AL-QADISIYAH JOURNAL FOR ENGINEERING SCIENCES

Vol. 10, No. 4
ISSN: 1998-4456

FLEXURAL BEHAVIOR OF LIGHT WEIGHT CONCRETE SLAB PANELS REINFORCED WITH CFRP BARS

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Received on 26 July 2017 Accepted on 1 November 2017 Published on 25 March 2018
DOI: 10.30772/qjes.v10i4.482

Abstract: *The present study includes an experimental investigation of the behavior of simply supported lightweight aggregate concrete (LWAC) and normal weight concrete (NWC) square slabs reinforced by different ratios of carbon fiber reinforced polymer (CFRP) and/or steel bars reinforcement. The experimental program consists of testing nine two-way reinforced concrete square slab models under uniformly distributed load (UDL). They were of the same overall dimensions, (1050×1050×80) mm. The main variables considered in the experimental study are: type of concrete; LWAC or NWC, type of reinforcement; steel, CFRP and hybrid (steel and CFRP) bars with different ratios and arrangements, the behavior of slabs with bottom and top CFRP bars reinforcement and the efficiency of using CFRP bars for strengthening slabs in two directions by using near surface mounted (NSM) technique. In this study, a waste of clay bricks was used as a coarse lightweight aggregate (CLWA) to produce structural lightweight aggregate concrete (SLWAC).*

It was found that LWAC slab model reinforced by CFRP bars has a lower total weight by amount 20% in comparison with NWC slab model reinforced by CFRP bars with rather a small reduction in slab ultimate load capacity by amount not more than 6.5%. However, it was found that the CFRP reinforced LWAC slab model can achieve ultimate load capacity higher than equivalent steel reinforced LWAC slab model by about 34.62%. NSM technique by CFRP bars in two directions of LWAC slab is very effective and nearly provided the same efficiency of equivalent internal reinforcement.

Keywords: flexural behavior of RC slab, CFRP bars reinforcement, lightweight aggregate

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concrete (LWAC) .

INTRODUCTION

Reinforced concrete (RC) is a combination of concrete and steel that has been successfully used in all types of infrastructure for more than a century. However, every material has its own advantages and disadvantages. The principal disadvantages of reinforced concrete as a structural material is its high self-weight and steel corrosion.

Lightweight concrete (LWC) has been used successfully in various constructions for many years. The main reason of using LWC for structural purposes is to reduce the self-weight of concrete structures. Reducing the dead load of the structure is very important in earthquake regions, for tall buildings, and special concrete structures [1].

Corrosion problems in steel reinforced concrete structures are inevitable and also still cause concern to most engineers. In order to eliminate the possibility of steel corrosion, non-corrosive reinforcement seems the last resort. Lately, fibre reinforced polymer (FRP) reinforcing bars have been developed and used as reinforcement in new construction, and in structures wherein nonmagnetic properties are required [2].

The unique advantages of FRP materials such as excellent resistance to corrosion, high strength-to-weight ratio, electromagnetic neutrality, and ease of handling make these materials potentially suitable for the use in reinforced concrete under conditions where conventional steel reinforced concrete has resulted in unacceptable serviceability problems. Also, they are used for strengthening or repair of concrete structures by using near surface mounted (NSM) technique, which is now prevailing as a promising technology for increasing flexural and shear strength of deficient RC members [3].

In spite of the increasing use and demand, there is still a lack of adequate explanations to understand the mechanisms responsible for the behavior of LWC with FRP bars as a flexural or shear reinforcement to applications in structures.

1. OBJECTIVE OF RESEARCH

The basic objective of the present work is to investigate experimentally the behavior of LWAC two way slab reinforced by CFRP bars and hybrid or combination reinforcement (CFRP and steel bars) by different ratios and arrangements.

Study the behavior of LWAC slab models reinforced by CFRP bars in single and double layers. As well as investigate experimentally the efficiency of using CFRP bars in strengthening LWAC two way slab in two directions by using NSM technique. Also, make comparison in the weight and overall structural behavior between identical slabs in dimensions and concrete strength but differ in type of concrete; NWC or LWC which reinforced by CFRP bars.

2. SLAB MODELS DESCRIPTION

The experimental program consists of testing nine two-way reinforced concrete square slab models under UDL as shown in **Figure 1**. They are of the same dimensions; 1050×1050 mm (overall dimensions), 950 mm (span length), 80 mm (overall depth), 20 mm (clear bottom cover), 16 mm (clear top cover in double reinforcement) and side covers are 25 mm.

The slab models are simply supported on four edges. The ends of all slabs extended 50 mm beyond the support's centerlines to prevent splitting (crushing) failure and any local failure. Therefore, the effective span after supporting is 950 mm.

In order to identify the test NWC and LWAC slab models with different ratios and types of reinforcement bars, the following designation system is used:

1- Type of concrete: (L) for lightweight aggregate concrete, and (N) for normal weight concrete.

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2- CFRP bars reinforcement ratio: (F_1) for $\rho_f = 2.6176\times10^{-3}$ and (F_2) for $\rho_f = 3.1411\times10^{-3}$.

3- Percentage of replacement CFRP bars by steel bars in hybrid reinforcement: (R_0) for 0%, (R_{40}) for 40%, (R_{60}) for 60% and (R_{100}) for 100%

4- Number of reinforcement layers: (S) for single layer and (D) for double layers.

5- Type of reinforcement: (I) for slab reinforced internally only and (M) for hybrid slab reinforced partially by steel reinforcement bars internally then strengthened by near surface mounted (NSM) for other CFRP bars.

6- Arrangement of hybrid reinforcement (CFRP and steel bars): (A_1) for arrangement of CFRP bars at spacing of 240mm c/c from center of slab panel and (A_2) for arrangement of CFRP bars at spacing of 480 mm c/c from center of slab panel.

The parameters considered in this study based on many variables which are investigated to show their effects on the structural behavior of slab model tested under UDL. These are used to study five parameters and each parametric study includes number of slab models as shown in **Figure 2** as following:

Study No.1: Investigate the effect of replacement CFRP bars reinforcement of ratio $\rho_f = 2.6176\times10^{-3}$ by traditional steel reinforcement using different percentage of replacement (0, 40, 60 and 100)% and using two arrangements 240 mm and 480 mm c/c for hybrid (CFRP and steel bars) reinforcement in LWAC slab models reinforced internally by single layer. This study includes LF_1R_0SI, $LF_1R_{40}SIA_1$, $LF_1R_{40}SIA_2$, $LF_1R_{60}SIA_2$ and $LF_1R_{100}SI$ slab models.

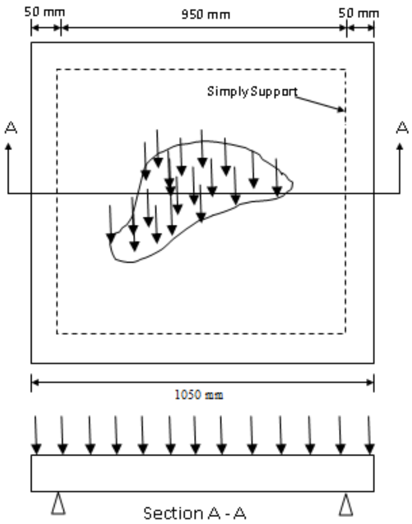

Figure 1: Details of dimensions concrete slab models.

Study No.2: Investigate the effect of increasing CFRP bars reinforcement ratio 20% from lower ratio $\rho_f = 2.6176\times10^{-3}$ that can be used at maximum spacing (ACI 440.1R, 2006) [4] 240 mm c/c to $\rho_f = 3.1411\times10^{-3}$ at spacing 190 mm c/c in LWAC slab model reinforced internally by single layer (steel reinforcement ratio $\rho_s = 0$). This study includes LF_1R_0SI and LF_2R_0SI slab models.

Study No.3: Investigate the effect of using balanced ratio of CFRP bars as top reinforcement in LWAC slab model reinforced internally by single layer of CFRP bars of $\rho_f = 3.1411\times10^{-3}$. This study includes LF_2R_0SI and LF_2R_0DI slab models.

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Study No.4: Investigate the efficiency of using CFRP bars in near surface mounted (NSM) technique in two directions at 480 mm c/c in LWAC slab model reinforced internally by single layer of steel bars only. This study includes $LF_1R_{60}SIA_2$ and $LF_1R_{60}SMA_2$ slab models.

To apply NSM CFRP bars, many wooden strips were installed at the bottom of the wooden mould to provide these two grooves in X and Z-directions prior to concrete casting. All the grooves had rectangular cross-sections, with a size of 10 mm width and 20mm depth for CFRP bars of 6mm diameter according to (ACI 440.2R, 2008) [5] which limited width and depth by equal or more than 1.5 of bar diameter. The slab were cured for 28 days and then the ply wood strips were removed, the desired grooves left at the bottom (tension) surface of the slab. The groove is then filled halfway with epoxy paste, and the CFRP bars is placed in the groove and lightly pressed. This forces the epoxy paste to flow around the bar and fill completely between the bar and the sides of the groove. The groove is then filled with more epoxy paste, and the surface is leveled.

Study No.5: Investigate the effect of concrete type (NWC and LWAC) on slab models reinforced internally by single layer of CFRP bars reinforcement of ratio equal to $\rho_f = 2.6176 \times 10^{-3}$. This study includes LF_1R_0SI and NF_1R_0SI slab models.

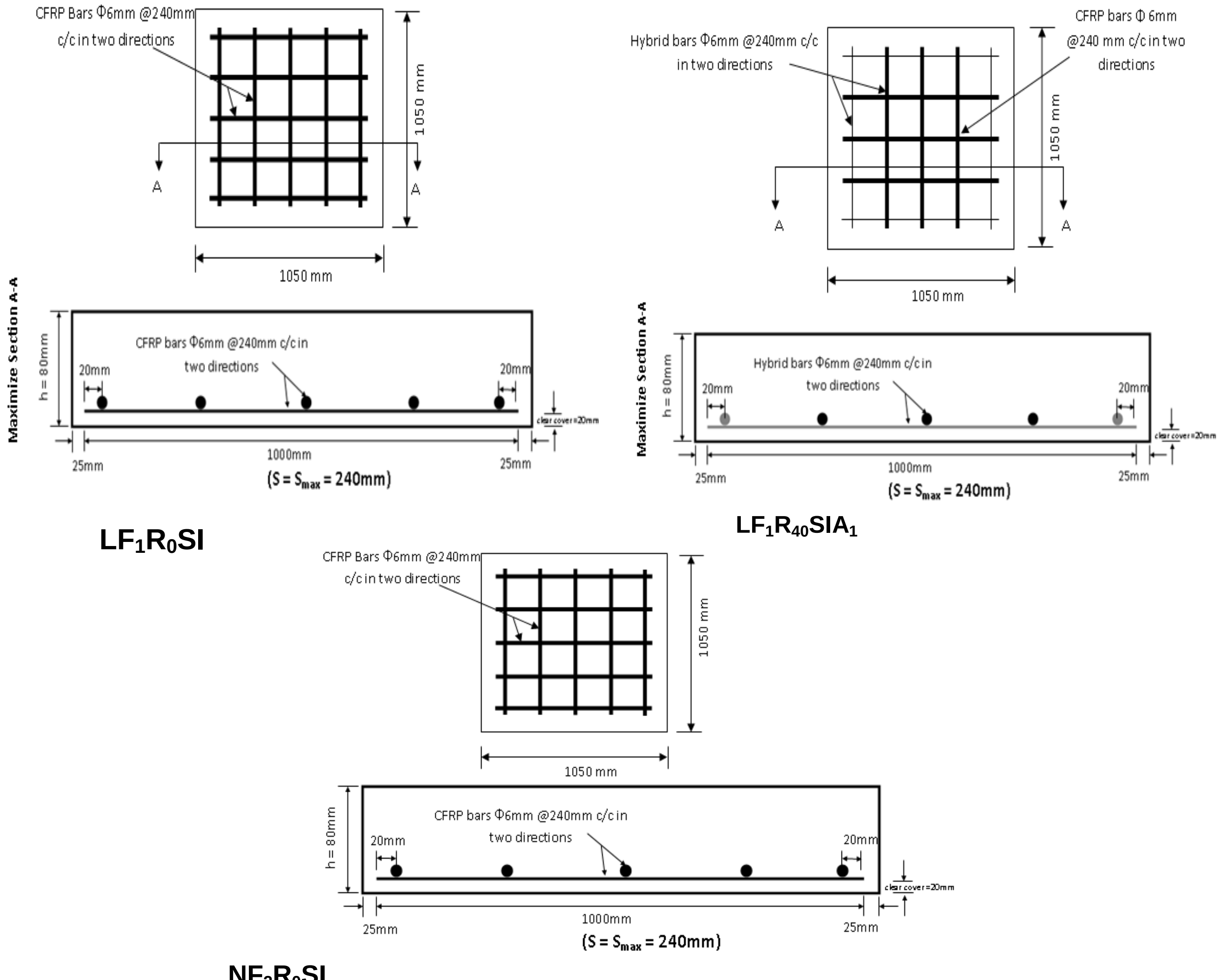

Figure 2 Details of reinforcement of slab models

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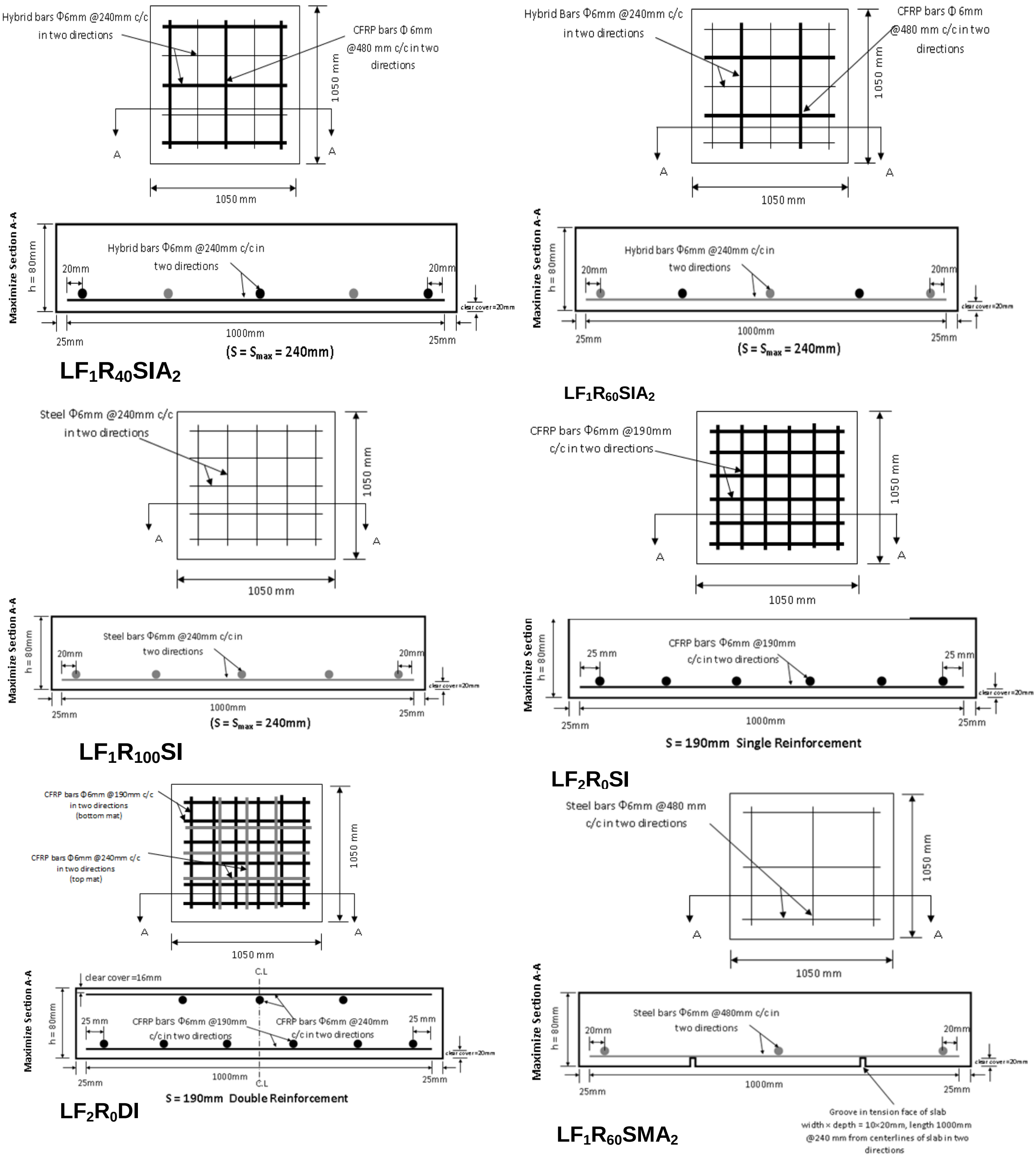

Continued of **Figure 2** Details of reinforcement of slab models

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3. MATERIAL PROPERTIES AND MIX PROPORTIONS

The cement used in casting all the slab models was Ordinary Portland Cement which has been brought from local market known as (Kbaisa), The compliance of the cement is done according to the Iraqi standard (IQS No.5, 1984) [6]. Also, natural sand within the zone 2 from (Al-Akaidur) region was used as fine aggregate, the grading is conformed to the requirements of the limits of the IQS (IQS No.5, 1984) [6].

Crushed clay bricks (waste of local bricks manufactory) were used as coarse lightweight aggregate for lightweight concrete with a maximum nominal size of 12.5 mm. It was separated by sieve analysis and recombined it to satisfying the grading according to (ASTM C 330, 2005) [7]. Normal weight coarse aggregate of maximum aggregate size 14 mm from (Al-Nebai) quarry were used for normal weight concrete, the grading of this aggregate conforms to the (IQS No.5, 1984) [8].

Microsilica fume (SF) under commercial name (LEYCO®-ACC Micro silica/Grade 85D) has been used as a mineral admixture added to the mixture of the lightweight aggregate concrete as a partial replacement of 8% by weight of cement. SikaViscocrete-5930 (SP) is a high range water reducing admixture which was used in LWAC. It was imported from Sika company. Clean tap water of Babylon, was used for casting and curing of all the specimens.

Deformed steel bars (6 mm) in diameter were used in this study which was obtained from BRC Turkish production. The results of testing steel reinforcement according to (ASTM A496,2002) [9] are summarized in **Table 1**.

Table 1: Properties of Steel Bars.

Nominal Diameter Φ (mm)	Measured Diameter (mm)	Weight (kg/m)	Yield Stress f_y (MPa)	Ultimate Strength f_u (MPa)
6	5.84	0.223	538	755

Aslan 201 CFRP bar, of 6 mm nominal diameter, used for internal reinforcement and as a strengthening material for the recent technique known as Near Surface Mount (NSM) strengthening. The physical properties was provided by the manufacturer, (Hughes Brothers), are presented in **Table 2**.

Table 2: Aslan 201 CFRP Bar Physical Properties.

Item	Standards	Result	Test method
Tensile Strength, MPa (Average-3.0 Sigma per ASTM D7205)	≥2068	2704	ASTM D7205
Modulus of Elasticity, GPa (Average Value)	≥124	163	ASTM D7205
Ultimate Strain	0.017	0.017	ASTM D7205
Weight (kg/m)	0.0557		

The Sikadur-30 Epoxy Adhesive used as adhesive material with CFRP bar in NSM technique. After many trial mixes, the mix of NWC was by weight is 1:1.46:1.88 for cement, sand and gravel; respectively. The water cement ratio was equal to 0.4 with SP% weight of cement is 0.4% and cement content was 500 kg/m^3. Results of 39.2 MPa of cylinder compressive strength (150×300 mm) and 2371 kg/m^3 of air dry density at 28 days.

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The mix of LWAC was by weight is 1:1.091:1.127 for cement, sand and saturated surface dry (SSD) crushed bricks; respectively. The water cement ratio was equal to 0.294 with SP% weight of cement is 3.5% and SF% weight of cement is 8%. Cement content was 550 kg/m^3. Results of 38.3 MPa of cylinder compressive strength (150×300 mm) and 1896 kg/m^3 of air dry density at 28 days.

4. TEST SETUP

All slab models were tested in a universal testing machine with capacity of 2000 kN under monotonic loads up to ultimate load at the Structural Laboratory in Kufa University. A rigid steel frame of channel-sections, which was designed as a supporting system to obtain a simply supported condition for a square shape slab of effective span of 950 mm.

The uniformly distributed load (UDL) was achieved by the arrangement of the loading system as shown in **Figure 3** which was consisted from the following items:

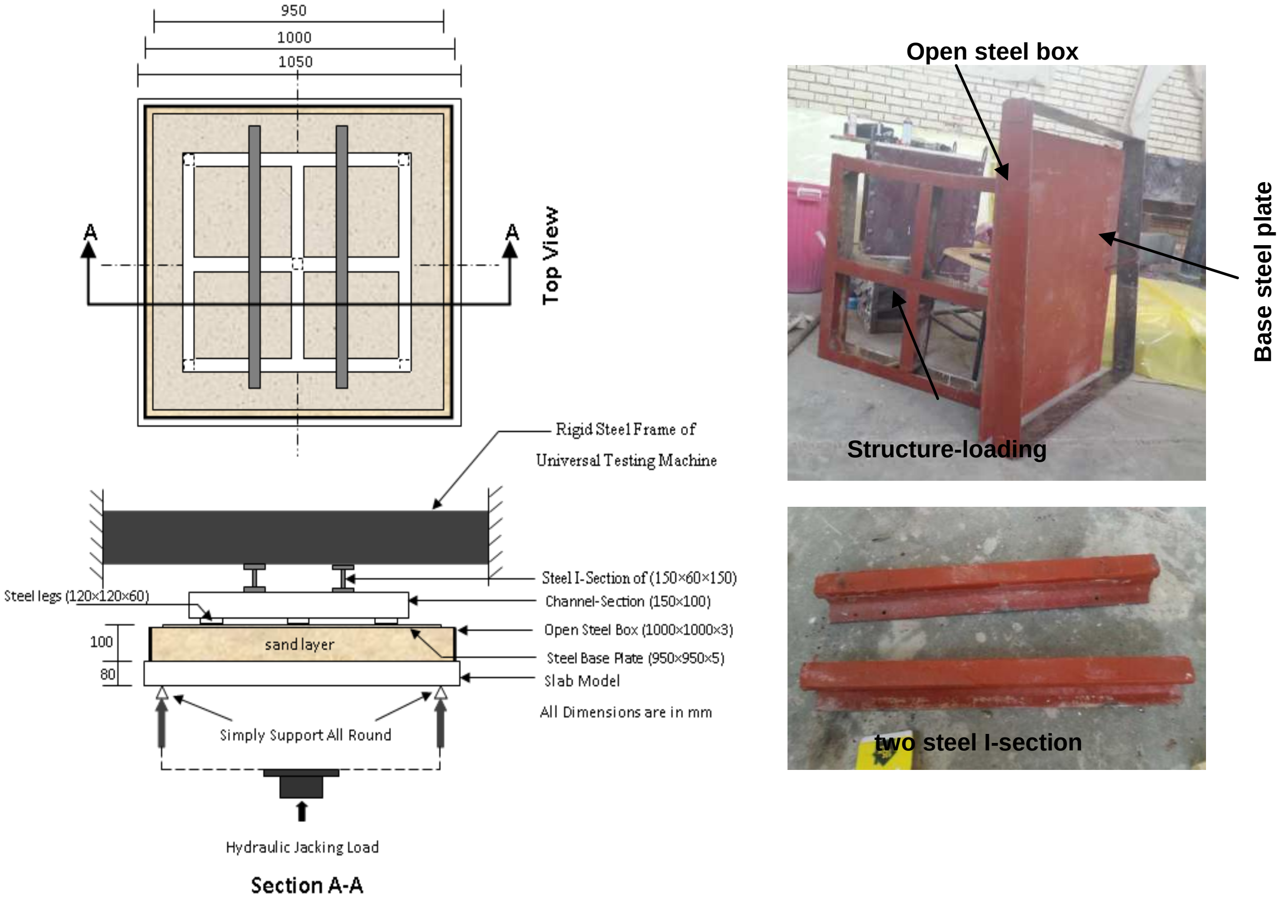

Figure 3: Loading system for test slab models under uniformly load.

(1) An open box of steel plate of thickness 3 mm with inside dimensions 1000×1000×100 mm, (2) Fine sand layer of 100 mm in thickness, (3) Base steel plate of size 950×950×5 mm, (4) Five square rigid steel legs of size 120×120×60 mm, (5) Structure-loading points which consisted of six steel members from channel-section of 150×100 mm and length of 850 mm, three of these members were parallel and the other welded perpendicularly inside them for fixing the symmetric dimensions. The outer dimensions of structure-loading points were 850×850 mm and (6) Two steel I-section of size 150×60×150 mm and length of 900 mm

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5. EXPERIMENTAL RESULTS

5.1. General Behavior Under Transverse Load and Cracks Pattern

The cracks pattern for all slab models tested under UDL are shown in Plate 1 and the general behavior of the tested slab models under UDL can be summarized as below:

At early stages of loading, the deformations were initially within the elastic ranges (linear), then the applied load was increased until the first crack became visible which was observed in the tension face of slab at about 9.47% to 12.24% of ultimate load.

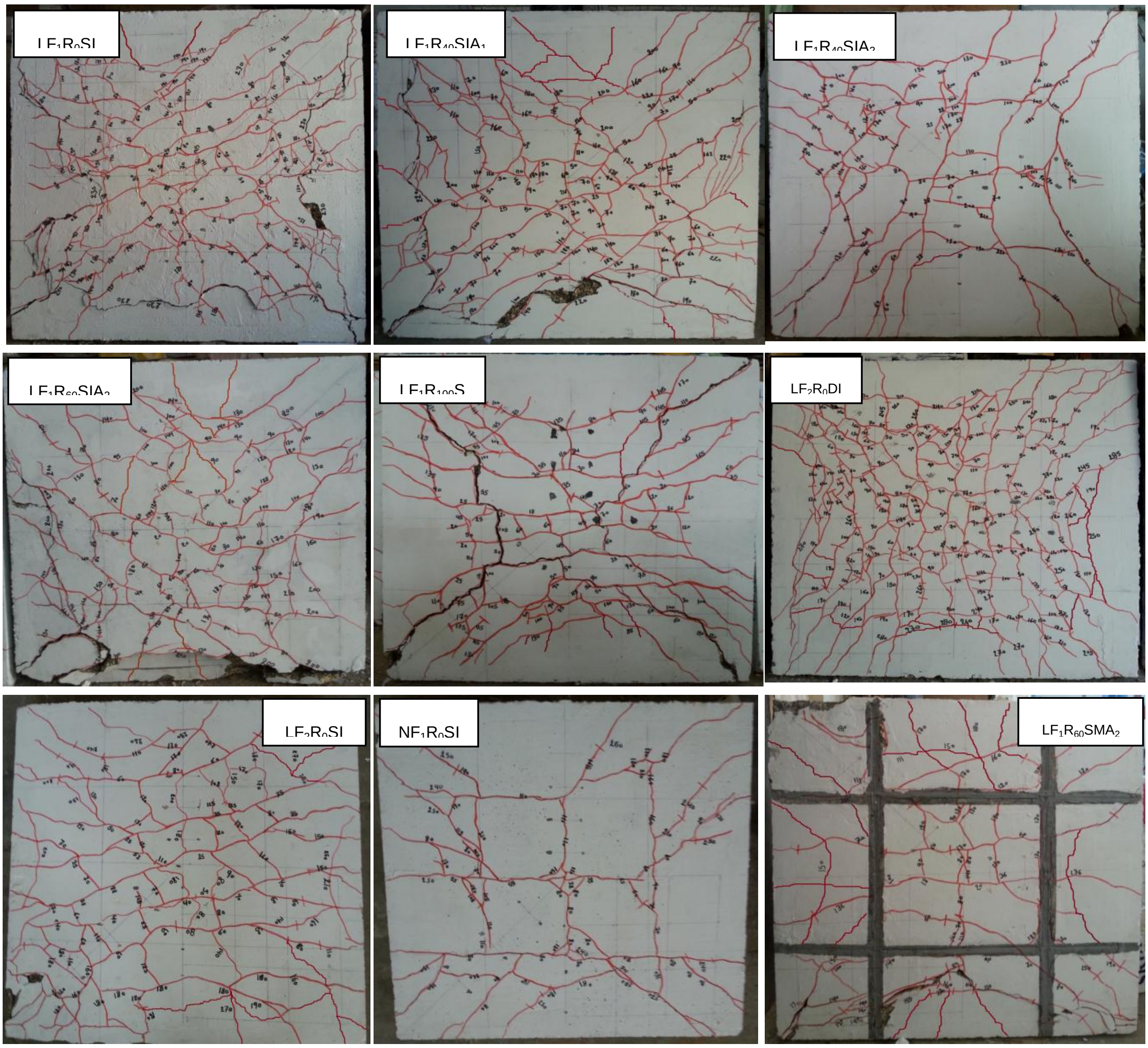

Plate 1 Cracks patterns at failure for all slab models (tension)

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Many cracks of flexure began to appearing in the tension face throughout slab at periods of loading with increased load, gradually increased in number, became wider and moved upwards as noting through four sides of slab models. As the load was increased further, a loss of stiffness occurred and one mode of failure appeared which can be classified as flexural failure in tension by steel yielding then concrete crushing in compression face for steel reinforced slab models.

The CFRP slab models also showed similar behavior, but no rupture of CFRP occurred, the CFRP reinforcement contributed mainly in resisting the loads and increased the stiffness of the concrete slab models up to the suddenly flexural failure by crushing of concrete.

The hybrid reinforcement have the same stages of mechanism, but the failure was usually recorded due to crushing of concrete in compression fiber of slab models that is happened simultaneously with few popping sounds due to rupture of CFRP bars or yielding of steel. This failure which was more gradually than CFRP slab models.

In strengthened slab model by using NSM Technique, the failure was observed at the NSM of CFRP bars by concrete splitting, since failure occur in the concrete adjacent to the concrete-adhesive interface due to the high tensile force exerted on the concrete under transfer of force from the adhesive.

5.2. Crack Width

The cracking occurs when the concrete tensile stress in a slab model reaches the ultimate tensile strength.

The formation of cracks were monitored throughout the test to record the width of these cracks with increasing load at each 20 kN/m^2 until near failure of all slab models in order to know the difference between types of slabs. The relation between load and maximum crack width for all slab models tested under UDL are shown in **Figure 4**.

The width of the first crack load, the width of the crack at service load (70% ultimate load) and maximum crack width at failure in tension face are listed in **Table 3**.

The crack width for slab models at 70% of ultimate load was compared with crack width limitations. Following (ACI 440.1R, 2006) [4] the crack width for the FRP RC experimental slabs is generally limited to 0.7 mm and (ACI 318M, 2011) [10] limited the crack width for the steel RC experimental slabs is generally to 0.4 mm. In current study, it is reasonable to assume the crack width limitation for hybrid reinforcement (steel and CFRP bars) equal to 0.4 mm as a for the steel RC experimental slabs.

Study No.1: The width of the first crack load was different between slab models although they have approximately the same LWAC properties and all have the same spacing of reinforcement (240 mm). They are ranged between (0.031-0.04) mm.

From the **Figure 4**, the CFRP bars slab model LF_1R_0SI, have maximum cracks width smaller than the other slab models of study No.1 at all stages of loading. This is due to using CFRP bars reinforcement delays the crack initiation and arrested their propagation. Therefore, as the percentage of replacement of CFRP bars by steel bars increase, the maximum crack width increase with taken into account the arrangement of hybrid reinforcement.

At service load (at a load 70% W_u), the crack width of the CFRP bars slab model LF_1R_0SI was 0.696 mm while the crack width of the other slab models $LF_1R_{40}SIA_1$, $LF_1R_{40}SIA_2$, $LF_1R_{60}SIA_2$ and $LF_1R_{100}SI$ were 1.010, 0.720, 0.840 and 1.075 mm; respectively. Which exceed the crack width limitations except LF_1R_0SI that within the crack width limit.

Since, the maximum spacing for CFRP bars reinforced LWAC two way slab can be adopted as three of thickness value ($S_{max.}$=3h) according to (ACI 440.1R, 2006). But, for steel and hybrid reinforced LWAC two way slab, reinforcement ratio should be increased to reduce spacing between bars in order to satisfying the crack width limitation at service load.

Study No.2: The increase in CFRP bars ratio 20% reduces crack width at service load by 23.56% and reduces maximum crack width especially after 140 kN/m^2 as shown in **Figure 4**. This is due to reduction in spacing between CFRP bars.

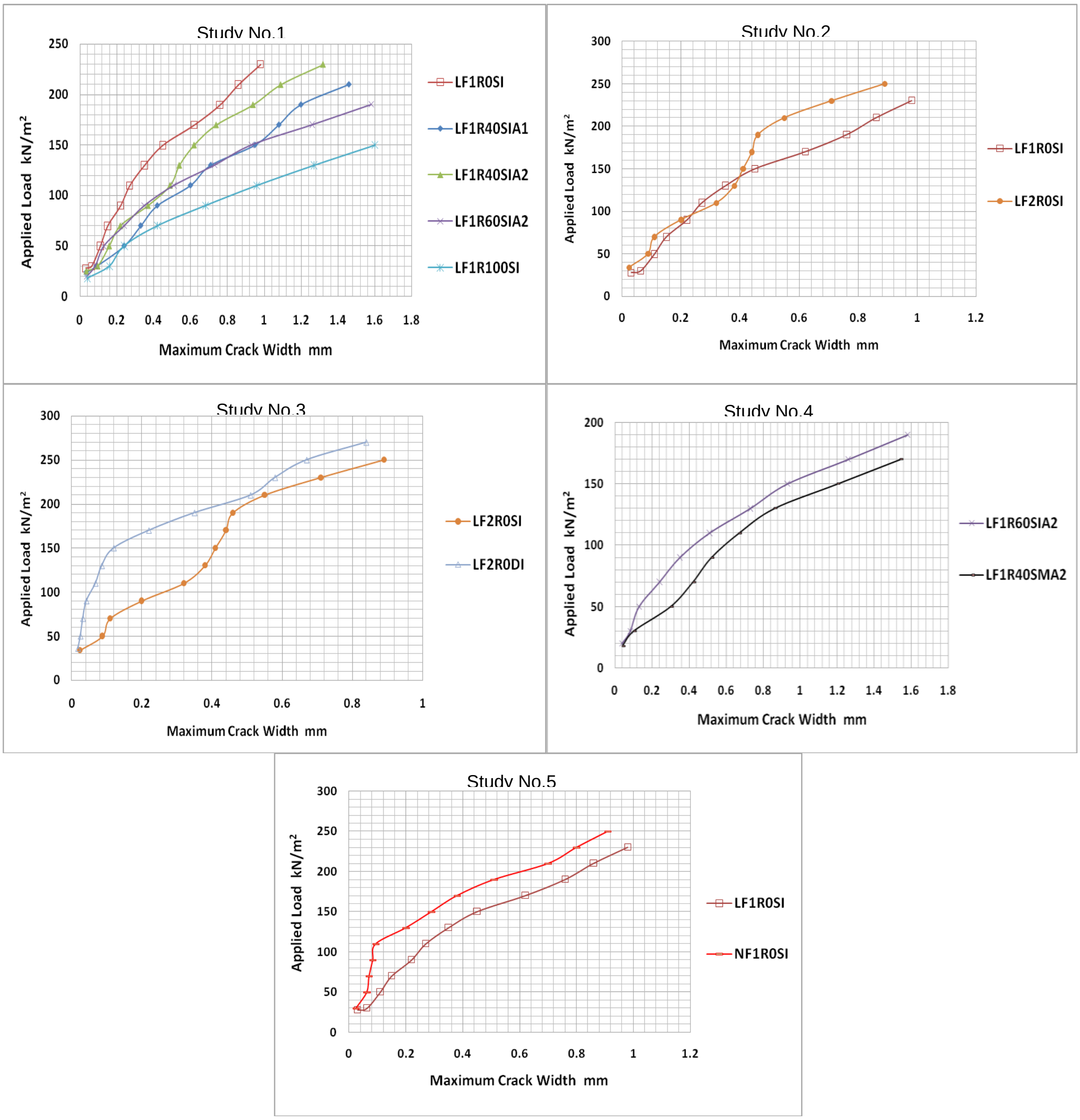

Figure 4 Maximum crack width versus load for all slab models

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Table 3: Results of Cracks For All Slab Models.

Slab Model Symbol	Ultimate Load W_u (kN/m^2)	1_{st} Crack in Tension Face		(W_t/W_u)%	Crack Width at 70%Wu W_s (mm)	Maximum Crack Width in Tension Face at Failure W_m (mm)
		Load W_t (kN/m^2)	Width W_{cr} (mm)			
LF_1R_0SI	260	28	0.031	10.77	0.696	3.40
$LF_1R_{40}SIA_1$	225	24	0.035	10.67	1.010	4.50
$LF_1R_{40}SIA_2$	241	25	0.036	10.37	0.720	4.00
$LF_1R_{60}SIA_2$	201	20	0.038	9.95	0.840	5.00
$LF_1R_{100}SI$	170	18	0.040	10.59	1.075	7.00
LF_2R_0SI	286	35	0.024	12.24	0.532	2.72
LF_2R_0DI	295	36	0.018	12.20	0.440	2.24
$LF_1R_{60}SMA_2$	190	18	0.040	9.47	0.920	6.50
NF_1R_0SI	278	32	0.025	11.51	0.560	3.02

At 70% W_u, the crack width for LF_2R_0SI is 0.532 mm within the limit, see Table 4. The reducing 20% in spacing between bars, increasing the service load by about 27.78%.

Study No.3: The use of balanced CFRP bars ratio as top reinforcement in LF_2R_0DI reduces crack width as shown in Figure 4. The crack width for LF_2R_0DI is 0.440 mm at 70% Wu, within the limit of 0.7 mm for CFRP RC members by CFRP bars. The use of top reinforcement reducing crack width at service load by about 17.29%.

Study No.4: NSM slab model exhibited higher values of crack width compared to the same slab model reinforced internally at the same load level. At 70% W_u, the maximum crack width of NSM slab model is 0.920 mm which exceed the crack width limitations.

The maximum cracks width at failure in NSM slab model is more than it in an internally reinforced slab model by about 23.08%.

Study No.5: The NWC approximately at the same compressive strength of LWAC gives somewhat lower first crack width and maximum crack width at failure in NF_1R_0SI by about 24.00% and 12.58%; respectively in comparison with LF_1R_0SI.

At 70% W_u, the maximum crack width is 0.560 mm for NF_1R_0SI within the limit of crack width of (ACI 440.1R, 2006) [4] which is less than the maximum crack width for LF_1R_0SI.

5.3. Ultimate Load and Deflection

Four dial gages were placed one at the centre (DC), two at (237.5mm) from the centre of slab in both X and Z-directions (DX and DZ; respectively) and one at (335.8mm) from the centre of slab in diagonal direction (DXZ) to measure the deflection. The recorded ultimate load, deflection and failure mode are presented in **Table 4**.

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Table 4: Deflection at Ultimate Load and Failure Mode For Each Slab Model.

Slab Model Symbol	Ultimate Load Wu kN/m^2	Deflection mm					Failure Mode
		Center (DC)	Quarter in Diagonal (DXZ)	Mid of Side			
				X-Direction (DX)	Z-Direction (DZ)	Average of X and Z Directions (DA)	
LF_1R_0SI	260	23.02	12.61	17.55	16.62	17.085	Flexure failure
$LF_1R_{40}SIA_1$	225	24.92	13.76	19.42	20.02	19.720	Flexure failure
$LF_1R_{40}SIA_2$	241	23.31	14.92	18.94	19.82	19.380	Flexure failure
$LF_1R_{60}SIA_2$	201	23.77	12.91	18.57	17.47	18.020	Flexure failure
$LF_1R_{100}SI$	170	24.85	13.62	16.99	18.14	17.565	Flexure failure
LF_2R_0SI	286	20.04	10.84	14.67	15.42	15.045	Flexure failure
LF_2R_0DI	295	17.15	9.36	13.25	13.04	13.145	Flexure failure
$LF_1R_{60}SMA_2$	190	24.01	12.17	16.24	15.66	15.950	Flexure failure
NF_1R_0SI	278	21.94	12.07	16.92	15.78	16.350	Flexure failure

5.4. Load-Deflection Curves

When a reinforced concrete slab model is subjected to gradually increasing loads it will be in general exhibit the following stages of behavior:

The First Stage: is being an initial straight portion of the load-deflection curve representing (the elastic stage). This stage was characterized by an approximately linear relationship between the load and the deflection. During this stage of behavior, the section was uncracked and both the concrete and reinforcement, behave essentially elastic.

The Second Stage: is a nonlinear portion with distinct change in slope with increasing deflections (elastic-plastic stage). This stage represents the behavior beyond the initial cracking of the section where the stiffness of the slab decreased as indicated by the reduced slope of the load versus deflection curve.

The Third Stage: is also a nonlinear portion but has characteristics in which a slight increase in load results in a larger deflection (represent the plastic stage). This stage was characterized for steel reinforcement of slab models by a decreasing slope of the curve (post-yielding), where the tension steel reinforcement reached the strain ultimate stage.

In hybrid reinforcement slab models, this stage appeared with different degrees of evident depending upon CFRP bars reinforcement ratio. While, the CFRP reinforcement slab models exhibit same behavior as in the second stage until sudden (non ductile) failure by rupture if it reach to the ultimate strain of CFRP

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reinforcement or crushing concrete or rupture followed simultaneously by crushing concrete also, depending upon CFRP bars reinforcement ratio.

The load-deflection curve at central span was examined to evaluate the effect variables on the load carrying capacity and deformation ability of the slab models, as shown in **Figure 5.**

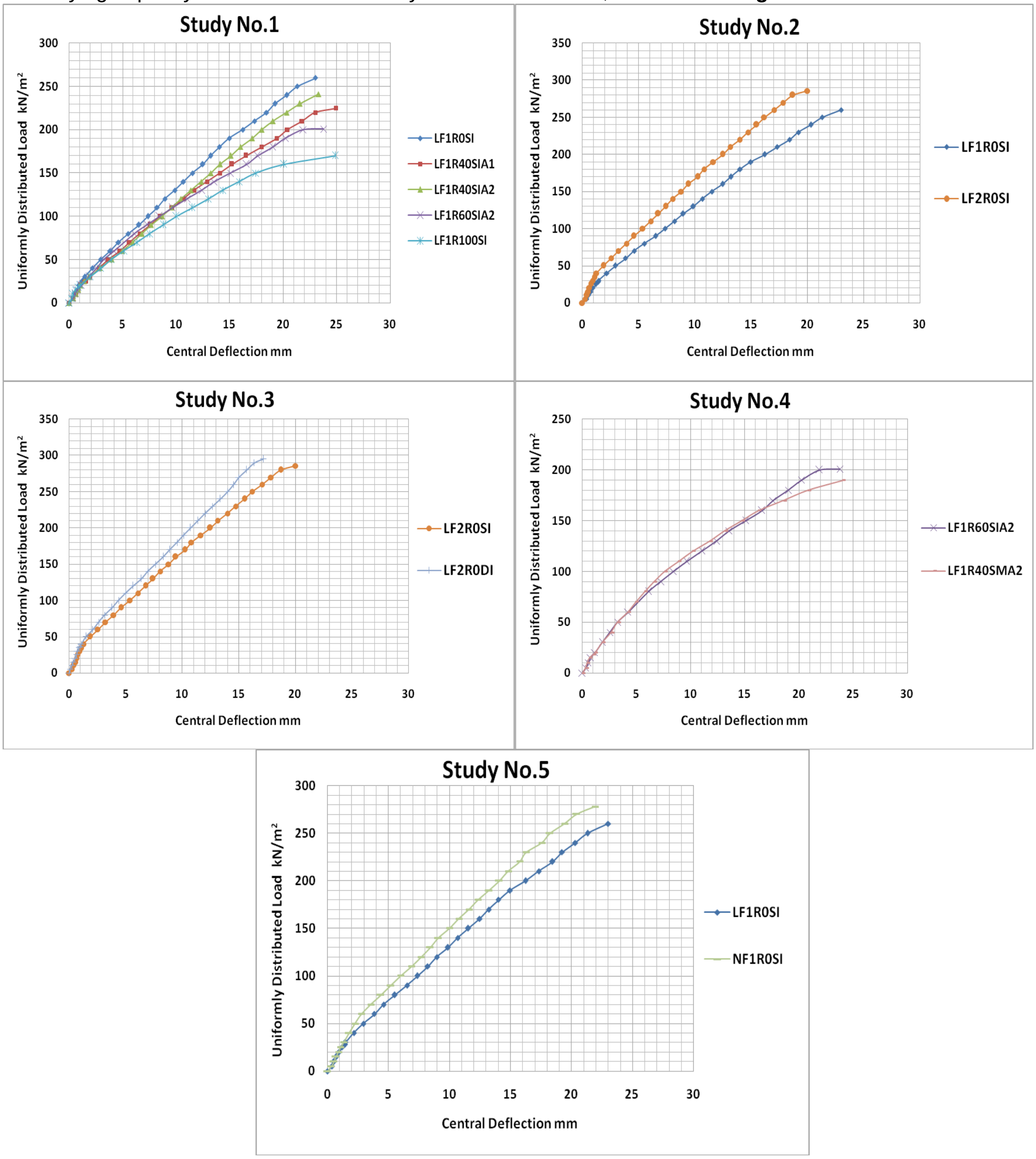

Figure 5 Load–central deflection curve for all slab models

The initial change of slope of the load-deflection curves for all slab models started between 9.47% to

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12.24% of ultimate load. This change in slope indicated the first cracking load as mentioned previously. Beyond that, all slab models behave in a rather certain manner as the following:

Study No.1: The experimental ultimate load capacity of LWAC CFRP bars slab model LF_1R_0SI is higher by about 13.46%, 7.31%, 22.69% and 34.62% than that of the LWAC slabs reinforced with hybrid reinforcement $LF_1R_{40}SIA_1$, $LF_1R_{40}SIA_2$, $LF_1R_{60}SIA_2$ and $LF_1R_{100}SI$; respectively.

Also, LF1R0SI slab model exhibited less deflection at the same load level for all stages of loading than these slabs as shown in Figure 5. Under UDL test, the arrangement of hybrid reinforcement somewhat affect on the ultimate load of the slab model.

Study No.2: The increasing in the CFRP bar reinforcement ratio by about 20% in LWAC slab model tested under UDL lead to increase in the ultimate load carrying capacity by about 10% with significant enhancement in stiffness by reduce deflection at all stages of loading

Study No.3: The use of balanced ratio of CFRP bars as top reinforcement in LF_2R_0DI which was tested under UDL increases stiffness by reducing deflections but without significant increasing in the load carrying capacity.

Study No.4: NSM slab model $LF_1R_{60}SMA_2$ tested under UDL shows similar behavior of the same slab model reinforced internally. The ratio of ultimate load for $LF_1R_{60}SMA_2$ to ultimate load for $LF_1R_{60}SIA_2$ is 94.5%. At load 160 kN/m^2 $LF_1R_{60}SMA_2$ shows suddenly reduced stiffness due to concrete splitting occur in some location of NSM CFRP bars.

Study No.5: Figure 5 shows that the overall response of NWC slab tested under UDL closely resembles that of equivalent slab model with LWAC. However, NWC slab demonstrated stiffer post-cracking response than the corresponding LWAC slab. The higher deflection observed for the case of LWAC slab model is due to lower stiffness of lightweight aggregate crushed clay bricks and higher cement content result in lower modulus of elasticity which is lead to larger deformation than NWC.

CONCLUSIONS

1- SLWAC can be produced with an average cylinder compressive strength about 37.3 MPa and average air dry density of 1896 kg/m^3 from crushed clay bricks as coarse LWA with the use of natural sand, high performance superplasticizers and silica fume.

2- The LWAC slab model reinforced by CFRP bars has a lower total weight by amount 20% in comparison with NWC slab models reinforced by CFRP bars with rather a small reduction in slab ultimate load capacity by amount not more than 6.5%.

3- The CFRP reinforced LWAC slab model can achieve ultimate load capacity higher than equivalent steel reinforced LWAC slab models by about 34.62%.

4- The increase in ultimate load capacity of hybrid reinforced slab model is ranged between (15.42-29.46)% when compared with steel reinforced slab model.

5- The use of top reinforcement has a slight effect on ultimate load capacity but has a major effect on reducing measured central deflection by about 14.46% when compared with central deflection at service load.

6- The overall response of the LWAC slab using NSM technique of CFRP bars in two ways are nearly similar to that of corresponding slab using internal CFRP bars. It was found that the ratio of the ultimate load carrying capacity of a NSM technique to internal CFRP bars is 0.945.

7- From load-deflection plots, the failure is brittle for slab models reinforced with CFRP bars only, less brittle for slab models reinforced by hybrid (steel and CFRP) bars depending upon steel and CFRP bars ratio and ductile in slab model reinforced by steel bars only. This means that, the use of steel bars in combination with CFRP bars (hybrid reinforcement) improved the ductility in comparison with slab model reinforced by CFRP bars only.

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8- The reduction in spacing between CFRP bars from 240 mm to 190 mm shows enhancement in first crack load by about 25%.

9- In general, the use of hybrid reinforcement gives improvement in first cracking load in comparison of steel reinforcement depending on the ratio of replacement CFRP bars by steel bars.

10- The arrangement of hybrid reinforcement have not impact factor on the first crack load in tension face of the slab model.

11- The crack pattern in CFRP reinforced slab models was different from that of similar spacing of steel and hybrid reinforced slab models, in terms of crack width and crack spacing. e.g., the maximum crack width at failure in steel reinforced slab model was wider by 51.43% than CFRP reinforced slab models tested under UDL.

12- According to the maximum crack width at service load (70% of ultimate load), the maximum spacing for CFRP bars reinforced LWAC two way slab tested under UDL can be adopted as three of thickness value ($S_{max.}$=3h) according to ACI 440.1R-06.

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