Journal of Asian Concrete Federation
Vol. 1, No. 1, pp. 22-27, Sep. 2015
ISSN 2465-7964 / eISSN 2465-7972
http://dx.doi.org/10.18702/acf.2015.09.1.22

Flexural performance evaluation of composite steel deck one-way slab system with SFRC

Geonho Hong*

(Received: February 27, 2015; Accepted: September 7, 2015; Published online: September 30, 2015)

Abstract: The slab is one of the most important members in building structures because it covers the largest area of the building. The structural type and construction method of a slab can have a large influence on the construction period and the amount of structural materials. This study investigates a simplified one-way slab system with simple construction procedures. The simplified slab system consists of a composite steel deck plate and steel fiber reinforced concrete (SFRC) without conventional steel reinforcing bars. The composite steel deck plate can replace the tensile reinforcing bars and concrete form, and the SFRC makes temperature reinforcement unnecessary. Four specimens were tested to analyze the flexural performance and serviceability. The test results were analyzed from the viewpoints of flexural performance regarding flexural load capacity, stiffness, deflection, crack development, and failure mode. The test results indicate that the overall flexural performance of the system was suitable in slab members, even though reinforcing bars were not used. It has higher flexural stiffness and shows lower crack height than a conventional RC slab.

Keywords: composite deck plate, SFRC, slab system, flexural performance.

1. Introduction

The slab is one of the most important parts in building structures because it covers the largest area of the building. The structural type and construction method of the slab can have a large influence on the construction period and the amount of structural materials. [1,2]This study investigated a simplified one-way slab system with simple construction procedures. The simplified slab system consists of a composite steel deck plate and steel fiber reinforced concrete (SFRC) without conventional steel reinforcing bars. Reinforcing bars are not needed in the slab construction procedure. In this system, the composite steel deck plate replaces the tensile reinforcement and eliminates the need for concrete forms and shores, which results in simpler construction. The steel fibers can replace the temperature reinforcement of slabs, and reduce cracks. [3]

2. Experimental program

2.1 Experimental plan

Four slab test specimens were planned, fabricated, and tested for their structural performance under flexure. The details of the test specimens are summarized in Table 1. The first specimen is a conventional RC slab with top and bottom reinforcing bars. The second one is also a conventional RC slab with SFRC rather than normal concrete to evaluate the effects of the steel fiber. The third one uses a composite steel deck plate that replaces the tensile reinforcement, along with welded wire fabric for temperature reinforcement. This kind of slab is often used in Korea in actual construction. The fourth specimen is the proposed slab system. It does not have any reinforcing bars, and has a composite steel deck plate and SFRC.

The thickness of all slab test specimens was 180 mm, and the concrete design compressive strength was 21 MPa. The width of the specimens was determined to be 1,200 mm so that two composite steel deck plates could be used side by side. For the SFRC of Specimens 2 and 4, a steel fiber content of 15.7kg/m^3 was used. This amount corresponds to about 50% of the weight of the temperature reinforcing bars provided in Korean Design Code. [4] Section details of all specimens are shown in Fig. 1.

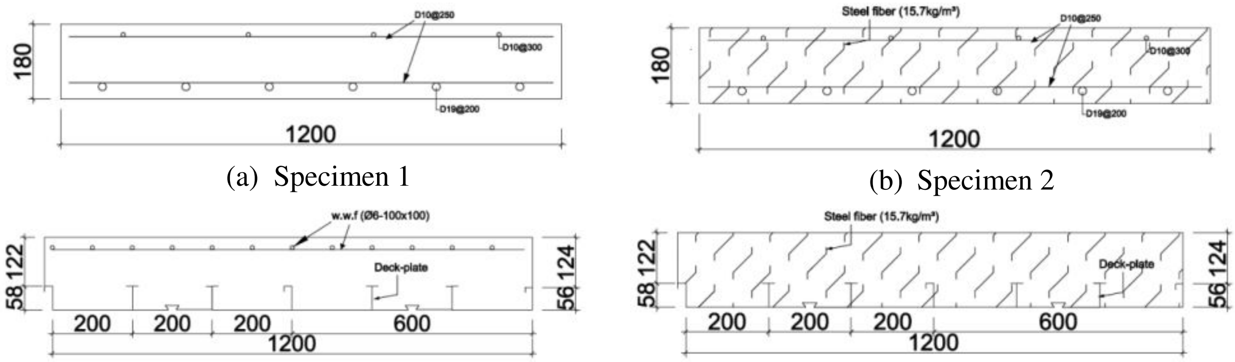
2.2 Test method

All slab test specimens were fabricated in a precast concrete manufacturing factory, and concrete was delivered from an adjacent ready

Geonho Hong is a Professor of Department of Architectural Engineering at Hoseo University, Korea.

Table 1 – Details of the slab test specimens

No.	Details	Tensile reinforcement	Compressive reinforcement	Steel fiber content
1	Conventional RC slab	D19@200	D10@300	--
2	Conventional RC slab + SFRC	D19@200	D10@300	15.7kg/m^3
3	Deck plate + normal concrete + w.w.f	1.0 mm thk. deck plate	Ø6-100X100	--
4	Deck plate + SFRC	1.0 mm thk. deck plate	--	15.7kg/m^3



(a) Specimen 1 (b) Specimen 2

(c) Specimen 3 (d) Specimen 4

Fig. 1 – Slab section details

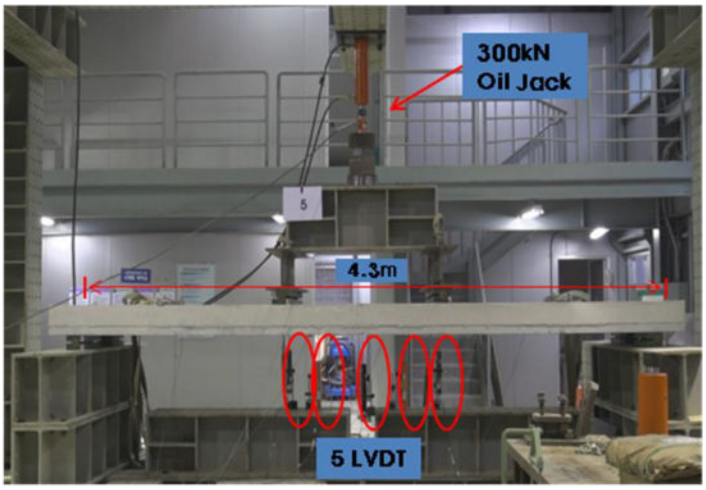


Fig. 2 – Test setup

mixed concrete plant. Steel fibers were mixed on site using a truck-mixer following the mix design shown in Table 1. Slab test specimens were set in a strong frame and four-point loading was conducted using a 300-kN hydraulic cylinder system in a strong frame, as shown in Fig. 2. The net span was 4.3 m, and there were two loading points 1.55 m away from each support. Deflections were measured using LVDTs at five locations, including the mid-span and loading points. Electronic strain gauges were installed on the reinforcing bars and steel deck plate to measure the strains during the test. Tests were carried out under load control up to the yield point, and then the test continued under displacement control with a rate of 5 mm/min after yielding of the reinforcing bar or steel deck plate. Cracking was visually monitored during tests. [5]

2.3 Materials

Φ100x200 mm concrete cylindrical specimens were cast and tested to determine the compressive strength. The cylinders were tested on the day of the flexural member test. SD400 reinforcing bars were used, and tensile tests were carried out to determine the actual yield and tensile strength.

The actual mechanical properties of the composite steel deck plate were not tested, but the minimum strengths required by KS D 3506[6] were used instead. Tables 2 and 3 present the section and mechanical properties of composite steel deck plate, respectively, and Table 4 summarizes the mix design of the concrete. The composite steel deck plate product was certified as fireproof by the Korean Government.

Table 2 – Section properties of steel deck plate

Thickness (mm)	Weight (kg/m^2)	Section property (1 m)		
		Area (mm^2)	Neutral axis (mm)	Moment of inertia (mm^4)
1.0	15.45	1,947	17.72	948,000

Table 3 – Mechanical properties of steel composite deck plate

Standard	Symbol	Mechanical Property		
		Yield strength (N/mm^2)	Tensile strength (N/mm^2)	Elongation (%)
KS D 3506	SGC400	295	400	18

Table 4 – Mix design of concrete, volume = 1 m^3

f_{ck} (MPa)	W/C (%)	Water (kg)	Cement (kg)	Aggregate (kg)	Admixture (kg)
21	56.1	179	308	1,771	1.6

3. Results and discussions

3.1 Flexural capacity

The flexural test results are summarized in Table 5. Because of low strength gain in the winter season, the concrete compressive strength was slightly low and had some variation at the time of flexural testing. All specimens were initially designed to have similar amounts of tensile reinforcements, but each specimen had different types of reinforcement areas and yield strengths. The actual amount of tensile reinforcements differed due to the increase of the actual yield strength of the steel reinforcing bars. The actual yield strengths of D10 and D19 were 510 MPa and 485 MPa, respectively.

Specimens 1 and 2 (the conventional reinforced concrete slabs, with normal concrete or SFRC) presented similar flexural performance, but specimen 2 had slightly higher flexural loading capacity and lower concrete compressive strength. This was due to the tensile strength increase in the SFRC. Specimens with a deck plate generally had lower flexural capacity than specimens with reinforcing bars. This was due to the actual yield strength of the tensile reinforcement. In general, reinforcing bars have about 20% margins in yield strength to assure the quality of the reinforcement, but normal steel plate to used make the deck plate generally does not have sufficient margins. [7]

Table 5 shows that specimens 1 and 2 present about 20% higher flexural capacity than specimens 3 and 4. Comparison between the analytical nominal strength by the Korean design code[4] and the test results indicates similar values except for specimen 4. The maximum flexural capacity of specimen 4 was 92% of its nominal flexural strength, due to the fluctuation of the concrete strength.

3.2 Stiffness and load-deflection behavior

The overall load-deflection relationship of the specimens is shown in Fig. 3, and the results of section analyses are shown in Fig. 4 and Table 6. In Fig. 3, the two groups of specimens show similar load-deflection curves. The first group (specimens 1 and 2) has very similar aspects in the load deflection curves except for the maximum load.

This indicates that the SFRC increases the flexural load capacity by about 2% but it does not affect other properties of the flexural performance. The second group (specimens 3 and 4) also shows similar aspects to the first group. This means that SFRC can fill the role of wire-mesh in the flexural performance.

In Table 6, the slabs with composite steel deck plate have 6~7% higher gross moment of inertia than the conventional RC slab, but the cracking moment of inertia of the slabs with the deck plate is more than 50% higher. This is due to the larger area of the steel deck plate because of the lower yield strength than reinforcing bars, as well as the location of the neutral axis.

The test results indicate that the second group (specimens 3 and 4) has a 6~28% higher initial slope ratio than specimen 1, but the tangential slope between the origin and yielding point show a slightly higher value in specimen 3. Overall, the slabs with the deck plate have higher stiffness than the conventional RC slabs with the same amount of steel reinforcing bars. Fig. 4 summarizes the relative section properties and a comparison of the test results.

Table 5 – Test results and comparison with analytical results

No.	Details	f_{ck} (MPa)	Steel			Equivalent stress block depth, a (mm)	Loading capacity		
			Area (mm²)	Yield strength (MPa)	Tensile force (kN)		Nominal strength (kN) ①	Test result (kN) ②	②/①
1	Conventional RC slab	20.5	1719	485	834	27.5	147.6	145.9	0.99
2	Conventional RC slab + SFRC	18.5	1719	485	834	30.4	146.1	148.2	1.01
3	Deck plate + normal concrete + w.w.f	19.9	2,336	295	689	29.4	130.2	128.1	0.98
4	Deck plate + SFRC	19.0	2,336	295	689	35.6	128.3	118.1	0.92

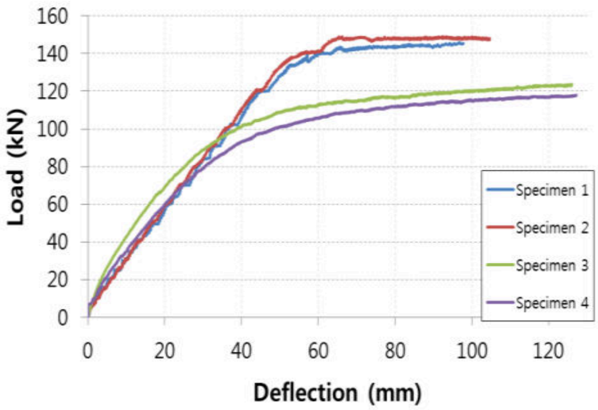


Fig. 3 – Load-deflection curve

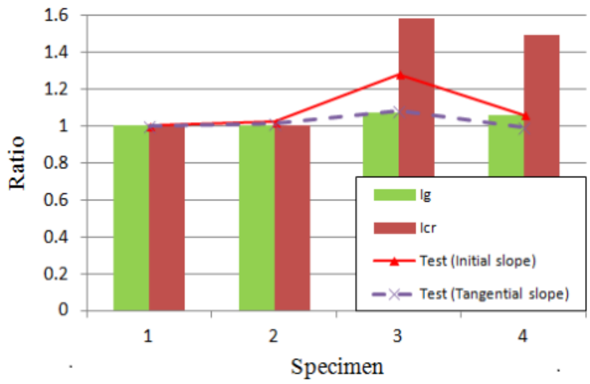


Fig. 4 – Section analyses

Table 6 – Results of section analyses

No.	Section properties					Test results		
	Neutral axis (mm)	Gross moment of inertia (mm⁴)	Ratio of I_g	Cracking moment of inertia (mm⁴)	Ratio of I_{cr}	Initial slope (kN/mm)	Relative ratio of initial slope	Tangential slope on yield point
1	32.3	$640*10^6$	1.00	$220*10^6$	1.00	3.09	1.00	2.34
2	35.8	$642*10^6$	1.00	$220*10^6$	1.00	3.14	1.02	2.36
3	34.6	$684*10^6$	1.07	$348*10^6$	1.58	3.97	1.28	2.53
4	41.8	$679*10^6$	1.06	$328*10^6$	1.49	3.26	1.06	2.32

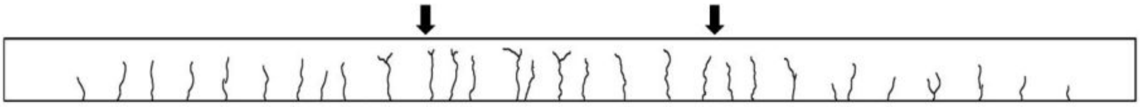
3.3 Crack development and failure mode

All slab test specimens failed in flexure. In specimen 1, typical flexural cracks developed in the middle portion of the slab up to the neutral axis located 32.3 mm from the top compression surface, and extensive cracking spread to the entire span. Specimen 2 also showed a similar mode of crack development, but the height of the middle span cracks was slightly lower than in specimen 1. Flexural cracks developed in specimens 3 and 4 reached a lower height than in specimens 1 and 2, as shown in Fig. 5 and 6. At the point of crack dispersion shown in the figures, the flexural cracks developed in the slabs with a composite steel deck plate were evenly spaced and concentrated between the loading points, but they did not spread over the entire span.

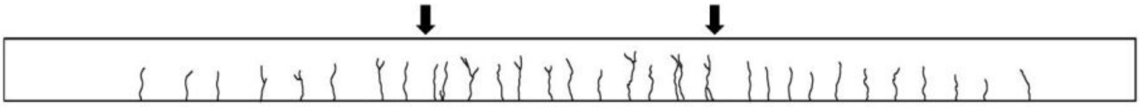
4. Conclusions

The conclusions from this experimental study are as follows:

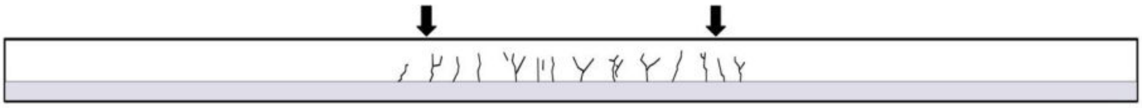
(1) Slab specimens with a composite deck plate show slightly lower flexural capacity compared with its nominal strength, but the overall flexural performance is suitable in slab members, eventhough reinforcing bars are not used. The steel fiber reinforced concrete increased the flexural loading capacity in the comparison with the two conventional slab specimens.



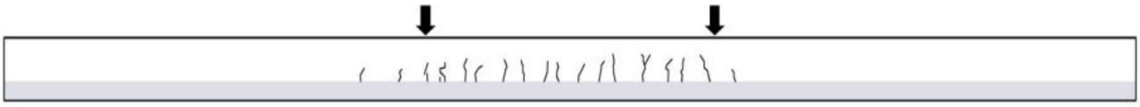
(a) Specimen 1 (RC)



(b) Specimen 2 (SFRC)



(c) Specimen 3 (Deck plate)



(d) Specimen 4 (Deck plate + SFRC)

Fig. 5 – Schematic drawings of crack development

(a) Specimen 1 (RC)

(b) Specimen 2 (SFRC)

(c) Specimen 3 (Deck plate)

(d) Specimen 4 (Deck plate + SFRC)

Fig. 6 – Crack development and failure mode

(2) Slab specimens with the composite deck plate have higher stiffness than the conventional RC slabs with the same amount of steel reinforcing bars. This is due to the larger area of the steel deck plate and the location of neutral axis.

(3) Flexural cracks developed in slab specimens with the composite deck plate reached a lower height than in conventional RC slab specimens. They were evenly spaced and concentrated between the loading points but did not spread over the entire span.

Acknowledgement

This work was supported by the National Research Foundation of Korea(NRF) Grant funded by the Korean Government(MOE) - No. 2013R1A1A4A01009276.

References

1. Sim, H.; Yang, G.; Lee, E.; and Chung, H. (2004) "The experimental study of flexural behaviour of continuous composite slab reinforced with structural steel deck plate," Proceedings of Architectural Institute of Korea, Korea (*in Korean*)
2. Lee, S.; and Lee, Y. (2007) "An evaluation of

structural safety for steel wire-integrated deck plate system," Journal of the Architectural Institute of Korea, 23(11), pp. 43-50.
3. Architectural Institute of Korea (2007) A study on the design of steel fiber reinforced concrete slabs on grade. AIK, Korea.
4. Korea Concrete Institute (2012) Design code for reinforced concrete structures. Ministry of Land, Infrastructure and Transport, Korea.
5. Hwang, H.; Hong, G.; Park, H.; Kim, Y.; and Kim, J. (2010) "Effects of shore stiffness and concrete cracking on slab construction load 2: Measurements and comparisons," Journal of the Korea Concrete Institute, 22(1), pp. 51-58.
6. Korean Agency for Technology and Standards (2013) KS D 3506 – Hot-Dip Zinc-coated steel sheets and coils, KATS, Korea.
7. Korea Concrete Institute (2009) Research report on development of high strength steel reinforcing bars. Ministry of Commerce, Industry and Energy, Korea.