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STRUCTURAL STRENGTH AND BEHAVIOR OF PROFILED STEEL SHEET- CONCRETE COMPOSITE SLAB

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ABSTRACT

Profiled Steel Sheet-Concrete Composite Slabs (PSSCCSs) are getting emerging importance for the construction industry for different purposes. The composite slabs can be performed as form work during construction. These composite slabs systems can be efficiently used as a permanent deck scaffolding. The local buckling of the slab is reduced by profile steel sheet. The slab thickness is reduced and the total construction cost of construction is lower than the normal slab construction. The main objective of this research is to measure the behavior of structure and strength of PSSCCSs. Three different types of PSSCCSs are prepared for experimental investigations. Type I: PSSCCS with studs; Type-II: PSSCCS with minimum reinforcement and Type-III: PSSCCS without reinforcement are considered for this research. A series of laboratory tests were conducted on PSSCCS. Static load is applied on each PSSCCS during laboratory test. The composite slabs are placed over supporting roller hinge supports and load is applied incrementally on universal testing machine. The ultimate capacity, failure modes, and the stress-strain behavior of PSSCCS are observed. From the test result, the load carrying capacity of Type-II slabs is two times of Type-III slabs. Type-I slab showed the maximum load carrying capacity and it is three times of the Type-III slabs. The experimental test results are validated by the analytical results. The analytical results have very good agreement with experimental results and this analytical model can predict properly the structural behavior and the load carrying capacity of composite slabs. This composite slab system may suitable to minimize cost and to provide an increase in stiffness and strength. The research also comprised the study of the strength of composite slab using various thickness of profile sheet. It is an advanced composite slab system made of a profile steel sheet which can be effectively used in high rise building.

Keywords: *Composite slab, Steel deck, Compressive strength, Strength behaviour.*

1. INTRODUCTION

Profiled Steel Sheet-Concrete Composite Slabs (PSSCCS) are very demanding for modern construction industry. The application of this slab systemvery simple. The construction period is very faster. Structurally this slab system is light weight. Construction formwork is minimized by the steel profile sheet and hence the total construction cost of the slab system is comparatively lower than the normal sab system. For the construction of high rise building this slab system are using widely. Steel cold-formed plates with a reduced thickness can be efficiently used as permanent deck scaffolding for concrete slabs. The main benefit of these structural systems is to make the construction speedy as they do not require the standard scaffolding and propping systems (Calixto and Lavall 1998). The system is well accepted by the construction industry due to the many advantages over other types of floor systems (Andrade 2004; Makelainen and Sum 1999; Stanislava 2015). Profiled steel deck performs some major roles that act as a permanent formwork during the concrete casting and also act as tensile reinforcement after the concrete become hardened (Chen 2003; Veljkovic 1998; Porter and Ekberg 1971). Wright et al. (1987) conducted more than 200 tests on composite slab specimens including studs and intermediate stiffeners with trapezoidal profile deck. Crisinel and Marimon (2004) developed a simplified design method to measure ultimate capacity of composite slabs. Leon and Rassati (2013) conducted experimental test of three specimens of continuous composite concrete slabs tested under two-point loading system at each span up to failure. These research works indicate that the analysis of the composite slab behavior is highly complex (Marimuthu et al. 2006). However, no research works have been done by other researchers to compare the structural behavior of three different types of steel profile composite slabs. The main objective of our work is to determine structural strength and behavior of PSSCCS and to compare the load carrying capacity between different three different types of steel profile composite slabs including studs, minimum reinforcement and without reinforcement. The results of the research offered in this paper are a contribution to new experimental findings on the mechanical behavior of composite slabs, and on the analysis of the bonding behavior of composite profile slabs by using three different types of composite slabs. The experiemntal test results are validated by proposed analytical results. The proposed analytical model is capable to predict the behavior and the load carrying capacity of composite slabs.

2. MATERIALS AND METHODOLOGY

Locally available corrugated galvanized steel profile sheet is used. Both surface of the steel sheet is galvanized during manufacturing to protect from corrosion. In Fig. 1, the corrugated galvanized profile steel sheet is presented. These steel decks present heights ranging from 38 up to 90 mm with thickness varying from 0.76 to 1.5 mm. The main purpose of this geometry of the steel profile sheet is to increase the concrete to steel deck interlock resistance in the bottom profile corrugations for the three-dimensional state of stress present in the deck. The detail specification of trapezoidal steel profile is presented in Fig. 2. The height of the deck, slope of deck and width of sheet rib is described in this figure (see. Fig. 2).

Fig. 1:Trapezoidal steel profile decking sheet

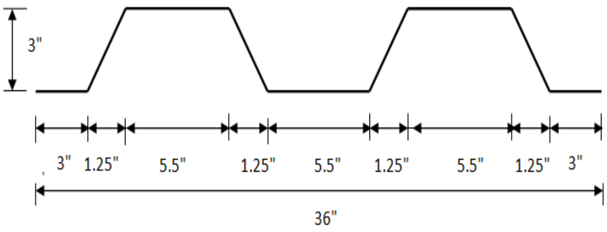

Fig. 2: Specification of trapezoidal steel profile decking sheet

Concrete mix is prepared by OPC cement, coarse aggregate and coarse sand with fresh water. The FM of coarse sand and coarse aggregate is 2.86 and 5.50 respectively. Concrete mix proportion is used in the mixture 1:2:4. Water-Cement ratio is 0.50 for the mix for making the mixture workable. Concrete mixture is prepared in the laboratory shown in Fig. 3. The well graded coarse aggregate and coarse sand is used in the concrete mix. The cement and water contents are higher in lightweight concrete because of the absorption of water by the aggregate. Lightweight concrete is commonly used because the obvious advantage of (typically) 25% weight saving can provide economic benefit for the overall design of the composite slab (Rackham et al. 2009). Workability is measured by slum test which is presented in Fig. 4.

Fig. 3: Concrete mixture (M20)

Fig. 4: Slum value test of M20 grade concrete

3. PREPARATION OF COMPOSITE SLABS

The composite slab specimens are constructed with 4 inch nominal depth 24 inch width and 36 inch span. The thickness of the concrete above the flange is 1 inch while depth of the profiled steel deck is 3 inch. All composite slab specimens are cast with full support on the plain surface concrete flooring in the Composite Testing Laboratory. Steel-decking surface is well cleaned before casting of the concrete. PSSCCSs are casted for measuring the structural strength. Total three types of PSSCCS slabs are made to test the axial load. Type-I: PSSCCS is prepared by welded the studs with the steel deck. The studs are 3.5 inch in length and ½inch diameter (see Fig. 5). Studs are placed @ 6inch c/c along the steel profile sheet. Studs fixed in a single line at a butt joint in the decking do not provide sufficient anchorage for the decking to contribute to the transverse reinforcement (see Fig. 6). In this slab minimum steel re-bars are used. Type-II: PSSCCS has steel deck with minimum reinforcement. Mild steel mesh reinforcement is used as shrinkage and temperature control reinforcements as specified in the ASCE (1985) specification and Type-III: PSSCCS are prepared using no reinforcement in which only concrete is placed over the steel profile deck. The slabs are tested after 28 days curing period. Once shear studs and transverse reinforecment are provided, the concrete mixute is pured to cast the slabs (Fig. 7).

Fig. 5:Studs connected with steel sheet

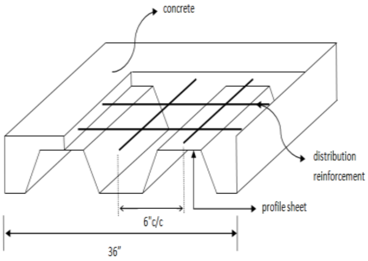

Fig. 6: Distribution of rebars

Fig. 7: Concrete placement

4. EXPERIMENTAL TEST SETUP

The tensile stability and compressive stability of the components is tested using a universal device referred to as Universal Testing Machine. The "universal" portion of the title shows that many conventional tensile and pressure experiments can be carried out. In this study, Universal Testing Machine capacity of 3000 KN is used for measuring the load carrying capacity of the specimens. The arrangement for the simply supported composite slab configuration with an effective length (L) of 36" subjected to one point located.

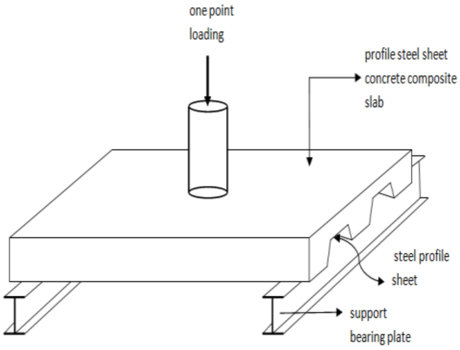

Fig. 8: Schematic view of experimental test setup

Fig. 9: Details view of experimental test setup in universal testing machine

The schematic view of one-point loading is shown in Fig. 8 and Fig. 9 shows the complete experimental setup in the laboratory. Each composite deck-reinforced slab was tested on simple span supports and subjected to a symmetrical mode of loading, consisting of either a single concentrated point load as shown in Fig. 9. In this experiment, load was applied by universal testing machine and deflection was measured by the strain gauge at the point of load application. Uniform load is applied by inflating a 0.5inch thick 24inch length cylinder, which is confined by the top surface of the test slab. A steel plate with 2inch thick by 4inch diameter is placed over the pad.

5. RESULTS AND DISCUSSIONS

5.1 Experimental results

The failure load, failure mode and types of failure have been observed for the specimens during testing. The failure mode of the slabs after peak load is observed. The crack propagation starts from the point of loading. Gradually the cracks increased with the increase of load. Different types of crack propagation are generated those are presented in Fig. 10 and Fig 11. Concrete cover is separated after reaching ultimate capacity of the slab and end plate also detached during applying load (see Fig. 12-13).

Fig.10: Failure modes of slab under loading

Fig.11: Crack propagation of slab under loading

Fig.12: Concrete cover separation

Fig.13: Plate end interfacial deboning

During test the failue modes are criritcally examine to understand the behaviour of the decking system. Ultimate capacity of the deking system is measured carefully. After reaching peak load shear bond and flexure failure modes were noticed. Shear bond leads the diagonal cracks and brittle failure has been occured. Due to brittle failure end-slip has been occured for separation of concrtete from steel sheet. Bending failures started after yielding of steel and crushing of concrete. Most of the major cracks are occured for the bending or flexural failures and the sudden failure at peak capacity. End-slip and debonding of steel sheet and concrete is not noticed for the bending failure. Bending failure are because of under reinforced steel decking system and sudden collapse is not experienced in the total composite system. Tearing of steel deck is the result of yielding of steel sheet and ductile behaviour of the sheet has shown in the entire section of the system. In case of over reinforced decking system, flexural crushing has been started and concrete crushing at ultimate load and sudden collapse of the entire system has experienced.

The test results for different composite slabs are presented in Table 1-3. Load-deformation curve is shown in Fig. 14 and the ultimate capacity of the Type-I slabs are much more than the other composite slabs.

Table 1: Variation of load with respect to deformation for Type-I slab (including studs)

Serial No.	**Load (KN)**	**Deflection (mm)**	**Serial No.**	**Load (KN)**	**Deflection (mm)**
1	0	0	6	50	2.10
2	10	0.40	7	60	2.40
3	20	0.75	8	70	2.65
4	30	1.25	9	80	2.90
5	40	1.65	10	90	3.05

Table 2: Variation of load with respect to deformation for Type-II slab (including reinforcement)

Serial No.	**Load (KN)**	**Deflection (mm)**	**Serial No.**	**Load (KN)**	**Deflection (mm)**
1	0	0	5	40	1.45
2	10	0.35	6	50	1.65
3	20	0.75	7	60	1.90
4	30	1.15	8	70	2.05

Table 3: Variation of load with respect to deformation for Type-III slab (no reinforcement)

Serial No.	**Load (KN)**	**Deflection (mm)**	**Serial No.**	**Load (KN)**	**Deflection (mm)**
1	0	0	3	20	1.10
2	10	0.45	4	30	1.40

The graphical presentation of the experimental test results is shown in Fig. 14. Typical load-deformation curve generated by the load gauge and deflection gauge. The failure of the specimen has occurred basically for the separation of concrete from the steel sheet. Regular failure modes are not noticed in reinforced steel decking system. Irregular cracks or failure starts and continues until exceeded bond strength and local bond failure due to flexural and bond stress. Collapse initiates from the end of the concrete slab and moves forward that initiates larger cracks. This failure has been occurred for debonding of concrete and steel sheet. Composite actions are not properly worked if shear studs are not used. Shear studs are acted as anchorage between steel sheet and concrete and composite actions effectively provided. Shear studs transfer the loads from concrete to the steel deck. From the load-deformation curves, it is found that the ultimate capacity of the system is 90 kN for type-III slab and failure occurs at 3.05 mm deflection.

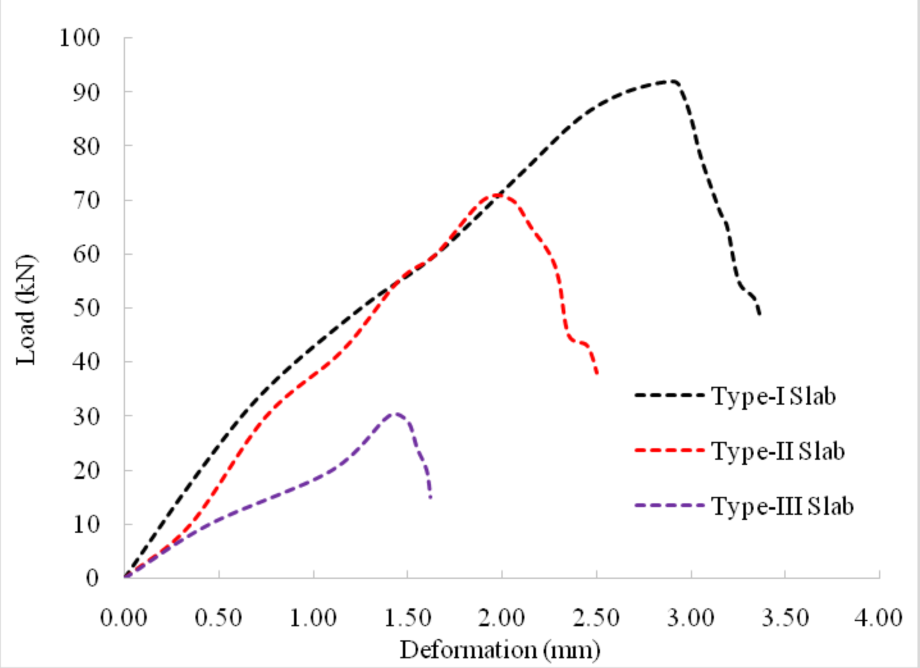

Fig. 14: Comparison of load-deflection curve of composite slab for different condition

To increase the shear bond capacity of the composite slabs without end anchorage shear studs are widely used. The composite actions are easily created by providing sufficient number of shear studs. The capacity of the composite slabs with end anchorage are compared with the one span composite slabs. Initially the capacity is almost same for both system before end slip initiation. With further increase of applied load shear bond slip has been started and the concrete is de-bonded for cracking.

The load-deflection curves were more linear for concrete composite slab including studs than including reinforcement before the shear-bond failure. After the load increase, the de-bonding cracking at the sheet-concrete interface and the load-deflection curves then became non-linear for composite slabs. The load carrying capacity of steel profile deck concrete composite slab increases with the increase of thickness of the steel profile sheet.

In this research three different types of steel profile concrete composite slabs were established including studs, minimum reinforcement and without reinforcement. Based on the experimental investigation, the following conclusion is arrived. The load carrying capacity of composite slab using reinforcement and studs was increased two times and three times than reference test of no reinforcement slab. The ultimate capacity of three composite systems are 22kN, 65kN and 90kN respectively and the comparison is shown in Fig. 15.

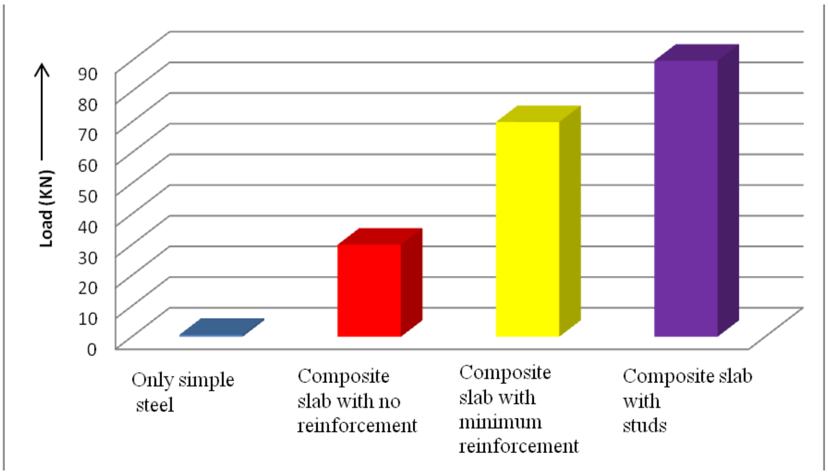

Fig. 15: Comparison of load carrying capacity of steel profile concrete composite slab

5.2 Experimental results validation

Analytical model is used for validation of experimental test results. For the analytical model load and deformation is calculated by the proposed equation. Deflection of the slab is obtained by the sum of deflections of the profiled sheets during the construction phase and deflection of the concrete slab. Traphezoidal cross section of the slab is shown in Fig 16. The slab spans work independently from each other, therefore for calculations,

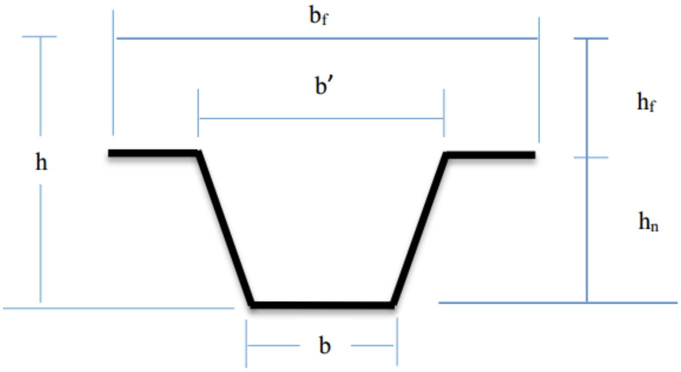

Fig. 16: Traphezoidal cross section of the slab

$P_u = s * l^2 * \left(\frac{1}{r}\right)_{max}$ where, $s = \frac{5}{48}$ = coefficient depending on the stress diagram and the type of a load. l = length of the span and $\left(\frac{1}{r}\right)_{max}$ = maximum curvature in the section with the maximum bending moment from the load. The load-deformation curve is developed for the analytical model results. The validation is performed for experimental test results and it shows very good agreement with experiemtal test results for all composite slabs (see Fig. 17).

$$J_{red} = \frac{b_f h_f^{\ 3}}{12} + \frac{b h_n^{\ 3}}{12} + b_f h_f (y_0 - \frac{h_f}{2})^2 + b h_n (\frac{h_n}{2} + h_f - y_0)^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$y_0 = \frac{b_f h_f^{\ 2} + b h_n (2h_f + h_n)}{2(b_f h_f + b h_n)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. (2)$$

J_{red} = momentof inertia of the effective cross-section relatively its center of gravity.

$(\frac{1}{r1}) = (\frac{M}{Eb1 \cdot Jred})$

Where, E_{b1} -deformation modulus of compressed concrete depending on duration of the load. The slab spans work independently from each other, therefore on-span beam is used as the stress diagram for calculations;

For short term loads

$E_{b1} = 0.85\ E_b = 0.85 * 10000000 = 8500000$ KN/m^2

For long term loads;

$E_{b1} = (\frac{Eb}{1+\phi b,cr}) = (\frac{10000000}{1+3.65})$, where, $\phi_{b,cr}$ = 3,65-creep coefficient for concrete

From the figure no (16),

Here, $b_f = 0.3429$m, $b = 0.1397$m

$h_f = 0.0254$m, $h_n = 0.0254$m

from equation no (1), $J_{red} = 5.06*10^{-5}$m^2

from equation no (2), $y_0 = 0.041$m

The load-deformation of different slabs is calculated by the analytical formula. Three different slabs carried different capacity at corresponding deformation presneted in table 4.

Table 4: Variation of load with respect to deformation for different types of slabs

Type-I Slab		**Type-II Slab**		**Type-III Slab**	
Deformation (mm)	**Load (kN)**	**Deformation (mm)**	**Load (kN)**	**Deformation (mm)**	**Load (kN)**
0	0	0	0	0	0
0.4	20	0.35	10	0.45	10
0.75	35	0.75	30	1.10	20
1.25	50	1.15	42	1.40	30
1.65	60	1.45	55	1.50	29
2.10	75	1.65	60	1.55	24
2.40	85	1.90	70	1.60	20
2.65	90	2.05	70	1.62	15
2.90	92	2.15	65	--	--
2.95	90	2.25	60	--	--
3.00	85	2.30	55	--	--
3.05	78	2.35	45	--	--
3.15	68	2.45	43	--	--
3.19	65	2.50	38	--	--
3.25	55	--	--	--	--
3.33	52	--	--	--	--
3.36	49	--	--	--	--

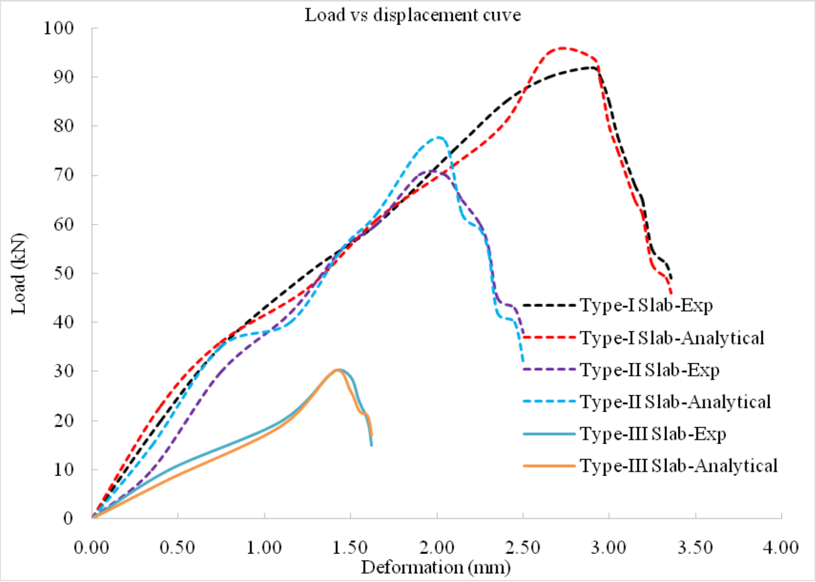

Fig. 17: Validation of experimental test data by analytical model for different condition

6. CONCLUSIONS

In this research three different types of steel profile concrete composite slabs are introduced including studs, minimum reinforcement and without reinforcement. Based on the experimental investigation, the following conclusion is drawn. The ultimate capacity of composite slab using reinforcement and studs is increased two times and three times than reference test of no reinforcement slab. The load-deflection curves are more linear for concrete composite slab including studs than including reinforcement before the shear-bond failure. After the load increase, the de-bonding, cracking at the sheet-concrete interface and the load-deflection curves then became non-linear for composite slabs. Comparisons of the experimental and analytical results agrees well with the test results, and is capable of predicting the behavior and the load carrying capacity of composite slabs.

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