Effect of cases of loading and distribution of shear connectors on the behavior of One-Way composite pre-slabs

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Abstract: Many structures have been recently constructed using composite reinforced concrete elements. One of the most common types is the pre-slabs which are used extensively in the construction of both buildings and bridges. It consists of a pre-cast concrete layer serves as a form or shuttering for the cast-in-place concrete layer. Also the cast-in-place concrete layer can be used for strengthening an existing slab. One of the most governing factors in design of sections of these elements is the shear transfer along the interface which is major factor to achieve the composite action between the two layers. In this research, the behavior of one way composite pre-slabs was studied. An experimental program was carried out to test nine simply supported slabs, three of them were reference monolithic slabs and the remaining six slabs were composite pre-slabs composed of two layers with different distributions of shear connectors according to shear force distribution. All slabs were tested under different cases of loading. Finally; comparison between experimental results of tested specimens and theoretical results obtained from analysis using finite element program was made and valuable recommendations for structural designers were suggested.
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Key Words: Concrete, Shear transfer, Composite, Pre-slabs

Introduction:

The composite concrete-concrete construction, as one of several techniques of prefabrication and precasting, has been more and more employed. In the composite construction, the precast concrete acts in conjunction with the cast-in-place concrete to form what are called “composite section”.

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.

Abd El-Hay A.S. (1) tested nine composite continuous one way pre-slabs 2.36x0.8x0.1 m. under the action of distributed load, the results showed that the pre-slab with rough interface and concentration of dowels in the outside ¼ span gives an ultimate load as monolithic slab, also the use of epoxy painting without dowels or roughness was very poor in resisting the shear stress along the interface.

Rabie(2) tested four composite two-way simply supported pre-slabs 2x2x0.1 m. under the effect of distributed load, the result showed that the ultimate load for the composite slab with rough interface only was about 87% of that of monolithic slab, also a slightly higher values of both deflection and concrete compressive stress was measured up to the complete separation of the two layers. Also; the pre-slab with distributed dowels 1ϕ8@ 40 cm. gives ultimate load about 92% of that of monolithic slab. While the use of concentrated dowels decreases both deflection and stress in dowels till the separation of the two layers in the interior zone which led to sudden increase in both deflection and stress in dowels.

EL-Behairy S.A, and Abou El-Enin A.W.(3) carried out tests on concrete pre-slabs cast in different ages; the effect of surface condition was studied. The result showed that the specimens with roughened interface gave the best results while the pre-slabs with smooth or toweled interface with steel dowels of area less than 0.15% did not reach the monolithic stage.

El-Rakib (4) made a series of push-off specimens for the evaluation of shear transfer parameters, he concluded that the use of shear connectors had a significant effect on increasing the ultimate shear strength and decreasing both slippage and crack width. Also he recommended that the imbedded length of the shear connectors not less than 10ϕ in the old concrete layer and 20ϕ in the new concrete layer.

Dong *et al.* (5) made a test on eight concrete pre-slabs 4x1.4x0.2 m. with four different concrete strength 19, 28, 32 and 51 Mpa.

He concluded that the shear stress versus slippage behavior of unbounded-smooth interface was distinctly different from that of an unbounded-rough interface.

Ihab A. H.(6) and El-Sayed M. (7) discussed the shear transfer.

Abou El-Matty (8) and Easterling W.S., and Young C.S. (9) discussed the behavior of composite slabs.

Experimental work:

Experimental program was carried out on six composite pre-slabs and three monolithic slabs; all slabs were supported on 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 Φ 12 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 (1): 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, one line load and two line loads, but they had a different dowels distribution as follows:

S1: Monolithic slab tested under the effect of uniformly distributed loads.

S2: Monolithic slab tested under the effect of one line load acts at a distance of 20 % of the span from one edge.

S3: Monolithic slab tested under the effect of two line loads act at a distance of 20 % of the span from the two edges.

S4: Composite slab tested under the effect of uniformly distributed loads and had a uniform dowels distribution.

S5: Composite slab tested under the effect of uniformly distributed loads and had a concentrated dowels distribution according to the shearing force diagram.

S6: Composite slab tested under the effect of one line load acts at a distance of 20 % of the span from one edge and had a uniform dowels distribution.

S7: Composite slab tested under the effect of one line load acts at a distance of 20 % of the span from one edge and had 50 % of dowels area put in one quarter of the span under the line load as the other 50% of dowels area put uniformly in the remaining span.

S8: Composite slab tested under the effect of two line loads acts at a distance of 20 % of the span from the two edges and had a uniform dowels distribution.

S9: Composite slab tested under the effect of two line loads acts at a distance of 20 % of the span from the two edges and had 50 % of dowels area put in each one quarter of the outside span while the middle part of the span was without any dowels.

The concrete compressive strength of tested slabs are shown in table (1).

Table (1): Compressive strength of tested specimens at testing time

specimen	F_{cu}(first layer)	F_{cu}(second layer)	Notes
S1	368.5		Monolithic slabs
S2			
S3			
S4	349.8	366.5	Composite pre-slabs
S5	379.2	391.2	
S6	351.2	385.2	
S7	379.2	391.2	
S8	348.5	367.2	
S9	348.5	367.2	

Test Set-Up and Loading Arrangement:

The specimens were tested under the effect of three types of loading; the first case of loading was the effect of uniform distributed load through a whiffel tree arrangement, the second case of loading was the effect of one line load while the third case of loading was the effect of two line loads using a hydraulic jack with increment equal to 1 ton as shown in figure (2).

Demic mechanical strain gages of 20 cm. length were used to measure the concrete strain and electrical strain gages were fixed on the steel dowels surface to measure the dowels strain.

Dial gages with 0.01 mm. accuracy were used for vertical deflection measurements. Also a horizontal dial gauge with 0.01 mm. accuracy was used to measure the slippage between the two concrete layers.

Figure (2): Loading set-up

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.

Cracking Pattern and Mode of Failure:

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

1- Monolithic slab (S1):

The first crack was observed at a load of 12.8 t/m^2 on the bottom surface at the section of maximum moment i.e. nearly at the middle of the span. After this load level, another bottom flexure cracks appeared with the increasing of load.

The diagonal shear crack started to appear at load of 32.6 t/m^2, it was near the support from the two sides. Increasing the load after the diagonal shear crack led to an increase in the diagonal shear crack width till the specimen had a complete shear failure as shown in figures (3) and (4).

Figure (3): Crack pattern of slab S1

Figure (4): Shear failure of slab S1

2- Monolithic slab (S2):

The first crack was observed at a load of 12.6 t/m on the bottom surface at the section of maximum moment i.e. nearly at the location of applied line load. After this load level, another bottom cracks appeared adjacent to the applied line load as the increasing of load. The diagonal shear crack started to appear at load of 30 t/m and it was near the support increasing the load after the diagonal shear crack led to increasing in the shear crack width till failure in a complete shear failure as shown in figure(5).

Figure (5): Shear failure of slab S2

3- Monolithic slab (S3):

The first crack was observed at a load of 12.75 t/m on the bottom surface at the section of maximum moment i.e. nearly at the middle of the span. After this load level, another bottom flexure cracks appeared on the both sides of the first crack as the increasing of load. The diagonal shear crack started to appear at load of 21.25 t/m of each line load and it was near the support , increasing the load after the diagonal shear crack led to increasing in the shear crack width till the specimen had a complete shear failure as shown in figure (6).

Figure (6): Shear failure of slab S3

4- Pre-slab (S4):

The first crack was observed at a load of 17.75 t/m^2 on the bottom surface at the section of maximum moment. After this load level, another bottom cracks appeared as the increasing of load.

The first diagonal shear crack was observed at a load of 30 t/m^2, it was near the support from the two sides. Increasing the load after the diagonal shear crack led to an increase in the shear crack width till the specimen failed in a complete shear failure as shown in figure (7).

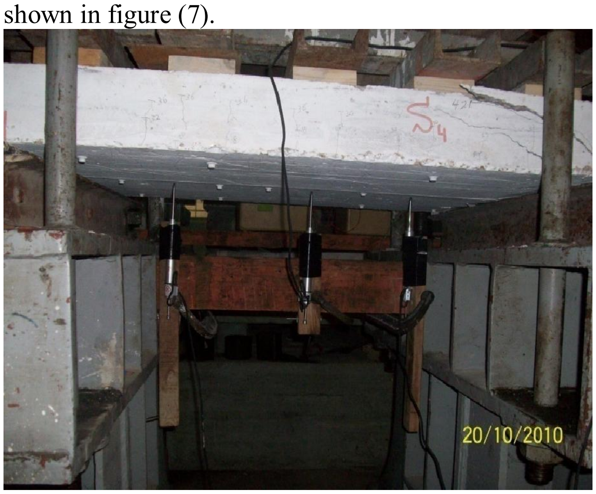


Figure (7): Shear failure of pre-slab S4

2- Pre-slab (S5):

The first crack was observed at a load of 12.75 t/m^2 on the bottom surface at the section of maximum moment i.e. nearly at the middle of the span. After this load level, another bottom cracks appeared as the increasing of loads

The first diagonal shear crack was observed at a load of 40 t/m^2, it was near the support from the two sides. Increasing the load after the diagonal shear crack led to increasing in the shear crack width till a complete shear failure occurred as shown in figure (8).

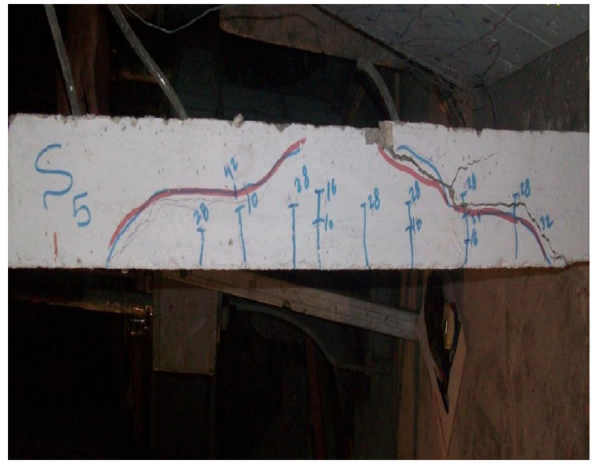


Figure (8): Shear failure of pre-slab S5

6- Pre-slab (S6):

The first crack was observed at a load of 9.5 t/m on the bottom surface at the section of maximum moment i.e. nearly at the location of applied line load. After this load level, another bottom cracks appeared adjacent to the applied line load as the increasing of load. The diagonal shear crack started to appear at load of 27.2 t/m and it was near the support, increasing the load after the diagonal shear crack appeared led to increasing in the shear crack width till failure in a complete shear failure as shown in figure (9)

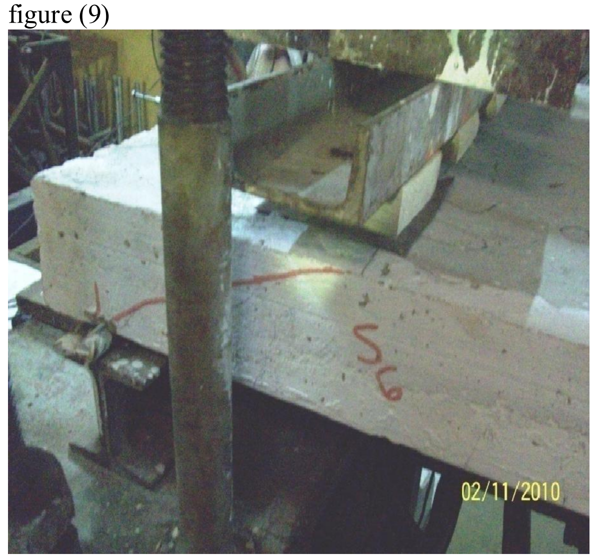


Figure (9): Shear failure of pre-slab S6

7- Pre-slab (S7):

The first crack was observed at a load of 15.1 t/m on the bottom surface at the section of maximum moment. After this load level, another bottom cracks appeared adjacent to the applied line load as the increasing of load. The diagonal shear crack started to appear at load of 35 t/m and it was near the support, increasing the load after the diagonal shear crack appeared led to increasing in the shear crack width as shown in figure (10).

Figure (10): Shear failure of pre-slab S7

8- Pre-slab (S8):

The first crack was observed at a load of 5.1 t/m of each line load on the bottom surface at the section of maximum moment. After this load level, another bottom cracks appeared on the both sides from the first crack as the increasing of load. The diagonal shear crack started to appear at load of 21.8 t/m of each line load and it was near the support.
Increasing the load after the diagonal shear crack led to increasing in the shear crack width till the specimen failed in a complete shear failure as shown in figure(11).

Figure (11): Shear failure of pre-slab S8.

9- Pre-slab (S9):

The first crack was observed at a load of 5.1 t/m of each line load on the bottom surface at the section of maximum moment. After this load level, another bottom cracks appeared on the both sides from the first crack as the increasing of load. The diagonal shear crack started to appear at load of 18 t/m of each line load and it was near the support. Increasing the load after the diagonal shear crack led to increasing in the shear crack width till complete shear failure occurred as shown in figure (12).

Figure (12): Shear failure of pre-slab S9.

Cracking and Ultimate Loads:

Table (2) shows the values of the cracking load for both monolithic and pre-slabs, the first cracking load occurred at the bottom surface of the specimens at the section of maximum bending moment according to the loading type.

Table (2) also shows that for group (1) under uniformly distributed loads, the ultimate load for the pre-slab S4 with uniform dowels distribution was about 94% of corresponding monolithic slab S1, while the ultimate load for the pre-slab S5 with concentrated dowels distribution was approximately the same of corresponding monolithic slab s1.

For group (2) under uniformly one line load, the ultimate load for the pre-slab S6 with uniform dowels distribution was about 91% of corresponding monolithic slab S2 while the ultimate load for the pre-slab S7 with concentrated dowels distribution was approximately the same of corresponding monolithic slab s2.

For group (3) under uniformly two line loads, the ultimate load for the pre-slab S8with uniform dowels distribution was about 90% of corresponding monolithic slab S3 while the ultimate load for the pre-slab S9 with concentrated dowels distribution was about 98% of corresponding monolithic slab s3.

Table (2): Results of tested slabs.

Specimen		F_{cu} (kg/cm^{2}) First layer	F_{cu} (kg/cm^{2}) Second layer	Cracking load $P_{cr.}$ (ton)	Ultimate load $P_{ult.}$ (ton)	Shear strength q_u (kg/cm^2)	Vertical deflection $\delta_{max.}$ (mm)	Max. Slip. (mm)
Group (1)	S1	368.5		10.3	47.1	23.2	11.41	---
	S4	349.8	366.5	14.2	44.2	21.4	11.5	0.06
	S5	379.2	391.2	10.2	47.4	22.9	8.25	0.02
Group (2)	S2	368.5		10.1	28.6	41.07	5.6	---
	S6	385.2	351.2	7.6	27.1	36.61	5.5	0.05
	S7	379.2	391.2	12.1	29.1	41.48	4.8	0.03
Group (3)	S3	368.5		10.2	38.9	33.53	7.6	---
	S8	348.5	367.2	8.2	35.2	29.9	6.97	0.125
	S9	348.5	367.2	8.2	38.2	33	7.95	0.075

From these results it is clear that the concentration of the shear dowels distribution according to the shearing force distribution led to an increase in the ultimate capacity of the section which means increasing in the composite action between the two concrete layers of the pre-slabs.

Load- Deflection Diagrams:

The vertical deflection of the tested monolithic and pre-slabs was measured at 0.2, 0.5 and 0.8 span and the maximum deflection plotted against the applied load from zero loading up to failure as shown in figures (13) through figure (15).

It can be noticed that the relation between the load and deflection was nearly linear up to cracking load then it was nonlinear distribution due to excessive cracking in the concrete.

Comparing the load-deflection curve of the pre-slabs S4, S5 and monolithic slab S1, it can be noticed that the pre-slab S4 had approximately the same deflection curve of the pre-slab S5 and had a maximum deflection less with about 30% than the maximum deflection of monolithic slab S1.

On the other hand, comparing the load-deflection curves of the pre-slabs S6, S7and monolithic slab S2, it can be noticed that the pre-slab S7 had approximately the same maximum deflection of the monolithic slab S2 while the pre-slab S6 had an increase in the maximum deflection by about 18.5% of that of the monolithic slab S2.

For the load-deflection curve of the pre-slabs S8, S9 and monolithic slab S3, it can be noticed that the pre-slab S8 had a maximum deflection of about 78% of that of the monolithic slab S3 while the pre-slab S9 had a decrease in the maximum deflection by about 21% of that of monolithic slab S3, also the dowels concentrated distribution in the pre-slab S9 led to an increase in the maximum deflection by about 4% over that of S8, this is attributed to the absence of the shear dowels in the middle span zone of the pre-slab S9.

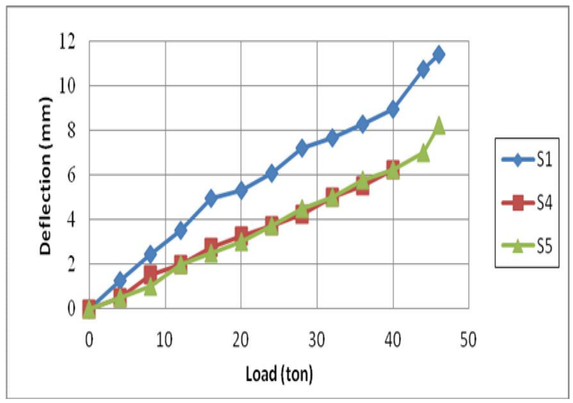


Figure (13): Vertical deflection at mid-spans (Group 1).

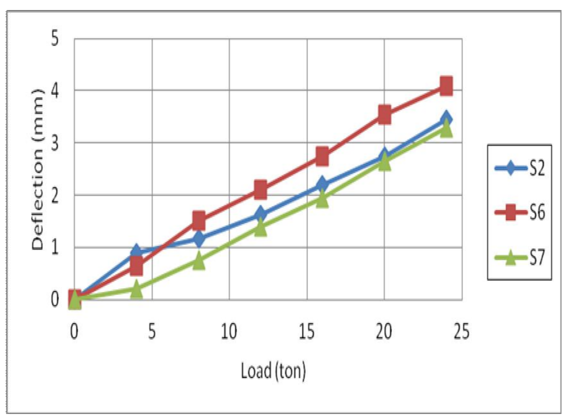


Figure (14): Vertical deflection at 0.2 spans (Group2).

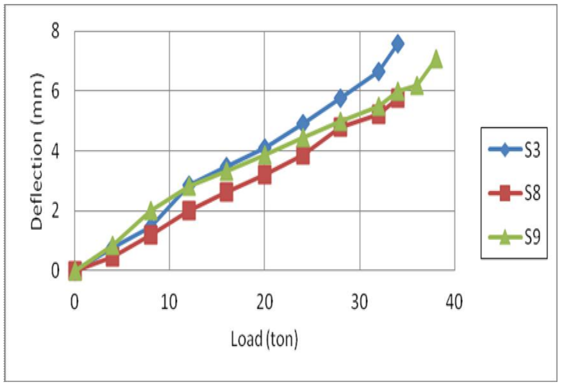


Figure (15): Vertical deflection at 0.2 spans (Group 3).

Deflection Pattern:

The deflection pattern at cracking load, as shown in figure(16), indicates that the monolithic slabs had deflection values higher than corresponding pre-slabs except in group(3) where the pre-slab S9 had deflection more than the pre-slab S3 because of the absence of shear connectors in the middle region of the pre-slab S9.While the deflection pattern at ultimate load as shown in figure(17) indicates that the monolithic slabs had deflection values less than corresponding pre-slabs except in group(1) where the monolithic slab S1 had a deflection more than the pre-slabs S4 and S5.

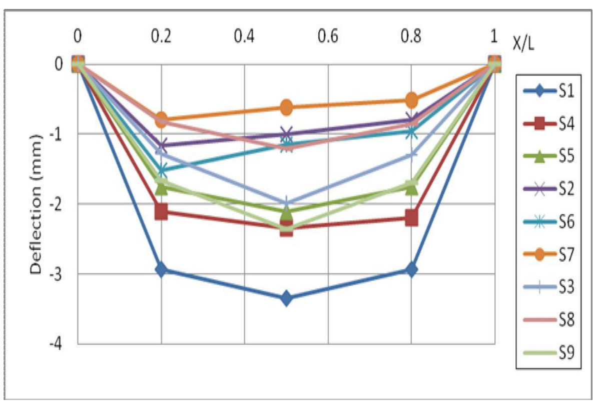


Figure (16): Deflection pattern of tested slabs at cracking loads.

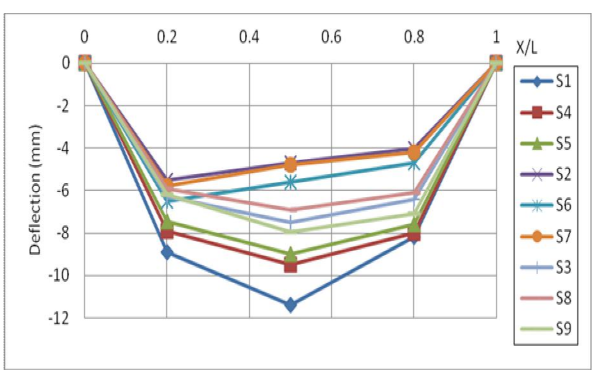


Figure (17): Deflection pattern of tested slabs at ultimate loads.

Concrete Tensile Strains:

The distribution of the tensile strains in concrete bottom fibers at the cracking load are plotted along the slabs axes as shown in figures (18) through (20).

From figure (18), it can be noticed that the tensile strain of slabs S1 and S5 was approximately the same while the tensile strain for slab S4 was less with about 17% of that for slab S5. Also, from figure (19), the maximum tensile strain was under the location of the line load (i.e. approximately at 0.2 span) and the tensile strain of the pre-slabs S6 and S7 was approximately the same and less with about 31% of that of monolithic slab S2.

The tensile strain for the last three slabs under the application of two line loads were approximately the same for S3, S8 and S9 as shown in figure (20).

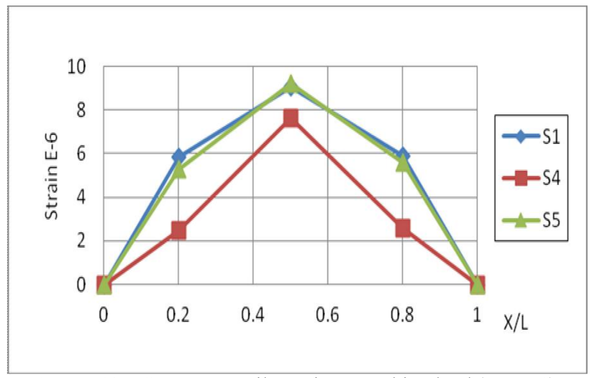


Figure (18): Concrete tensile strain at cracking load (group 1).

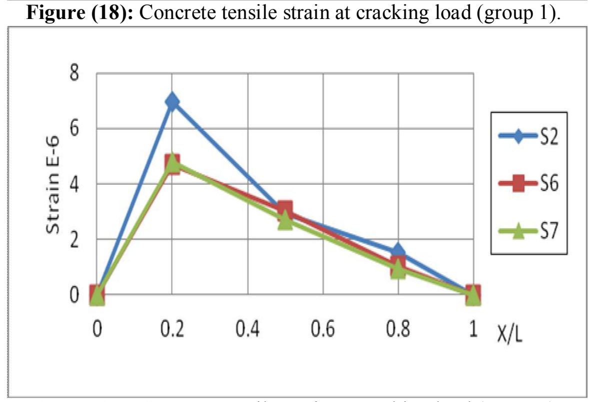


Figure (19): Concrete tensile strain at cracking load (group 2).

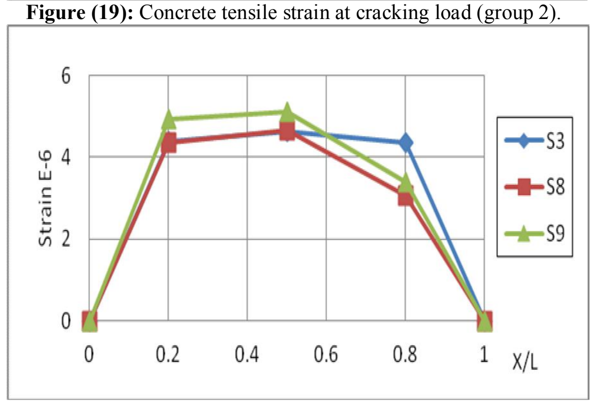


Figure (20): Concrete tensile strain at cracking load (group 3).

Dowels Strains:

The maximum strain in the shear connectors plotted against load are shown in figure (21), it is clear that the concentration distribution of dowels as done in the pre-slabs S5, S7 and S9 led to a decrease in the dowel's strain because of the large dowel's cross sectional area at the location of the maximum shear stresses along the interface.

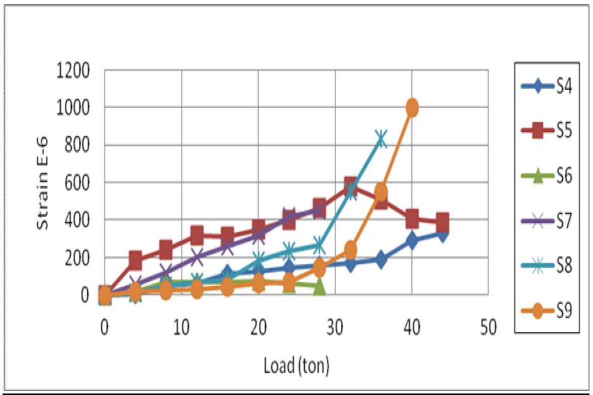


Figure (21): Strain in dowels of pre-slabs.

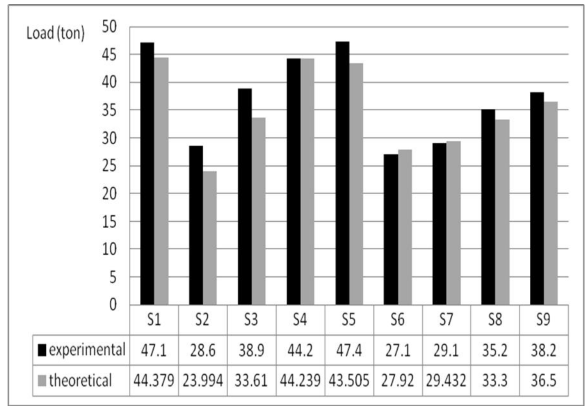
Finite Element Program (ANSYS):

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.

Correlation between theoretical and experimental results:

The comparison of the ultimate load between the theoretical and experimental values is shown in figure (22). It can be noticed that the theoretical ultimate loads were about (84%: 96%) of that of corresponding experimental results for all slabs except for slabs S4, S6 and S7 the ratio was approximately 100%.

Also, the finite element model gave a good agreement with the experimental results in vertical deflection measurements as shown in figures (23) through (25).



	S1	S2	S3	S4	S5	S6	S7	S8	S9
experimental	47.1	28.6	38.9	44.2	47.4	27.1	29.1	35.2	38.2
theoretical	44.379	23.994	33.61	44.239	43.505	27.92	29.432	33.3	36.5

Figure (22): Ultimate load for tested slabs.

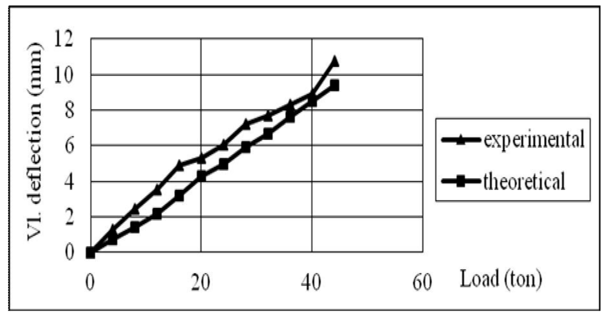


Figure (23): Maximum vertical deflection of slab S1.

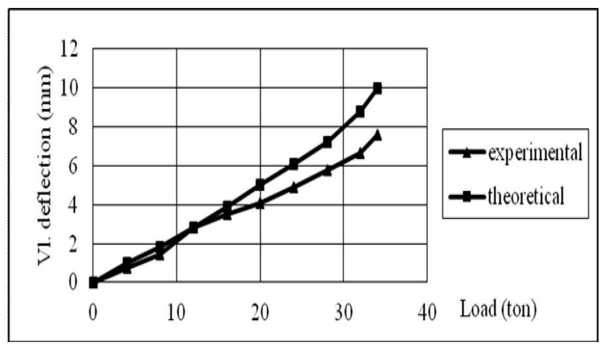


Figure (24): Maximum vertical deflection of slab S3.

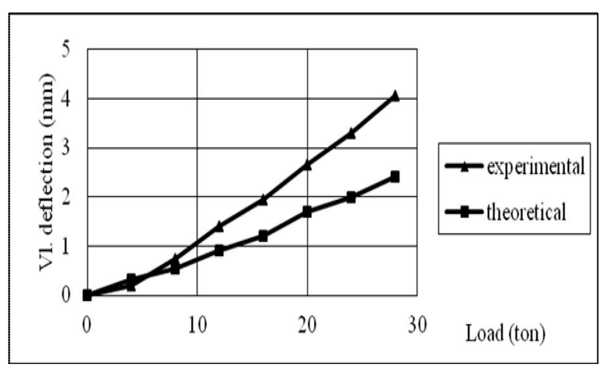


Figure (25): Maximum vertical deflection of slab S7.

Conclusions:

1- The design of the tested specimens successes to change the mode of failure from flexure failure to shear failure.

2- Shear connectors concentration in the tested pre-slabs led to the following results:

a- Approximately the same ultimate loads for the pre-slabs as the corresponding monolithic slabs (as in case of the pre-slabs S5 and S7 and monolithic slabs S1 and S2).

b- Increasing in shear strength of the tested pre-slabs comparing to the tested pre-slabs with uniform distribution of shear connectors (the pre-slaps S7 and S9 had an increase in shear strength with about 10% above the shear strength of the pre-slabs S6 and S8 which had a uniform dowels distribution).

c- Approximately the same shear strength of the tested pre-slabs comparing to the monolithic slabs (pre-slabs S5, S7 and S9 had approximately the same shear strength of the corresponding monolithic slabs S1, S2 and S3 respectively).

d- Decrease in horizontal slippage by about 67% in case of tested specimens under the effect of uniformly distributed loads and about 40% in case of tested specimens under the effect of either one or two line loads.

e- Decrease in dowel's strains in case of two line loads as the increase in dowel's ratio happened due to the concentration of dowels on both outer quarter part as in the tested pre-slab S9.

3- The changing of loading type from uniformly distributed loads as in the tested specimens (S1, S4, S5) to concentrated one line load as in the tested specimens (S2, S6, S7) led to achieve the ultimate shear strength .

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