INFLUENCE OF REINFORCEMENT ORIENTATION ON THE BEHAVIOR OF FERROCEMENT SLABS

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ABSTRACT

An experimental investigation was carried out on five slabs reinforced with steel wire mesh (ferrocement) to study the effect of reinforcement orientation on the behavior of the slabs. The slabs had the same overall dimensions and were subjected to uniformly distributed load. Four slabs had different reinforcement orientation, while the fifth one was a conventional reinforced concrete slab and was considered as a control one. The general behavior, deflection, cracking and ultimate load capacities of the slabs were recorded. In addition, strains in the concrete section and crack patterns were monitored. It was found that the reinforcement orientation had a significant effect on the behavior of the studied slabs. On the basis of the test results, a design approach for the ferrocement flexural members was proposed for the Egyptian Code of Practice ECC-89.

INTRODUCTION

Ferrocement is a form of reinforced concrete using closely spaced multiple layers of wire mesh and/or small diameter bars completely encapsulated in mortar [1]. Recently, a great deal of interest has been created on the potential application of ferrocement in the field of housing. Generally, the use of ferrocement in constructing new buildings can be classified into two classes. The first one is devoted for the use of ferrocement in small housing developments, while the second class involves roof covering of long spans and public buildings [2]. The most common type of ferrocement applications involves roofing in various forms and is located primarily in the developing areas of the world [3]. The modern technique for applying ferrocement includes multiple layers of wire mesh encapsulated in mortar. This has been used successfully for a wide variety of structural repairs and has proven to be impact and corrosion resistant [4]. The true value of ferrocement comes when it is used as a thin wall liner for rehabilitation and strengthening of structures [5]. In addition, it has inherent properties of toughness and crack resistance that make it superior to conventional concrete for the application in water structures [6].

The lack of use of ferrocement as a structural material has been due primarily to the fact that it has not been regulated, in many areas, by a formal code of practice [7]. Codes of ferrocement have been defined recently; for example, in Russia since 1967 and a tentative code was written by the ACI Committee 549 in 1988 [1,7].

In Egypt, it is believed that the use of ferrocement in the construction can be a competitive modern building material than the conventional concrete material. This is because of its low cost in comparison with conventional concrete. Therefore, it can be considered one of the ideal solutions for the housing problem. This can be achieved by using it in the construction of low cost housing for youth.

In recent years, a tremendous research work has been carried out into ferrocement properties and applications[8]. Earlier experimental studies [4,6,9,10] dealt with varying percentages of steel content, types of mesh, wire size and number of cast layers. On the other hand, there were studies carried out in order to optimize the use of ferrocement for repair of reinforced concrete structures [4,5,9,10]. It was found that casting ferrocement in multiple layers is an appropriate method for repair of concrete members since it does not require any formwork. Furthermore, this technique slightly improves the behavior by reducing the deflection and strains in the concrete section [10].

The objective of this investigation is to study the influence of reinforcement anisotropy on the behavior of slabs newly cast or those repaired using ferrocement. In addition, it was intended to propose a design approach for the flexural members made of or repaired with ferrocement. This design approach was aimed to be incorporated in the Egyptian Code ECC-89 as a helpful tool for structural engineers.

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DETAILS OF TESTED SLABS

The experimental program included five slabs of 90cm length and 50cm width. All slabs were reinforced with a traditional reinforcement of steel bars ϕ3/6cm in both longitudinal and transverse directions (see Fig. 1). The control specimen, P-cont, was cast at one layer of 7.0cm thickness, as shown in Fig. 1, to represent conventional concrete slab. The remaining four slabs were cast in two layers to simulate the case of repaired slabs. The first layer has 5.0cm thickness and reinforced with the same reinforcement of the control slab. The second layer which represents the repair layer has 2.0cm thickness and reinforced with an additional high tensile strength welded steel wire mesh with square opening @0.64cm to resist the applied loads (see Fig. 1). The difference between these slabs was the angle of orientation of the steel wire mesh placed in the second layer. The angle of inclination was measured with respect to the longitudinal direction. The plates were designated as P- 0, P-30, P-45 and P-60 as an indication for the chosen orientation angles (see Fig. 1).

TEST PROGRAM

Testing was conducted using a 50 ton Shimadzu universal testing machine as shown in Fig. 2-a. It was chosen similar to that used earlier [10]. A photograph for the arrangement of test equipment is shown in Fig. 2-b. Slabs were spanned in the 90cm direction with a distance of 84cm between supports. Loading was applied to the top surface of the slabs by means of a pyramid system of wood blocks to achieve a uniformly distributed load. The load was applied incrementally with a constant rate. After each increment of about 250 kg., the load was kept steady until deformation readings became almost steady, then strains, deflection and crack pattern were recorded.

Three dial gauges with accuracy of 0.01mm were positioned at the locations shown in Fig. 2-b to measure the resulting deflection. Mechanical demec strain points with distance 10cm apart were placed on both sides of the slab thickness to measure the flexural strains in the concrete section by means of strain gauge of accuracy 0.002mm.

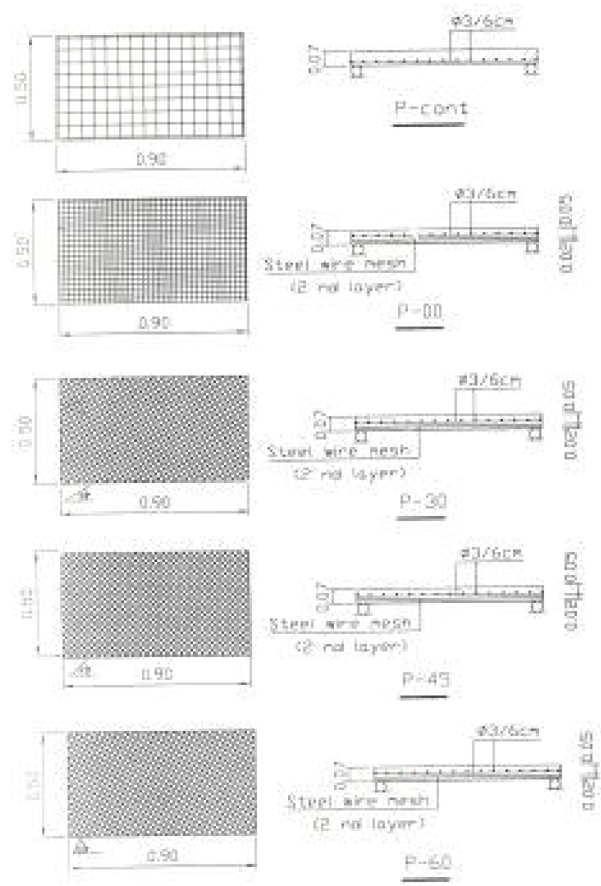


Fig. 1- Overall dimensions and reinforcement details of slabs

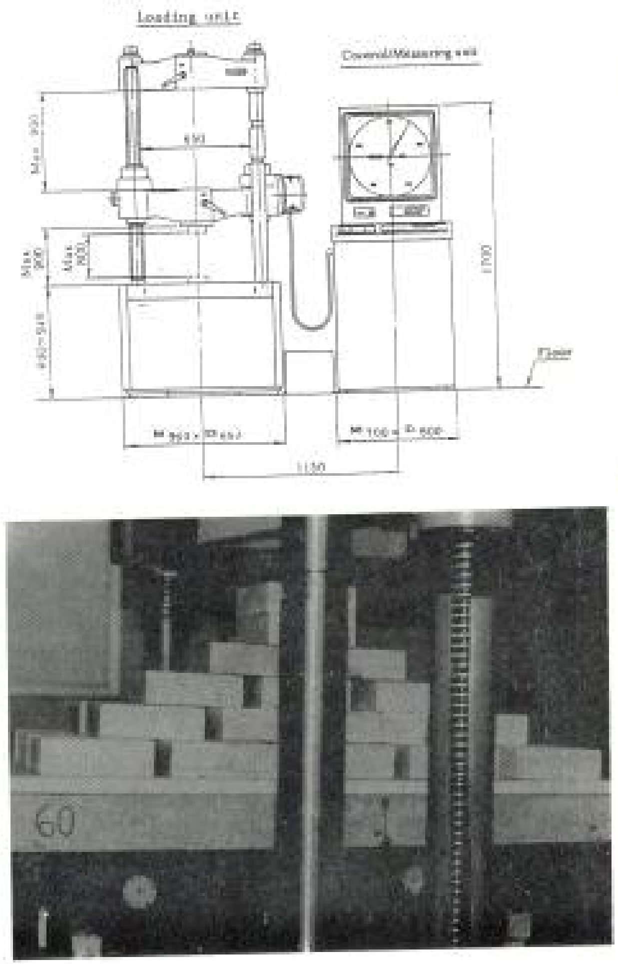


Fig. 2- Test setup; a) testing machine , b) arrangement of test equipments

DISCUSSION OF RESULTS

Load-Deflection Relationship

The load deflection relationship for the tested slabs is shown in Fig. 3. It is clear from the figure that before cracking, slabs reinforced with wire mesh have greater stiffness than conventional concrete slab (P-cont). This may be attributed to the addition of steel wire mesh to the original steel reinforcement of the repaired slabs. As a result, the deflection within service load for the ferrocement slabs was less than that of the control slab by about 23.8%. Also, it was found that the deflection decreased with the increase of orientation angle. For example, the increase of orientation angle from 0° to 60° lead to a reduction in the deflection by about 24%.

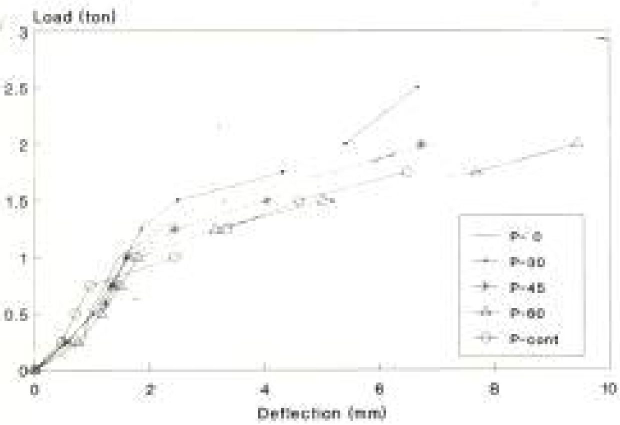


Fig. 3- Load-Deflection relationship for the tested slabs.

After cracking, it was noticed that deflection of all slabs was almost the same with a margin of variation of about 7%. However, slab P-60 sustained a greater value of deflection till failure (about 1.46 times that of control slab). Figures 4-a and 4-b show the deflection profile of the slabs in both longitudinal and transverse directions.

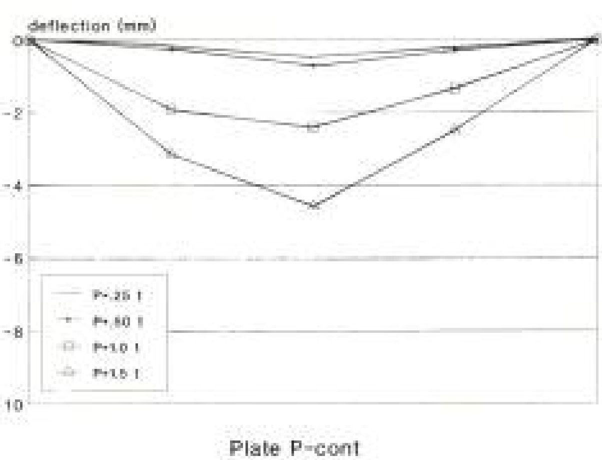


Plate P-cont

Fig. 4-a- Deflection profile of the control slab.

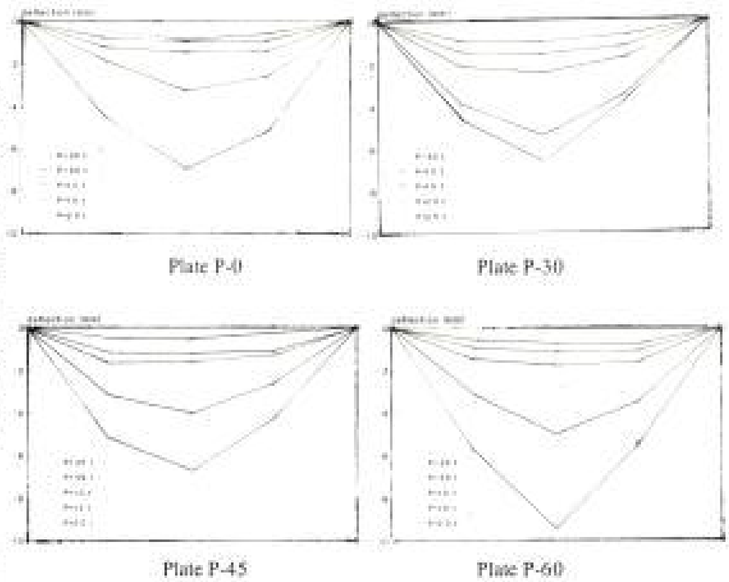


Fig. 4-b- Deflection profile of the tested ferrocement slabs.

Crack Pattern and Ultimate Capacity

The observed crack pattern for the tested slabs is shown in Fig. 5. It can be seen from the figure that using ferrocement improved the cracking performance by increasing the number of closely spaced cracks with narrow crack width. For ferrocement slabs, the maximum crack width was less than 0.05mm, while it was more than that for the control slab. In addition, the penetration depth of cracks in the slab thickness was approximately 4.0cm for the control slab, while it ranged from 2.0cm to 2.6cm for the ferrocement slabs. The first crack load and the ultimate capacity of the slabs as well as the corresponding deflection are listed in Table 1. It was found that, generally, the cracking load increased with the use of ferrocement. The amount of increase was about 58% of the control slab deflection. Moreover, the increase of orientation angle up to 30° increased cracking load by about 19.5%. After that the cracking load decreased. The same observation was found for the ultimate load capacity of the tested slabs. It was increased by about 11.3% with the increase of the orientation angle up to 30° and decreased again for greater angles.

Table 1- Deflection and load capacity of the tested slabs

Slab No.	Cracking Stage		Ultimate Stage	
	Deflection (mm)	P_{cr} (ton)	Deflection * (mm)	P_u (ton)
P-cont	2.40	0.980	6.48	1.912
P- 0	2.41	1.297	6.95	2.412
P-30	2.40	1.550	6.66	2.685
P-45	2.10	1.150	6.63	2.572
P-60	1.83	1.015	9.45	2.340

* Dial gauges were removed before failure of specimen.

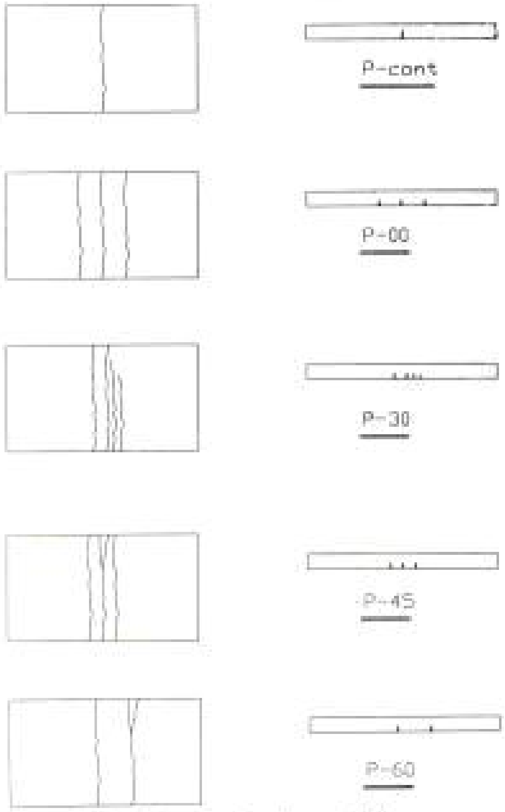


Fig. 5- Crack pattern for the tested slabs

Strains

The measurements of the horizontal strain across the thickness of the tested slabs were recorded and plotted as shown in Fig. 6. It can be noticed from the figure that the tensile strains are much higher than the compressive strains. This finding reflected the ductile behavior of the slabs as the tensile reinforcement reached its yield strength. Before cracking, strains increased with a small rate as the load increased, while after cracking the rate of increase was much higher until failure. The strain distribution was almost linear except at the top of slab section. This was attributed earlier [10] to the loading scheme using wood blocks and the friction between them which may have restrained the upper zone.

Proposed Design Approach

It is aimed in this section to suggest a design guide lines to help structural engineers and provide them with a procedure to check the acceptability of a ferrocement section. This procedure may be considered as a basis for the design of ferrocement members to be incorporated in the Egyptian Code ECC-89. The design approach was based on the design guides presented by ACI Committee 549[7]. However, it was modified to include the effect of reinforcement orientation angle. It can be carried out using either working stress method or ultimate limit state method. The design steps are summarized in Appendix-I and detailed elsewhere [7].

The results from the experimental program, the design method of ACI [7] and the proposed design approach are listed in Table 2. It was found that the results obtained from the modified design approach were in good agreement with those of the experimental tests. The difference between the load capacity calculated by the proposed method (P_3) and that obtained experimentally (P_1) ranged from 6.9% as a minimum value to a maximum value of 16.9%.

Within the limited scope of this research work, the results from the proposed design approach are satisfactory. However, a thorough investigation of this new technique (ferrocement) must be done on various applications to check the presented design approach.

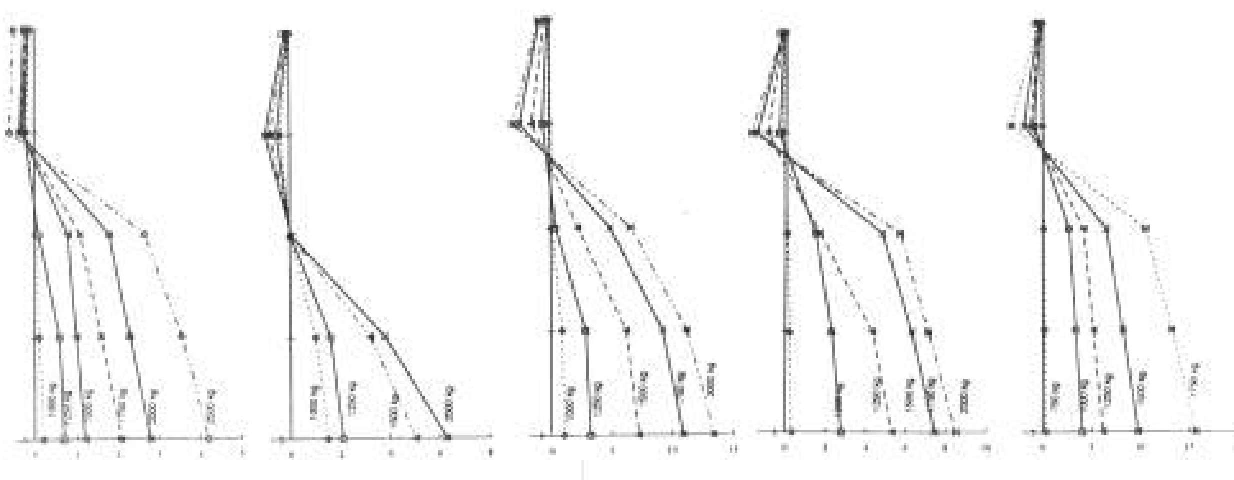


Fig. 6- Strain distribution for the tested slabs.

Table 2 Ultimate load capacity of the tested slabs

Slab No.	Test results (1)		ACI method (2)		Proposed method (3)		$[P_3 - P_1]/P_3$ %
	moment (t.m)	load P_1 (ton)	moment (t.m)	load P_2 (ton)	moment (t.m)	load P_3 (ton)	
P-cont	375×10^{-5}	1.912	480×10^{-5}	2.449	480×10^{-5}	2.449	21.9
P- 0	472×10^{-5}	2.412	442×10^{-5}	2.255	442×10^{-5}	2.255	6.90
P-30	526×10^{-5}	2.685	442×10^{-5}	2.255	632×10^{-5}	3.225	16.7
P-45	504×10^{-5}	2.572	442×10^{-5}	2.255	598×10^{-5}	3.051	15.7
P-60	458×10^{-5}	2.340	442×10^{-5}	2.255	552×10^{-5}	2.816	16.9

SUMMARY AND CONCLUSION

Test results of five investigated one way ferrocement slabs are presented. Crack patterns, deflection, deflected profile, concrete strains as well as ultimate capacity were discussed in details. In addition, a design approach for this type of elements was proposed. Within the limits of this investigation, the following conclusions are drawn:

1. Ferrocement was found to be a low cost technique for construction and/or repair of concrete structures especially for developed countries.

2. The deflection within service load for the ferrocement slabs was small compared with that of conventional concrete slab. Also, it was found that the deflection decreased with the increase of orientation angle.

3. Using ferrocement improved the cracking performance by increasing the number of closely spaced cracks with narrow crack width. The increase of orientation angle up to 30° increased both cracking and ultimate loads. However, they were decreased for higher angles.

4. A design procedure for ferrocement members was proposed to be incorporated in the Egyptian Code ECC-89. The design approach was based on the design guides presented by ACI Committee 549 and it was modified to include the effect of reinforcement orientation angle. Within the limited scope of this research work, the results from the proposed design approach were satisfactory.

5. A thorough investigation is needed for the acceptance of this new technique (ferrocement) as a building material, especially, development of a guide or recommended practice and development of simplified methods of analysis.

APPENDIX-I

The steps of the proposed design approach are summarized herein after. A more detailed information about the used parameters and expressions is found elsewhere[7].

Step 1: Calculation of volume fraction of mesh reinforcement (V_f) according to the number of layers, thickness of the section, wire mesh diameter and spacing between wires in both directions.

Step 2: Determination of the wire mesh reinforcement properties (F_Y , E_s , η) based on standard recommended values in Ref.[7]. These values are the wire mesh yield strength, the effective modulus of steel mesh and the efficiency factor of the mesh reinforcement in the loading direction, respectively.

Step 3: Modifying the previously determined factor η according to the angle of reinforcement orientation as:

$$\eta_m = \eta \qquad \text{for } \theta = 0.0 \text{ or } 90$$
$$\eta_m = \eta\,(1 + 0.5 \cos\theta) \qquad \text{for } 90 > \theta > 0.0$$

Step 4: Determination of the effective area of reinforcement for each layer as:

$$A_{sl} = \eta_m V_f A_c$$

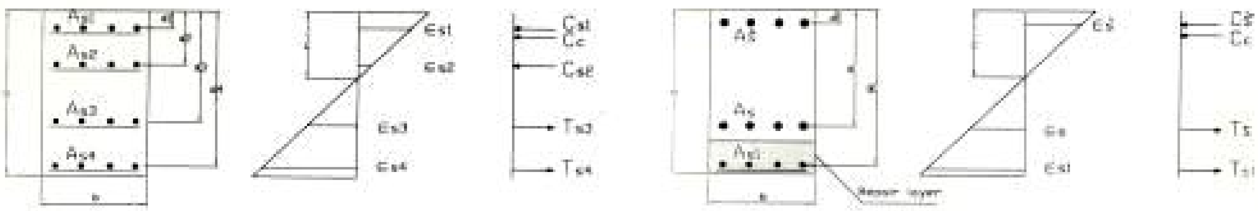
where: A_c is the concrete cross sectional area.

Step 5: Calculating the depth of each reinforcing layer as shown in Fig. 7.

Step 6: Determination of the distance from the extreme compression fiber to the neutral axis c by trial and error to satisfy equilibrium conditions.

Step 7: Calculating the strain ε_s in each reinforcement layer, as shown in Fig. 7, and the corresponding tensile stress f_s.

Step 8: Calculating the moment capacity of the section from the equilibrium of the total forces on the section.



Newly cast ferrocement section Repaired R.C. section

Fig. 7 Strain distribution across new cast or repaired section using ferrocement

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