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Experimental Investigations on Ferrocement Roof Slab System for Low Cost Housing

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ABSTRACT

The paper presents the results of an experimental investigation carried out to assess the strength of pre-cast roof slab system comprising of ferrocement slab panels resting over RC beams. In the ferrocement panels, the cement was replaced by 0 % and 20 % fly ash. This roof slab system proves out to be a cost effective and structurally safe and viable alternative for low cost housing, much better than the conventional roofing system comprising of steel girder and brittle sand stone panels commonly used in regions where sand stone panels are easily available. The testing includes three sets of roof system comprising of 12 ferrocement panels placed on two pre-cast RC beams, and an enclosure of brick walls on four sides. A similar set of roof slab system comprising of 12 sand stone panels in place of ferrocement panels were also tested for comparison. The testing was continued till the cracks were pronounced. It was observed that load carrying capacity of RC beam and ferrocement panel system with same thickness is higher as compared to similar arrangement of RC beam and sand stone panels. The crack propagation phenomenon was also studied. The ferrocement roof slab system exhibited ductile failure whereas brittle failure was observed in case of sand stone roof slab system. Cost analysis reveals that two pre-cast systems of RC beams and ferrocement panels with and without fly ash are economical as compared to red sand stone panels or RC slab system.

KEYWORDS: Roof slab system, low cost housing, ferrocement, fly ash, flexural test.

INTRODUCTION

Due to acute housing shortage there is a need for the development of an appropriate cheap construction technology. Thus any effort in the direction of cost reduction of housing elements will be a valuable contribution and service to the society. Ferrocement is a composite material in which filler material called matrix, is reinforced with fibers dispersed throughout composite. The distribution of the reinforcement is made uniform by spreading out the wire meshes throughout the thickness of the member. This dispersion of the wire meshes in the brittle matrix offers not only convenience and practical means of achieving improvements in many structural engineering properties of the material such as fracture, tensile and flexural strength, toughness, fatigue and impact resistance and at the same time provide ease of construction. The uniform distribution and larger surface area of reinforcing material provides better crack prevention properties. Thus, ferrocement can be considered as a promising material system to address the low cost housing issue.

Numerous investigations have been carried out in past to establish the mechanical behavior of ferrocement under both static and dynamic loads. Balaguru et al. [1] carried out a study to determine the behavior of ferrocement in flexure and concluded that strength bears direct relation with number of layers and fineness of mesh. Yen and Su [2] studied the influence of skeletal steel on flexural behavior of ferrocement and concluded that skeletal steel does not contribute significantly towards the cracking strength. Walraven and Spierenburg [3] the cracking behaviour of ferrocement. Swamy and Spanos [4] investigated crack arrest performance of ferrocement. Shirai and Ohama [5] carried out experimental studies to determine the flexural behavior of polymer mixed ferrocement and concluded that first cracking load and ultimate load increases with the increase of polymer cement ratio. The effect of partial replacement of cement with fly ash in the ferrocement panels, was investigated by Arif et al. [6]. No significant drop in the flexural strength of panels using fly ash was observed up to 20% partial replacement of cement.

The main objective of the present investigation is to assess the strength and structural performance of ferrocement roofing system comprising of pre-cast ferrocement panels resting on two RC pre-cast beams and brick masonry walls on all four sides of an enclosure of size 2400´2250 mm. A similar test was also undertaken on roofing system using RC pre-cast beam and red sand stone panels for comparison of strength and cost.

EXPERIMENTAL PROGRAMME

Two sets of ferrocement panels with 0% and 20% partial replacement of cement with fly ash in three replications each, were prepared. The roof slab system comprised of these pre-cast panels resting on two pre-cast RC beams and brick masonry walls on all four sides of an enclosure as shown in Fig. 1. Thus for each set of roofing system, 12 pre-cast ferrocement panels were used. The load was transferred through a load tree at a total of 48 points on slab surface. The load was applied on incremental basis. For each increment of load, the deflection was measured up to failure for all the six sets (three replications each for 0% and 20% replacement of cement by fly ash). The first crack load, ultimate load and failure pattern was studied. In a similar manner tests were also conducted on roofing system assembly using sand stone panels in place of ferrocement panels.

MATERIALS USED

Ordinary Portland cement (43 grade) conforming to IS:8112-1989 [7] was used. The physical properties of cement were determined in the laboratory and presented in Table 1. The electro-statically precipitated fly ash was procured from NTPC Dadari (U.P.). The fly ash had a fineness of 3800 cm^2/g. The constituents of the fly ash were SiO_2 (45-60%) Al_2O_3 (10-30%) and Fe_2O_3 (5-25%) conforming to IS: 3812-1981 [8]. The physical properties of fly ash are given in Table 2. Locally available coarse sand (called Badarpur) with a silt content of 2.3 % was used. The grading and fineness modulus of the sand are given in Table 3. The crushed granite aggregate was used as coarse aggregate in RC beams. The grading and fineness modulus of the coarse aggregate are given in Table 4. The fineness modulus of fine and coarse aggregate was determined as per IS:2386 (Part I and II)-1963 [9]. Woven galvanized steel wire mesh with a wire diameter of 0.5 *mm* was used. The properties of the woven mesh are given in Table 5.

MIX PROPORTIONS

Two cement mortar mixes 1.0:0.0:2.5 and 0.8:0.20:2.5, comprising of cement: fly ash: sand (fine aggregate) were used in ferrocement panels. To achieve proper workability, water cement ratio of mortar was kept as 0.40. For RC beams, concrete mix in proportion of 1:2:4 comprising of cement: fine aggregate: coarse aggregate was used. To achieve

proper workability, water cement ratio in the concrete mix was kept as 0.5. Control specimens were cast to determine the strength of mortar. These cubes and briquettes were cured for 28 *days* and tested in accordance with the codal provisions. The strength of mortar control specimens is given in Table 6.

DETAILS OF FERROCEMENT PANELS AND RC BEAMS

For each set of roof floor system a total of 12 pre-cast ferrocement panels were used to cover the enclosed area of 2400´2250 mm. The top levels of the two pre-cast RC beams spanning along 2400 mm span and resting directly on two opposite side walls at 1/3 locations of 2250 mm span from both sides, were flushed with the top of the walls. Each ferrocement panel thus had sufficient bearing either on beams and walls or on the beams. The panels dimensions were 750×600×18 mm with two layers of woven wire mesh whereas the beam cross-section was 150×100 mm. The beams were reinforced with 2 Nos. 8 mm diameter Fe415 steel at top and bottom corners with 2 legged 6 mm diameter shear stirrups @ 100 mm c/c. The details of ferrocement panels and RC beams are given in Table 7.

CASTING OF TEST PANELS AND RC BEAMS

For the casting of test panels, mortar was spread in the wooden mould. The first wire mesh layer is laid on this 6 *mm* thick uniform mortar layer. After the mesh has been laid, the next set of ply sheet is put and again the mortar layer is spread on the wire mesh layer. This process is repeated till the required thickness of panel is obtained. These panels were demoulded after 24 hours and cured with gunny bags for 28 *days*. The cured panels were air dried for 4 *days* before the actual testing. For the casting of the RC beam, the material was weighed, dried and then mixed in a concrete mixture. Before casting, oil was smeared on inner surface of the mould and concrete was poured in layers. Care was taken to ensure that concrete was properly laid and compacted beneath the reinforcement and also along the side of the mould.

TEST SETUP

The test setup consists of loading frame of 500 *kN* capacity. Half brick thick wall (115 *mm*) was erected on the beams of the loading frames. Two RC beams were put on the brick walls and slab panels were placed on the beams and walls, which form roof slab systems. The loading arrangement and the position of dial gauges are shown in Figs. 2 and 3 respectively. The loads were applied through a reaction frame using hydraulic jack of 100 *kN* capacity activated by a high pressure manually operated pump fitted with a bourdon tube pressure gauge. A proving ring of 100 *kN* capacity was used to measure the applied load accurately. The load was uniformly transferred at 48 points. The deflections were recorded with the help of 12 dial gauges set below the centre of each panel. The first crack load, ultimate load and deflection at each increment of load were recorded. Similar tests were made on another roofing system comprising of red sand stone panels in place of ferrocement panels keeping the dimensions of red sand stone panels same as that of ferrocement panels.

The roof slab system was tested under flexure as shown in Fig. 4. Mechanical dial gauges mounted on magnetic base having least count of 0.01 *mm* were used to obtain the deflection at various stages of loading at the centre of each panel. The load was increased gradually till the slab panels failed. In all the tests carried out, the first crack load, ultimate load and corresponding deflection were observed. The crack pattern and failure mechanisms were also studied. All the ferrocement panels failed in flexure modes with the cracks parallel to the supported sides as shown in Figs. 5-6. The test results have been presented in Tables 8-9. Similarly test on roof slab system consisting of sand stone panels under same support condition was also undertaken. However, for the roof in sand stone panels, only the ultimate load and the cracking pattern were observed. The tested roof slab system consisting of sand stone panels resting over RC beams is shown in Fig. 7.

RESULT AND DISCUSSION

The load-deflection values for ferrocement panels with 0 % and 20 % fly ash are given in Tables 8-9 respectively. The ferrocement panels without fly ash possess larger load carrying capacity as compared to panels with 20 % fly ash. The first crack load and the ultimate load of the slab system with 0% fly ash are found to be 7.9 kN/m^2 and 9.8 kN/m^2 respectively. The maximum deflection is found in panel No. 6 and is observed to be 9.23 *mm* at ultimate load. Similarly the first crack load and the ultimate load of the panels with 20 % fly ash are observed to be 7.0 kN/m^2 and 8.4 kN/m^2 respectively. The maximum deflection is found in panel No. 6 which is 7.26 *mm* at the ultimate load. Multiple cracks were observed in all the slab panels. The crack width at the center of panels widened with the increase of load as shown in Figs. 5-6. The load deflection curves for different ferrocement panels with 0 % and 20 % fly ash in the roof slab system are shown in Figs. 8-9. The roof slab system comprising of red sand stone panels resting over RC beams shows brittle failure with an ultimate load level of 6.55 kN/m^2. A single transverse crack parallel to the support at the centre of the individual panel was observed at failure. The crack pattern is shown in Fig. 7. The load deflection values reveal that the load carrying capacity and the deflection decreases with increase in fly ash content. The ferrocement panels exhibit a ductile failure and their load carrying capacity is greater than the red sand stone panels. The red sand stone panels exhibit a brittle failure. The first crack load and ultimate load carrying capacity of ferrocement slab system with 0 % fly ash are 12.86% and 16.67% greater than that for the ferrocement slab system with 20 % fly ash. The ultimate load carrying capacity of the ferrocement slab system with 0 % fly ash is 49.62 % higher than the red sand stone slab system whereas ultimate load carrying capacity of the ferrocement slab system with 20 % fly ash is 28.24 % higher than the red sand stone slab system.

COST COMPARISON

To cover the same area of 2400´2250 mm, the cost comparison of different slab systems e.g. ferrocement panels with 0% fly ash resting over RC beams and walls, ferrocement panels with 20% fly ash resting over RC beams and sand stone panels resting over RC beams. Although experimental tests were not carried out on other slab systems e.g. sand stone panels resting over steel girders, RB slab and RC slab etc. However for the purpose of cost comparison the latter slab systems were also included and their cost was considered on the basis of prevailing market rates. The estimated cost includes the cost of slab as well as the beams wherever provided. The cost comparison is presented in Table 10. The cost of ferrocement panels resting over RC beams is found to be cheaper than the cost of red sand stone panels resting over RC beams. It is also observed that cost of ferrocement slab system with 0 % and 20 % fly ash is less than the cost of conventional RC slab by 59 % and 62 % respectively.

Although in the present investigation the supported span of the beam has been taken as 2400 *mm* (8 *feet*), the beam cross section was found to be safe even for 3000-3600 *mm* (10-12 *feet*) span. Thus even if the longitudinal dimension is increased to any size, as per the requirement, by using additional number of beams, it is apparent that the proposed floor system can be safely adapted for almost all sorts of commonly used room sizes.

CONCLUSION

The investigations undertaken clearly highlight the suitability of using roof slab system comprising of ferrocement panels with 0 % and 20 % fly ash resting over RC beams for low cost housing as it has lower crack width, compared to other alternatives. The aforesaid system is ductile and economically viable as compared to the other prevalent floor systems. The technology can be used not only for greater cost reduction benefits but also for effective utilization of fly ash waste thereby conserving the environment as well without any compromise on the structural integrity of the resulting system. The approach will be especially useful for low cost row housing schemes and emergency shelter housing projects for disaster affected areas.

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Table 1 Properties of Cement

S. No.	Properties	Values
1.	Consistency	29%
2.	Initial setting time (min.)	35
3.	Final setting time (min.)	510

Table 2 Properties of Fly Ash

S. No.	Properties	Values
1.	Color	Light grey
2.	Specific gravity	2.23
3.	pH	7.40
4.	% retained on 90 *micron*	48
5.	% retained on 75 *micron*	67

Table 3 Sieve Analysis of Fine Aggregate (Coarse Sand)

S. No.	I.S. Sieve Size	Weight retained (*g*)	Cumulative Weight retained (*g*)	% Cumulative weight retained
1.	4.75 *mm*	Nil	00	0.0
2.	2.36 *mm*	18	18	0.90
3.	1.18 *mm*	230	248	12.40
4.	600 *micron*	565	813	40.65
5.	300 *micron*	1108	1921	96.05
6.	150 *micron*	79	2000	100.00

Fineness Modulus = 2.5

Table 4 Sieve Analysis of Coarse Aggregate

S. No.	I.S. Sieve size	Weight retained (*g*)	Cumulative weight retained (*g*)	% Cumulative weight retained
1.	20 *mm*	140	140	2.8
2.	10 *mm*	4685	4825	96.5
3.	4.75 *mm*	105	4990	98.8
4.	2.36 *mm*	00	5000	100.00
5.	1.18 *mm*	00	5000	100.00
6.	600 *micron*	00	5000	100.00
7.	300 *micron*	00	5000	100.00

Fineness Modulus = 598.1/100 = 5.981

Table 5 Properties of Wire Mesh

S. No.	Properties	Values
1.	Average diameter	0.5 mm
2.	Size of opening	10×5 mm
3.	Ultimate tensile strength	350 N/mm^2
4.	Modulus of elasticity	0.9×10^5 N/mm^2

Table 6 Tests on Mortar Control Specimens

S. No.	Specimen designation	Mix used (Cement : Fly Ash : Sand)	Compressive strength of 70.6 mm cube tested after 28 days (N/mm^2)	Tensile strength of briquettes tested for 28 days (N/mm^2)
1.	M00	1 : 0: 2.5	30.00	3.00
2.	M20	0.8 : 0.2 : 2.5	21.00	2.30

Table 7 Details of Ferrocement Panels and RC Beams

S. No.	Element	Mix used	Size (mm)	Reinforcement
1.	Ferrocement panel without flyash	1 : 0 : 2.5 (Cement : Fly Ash : Sand)	750×600×18 mm	2 Nos. woven wire mesh
2.	Ferrocement panel with flyash	1 : 0 : 2.5 (Cement : Fly Ash : Sand)	750×600×18 mm	2 Nos. woven wire mesh
3.	RC Beam	1: 2 :4 (Cement : Fine Aggregate : Coarse Aggregate)	150×100 mm cross section	2#8 mm dia. Fe415 steel at top and 2#8 mm dia. Fe415 steel at bottom with 6 mm dia. 2 legged shear stirrups @ 100 mm c/c.

Table 8 Load Deflection Values for Ferrocement Slab System without Fly ash

S. No.	Load in *kN/m*^{2}	Deflection in *mm*				Remark
		Panel No.1	Panel No.2	Panel No.5	Panel No.6	
1.	0.00	0.00	0.00	0.00	0.00	
2.	0.53	0.22	0.25	0.23	0.27	
3.	1.20	0.42	0.47	0.44	0.51	
4.	1.5	0.54	0.57	0.55	0.72	
5.	1.9	0.76	0.82	0.78	1.00	
6.	2.4	0.90	1.01	0.97	1.30	
7.	2.8	1.14	1.36	1.31	1.67	
8.	3.3	1.35	1.62	1.57	2.16	
9.	3.8	1.54	1.89	1.84	2.42	
10.	4.4	1.83	2.30	2.23	3.00	Edges detached
11.	4.8	1.97	2.50	2.41	3.28	
12.	5.2	2.16	2.65	2.68	3.70	
13.	5.6	2.31	3.01	2.81	3.96	
14.	6.1	2.52	3.34	3.14	4.45	
15.	6.5	2.68	3.58	3.33	4.86	
16.	7.0	2.92	3.93	3.65	5.26	
17.	7.5	3.14	4.28	3.90	5.70	
18.	7.9	3.78	5.10	4.43	6.70	First crack in panels 5,6,7,8
19.	8.4	4.17	6.38	4.79	7.36	
20.	8.9	4.63	7.73	5.33	8.21	
21.	9.3	5.43	8.57	5.83	9.23	Second crack in the panels 5,6,7,8 and fist crack in panels 1,2,3,4,9,10,11,12
22.	9.8	-	-	-	-	Collapsing of the panels 5,6,7,8, and second crack in panels 1,2,3,4,9,10,11,12,

Table 9 Load Deflection Values for Ferrocement Slab System with 20% Fly ash

S. No.	Load in *kN/m*^{2}	Deflection in *mm*				Remark
		Panel No. 1	Panel No. 2	Panel No. 5	Panel No. 6	
1.	0.00	0.00	0.00	0.00	0.00	
2.	0.53	0.20	0.30	0.27	0.32	
3.	1.00	0.40	0.55	0.51	0.58	
4.	1.50	0.55	0.78	0.73	0.84	
5.	1.90	0.72	1.02	0.94	1.17	
6.	2.40	0.87	1.20	1.13	1.47	
7.	2.80	1.05	1.48	1.36	1.72	
8.	3.30	1.19	1.79	1.62	2.02	
9.	3.80	1.36	2.05	1.85	2.30	
10.	4.20	1.49	2.25	2.00	2.51	Edges detached
11.	4.70	1.65	2.53	2.25	2.77	
12.	5.20	2.18	2.81	2.48	3.04	
13.	5.60	2.20	3.11	2.74	3.34	

14.	6.10	2.21	3.44	3.00	3.65	
15.	6.50	2.42	3.82	3.13	4.02	
16.	7.00	2.79	4.79	4.09	4.82	First crack in panels 5,6,7,8
17.	7.50	3.44	5.49	5.18	5.76	
18.	7.90	4.22	6.55	5.93	7.26	Second crack in panels 5,6,7,8 and first crack in panels 1,2,3,4,9,10,11,12
19.	8.4	-	-	-	-	Collapse panels 5,6,7,8 and second crack in panels 1,2,3,4,9,10,11,12

Table 10 Comparison of Cost for Various Types of Roofing Systems

S. No.	Different Roofing Systems	Rate/m^2	% less than RC Slab
1.	RC beams with 20% fly ash in ferrocement panels	Rs. 134	62
2.	RC beams with 0% fly ash in ferrocement panels	Rs. 140	59
3.	RC beams and sand stone	Rs. 155	56
4.	Steel girders and sand stone panels	Rs. 219	37
5.	RB slab	Rs. 311	11
6.	RC slab	Rs. 350	00

RC Beams

4@600=2400 *mm*

1	5	9
2	6	10
3	7	11
4	8	12

3@750=2250 *mm*

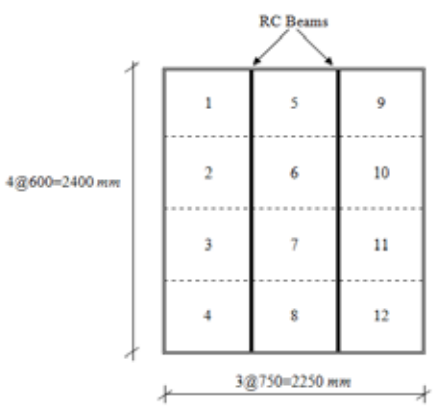

Fig. 1Placement of the panels (marked 1-12) resting on RC Beams and Brick Masonry Walls



Fig. 2 Loading arrangement on slab panels



Fig. 3 Set-up of dial gauges under slab panels (underside view)



Fig. 4 Ferrocement slab panel under test



Fig. 5 Crack pattern in ferrocement panels with 0% flyash (underside view)

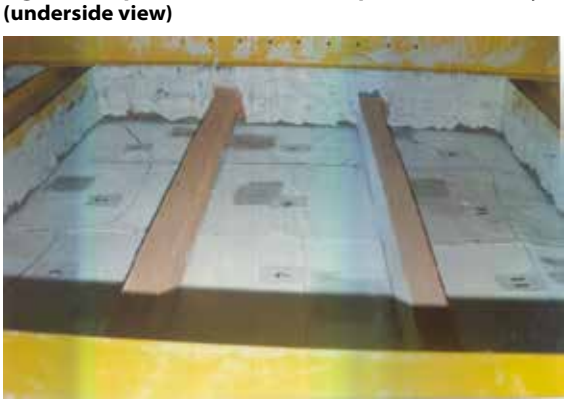

Fig. 6 Crack pattern in ferrocement panels with 20% flyash (underside view)

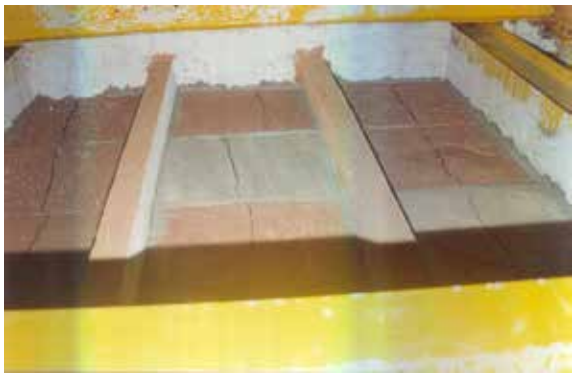

Fig. 7 Crack pattern in sand stone panels (underside view)

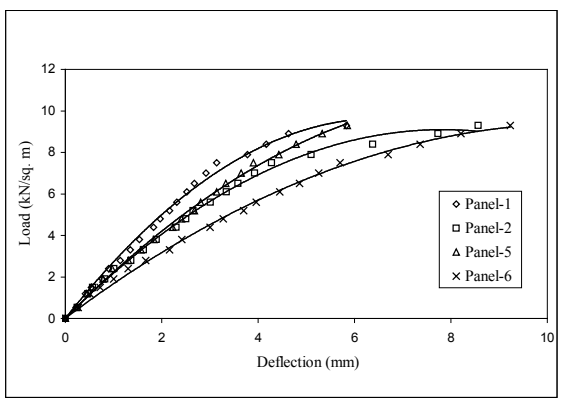

Fig. 8 Load-Deflection curves for ferrocement system without flyash

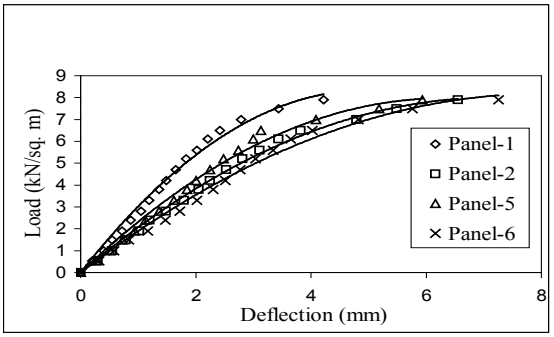

Fig. 9 Load-Deflection curves for ferrocement system with 20% flyash

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