ISSN (ONLINE): 2395-695X
ISSN (PRINT): 2395-695X

International Journal of Advanced Research in Basic Engineering Sciences and Technology (IJARBEST)
Vol.3, Special Issue.24, March 2017

Finite Element Modelling of the behaviour of Profiled Composite Deck Slab subjected to Bending

Sundararooban, S.R [#1], P.A.Krishnan [*2]

[#1] *M.tech, Stuctural Engineering, Dept. of Civil Engineering , NIT Trichy, INDIA*

[*2] *Professor, Department of CiviEngineering, NIT Trichy, INDIA*

Abstract— Cold formed profiled deck sheets have been popularly used in composite floor systems, since it acts as a working platform as well as formwork during construction stage and also as tension reinforcement for concrete slab during service. This paper is concerned with the nonlinear finite element modeling of the behavior of profiled deck composite slabs under bending loads. Shell elements are used to model the steel sheet and 3D Solid elements are used to model concrete. The interface between concrete and steel is characterized by penalty friction between these two surfaces which generates shear forces to resist tangential sliding. Elasto-plastic stress-strain curve is used for defining material properties of steel and concrete damaged plasticity model is used for defining material properties of concrete. Parametric studies are conducted to examine the effect of sheet thickness, grade of concrete, steel concrete interaction contact on the load and moment carrying capacity of composite slab. Finite element modeling of continuous composite slab is done and the negative moment carrying capacity of the slab is calculated for various percentage of reinforcements. The results of continuous composite slab is compared with slab with simply supported end conditions. This type of modeling gives reasonably acceptable results for modeling the behavior of simply supported as well as continuous profiled deck slabs under static loads.

Keywords: composite slabs, continuous composite slabs, concrete damaged plasticity model

I. INTRODUCTION

In a composite steel floor deck, the hardened concrete slab, acting compositely with the profiled steel decks, spans the supporting beams and carries the imposed live loads. 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 the 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 suitable shape in trapezoidal profile and also by the embossments. There are three distinct phases in the structural action of a composite deck system. In the first phase i.e. during the construction phase, the steel sheeting must rigidly support the wet concrete during casting. In the composite slab action phase, the composite steel concrete slab should support the imposed loads on the slab and in the composite beam action phase, the steel beams, which act compositely with concrete through the stud shear connectors, must support the imposed loads in the transverse

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direction. **Kmiecik et al.,** (2011) concentrated in the field of computer simulations of reinforced concrete structures. Since, concrete when subjected to compression exhibits nonlinearity right from the start and undergoes degradation under tension, they focused on parameters needed to correctly model concrete under compound stress. The parameters are illustrated using the Concrete Damaged Plasticity model included in the ABAQUS software. **Majdi, et al.,** (2014) investigated the structural behavior of a new type of composite floor system through finite element modeling. A local bond-slip model is applied to simulate the slip of the shear connector inside the concrete slab. A nonlinear analysis is performed on the composite floor considering all different types of structural nonlinearities and the behavior of the system is monitored from beginning of loading all the way to a defined point of failure. Results of finite element analyses are compared with experimental data. Further, parametric studies are conducted to determine the effect of shear connector's slip on reducing ultimate strength and initial stiffness of such a floor system.

B. Objectives

This study aims to investigate the behaviour of profiled steel concrete composite deck slab using finite element software package ABAQUS. The major objectives are

- To model the behavior of simply supported and two span profiled composite deck slab in finite element software.
- To obtain the load and moment carrying capacity of the respective slabs.
- To study the effect of thickness of steel sheet, grade of concrete and percentage of reinforcement on the sagging and hogging moment carrying capacity of composite slabs.

C. Methodology

The analytical investigation process consists of mainly 6 steps which start from identification of parameters up to the final result. Those steps are as following.

1) Identification of parameters for analysis.
2) Finite element modelling of profiled deck composite slab by using the commercial finite element software package ABAQUS.
3) Model validation.
4) Nonlinear static analysis for simply supported profiled deck composite slab.
5) Nonlinear static analysis for two span continuous composite slab.
6) Results and Discussions.

II. GEOMETRIC MODELING

Simply supported composite slab consists of two parts namely concrete slab and steel deck. Concrete slab is modeled by using solid elements and steel deck sheet is modeled by using shell elements. Trapezoidal steel deck with dimensions as shown in Fig.1 is considered for the study. The span of simply supported slab is 3.1 m. Continuous composite slab, in addition to concrete and steel deck contains reinforcement bars as shown in fig. 2. Reinforcement bars are modeled as truss elements. The length of each single span of two span slab considered is 3.1 m.

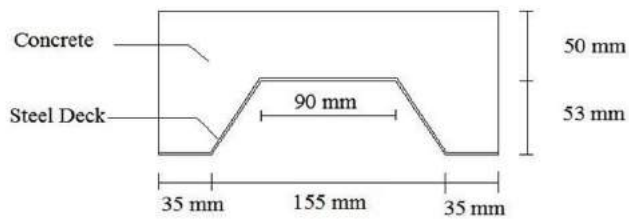

Fig. 1 Dimensions of Slab Section of Simply Supported Slab

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Concrete Property	Value
Modulus of elasticity for M20 concrete	22360 Mpa
Poisson's ratio	0.2
Density	25 kN/m^3

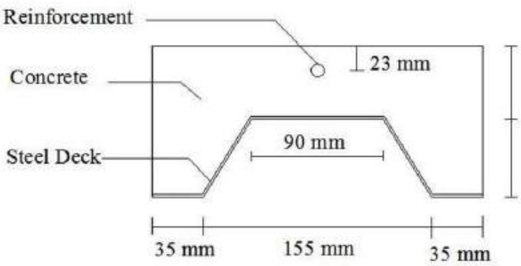


Fig. 2 Dimensions of Slab Section of Continuous Composite Slab

A. *Material Properties*

Steel Modelling- The properties of steel is shown in table 1. The plastic property of steel is incorporated in the model using the bilinear relationship which is reproduced in Fig. 3. In this model, the material is linear up to the yield stress (f_y). Thereafter, the behaviour becomes inelastic with hardening until the ultimate stress (f_u) is reached.

Table 1. Properties of Steel

Young's modulus	210000 MPa
Poisson's ratio	0.3
Yield stress	240 MPa
Density	78.5 kN/m^3

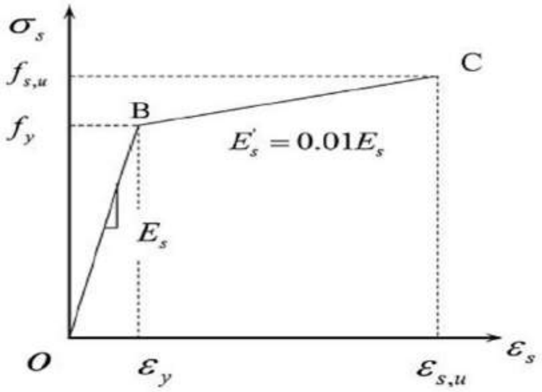


Fig 3. Stress-Strain model for the steel material (after Yan et al [5])

Concrete Modelling- The concrete was modelled using the concrete damaged plasticity (CDP) model in ABAQUS. In this model, the assumed two main failure mechanisms are compressive crushing and tensile cracking of the concrete. The material behaviour is defined in terms of the elastic, plastic, compressive and tensile properties. The elastic properties of concrete is shown in table 2.

Table 2. Properties of Concrete

The uniaxial compressive response of concrete was represented in the model as shown in fig 4. The charactersitc points in the graph such ε_{c1} and ε_{cu} are calculated using Majewski formulae given in eqs (1) and (2) (Kmiecik et al[7])

$$\varepsilon_{c1}=0.0014[2-e^{(-0.024fck)}-e^{(-0.140fck)}] \quad (1)$$

$$\varepsilon_{cu1}=0.004-0.0011[1-e^{(-0.0215fck)}] \quad (2)$$

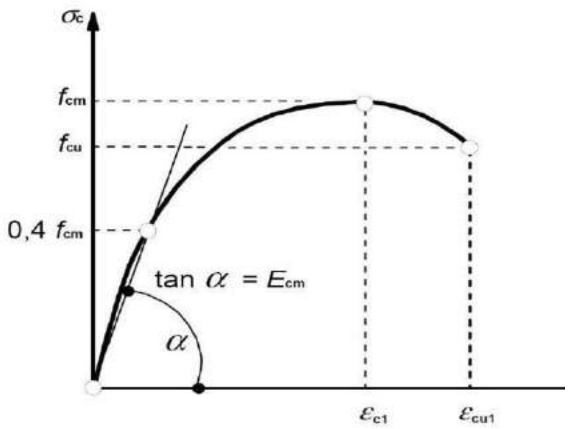


Fig. 4 Compression Stress-Strain Response of Concrete Subjected to Uniaxial Loading in ABAQUS

The tensile behaviour of concrete is employed by using Wang and Hsu approach. The model is shown in Fig. 5 and defined by Eqs. (3) and (4) (Kmiecik et al[7])

$f = E\,\varepsilon \qquad \varepsilon \leq \varepsilon_{cr}$

(3)

$f = f_{cr}\left(\frac{\varepsilon_{cr}}{\varepsilon}\right)^{0.4} \qquad \varepsilon > \varepsilon_{cr}$

(4)

where f is the concrete stress, E is the modulus of elasticity of concrete, f_{cr} is the cracking stress of concrete and ε_{cr} is the cracking strain. In addition to the compressive and tensile constitutive relationships, a number of other parameters are required in the CDP model, including: (i) dilation angle (Ψ); (ii) eccentricity (e); (iii) ratio of the strength in the biaxial state to the strength in the uniaxial state (σb0/σc0); (iv) parameter K; and (v) viscosity parameter. These parameters are assigned default ABAQUS values

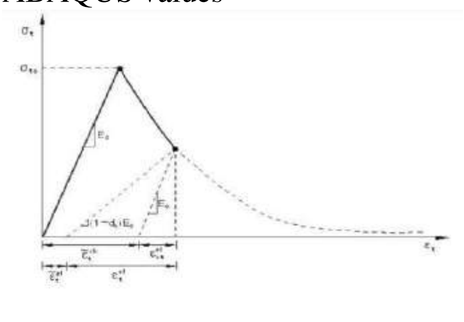
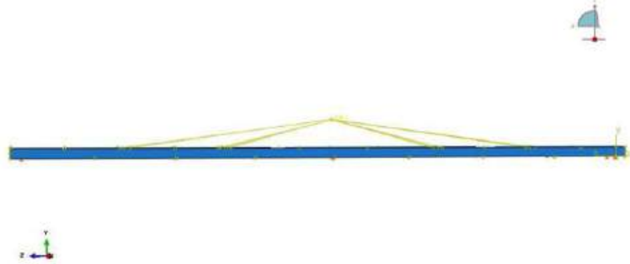


Fig. 5 Stress-Strain response of concrete in Tension Subjected to Uniaxial Loading in ABAQUS

B. *Element type and meshing*

The Steel section is modelled using shell element. S4R element type was chosen. S4R is a 4-noded doubly curved thin shell element, reduced integration, hourglass control. Concrete is modeled using solid elements. C3D8R element type was chosen. C3D8R is a 8-noded linear brick 3D solid element, reduced integration, hourglass control. Reinforcement bar is modeled using T3D2 element type, a two noded linear 3D



Truss element.

C. *Steel-Concrete Interaction*

The interface contact properties between the concrete and steel sheet were defined as follows:

- To produce a friction model that enables force resisting the relative tangential motion of the surfaces in the mechanical contact analysis, the 'tangential behaviour' was specified. Friction formulation field between the contact surfaces was selected as 'penalty' to allow some relative motion of the surface
- The normal contact behaviour for the interface was also defined as "Hard" contact for pressure-over-closure, and the "Default" constraint enforcement method was selected to enable the ABAQUS/Explicit analysis.

D. Loading and Boundary Conditions

Simply supported slab- All the translational degrees of freedom were

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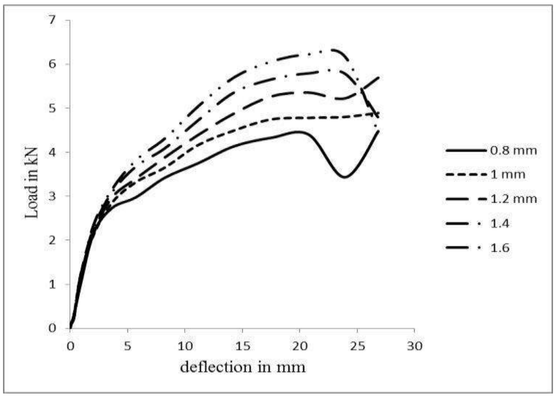
restrained at both the ends except the translational degrees of freedom in the axial direction at one end**.**

Continuous slab- At the end supports, translational degree of freedom in U2 direction is arrested and at the interior support the translational degrees of freedom in both U2 and U3 directions are arrested.

Loading- Load is applied in the form of displacement via a reference point to surfaces of 100 mm width at a shear span of 1050 mm from the nearby support.



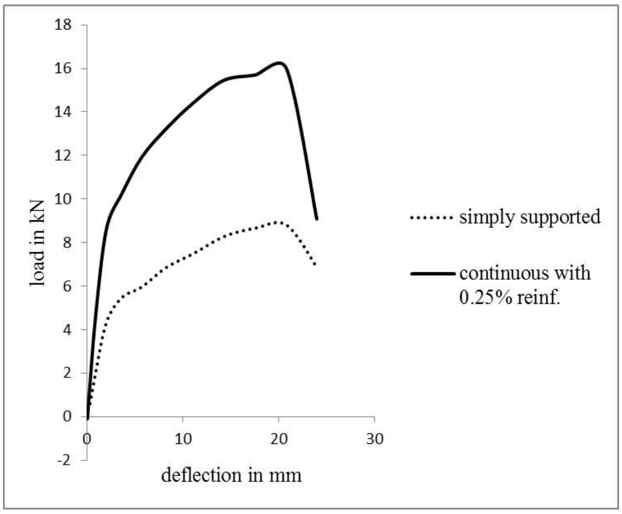
Kinematic constraint is introduced between the reference point and surfaces such that the displacement in U2 direction in the reference point is applied to the surfaces.

Fig. 5 Boundary Conditions and Loading

III. RESULTS AND DISCUSSIONS

A. Simply supported slab

The parameters used for the study are thickness of steel deck sheet and grade of concrete. Two point loading was applied on the shear span of 1050 mm. By increasing the thickness of steel sheet from 0.8 mm to 1.6 mm while keeping all the other parameters such as thickness of sheet, shape of profiled sheet, depth of concrete constant, the increase in load carrying capacity and



moment carrying capacity is about 37.75%. By using M40 grade concrete instead of M20 concrete while keeping all the other parameters such as thickness of sheet, shape of sheet, depth of concrete, there is about 14.91 % increase in load carrying capacity and moment carrying capacity of simply supported profiled composite slab.

B. Continuous Composite Slab

If the slab runs continuous over the supports instead of being simply supported, there is a significant increase in load carrying capacity of the slab. This is attributed to the fact that the presence of reinforcement at the tension zone at the support increases the negative moment carrying capacity of the slab significantly. About 92.5 % increase in load carrying capacity is achieved for this particular case, when the slab is made continuous with 0.25 % reinforcement instead being simply supported at internal supports because of the enhanced negative moment carrying capacity from zero to 5.084 kNm.

Fig 6 Effect of Thickness of Steel Sheet on Load Carrying Capacity

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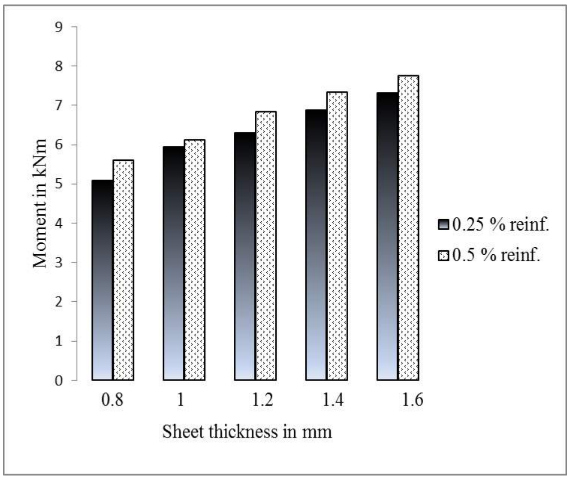
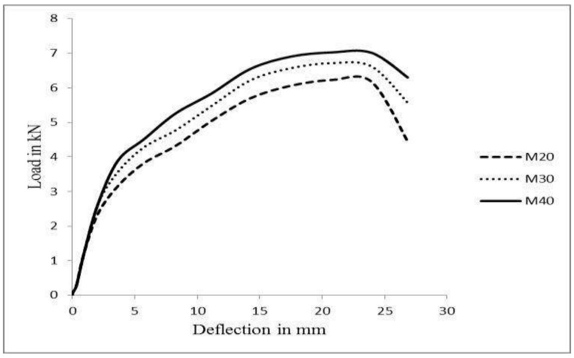
Fig. 7 Effect of Grade of Concrete on Load Carrying Capacity.



The effect of reinforcement percentage and thickness of steel sheet on the load and moment carrying capacity of the two span continuous slab is studied.

Fig 8 Comparison of Two Span Simply Supported Slab with a Two Span Continuous Slab



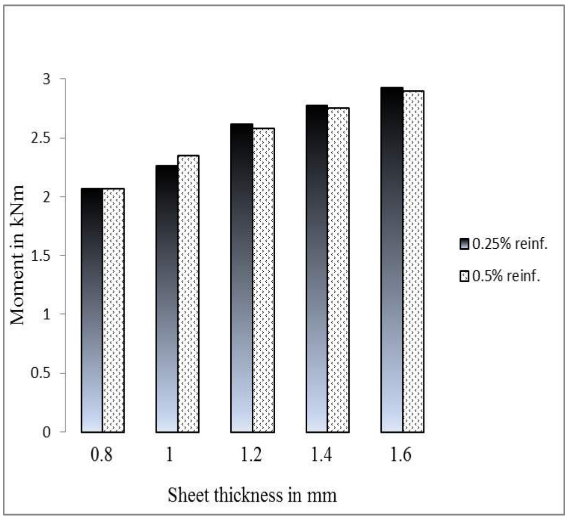


Fig. 9 Effect of Reinforcement Percentage on Maximum Sagging Moment

By increasing the thickness of steel sheet from 0.8 mm to 1.6 mm when keeping all the other parameters constant, it can be seen that the sagging moment value increases from 2.067 kNm to 2.928 kNm for a reinforcement percentage of 0.25%. This increase in sagging moment is almost 41.66%. Also it can be seen that if the percentage of reinforcement is increased from 0.25 to 0.5, there is significant increase in the hogging moment carrying capacity of the continuous composite slab. The increase in hogging moment for continuous composite slab with thicknesses 0.8 mm, 1 mm, 1.2 mm, 1.4 mm, 1.6 mm are 9.93%, 2.81%, 8.41%, 6.71%, 5.86% respectively.

Fig. 10 Effect of Reinforcement Percentage and Sheet Thickness on Hogging Moment

SUMMARY AND CONCLUSIONS

The simply supported and continuous composite slabs are modelled by changing the parameters. The non-linear analysis have been carried out with the Finite Element Analysis software ABAQUS. Based on the results obtained from the finite element modelling the following conclusions can be made. 1. The modelling of interface between

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steel and concrete by using contact properties, hard contact for normal behaviour and penalty friction for tangential behavior gives satisfactory results.

2. The increase in thickness of steel deck sheet and characteristic compressive strength of concrete increases the load and moment carrying capacity of slab.

3. There is huge increase in load carrying capacity if the slab is used as continuous slab with reinforcements to resist hogging moment than using the slab with end conditions as simply supported.

4. The increase in thickness of steel deck sheet increases the sagging moment carrying capacity and hogging moment carrying capacity of continuous profiled deck composite slabs.

5. The increase in percentage of reinforcement results in small amount of increase in the sagging moment carrying capacity.

6. The increase in percentage of reinforcement results in increase in the hogging moment carrying capacity of profiled composite deck slabs

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