Diyala Journal of Engineering Sciences

ISSN 1999-8716

Printed in Iraq

First Engineering Scientific Conference
College of Engineering –University of Diyala
22-23 December 2010, pp. 237-248

STRUCTURAL BEHAVIOUR OF FERROCEMENT SYSTEM FOR ROOFING

Wail N. Al-Rifaie [1] and Muyasser M. Joma'ah[2]
(1)University of Nottingham, U.K. and Professor Emeritus, University of Tikrit
(2) Civil Engineering Dept, Eng. College, University of Tikrit

ABSTRACT:- The growing need for cheaper construction is much-discussed subject. Prefabricated ferrocement panels present a series of possibilities for the solution of construction problem. 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, two ferrocement channel-like beams to form I-cross section beam and four ferrocement plates are cast and tested due to flexural loading. The structural behaviour 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.

***Keywords*:-** construction, structural, ferrocement.

INTRODUCTION

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.

The use of ferrocement in pre-fabricated buildings provides many advantages in terms of lightness of weight, ease of handling, low labour cost (skilled and non- skilled) in its production and a durable material requiring little maintenance. Evidently, for these reasons ferrocement has gained advantage over other reinforced concrete and steel structures.

Ferrocement is characterized by fine diameter mesh reinforcement (ø), $0.5 \leq ø \leq 1.5$mm and mesh size (S), $6 \leq S \leq 25$mm. The surface area per unit volume of mortar may be as much as ten times that of conventional reinforced concrete. The volume fraction of reinforcement normally lays between $2\% \leq V_f \leq 8\%$ for balanced, bidirectional meshes. Conventional mortars use sand-cement ratios of 1 to 3 and water-cement ratios of 0.35 to 0.5.

Regular reinforcing bars in a skeletal form are often added to thin wire meshes in order to achieve a stiff reinforcing cage.

In the present work, an experimental investigation on ferrocement channel-like beams and ferrocement square slab specimens were carried out. These beams having channel-like cross-section and square slabs can be used as flooring and roofing structural members. The main aim of this research was to study the behaviour and strength of ferrocement I beams and slabs subjected to flexural loads. The influences of parameters considered in the present investigation are number of layers and thickness of the slab specimens[1-29].

EXPERIMENTAL WORK

In order to study the structural behaviour and ultimate strength of ferrocement I cross section beam models by having two ferrocement channel-like cross section beams when subjected to point load. Each of the two channel beams is to be rotated 90 degrees and fixed back to back. Other two ferrocement channel beams were considered to support the slab specimens during their flexural tests. The four ferrocement channel-like cross section beam models were cast and tested, in which each of the four channel beams having a total length equal 2 meter were fabricated using the timber and play wood as formworks. The cross sectional dimensions and reinforcing details are shown in Figure 1.

In addition, 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 levelled off by a trowel.

For ferrocement beam models, skeletal smooth mild steel bar with an average diameter of 5 mm is used. The details of cross section of the two beams considered are shown in Figure 1.

Several strands of wires were taken from the mesh with samples of mild steel bar and tested in tension. The average value of the yield stress (f_{my}), ultimate stress (f_{ult}), and the modulus of elasticity (E_s) calculated from the tests of wire meshes and mild steel bars are given in Table (1).

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.

The mesh layers for the beam models were stretched, straightened and bounded to the skeletal reinforcement using mild steel binding wires.

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 30^{o}C and finally taken out of the water tank and kept in the open at room temperature before testing them.

Since it was necessary to carry out test on each model, it was important to establish a cube and cylinder mortar compressive strength (f_{cu}) and (f'_c), modulus of rupture (f_r), modulus of elasticity (E_m) and Poisson's ratio (ν). Thus a number of control specimens were made, as given in Table (2). These tests were in accordance with BS 1881.

Test samples were taken directly from the material used for casting slab specimens and beam models. Curing condition of test samples and models were the same. The results of the control slab specimens and beam models tested are given in Table (3).

The lateral deflections were measured using dial gauges graduated in units of 0.01 mm. The positions of these dial gauges are shown in Figure 1.

TESTING PROGRAM

As it was mentioned earlier that the present investigation concerned first of studying the structural behaviour of ferrocement I-section made of two ferrocement channel-like cross-section beams under flexural load by means of patch load at mid-span as shown in Figure 1.

The beam models and slab specimens were tested in a 2450 kN capacity hydraulic Avery-type testing machine. Hinged end conditions were considered. All beam models and slab specimens were painted white before testing so that cracks would be easily observed.

First, the (I) beam model was positioned on the support with a clear span of 1.8 m, so that the following criteria are satisfied:

i. To restrain all the end movement of the beam model.
ii. To restrain the rotations about the longitudinal axis.
iii. To permit free rotations of the end beam model normal to their plane, i.e., about the transverse axis.

Having placed and accurately aligned the I-section beam in testing machine, 100 mm square steel plate of 5 mm thickness was placed in its position and the load was applied as shown in Figure 1. The dial gauge was fixed at its appropriate location and the initial reading of dial gauge was recorded at the beginning of the test. The dial gauge readings were taken at least 2 min after each load increments to allow for the reading to become stable, and crack initiation was marked. The load application was continued until deformation became excessive.

The load was applied in increment of 10 N in a 2450 kN capacity hydraulic Avery-type testing machine and mid-span deflections were measured. The applying load was continued until failure occurred.

The second 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.

RESULTS

1. In Figure 3 the measured deflection values versus applied loads for the I-beam model are plotted.
2. It may be seen that the load-deflection curve for beam model is linear up to ultimate (failure) load.
3. The ferrocement I-beam was cracked at the web at each of bolt position and the cracks pattern are shown in Figure 4. The failure of the ferrocement I- beam occurred first by having fine cracks in the webs at the bolts position, then the length of cracks and their width were increased. It was noticed that there was no sign of cracks at flanges.
4. For slab specimens, in general, all slabs were cracked at the middle along the width (one way action):
5. 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.
6. 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.
7. Slab specimen S3, the ultimate load was 20 N. The crack pattern is shown in Figure 6.
8. 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.

CONCLUSIONS

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

REFERENCES

1. IFS Committees 10, 2001"Ferrocement Model Code," Building Code Recommendations for Ferrocement (IFS 10-01).
2. ACI Publication SP.61, 1979 "Ferrocement–Materials and Applications", pp 1-195.
3. ACI committee 549, 1980, "Guide for the Design, Construction, and Repair of Ferrocement" ACI Structural Journal, May. June, pp 325-351.
4. Shah, S.P., Namman, A.EandS.P., 1971, "Tensile Tests of Ferrocement", ACI Journal.68 (a), sep., pp 693-698

5. Namman, A.E. and Homrich, J.R., 1986, "Flexural Design of Ferrocement: Computerized Evaluation and Design Aids" Journal of Ferrocement, April, pp101-6.
6. Namman, A.E. and Homrich, J.R., 1986, "Flexural Design of Ferrocement: Computerized Evaluation and Design Aids" Journal of Ferrocement, April, pp101-117.
7. Mansur, M.A. and Ong, K.G.G., 1987 "Shear Strength of Ferrocement beams" ACI Journal Structural Journal, Jan – Feb pp 10-27
8. Lan Baugh, and Bowen, G.L, 1976, "Corrosion in Ferrocement", the Journal of Ferrocement Vol. 5, No. 4, pp 13-40.
9. ACI Committee 549, 1988 "State–of–the Art Report on Ferrocement", ACI Manual of Concrete Practice, part 5.
10. Shah, S.P, Key, W.H, 1972, "Impact Resistance of Ferrocement", Journal of the Structural division proceedings of the American Society of Civil Engineering, Jan. pp 111-123.
11. Al-Rifaie, W.N. and Al-Shukur, A.H.K., "Effects of Wetting and Drying Cycles in Fresh Water on the Flexural Strength of Ferrocement" Journal of Ferrocement: Vol. 31, No. 2, April 2001.
12. Al-Rifaie, W.N. and Al-Lami, M.S., "Durability of Ferrocement Exposed to Petroleum Products: Permeability", Industrialised Building Systems and Structural Engineering, World Engineering Congress, University of Putra, Faculty of Engineering1999 Malaysia.
13. Al-Rifaie, W.N.and Trikha, D.N., **"**Experimental Investigation of Secondary Strength of Ferrocement Reinforced With Hexagonal Mesh**".** Journal of Ferrocement, Vol. 17, No. 3, July 1987.
14. Al-Rifaie, W.N.and Trikha, D.N., "Effect of Arrangement and Orientation of Hexagonal Mesh of the Behaviour of Tow-Way Ferrocement Slabs**".** Proceedings of the Third International Symposium on Ferrocement, 1988, India, Journal of Ferrocement, Volume 20, No.3, 1990.
15. Al-Rifaie, W.N.and Trikha, D.N., 1988, "Assessment of Quality of Ferrocement Structures By Ultra Sonic Test". Proceedings of the Third International Symposium on Ferrocement, India.
16. Al-Rifaie, W.N. and Al-Lami, M.S. 2000, "Structural Behaviour of Ferrocement Exposed To Oil". Journal of Engineering and Technology, University Of Technology, Iraq, Vol. 19, No.2nd

17. Al-Rifaie, W.N. and Nimnim, H.T., January 2001, “An Experimental and Theoretical Investigation of the Behaviour of Ferrocement Box-Beams” Journal of Ferrocement: Vol. 31, No. 1.
18. Al-Rifaie, W.N.and Mahmood, K., January 2000., ”Ferrocement-Brick Composite Columns”. Journal of Ferrocement Vol.30, No, 1
19. Al-Rifaie, W.N.and Mahmood, K., 1999, ”Ferrocement-Brick Composite Walls”. Proceedings of Jordan Second Civil Engineering Conference, Amman - Jordan.
20. Al-Rifaie, W.N. , 1995,”The Behaviour of Two-Way Ferrocement Slabs under Impact Loads**”.** Proceedings of the Sixth Arab Conference in Structural Engineering,.
21. Al-Rifaie, W.N., February, 2006, “Ferrocement Wall: Penetration Testing”. The Eighth International Symposium and Workshop on Ferrocement and Thin Reinforced Cement Composites, 6-8, Bangkok, Thailand.
22. Zaki, M**.** and Al-Rifaie, W.N., 1999**, ”**Design Of Ferrocement in Flexure**”.** , Journal of Engineering and Technology, University Of Technology, Vol 18, No. 4, Iraq.
23. Al-Rifaie, W.N.and Mahmood, N.S, 2001**, ”**Finite Element Method for Non-Linear Analysis of Ferrocement Slabs and Box-Beams”**.** Proceedings of the Seventh International Symposium on Ferrocement and Thin Reinforced Cement Composites (FERRO-7), Singapore.
24. Al-Rifaie, W.N.and Mahmood, N.S, January 2000, ”Computational Model for Non-linear Analysis of Ferrocement Shells Using F.E.M”. Journal of Ferrocement, Vol. 30, No. 1.
25. Al-Rifaie, W.N.and Majeed, A., 1994, ” Structural Behaviour of Thin Ferrocement One-Way Bending Elements”. Journal of Ferrocement, Volume 24, No. 2.
26. Al-Rifaie, W.N.and Abdul-Aziz, A. , 1995,**”** Thin Ferrocement Bearing Walls”. Journal of Ferrocement, Volume 25, No.3.
27. Al-Rifaie, W.N.and Al-Hmedawi, A., Jan. 2000,” Structural Behaviour of Ferrocement Shells Roofs”. Journal of Ferrocement, Vol. 30, No. 1.
28. Al-Rifaie, W.N.and Mnasrah, A., January 2001,**”** Connection for Segmental Ferrocement Semi-Cylindrical Shells as a Roofing System**”.** Journal of Ferrocement, Vol. 31, No.1.
29. Al-Rifaie, W.N.and Kalaf, S**.**, 2001, **”**Experimental Investigation of Long-Span Roofing System”**.** Proceedings of the Seventh International Symposium on Ferrocement and Thin Reinforced Cement Composites (FERRO-7), Singapore.

Table (1): Properties of wire mesh and skeletal reinforcement.

	Wire mesh 0.7 mm dia.	Smooth steel bar 5 mm dia.
Yield stress (f_{my})*, (N/mm^2)	300	510
Standard deviation	8.2	12.8
Ultimate Strength (f_{ult}), (N/mm^2)	520	582
Standard deviation	18.6	17.5
Modulus of elasticity (E_s) (N/mm^2)	67000	198820
Standard deviation	126	287

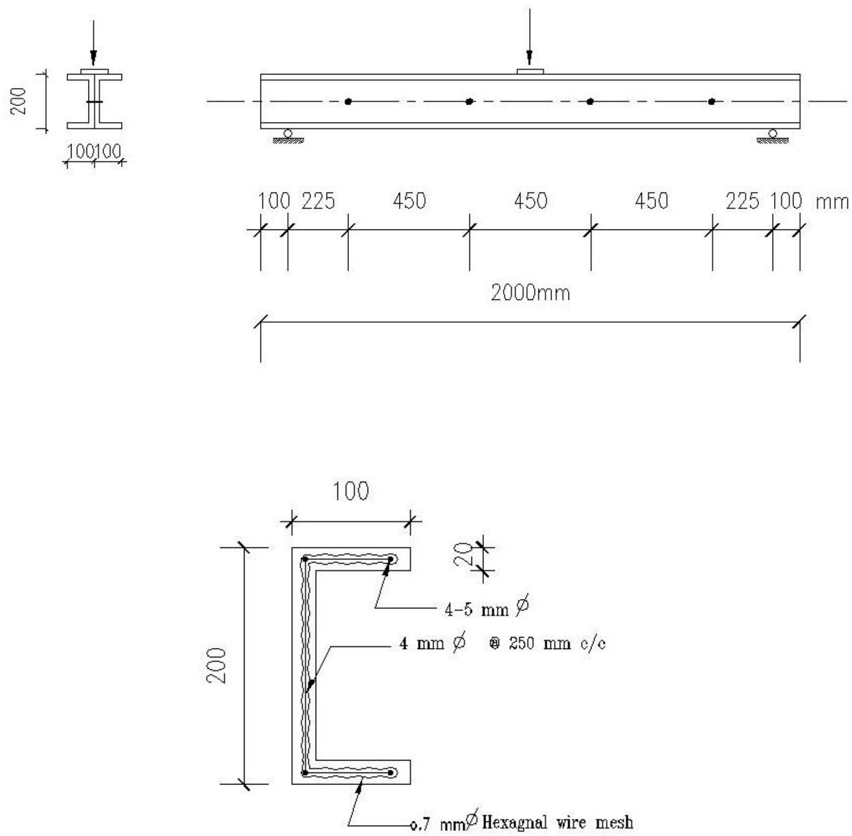
* The yield strength was selected as the stress corresponding to a total strain of 0.005.

Table (2): Details of the control specimens.

Test type	Compressive strength		Modulus of Rupture, fr	Modulus of elasticity, Em and Poisson's ratio, v
	f'c	$f$cu		
Number and size of the specimens	Three 100x200 mm cylinders	Three 100 mm cube	Three 100x100x400 mm prisms	Three 150x300 mm cylinders

Table (3): Test results of control specimens.

Wall No.	Mortar 2:1 sand : cement				
	Compressive strength (N/mm^2)		Modulus of rupture, fr (N/mm^2)	Modulus of elasticity, Em (N/mm^2)	Possion's ratio, v
	f'_c	f_{cu}			
W1	39.55	40.12	2.8	27562	0.24
W2	39.9	42	2.81	27956	0.236
W3	39.32	42.5	2.85	27836	0.234
W4	36.42	40.65	2.83	27230	0.2
Av	38.79	41.31	2.82	27646	0.2275



All dimensions are in mm

Fig.(1): Details of cross section of the tow beams.

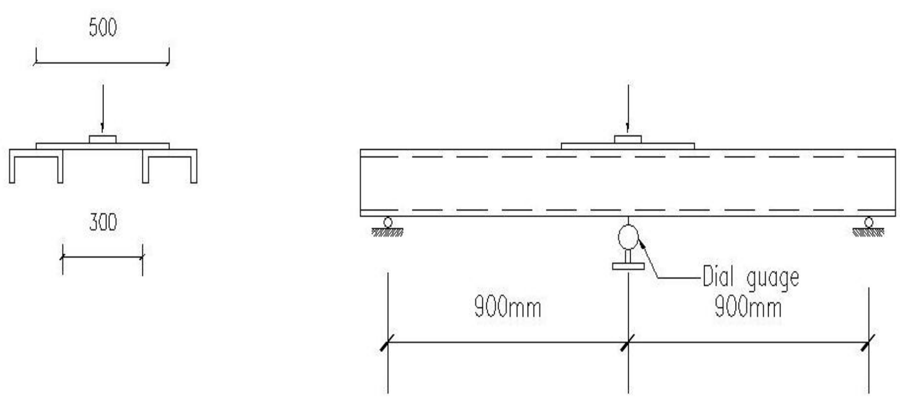


Fig. (2): Tow edges simply supported beams.

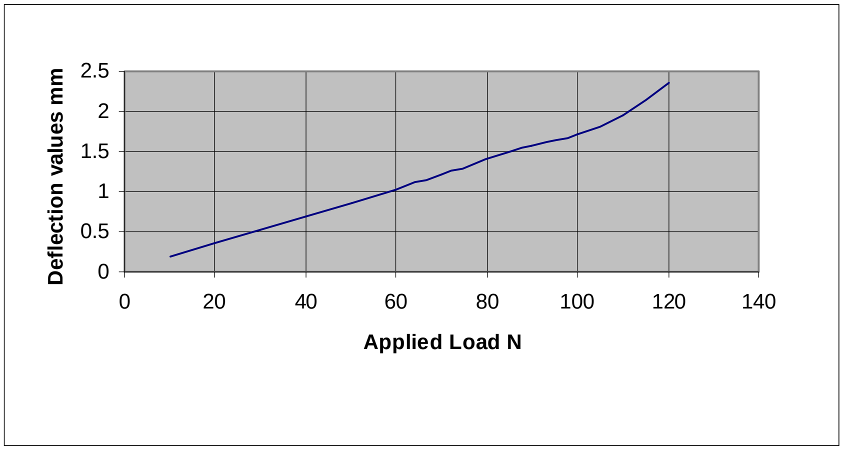


Fig. (3): Measured deflection values versus applied loads .

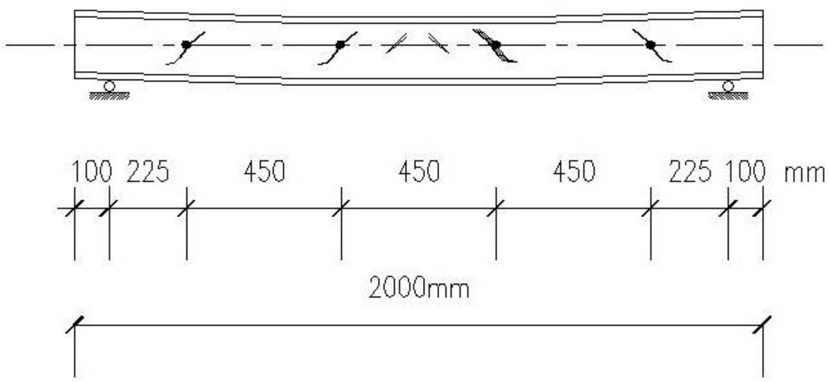


Fig. (4): Bolt position and the cracks pattern.

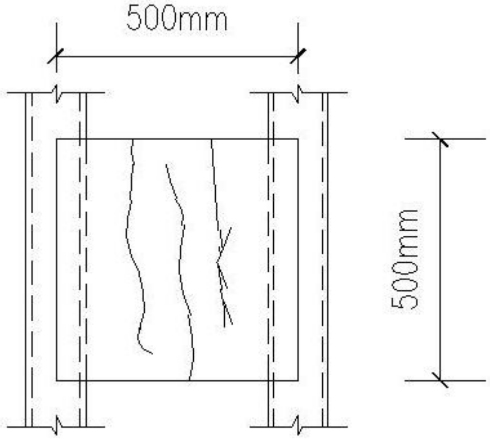


Fig.(5): The crack pattern (S_2).

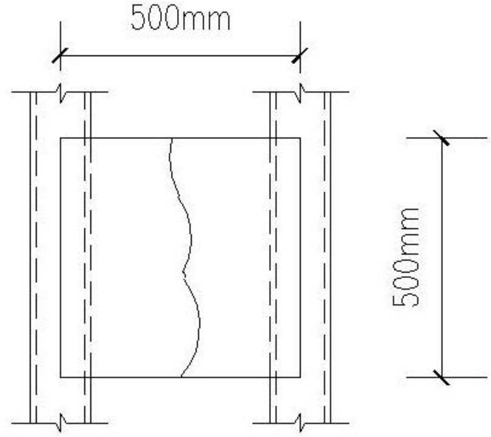


Fig.(6): The crack pattern (S_3).

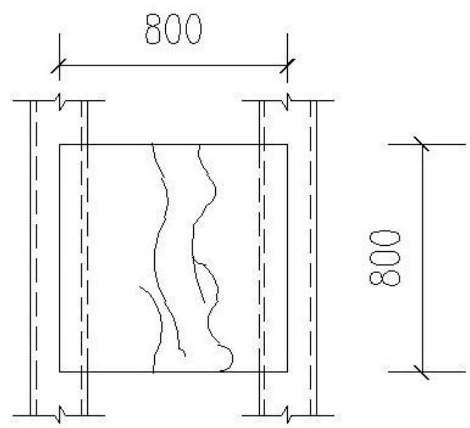


Fig.(7): The crack pattern (S_4).

السلوكية الإنشائية لنظام تسقيف من الفيروسمنت

د. وائل نورالدين الرفاعي
أستاذ
قسم الهندسة المدنية_كلية الهندسة_ جامعة تكريت

د. ميسر محمد جمعة
مدرس
قسم الهندسة المدنية_كلية الهندسة_ جامعة تكريت

الخلاصة

ان زيادة الاحتياج إلى وحدات سكنية واطئة الكلفة تتطلب إيجاد أنظمة إنشائية جديدة تتميز بأنها اقتصادية مع الحفاظ على متطلبات المتانة وسرعة الانجاز والإيفاء بالمتطلبات البيئية. وبذلك أصبح من الضروري السعي في إيجاد عناصر إنشائية مسبقة الصنع تمتاز بخفة الوزن وسهولة المناولة والحد الأدنى من الصيانة والكلفة الواطئة. ان الكلفة الواطئة ومتطلبات العمالة تجعل السمنت الحديدي مادة إنشائية تفي بالمتطلبات المذكورة لبناء مجمعات سكنية ومنشات خدمية. وقد تم استحداث نظام انشائي حديث لتشييد المباني تكون عناصره الانشائية مصنعة من مادة الفيروسمنت.

يعد الفيروسمنت احد أنواع الخرسانة المسلحة الرقيقة يتم تسليح مونة السمنت فيه بطبقات من المشبكات السلكية ذات أقطار صغيرة نسبيا موزعة بشكل منتظم خلال المقطع العرضي. وللفيروسمنت تطبيقات واسعة وذلك لتوافر مواده الخام الأساسية في معظم البلدان. ان هذا النظام الإنشائي الحديث الذي هو أكثر اقتصاديا من الأنظمة الإنشائية الأخرى يعتمد على عناصر إنشائية مسبقة الصنع.

ان التحريات المذكورة في هذا البحث تضمنت تصنيع وفحص ست عتبات بمقاطع على شكل ساقية وأربعة صفائح مصنعة جميعها من الفيروسمنت واقعين تحت تأثير أحمال عرضية. ولقد اثبتت الفحوصات من خلال قياس الانحرافات ان الفيروسمنت يمكن استخدامه بشكل فعال في تصنيع عناصر إنشائية في تشييد الأبنية.

كلمات الدالة: إنشاء، هيكلي ,مواد مركبة.