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Finite Element Analysis of Composite Slab with Intermediate Stiffeners

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Abstract: The use of steel deck in combination with concrete results in an optimum solution bringing with it great advantages such as no form work, quick installation, and reduced dimensions and weight to construction of building floors. Essentially behaviour of composite slabs is governed by the horizontal shear bond at the interface of the steel deck and the concrete. The profile steel deck serves as tension reinforcement.The composite flooring system essentially consists of one-way spanning structural components. The slab spans between the secondary floor beams, whereas these secondary beams span transversely between the primary beams. In this paper, FE modelling of composite slab with considering different parameters like thickness of profiled steel sheet and number of intermediate stiffeners has been carried out by using ANSYS Workbench-14 software. Analysis was carried out to know the overall and load-deflection behaviour of the composite slab. It has been observed that as the thickness of sheet increases, deflection decreases for the constant load. Furthermore, the analysis shows that the intermediate stiffeners play major role to reduce the deflection

Keywords: *Composite slab, profile sheet, FE modelling, shear bond, intermediate stiffeners*

1. Introduction

The use of steel deck in construction of floor began in the 1920's. The deck commonly used was the main structural component for the floor of steel framed buildings. The concept of using steel deck, to act compositely with the concrete slab began in the 1950's. The behavior of steel profiled sheeting and concrete under load in composite structures is governed by the strength and stiffness of the connection between these layers. The behavior of composite slab is complex due to involvement of various parameters such as, thickness of sheet, embossment, stiffeners and shear studs. Attempts have been made by the researchers to predict the behaviour of composite slab using different methodologies such as FE analysis, numerical analysis and experimental studies. The behavior can be improved by achieving mechanical interlocking between steel and concrete using intermediate stiffeners, shear connectors, end anchorages and embossments.

Now a days in the world wide pertaining to technological development there is an enhanced intention imposed on building construction industry to improve time, economy and structural efficiency of structures over other traditional slab system. These advantages have been listed by Wright and Evans. Composite slab comprises profile steel sheet as permanent formwork during the construction and it serves as tensile reinforcement after the hardening of concrete, concrete, light mesh reinforcement (temperature reinforcement), shear studs, intermediate stiffeners and embossment. It is essentially consisted of one way spanning structural components. The slab spans between the secondary beams, whereas these beams span transversely between the primary beams.

There are three possible ways of failure types in composite slabs: flexural failure, longitudinal shear failure and vertical shear failure. Therefore, the efficiency of the composite slabs depends on the composite action between the steel sheet and concrete, and this action can be achieved by transferring shear forces between these two materials. The size, shape and position of the intermediate stiffeners exert a strong influence on the dominant buckling mode of the flange. Apart from the local mode of buckling involving deformation of the flat plate regions between stiffeners or webs, flanges may display distortional modes in which the stiffener moves normal to the plane of the element which is being stiffened. This mode involves deformation of the stiffener in such a manner that membrane stresses in the stiffener and the adjacent plate get involved in the solution of the governing equations.

2. Composite Slab

2.1. Geometry of Sections

Trapezoidal shape of the profiled steel sheet of CRIL-DECKSPAN was considered for the present analysis. The intermediate stiffeners were in the shape of a 'V' and a rectangle, hence the names V and R stiffeners. The intermediate stiffeners were present in the middle of the compression and tension flange as well as in the web of the steel sheet, with two longitudinal ribs. As depicted in fig 1 depth of V as well as R stiffener is 9.5 mm, 17 mm inclined length and width is 28mm. Total width of folded plate was 534 mm, height of sheet was 52 mm, while length was 2000 mm.

Thickness of profiled sheet have been considered as 0.6, 0.8, 1.0 and 1.2 mm. Depth of the concrete is kept as 102 mm. Composite slab is studied for bending test. For pure bending failure, shear must be zero. So two point loading is the better loading arrangement than one point load. Static loading 20 kN is applied at the top surface of the concrete slab.

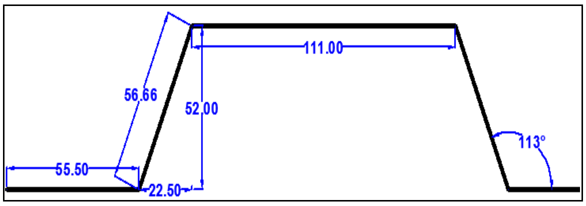
Material properties used for the profiled steel sheet andconcrete are as listed in table 1 and 2 respectively.

Table 1: *Concrete properties used in FE model*

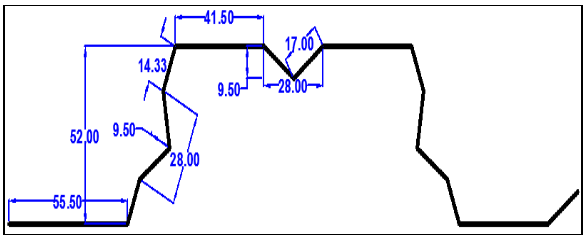
Density	**2300 kg/m3**
Poisson's ratio	0.2
Elastic modulus	21572 N/mm^2
Characteristic cylinder strength of concrete	30 N/ mm^2
Ultimate uniaxial tensile strength	2.58 N/ mm^2

Table 2: *Steel decking properties used in FE model*

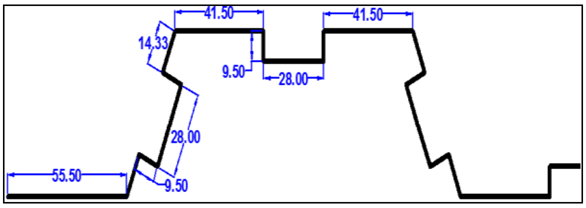
Density	**7850 kg/m^3**
Poisson's ratio	0.3
Yield stress	250 N/mm^2
Ultimate tensile strength	330 N/mm^2
Ultimate uniaxial tensile strength	2.58 N/ mm^2



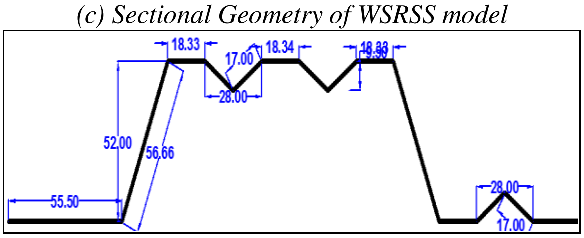
(a) Sectional Geometry of WoS model



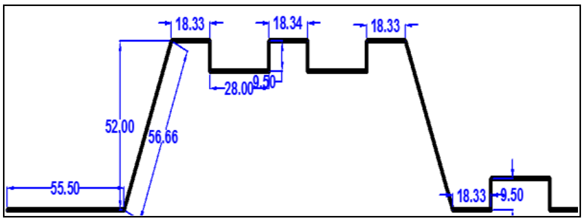
(b) Sectional Geometry of WSVSS model



(c) Sectional Geometry of WSRSS model



(d) Sectional Geometry of WDVS model



(e) Sectional Geometry of WDRS model

Figure 1: *(a), (b), (c), (d) and (e) shows the dimensions of profiled steel sheet with V and R stiffeners and without stiffener (all dimensions are in mm)*

Parameters shown in table 3 are considered for the analysis of the composite slab, where WSVS, WSRS, WDVS and WDRS are provided at the top and bottom flange of the sheet. WSVSS and WSRSS are provided in the web of the profiled steel sheet.

3. Finite Element Analysis

In the recent years, the study on modeling and analysis of composite slabs using finite element method has been a subject of research. Composite slab systems have a complex nature of interaction, due to which finite element modeling has become a powerful tool in predicting the slab strength and stiffness. For composite slabs, various models have been proposed. The selection of model types depends on the physical system of the slabs and specific need of the study. A few FE based studies were carried out to investigate behavior of one-way composite slabs. Daniels et al. used plane-beam elements to model one-way composite slabs. Special ten-degrees of freedom beam elements that can take into account nonlinear slip behavior between the steel deck and concrete slab was used. For this purpose, a special finite element code was developed.

This study focuses on FE modeling of composite slabs considering intermediate stiffeners on the top and bottom flange of profiled steel decking. Nonlinear three dimensional FE models are proposed, in which all main structural parameters and associated nonlinearities are included (concrete slab, profiled steel sheeting and its interface). ANSYS version 14.0 is used to conduct the analysis. It's pre-processor and postprocessor mode is excellent and its user interface is also good.

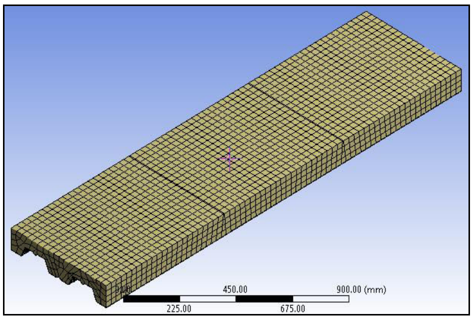


Figure 2: *Meshing of composite slab*

In the preliminary development of the FE model, material properties of concrete and steel decking as listed in table 1 and 2 respectively were taken into consideration. Contact problems are highly non-linear and require significant computer resources to solve. Contact body sizing mesh was done for all the models with 30 mm element sizes (fig. 2).

Total 28 models have been prepared of different combinations of shape, position and number of stiffeners as shown in the figure 1. FE models were prepared by considering different parameters and analysis was carried out. Models were simulated after defining the load. Comparative study of these parameters was done and the behavior of composite slab was observed. As a result mid span displacement, end slip, gap, external stresses are obtained.

- FE modeling for SV stiffener: In this modeling, single V stiffener was provided at the top and bottom flange of the sheet and analysis was carried out.
- FE modeling for SR stiffener: In this modeling, single R stiffener was provided at the top and bottom flange of the sheet and analysis was carried out.
- FE modeling of for DV stiffeners: In this modeling, double V stiffeners were provided at the top and bottom flange of the sheet, for all the thickness of the sheet and analysis was carried out.
- FE modeling of for DR stiffeners: In this modeling, double rectangular stiffeners were provided at the top and bottom flange of the sheet, for all the thickness of the sheet and analysis was carried out.
- FE modeling for SVS stiffener: In this modeling, single V stiffeners were provided at the top and bottom flange as well as web of the sheet and analysis was carried out.
- FE modeling for SRS stiffener: In this modeling, single R stiffeners were provided at the top and bottom flange as well as web of the sheet and analysis was carried out.

4. Results and Discussion

The parametric study was conducted with the different number, shape and position of the stiffeners and the total deflection, stress, slip and gap between concrete and profiled steel sheet has been observed. The results are tabulated in table 4 and 5.

Basically, this study covers two types of stiffeners according to the shape of stiffeners i.e. V Shape stiffeners and Rectangular (R) shape stiffeners. In this study two approaches are taken to determine the economical and viable intermediate stiffener model which enables a good strength, less slip, gap and deflection as compare to other models, so as to make it beneficial for industry. In the first approach, single and double stiffeners of both the shape were modeled on the top and bottom flange of the profile deck and results were compared with WoS. In the second approach, one more stiffener was added in the web of profile deck sheet and FE analysis was conducted on all the models to understand the behavior of the composite slab.

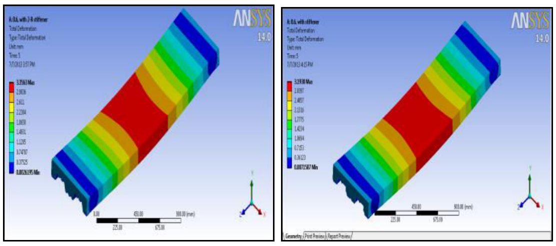


Figure 3: *Deflection contours for 0.6 mm thick profile sheet with WDRS and SVSS*

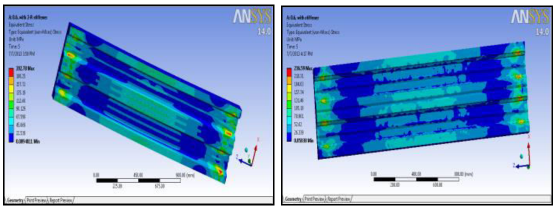


Figure 4: *Stress contours in WDRS model and WSVS*

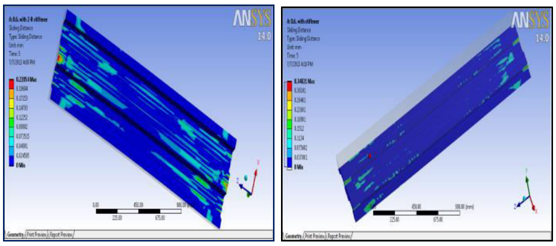


Figure 5: *Slip between concrete and steel sheet for WDRS and WSVS.*

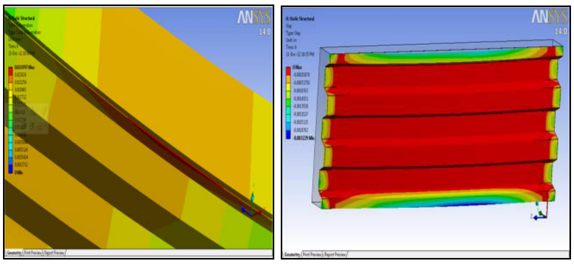


Figure 6: *Gap between concrete and steel sheet*

4.1. Effect of Single Stiffeners

WoS FE model is analyzed for all four thicknesses while keeping all the dimensions same. Figures 3 to 6 and tables 4 and 5 shows the comparison of total deflection at mid-span, stress, slip and gap for all four thicknesses. Figure 7 shows that WSRS undergoes very less deformation as compared to WSVS and WoS. Similar behaviour is observed in stress, slip and gap results. This observation shows that R stiffener reduces the deflection, slip, gap and stress as compared to V stiffeners because surface area of R stiffeners is more as compared to V stiffeners.

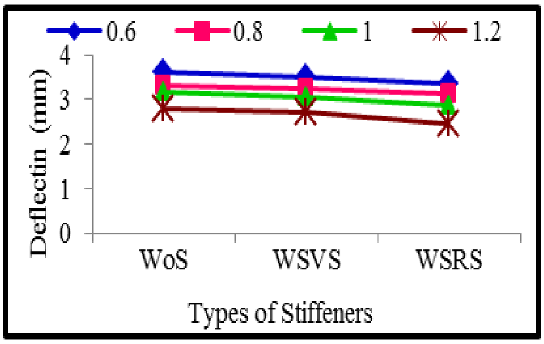


***Figure 7:** Deflection vs. type of stiffeners*

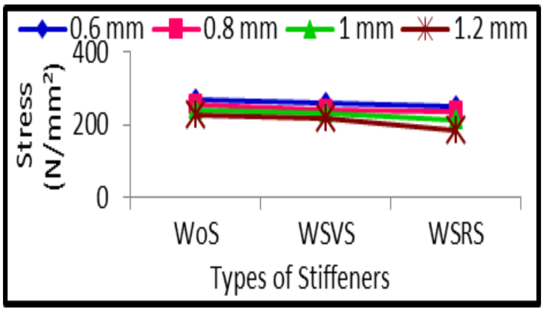


***Figure 8:** Stress vs. type of stiffeners*

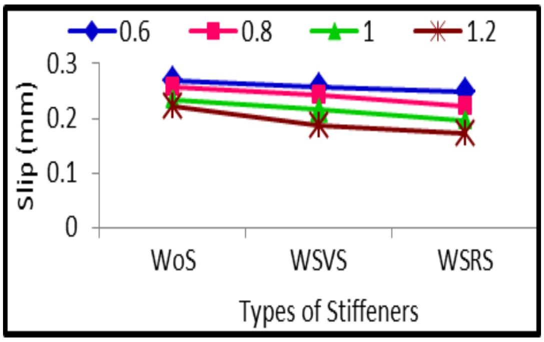


***Figure 9**: Slip vs. type of stiffeners*

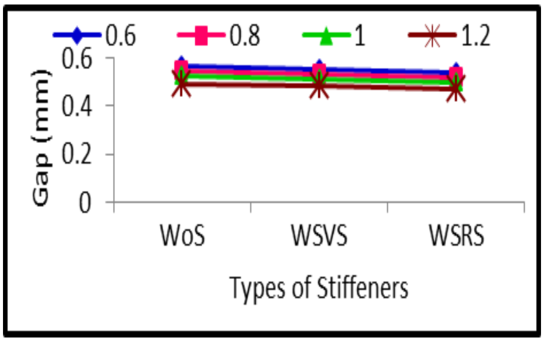


***Figure 10**: Gap vs. type of stiffeners*

4.2. Effect of Side Stiffeners and Double Stiffeners

In order to investigate the effect of different positions and numbers of stiffeners, two stiffeners were considered at the top and bottom flange. One more stiffener was added to existing shape of single stiffeners on the web of profiled steel sheet and in another case, one stiffener was added parallel to existing one on flanges of the sheet. Among these, 4 numbers of models were without stiffeners. Table 4 and 5 shows results of the parametric study of different stiffeners with sheet thickness varying 0.6 mm to 1.2 mm. Results indicate that side stiffeners are better than double stiffeners for all parameters i.e., deflection, stress, slip and for the gap. Also, this study indicates that R stiffeners are better than V stiffeners in the both the cases.

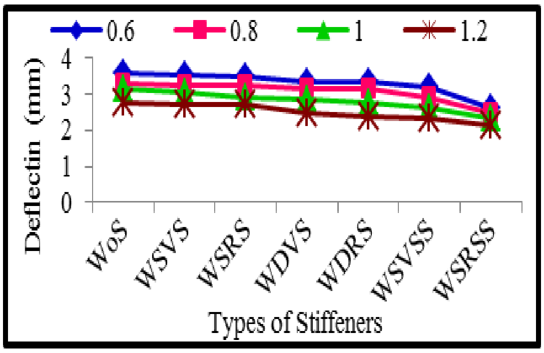


***Figure 11:** Deflection vs. types of stiffeners*

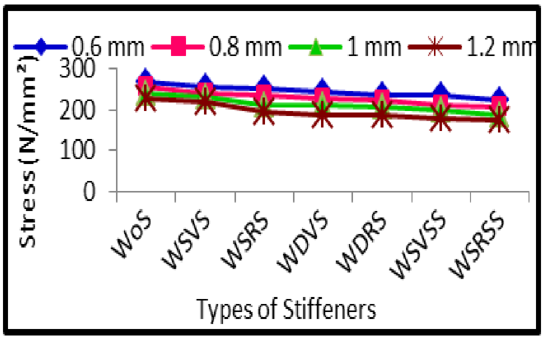


***Figure 12:** Stress vs. types of stiffeners*

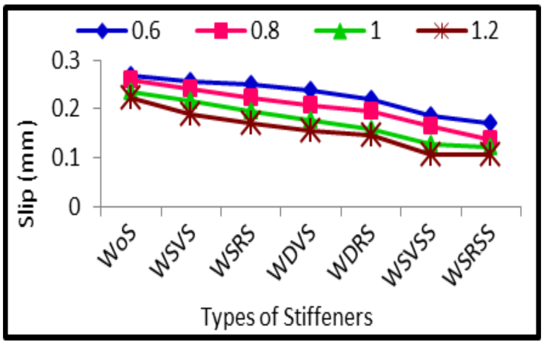


***Figure 13:** Slip vs. types of stiffeners*

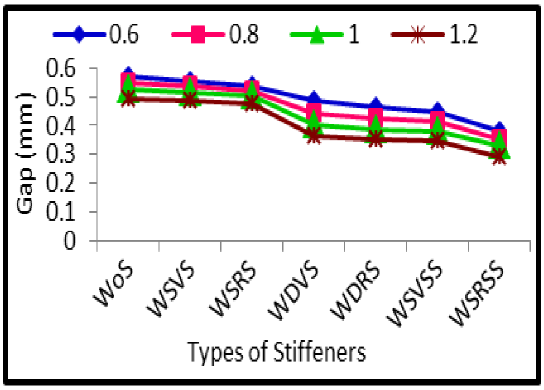


***Figure 14** Gap vs. types of stiffeners*

Table 3: *Parameters covered in this study are as below*

↓ Parameters Thickness →	0.6mm	0.8mm	1.0mm	1.2mm
Sheet without Stiffener (WoS)	√	√	√	√
With Single-V Stiffener (WSVS)	√	√	√	√
With Double-V Stiffener (WDVS)	√	√	√	√
With Single-R Stiffener (WSRS)	√	√	√	√
With Double-R Stiffener (WDRS)	√	√	√	√
With Single-V side Stiffener(WSVSS)	√	√	√	√
With Single-R side Stiffener (WSRSS)	√	√	√	√

Table 4: *Comparison of deflection and stresses in composite slab obtained from finite element analysis*

Description	Deflection (mm)				Stress (N/mm^2)			
Thickness	0.6 mm	0.8 mm	1 mm	1.2 mm	0.6 mm	0.8 mm	1 mm	1.2 mm
WoS	3.605	3.299	3.156	2.7865	267.12	254.25	241.38	228.51
WSVS	3.52	3.2585	3.0645	2.719	257.54	241.21	233.41	218.54
WDVS	3.4681	3.17	2.9125	2.6954	243.5	228.54	211.5	193.8
WSVSS	3.1959	2.9091	2.6225	2.3312	237.13	211.7	199.99	178.28
WSRS	3.3563	3.2373	2.8645	2.4517	257.26	234.13	210.4	186.67
WDRS	3.321	3.1286	2.7784	2.3545	236.11	223.34	208.57	186.15
WSRSS	2.6177	2.4654	2.3086	2.1518	224.03	205.61	184.56	175.54

Table 5: *Comparison of slip and gap between steel sheet and concrete obtained from finite element analysis*

Description	Slip (mm)				Gap (mm)			
Thickness	0.6 mm	0.8 mm	1 mm	1.2 mm	0.6 mm	0.8 mm	1 mm	1.2 mm
WoS	0.262	0.2583	0.2354	0.2225	0.5686	0.5465	0.5244	0.4923
WSVS	0.2564	0.2414	0.2154	0.1876	0.5554	0.5354	0.5154	0.4854
WDVS	0.238	0.2077	0.1946	0.1715	0.5363	0.5173	0.5004	0.4735
WSVSS	0.1846	0.1642	0.1279	0.1072	0.4652	0.4251	0.385	0.3449
WSRS	0.256	0.2211	0.1754	0.1555	0.4838	0.4431	0.4024	0.3617
WDRS	0.2205	0.2045	0.1574	0.1453	0.4461	0.4145	0.3829	0.3513
WSRSS	0.1706	0.1381	0.1225	0.1057	0.3821	0.3511	0.3324	0.2899

5. Conclusions

Modelling was done with ANSYS Version-14 for various parameters and the conclusions are summarized as:

The thickness of plate has a considerable effect on the behavior of composite slab. It is observed that all the results viz. deflection, stress, slip and gap decreases by 25% to 30% as the thickness of plate is increased from 0.6 mm to 1.2 mm.

Considering the V stiffeners, the results of WDVS are more acceptable compared to WSVS and similar behavior of WDRS is observed compared to WSRS. Comparing the WDVS and WDRS, it is observed that both the stiffeners are giving better results for all the parameters but amongst them, in general WDRS are giving 5 - 11% better results than WDVS.

When WDVS and WDRS were compared to WoS, WDVS reduces the slip and gap by 7-15% and 6-10% respectively whereas, with WDRS, slip and gap reduced by 18-20% and 15-19% respectively.

WSVSS reduces deflection and stresses by 10-15% compared to WSVS and WSRSS reduces deflection and stresses by 20-30% compared to WSRS.

When the behavior of side stiffeners is compared, it is observed that WSRSS are better than WSVSS, as WSRSS reduces results by 25% compared to WSRS, whereas, WSVSS reduces results only by 10% compared to WSVS. Also, the results of WSVSS are better than WDVS by 5 to 9% in deflection and stresses.

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