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Load-deflection behaviour of hybrid concrete flat slab

Key words: load-deflection behaviour, normal strength concrete, high strength concrete, hybrid concrete, flat slab

Introduction

Strengthening structural members based on layers of several concrete types to produce hybrid concrete gets more interest by researchers in recent years (Kang, Hong & Kwon, 2017; Moon, Reda Taha & Kim, 2017). Hybrid concrete, in addition to the normal strength concrete, may include fibrous concrete, high strength concrete, ultra high performance concrete or any concrete types have special characteristics (Annadurai & Ravichandran, 2016; Kang et al., 2017; Moon et al., 2017). High strength concrete gets more significant role when it needed to be used within the structural systems that have certain properties such as light weight parts, special architectural requirements or economic considerations (Annadurai & Ravichandran, 2016). For instance, reducing the depth of concrete in tension zone of beams, by the replacement of normal strength concrete by high strength concrete, could produce smaller and lighter structural members with better performance (Aziz, Al-Nu'man & Husain, 2006). Also, structural members exposed to severe ambient conditions require satisfying certain design criteria represented by using of high strength concrete. Even if the cost of using high strength concrete in such structures is relatively high, but it serve significantly in this case (Hassan, 2015). This technology leads to the optimal use of the structural system based on its constructional target (Delef, Jarallah & Salman, 2013; Abtan & Jaber, 2016) studied the shear behaviour of hybrid concrete beams using two layer of concrete: self-compacting concrete layer in compression zone and normal concrete layer in tension zone by using 15 models. The experimental data explained the hybrid concrete beams failed in shear failure in analogous behaviour compared to the control beam but increased in cracking shear loads and ultimate loads capacity (Sarsam & Mohammed, 2014) investigated the flexural behaviour for

24 specimens of reinforced concrete beams, of which 16 as hybrid concrete beams containing two type of concrete (CC and RPC). RPC is used once in the compression zone and again in the zone of tension. The results obtained from experimental tests revealed that there was an increase in the flexural ultimate load when increasing the thickness of the RPC layer (h_R / h), the ratio of the volume of steel fiber and the ratio of longitudinal reinforcement for the hybrid beams in both tension and compression zone (Suha & Haitham, 2017) examined the shear behaviour for 12 models of the reinforced concrete beams using two type of high strength of concrete (HSC) by using additives (GL51 and SP100) into four group, of which two group each one containing three hybrid beams. The results obtained from hybrid concrete beams tests indicated an increase in shear load about (10.28–42.30%) in comparison with normal concrete in compression zone (Al-Jaberi, Abbas & Jaffar, 2016) investigated punching shear behaviour of five concrete flat slab using three type of concrete (NSC, LWC and RPC) in two set. The first set consists of two flat slabs fully with one type of concrete; NSC and LWC without any ratio of volume of the steel fiber as control flat slab, while the other set consist of three flat slabs as hybrid flat slabs of two types of concrete LWC and HSC with different ratio of steel fiber. The experimental work showed that the load-deflection behaviour for all flat slab examined behaves initially in linear and then non-linearly until failure. In hybrid concrete flat slabs, the increasing the value of steel fiber over (V_f = 0.5%) cause to sudden failure in the LWC zone in the hybrid flat slabs. The present work is deals with load-deflection behaviour of hybrid concrete flat slabs made with two type of concrete in the same slab (NSC and HSC).

Experimental work

Experimental program

Eight flat slab specimens with 1,000 × 1,000 × 120 mm dimensions have been tested, two of which were made fully with one type of concrete; NSC and HSC as a control flat slab, while, the other six specimens were made as hybrid flat slabs including two types of concrete (both of NSC and HSC). Concrete mixture HSC was used in tension zone in three hybrid flat slab specimens and also in compression zone in other three speci-

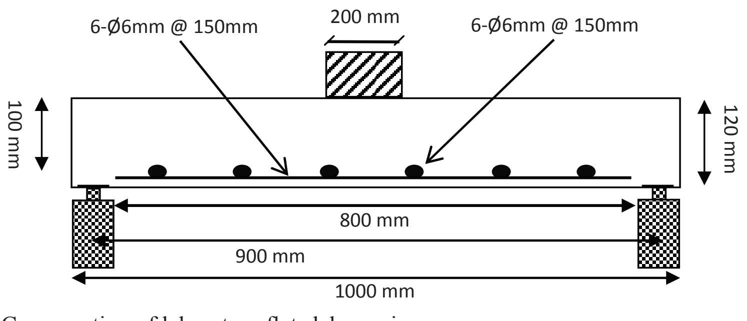


FIGURE 1. Cross section of laboratory flat slab specimens

mens. All flat slab specimens were simply supported along the edges with effective length (900 mm) and subjected to single point load applied vertically at the center of the top face of flat slab. The vertical single point load was transformed from testing machine through a rigid box steel of dimensions (200 × 200 × 150 mm). Figure 1 shows the details, dimensions and flat slab reinforcement.

Specimens description

In this study, the flat slab specimens have been divided into three groups according to type of concrete. The first group consists of two flat slabs fully with one type of concrete; NSC and HSC as control flat slab. The second and third groups consist of six flat slabs as hybrid flat slabs of two layer of concrete with different thicknesses. Concrete mixture HSC was used in tension zone in three hybrid flat slabs (second group) with three thicknesses (30, 60, 90 mm), while the remaining three hybrid flat slabs (third group) was used the HSC in compression zone with the same previous thicknesses as shown in Table 1 and Figure 2.

Concrete mixes and steel bar reinforcement

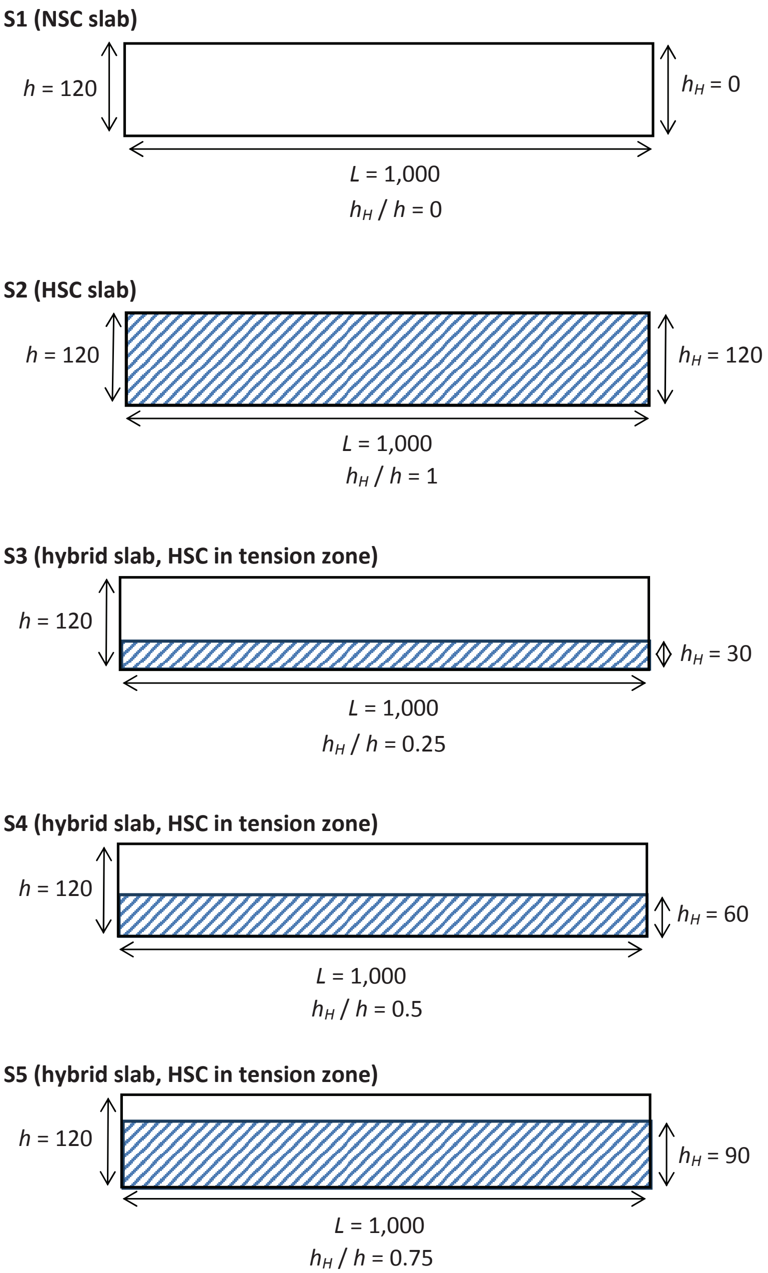
Concrete mixture NSC was prepared using ordinary Portland cement based on the ratio of 1 : 2 : 3.43, cement, sand and gravel, respectively with water cement ratio (w/c) equal to 43%, while the ratio was 1 : 1.5 : 2 for the HSC with water cement ratio (w/c) equal to 30%. For both mixes, a super plasticizer (CP555) was used as an admixture (5 $l \cdot m^{-2}$). These mixes have given an average ultimate compressive strength of (fcu = = 32.84 MPa) for NSC at 28 days and (fcu = 52.38 MPa) for HSC as shown in Table 2. However, all specimens of slab panels were reinforced using deformed steel bars of 6mm diameter at 150 mm spacing center to center satisfying the American code ACI-318 requirements based on the model dimensions (ACI, 2014) as shown in Figure 1.

Test measurements and instrumentation

Inside the laboratory of Faculty of Engineering at the University of Kufa, flat slab specimens were cured during

TABLE 1. Details of the tested flat slab specimens

Group	Specimens	h_H [mm]	h_H / h	Type of specimens
First	S1	0	0	NSC slab (control slab)
	S2	120	1	HSC slab (control slab)
Second	S3	30	0.25	hybrid slab (HSC in tension zone)
	S4	60	0.5	hybrid slab (HSC in tension zone)
	S5	90	0.75	hybrid slab (HSC in tension zone)
Third	S6	30	0.25	hybrid slab (HSC in compression zone)
	S7	60	0.5	hybrid slab (HSC in compression zone)
	S8	90	0.75	hybrid slab (HSC in compression zone)


S1 (NSC slab)
h = 120
h_H = 0
L = 1,000
h_H / h = 0
S2 (HSC slab)
h = 120
h_H = 120
L = 1,000
h_H / h = 1
S3 (hybrid slab, HSC in tension zone)
h = 120
h_H = 30
L = 1,000
h_H / h = 0.25
S4 (hybrid slab, HSC in tension zone)
h = 120
h_H = 60
L = 1,000
h_H / h = 0.5
S5 (hybrid slab, HSC in tension zone)
h = 120
h_H = 90
L = 1,000
h_H / h = 0.75

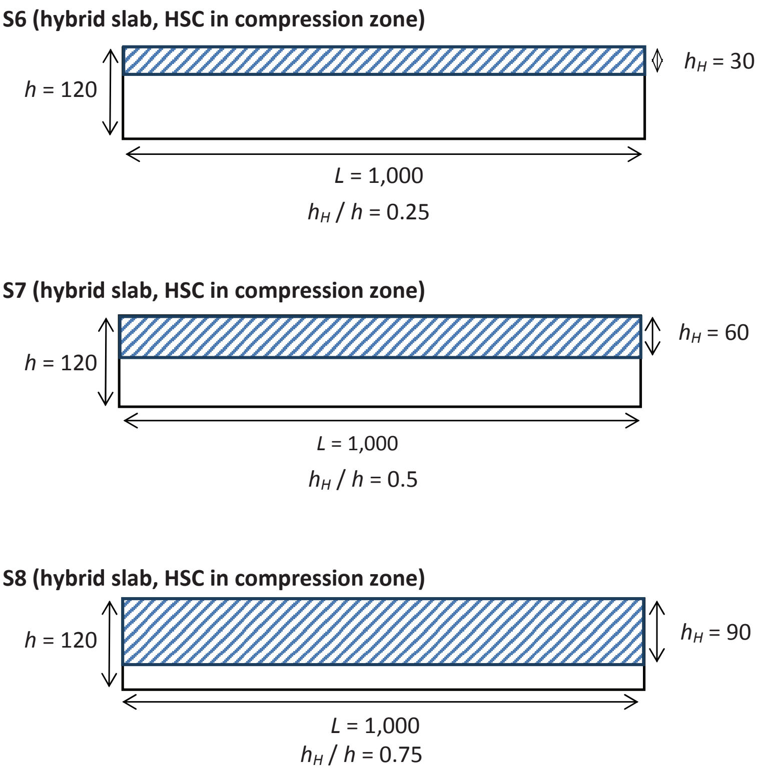


FIGURE 2. Type of the tested flat slab specimens (all dimensions are in mm)

TABLE 2. Mix proportions of NSC and HSC

Specification	Concrete type	
	NSC	HSC
Cement [kg·m^{-3}]	350	500
Sand [kg·m^{-3}]	700	750
Gravel [kg·m^{-3}]	1 200	1 000
Water [kg·m^{-3}]	150	150
Super plasticizer – CP555 [l·m^{-3}]	5	5
Ultimate compressive strength – *fcu* [MPa]	32.84	52.38

28 days and then tested using 1,000 kN capacity tested machine within the loading increment rate of 5 kN. The applied load was subjected as a point load on the center of the upper face of the flat slab while under the lower face the dial gage (ELE type) with (50 mm) capacity was installed to measure the deflection at each 5 kN stage of loading as shown in Figure 3.

FIGURE 3. Flat slab setup

Results and discussion

Cracking loads and crack patterns

The initial cracking (flexural cracking) of flat slab was observed in the form of a straight line in tension zone in the middle of slabs, approximately 25 and 35 kN for specimens S1 and S2 respectively. While the first flexural cracks were at value between 25.5 and 28 kN for second group (hybrid slab, HSC in tension zone) and for third group (hybrid slab, HSC in compression zone) were between 27 and 33 kN). After load increases, the flexural cracks have been observed in different directions toward the edges of flat slabs. With increasing loads, the thickness of cracks increases, eventually causing the final failure (flexural failure for slab). The percentage increase in initial cracking loads due to the use HSC in hybrid flat slabs relative to the NSC slab was noted between 2 and 40%. Figure 4 and Table 3 show first cracking loads and crack patterns.

Ultimate load and deflection capacity

The ultimate loads and deflections of the flat slabs examined are shown in Table 3. It was noted that the ultimate load increased about (19.4%) when HSC was used fully ($h_H / h = 1$) in flat slab (S2) instead of using NSC in the control flat slab (S1), while the increase in the ultimate deflection was 28.13%. In general, the load-deflection behaviour before initial--cracking stage was much closed when used HSC in all flat slabs tested as compared to control flat slab (S1) as shown in Figures 5, 6 and 7. However, when the

a b

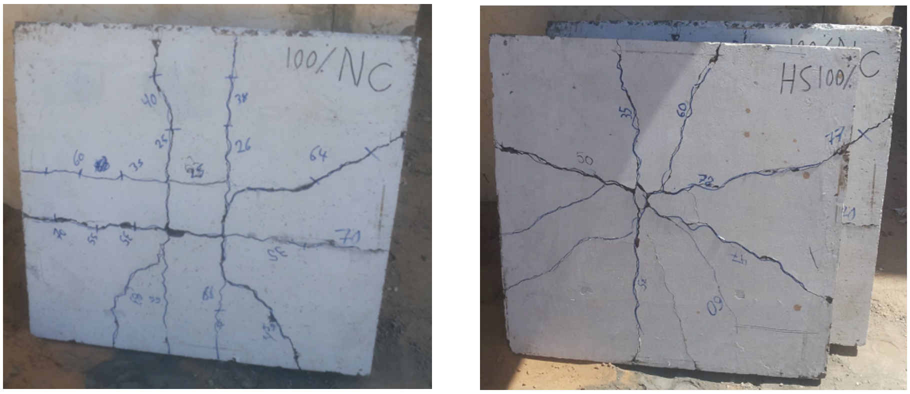


FIGURE 4. Crack patterns for control slabs S1 (a) and S2 (b)

TABLE 3. Cracking and ultimate loads and deflection of the tested flat slabs

Group	Specimens	P_C	P_U	Δ_U	P_C / P_U%	P_U / P_U(S1)%
First	S1	25	72	12.3	34.7	–
	S2	35	86	15.76	40.7	1.194
Second	S3	25.5	76	12.7	33.6	1.056
	S4	27	78	13.2	33.8	1.083
	S5	28	80	13.6	35	1.111
Third	S6	27	79.5	13.4	33.8	1.104
	S7	29	82	14.1	35.4	1.139
	S8	33	84	14.9	39.3	1.167

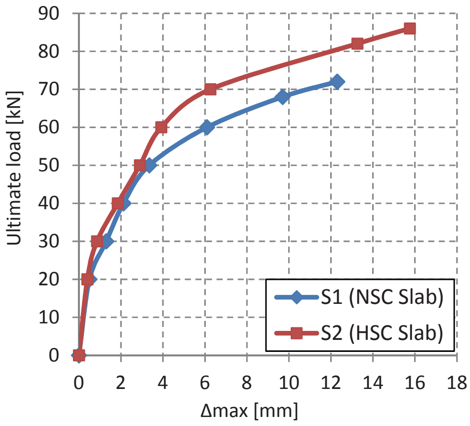


FIGURE 5. Load-deflection curve first group (S1 and S2)

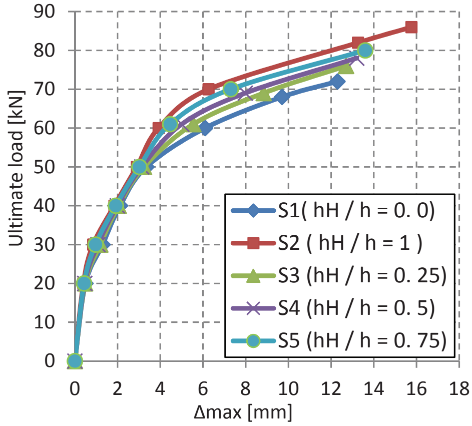


FIGURE 6. Load-deflection curve second group (hybrid slab)

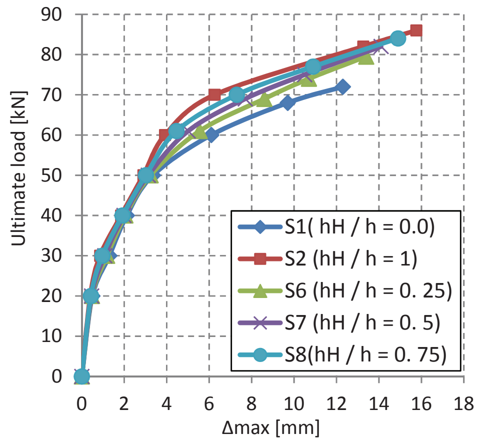


FIGURE 7. Load-deflection curve third group (hybrid slab)

loads are increased in the post-cracking stage, it was observed that the load-deflection behaviour was stiffer when HSC was used fully in flat slab (S2) or in hybrid flat slabs (second and third group) compared to control flat slab (S1).

Effect of HSC in tension and compression zone

The results showed that the ultimate loads increases with the increase of thickness of HSC layer as a proportion of thickness of HSC layer to the depth of flat slab (h_H / h). Hybrid flat slab with HSC in compression zone show higher ultimate loads compared with those of the hybrid flat slab with HSC in tension zone and also were more stiff with the hybrid flat slab with HSC in tension zone as shown in Figures 6, 7, 8 and 9. The ultimate loads for the hybrid flat slab with HSC in tension zone (second group) were 5.6, 8.3, 11.1 and 19.4% higher than those of control flat slab (S1) for (h_H / h) of 0.25, 0.50, 0.75 and 1 (HSC in tension zone) respectively as shown in Figure 10. While the ultimate loads for the hybrid flat slab with HSC in compression zone (third group) were 10.4, 13.9, 16.7 and 19.4% higher than those of control flat slab (S1) for (h_H / h) of 0.25, 0.50, 0.75 and 1 (HSC in compression zone) respectively as shown in Figure 11.

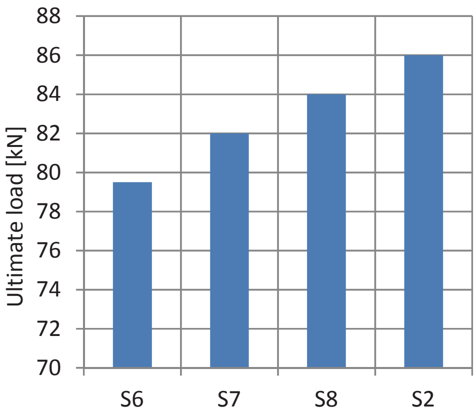


FIGURE 8. Ultimate load capacity for second group (hybrid flat slab, HSC in compression zone)

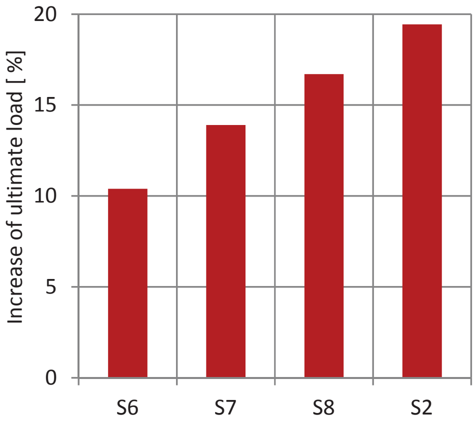


FIGURE 10. Increase of ultimate load for second group (hybrid flat slab, HSC in compression zone)

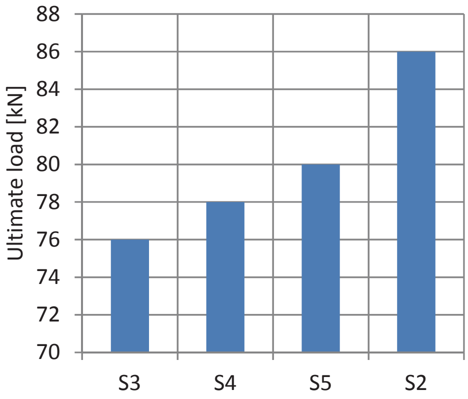


FIGURE 9. Ultimate load capacity for third group (hybrid flat slab, HSC in tension zone)

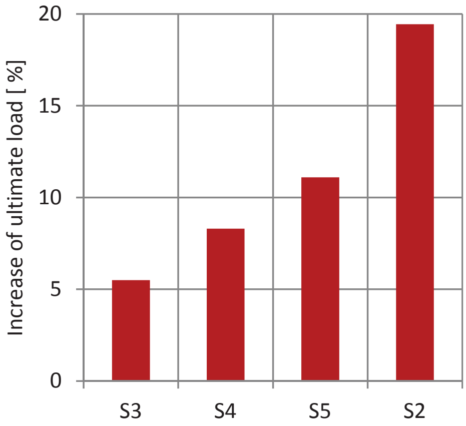


FIGURE 11. Increase of ultimate load for third group (hybrid flat slab, HSC in tension zone)

Conclusions

Depending on the experimental results of the eight flat slabs was made from NSC, HSC and hybrid flat slabs, the several conclusions have been identified:

1–2. The percentage increase in initial flexural cracking loads due to the use HSC in hybrid flat slabs relative to the control slab (NSC slab) was noted between 2 and 40%.

3. It was observed that the ultimate load increased about (19.4%) when HSC was used fully ($h_H / h = 1$) in the control flat slab (S2) instead of NSC in the control flat slab (S1).

4. It was noted that the load-deflection behaviour was stiffer in post-cracking stage when HSC was used fully in the control flat slab (S2) or in the hybrid flat slabs (second and third group) compared to control flat slab (S1).

5. Hybrid flat slabs with HSC in compression zone show higher ultimate loads compared with those of the hybrid flat slabs with HSC in tension zone and also were stiffer in load--deflection curve with the hybrid flat slabs with HSC in tension zone.

6. The ultimate loads for the hybrid flat slab with HSC in tension zone (second group) were 5.6, 8.3 and 11.1% higher than those of control flat slab (S1) for (h_H / h) of 0.25, 0.50 and 0.75 (HSC in tension zone) respectively.

7. The ultimate loads for the hybrid flat slab with HSC in compression zone (third group) were 10.4, 13.9 and 16.7% higher than those of control flat slab (S1) for (h_H / h) of 0.25, 0.50 and 0.75 (HSC in compression zone) respectively.

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Summary

Load-deflection behaviour of hybrid concrete flat slab. Due to the important role of high strength concrete in the structural systems, present work focuses on the use of this material as a strengthening technique incorporating with the normal strength concrete in flat slab system. Eight simply supported flat slab models with (1,000 × 1,000 × 120 mm) dimensions are investigated based on three groups including normal strength concrete and high strength concrete. The first group represents models containing of two flat slabs fully with one type of concrete; NSC and HSC as control flat slab. The second and third groups consist of six flat slabs as hybrid flat slabs of two layer of concrete with different thicknesses. Concrete mixture HSC was used in tension zone in three hybrid flat slabs (second group) with three thicknesses (30, 60 and 90 mm), while the remaining three hybrid flat slabs (third group) was used the HSC in compression zone with the same previous thicknesses. The experimental results shown that the ultimate load increased about (19.4%) when HSC was used fully ($h_H / h = 1$) instead of using NSC in the control flat slab (NSC slab). The hybrid flat slabs with use HSC in compression zone showed higher in cracking and ultimate flexural loads compared with those of the hybrid flat slabs with use HSC in tension zone and also were stiffer in load-deflection curve with the hybrid flat slabs with HSC in tension zone, also the hybrid flat slabs showed an improvement in the cracking load and ultimate flexural load when increasing the thickness of the HSC layer (h_H / h) in both tension and compression zone as compared to control flat slab (NSC slab).

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