Using Steel Fiber Reinforced Concrete (SFRC) as an Alternative to Negative Reinforcement in Continuous RC Slab Panels

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Abstract

This study presents an experimental investigation performed to investigate the using of steel fiber reinforced concrete (SFRC) as an alternative to negative reinforcement in continuous RC thin slab panels. More rational way has been used by replacing negative reinforcement near interior supports by steel fiber reinforced concrete (SFRC). Tests were carried out on four slab panels, simply supported under single point loading. One of which were made fully with NSC, and the others were made partially with SFRC in negative moment zone.

Experimental results show that the ultimate load capacity are increased (23% -58%) and the cracking loads are increased (25% -62.5%) for tested specimens strengthened with SFRC, in comparison with the reference specimens. Crack arrest mechanism of steel fibers limits crack propagation, improves the ultimate and tensile strength. So, more practical technique can be concluded from this study and employed in manufacturing of thin slabs.

Key Words: **Steel fiber, Slab, Panel, Concrete, NSC, SFRC**

استخدام الخرسانة المسلحة بألياف الحديد كبديل عن حديد التسليح السالب في البلاطات الخرسانية المسلحة المستمرة

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تحظى البلاطات الخرسانية الصفائحية المستوية بالكثير من الاهتمام في التطبيقات الإنشائية مثل المباني والمنشات السكنية والتجارية والصناعية ، كما أن الحاجة الى تصميم منشأ اقتصادي ذو كفاءة عالية لمقاومة الأحمال المسلطة جعلت المصممين يحاولون استخدام مواد إنشائية مختلفة لزيادة مقاومة الجزء الخرساني النحيف(البلاطة) دون الزيادة في السمك أو كمية حديد التسليح، فكان استخدام الخرسانة المسلحة بالألياف احد الحلول المثالية التي توفر في السمك الكلي وكمية حديد التسليح وبالتالي يقلل التكلفة الكلية للمنشأ.

تم في هذا البحث عمل دراسة عملية لسلوك البلاطات الخرسانية المستمرة ذات الارتكاز البسيط والمصنوعة من الخرسانة الاعتيادية و الخرسانة الحاوية على الألياف الحديدية في منطقة الشد او العزم السالب (عند المساند الوسطية). تم فحص أربعة بلاطات (واحدة بدون الياف الحديد وواحدة حاوية على ألياف الحديد ذات النهايات المثنية وواحدة حاوية على ألياف الحديد الأملس المستقيم وواحدة حاوية على ألياف الحديد المتعرجة).

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اظهرت النتائج زيادة في الحمل الاقصى بمقدار(23%-58%) وزيادة في احمال التشقق بمقدار (25%-62.5%) في البلاطات المسلحة بالياف الحديد (في منطقة العزم السالب في المسند الوسطي) عند مقارنتها مع البلاطة المرجعية. مما تقدم، يمكن ان نستخلص ان الاسلوب المشار الية يمكن اعتمادة في تصنيع البلاطات الخرسانية الصفائحية المستوية.

1-Introduction

Slab panels can be used as floor or roof simply supported on masonry components or load bearing walls, steel or concrete beams. This technique of construction is widely used and suitable for residential, commercial, prefabrication, industrial buildings. A thin slab is widely used in shell structures such as hangers, exhibition halls, industrial buildings and a variety of other large span structures.

For bridges, there are two main types of precast concrete slab panels (deck), full-depth slab panels and partial-depth slab panels. Full-depth and partial-depth deck panels may be poured away from the site at a precasting plant and shipped to the site once they have cured and are ready for placement (Erection). This feature helps to minimize disruptions to traffic, improve construction quality, and lower overall construction time. Once at the site the slab panels may be placed directly on precast girders and connected through different methods between adjacent slab panels and connections between panels and supporting elements (girders).

Generally, this type of slabs reinforced in longitudinal direction by two layers (top and bottom) to resist positive and negative bending moments produced due to applied loads. According to ACI-318[(1)] Code, the negative reinforcement extends to adjacent span distance equals to one third of adjacent spans.

Several experimental investigations were conducted to increase the flexural or shear strength of slabs or beams by using steel fiber reinforced concrete[(2,3,4)] or high strength concrete or concrete polymer composite[(5)]. Crack arrest mechanisms of steel fibers limits crack propagation, improves the ultimate, cracking and shear strength.

This study presents an experimental investigation performed to investigate the using of steel fiber reinforced concrete (SFRC) as an alternative to negative reinforcement in continuous RC thin slab panels.

2- Experimental Study

2-1 Experimental Program

Tests were carried out on four slab panels, simply supported under single points loading (at each span). All slab panels were reinforced with tension bars at mid of right and left spans (positive reinforcement at bottom), while, for reference slab panel, tension bars were used at medium support (negative reinforcement at top). The tested panels were made without shear reinforcement.

The variables were the type of steel fibers (straight, hocked-end and crimped) of steel fiber reinforced concrete. The span, cross-section, concrete strength, steel fiber volume friction, and positive reinforcement (bottom reinforcement) were kept constant without any changed for all tested specimens.

2-2 Specimen Details

All slab panels were made with (2000x250x50mm) dimensions for length, width and thickness respectively. Figures (1) to (3) presents the detailed testing program and nominal dimensions of the tested slab panels. The main reinforcement consisted of (2ϕ10mm) mild, hot-rolled, deformed steel bars employed as tension reinforcement (flexural reinforcement).

Longitudinal tension reinforcement was bent with (90!) angle at the ends to prevent any steel-concrete bond slip. The reinforcement bars were placed inside the mold with (10mm) concrete cover. The tested slab panels are designated as shown in Table (1).

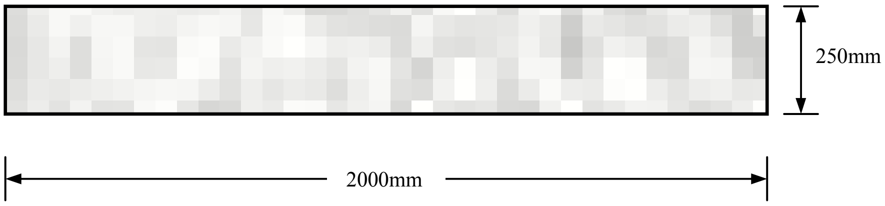

Figure (1) Slab Panel Dimensions (top view)

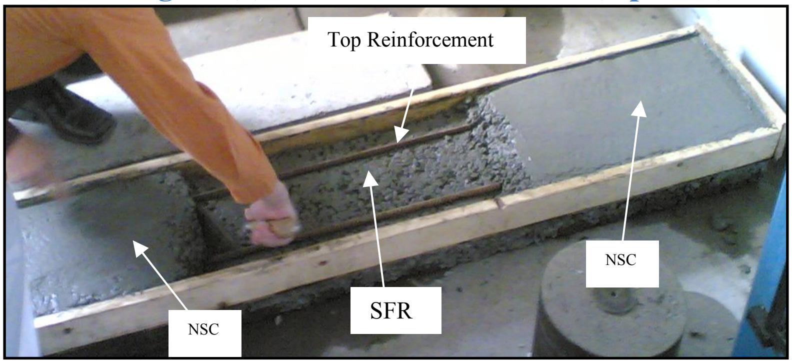

Figure (2) Details of Test Slab Panel

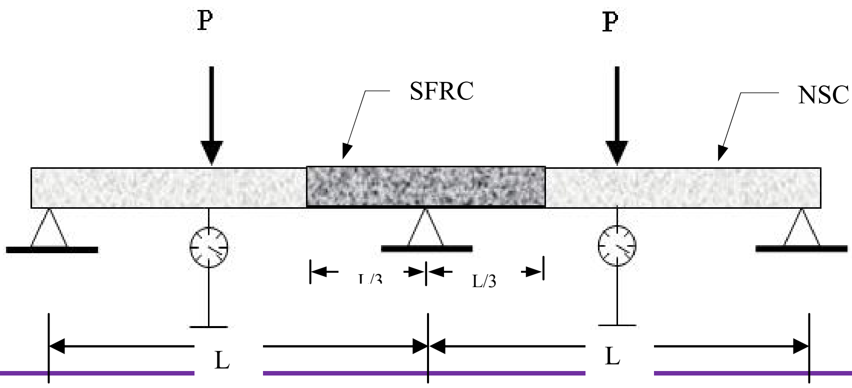

Figure (3) Slab Panel Setup

Table (1) Properties of Test Slab Panels

Slab Designation	***Reinforcement***	
	Positive**	***Negative******
SP-1 *	2ϕ10	2ϕ10
SP-2		SFRC (Hocked-end Fiber)
SP-3		SFRC (Straight Fiber)
SP-4		SFRC (Crimped Fiber)

* Reference Slab (Full Beam made with NSC) ** At mid spans (positive reinforcement at bottom).
*** At medium support (negative reinforcement).

2-3 Materials

In manufacturing the test slab specimens, the properties and description of materials used are reported and presented in Tables (2) and (3), and the mix proportions for the normal strength concrete (NSC) and steel fiber reinforced concrete (SFRC) are presented in Table (4).

Table (2) Properties and Description of Materials

Material	*Descriptions*
Cement	Ordinary Portland Cement (Type I).
Sand	Natural sand from Al-Ukhaider region with maximum size of (4.75mm).
Gravel	Crushed gravel with maximum size of (12mm).
Reinforcing Bars	(ϕ 10 mm) deformed steel bars having yield strength f_y= 410 MPa.
Water	Clean tap water.

Table (3) Properties and Description of Steel Fibers

Steel Fiber Type	*Shape*	*Properties**
Hocked-end		Mild carbon steel fibers with average length of (50mm), nominal diameter of (0.5mm), aspect ratio of (100) and yield strength of (1130MPa).
Straight		Smooth mild carbon steel fibers with average length of (25mm), nominal diameter of (0.5mm), aspect ratio of (50) and yield strength of (1650MPa).
Crimped		Mild carbon steel fibers with average length of (25mm), nominal diameter of (0.5mm), aspect ratio of (50) and yield strength of (1130MPa).

*From manufacturers

Table (4) Proportions of Concrete Mixes

Parameter	*Concrete Type*	
	NSC	*SFRC*
Water/cement ratio	0.5	0.5
Water (kg/m^3)	180	180
Cement (kg/m^3)	350	350
Fine Aggregate (kg/m^3)	800	800
Coarse Aggregate (kg/m^3)	1000	1000
Steel Fiber volume (%)	-	1.0

2-4 Test Measurements and Instrumentation

Hydraulic universal testing machine (MFL system) is used to test the slab specimens as well as control specimens. Central deflection has been measured by means of (0.01mm) accuracy dial gauge (ELE type) and (30mm) capacity. The dial gauges were placed underneath the bottom face of each span at mid.

2-5 Test Results of Control Specimens

Test results of mechanical properties of specimens are summarized in Table (5). Compressive strength for cylinders was carried out on NSC and SFRC in accordance with ASTM-C39(6). Tensile strength (Split cylinder) test were carried out in accordance with ASTM-C496(7).

Table (5) Mechanical Properties of Concrete

Property (MPa)	*Concrete Type*			
	NSC	*SFRC*		
		Hocked-End	*Straight*	*Crimped*
Cylinder compressive strength (f'_c)*	22	24	22.5	24
Split cylinder (f_{ct})**	4.7	7.5	6.2	7.25

*Average of three samples (per concrete type) using (150x300mm) cylinders.
** Average of three samples (per concrete type) using (150x300mm) cylinders.

2-6 Test Procedure

All slab specimens were tested using universal testing machine (MFL system) with monotonic loading to ultimate states, Figure (4). The tested slabs were simply supported over effective spans of (950mm) and loaded with a single-point load at mid of effective spans.

The slabs have been tested at ages of (28) days. The slab specimens were placed on the testing machine and adjusted so that the centerline, supports, point loads and dial gauges were in their correct or best locations. Loading was applied slowly in successive increments. At the end of each load increment, observations and measurements were recorded for the mid-span deflections and crack development and propagation on the slab surface.

When the samples reached advanced stage of loading, smaller increments were applied until failure, where the load indicator stopped recording any more and the deflections increased very fast without any increase in applied load.

The developments of cracks (crack pattern) were marked with a pencil at each load increment.

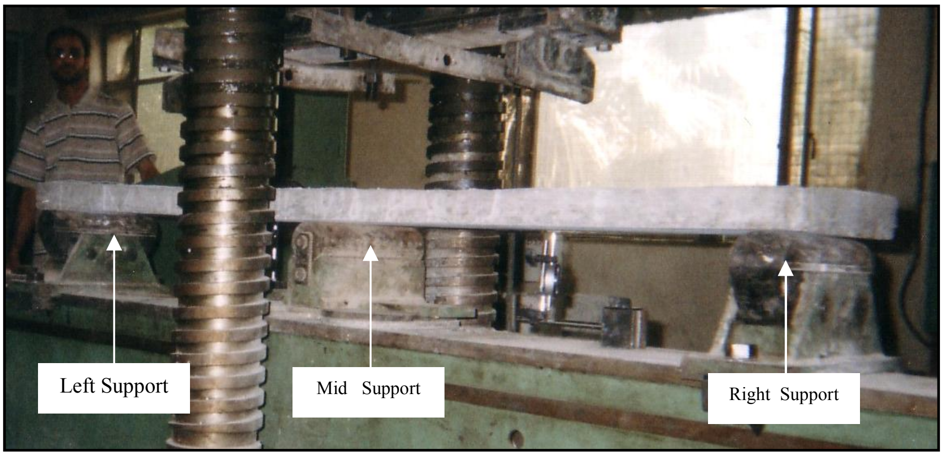

Figure (4) Set up of Slab Specimens

3-Results and Discussion

As mentioned before, the main objectives of this study are to investigate experimentally the using of steel fiber reinforced concrete (SFRC) as an alternative to negative reinforcement in continuous RC thin slab panels. During the experimental work, cracked and ultimate loads, load versus deflection at mid-span were recorded. Photographs for the tested specimens are taken to show the crack pattern and some other details.

The recorded data, general behavior and test observations are reported as well as recognizing the effects of various parameters on the flexural behavior.

3-1 General Behavior

Photographs of the tested beams are shown in Figure (5) and test results are given in Table (6). All specimens were designed to fail in flexure with tensile mode, which was characterized by the formation of cracks in the tensile stress zones, then yielding of steel bars and shifting the neutral axis upwards. The general behavior of the tested specimens can be described as follows:

At early stages of loading, several cracks initiated in the tension zones at the maximum moment regions. With further loading, these cracks extended and became wider. At about (60%) of the ultimate load, more cracks developed at the bottom of the slab and proceeded towards the main cracks and often joined together.

As expected, the main cracks for all tested specimens commenced at the middle zone and all slab specimens exhibited ductile flexural failure, as shown in Figure (5).

Table (6) Mode of Failure, Ultimate and Cracking Loads of tested Specimens

Specimens Designation	Load (kN)		$\frac{P_u}{(P_u)_R}$	$\frac{P_{cr}}{(P_{cr})_R}$	Mode of Failure
	P_u	P_{cr}			
SP-1 *	31	8	1.0	1.0	Tensile Failure
SP-2	43	10	1.39	1.25	=
SP-3	38	10	1.23	1.25	=
SP-4	49	13	1.58	1.625	=

* $(P_u)_R$ =31 kN ** $(P_{cr})_R$ = 8 kN

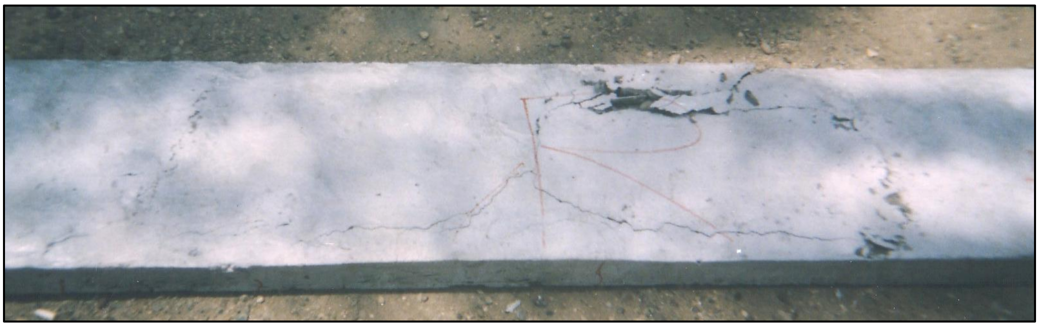

Figure (5) Crack Patterns for tested specimens (bottom face)

3-2 Ultimate Strength (Pu)

The recorded ultimate loads of the tested specimens are presented in Table (6). For tested specimens (SP-2, SP-3 and SP-4), which had SFRC instead of tension reinforcement in negative moment at medium support, the increase in strength were (39%, 23% and 58%). This enhancement is due to the high aspect ratio, fiber length and adequate volume fraction of the used fibers. The randomly oriented steel fibers have the ability to arrest cracking and restrain propagation and these caused an increase in the load carrying capacity beyond the first cracking.

Generally, it can be seen that the tested specimens strengthened with SFRC exhibit larger ultimate strength than reference specimens which fully with NSC.

3-3 First Cracking Loading (Pcr)

The first cracking loadings are presented in Table (6), and crack patterns for tested specimens are shown in photograph of Figure (5). For all tested specimens, comparison will be made with first cracking load for the reference beams (Pcr)R.

For slab specimen containing SFRC, (SP-2, SP-3 and SP-4), the addition of steel fibers increased the cracking load that induces first crack by (25%, 25% and 62.5%) comparing with the average first cracking load of reference slab (SP-1). This is due to the ability of steel fibers in arresting crack growth and restraining cracking widening. As expected, slab specimens made with SFRC exhibit larger cracking loads comparing with the reference one.

3-4 Deflections

Load-deflection curves of the tested slabs at mid-span at all stages of loading up to failure are constructed and shown in Figures (6) to (9). At the beginning, all curves were identical and the tested specimen exhibited linear behavior and the initial change of slope of the load-deflection curves occurred at (8kN), which indicated the first crack loads. Beyond the first crack loading, the slabs behaved in a certain manner.

As shown in Figure (6), the spans of the reference specimen, (SP-1), each had approximately same load- deflection behavior, which indicated that the spans behaves in same manner.

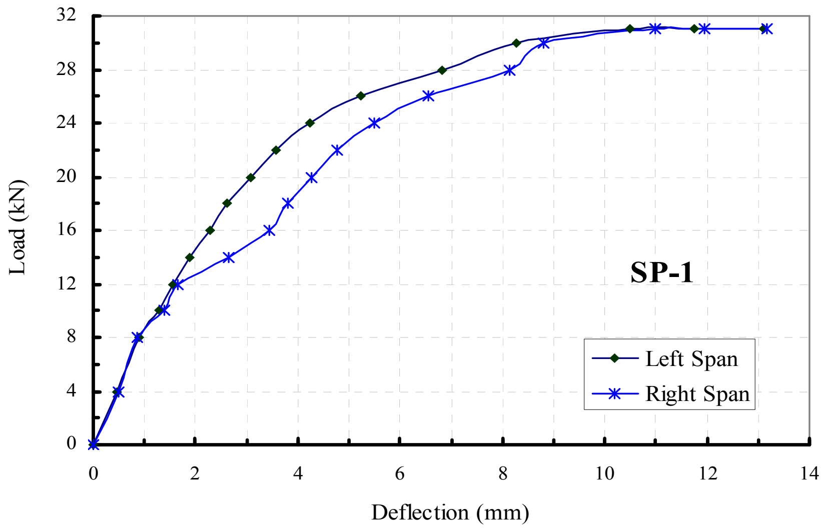

Figure (6) Load-Deflection Relationship of SP-1

As shown in Figure (7), increase in ultimate load of slab (SP-2) was observed in comparing with (SP-1). This enhancement is due to presence of SFRC and the ability of steel fiber to arrest cracking and restrain propagation and these caused an increase in the load carrying capacity beyond the first cracking.

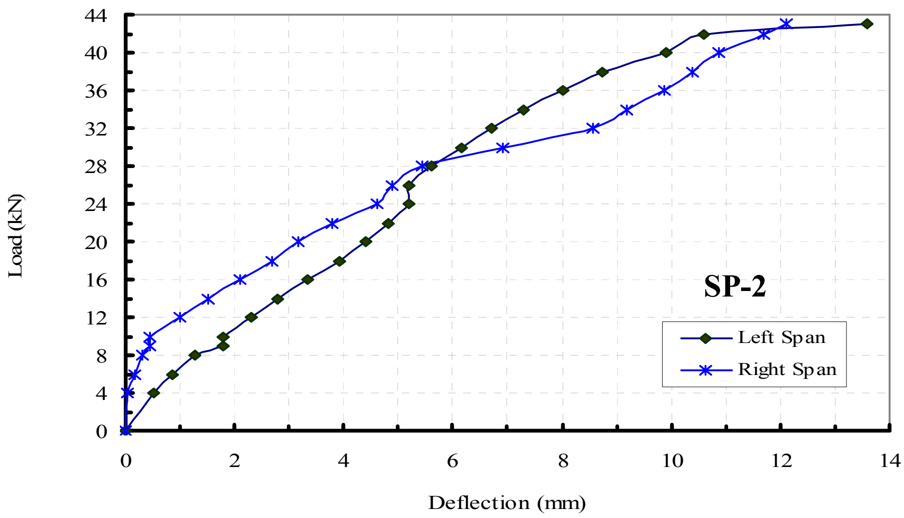

Figure (7) Load-Deflection Relationship of SP-2

Load-deflection curve for slab (SP-3) exhibits smooth increase in both applied loads and deflections. Presence of SFRC in caused an increase in the load carrying capacity beyond the first cracking and this was reflected on the corresponding deflections, Figure (8).

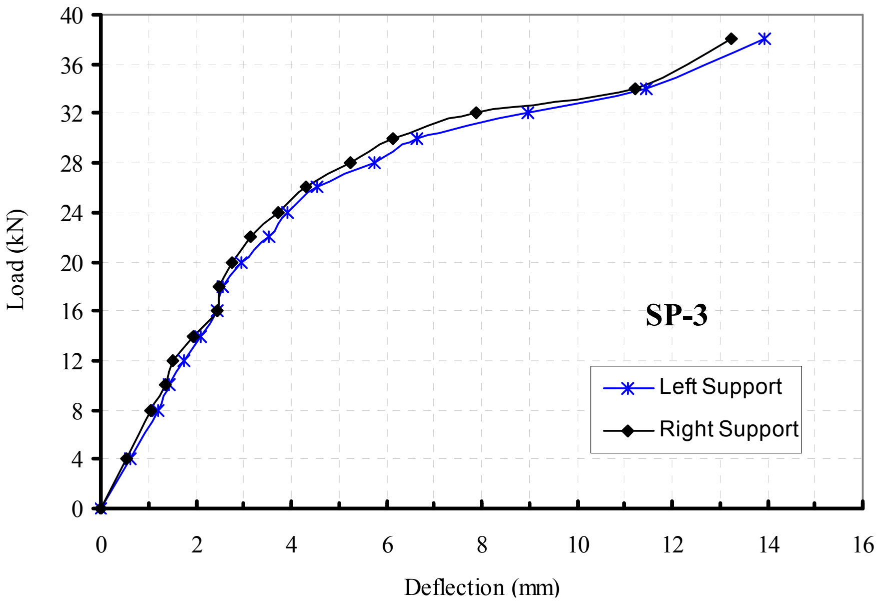

Figure (8) Load-Deflection Relationship of SP-3

Behavior of slab (SP-4) exhibited greater loads and deflections in comparison with the other slabs. This panel had the greatest stiffness due to presence of high efficient fiber (crimped fibers) in SFRC. Behavior of slab (SP-4) is similar to slab (SP-3), but the curve deviates gradually with increasing loads.

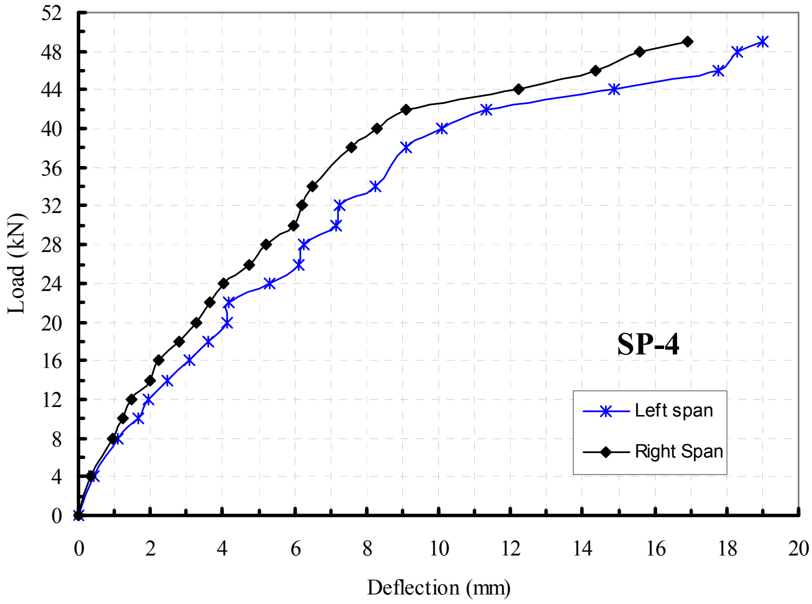

Figure (9) Load-Deflection Relationship of SP-4

3-5 Steel fiber type effect

As shown in Table (6), when the SFRC which content hocked end fibers are use, the ultimate strength and cracking load increased (39%) and (25%) respectively. When the steel fiber changed to straight type, the ultimate strength and cracking load increased (23%) and (25%) respectively. While, when the crimped type employed, the ultimate strength and cracking load increased (58%) and (62.5%) respectively. This may be due to geometrical shape of crimped fiber which makes it extended through large surface are.

4-Conclusions

Based on the results obtained by the experimental work, the following conclusions are presented:-

1- For tested specimen's strengthening with SFRC in tension, the increases in ultimate strength were (23% - 58%). Addition of steel fibers increased the cracking load by about (25%-62.5%). This enhancement is due to high aspect ratio, fiber length and adequate volume fraction of used fibers. Randomly distributed steel fibers in concrete increase its homogeneous and isotropic characteristics and improve tensile response prior to and beyond the first cracking.

2- Presence of SFRC in tension regions improves ductility of slab panel and this feature can improved the ability to absorb of larger impact and vibration loads, especially for deck slab panels of reinforced concrete bridges.

3-Presence of SFRC in tension regions increased the cracking load and as a result improves the stiffness of the tested slab panel, so, long service age can be reachable.

4-Traditional negative steel reinforcement (steel bars) can be eliminated by using SFRC in manufacturing of thin slabs panels.

5-When the crimped steel fibers employed, the ultimate strength and cracking load increased greater than the other types. This may be due to geometrical shape of crimped fiber which makes it extended through large surface area.

5-Notation and Abbreviations

f'_c = cylinder compressive strength of concrete;

f_{ct} = indirect tensile strength (splitting tensile strength);

f y = yield strength of steel;

Vf = steel fiber volume fraction;

Pu = ultimate load;

Pcr = cracking load;

(Pu)R = ultimate load of reference slab;

(Pcr)R = first cracking load of reference slab;

ϕ = diameter of reinforcement bar;

NSC = normal-strength concrete;

SFRC = steel fiber reinforced concrete

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