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Study on shear embossments in steel-concrete composite slab

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Abstract. The horizontal in-plane shear interaction between the profiled cold-formed steel decking and concrete over is the prime factor that determines the strength of a composite concrete-steel deck slab. The control of slippage between concrete and steel is the most vital part to curb the central deflection. The means to reduce the slippage thereby to improve the shear interaction includes the provision of shear studs, ribs, embossments and other means. In this paper, the study on presence of embossments in steel sheeting and the effect of various parameters such as size, shape such as rectangular, square and circular, and the alignment of embossments, in the shear capacity and ultimate strength of the composite slab using three-dimensional computational finite element modeling is presented. It is found that change in shape, size and alignment of embossments is affected in the shear resistance of the composite slab.

1. Introduction

In composite slab, the cold-formed thin steel sheeting and concrete are bound together firmly and acts as a single structural unit in composite action. It is a cost effective and rapid mode of construction and is practiced worldwide. The thin-walled cold-formed profiled steel decking has many benefits, such as high strength/weight ratio, quicker installation, a good ceiling surface, expedient ducting for routing utility services, etc. we used fly ash as cement replacement material and pond ash as fine aggregate replacement material.

1.1. Failure Modes of the Composite Slab

By sufficient transmitting of longitudinal shear forces, the composite action is accomplished amid the profiled steel deck and the concrete slab. The steel then takes the tensile force henceforth acting as tensile reinforcement. The steel bars are provided on account of taking temperature and shrinkage [1]. Before even achieving full strength of either concrete or steel, often the bending action leads to vertical detachment of concrete and steel deck. Generally by appropriate trapezoidal shape profile, shear connectors and embossments, the resistance to vertical detachment is gained [2]. Failure pattern observed when the slab is subjected to bending is classified into three, viz. flexural failure at the mid-span, vertical shear failure near the supports and horizontal shear failure at concrete-steel interface [3]. Flexural failure happens in moderate to long slabs when the slab assumes full scale interaction between the concrete and the steel, which is not normally achieved. Vertical shear failure occur near the supports of thicker composite slabs with shorter span when applied force near to end of span is larger than its vertical shear capacity. This failure mode is not often significant. Horizontal shear failure is the most recurring failure, which occurs at interface of concrete and steel. Diagonal crack is formed prior to failure adjacent to concentrated load. Subsequently end slip occurs within the shear span. The performance with regard to this failure relies on shear connectors, steel thickness, concrete type, embossments and slenderness.

The failure behaviour can be either brittle or ductile based on load-slip curve as mentioned in Eurocode 4 [4]. If the failure load goes beyond 10% of the load which effect in a recorded end slip of 0.1 mm, the shear behaviour is treated as ductile.

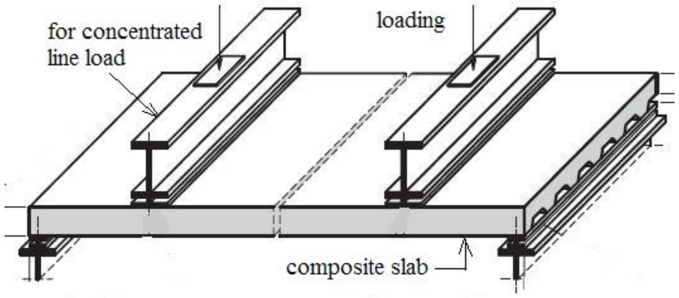

Figure 1. Loading of composite slab as per Eurocode 4

1.2. Studies to Determine and Improve Shear Strength

Equation for normal shear strength of composite slab was developed; popularly known as m-k method and is adopted in Eurocode 4 part 1-1 [4]. In m-k method, 'm' is mechanical interlocking and 'k' is friction between the profile deck sheets and can be assessed by full scale experiments. In general the values are given by profile sheet maker. The value of m and k varies with the embossment size and depth, deck profile, steel sheet thickness and concrete grade and type. For shear bond capacity, the design equation was given by Porter et al. [5].K.M.A. Hossain et al. demonstrated the improvement and efficiency assessment of an innovative high performance composite flooring scheme integrating the upcoming green lucrative Engineered Cementitious Composites (ECCs) [6]. It has shown enhanced performance in contrast with their SCC equivalents based on strength, energy absorbing capacity, ductility and shear bond resistance.Ganesh G. M. et al. demonstrated the application of Artificial Neural Network in predicting the m and k values required for assessment of shear capacity of composite steel concrete slab [7]. The predictions showed relatively accurate resultsV.Marimuthu et al. did experimental studies to calculate the k and m values of profiled sheet that were embossed [8]. They observed that the performance of the composite profiled steel deck slab with embossment depends on the shear span primarily; the slip is examined from premature loading state. Such shortfall can be recovered by changing the features of embossment such as height, breadth and place of embossment. It can be also enhanced with raising the depth of portion of concrete and giving shear stud connectors at ending.Miquel Ferrer et al. did an FEM approach to solve problems of slip failure mechanisms [9]. FEM models were built up to reproduce the horizontal slip mechanics of composite slabs under pull-out tests. The embossing slope has proved to be the noteworthy parameter enhancing the shear resistance. Slight variations of slope effects largely shear resistance. But the enhancement of shear resistance is constantly achieved at the outlay of ductility, and brittle separation failure of concrete is restraining this parameter. Embossment depth is directly proportional in addition. From 1.5mm depth to 3mm depth, shear capacity is becoming thrice more. After the yielding of the cold formed steel in its thickness, there is no gain in strength by raising the embossment depth. The vertical embossments work better than slanted ones (end locations retained) as no asymmetries amid ribs are brought out.Full scale experiments are very difficult and time consuming, hence simple tests or other alternative methods are to be ascertained to find the horizontal shear resistance and to know the dependency of various shear enhancing parameters [10]. Up to a defined point of failure the research study utilizes simulation for structural behaviour study of these composite floor systems. For structural modeling and analysis finite element method is being employed. In keeping composite action between concrete slab and steel decking capability of the embossments and effects in its change in size, shape and alignment has been studied and evaluated.

2. Material and methods

2.1. FEM model description

To validate the analytical model, the sample used in experimental and analytical study conducted by T. Tsalkatidis and A. Avdelas [11] was used. The modeling work was an extension from the literature study. Composite slabs with the following configuration were analyzed. Length: 1100mm; width: 300mm; height: 175mm. The slab was considered as simply supported hence rotation of the slab at supports was not restrained. Load was applied at a distance of span/4 length from both supports in order to create a shear span. Modeling was done with longitudinally half of the experimental sample. Embossments were provided on the deck sheet as shown in table with different shapes as well as normal size, as chosen from literature and with 50% of size reduced and 50% size increased. Thirteen FE models were created. One was without embossment and rest all was having embossed steel sheeting.

Figure 2. Dimensions of the profiled sheet

2.2. Material properties

Concrete of grade M25 was used. The ultimate tensile strength of concrete was determined at 2.6MPa and the modulus of elasticity at 30.5 GPa. The parameters in ANSYS, namely shear transfer coefficients for an open crack and for a closed crack were taken as 0.2 and 0.6 respectively. The shear transfer coefficient, represents conditions of the crack face and the value ranges from 0 to 1.0. Where 0 representing a smooth crack, that is a complete loss of shear transfer and 1.0 representing a rough crack, with no loss of shear transfer. When the element is cracked or crushed, a small amount of stiffness is added to the element for numerical stability. Concrete material was considered isotropic and Poisson ratio for concrete was assumed as 0.2 and for steel as 0.3. Yield stress of steel is 320 MPa, Ultimate strength 480 MPa and Modulus of elasticity 210 GPa.

Table 1. Embossment types

Type	Cement Tests	Size (mm)	Nomenclature
Regular			
Square	Base area	19.8	SR
	Top area	16.25	

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Circular	Base diameter	22.3	CR
	Top diameter	18.33	
Rectangular Horizontal/Vertical	Base area	36x10.9	RHR/RVR
	Top area	29x9.1	
Smaller			
Square	Base area	14	SS
	Top area	11.5	
Circular	Base diameter	15.8	CS
	Top diameter	12.9	
Rectangular Horizontal/Vertical	Base area	25.5 x 7.7	RHS/RVS
	Top area	20.5 x 6.4	
Bigger			
Square	Base area	24.3	SB
	Top area	19.9	
Circular	Base diameter	27.4	CB
	Top diameter	22.45	
Rectangular Horizontal/Vertical	Base area	44.1 x 13.4	RHB/RVB
	Top area	35.5 x 11.1	

2.3. Material geometry and meshing

The concrete part was modeled as volume element and steel as area element with profiling. An eight-node solid element namely SOLID65 [12] was used to model the concrete and shell 181-element type for steel was used. Steel sheet was considered as an area element hence it was meshed as a 2D element with quadrilateral shape. The concrete was considered as a volume element and hence it was meshed as a 3D element with hexahedral shape. Quadrilateral is most common in structured grids and the accuracy of solutions in hexahedral meshes is the highest. Figure 3 shows different meshed sheets with varying embossments.

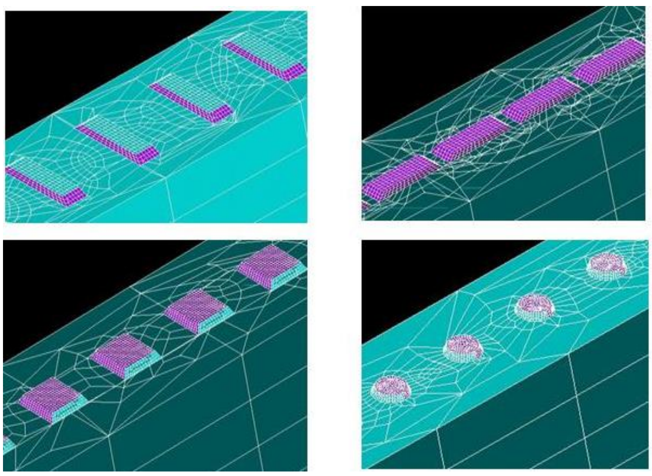

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Figure 3. Meshed sheets clockwise from top left: with rectangular horizontal, rectangular vertical, circular and square embossments

2.4. Loading and analysis

Finite Element modeling has grown sophisticatedly and it can predict failure behaviour of concrete such as cracking (in three orthogonal directions) in compression, crushing in tension, plastic deformation and creep. Solid 65 is outfitted with such capability. The smeared crack approach has been adopted for predicting non-linear behaviour of concrete (William-Warnke criteria) [13]. In this, cracks are modeled as local discontinuities distributed within the FE model. ANSYS software uses this failure criterion for analysis. The loading procedure was performed as per specifications of the Eurocode 4. Figures 4 and 5 are the plot indication for loading on the composite slab.

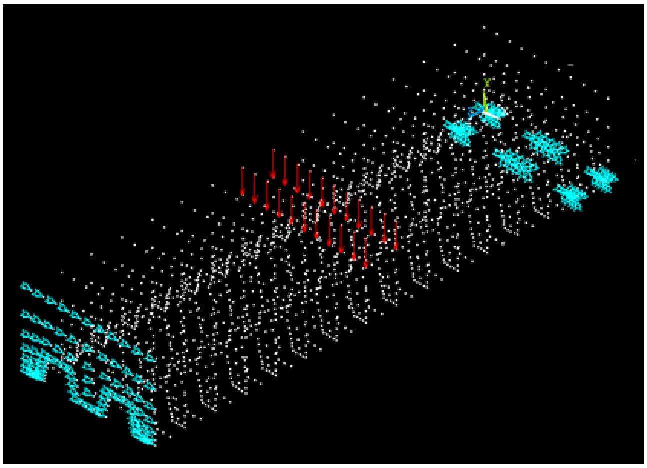

Figure 4. Plot of nodes with constraints and loading applied at nodes

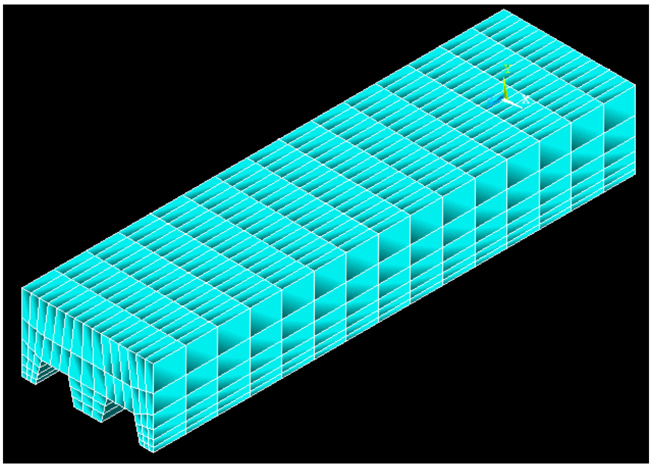

Figure 5. Elemental plot of the composite slab

3. Computational results and discussion

Non-linear behaviour was exhibited and ultimate load and deflection values were obtained. The solution is found out through a number of iterations in Finite Element Analysis in Ansys Software. For advanced non-linear solution, arc-length method was used. Deflected shape of composite slab, end constraints, concrete cracks and reactions are as shown in Figure 6. Load deflection comparison curves for each parameter are plotted in Figures 7 to 13. The deflection was measured from FEM models at a mid-node in the lower side in mid-span of the longitudinal section of composite slab. Similar Load-deflection curve was obtained for validation work.

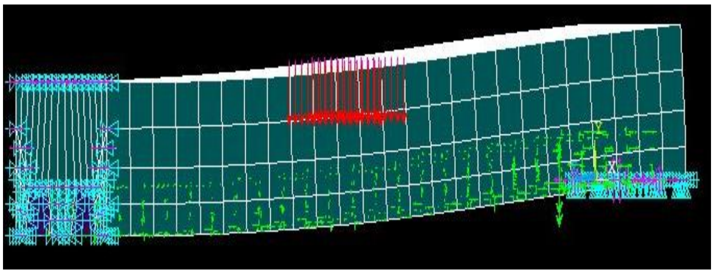

Figure 6. Deflected shape of composite slab after reaching ultimate load

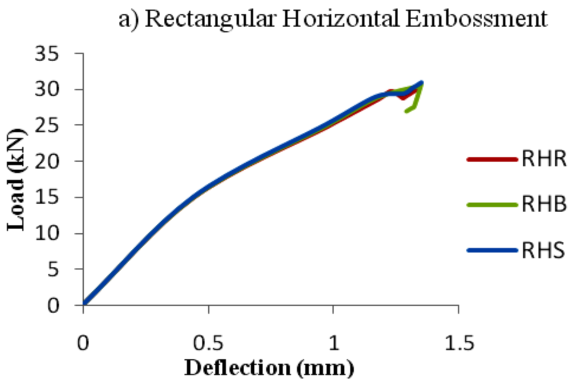

Figure 7. Comparison of load deflection curves for different sized embossments of rectangular shape horizontally aligned

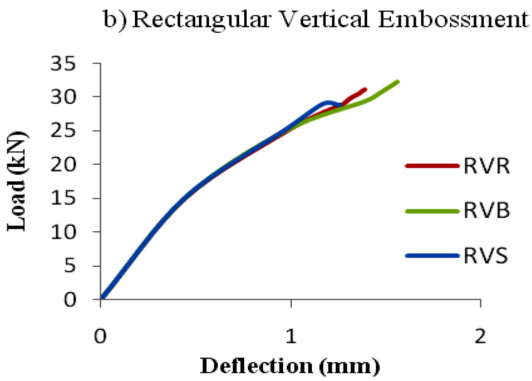

Figure 8. Comparison of load deflection curves for different sized embossments of rectangular shape vertically aligned

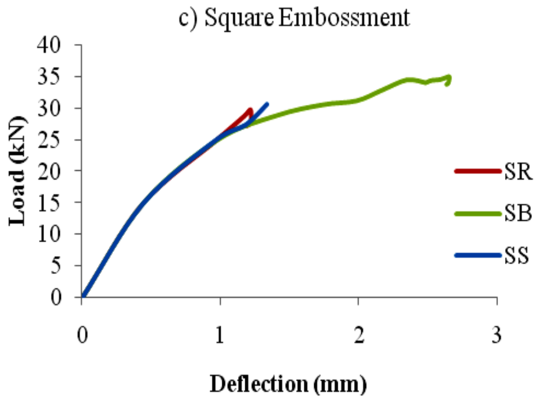

Figure 9. Comparison of load deflection curves for different sized embossments of square shape

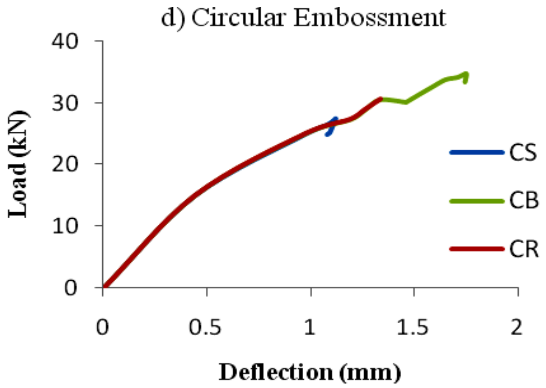

Figure 10. Comparison of load deflection curves for different sized embossments of circular shape

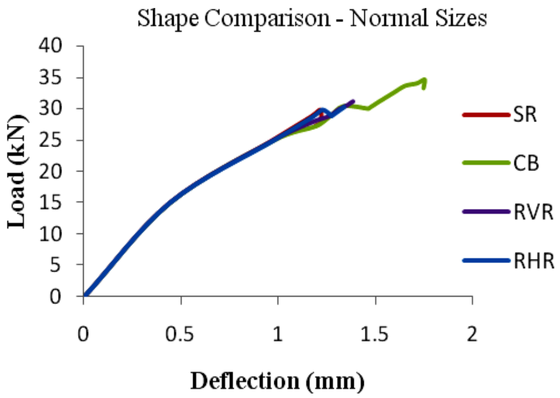

Figure 11. Comparison of load deflection curves for different shapes with normal sizes

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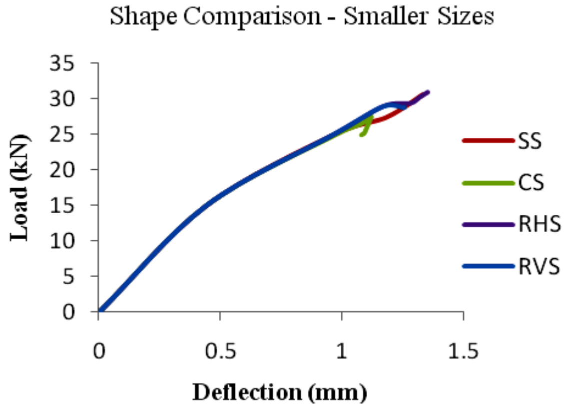

Figure 12. Comparison of load deflection curves for different shapes with smaller sizes

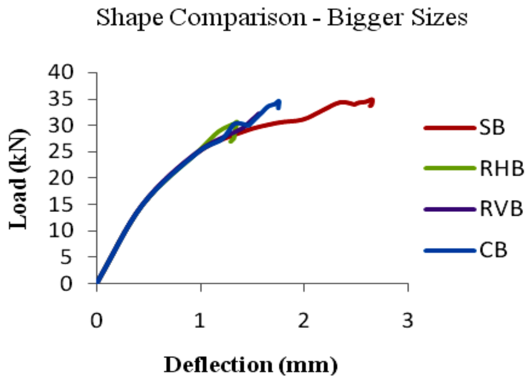

Figure 13. Comparison of load deflection curves for different shapes with bigger sizes

It is seen that the bigger sized embossments among all shapes produced considerable higher ultimate load. Hence it can be concluded clearly that when the size of the embossment is bigger, the ultimate load bearing capacity of the composite system is increased. It is evident from the graphs that among the smaller and bigger sized embossments, square shaped one produced highest ultimate load whereas for normal sized, circular shaped one produced much higher ultimate load. Vertically aligned embossment showed improved result in bigger sized whereas horizontal aligned showed better result in smaller sized. For regular size, both produced almost similar result.

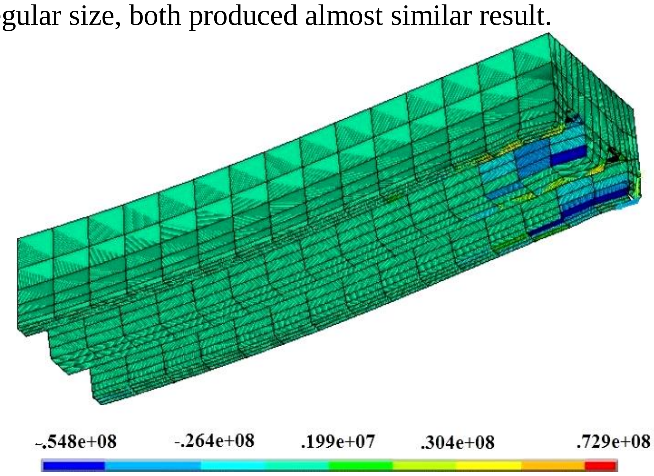

Figure 14. Longitudinal Shear Stress Plot for Slab with Square Bigger Type Embossment; values shown on scale in N/m^2

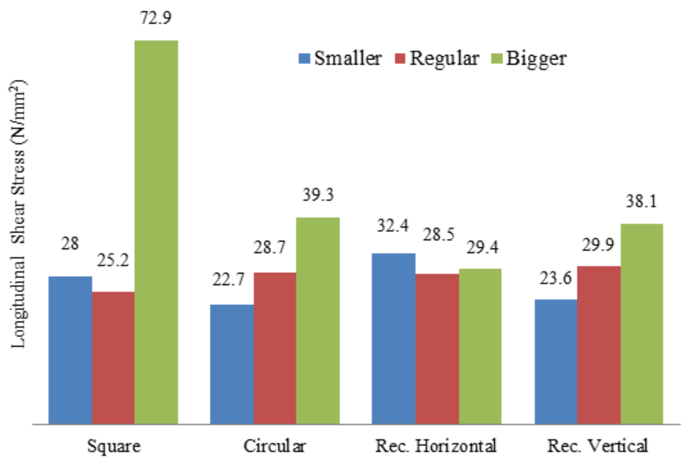

Figure 15. Graphs Showing Comparison of Horizontal Shear Stress

Longitudinal shear resistance in the shear span shows a higher value for composite slabs with embossments. It is observed that the composite slab with bigger sized embossed sheets produced highest resistance in longitudinal shear. That with square shaped with bigger embossment showed much higher value in shear resistance. Circular and rectangular vertical ones showed direct proportionality over the resistance to shear force, whereas square and rectangular didn't show such a general trend

4. Conclusions

From the present work it can be brought out that:
The presence of embossments increases the ultimate strength of the composite slab

- The shear resistance has been considerably increased with the presence of embossments; 16% as comparison with that having highest ultimate load.
- Composite slab with steel sheeting with square type embossment with 50% increased size that normal sized took the highest load.
- For smaller sized embossments, slab with rectangular horizontal type embossed sheet had highest ultimate load; normal sized, rectangular vertical and among bigger sized, square shaped had highest ultimate load.
- Circular embossment showed a quick response to change in size of the embossment.
- From the analysis results, as size of embossment increase, ultimate load also increases.
- For normal sized embossments, both vertically and horizontally aligned embossments produced same results, for smaller sized, slab with horizontally aligned embossment showed better strength and for bigger sized embossment, slab with vertically aligned embossment showed better strength.

Further work can be done by analyzing the composite slab with different size, shape and alignment of embossments in the steel sheet apart from that used in this work.

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