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Experimental Study on Composite Floor Panels

Osman KAYA*[1]

Abstract

This paper presents experimental investigations carried out on various composite floor deck panel systems. The effects of parameters such as concrete shear length, steel thickness, and concrete thickness on the shear and flexural behavior of panels were examined. Shear tests were carried out on identical specimens with four different shear span lengths. Four-point flexural tests were carried out on single-span and double-span specimens. Shear stress-slip, load-deformation, and moment-curvature behaviors were compared. From the test results, the effect of shear strength between the corrugated sheets and concrete governs the failure mechanisms of the flexural test, if there is no shear connector. In all flexural tests the failure is became due to the slippage between the steel panel and concrete.

Keywords: sandwich panels, corrugated steel, shear test, flexural test

1. INTRODUCTION

Due to the effective use of concrete and steel, the use of composite structures in industrial structures becomes more important all over the world. Composite floor slabs consist of concrete blocks and profiled steel sheets. The profiled sheet used in composite flooring systems has two functions. It takes the tensile stresses, so no need to use tensile reinforcement. And it acts as a mold while pouring concrete, so no need for an additional formwork system. Additional wire mesh on top is used to prevent shrinkage and temperature effects.

Under service loading, the sheet and concrete interface is subjected to longitudinal shear stress. To overcome the slip, friction at interface of steel and concrete should be increased. For this reason shear connectors or embossment are implemented on corrugated sheets.

The effects of embossment without shear connectors, on the flexural behavior of deck panel are experimentally investigated in this study

2. LITERATURE REVIEW

Several experimental studies on composite deck panels with shear connectors can be found in the literature [1-10]. However, limited experimental tests have been performed on composite deck panel without shear connectors. Marimuthu et al. [11] studied moment curvature behavior of composite deck slabs with embossed profiled sheets. It was concluded that, shear connectors should be used to increase the shear strength between steel and concrete. In 2007, Ferrer studied use of cold form steel sheet for composite slabs. It is concluded that the critical issue for failure is shear slip [12].

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Baskar [7, 13] studied on composite deck slabs with and without embossment sheets. It is concluded that using embossed profile increases the load carrying capacity and delays the delamination. In order to improve the shear strength, Lakshmikandhan et al. [14] investigated three different shear transferring mechanisms namely mechanical interlock through indentations, embossments, and fastening studs. The mechanical shear connectors increase the load and bending moment capacity and also increase stiffness.

Hyeong Yeol Kim and Youn Ju Jeong [15] proposed a new type of full-scale composite deck slabs with longer and light-weight span when compared with conventional RC deck slabs. They concluded that the flexural rigidity of the composite deck slabs is approximately twice than that of traditional RC decks. Also the load capacity was increased by two and half times in the composite decks. It is stated by Wright, that the load -deformation behavior of composite deck slab behaves linear elastic until the buckling of corrugated steel. After the buckling, the behavior becomes non-linear. The yielding of steel profile developed in elastic region, so that the load carrying capacity is higher than traditional RC deck slabs [16].

In order to investigate the effects of embossment on the shear capacity and the flexural capacity of floor panels, an experimental study was carried out.

3. EXPERIMENTAL STUDY

The shear capacities and flexural capacities of composite deck panels were investigated experimentally. Test setups and Specimen properties are defined in following section. In Figure 1, dimensions of corrugated sheet were illustrated. The same corrugated sheet was used for both shear and flexural specimens. The photo from production of test specimens was given in Figure 2.

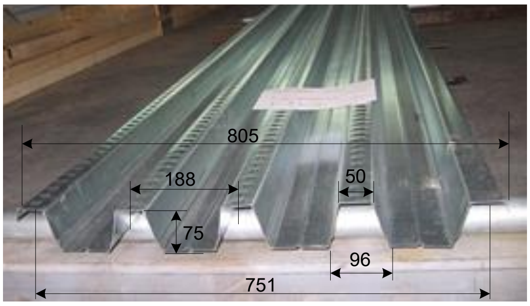


Figure 1 Dimensions of corrugated sheet (in mm)

Figure 2 Production of test specimens

3.1. Shear Tests

The test setup was composed of a trapezoidal steel panel, and a shearing concrete block of specific length and a reaction concrete block. 3m long composite deck panel system were produced. The hydraulic actuator, load cell and displacement transducers were placed in the test area, which is between the shearing concrete block, and the reaction concrete block, as seen in Figure 3.

3.2. Shearing Test Specimens

A total of 4 identical composite deck panel specimens were tested for shear resistance. Four different shearing surface lengths (L) were chosen with constant concrete width (Figure 3).

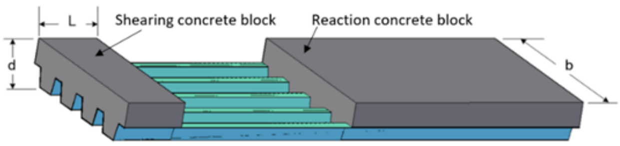


Figure 3 Dimensions of shearing test specimens

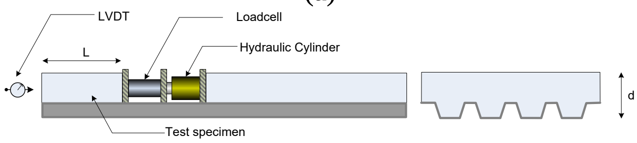
In Table 1 and Figure 4, dimensional properties of test specimens are described. Where, d is the overlaying concrete thickness, t is the thickness of steel plate, *b* is width of panel and *L* is the shear length.

Table 1 Description of shearing test specimens

Specimen ID	d *mm*	t *mm*	L *mm*	b *mm*
S1	215	1.0	250	815
S2	215	1.0	500	815
S3	215	1.0	750	815
S4	215	1.0	1000	815

The load was applied by a manually-operated 100 kN capacity hydraulic ram and was measured by a 200 kN capacity load cell. Figure 2 shows the pictures of the test set-up (a), and illustrates schematically the test set-up and the loading applied to the specimen in the test rig (b). All the load and displacement data were recorded by data logger equipment.

(a)

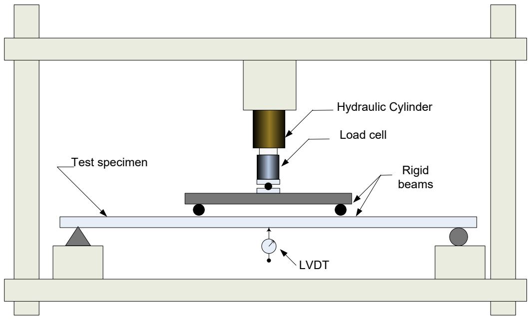


(b)

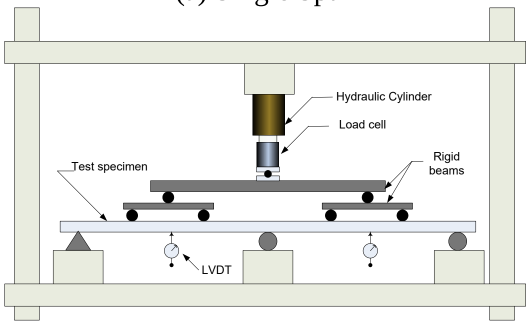
Figure 4 Test set-up for shearing test specimens

3.3. Bending Tests

The main components of the test rig included simple supports and rigid beams to distribute the point loads. The main load was applied by a manually-operated 300 kN capacity hydraulic ram and was measured by a 200 kN capacity load cell. The main load was equally distributed via rigid beams and supports underneath the applying point loads at two locations on each span where each point load was applied at 1/3 span distance. Also two LVDTs were used for curvature readings on each span. Figure 5 illustrates schematically the test set-up and instrumentation in the test rig for single span (a) and for double span (b).



(a) Single Span

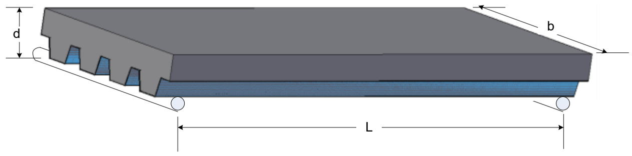


(b) Double Span

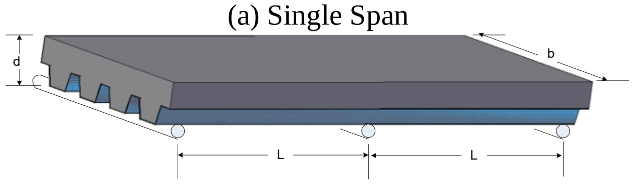
Figure 5 Bending Test Set-up

3.4. Bending Test Specimens

A total of 10 single span and 4 double span composite deck panel specimens were tested. Span lengths in double span specimens were kept equal. The overall dimensions of single and double span test specimens are shown in Figure 6 and Table 2.



(a) Single Span



(b) Double Span

Figure 6 Dimensions of bending test specimens

The height of the corrugated steel panel was 75 mm and the overlaying concrete thicknesses, were 125 mm, 175 mm and 215 mm measured from bottom of steel panel. The width of the deck panel in the test rig was taken as 770 mm. The steel panels had a varying thickness of 1.0 and 1.2 mm.

Table 2 Description of bending test specimens

Specimen ID	Span	d mm	t mm	L mm	b mm
F1a	Single	125	1.2	2000	770
F1b	Single	125	1.2	2000	770
F1c	Single	125	1.2	2000	770
F2a	Single	125	1.2	3000	770
F2b	Single	125	1.2	3000	770
F2c	Single	125	1.2	3000	770
F3	Single	215	1.0	3000	770
F4	Single	215	1.0	2750	770
F5	Single	215	1.0	2500	770
F6	Single	215	1.0	2200	770
F7	Double	125	1.2	2000	770
F8	Double	175	1.2	2000	770
F9	Double	125	1.0	2000	770
F10	Double	175	1.0	2000	770

3.5. Material Tests

The tests on 20x20x20 cm concrete cubes were carried out on test dates. An average value of 30 MPa compressive strength was found. The tensile yield strength of corrugated steel material was given by the manufacturer as 280 MPa.

4. TEST RESULTS

4.1. Shear Tests

For each test specimen, slippage between concrete and steel was observed. For specimen S1, which has 250 mm length of shearing block, the maximum load was recorded as 14 kN, whereas for specimen S4, which has 1000 mm shearing block length, the maximum load was recorded as 29 kN. Typical failure mechanism can be seen in Figure 7. Measured load vs. deformation relationships were plotted for shearing tests (Figure 8). For all specimens, the load capacity dropped suddenly after the loss of connection between steel and concrete, however, due to small shearing struts on corrugated steel, shear load capacities do not fall totally down to zero up to 10 mm slip value.

Figure 7 Testing of Specimen S1 and S2

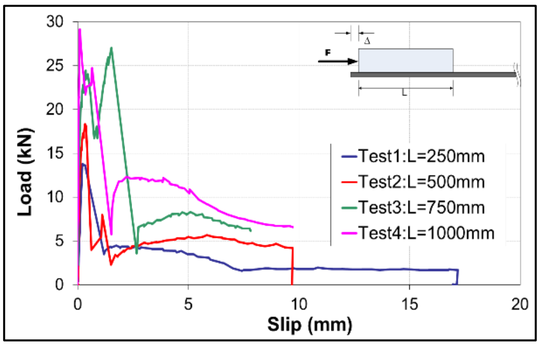


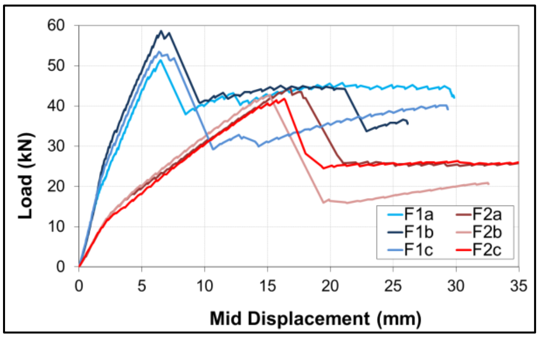
Figure 8 Test results of shearing test

4.2. Single Span Bending Tests

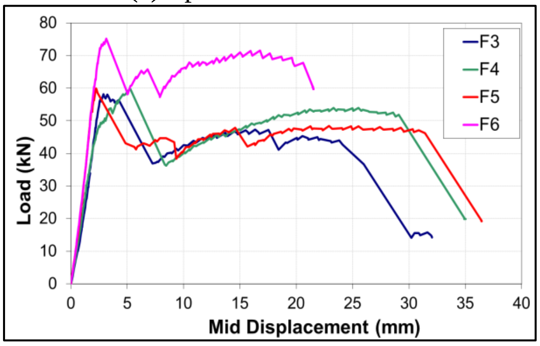
As defined in test setup, four-point loading was applied for single span bending tests. In all specimens, during the loading, first cracking of concrete was observed at the mid span locations. However, the tests were ended by due to the slippage between steel and concrete. In none of the tests did the specimens reach their flexural capacities. In Figure 9, typical failure due to slippage is shown.

Figure 9 Testing of single span bending tests

Also the test results are shown in Figure 10 in terms of applied load and mid span deflection. Three identical specimens for F1 and F2 specimens behave almost similar.



(a) Specimen F1 and F2



(b) Specimen F3, F4, F5 and F6

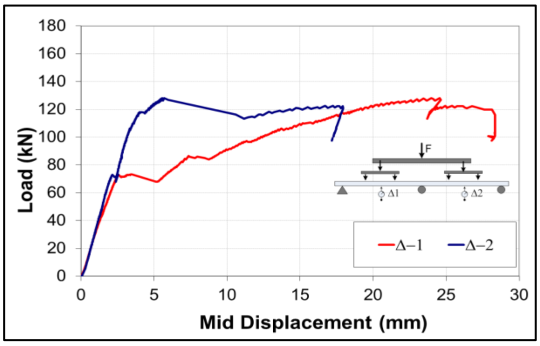
Figure 10 Test results of single span bending tests

4.3. Double Span Bending Tests

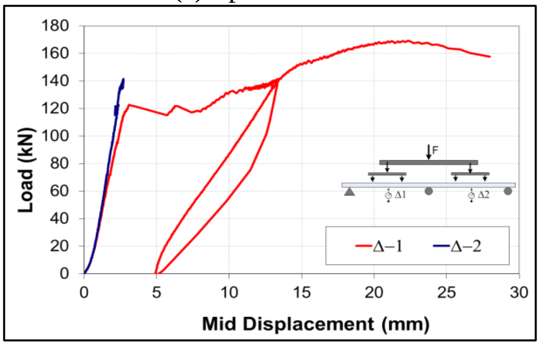
In double span tests, similar to single span tests, first flexural cracks were observed in each mid span location. Crushing of steel was observed at support region (Figure 11).

Figure 11 Testing of double span bending tests

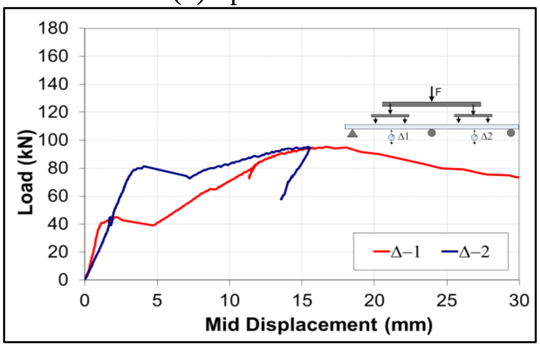
However, the tests were ended again due to the slippage. The test results are shown in Figure 12 in terms of applied load and two mid span deflections.



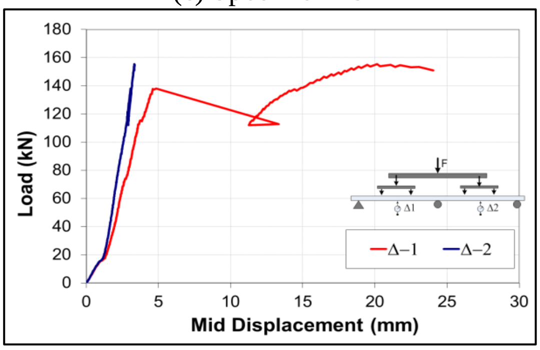
(a) Specimen F7



(b) Specimen F8



(c) Specimen F9



(d) Specimen F10

Figure 12 Test results of double span bending tests

5. ANALYSIS OF TEST RESULTS

5.1. Shear Tests

The objective of this test was to determine the longitudinal shear resistance between concrete block and the corrugated steel panel. Different shear lengths were tried and their corresponding failure loads were measured and thus, shear stresses were calculated. The calculation of shear stresses involved finding the total contact area between the steel and concrete materials in shearing concrete block side and dividing the failure load by that area. Figure 13 shows the variation of the shear stress values vs. slippage of block.

The value of shear stress was found to be between 0.03 MPa and 0.06 MPa, which decreases while shearing length increases.

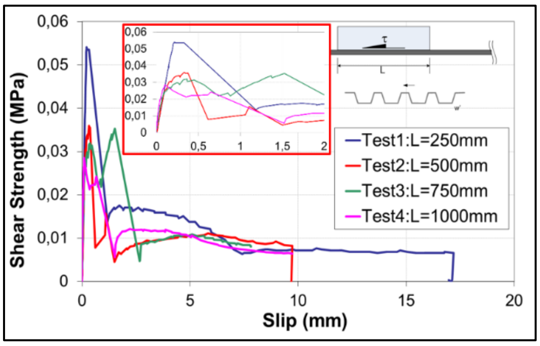


Figure 13 Shear stress vs. slip relationship

5.2. Single Span Bending Tests

A typical four-point load test was conducted in order to determine experimentally the moment-curvature relationship. The moment was calculated for each incremental load application as,

$$M = \frac{1}{2} F \frac{L}{3} = \frac{FL}{6} \qquad (1)$$

where M is the moment and F is the applied load.

Referring to Figure 14, Linear Variable Displacement Transducer (LDVT) 1 and LVDT 2 were used to measure the curvature of the composite panel at mid span location. ε_1 and ε_2 are the strain values within the length of measurement of LVDT 1 and LVDT 2 and are calculated as follows:

$$\varepsilon_1 = \frac{\Delta_1}{e_1} \ , \ \varepsilon_2 = \frac{\Delta_2}{e_2} \qquad (2)$$

where Δ_1 and Δ_2 are the corresponding displacement measurements of LDVTs. e_1 and e_2 are the gage lengths.

Thus the panel curvature, φ, is calculated with the following equation:

$$\varphi = \frac{\varepsilon_1 - \varepsilon_2}{g_1 + g_2 + w_c} \qquad (3)$$

where g_1 and g_2 are the distances of LVDTs from the panel. w_c is panel thickness.

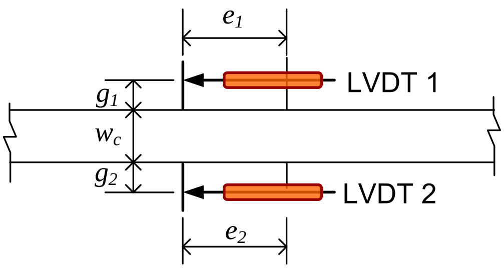
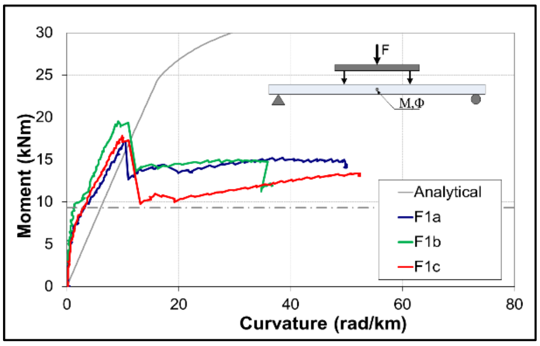


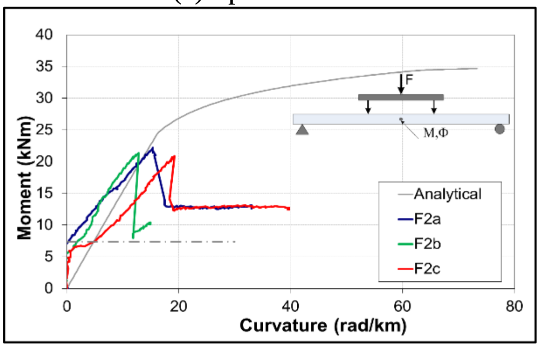
Figure 14 Instrumentation for curvature calculations

Experimentally obtained moment-curvature relationship for each test specimen was plotted in Figure 15. Also, Figure 15 contains theoretical moment-curvature relationship based on full composite action assumption and the nominal material properties of 30 MPa of concrete compressive strength and 280 MPa of steel tensile yield strength, calculated using standard reinforced concrete procedure. The limits of shear stress of 0.03 MPa, which is obtained from shearing tests and the deflection of L/360 were also found corresponding to their respective moment values. These limits are also shown in Figure 15.

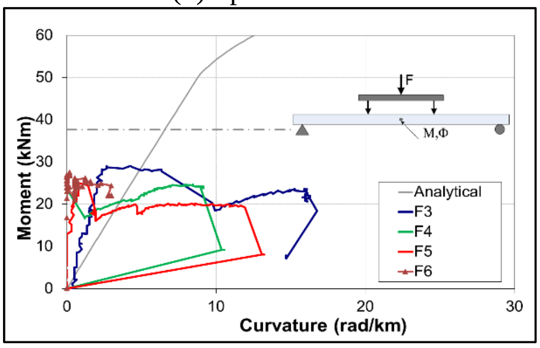
The slope of ascending branch of theoretical moment-curvature curve approximately matches to those of experimentally obtained slopes. In theoretical calculation, it is assumed that the concrete and the steel work together without any slippages. However, in the experiments, a separation between concrete and steel was observed indicating shear failure before full composite action was taken in place. These observations along with theoretical calculations are verified in Figure 15.



(a) Specimen F1



(b) Specimen F2

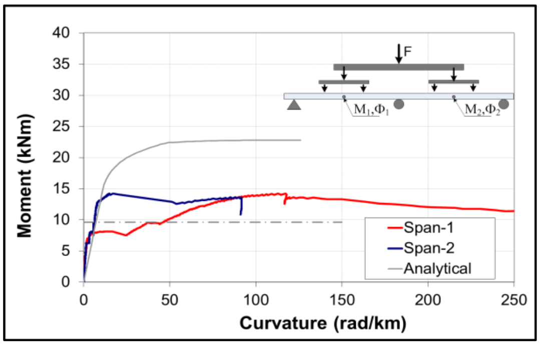


(c) Specimen F3, F4, F5 and F6

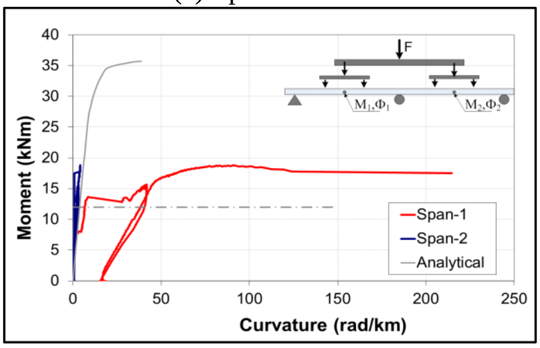
Figure 15 Analysis of single span bending tests

5.3. Double Span Bending Tests

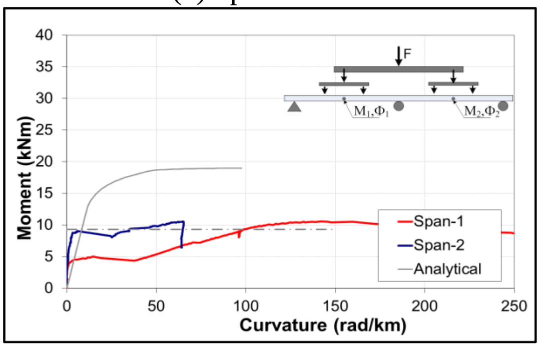
The analyses were carried out similar to single span case and as it is seen from Figure 16, same conclusions could be drawn as the case of single span test.



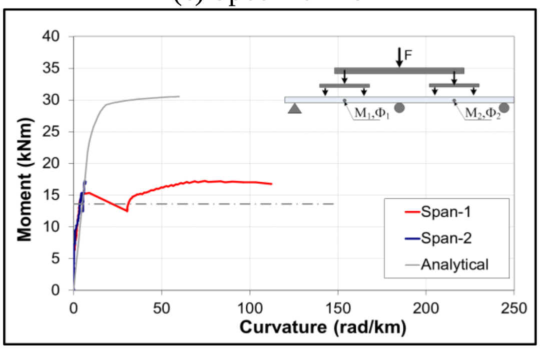
(a) Specimen F7



(b) Specimen F8



(c) Specimen F9



(d) Specimen F10

Figure 16 Analysis of double span bending tests

The moment in this case was calculated as the maximum positive moment for each span which is

$$M = 0.222\left(\frac{F}{4}\right)L = 0.056FL \quad (4)$$

where M is the maximum span moment, F is the applied load mid span and L is the length of span.

As in single span test, a separation between concrete and steel was observed in the tests of double span specimens. That separation causes a slip so that full composite action was not taken in place.

When the thickness of concrete layer is increased, the theoretical moment capacity is increased as expected. However, for the thicker member, the slippage occurs at small curvature level.

6. CONCLUSIONS

Experimental investigation conducted on composite floor panels without shear connectors has been presented. 4 longitudinal shear tests with different shearing length, 10 single-span simply supported flexural tests and 4 two-span flexural tests on Composite Floor Panels were carried out. From the shear tests, It is found that shear strengths at steel-concrete interface varies between 0.03 MPa to 0.06 MPa for 250 mm and 1000 mm shear length respectively. And the longitudinal shear strength between the steel and concrete has significant effect on flexural capacity. In all flexural tests, the specimens show semi-composite behavior due to slip between concrete and steel layer. The maximum moment value shown in M-Φ curves are almost half of the flexural capacity of the composite panels. Due to the slip, yielding of steel panel is not developed.

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