Effect of shear connectors and interface roughness on the behavior of one way composite pre-slabs

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Abstract—The behavior of one way composite pre-slabs were studied. An experimental program was carried out to test nine simply supported slabs, one of them was reference monolithic slab and the remaining eight slabs were composite pre-slabs composed of two concrete layers. The composite pre-slabs were divided into three groups to investigate the effect of shear connectors length and ratio, and interface roughness on the behavior of pre-slabs. Also a theoretical analysis was carried out to confirm the experimental program. It was concluded from these experiments that increasing of shear connectors length or ratio led to increase horizontal shear capacity. Also, the interface roughness had a pronounced effect on the horizontal shear capacity of the composite pre-slab.

Keywords— Concrete, Shear Connectors, Pre-slabs, shear transfer, Interface roughness

I.   Introduction

Previous research and observations of the horizontal shear capacity of composite concrete sections have been conducted since the 1950s. There were several experimental programs performed to determine the horizontal shear stress of a composite section's interface (3). Composite sections are the use of two or many dissimilar or similar materials in one section, which are working together as a one unit. Concrete–concrete composite flexural members are widely used in buildings and bridges construction as well as strengthening (4). The common types of the composite concrete-concrete sections are composite slabs with either deck floor or prefabricated beams (1). The transfer of shear across the interface plane between the old and new concrete layers is called "shear transfer" to distinguish this type of shearing action from that which usually occurs in reinforced concrete beams (1). Most of the recent codes of practice permit design of composite flexural member as monolithic one provided that its composite interface has enough shear transfer capacity. The increase of composite interface roughness and the use of steel ties, shear keys or adhesive materials, improve the shear transfer capacity and thus insure the full composite action (4).

II.   Experimental work

Experimental program was carried out to test nine simply supported slabs, one of them was reference monolithic slab and the remaining eight slabs were composite pre-slabs composed of two concrete layers. The composite pre-slabs were divided into three groups to investigate the effect of shear connectors length and ratio, and interface roughness on the behavior of pre-slabs ; all slabs were supported on

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two edge supports to represent the case of one way simply supported slabs. Each composite slab consists of two concrete layers; the first layer was slab with dimensions 106 *80*5 cm. with main bottom reinforcement of 10 Φ12 mm. and secondary reinforcement of 6 Φ 6 mm. The second layer had the same dimensions as the first layer 106 *80 *5 cm without reinforcement, as shown in figure (1).

Figure (1a): Pre-slab before casting the second layer.

All slabs are of total thickness of 10 cm and were tested under the case of uniformly distributed loads and had a uniform dowels distribution, but they had a different dowels length and ratio as shown in table (1).

TABLE 1. Tested Specimens

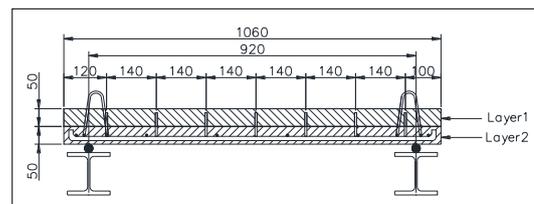| Specimens with shear connectors			Specimens without shear connectors	
Specimen	Dowels ratio	Dowels length	Specimen	Interface
S2	0.1%	15Φ	S1 (monolithic)	------
S3	0.1%	10Φ	S6	As cast with Epoxy
S4	0.1%	6Φ	S7	Rough
S5	0.1%	4Φ		
S8	0.06%	6Φ		
S9	0.15%	6Φ		

Figure (1b): Arrangement of shear dowels for pre-slabs S2-S5.

The concrete compressive strength of tested slabs are shown in table (2).

TABLE 2. Compressive Strength of Tested Specimens at Testing Time.

Specimen	Fcu (first layer) kg/cm²	Fcu (second layer) kg/cm²	Notes
S1	476.7		Monolithic slabs
S2	480.7	470.5	Composite pre-slabs
S3	475	474.1	
S4	475	474.1	
S5	470.5	461.8	
S6	472.7	466.5	
S7	463.3	461.3	
S8	465	478.5	
S9	460	470	

The above results were the average of testing 3 standards concrete cubes.

III. *Test Set-up and Loading Arrangement:*

The specimens were tested under the effect of uniform distributed load through a whiffed tree arrangement. All slabs were supported on two edge supports to represent the case of one way simply supported pre-slab and the loads were applied by a hydraulic jack, the loading was increased by an increment equal to 2 ton as shown in figure (2).

Figure (2): Loading set-up.

IV. *Measurements:*

Different types of measurements were used during testing such as:

A. *Loads :*

The vertical loads were applied by a hydraulic jack and measured by a load Cell; the hydraulic jack and the load cell were calibrated before testing.

B. *Concrete Strain:*

Small steel plugs were used as a gage points for measuring concrete strain during test; they were fixed in their positions at the bottom surface of the slabs by means of an adhesive material as shown in figure (3).

A demic mechanical strain gage of 20 cm. length was used to measure the concrete strain.
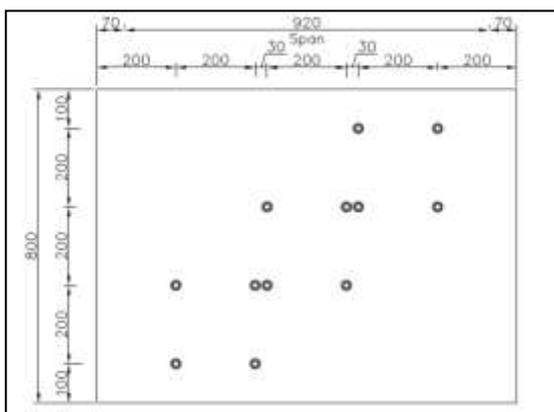

Figure (3): Demic points under uniformly distributed load.

C. *Deflection:*

Three LVDT with high accuracy were used for vertical deflection measurements. They were fixed at the bottom surface of the slabs as shown in figure (4).

Figure (4): Vertical deflection.

D. *Slippage:*

A horizontal dial gage with 0.01 mm. accuracy was fixed at the end of the pre-slabs to measure the slippage between the two concrete layers as shown in figure (5).

Figure (5): Horizontal dial gauges for slippage measurements.

V. *Discussion of experimental Results:*

Test results discussed here include mode of failure, cracking pattern, cracking and ultimate loads, maximum induced slippage, maximum deflection, deflection pattern, shear transfer along the interface and strains in both concrete and shear dowels.

A. *Crack Pattern and Mode of Failure:*

The initiation and pattern of cracks of the tested slabs can be explained as follows:

- ### *Monolithic Slab (S1):*

This slab subjected to uniformly distributed loads. The first crack was observed at a load of 9.0 ton on the bottom surface at the section of maximum moment (nearly to the middle of the span). After this load level, another bottom cracks appeared as the increasing of load as shown in figure (6).
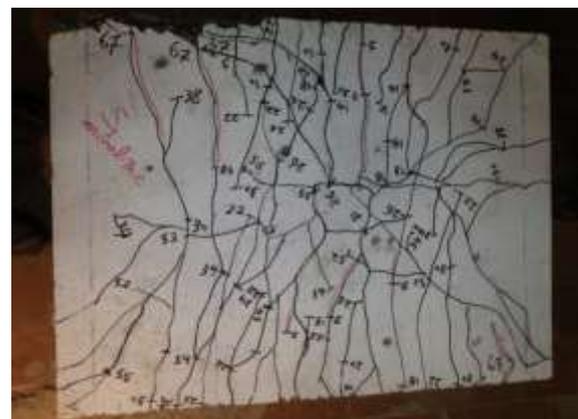

Figure (6): Crack pattern of slab S1.

The diagonal shear crack started to appear at load of 46.0 ton, it was near the support. Increasing the load after the diagonal shear crack appeared led to increase in the diagonal shear crack width and initiation of new shear cracks between the two main diagonal shear cracks till the specimen had a complete shear failure at load of 67.0 ton as shown in figure (7).

Figure(7): Shear failure of slab S1.

• Composite Slabs (S2-S9):

These slabs subjected to uniformly distributed loads. The first crack was observed on the bottom surface at the section of maximum moment i.e. nearly to the middle of the span .After cracking load level, another bottom cracks appeared as the increasing of load as shown in figure (8).

Figure(8): Crack pattern of slab S2.

The diagonal shear crack started to appear as the increasing of load, it was near the support. Increasing the load after the diagonal shear crack appeared led to increase in the diagonal shear crack width and initiation of new shear cracks between the two main diagonal shear cracks till the specimen had a complete shear failure as shown in figure (9).

Figure (9): Shear failure of slab S2.

B. *Cracking Load:*

Table (3) shows the values of the cracking load for both monolithic and composite slabs. As the loading type was uniform, the first crack occurred at the bottom surface nearly to the mid span of the specimens at section of maximum bending moment.

From table (3), for monolithic and composite slabs it can be noticed that:

- Increasing the shear connectors length led to increase the cracking load because of the improvement of the composite action.
- Increasing the shear connectors area led to increase the cracking load because it led to a large dowels area at the section of maximum moment.
- Using epoxy between the two concrete layers led to a decrease in the cracking load compared with roughened pre-slab.

C. *Ultimate Load:*

Table (3) shows the values of the ultimate load for both monolithic and composite pre-slabs. As the loading type was uniform for all slabs, it can be noticed that:

- For group (1), the ultimate load of composite pre-slab increases as the shear connectors length increase. The ultimate load of pre-slab S5 with shear connectors length equal to 4Ø was about 58% of the monolithic slab S1, and this ratio increased to reach about 97% in pre-slab S2 with shear connectors length equal to 15Ø.
- For group (2), the ultimate load for the pre-slab S6 "which Epoxy was used at the interface area" was about 67.0% of monolithic slab S1, while the ultimate load for the pre-slab S7 "which the only roughening was used at the interface area" was about 61.0% of monolithic slab S1.
- For group (3), the ultimate load of composite pre-slab increases as the shear connectors ratio increase. The ultimate load of pre-slab S8 with shear connectors area equal to 0.06% from the interface area was about 60.0% of the monolithic slab S1, and this ratio increased to reach about 93.0% in pre-slab S9 with shear connectors area equal to 0.15% from the interface area.

D. *Shear Transfer Along The Interface:*

Table (3) and figure (10) shows the average shear strength q_u values which calculated at the ultimate load for both monolithic and pre-slabs. From these results it can be noticed that:

- Increasing of shear connectors lengths led to increase in the shear strength as in case of specimens S2:S5. The pre-slab S2, which had a shear connectors length of 15Ø, had an increase in the average horizontal shear strength with about 65% above the pre-slab S5 which had a shear connectors length of 4Ø.
- Increasing of shear connectors ratio led to increase in the shear strength as in case of specimens S4, S8 and S9. The pre-slab S9, which had a shear connectors ratio of 0.15%, had an increase in the average horizontal shear strength

TABLE 3. Experimental Results of Tested Specimens

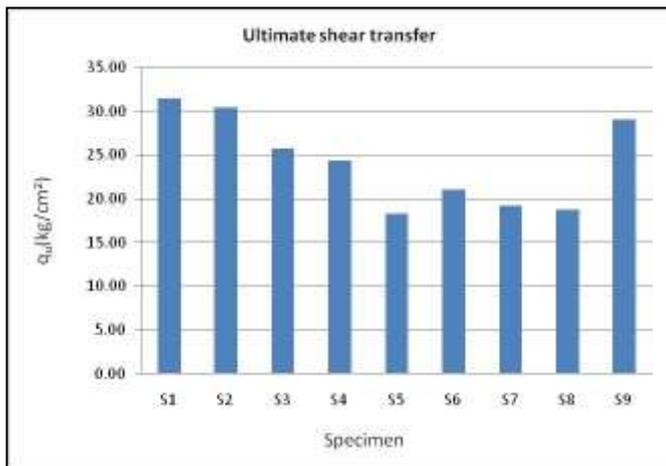| Specimen		F$_{cu}$ (kg/cm²)		P$_{cr.}$	First Shear Crack Load(ton)	P$_{ult.}$	Q$_{u.}$	q$_{u.}$	M$_{u.}$	Max. VL. Deflection	Max. HL. Slippage
		First layer	Second layer	(ton)		(ton)	(ton)	(kg/cm2)	(t.m)	(mm)	(mm)
Group(1)	S1	476.7		9.00	46.00	67.00	33.50	31.41	7.71	16.36	---
	S2	480.7	470.5	8.00	45.00	65.00	32.50	30.47	7.48	19.98	0.350
	S3	475	474.1	13.00	44.00	55.00	27.50	25.78	6.33	7.55	0.235
	S4	475	474.1	7.00	47.00	52.00	26.00	24.38	5.98	9.63	0.120
	S5	470.5	461.8	7.00	34.00	39.00	19.50	18.28	4.49	6.94	0.125
Group(2)	S1	476.7		9.00	46.00	67.00	33.50	31.41	7.71	16.36	---
	S6	472.7	466.5	6.00	26.00	45.00	22.50	21.09	5.18	16.45	1.410
	S7	463.3	461.3	8.00	40.00	41.00	20.50	19.22	4.72	5.74	0.120
Group(3)	S1	476.7		9.00	46.00	67.00	33.50	31.41	7.71	16.36	---
	S4	475	474.1	7.00	47.00	52.00	26.00	24.38	5.98	9.63	0.120
	S8	465	478.5	6.00	34.00	40.00	20.00	18.75	4.60	7.41	0.120
	S9	460	470	5.00	38.00	62.00	31.00	29.06	7.13	18.38	0.135

Figure (10): Ultimate shear transfer for the tested specimens.

with about 55% above the pre-slab S8 which had a shear connectors ratio of 0.06%.

• Using of Epoxy in composite pre-slabs at the interface area between the two concrete layers led to increase the shear transfer strength compared with specimens that had roughness only at the interface. The pre-slab S6 had an increase in the average horizontal shear strength with about 10% more than the specimen S7.

E. *Load-Deflection Curves:*

The deflection of the tested monolithic and composite pre-slab was measured at 0.25, 0.5 and 0.75 span and the maximum deflection plotted against the applied load from zero loading up to failure as shown in figure (11).

It can be noticed that the relation between the load and deflection was nearly linear up to cracking load then it was nonlinear due to excessive cracking in the concrete. Comparing the load-deflection curve of the pre-slabs S2, S3, S4, S5 and monolithic slab S1, it can be noticed that the pre-slab S4 and S5 had approximately the same load-deflection curve of the monolithic slab and had a maximum deflection of 42% and 59% of that of the monolithic slab S1 respectively, while the pre-slab S2 had a deflection more than the monolithic slab S1 at the same load level and the maximum deflection was more than the monolithic slab S1 with about 22%, and the pre-slab S3 had a deflection less than the monolithic slab at the same load level and the

maximum deflection was less than the monolithic slab S1 with about 54%.

Also when comparing the load-deflection curves of the pre-slabs S6, S7 and monolithic slab S1, it can be noticed that the pre-slab S7 had approximately the same load-deflection curve of the monolithic slab S1, and had a maximum deflection of about 33.5% of that of the monolithic slab, while the pre-slab S6 had a deflection more than the monolithic slab S1 at the same load level and the maximum deflection was approximately the same as the monolithic slab S1.

For the load-deflection curves of the pre-slabs S8, S9 and the monolithic slab S1, it can be noticed that the pre-slab S8 had approximately the same load-deflection curve of the pre-slab S9 and both are more than the monolithic slabS1, and the maximum deflection of pre-slabs S8, S9 was about 45.0% and 112% of that of the monolithic slabS1.
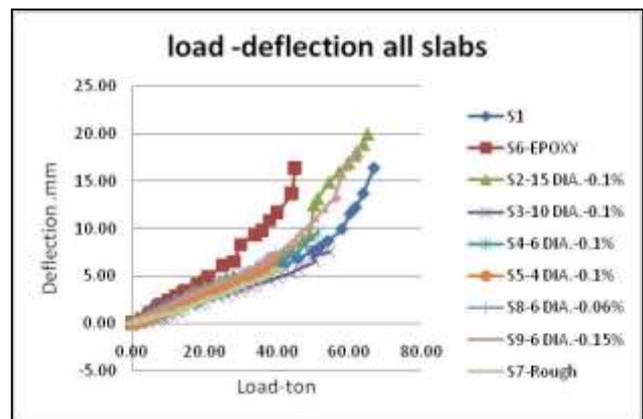

Figure (11): Load Deflection Curves.

VI. *Finite Element Program (ANSYS):*

Finite element program (ANSYS) version 11 was used in this study to simulate the behavior of the tested slabs which were modeled with finite element mesh. An eight node solid element (Solid 65) was used to model concrete and steel reinforcement bars, while the element (Beam4) was used to model the shear dowels connecting between the two concrete layers. The option (Concrete) was used to model concrete behavior and the option (Mises Plasticity) was used to model the steel behavior as shown in figure (12) for specimen S2.
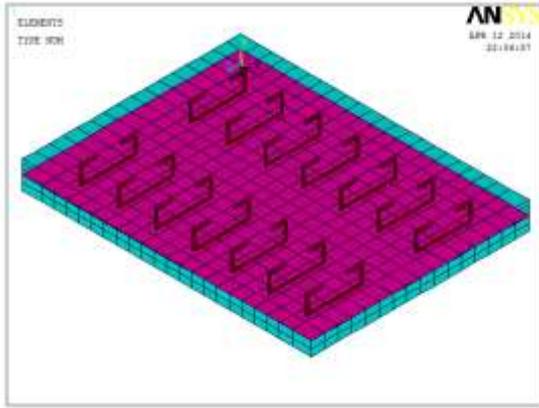
Figure(12): Finite element mesh for pre-slab S2.

A. *Flexure and Shear Cracks:*

The flexure and shear cracks, that obtained from the finite element modeling for all slabs were under the effect of uniformly distributed loads. It can be noticed that, the flexure cracks were in the middle zone of the span, while the shear cracks were near to the supports from the two ends as shown in figure (13).
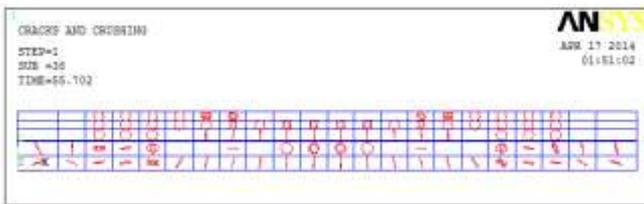
Figure(13): Shear cracks of pre-slab S2.

B. *Ultimate Loads:*

The theoretical and experimental ultimate loads are plotted in figure (14), from which it can be noticed that the theoretical ultimate loads were about (86%: 98%) of that of the experimental ultimate loads for tested pre-slabs S2:S9, while for the tested monolithic slab S1 the theoretical ultimate load was the same as the experimental ultimate load. From the previous results, it could be concluded that, the used modeling was sufficient enough to analyze both the monolithic slab and pre-slabs, where the experimental and finite element model were in good agreement.
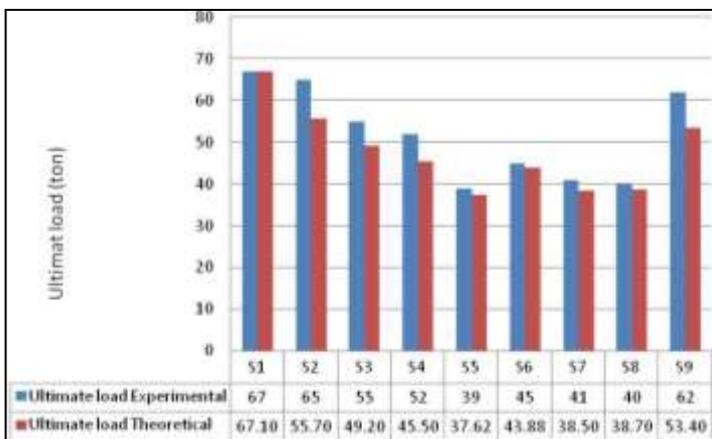

Figure (14): Ultimate load of tested

C. *Correlation between theoretical and experimental results:*

The used finite element program was sufficient enough to analyze the tested specimen, where the following results were obtained:

- The theoretical ultimate loads and shear strength were about (86%: 100%) of that of the experimental ultimate loads.

- The flexure and shear crack patterns were approximately the same in both the theoretical analysis and experimental tests.

VII. *Conclusions:*

- The design of the tested specimens changes the mode of failure from flexure to shear failure.

- Increasing of shear connectors length in the tested pre-slabs led to the following results:

    a- Increasing in the ultimate load and shear strength of the tested pre-slabs with about 65% as the shear connectors length increased from 4Ø to 15 Ø.

    b- Increasing in the applied load after the appearance of the first shear crack till the specimen had a complete shear failure.

    c- Increasing in the ductility of specimen, which was noticed in high deformation before the failure

- Increasing of shear connectors ratio in the tested pre-slabs led to increase in the ultimate load and shear strength.

- For specimens without shear dowels, it can be noticed that the following:

    a- Increasing of the interface roughening led to increase in the ultimate load and shear strength.

    b- Absence of shear dowel led to have a brittle failure, as the specimen had been failed after the appearance of first shear crack.

    c- Using Epoxy at the interface area between the two concrete layers led to increase in the ultimate load and shear strength with about 10% more than roughening only at the interface area.

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