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Shear Behavior of High Strength Ferro Cement Deep Beam

Dunyazad K. Assi

Abstract—The use of high strength concreting materials as well as mortars has taken a wide range of applications, whose mechanical properties are still at a research phase. However the application of ferrocement in many structural applications in many parts of the world started decades ago, many researchers around the world have tried to study the engineering properties of ferrocement. The present research work deals with the behavior of ferrocement deep beams tested in laboratory. A total of five rectangular reinforced concrete deep beams were tested. Test variables included the mortar strength and the ferrocement wire mesh layers. From the obtained test results reinforced with higher number of wire mesh are proved to have a higher ultimate load as well as having a lower deflection. In addition, the ultimate load capacity of normal strength beam is less than that of higher strength one. Moreover, A strut-and-tie model was proposed for better understanding of the shear behavior and to aid the design process.

Index Term: Deep Beams, Ferrocement, Wire Mesh, shear strength.

I. INTRODUCTION

Ferrocement is a composite comprising cement mortar as the matrix and fine wire mesh as the reinforcement.The uniform dispersion of steel wire mesh and the close distribution of its opening transform the usually weak and brittle mortar mixture into a high performance building material. Since ferrocement is made of the same cementations materials as reinforced concrete structures, It is used in thin-walled structural sections, typically employed for steel or fibre-reinforced polymer like box, channel, T- and I sections. The adoption of ferrocement panel facings on a large-scale basis is the first of its kind in marine structural works, although it has had widespread use in the construction of silos, tanks, roofs, boats and other non-structural elements. The main objective of the ferrocement panel facing in the design of the seawall is for it to function as a sacrificial protective cover layer within the wave-splashing zone. The uniform distribution and high surface area to volume ratio of its reinforced results in better crack arrest mechanism i.e. the propagation of cracks are arrested resulting in high tensile strength of the material, [8]. Deep beam is a beam having large regional span to depth ratio less than 2. For a deep beam,shear stress has the predominant effect. After inclined cracking occurs, this beam tends to behave like a tied arch wherein the load is carried by direct compression extending from the loading points to the supports in nearly a trapezoidal shape "Reference [2], studied the shear resistance of fibrocement deep beams, the variables covered in the study were two different shapes of beams,

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U beams and I-beams, different matrix strengths and different span to depth ratios. It was concluded that shear the shear failure may occur only when the shear span to depth ratio is smaller than 1.5; the shear span strength may increase by increasing the matrix strength, volume fraction of meshes, cross sectional area and amount of rebar. Also it is concluded that the main type of shear failure for I beams was diagonal splitting while for U beams it was shear flexural. A shear design guide for ferrocement beams was proposed, in addition to an improved strut and tie model.

The behavior of a beam strengthened with ferrocement laminate was studied through an experimental investigation by [4]. Beams strengthened with ferrocement laminate was compared with a control beam and it was concluded that, beams strengthened with ferrcement proves to have higher cracking load, ultimate load as well as having a lower deflection in comparison to a lower beam. "Reference [5]" through an experimental program, studied the effect of variation of depth over length ratio on the behavior of ferrocement deep beams under central point loading. It has been arrived at a conclusion that the diagonal strength cracking increases at decreasing a/h ratio and or at decreasing volume fraction ratio of reinforcement. Moreover an empirical formula relating V_f and h is proposed to predict diagonal cracking strength. However, the current "*Guide for Design, Construction, and Repair of Ferrocement*" provided by ACI structural journal (1988) provides design criteria for tensile, compressive and flexural strength, there is relatively little information on the shear strength of ferrocement structures . Shear can be critical for ferrocement beams that are used as transfer girders for water tanks on roofs and flanged beams in the foundations of offshore gravity type structures and several other structures. In normal reinforced concrete beams, shear failure could be indicated by yielding or failure of shear reinforcements, but in ferrocement by satisfying the requirement of a minimum volume fraction and specific surface, the shear reinforcement ratio can be greater than that in reinforced concrete beams. Therefore the shear capacity of ferrocement beams could be better than normal RC beams. In order to obtain a clear understanding of the shear behavior of ferrocement deep beams, appropriate tests were conducted in the present study and theoretical model based on strut and the model is proposed, for the load capacity of ferrocement deep beams.

Significance of the Research

This research work aims to study the shear behavior of ferrocement rectangular deep beams made from high performance mortar reinforced with both steel wire meshes and flexural steel bars, through experimental laboratory tests. The research also provides a model for calculating shear strength of rectangular ferrcement rectangular deep beams, from which equations can be obtained for design of such beams.

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The study can be utilized for producing precast ferrocement rectangular beams made from high strength mortar.

II. EXPERIMENTAL WORKS

A. Description of Test Specimens

The experimental investigation includes casting and Testing of five rectangular beams. All of the beams are in the same dimensions 0.12 × 0.3 × 1.1m. Beams (BH0, BH7, BH12 and BH16) are made from high strength 90 MPa, while beam (BN12) were made from normal strength with a compressive strength of 35 MPa. B0 is considered as a control beam without wire mesh, whereas Beams BH7, BH12, BH16 and BN12 contain 7, 12, 16 and 12 layers of wire mesh respectively. Table I shows the test specimens constituents.

Table I detail of test specimens

Beam designa	**Wire Mesh Layers, (N)**	**Total Volume Fraction of Mesh Reinf.(V_f)**	**Cube compressive Strength of mortar (N/mm^2)**	**Mix Proportion (Cement: Sand: w/c)**
BH0	-		90	1:1 (0.25)
BH7	7	0.00147	90	1:1 (0.25)
BH12	12	0.00252	90	1:1 (0.25)
BH16	16	0.00336	90	1:1 (0.25)
BN12	12	0.00252	30	1:2 (0.5)

B. Materials Properties

Two mortar mixes were selected to achieve compressive strengths of 35 and 90 MPa after 28 days. Ordinary Portland cement and crushed sand were used for ferrocement mortar mixes, details are shown in Table 1. To obtain the convenient workability particularly, for 1:1:0.25 mixes design, superplasticizer of (HRWR-reducing admixture) is added at 2% by weight of cement. Ø10 mm steel bars for all beams of yield strength of 416 MPa are used for the flexural reinforcement. No stirrups were used for shear, instead layers of wire mesh were provided according to the arrangement shown in Table 1, and these wire mesh made of steel, have square openings of 12,5mm and yield strength of 350 MPa.

C. Construction process of the ferrocement deep beams

All the specimens were cast in moulds made of timber dimensioned 0.12 × 0.3 × 1.1 m. after oiling the entire faces of the moulds, the mixes were prepared and cast was made by providing layers of mortar on each put of wire mesh layers. First about 1 cm of mortar is poured then a layer of wire mesh was being put over, another layer of l to 2 cm of mortar (this thickness differed for each beam according to the number of wire mesh in the beams) was cast, consequently the process was repeated for the alternate layers of wire mesh till filling the mould.

D. Test Set up and Instrumentation

All beams were tested under two point loading over a span of 1000 mm and also instrumented for the measurement of mid-span deflections. Fig. 1 shows the position of loading points on the beam at testing. Loading are applied in at rate of 0.3 MPa/sec til the beam is collapsed. Furthermore, Fig. 2 shows the arrangement of the beams inside the testing frame reading for testing.

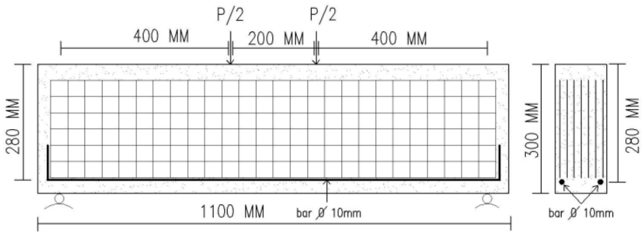

Fig.1 Beam dimensions, ferrocement wire mesh arrangement and the position of loading.

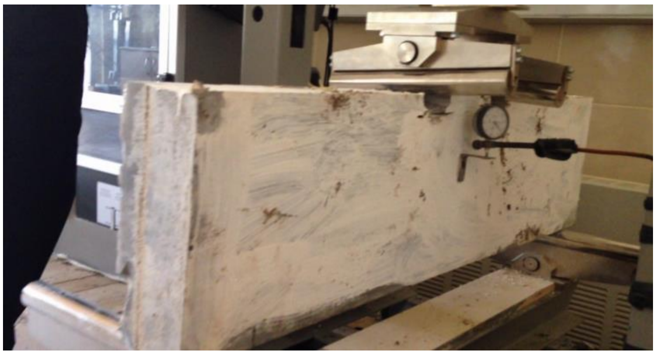

Fig. 2 The erection of a beam inside the loading frame

III. TEST RESULTS AND DISCUSSIONS

Table 2 shows the results of ultimate load capacity for tested beams. In Fig. 3 the Variation of ultimate load capacity with number of wire meshes for high strength ferrocement beams is illustrated. While Figs. 4 through 8 shows the cracking pattern of the tested beams.

A. Effect of Test Parameters on the Ultimate Load

Based on the obtained test results ultimate load capacity is a function of the existence of wire mesh layers, comparison among beams (BH7, BH12, and BH16) and concrete strength (comparison between beams BH12 and BN12) both factors seem to be important and influence the ultimate load capacity. For the control beam BH0 the ultimate load capacity is quite low compared with the other beams. Knowing that this beam contain no ferrocement wire mesh neither stirrups. In addition, the amount of flexural reinforcement is low. The ratio of flexural reinforcement for this beam and other beams is equal to 0.0049 lower than the minimum ratio given ACI 318 [6], $\rho_{min} = 0.00570.$ Therefore, mode of failure is different from that of other beams which is flexural cracking failure. This mode of failure is responsible for the low ultimate load capacity of this beam. Failure of this beam was as a result of a single flexural crack produced near the beam center as shown in Fig. 4.

The role of wire mesh on the ultimate load capacity of beams of normal mode of failure (flexure and shear) can be illustrated as follows.

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If the wire mesh layer is increased from 7b layer to 12 layers, there is an increase in the ultimate load capacity of 11%, and if increased to 16 layers there is increase of 18%. Therefore in high strength mortar beam contain sufficient amount of wire mesh, further addition of wire mesh has a moderate influence of the ultimate load capacity.

Comparison between the results of the tested beams reinforced with 12 layers of wire mesh, BH12 and BN12, indicates that the role of compressive strength of mortar is important, because there is an increase in ultimate load capacity equal to 32% when high strength mortar is used instead of normal strength mortar.

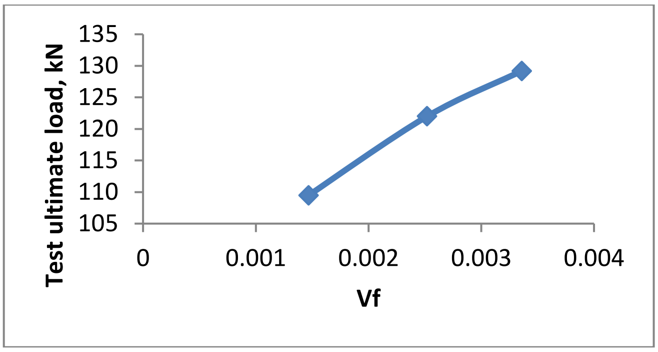

Fig. 3 Ultimate load capacity with number of wire meshes for high strength ferrocement beams

B. Mode of Failure

Mode of failure of the beams BH7, BH12 and BH16 as shown in Figs. 5, 6 and 7 is the shear failure represented by diagonal tension cracks indicating that wire mesh layers were able to increase flexural strength of the high strength mortar deep beams.

Beam BH12, as shown in Fig.6 as the amount of wire mesh reinforcement increased from 7 layer to 12 the mode of failure is clearly changed, as shown in the figure the crack starts widely from the bottom at nearly midspan of the beam and then become narrow as it spreads in an inclined path toward the top of the beam and this demonstrated that by increasing the number of wire mesh layers the shear resistance increases. However, due to the brittleness of high grade mortar in this beam it is obvious that the mode of crack is more stiffer and sharper than the mode of crack for the beam BN12 as it is noticed from the Fig.7, and from the test observation.

The mode of failure of beam BH16 as shown in Fig.8 is flexural steel yielding and this occurred because the beam was strong in shear. Therefore, high ratio of wire mesh in the beam able to control shear failure mode and increase shear resistance and change mode of failure from shear to flexure. This behavior is structurally desired and recommended by the designer because the mode of failure is gradual but not sudden. Therefore, there is a limit of wire mesh layers make from thedeep beam to change its shear mode of failure to a flexural mode.

It is concluded that any beam fabricated with cement mortar if reinforced with higher ratio of wire mesh without providing stirrups behaves similar to normal designed beam to fail in flexure which is currently used in practice.

Fig. 4 Failure pattern of ferrocement deep beam B0.

Fig. 5 Failure pattern of ferrocement deep beam BH7.

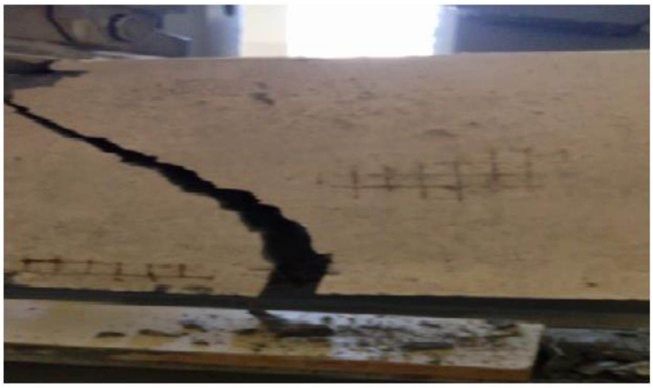

Fig. 6 Failure Pattern of Ferrocement Deep Beam BH12

Fig. 7 Failure pattern of ferrocement deep beam BH16.

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Fig. 8 Failure pattern of ferrocement deep beam BN12

C. Load Deflection Relationship

Fig.9 and Table II shows load –deflection relationship and the results for all of the tested beams. It can be seen that on the same value of ultimate load, the beam which is reinforced with higher number of ferrocement layers has relatively higher deflection value; this does mean that the type of failure is going to be more ductile failure at increasing volume fraction ratio of wire mesh. This behavior was demonstrated also by [2]-[3], however this provision is included high strength mortar beams , BH7, BH12, and BH16, whereas for the beam which is normal strength mortar, BN12, is proved to be more ductile, because at the same value of Load 92 kN the BN12 is recorded higher value of deflection than B12.

Table II results of four point load test on the ferrocement deep beams

Beam designation	Load (kN)	Max. Deflection (mm)
B0	16	0.4
B7	109.5	3.95
B12	122	4.15
B16	129.2	4.15
BN12	92.6	3.82

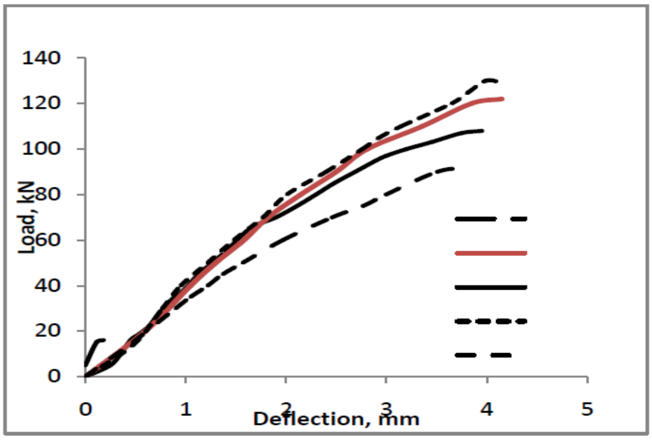

Fig.9 Load- deflection relationship of ferrocemt beams.

IV. THEORETICAL PREDICTIONS

According to strut and tie model (STM) any member subjected to tensile stresses are called ties and represent the location where reinforcement should be placed, and these members subjected to compression are called struts. The intersection points of struts and ties are called nodes. Knowing the forces acting on the boundaries of the STM, the forces in each of the truss members can be determined using basic truss theory. Fig. 10 shows the configuration of stress and forces expected and governed for this analysis of deep beam, which are consists of a closed loop of strut, ties and nodal zones. Following are calculations presented for load carrying capacity of the ferrocement deep beam.

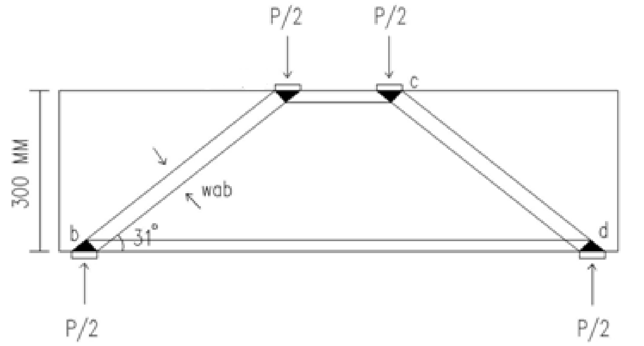

Fig. 10 Paths of forces and stresses in the tested beams

Dimensions of the beam are shown in Fig.11. The effective depth, d, is assumed to be;

$d = 300 - 20 = 280\ mm$

Knowing the forces acting on the boundaries of the STM, the forces in each member can be determined as shown in Fig. 11; the depth y is given by

$y = 0.8\,h\ = 240\ mm$;

$\tan\theta\ = \frac{240}{400}$ or $\theta = 31^{\circ}$

The force F_{ab} is given by

$F_{ab}\cos 59 = \frac{P}{2}\ \ or\ \ F_{ab} = 0.97P$

$T = 0.97P\ \cos 31^{0} = 0.83P$

Finally, F_{ac} is given by

$F_{ac} = F_{ab}\sin 59\ = 0.97P\ \sin 59 = 0.83P$

The member forces are shown in Fig. 11.

Referring to Fig. 11 assuming the width of the bearing plate is 50 mm and the width the beams are 120mm, nodal stress under the applied load is calculated;

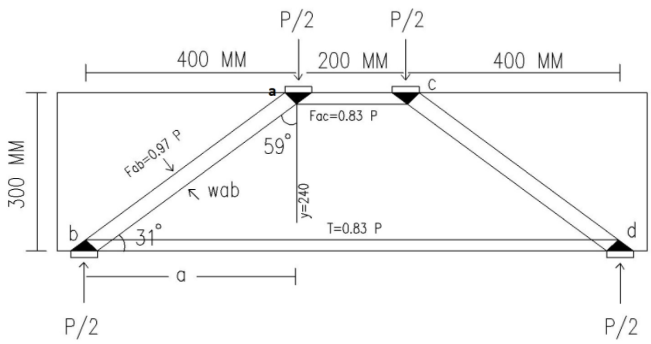

Fig. 11 Values forces in the beams

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$$Nodal\ stress = \frac{P/2}{50 \times 120}$$

$\frac{P}{12000} MPa$ as discussed by [7], for a hydrostatic node, the stress acting on each face of the node is equivalent and perpendicular to the surface of the node.

Knowing that this nodal stress is acting in a hydrostatic way along the shaded area shown in Fig.10, the width of each of strut w_{ac} and w_{bc} is calculated as the following,

$$\sigma_{nodal} = \frac{F_{ac}}{A_{ac}} = \frac{0.83P}{P/12000} ;$$

$$A_{ac} = \frac{F_{ac}}{\sigma_{nodal}} = \frac{0.83P}{P/12000}$$

$$b \times w_{ac} = 0.83 \times 12000$$

$$w_{ac} = \frac{0.83 \times 12000}{120} = 83\ mm \ ;$$

To find width of strut $w_{ab,}$ the area of strut is determined,

$$A_{ab} = \frac{F_{ab}}{\sigma_{nodal}} = \frac{0.97P}{120 \times P/12000} = 97mm$$

The width of stressed tie zone (w_t) when the bar is anchored [9] is :

$$w_t = 10 + 2 \times cover$$
$$= 10 + 2 \times 20 = 50mm$$

Although, concrete is known to have some tensile strength, its contribution to the tie resistance is normally neglected, therefore, only reinforcing steel or ferrocement wire mesh are used to satisfy the calculated tie requirements.

In order to obtain the ultimate load based on the strut and tie method, the tie force will be;

$$F_t = A_s f_y \times f_{ct}\, b w_t$$

In which; F_t is the strength in the ties $A_s f_y$ is the area and yield stress of flexural bars f_{ct} is the tensile strength of composite calculated as follows, [1],

$$f_{ct} = 0.2(f_c^{-})^{0.7} + 0.72\, V_R\, f_{yR} + 0.56$$

$f_c' = 0.85 \times (f_c'\ of\ cubes)$; $f_{yR} = 350\ MPa\ for\ wire\ mesh$ (based on test results)

So the final form of the predicted equation for calculating ultimate load based on strut and tie method is

$$F_t = A_s f_y \times \left[\left(0.2(f_c^{-})^{0.7} + 0.72\, V_R\, f_{yR} + 0.56\right) \times b w_t\right]$$

Sample of calculation is presented here for beam B7

$V_R\ is\ the\ wire\ mesh\ ratio,$ It is calculated by finding the number of wires in vertical and horizontal directions $N_H\ and\ N_v$ as follows:

$$N_H = \frac{300}{12.7} + 1 = 25 \ ; \ N_v = 7$$

$$V_R = \frac{N_v \times N_H \times \frac{\pi}{4} \times (d)^2}{h \times b}$$; d is the diameter of a wire mesh; b and h are the depth and the width of the beam, respectively.

Volume of wire mesh is;

$$V_R = \frac{7 \times 25 \times \frac{\pi}{4} \times (0.6)^2}{280 \times 120} =$$

0.00147(The values of V_R for each beam are shown in Table 1) $therefore;$

$$f_{ct} = 0.2(77)^{0.7} + 0.72 \times 0.00147 \times 350 + 0.56 = 5.14\ MPa$$

$Hence;$

$$F_t = A_s f_y \times f_{ct}\, b w_t = 65345 + 5.14 \times 120 \times 50 = 96184\ N$$

The mode of failure is flexural shear failure as the diagonal crack occurred from down close to the supports and then up warded in nearly arched path the strength of tie is control over the strut. With the forces in each strut and tie determined from basic statics, the resulting stresses within the elements themselves must be compared with specification permissible values, hence by equating the F_t to the tie force resulted in ;

$$0.83P = 96184$$
$$P = 113231\ N = 115.38\ kN$$

The same procedure is repeated for the other beams BH12, BH16 and BN12.

The same procedure is repeated to calculate the load capacity of beams BH12, BH16 and BN12.

The accuracy of the predictions can be assessed by making a comparison with the corresponding test results. Table III gives summary of the results of calculated ultimate load capacity for each beamand the test one for the comparison sake. The table also contains the ratio of test/calculated ultimate load. The mean test/calculated for all beams except beam BH0 is equal to 1.0, indicating that the predicted ultimate load using strut and tie model is accurate but without safety factor. However, if only high strength mortar beams are taken the mean value will be 1.02, and for normal strength mortar beam BN12 the mean value is 0.92. This indicates that the predictions are more conservative for high strength ferrocement mortar than normal strength mortar.

Table III Results of predicted and the test ultimate load.

Designation	$P_{u,\ Test}$	$P_{u,\ Theory}$	$P_{u,\ test}/P_{u,\ theory}$
B0	16	-	-
B7	109.5	115.38	0.95
B12	122	117.62	1.04
B16	129.2	119.2	1.08
B12N	92.6	100.7	0.92
Mean			1.0

V. CONCLUSIONS

- The strength offerrocement deep beam increases as the ratio wire mesh and strength of the mortar increase.
- If highratio of wire mesh is used (16 layers in this study) the ode of failure is changed to be flexure. This behavior is structurally desired and recommended for design, because the mode of failure for this case is gradual but not sudden.
- Deep beam fabricated with cement mortar if reinforced with higher ratio of wire mesh without providing stirrups behaves similar to normal designed beam to fail in flexure which is currently used in practice.
- Calculating ultimate load capacity of ferrocement deep beams can be made using strut-and-tie model. It was found that the predictions based on this model is more accurate for

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I. QULAIFICATIONS

B.Sc Civil Engineering –Al-Mustansiriya University-Baghdad- Iraq 1994.

- M.Sc Civil Engineering –Building material and Construction Al-Mustansiriya University –Baghdad- Iraq 2001.
- PhD Civil Engineering -London South Bank University –UK 2011. **Thesis Project Was "Steel Fiber Reinforced High Strength Concrete Slab On Ground"**

II. TITLES OF THESIS

M.Sc. Thesis : Internal Sulfate Attack of Different Strengths of Concrete .
Ph.D. Thesis: Numerical and Experimental Analysis of Steel Fibre Reinforced High Strength Concrete Slab on Ground

III. PAPERS

A. Published

1- G. F. Kheder, D. K. Assi (2010) "Limiting Total Internal Sulphates In 15–75 Mpa Concrete In Accordance To Its Mix Proportions" Materials and structure, January , Volume 43, Issue 1-2, pp 273-281

2- Mohammed , Azad A. and Assi , Dunyazad, K. " Estimating Tensile Stress of Ferrocement Used for Flexural Analysis", Al-Rafidain Engineering Journal, Vol.20, No.2, 2012, pp.27-40.

3- Mohammed, Azad. A. and Assi, Dunyazad K., "Behavior of Renforced Concrete Corbels Strengthened with Ferrocement Sheets," Accepted for publication, International Symposium on Engineering, Artificial Intelligence and Application, North Cyprus, 6-8 Nov. 2013.

B. Submitted for Publication

1. Minimum ratio of flexural reinforcement for high strength concrete beams