibers

Table-9: Flexural strength of ferrocement panels without steel fibers.

Panel No.	Cracking Load (N)	Ultimate Load (N)	Flexural strength (**σcr**) at cracking load (N/mm²)	Flexural strength (**σult**) at ultimate load (N/mm²)
R1	2400	3000	8.65	12.98
R2	2200	2800	7.93	11.89
R3	2200	3000	7.93	11.89
R4	4000	4400	14.42	21.63
R5	4600	4800	16.58	24.87
R6	4000	4800	14.42	21.63
R7	6200	8000	22.35	33.53
R8	6800	8800	24.51	36.77
R9	6800	8800	24.51	36.77

Table-10: Flexural strength of ferrocement panels with steel fibers.

Panel No.	Cracking Load (N)	Ultimate Load (N)	Flexural strength (**σcr**) at cracking load (N/mm²)	Flexural strength (**σult**) at ultimate load (N/mm²)
RP1	4000	4200	14.42	21.63
RP2	3800	4000	13.70	20.55
RP3	4000	4200	14.42	21.63
RP4	5200	6400	18.75	28.12
RP5	6000	7200	21.63	32.45
RP6	5200	6400	18.75	28.12
RP7	7400	8000	26.68	40.02
RP8	7000	8000	25.24	37.86
RP9	7400	8000	26.68	40.02

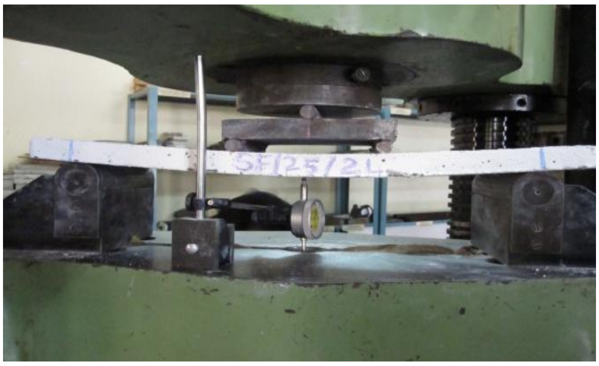


Fig-10: (25 mm-2 layer) panel failure

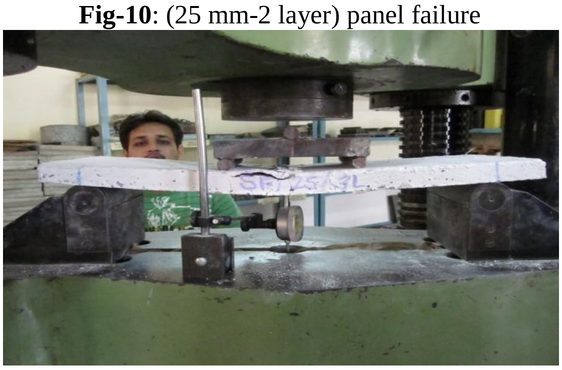


Fig-11: (25mm-3 layer) panel failure

5. CONCLUSIONS

Based on experimental test results the following conclusions can be made

1. The flexural loads at first crack and ultimate loads depend on number of reinforcing mesh layers used in ferrocement panel.
2. Increasing the number of layers of wire mesh from 2 to 4 layers significantly increases the ductility and capability to absorb energy of the panels.
3. Presence of steel fibers also increases the flexural strength of panels as compared to those without fibers.

4. Steel fibers also increases the ductility of panels and decreases the central deflection tendency as compared to others without steel fibers.
5. Result shows that incorporation of steel fibers long with increment in number of layers leads to 58% increase in load carrying capacity and 33% decrease in deflection.

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BIOGRAPHIES

Randhir J. Phalke is pursuing Master's in Structural Engineering from Maharashtra Institute of Technology, Pune.

Prof. Darshan G. Gaidhankar is currently working as Associate Professor at Applied Mechanics and Structural Engineering Department of Maharashtra Institute of Technology, Pune. His research field is Ferrocement Technology.