Strengthening the Region of Intermediate Support of Continuous Reinforced High-Strength Concrete Slabs with New Cement

Dr. Wissam Kadum Al-Saraj Dr.Nagham Tarq. H. Al-Shafi'I Dr. Leath A. Al-Jabri
College of Engineering, Al-Mustansireyah University , Baghdad, Iraq

Abstract
Concrete is being widely used as a construction material, hence it is necessary to improve its properties. These days supplementary cementecious materials are used for enhancement of concrete properties. Use of Nano materials is gaining importance due to its vital characteristics, these materials help in developing high performance concrete (Zhang Zenan, et al 2006).In this paper, the use of steel fibers instead of the reinforcement steel bars in the continuous nano-high strength concrete (NHSC) slab panel was experimentally investigated. Tests were carried out on three two-span slab panels under mid span point loads and simply supported at the panels end. The first slab was reinforced by steel bars to resist the negative moments near the internal supports while the other two slab panels were reinforced by steel fibers only of percentage of volume fraction (1 and 2.0) in this zone, without negative steel bars. 5% nano-SiO2 (NS) and 15% of silica fume (SF) contents were used. The load-deflection relationship for the tested slab spans is determined, the first crack load, failure load and deflections were recorded. Also a comparison between the results obtained from this study and that obtained from other study of two continuous slabs made of self compacted concrete (SCC) was made , one of these slabs was reinforced by steel bars near the interior supports and the other is reinforced by steel fibers of (1% and 2%) in this zone. Experimental results show that the ultimate load capacity are increased (15.4% - 32.9%) and the cracking loads are increased (40%-56%) for tested specimens strengthened with SFRC, in comparison with the reference specimens. The comparison between the NHSC slabs and corresponding SCC slabs shows a similar load-deflection curve but the ultimate strength capacity for the NHSC slabs with steel fiber gives ultimate strength larger than SCC slabs with steel fibers, while the NHSC slabs reinforced by steel bars which show an important effect on the first cracking loading in comparison with SCC slabs.
loading in comparison with CC slabs.
Keywords: key words, Nano, negative moment, Self-Compacting Concrete

1. Introduction

High strength concrete and mortar with high strength and durability properties offer many advantages. They have been gradually replacing normal strength concrete due to their improved mechanical characteristics and low permeability. With such outstanding characteristics they can be utilized in structure, exposed to severe loading or influenced by environmental conditions, for instance large bridges and offshore constructions (Serdar , et. al2008, ; Toutanji et. al.1998).

Silica fume has been widely used as a supplementary cementing material for producing high performance concrete. It is used to enhance the strength and durability of concrete. It has been reported that use of SF as a cement replacement increased sulfate and acid resistance and decreased chloride permeability of concrete. When SF is added to cement/concrete, it acts as a filler to fill the gaps between cement particles resulting in finer pore structure. Also more CSH gel can be formed in SF concrete due to the reaction that occurs between the silica in SF and the Ca(OH)2 in hydrating cement (pozzolanic reaction)(Dotto et al 2004 ;, Anderson et al 2000).

Recently with the help of advanced nanotechnology developments, nano-SiO2 with finer particles size and higher pozzolanic activity has been introduced. Studies have shown that incorporating nano-SiO2 into cement based materials improved mechanical properties of the products. Qing Ye (reported that nano-SiO2 improved the bond strength of paste-aggregate interface. Additional studies have also concluded that pozzolanic activity of nano-SiO2 was much greater than that of silica fume (Qing et al 2007). The abrasion resistance of concrete containing nano-SiO2 was studied by(Hui Li et al 2006). He suggested that nano-SiO2 was valuable for enhancing abrasion resistance of pavement. (Li Gengying2004) showed that nano-SiO2 added to high-volume fly ash high-strength concrete could improve short and long term strengths. Reported that nano-SiO2 particles could potentially improve the negative influences caused by sewage sludge ash (SSA) replacement mortar. It has been found that when nano-SiO2 particles are uniformly dispersed in cement paste they will accelerate cement hydration due to their high activity .

2. Experimental Program

The experimental program of this study consisting of preparation and testing of three slab panels, which are of (2000x250x50)mm dimensions for length, width and height, which is have symmetrically two span and subjected to point load at mid spans. The bottom reinforcement for positive moments is continuous for all panels while the reinforcing steel bars for negative moment are used only for one panel (reference) at mid support only. No shear reinforcement is needed. Steel fiber of ratios (1% and 2%) is used for the other panels for the same nano-high strength concrete (NHSC) mix and cross section dimensions. Figures 1 and 2 show the details of the slab panel.

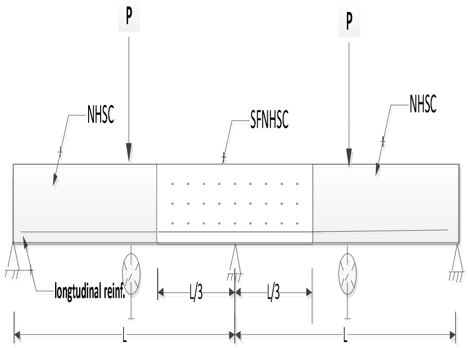


Figure 1. Slab Panel Setup

Figure 2. Slab Panel Details

Table 1. Identification of the Slab Panels

Slab Designation	**Reinforcement**	
	Positive	**Negative**
NHSC1	2 10mm Steel reinforcing bars at bottom	2 10mm Steel reinforcing bars at top of the interior supports
NHSC2		Straight Steel Fiber (1%)
NHSC3		Straight Steel Fiber (2%)

2.1 Materials and Mix Design

The cement used in this research was Tasloja ordinary Portland cement (ASTM Type I) manufactured in Iraq. Densified silica fume from Sika Materials Company in Baghdad has been used as a mineral admixture added to the mixtures. The used percentage is 15% of cement weight (as an addition, not as replacement of cement) for NHSC. nano-SiO2 particle with 5% content was used The chemical compositions of SF and nano-SiO2 Were listed in Tables 2 and 3. Figure 3 Show Fine silica sand known as glass sand is used for the NHSC mix. This type of sand is by- produced in Al- Ramadi Glass factory. The fineness modulus is 2.32. Al-Ukhaidher fine sand grading and limits of ASTM C33. The steel fiber manufactured by Bekaert Corporation was used in NHSC show Figure 3 mix with volume fraction (V_f) of 0%, 1% and 2%. The fiber hase the properties described in Table 4. In order to achieve the desire fluidity and better dispersion of nano particles, a polycarboxylate ether based superplastisizer was incorporated into all mixes.

Table 2. Composition and Properties of Silica Fume*

Composition (%) - property	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	Na2O	Blaine fineness (m^2/kg)
Silica fume	98.87	0.01	0.01	0.23	0.01	0.08	0.00	20000

*Manufacturer Properties.

Table 3. Basic material properties of nano-SiO_2

Item	Diameter (nm)	PH value	Composition (mass%)
Target	50	10	SiO2(30%) + H2O(70%)

Table 4. Properties of the Steel Fibers*

Description	length (mm)	diameter (mm)	density (kg/m3)	Tensile strength fu(MPa)	Aspect ratio
Straight fibers	13	0.216	7800	2600	65

Table 5. Properties of the Steel Bars in Tension*

Nominal Diameter mm	Bar Area mm^2	Yield Stress MPa	Yield Strain mm/mm	Ultimate Stress MPa	Modulus of Elasticity MPa
10	78.5	611	0.00305	710	200000

* Carried out at the College of Engineering, Al-Mustansereyah University

Figure. 3. Binding and Filling Materials used in NHSC

The superplasticizer used in the mix was Flocrete PC 260. The mix design of NHSC using local constituent is 1:1: 0.15 (cement: sand: silica fume) with water cement ratio 0.2 plus 2.0% by weight of binder (Cement + Silica Fume) of Flocrete PC 260 admixture.

In this study, deformed steel bars of (10) are used, Table 3 shows the full properties of these reinforcing bars.

All the constituents were batched by an electronic balance and mixed in a horizontal rotary mixer of 0.5 tone capacities.

In order to achieve the desired properties, it is essential to disperse nano particles uniformly. Accordingly, mixing was carried out in a rotary mixer .The nano-SiO2 particles were stirred with 90% of mixing water at high speed and for about 1 min. The Cement and SF were premixed for 30 s. Then dry mixed cement and SF. were added to the mixture. After adding, the mixer was allowed to run for 1min at medium speed.The sand was gradually added at 30s while the mixer was running at medium speed. .The superplastisizer and remaining water were added and stirred at high speed for 30s.For the SFNHSC mix the fibers were uniformly distributed into the mi slowly in 3 minute during mixing process,6 The mixture was allowed to rest for 90s. Then mixing was continued for 2 min at high speed.

All specimens were cast vertically in wood forms. The molds were cleaned and greased to allow smooth stripping. The fresh NHSC was compacted using external vibrators which were attached to the wood molds. Within one hour of casting, the specimens and test control samples were covered under plastic nylon until the day of demoulding. After stripping at age 1 days, the specimens were cured for 2 days at 80°C in a hot water bath as shown in Figure 4. At age 3 days the specimens were removed from the hot water bath and stored in water at 25°-30° C for 28 days then stored in the laboratory until the time of testing.

Figure 4. Heat curing of specimens

Table 6. Properties of Hardened NHSC.

mix	Fiber %	f'c (MPa)	fsp (MPa)	fr (MPa)
NHSC	0	102.4	4	4.3
	1%	134.6	14.1	15.4
	2%	137.3	17.3	19.0

2-2 Test Measurements and Instrumentation

Hydraulic universal testing machine (MFL system) has been used to test the slab specimens as well as the cylinders. Central deflection has been measured by means of (0.01mm) accuracy and (30mm) capacity dial gauges . They have been placed at mid span of each span panel.

2-3. Mechanical properties

The results of the material control tests are summarized in Table 6 the mean compressive strength (f'c) was determined from six 200 mm high by 100 mm diameter cylinders stressed under load control at a rate of 20 MPa per minute. The ends of the cylinders were ground flat. The tensile strength of the material was evaluated using split cylinder (Brazil) tests. The split cylinder tensile strength (fsp) was obtained from tests on six 200 mm high by 100 mm diameter cylinders loaded at 1.0 MPa per minute via a 10 mm wide loading strip. The two point flexural tension strength (fr) was obtained from 100 mm square prisms spanning 500 mm to find modulus of rupture (fr). As shown in Figure 5.

Figure 5. Compressive Strength (f'cf) , Tensile Strength (fsp) and Modulus of Rupture Tests

2-4 Test Procedure

The slab panels have been tested using a universal testing machine (MFL system) by applying monotonic loading up to the ultimate state. The slab spans rest on a simple support over effective spans of 950 mm and loaded with a single point load at midspans.

The slabs have been tested at ages of (28) days by placing them on the testing machine and adjusting so that the centerlines, supports, point loads and dial gauges were in the correct locations.

Loading has been applied slowly in successive increments, and the corresponding deflections were recorded with the observation of the crack developments until the slab failure.

3- Results and discussion

The obtained results from the experimental work are recorded to compare the failure loads of the slabs reinforced with negative reinforcement consist of steel reinforcing bars , (1%) and (2%) steel fibers. Also the load-deflection relationship for the tested slabs was drawn.

3-1 First Cracking Loading, Ultimate Strength and Failure modes

It was observed that the crack pattern in all NHSC slabs is similar in nature. Initially, hairline cracks were formed at the first crack load, then the increment of load caused the cracks to be greater and the slabs showed a tension flexural failure.

Table 7 shows the values of the first cracking loads, failure loads and mode of failure for the continuous nano-high strength concrete slabs tested in this paper and for the continuous self compacted concrete slabs of (Al-Saraj et. al. 2014).

Figure 6 shows the failure forms of tested NHSC slabs.

From Table 7, it is seen that when the steel fibers is used by ratio (1%) instead of the reinforcing steel bars for the NHSC specimens the first cracking load (Pcr) increases by (40%), while when this ratio increases to (2%) the value of Pcr increases by (56%) this is due to the ability of the steel fibers to reduce micro cracks and crack propagations, the use of (2%) steel fibers is more effective than the value of (1%).

It can be noticed that the value of Pcr in the SCC with reinforcing steel bars is less than the corresponding slab of NHSC by (38.9%), while the value of Pcr in the SCC with (1%) steel fibers is less than the corresponding slab of NHSC by (40%), the reason is the NHSC slab had fewer pores and better bond with reinforcement and it usually spalled in smaller pieces than SCC slabs.

Also Table 7 shows that the failure load of the NHSC slabs that uses steel fibers of (1%) increases by (15.4%) when using reinforcing steel bars, while the failure load increased greatly by (32.9%) when the steel fibers is (2%), the ultimate strength of the NHSC slabs with comparison with the corresponding SCC slabs is increases by (167.6%) and (118.8%) when the reinforcing steel bars and steel fibers (1%) in the negative moments near internal supports of the slab spans is used respectively.

Table 7.. Load - Deflection Characteristics and Modes of Failure of the Slabs.

Slab NO.	Thickness (mm)	Steel fiber% by vol.	$f'c$ (MPa)	First crack load (F.C.L) (kN)	Ultimate load (U.L) (kN)	Midspan deflection (mm)		Mode of failure
						first crack	ultimate load	
NHSC1	50	0	102.4	25	91	0.46	12.2	Tension
NHSC2	50	1	134.6	35	105	0.76	15.7	Tension
NHSC3	50	2	137.3	39	121	0.79	17.3	Tension
SCC1	50	0	29	18	34	---	---	Tension
SCC2	50	0.5	31.2	21	38	---	---	Tension
SCC3	50	1	33	25	48	---	---	Tension

Figure 6. Failure of NHSC without Steel Fibers and with Steel Fibers (1%)

3-2 Load-Deflection Relationships

Figure 7 shows the load-deflection relationship at the mid span of the right and left spans of the tested slabs, it is seen from these figures that the NHSC slab with reinforcing steel bars deflects with the increase of the load in the same manner of the NHSC slabs if steel fibers is used, the curve for the right and left span for a specified slab is approximately the same. It is seen that the load-deflection curves for (1%)VF NHSC in the right and left spans are identical. Figure 10 shows a comparison of the load-deflection curve of the three tested slabs for each span, it is clearly observed that the ultimate load capacity of the slab increases largely when replacing the reinforcing steel bars with (2%) steel fibers content due to the good tensile strength of the fiber reinforced NHSC, while there is no important effect on the deflection increment. It may be noted that the ultimate strength increases as the fiber content increases from (1 %to 2%).

Figures 8 to 9 show a comparison between the two tested NHSC slab spans (reinforcing steel bars and 1% steel fibers content) with the corresponding SCC slab spans, it is observed from these figures that the NHSC slabs and CC slabs have the same manner. Also it is noted that the ultimate strength of the NHSC slabs increases in comparison with the SCC slabs because of the good bond strength between the NHSC materials, it is very clear that the difference in the strength capacity between the SCC slabs and NHSC slabs reinforced by (1%) steel fibers is large and more important in addition that the deflection values in the NHSC slabs is less than the SCC slabs which leads to recommend to use NHSC with steel fibers in the continuous slabs in the negative moments zone.

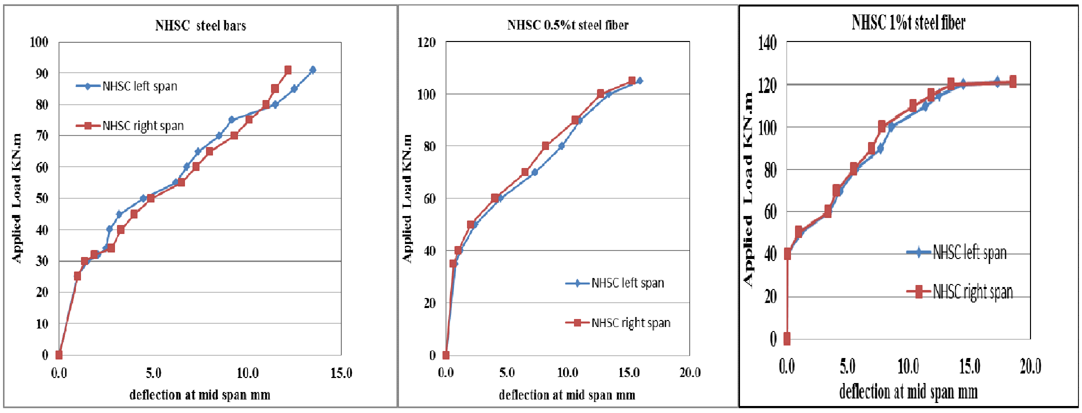


Figure 7. Load-Deflection Curve of the NHSC Slab

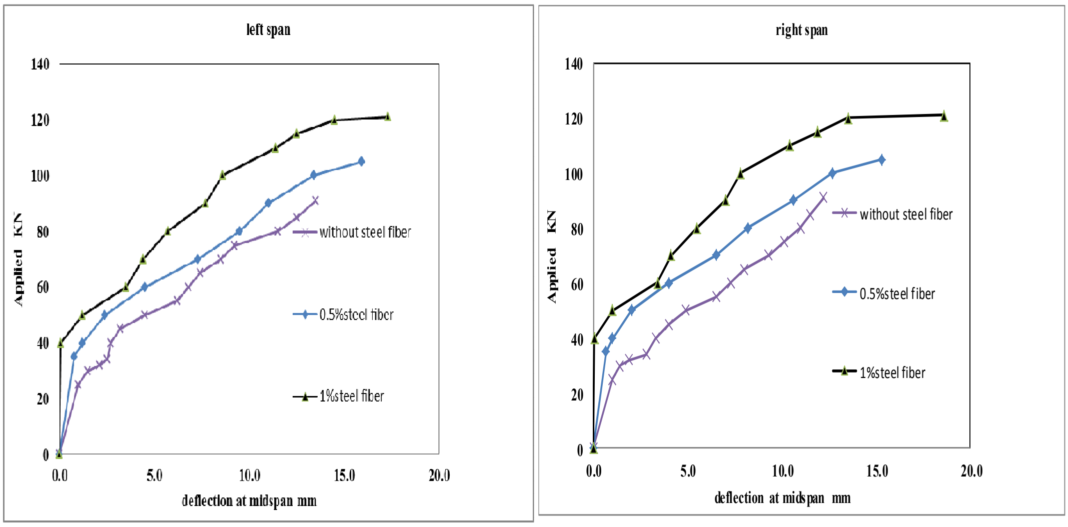
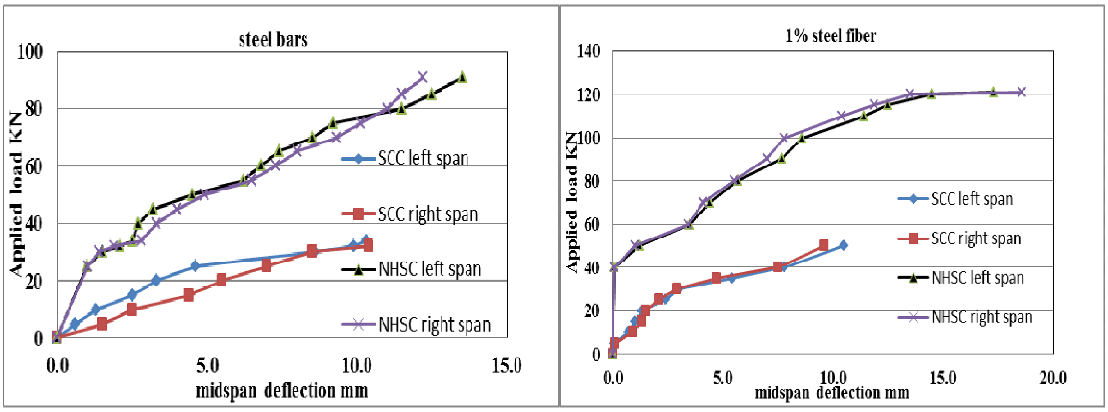


Figure 8. Comparison of Load-Deflection of the Right and left Span of Tested NHSC Slabs



(a) Steel Bar (b) 1% Fiber Reinforcement

Figure 9. Comparison of Load-Deflection of the CC and Tested NHSC Slabs

4. Conclusions

- Based on the results of the performed experiments on the design of NHSC mixes with steel fiber of volume fraction (1 and 2.0) and their effect on the mechanical properties, the following conclusions can be drawn:
- 1. The compressive and tensile splitting strengths of NHSC were improved by the addition of Steel fibers. The highest compressive strength and highest splitting tensile strength was found when used 2% of steel fiber in NHSC.
- Replacing reinforcing steel bars with steel fibers in the continuous NHSC slab panels at the interior supports increase the first cracking load from (25) to (35kN) if the steel fiber percentage of volume fraction is (1%) while it increases to (39kN) if the steel fiber percentage of volume fraction is (2%).
- For tested specimen's strengthening with steel fiber in tension, the increases in ultimate strength were (15.4% - 32.9%). Addition of steel fibers increased the cracking load by about (40%-56%). This enhancement is due 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.
- The load-deflection curves for the tested slab panels have the same manner, but when using steel fibers of percentage (2%) the deflection values are very small In comparison with the SCC slab panels, the load-deflection curves of the NHSC slab panels show the similar behavior of the SCC slabs.
- 6. When a comparison is made between the SCC slabs and NHSC slabs reinforced by steel bars in the negative moment zone, it is seen that the ultimate strength of the NHSC slab increases by (167.6%%) and the first cracking load increases by (118.8%).
- 7. Traditional negative steel reinforcement (steel bars) in NHSCcan be eliminated by using SFNHSC in manufacturing of thin slabs panels.

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