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Analytical Study on Behaviour of Composite Slabs with Profiled Steel Decking

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Abstract- ***In this modern era, composite deck slab floors with profiled steel decking are widely accepted in many countries as they lead to faster, lighter and economical construction. This paper aims at studying the behavior of composite slabs under flexural loads. The strength of composite deck slabs depends on the strength of contact between the profiled steel sheeting and concrete layer. An analytical 3-D finite element model of composite slab is developed and the interface between profiled steel sheet and concrete is modeled with the help of contact elements in ANSYS 11.0 Multi physics utility tool. Material nonlinearities are considered in the finite element model. Analysis is carried out on simply supported composite slabs under two point line loads by varying parameters: span and thickness of profiled steel sheet. Results are illustrated in the form of load carrying capacity, ultimate load and maximum deflection.***

Keywords Composite slab, Profiled steel deck, Finite Element Analysis, Contact element, ANSYS, Span, Thickness.

1. Introduction

Composite slabs consisting of profiled steel sheeting and concrete are widely used in buildings now a days. A composite slab is defined by EN 1994-1-1:2004 as, ñA slab in which profiled steel sheets are used initially as permanent shuttering and subsequently combine structurally with the hardened concrete and act as tensile reinforcement in the finished floorò. Elements of composite slab with profiled steel decking are shown in Figure 1.

This slab is associated with two stages:

i) Construction stage wherein wet concrete is poured on steel deck. Profiled sheet in this stage acts as permanent formwork.

ii) Composite stage wherein profiled steel sheet acts as tensile reinforcement after the concrete has hardened. Steel sheet and concrete are interconnected in such a manner that horizontal shear forces can be transferred at the steel-concrete interface.

Composite floor construction used for commercial and other multi-storey buildings offers many advantages as follows:

i) Speedy Construction.

ii) Offers immediate safe working platform protecting workers below.

iii) Lighter construction than a traditional concrete building.

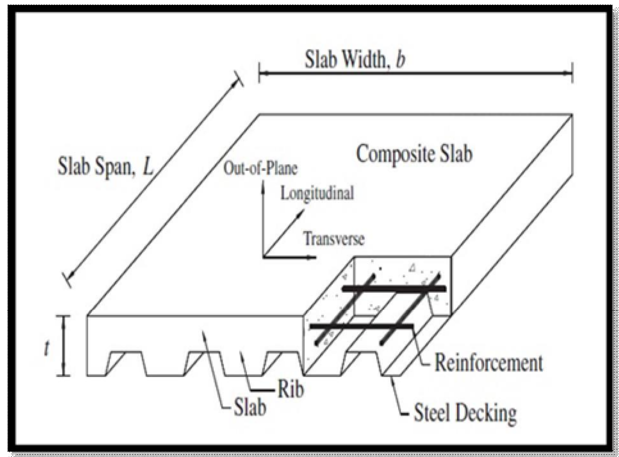

Figure 1. Elements of Composite Slab with Profiled Steel Decking

iv) Economical

v) Geometry of deck permits formation of ducting cells within the floor so that services (telephone, communication wiring, etc.) can be installed. This increases headroom or reduces building height.

Composite floors are used in both single storey as well as multi-storey buildings.

i) High rise commercial buildings

ii) Mezzanine in industrial buildings

iii) Multi-storey car parks

iv) Sky walk

In a composite steel floor deck, after hardening of concrete, both steel sheet and concrete act compositely with each other. The composite action depends upon adequate transfer of horizontal shear forces between the concrete slab and the steel deck to enable the deck to act as tensile reinforcement. In addition to horizontal shearing forces, the bending action also leads to vertical separation between the steel and the concrete. The profiled sheet, therefore, has to be designed to resist vertical separation, in addition to transferring the horizontal shears. Resistance to vertical separation is achieved by embossments or stiffeners [7].

The three primary failure modes important for design of a composite deck slab are: (1) flexure, (2) shear at support and (3) shear bond mode. Failure of the slab is said to be ductile if the failure load exceeds the load causing first recorded end slip by more than 10%. The failure load is taken as the load at mid span deflection of L/50 unless failure has already taken place [8]. One of the principal modes of failure of steel deck slabs is by the shear bond. The shear bond mode of failure is characterized by the formation of diagonal tension crack in the concrete at or near the load points, followed by a loss of bond between the steel deck and the concrete. There is a slippage between the steel and concrete causing a loss of composite action in the shear span region, which lies between the support reactions and the concentrated load: Slippage usually occurs when the load reaches its ultimate value and this is followed by a significant drop in loading [6].

V. Marimuthu, et.al.[1] have carried out an experimental study to investigate the shear bond behavior of the embossed composite deck slab under simulated imposed loads and to evaluate the m-k values. 18 numbers of specimens were split into six sets of three specimens each in which three sets were tested for shorter span loading and other three sets for longer span loading. Load deflection behavior and failure modes of slabs were studied. N. A. Hedaoo, et.al.[2] have presented the structural behavior of composite concrete slabs by experimental and analytical studies. Specimens were tested for different shear span lengths under static and cyclic loading on simply supported slabs. The longitudinal shear bond strength is evaluated using m-k and partial shear connection methods and compares the values. Baskar R.[3] presented a study on experimental and finite element modeling of composite deck slabs with and without embossments. Slabs are tested for flexure characteristics, ultimate strength and ductility. Experimental and analytical results were compared. Merool D. Vakil, et.al.[4] studied the deflection characteristics of simply supported composite deck by varying parameters: concrete height and concrete grade. It was observed that composite slab without embossment deformed more as compared to slab with embossment. Shiming Chen, et.al.[7] presented a universal finite element approach in which shear bond interaction between the steel deck and concrete is treated as a contact problem considering adhesion and friction. The preliminary FE analysis is verified in simulation of pull-out tests as far as the cohesion and the frictional bond of the contact interface are considered. The fine FE analysis using the contact model is carried out in study of the composite slabs in flexural bending. It was observed that the FE analysis is capable of predicting the performance and load carrying capacity of the composite slabs.

2. FEM Model for Composite Deck Slab

The present study aims at determining the deflection of simply supported slab with varying parameters: span and thickness of profiled steel sheet. The shape and dimensions of the sheet are shown in Figure 2; all dimensions are in mm.

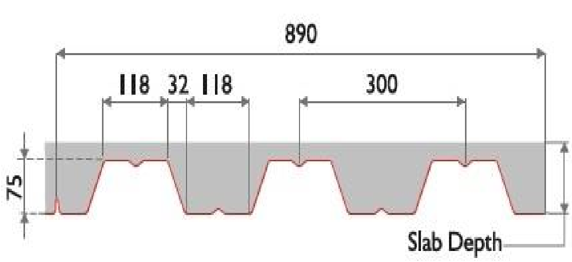

Figure 2. Dimension of steel sheet (75-300 profile)

(All dimensions are in mm)

The finite element method is one of the powerful tools to study the behavior of the composite slabs. 3-D model of composite slab consisting of concrete and profiled steel deck is modeled in ANSYS 11.0 to identify the behavior of composite slab considering different parameters. ANSYS allows for the implementation of specific material models and boundary conditions and bond behavior. Depth of steel sheet is 75mm and depth of concrete is 50mm. Total depth of slab is 125mm.Concrete is modeled by SOLID65 element. This element can be used for the 3-D modeling of solids with or without reinforcing bars. The solid is capable of cracking in tension and crushing in compression. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y and z directions. Profile deck is modeled with SHELL181element. It is used for analyzing thin to moderately thick shell structures. It is a 4-node element with six degrees of freedom at each node: translations in x, y and z directions, and rotations about the x, y and z axes.Bilinear Isotropic property is used for profile sheet. Multi linear Isotropic material properties are used for concrete. The material properties of steel sheet and concrete are listed in Table 1 and Table 2 respectively.

Table 2. Material Property of Steel

Density	7850 kg/m3
Poissonôs ratio	0.3
Elastic Modulus	2.03 x 105 N/mm2
Yield strength	250 N/mm2

Table 3. Material Property of Concrete

Density	2500 kg/m3
Poissonôs ratio	0.18
Elastic Modulus	25000 N/mm2
Characteristic Compressive strength	25 N/mm2

The composite slab models considered for finite element analysis are listed in Table 4. The following slabs are modeled with constant thickness of profile steel sheet as 1mm. The shear span is defined as the distance between the centres of support at either end to the point of application of the line load in the slab. For particular thickness and span, two shear spans of L/4 and L/6 are studied. The designation of slab is given by TSE75-2-4 wherein TSE75 indicates the profile steel sheet having 75mm depth, second digit ó2ô indicates span of 2.0 m and the third digit ó4ô indicates the shear span length.

Table 4. Models of slabs for analysis

Slab Designation	Span (mm)	Shear span (mm)
TSE75-2-4	2000	500
TSE75-2-6	2000	335
TSE75-3-4	3000	750
TSE75-3-6	3000	500

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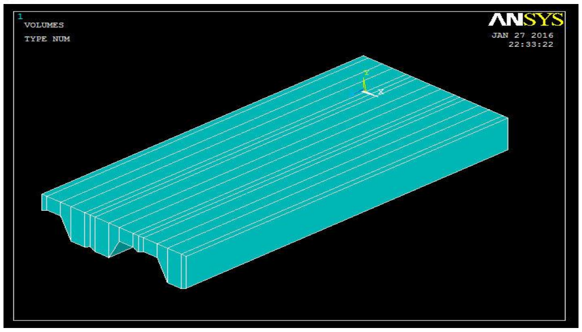

Figure 3. Model of Composite Slab

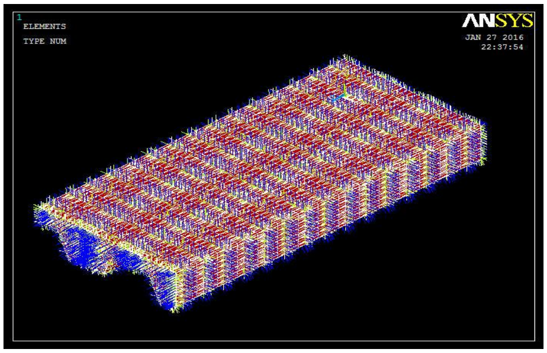

Figure 4. Meshing

Similarly, the composite slab models for thickness of profile sheet 1.5mm are also considered with the span and shear span data same as above. The steps involved in finite element analysis comprise of modeling the steel sheet and concrete as depicted in Figure 3, fine meshing as depicted in Figure 4, contact pair as shown in Figure 5, assigning supports and applying load.The contact pair (element target 173 and element contact 170) is constructed by using the surface-to-surface contact elements defined with the same real constant. As illustrated in Figure 5, the interface between the steel deck and the concrete is modeled by contact elements, where the surface of the concrete is selected as the target surface, and the surface of the steel deck is set as the contact surface accordingly.A simply supported boundary condition is assumed for the composite deck slab, one end considered as hinged support and other end as a roller support.The analysis is performed by applying an incremental load, with iterations in each increment. The modified time to time algorithm with assumed proportional loading history is used.

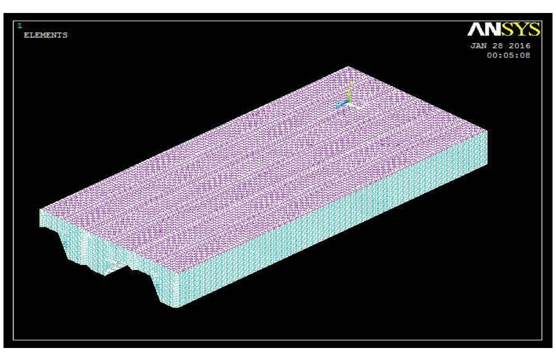

Figure 5. Surface to Surface Contact

3. Results

In an effort to gain a fundamental understanding of the behavior of composite slabs, by varying the span length including the shear span length and thickness of profile steel sheet, a parametric study is carried out.

The finite element model utilizing interface elements to model the bond properties between steel decking and concrete slab is described and used to investigate the load carrying capacity of the slabs through load increment in time steps. Each slab has a roller support at one end and a pin support at the other end. The deflection at mid-span is obtained from the analysis. The maximum load carried by the slab is observed and maximum deflections are obtained.

The result of first time step for the slab model TSE75-2-4 and thickness 1mm is depicted in Figure 6. Results for each thickness of profile sheet are illustrated below in Table 5 and Table 6.

Table 5. Analysis results for slab with profile sheet 1mm thick

Slab Designation	Span (mm)	Shear span (mm)	Load (kN)	Deflection (mm)
TSE75-2-4	2000	500	21.42	10.96
TSE75-2-6	2000	335	31.56	12.25
TSE75-3-4	3000	750	26.23	8.24
TSE75-3-6	3000	500	35.12	9.36

Table 6. Analysis results for slab with profile sheet 1.5mm thick

Slab Designation	Span (mm)	Shear span (mm)	Load (kN)	Deflection (mm)
TSE75-2-4	2000	500	25.70	11.57
TSE75-2-6	2000	335	37.07	13.97
TSE75-3-4	3000	750	33.87	9.64
TSE75-3-6	3000	500	45.14	10.39

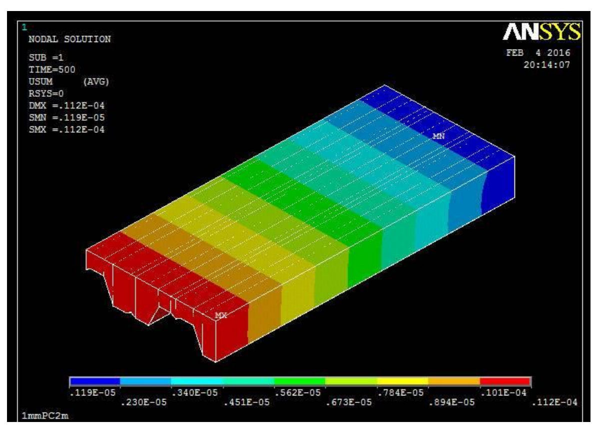

Figure 6. Result for TSE75-2-4 with 1mm thick profile sheet

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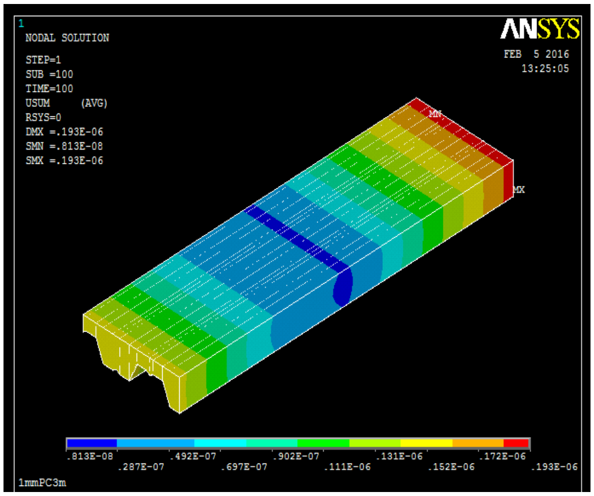

Figure 7. Result for TSE-3-4 with 1mm thick profile sheet

4. Conclusions

In this paper, analytical study of composite deck slabs using finite element analysis is carried out. Results from slab models with varying thickness and spans are presented. The ultimate load and maximum deflection are obtained from the analysis and the following conclusions are made:

i) For thickness of profile sheet to be 1mm, it is observed that load carrying capacity of composite slab increases by 40% with decrease in shear span length. The ultimate failure load of the composite slab decreases from shorter to longer shear span and moves towards the mid-span.

ii) For the same thickness, load carrying capacity increases by 25% as the span increases.

iii) As span of the slab increases from 2.0m to 3.0m, deflection is observed to decrease by 10%.

iv) Load carrying capacity of the slab increases by 20% as thickness of the profiled steel sheet increases from 1.00mm to 1.50mm.

v) It is observed that shear span is the factor which governs the longitudinal shear strength.

vi) The behavior of the profiled composite sheet deck slab depends mainly on the shear span.

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