VI International Conference on Textile Composites and Inflatable Structures
STRUCTURAL MEMBRANES 2013
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Behavior of One – Way Concrete Slabs with Edge Beams Reinforced/Strengthened by CFRP Rods under Uniformly Distributed Load

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Key words: One-Way Concrete Slab, CRFP Rods, Uniform Load, Strengthening.

Summary: This research presents an experimental investigation on the flexural behavior of eight one-way concrete slabs with edge beams under uniformly distributed load. The models are reinforced or strengthened using CFRP rods and two control models reinforced by deformed steel bars.The dimensions of one-way slab is 1.05 m width, 1.25 m length and 0.1 m thick., while each edge beam is of length 1.25m and depth 0.2m by width 0.1m. Different reinforcement ratios were used. The models were tested under universal testing machine and supported at corners on four stiff steel columns. The models were tested up to failure to study their flexural behavior including load-deflection curves, crack patterns and mode of failure. Among the conclusions obtained, the models reinforced by CFRP rods can attain flexural strength higher than those reinforced by deformed steel bars of same amount. This increase is about (38-44%).

1. INTRODUCTION:

Fiber reinforced polymer (FRP) composites are currently used as reinforcement or strengthening for concrete structures where durability is the controlling parameter. Carbon fiber reinforced polymer (CFRP) rods reinforcement represents a suitable replacement for steel reinforcement in some concrete structural members subjected to aggressive environmental conditions that accelerate corrosion of the steel reinforcements and cause deterioration of the structures.

2. RESEARCH SIGNIFICANCE:

This paper presents the experimental results of eight one-way concrete slabs, including two RC one way slab with edge beams reinforced by CFRP bar as a main reinforcement, two RC models reinforced by steel reinforcement tested for comparison purposes, two RC models reinforced by CFRP bar as a main reinforcement and strengthened using near surface mounted with CFRP bar and two RC models reinforced by steel reinforcement and strengthened using near surface mounted with CFRP bar. The models were tested up to failure under static and repeated loading conditions. The research investigates various limit states behavior including pre-cracking behavior, cracking pattern and width, deflections, ultimate capacities and mode of failure. The behavior of concrete slabs reinforced with CFRP rods is compared with the behavior of a slab reinforced with steel reinforcements. The information obtained throughout this investigation is valuable for future field application and development of design guidelines for one-way concrete slabs reinforced with FRP rods.

3. MATERIAL PROPERTIES OF FRP RODS:

The Aslan 200/201 series provides designers the greater modulus and tensile strengths of carbon fiber in a non-metallic reinforcing bar. Aslan 200/201 can be used for both new construction and as a strengthening material for the novel technique known as "Near Surface Mounted" or NSM strengthening. With a proprietary end anchorage, the Aslan 200/201 bar can be used in un-bonded post tension or pre-stressing applications. The Aslan 200 series features a textured surface whereas the Aslan 201 series is a sand coated surface. Both versions have the same physical properties.
Table (1) contains properties of Aslan 201 FRP 6 mm diameter rebar as measured or supplied by the manufacturer.

Table (1) : Physical Properties of Aslan 201 CFRP Bar, (Hughes Brothers,2010)

Bar Diameter	Cross Sectional Area	Nominal Diameter	Tensile Strength	Tensile Modulus of Elasticity	Ultimate Strain
(mm)	(mm2)	(mm)	(MPa)	(GPa)	(%)
6	31.67	6	2704	163	0.017

4. EXPERIMENTAL PROGRAM

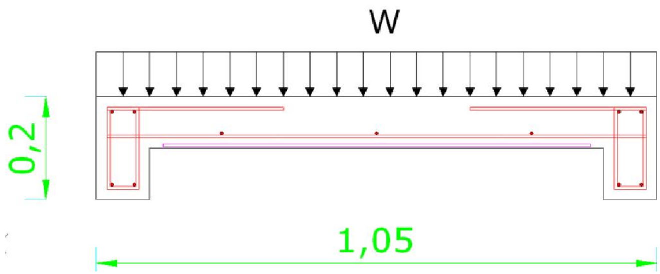
4.1. Slab Models

The one way slab with edge beams symbols are represented as follows:

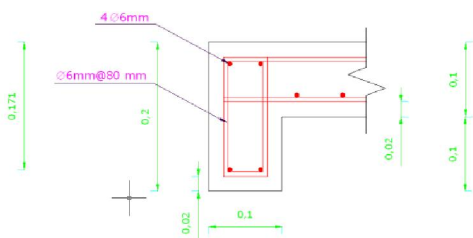
(C or S)*-N**

C	CFRP reinforcement .
S	Steel reinforcement.
*	Number of (Ø 6mm) CFRP bars as main reinforcement.
N	Near surface mounted with CFRP bars.
**	Number of (Ø 6mm) CFRP bars for strengthening.

The test slab-beam system models had a rectangular slab 1.05 m wide and 1.25 m long with 100mm thickness and for edge beams had cross section 100 mm wide by 200 mm deep with an effective depth (d) of 171 mm for steel RC and FRP RC one way slab with edge beams and these dimensions are the same for all models, as shown in Figure (1) .The properties of the tested models are summarized in Table(2).



a. Details of model under Distributed Load



b. Edge Beam Detail

Figure (1) One Way Slab Model

Table (2) : One Way Slab Models Details

model	Main(transverse) reinforcement in slab						Secondary(longitudinal) reinforcement in slab		
	Top			Bottom			Bottom		
	Bars	As, mm^2	Bars Type	Bars	As, mm^2	Bars Type	Bars	As, mm^2	Bars Type
(C6)	5 No. 2	158.35	**CFRP**	6 No. 2	190.02	**CFRP**	3 No. 2	95.01	**CFRP**
(C7)	5 No. 2	158.35	**CFRP**	7 No. 2	221.69	**CFRP**	3 No. 2	95.01	**CFRP**
(S6)	5 No. 2	141.37	**Steel**	6 No. 2	169.64	**Steel**	3 No. 2	84.82	**Steel**
(S7)	5 No. 2	141.37	**Steel**	7 No. 2	197.92	**Steel**	3 No. 2	84.82	**Steel**
(C3-N3)	5 No. 2	158.35	**CFRP**	3 No. 2	95.01	**CFRP**	3 No. 2	95.01	**CFRP**
(C4-N3)	5 No. 2	158.35	**CFRP**	4 No. 2	126.68	**CFRP**	3 No. 2	95.01	**CFRP**
(S6-R5)	5 No. 2	141.37	**Steel**	6 No. 2	169.64	**Steel**	3 No. 2	84.82	**Steel**
(S7-R6)	5 No. 2	141.37	**Steel**	7 No. 2	197.92	**Steel**	3 No. 2	84.82	**Steel**

f'c = 40.35 MPa

4.2. Instrumentation

The models were positioned in the universal testing machine and supported on four stiff steel columns at their corners and tested up to failure under uniformly distributed load**,** as shown in figure (2)**.**

To accomplish the required boundary conditions the following setup has been used:

Rigid steel supporting frame is designed as a supporting system and placed on the top face of the testing machine base. Four rigid steel plate (100×100×120) mm in dimensions are welded at the corners of the rigid steel supporting frame that can be assumed as pin support on four stiff steel columns. The clear distances between these steel columns are 1050 mm in long directions and 850 mm in short directions.

To have a uniformly distributed load subjected on one way slabs a hydraulic jack of the testing machine is used through the following setup:

The sand furnishes a good media to distribute the load uniformly , a box of steel plate of thickness 5 mm with inside dimensions (depth 100 mm and same surface area of one way slab) is used to hold the sand to be placed over the slab as a method to uniformly distribute load. The box coated on the inner surfaces by a sheet of nylon to reduce any possible friction that can result from the contact of sand with steel and concrete.

To maintain more distribution for loading the single point load from the universal machine was distributed equally into nine points load approximately on a steel plate of (1230×1030×5) mm that capping the supporting layer of sand by using 3 I-section beam in longitudinal direction of slab over 3 I-section beam in transverse direction.

At each increment the manual measurements were recorded, which included the following:

1- the applied load are measured by a hydraulic machine with capacity of 2000 kN as mentioned above, the load was applied with a loading increment rate of about 150 N/sec.

2-The deflections are measured using a dial gauge with a capacity of (50) mm and accuracy of (0.01) mm, beneath the center point of the slab and, at the two quarter points of slab and at mid span of the two edge beams in the slab-beam systems. The dial gauge is fixed in such a way that it can contact the lower surface of models. The deflection readings of dial gauge are taken at each 5 kN/m^2 .

3- The crack width is measured at each 10 kN/m^2 by crack meter (Electrometer 900), in addition to that, the cracks are detected and drawn on the bottom face of the tested slabs and the edge beams.

5. TEST RESULTS AND DISCUSSION

All models were designed with a clear cover to the reinforcement of 20 mm, All details reviewed in previous section. The slab- beams models were designed to fail in flexure. The general behavior of the tested slab-beams models can be summarized as below. For the control models, 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 at the center line of slab in long direction and at mid-span of edge beams. As

Figure (2) Apparatus of Testing One Way Slab Models

the load was further increased, several flexural cracks were initiated in the tension face at intervals throughout the slab and beams, gradually increased in number, became wider and moved upwards reaching the compression face of the slab and beams. 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 yielding of the steel reinforcement followed by crushing of concrete. The CFRP models also showed similar behavior, but not yielding of steel occurred, the CFRP reinforcement contributed mainly in resisting the loads and increased the stiffness of the concrete models up to failure by crushing of concrete in beams and diagonal shear cracks near the edge of slab.

5.1 Ultimate Loads

Crack formation was monitored throughout testing to assess the behavior of the CFRP one way slab with edge beams in comparison with the behavior of steel reinforced concrete control models. Figures (3) to (4) show samples of crack patterns for some tested models.

Table (3) shows the ultimate load, first crack load and ultimate deflections in slab and beams for all models.

Table (3): Ultimate load and deflection for all models

model	First Crack Load in beam	First Crack Load in slab	Ultimate Load W_u (kN/m^2)	Δ_u (mm) under slab center	Δ_u (mm) under slab quarter point*	Δ_u (mm) at beam mid-span*
S6	30.5	38	146	17.79	15.455	11.70
S7	38	45.7	153	19.56	16.565	13.015
C6	45.7	53.3	202	17.21	15.68	10.725
C7	49	55.6	221	19.55	17.655	10.59
C3-N3	42	49.5	191	15.37	13.895	11.095
C4-N3	45.7	53.3	210	16.506	16.08	12.5645
S6-R5	30.4	38	149	12.73	11.345	8.715
S7-R6	38	45.7	160	14.50	13.5015	11.24

***Average value.**

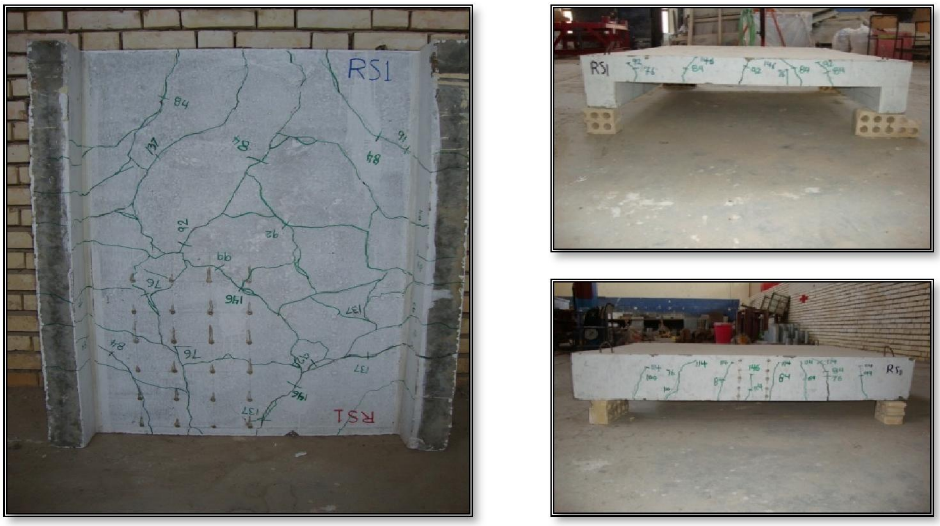


Fig.(3): Cracking Pattern at Failure for Model (S6)

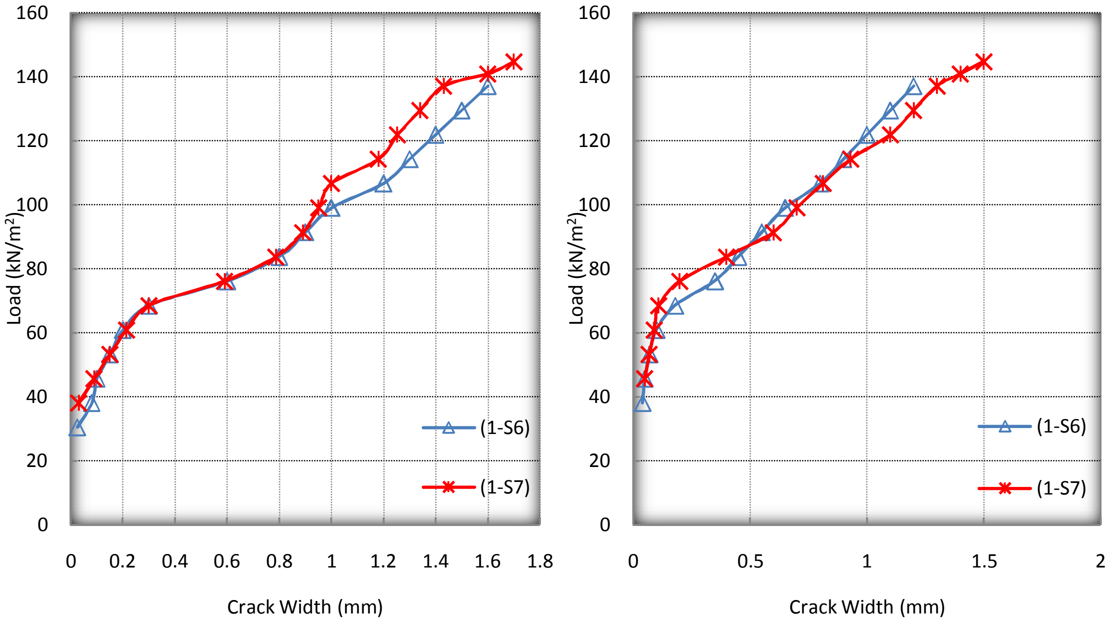
Figure (4) Models Cracking Patterns at Failure of (C6)

5.2 Maximum Crack Width

The main observations which can be made from crack width measurements are listed below:

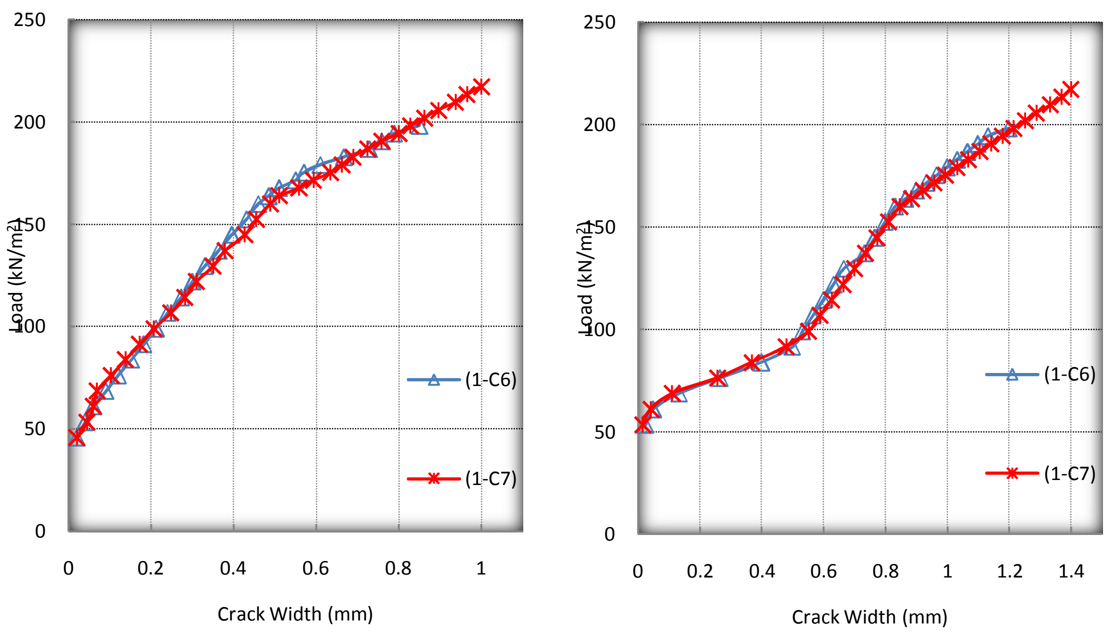
1- At the same load level, steel reinforced concrete models (control models) ((S6) and (S7)) showed greater crack width than CFRP models ((C6) and (C7)) of similar reinforcement ratio respectively.
2- The smaller crack width is true for NSM models (C4-N3) and (C3-N3) in comparison with control models.
3- However, Control models ((S6) and (S7)) showed rather smaller crack width than repaired model ((S6-R5) and (S7-R6)) respectively at same loading stage.

Figures (5 to 7) show load versus crack width for some tested models . It is clear, with using CFRP reinforcement of percentage (1-1.2)ρ_b , as in the present study will control more the cracking width and deflection up to failure.



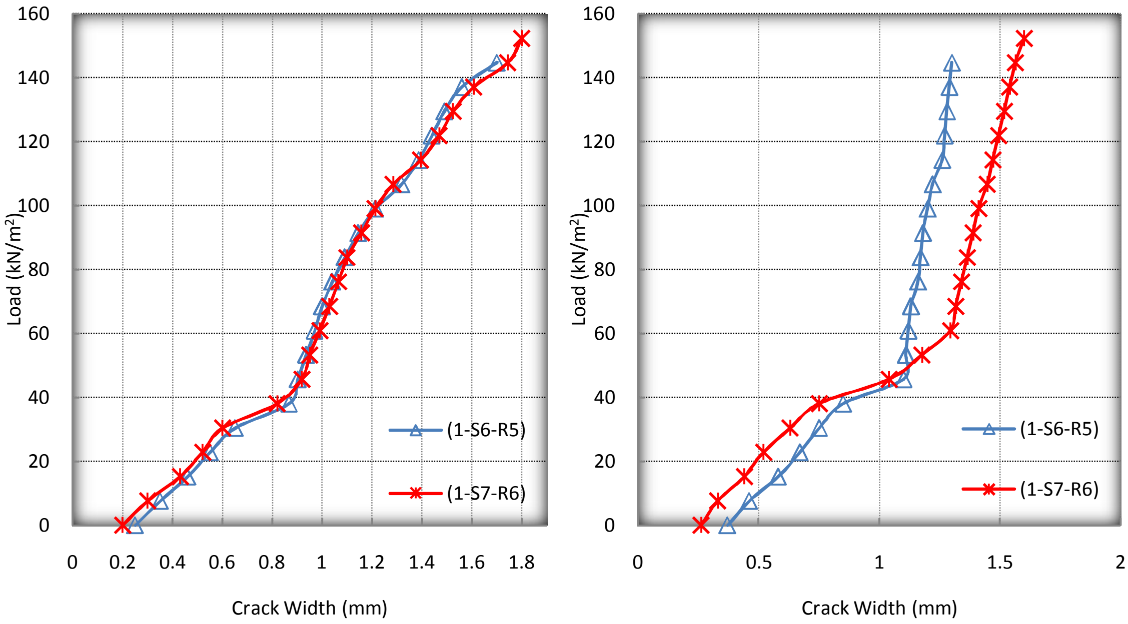
a. Max. Crack Width at Edge Beam (mid span) b. Max. Crack Width at Slab (center line)

Figure (5) Load Verses Crack Width of (S6) and (S7)



a. Max. Crack Width at Edge Beam (mid span) b. Max. Crack Width at Slab (center line)

Figure (6) Load Verses Crack Width of (C6) and (C7)



a. Max. Crack Width at Edge Beam (mid span)   b. Max. Crack Width at Slab (center line)

Figure (7) Load Verses Crack Width of (S6-R5) and (S7-R6)

5.4 Deflection Distribution Plots

Figure (8) show locations of dial gauges in short direction of one way slab with edge beams. Deflected shape of the slab with edge beam at beam mid-span versus distance at different load stages are presented in Figures ((9) to (10)).

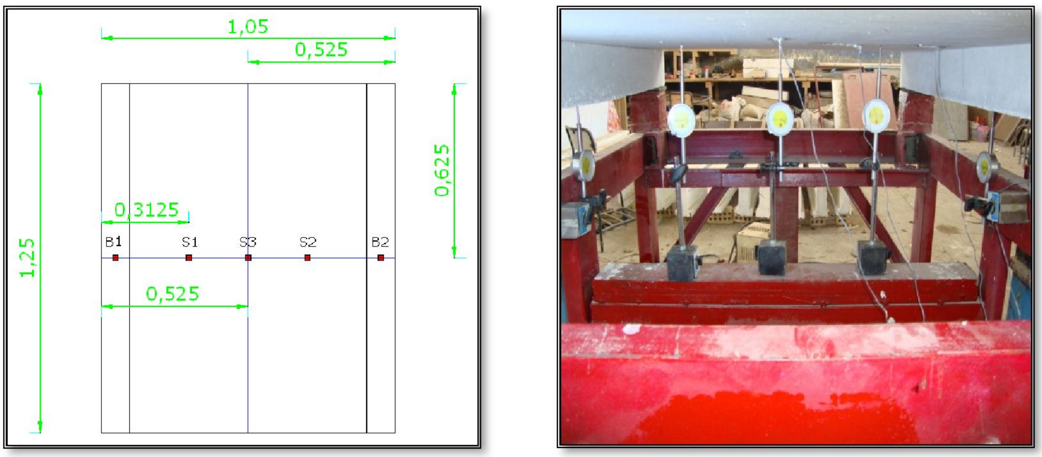


Figure (8) Locations of Dial Gauges in Short Direction of One Way Slab

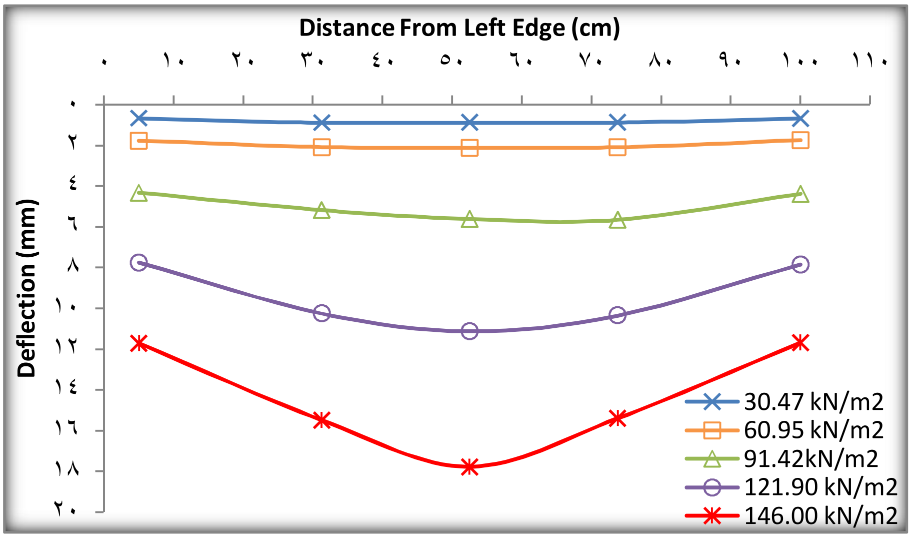


Figure (9) Deflection Distribution Along Short Direction of slab For (S6)

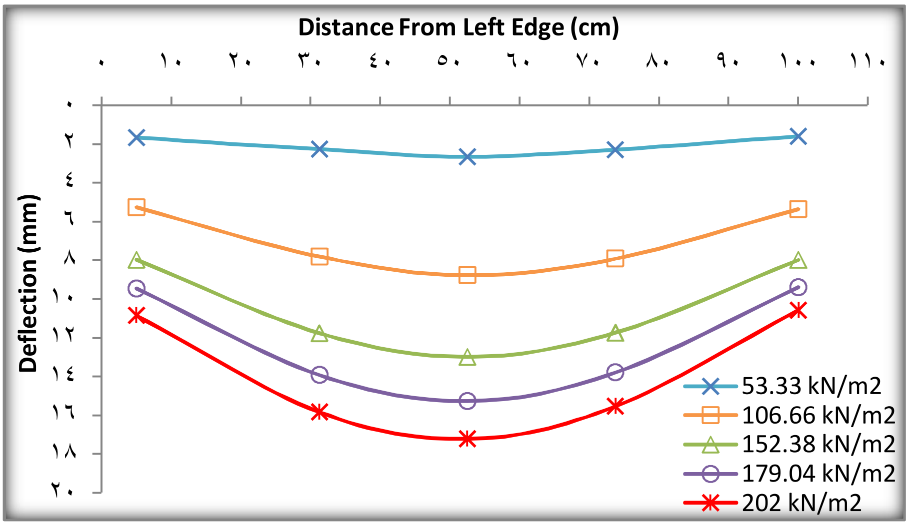


Figure (10) Deflection Distribution Along Short Direction of slab For (C6)

6. CONCLUSIONS

Main conclusions drawn from experimental work can be summarized as given below:

-It was found that CFRP reinforced specimens can achieve flexural strength values higher than those of similar steel reinforced models by about (38 % - 44 %), and for NSM specimens about (31% - 37 %) and, for repaired specimens about (2. % - 5%).

-The CFRP RC models showed about (34% - 47%) for beam and (29 % - 30%) for slab lesser deflection than control models. Also, the near surface mounted RC models showed about (43% - 50%) for beam and (43% - 51%) for slab lesser deflection than control models. For models under repeated load, the repaired RC models showed about (20% - 34%) for beam and (32% - 34%) for slab lesser deflection than the control models.

-Using CFRP rods as tensile reinforcement or strengthening in RC slab-beam systems had a significant effect on the crack width of tested models. The low modulus of elasticity of CFRP rods was substituted by using balanced and over reinforcement ratios and was found it reduced significantly the max crack width of reinforced concrete one way slab with edge beams under (UDL).

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