iJET International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 2 No. 7, July, 2012

Experimental and Numerical Studies on Composite Deck Slabs

Baskar. R
Department of Civil & Structural Engineering,
Annamalai University, Annamalainagar – 608 002, Tamilnadu, India

ABSTRACT

This paper describes a study on experimental and finite element modeling of Composite deck slabs with and without embossments. In the composite slabs, mechanical interlocking in the form of embossments or shear connectors were used to transfer shear between the outer skin of the plate and the concrete core. The current study was based on finite element analysis using ANSYS8. In the experimental programme, carried out by author, ten simply supported composite deck slabs were tested to failure under two point line load at L/4 (Shear span) of the span. These tested specimens were analysed by the finite element method and the analysis have shown these slabs displayed a high degree of flexural characteristics, ultimate strength and ductility. Close agreement had been observed between the finite element and the experimental results for ultimate loads and load deflection responses. The finite element model was thus found to be capable of predicting the behaviour of composite deck slab accurately.

Keywords: *Composite deck slab, Embossments, Shear connectors, Cold form steel section, Finite elements, Non linear analysis.*

1. INTRODUCTION

Composite behaviour is the one which occurs after a floor slab comprising profiled steel sheet, additional reinforcement if any, and hardened concrete are formed into a single structural element. The profiled steel sheet shall be capable of transmitting horizontal shear at the interface between the sheet and the concrete; pure bond between steel sheeting and concrete. Composite behaviour between profiled sheet and concrete shall be ensured by one or more of the following means:

i) Mechanical interlock provided by deformations in the profile (indentations or embossments).

ii) Frictional interlock for profiles shaped in a re-entrant form.

iii) End anchorages provided by welded studs or another type of local connection between the concrete and the steel sheet.

iv) End anchorages by deformation of the ribs at the end of the sheeting.

v) Natural bond between concrete and steel due to adhesion.

The understanding of the relative economics of steel and concrete resulted in increasing use of combinations of these materials. The major advantages of steel are its speed of construction, high strength-to-weight ratio, and relative ease in fabricating complex arrangements. Concrete, on the other hand, is more economical for providing rigidity in structural systems.

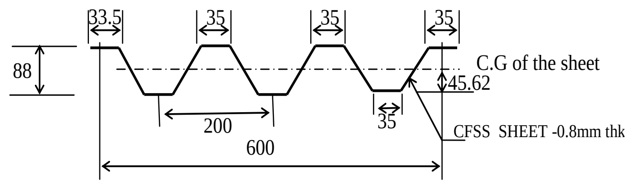
Samuel Easterling W. and Craig S. Young (1), presented an analytical approach for the strength determination of composite slabs. The approach was based upon conventional reinforced concrete concepts along with elastic analysis principles. Results from nine experimental slab tests, which were used to validate the analytical approach, had been presented. Veljkovic (2), studied the behaviour of shear-bond resistance which comprises of three components: friction, chemical adhesion, and mechanical interlocking. He predicted that friction effects were greatest at the supports where the normal force was the greatest, but friction also acts along the span for decks with re-entrant geometries. Luttrell and Prasannan (3), reconsidered the assumption that in the flexure mode, the slab behaves like a reinforced concrete section with the deck's tensile force acting at its centroid. They argued that the steel deck behaves differently than embedded reinforcing bars because the deck was only bonded on one surface and was free to deflect on the other surface. Makelainen and Sun (4), studied the embossment location and predicted that optimal was at the middle of the web. Embossments at the corner of the web and flange were very difficult to construct and did not display much improvement in shear resistance. Embossments in the tension flange flattened upon loading, decreasing their effectiveness. Penetrant embossments greatly improved shear resistance by the concrete that entered the holes. Increased deck thickness also improved shear resistance.

Veljkovic (5), determined some deficiencies in the prescribed partial shear connection method. Its applicability was limited to ductile slabs only, a constraint that must be checked especially for short span slabs which tend to be brittle. Veljkovic (6), conducted a parametric study on the behaviour of composite slabs consisting of profiled steel sheeting and concrete. The finite element programme DIANA was used to model the slab as a two-dimensional structure. Non-linear material and interface properties were considered as well as discrete cracking of the concrete. Shanmugam, N. E., Ghanshyam Kumar, and V. Thevendran (7), dealt with finite element modelling of double skin composite slabs using ABAQUS. In a double skin composite slab, shear connecters in the form of welded studs were used to transfer shear between the outer skin made of steel plates and the concrete core. Clinton O. Rex, and W. Samuel Easterling (8), presented a component model that could be used to predict the load-deformation behaviour. The load-deformation behaviour of a reinforced composite slab was required to determine the moment-rotation behaviour of a composite partially restrained connection. Oreste S. Bursi et al. (9), investigated the seismic performance of moment-resisting frames consisting of steel-concrete composite beams with full and partial shear connection. Six full-scale composite substructures with headed stud shear connectors had been tested. The corresponding inelastic responses to both monotonic and variable reversed displacements had been investigated. All together, they represent basic aspects of the composite deck systems and are the issues that the paper explores further. This paper primarily considers the development of new finite element model for the composite slabs without embossment, composite slabs with embossments, and composite slabs with embossment and with shear connectors and the results are validated with the experimental results.

2. COMPOSITE DECK SLABS

2.1 Deck Sheet Description

In this study, the deck sheet used was 0.8 mm thick and tested by conducting a coupon test and the results are shown in Table 1. The shape and dimensions of the deck sheet are shown in figure 1.



All dimensions are in mm

Figure 1 Dimensions of CFSS sheet (88-200 profile)

Table 1. Tension test on deck sheet

Modulus of Elasticity E_{ds}	Yield stress f_{yds}	Ultimate stress f_{uds}
2.1×10^5 N/mm^2	375 N/mm^2	400 N/mm^2

Table 2. Summary of test plan

Sl No.	Specimen identification	Details
1	WOE1	CFSS sheet without embossment
2	WOE2	
3	WOE3	
4	WE1	CFSS sheet with embossment
5	WE2	
6	WE3	
7	WE4	
8	WEWS1	CFSS sheet with embossment and with end anchorages
9	WEWS2	
10	WEWS3	

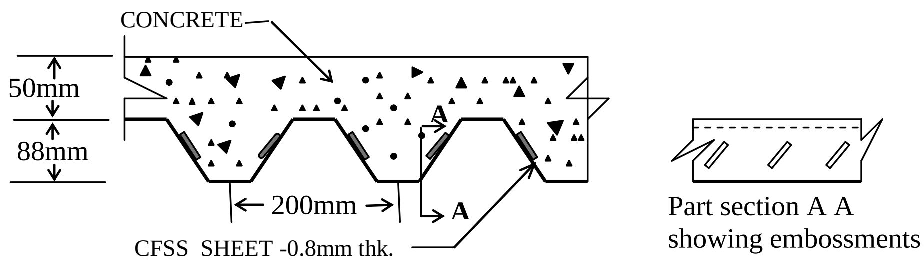


Figure 2 Composite slab with embossments

2.2 Embossment Details

Shear connection is provided either by pressed or rolled dimples as shown in figure 2 that project into the concrete, or by giving the steel profile a re-entrant shape that prevents separation of the steel from the concrete. In this study, embossments were introduced at the web portion of the deck sheet which acted as shear key between concrete and deck.

Embossments were projected for 3.75 mm towards the concrete portion as shown in figure 3 (a)**.** The embossments were spaced at 200 mm c/c and placed along the length of the sheet as shown in figure 3 (b)**.** The shape of the embossments is elliptical and the exact dimensions are shown in figure 3 (c). The size and shape of the embossments were measured for the sheets and the variation of shapes of embossments were well within the limit.

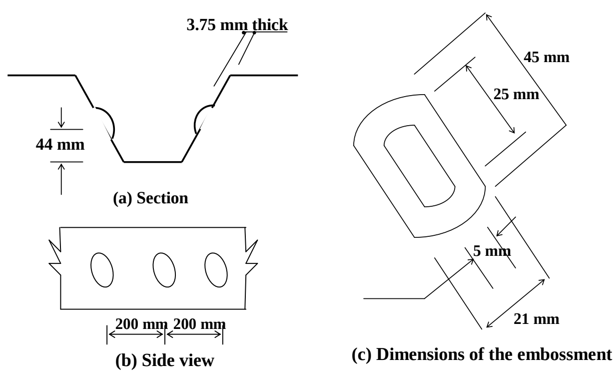


Figure 3 Embossment details

2.3 Shear Connectors

The most widely used type of connector is the headed stud. These vary in diameter (d_s) from 13 to 25 mm, and in length (h_s) from 65 to 100 mm, though longer studs are sometimes used. In this study, 16 mm diameter and 110 mm length with 24 mm head shear connectors as shown in the figure 4 were used.

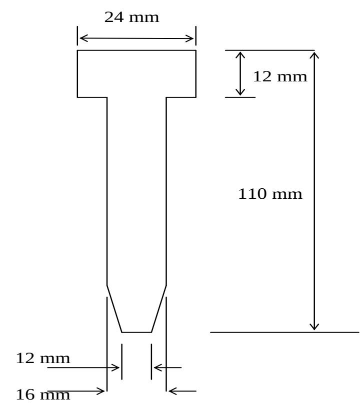


Figure 4 Details of the stud shear connector

2.4 Design Mix Ratio and Strength

For the high workability and control of slump loss, super plasticizer was used by reducing the water content by 15%. The mean strength of concrete used for composite slabs was 55.11 N/mm^2. The concrete mix proportion was 1: 1.16:2.93 with the water cement ratio of 0.38. An admixture of conplast SP 430 (Fosroc Chemical-0.625lit per 50 kg of cement) was used for this study.

3. EXPERIMENTAL PROGRAMME

Ten full-scale slabs were cast and tested for this experimental programme. Initially seven slabs (i.e., for WOE and WE group) were cast. WOE group of three slabs were cast with fully supported condition. Similarly WE group of four slabs were cast with fully supported condition. The details of specimens are shown in Table 2. WEWS group of three slabs were cast with end anchorages. WEWS groups were cast over the profiled deck sheet which was placed over the ISMB 200 (Indian Standard Medium Beam, Depth 200 mm) and welded through the headed studs on the top flange of the - I - beam. All the slabs were cast on the same day with same mix ratio.

3.1 Test Set Up

The flexural test for the deck slab was conducted to determine the flexural capacity of the slab. This test also gave the relation between the load and deflection, load and strain, and the moment and curvature of the slab. The flexural tests were conducted as per Eurocode4 specifications. The test set up is shown in figure 5.

The deck slab of size 3200 mm x 645 mm was simply supported on its shorter sides. Two line loads were applied to the slab at their respective quarter span points (Ls = L /4) with a hydraulic jack and a proving ring as shown in figure 5.

Seven dial gauges (DG_1 to DG_7) were used for the above study: one on each crest adjacent to the center of the slab (DG_1 and DG_2), one at the center of the slab (DG_3 - to compute the maximum deflection), one below each line load points (DG_4 and DG_5), and one on each support above the slabs (DG_6 and DG_7) were positioned (figure 6). Five strain gauges (SG1 to SG5) for each slab were pasted on the bottom of the deck sheet to measure the strain at the tensile zone. SG1 and SG5 were pasted below the load points, SG2, SG3, and SG4 were pasted along the midspan as shown in figure 6a. Ten demec pins each were pasted on the constant bending moment zone on both the compression and tension sides as shown in figure 6b.The test set up is shown in figure 7

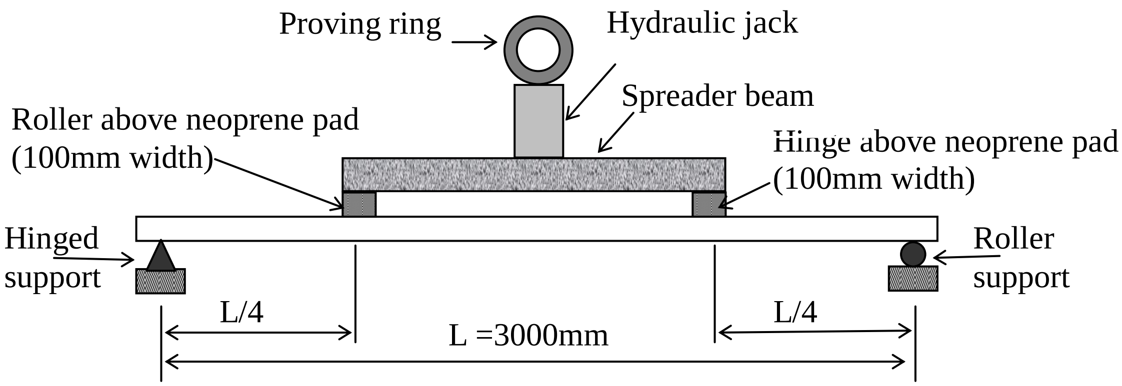
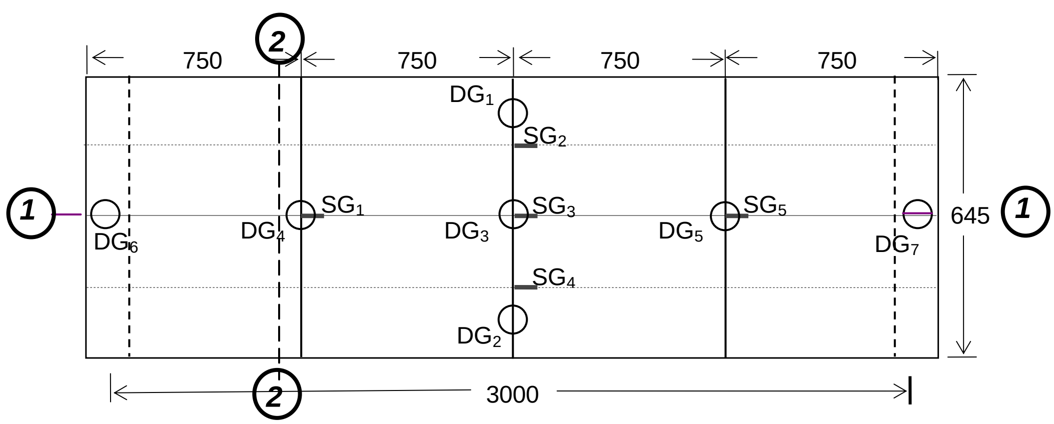
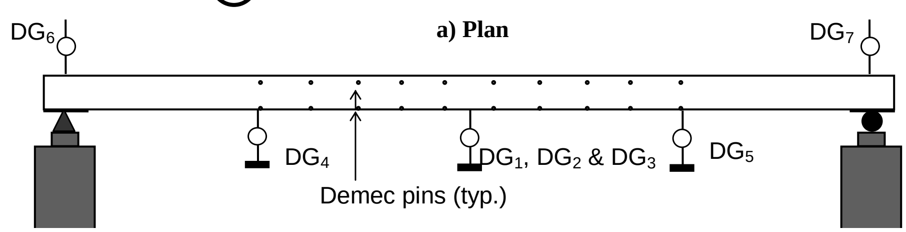


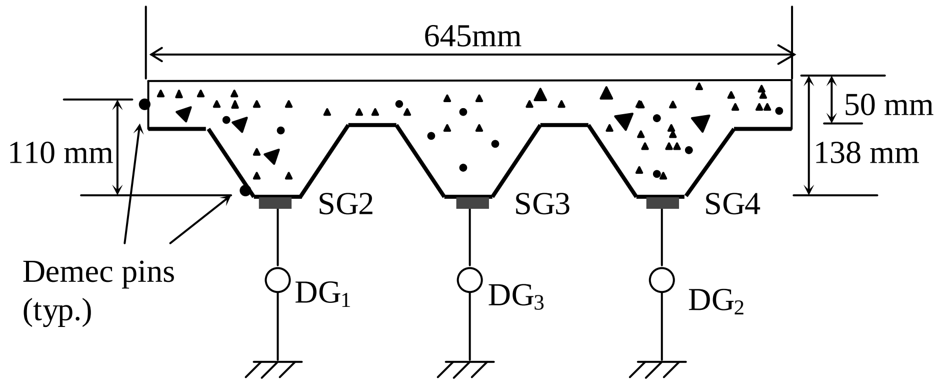
Figure 5 Flexural test set up as per Eurocode4



a) Plan



b) Elevation 1-1



c) Section 2-2

Figure 6 Instrumentation set up for flexural test

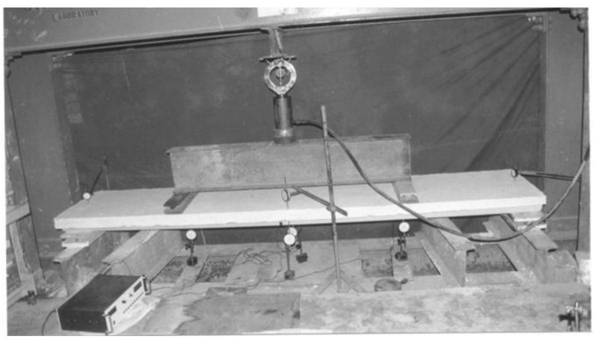


Figure 7 Flexural testing of composite deck slab

3.2 Experimental Procedure

Two - point line load was applied through the jack and the corresponding deflections were recorded. The load was increased gradually by 1 kN. For each increment of loading, the values of deflections at seven dial gauges, the strain readings from the five strain gauges, and nine demec gauge strain readings were recorded. The experiment was conducted till failure and the values of applied load, deflections, strain at the tensile zone from stain indicator, and strain from the demec gauge were recorded. The delamination of composite deck slab was also recorded for the specimens.

4. FINITE ELEMENT MODELLING AND NON – LINEAR ANALYSIS

The finite element (FE) method in comparison with the most common analytical methods is a powerful tool to study the behaviour of the composite slabs. A general purpose finite element code, ANSYS was utilized in this study to analyse the behaviour of the composite deck slabs. ANSYS, including a variety of its routines, allows for the implementation of specific material models (Profiled sheet, concrete, steel, and shear stud), and boundary conditions, and bond behaviour. The interaction between the profiled deck sheet (which act as reinforcement) and concrete, minimum reinforcement (provided to take care of shrinkage and handling stresses) and concrete could also be considered. In the numerical analysis, the brittle property of concrete was simulated with a solid element that could change its stiffness with the development of cracking and crushing of concrete. The two types of slips, both longitudinal and transverse among different materials were modelled with spring elements. Comparisons of the load versus deflection curves between FE analysis and laboratory tests were made. The methodology developed here could also be applied for other analysis on composite slabs.

The analysis was performed by applying an incremental load, with iterations in each increment. The modified time to time algorithm with assumed proportional loading history was used. This approach determined the static equilibrium solutions for unstable response in concrete, due to cracking in tension, yielding of reinforcement, and concrete softening in compression. It neglected any permanent strains associated with cracking. In this study, the analysis was carried out using the following elements of ANSYS library: SHELL93, SOLID65, BEAM4, COMBIN14, and COMBIN39.

4.1 Elements Modelled Through Software

Elements of composite slab modelled using SOLID65, SHELL93 (WOE, WE, and WEWS group), BEAM4 elements are shown in figures 8 to 11.

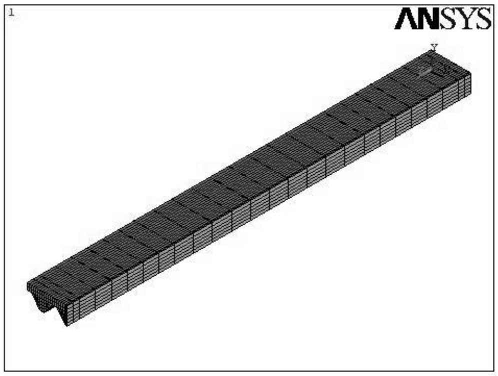


Figure 8 SOLID65 concrete model

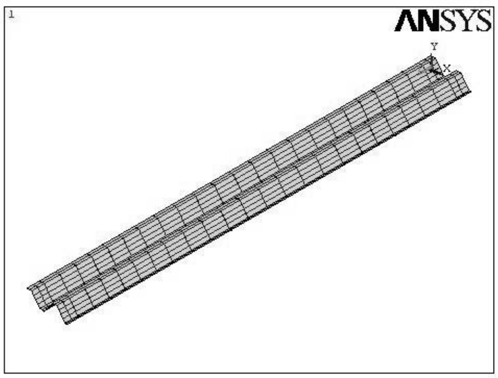


Figure 9 SHELL93 profiled deck sheet WOE model

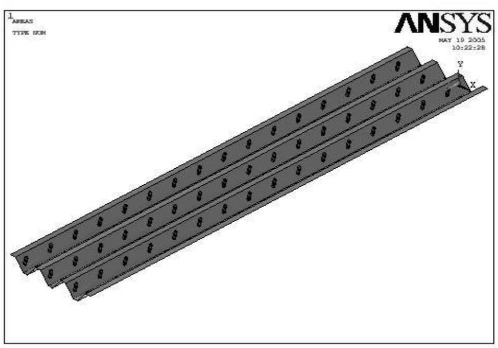


Figure 10 SHELL93 profiled deck sheet WE model

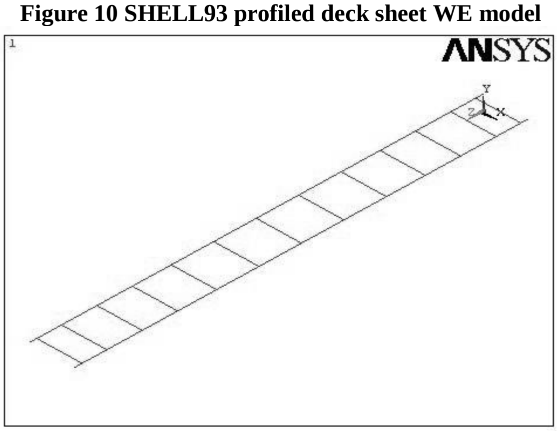


Figure 11 BEAM4 reinforcement (rebar)

4.2 Finite Element Property for Concrete

Concrete strength is high in compression and low in tension. When the composite slab was subjected to flexural bending, tension in the slab would result in the formation of cracks perpendicular to the principal stress direction. The SOLID65 element offered by ANSYS could simulate this non-linear property of concrete. The element behaves as a linear elastic material until the stress reaches the tension or compression strength. Once the principal stress exceeds the strength at an integration point, the stress-strain relation of the element would be modified by introducing a plane of weakness in the direction normal to the stress to represent the cracking.

The failure surface was defined by a total of five strength parameters, but it could also be specified by a minimum of two constants, tensile strength of concrete (f_{tconc}) and cylinder compressive strength of concrete (f_{cy}). After cracking, the tension stress of the concrete element was set to zero in the direction normal to the crack plane. The shear transfer coefficient β_t for open cracks and β_c for closed cracks determined the amount of shear transferred across the cracks. The value of the shear transfer co-efficient ranged from 0.0 to 1.0, with 0.0 representing no shear transfer at a crack section and 1.0 representing full shear transfer. In this study, β_t was assumed to be 0.3 and β_c was assumed to be 0.5. The higher values of the shear transfer coefficient were used to avoid convergence problems during iteration. The material properties of steel and reinforcement were specified with the typical bilinear idealization in both tension and compression (figure 12). The strain hardening modulus E' was assumed to be $0.005E_s$. The reinforcement was simulated using the BEAM4 element, and the profiled steel was simulated using the SHELL93 element.

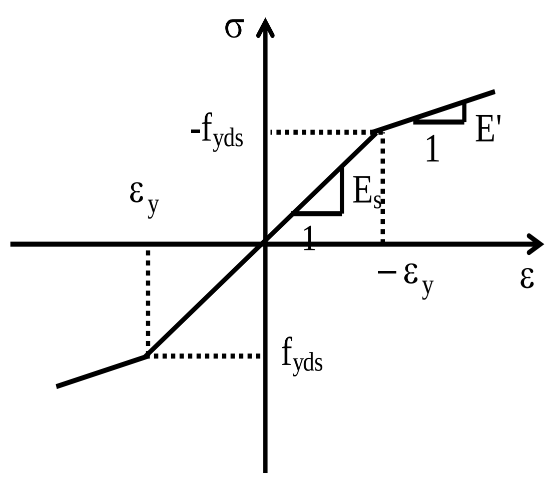


Figure 12 Assumed stress – strain relationship for steel and reinforcement

4.3 Bond-Slip Relationship

In the FE analysis the bond-slip relationship between concrete and profiled deck sheet was simulated using the COMBIN14 linear spring element. Every node between two BEAM4 elements was jointed with a spring element parallel to the reinforcement element. Thus, the bond stresses depend only on the longitudinal slip. The stiffness of the spring was obtained from the secant of bond stress versus slip curve Jianguo Nie, Jiansheng Fan, and C.S. Cai (10), and it is given by

$$K_r = \frac{l_{E1} + l_{E2}}{2} K_2 \qquad (1)$$

where l_{E1}, l_{E2} = lengths of two adjacent BEAM4 elements.

The shear studs were modelled by non-linear spring element COMBIN39. Typically, the actual load-slip curve of the stud connectors and embossments was obtained by push-out test. Wang (11), had shown that the curve was generally non-linear and it was reasonable to use a non-linear spring in modelling the mechanical behaviour of the connectors. The constitutive relationship of the spring was given by Ollgaard, J.G., R.G. Shelter, and J.W. Fisher (12)

$$F_s = P_{Rd}\left(1 - e^{-n_t s_i}\right)^{s_t} \qquad (2)$$

where F_s = load on a shear stud, s_i = slip at concrete steel interface. The parameters s_t and n_t define the shape of the curve, and the typical values used in this study are s_t = 0.558, n_t =1 mm^{-1}. Jianguo Nie, Jiansheng Fan, and C.S. Cai (10)

4.4 Three-Dimensional Modelling

The FE models subjected to flexural bending were developed to represent the tested specimens. Due to the symmetric geometry and loading in both transverse and longitudinal directions, only one half of the slab in longitudinal direction was modelled as shown in figure 13. A typical model of cross section of the composite slab used for this study is shown in figure 14. A typical load pattern and the support conditions are shown in figure 15. The typical length of the slab is 3200 mm. A simply supported boundary condition was assumed for the composite deck slab and the gravity of the materials was included in the element.

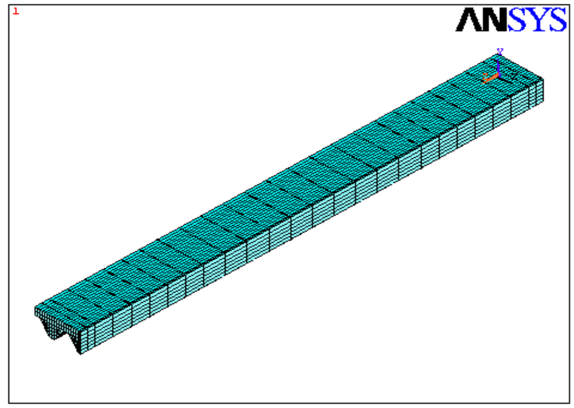


Figure 13 Three dimensional mesh for WOE

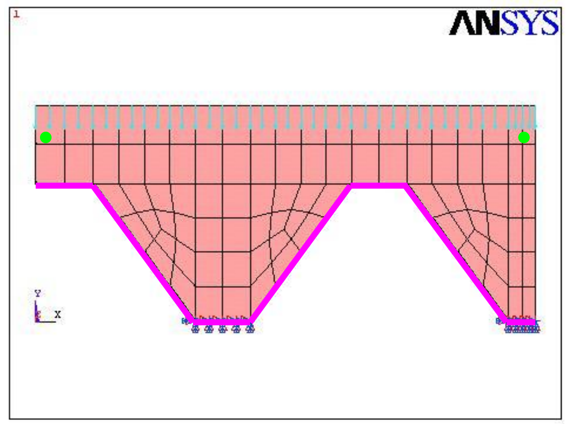


Figure 14 Cross section of three dimensional meshes for composite slab

To consider the effect of slips, a spring element was used to simulate the tested specimens including the slip effect. The primary parameters varied in the study were the profiled deck sheets without embossments (WOE), with embossments (WE), and with embossments and with end anchorages (WEWS).

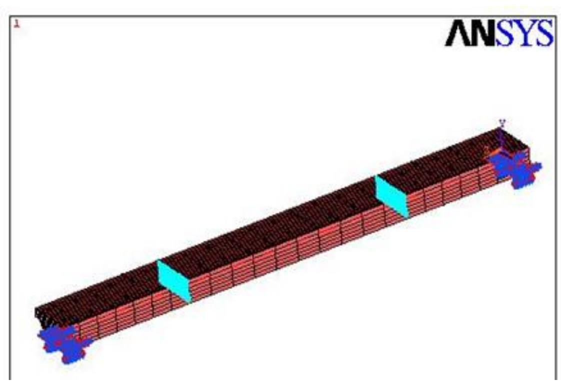


Figure 15 Load pattern and support conditions

4.5 Analysis Results

4.5.1 Composite Deck Slab without Embossments

Composite deck slab without embossments was analysed by using SHELL96, SOLID65 BEAM4, and COMBIN14 elements. The deformed shape of WOE is shown in figure 16. The load deflection behaviour of slabs of WOE group obtained experimentally and numerically are shown in figure 17. From the results, it was shown that the experimental and numerical solutions were reasonably in good agreement for WOE group.

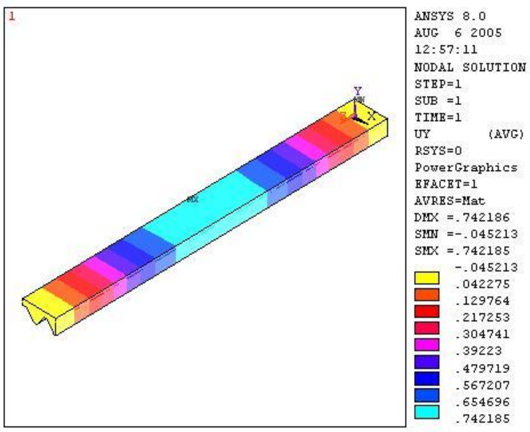


Figure 16 Deformed shape of WOE

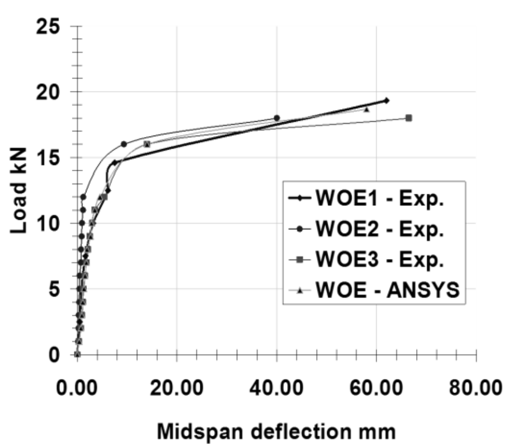


Figure 17 Load deflection curves of WOE group

4.5.2 Composite Deck Slab with Embossments

Composite deck slab with embossments were analysed with SHELL96, SOLID65, BEAM4, and COMBIN14 elements. In this case, embossments were modelled with the help of PRO Engineer (PRO E) software. A punch tool was modelled with exact dimensions of embossments. The same tool had been used over the sheet metal module to form the embossment over the profiled deck sheet. The model was imported to ANSYS software and the properties were assigned. The deformed shape of WE is shown in figure 18. The load deflection behaviour of slabs of WE group obtained experimentally and numerically are shown in figure 19.

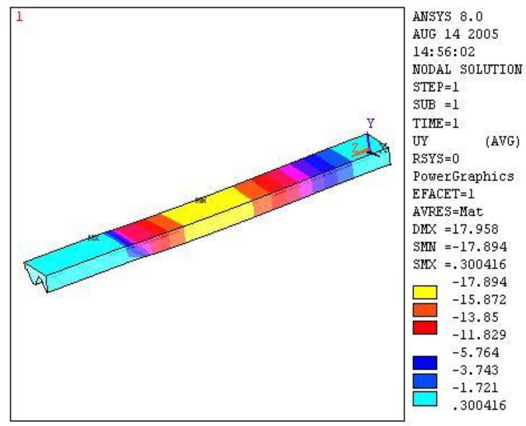


Figure 18 Deformed shape of WE

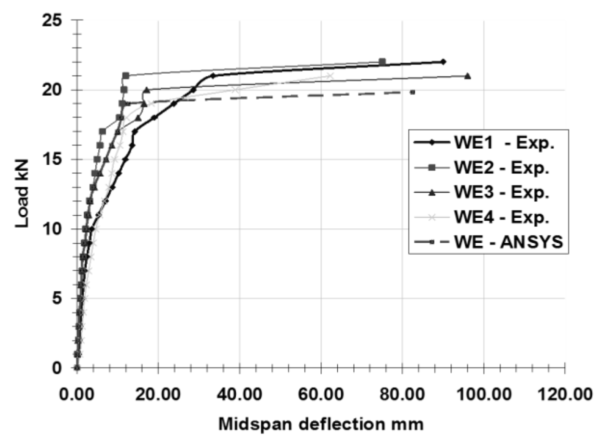


Figure 19 Load deflection behaviour of WE group

4.5.3 Composite Deck Slab with Embossments and with End Anchorages

Composite deck slab with embossments and with end anchorages were analysed with SHELL96, SOLID65, BEAM4, COMBIN14, and COMBIN39 elements. The deformed shape of WEWS is shown in figure 20. The load deflection behaviour of slabs of WEWS group obtained experimentally and numerically are shown in figure 21. From the results, it was shown that the experimental and numerical solutions are reasonably in good agreement for WEWS group.

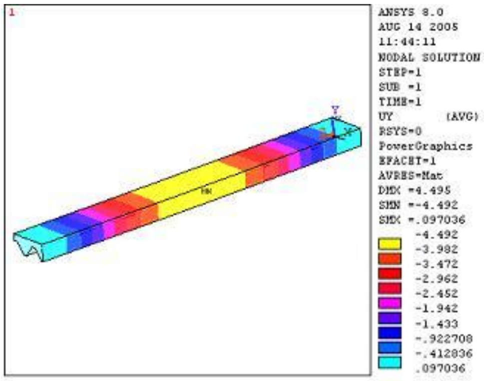


Figure 20 Deformed shape of WEWS

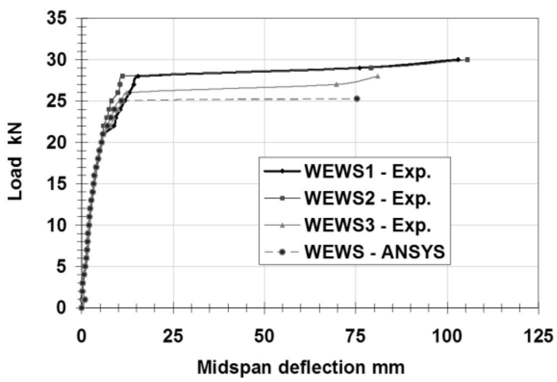


Figure 21 Load deflection behaviour of WEWS group

From the FE analysis, the ultimate load carrying capacity of the slabs were calculated and compared with the experimental results and the ratio between experimental and numerical values are shown in Table 3. From the values obtained by FE analysis, the WOE, WE, and WEWS groups showed closer solution with the experimental values.

Table 3. Comparison of ultimate composite slab capacity

Group identification	Ultimate load, kN		Load ratio Experimental/ Finite element analysis
	Finite element analysis	Experiment (Average)	
WOE	18.67	19	1.02
WE	19.84	21.63	1.09
WEWS	25.28	29.33	1.16

5. CONCLUSION

A study of the strength and behaviour of composite slabs in general, with a particular investigation of the use of composite slab systems, had been carried out analytically and experimentally. New numerical methods were developed for predicting composite slab strength. The non-linear finite element method was used to model the complex nature of composite slabs.

The slabs without embossments (WOE group) attained early ultimate load due to the initialization of its delamination of deck sheets. Further, the delamination developed not only on the shear span area but also in the flexure zone. Hence, the provision of end anchorage alone did not help for the sheets without embossments. The ultimate load carrying capacity of sheets with embossments (WE group) was 13% more than that of sheets without embossments. Even though the increase in ultimate load carrying capacity was marginal, the embossments arrested the delamination of the sheets at flexure zone. For WEWS group, the load carrying capacity was improved by providing end anchorages. The load carrying capacity of WEWS group was 54% more than WOE group, and 36% more than WE group. Among the three groups of WOE, WE, and WEWS, the experimental and numerical results were in good agreement. The load ratio between experimental and FE for WOE, WE, and WEWS groups were 1.02, 1.09, 1.16, respectively.

ACKNOWLEDGEMENTS

We gratefully acknowledge the financial support from the **Institution of Engineers (India)**, Kolkata, through a minor industry oriented project. We wish to thank **Japan Metal Building systems**, Bangalore, for the supply of cold form profiled deck sheet at concessional rates.

ABOUT AUTHOR

R.Baskar, completed his Ph.D in the Department of Civil & Structural Engineering, Annamalai University. He is presently Associate Professor in the Department of Civil and Structural Engineering at Annamalai University. He has been working in the field of Composite construction and with cold-form steel sections and has published/presented several research papers in National/International conferences.

REFERENCES

[1] **Samuel Easterling, W. and Craig S. Young,** Strength of Composite Slabs. Journal of Structural Engineering 1992; 118[9]: 2370-2389.

[2] **Veljkovic, M,** Sheeting-Concrete Interaction Performances in the Composite Floor Slab, Nordic Concrete Research, pp. 18: 1994

[3] **Luttrell, L. D. and S. Prassanan,** Strength Formulations for Composite Slabs, Proceedings of the Seventh International Specialty Conference on Cold-Formed Steel Structures, University of Missouri – Rolla;1984: 573-603.

[4] **Makelainen, P. and Y. Sun,** Development of a New Profiled Steel Sheeting for Composite Slabs, Journal of Constructional Steel Research, 1998; 46[1-3].

[5] **Veljkovic,M,** Behaviour and Design of Shallow Composite Slab, Proceedings of and Engineering Foundation Conference on Composite Construction in Steel and Concrete IV, ASCE, 2000; 1[1-12.]

[6] **Veljkovic,M,** An Improved Partial Connection Method for Composite Slab Design, Proceedings of and Engineering Foundation Conference on Composite Construction in Steel and Concrete III, ASCE, 1997; 644 - 659.

[7] **Shanmugam, N. E., Ghanshyam Kumar, and V. Thevendran,** Finite Element Modelling of Double Skin Composite Slabs, Journal of Finite Elements in Analysis and Design,2002; [38] 579-599

[8] **Clinton O. Rex, and W. Samuel Easterling,** Behaviour and Modelling of Reinforced Composite Slab in Tension, Journal of Structural Engineering, 2000; 126[7],764 – 771.

[9] **Oreste S. Bursi, Fei-Fei Sun and Stefano Postal,** Non-Linear Analysis of Steel-Concrete Composite Frames with Full and Partial Shear Connection Subjected to Seismic Loads, Journal of constructional steel research, 2005; 61[1], 67-92.

[10] **Jianguo Nie, Jiansheng Fan, and C.S. Cai,** Stiffness and deflection of steel-concrete composite Beams under Negative Bending, Journal of Structural Engineering, 2004;130[11],1842-1851.

[11] **Wang**, **Y.C** Deflection of Steel-Concrete Composite Beams with Partial Shear Interaction, Journal of Structural Engineering, 1998;124 (10), 1148-1158.

[12] **Ollgaard, J.G., R.G. Shelter, and J.W. Fisher,** Shear Strength of Stud Connectors in Lightweight and normal Weight Concrete, AISC, Engg.J, 1971;8(2), 55-64.

