Analytical Study on Bond Slip Behaviour of CSRC Slabs

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ABSTRACT

A composite slab with profiled steel deck and concrete are mainly used in steel framed building systems. The two major functions of profiled steel deck are it serves as a permanent formwork during the casting of concrete and after the concrete has dried and hardened, serve as a tensile reinforcement. The horizontal slippage is because of to the longitudinal shear stress developed when ultimate shear force is reached. In order to reduce the slippage, the steel deck should be properly connected to concrete and also to each other by mechanical shear connectors like stud shear connector, perfobond ribs and their combinations. Here a parametric study on different shear connector configurations including bolts and perfobond shear connector are done. The composite slab is modelled and analysed under push test in ANSYS to find out the effective shear connector configuration and also to find the effectiveness of shear connectors.

Keywords: Composite slab, Shear Connectors, Push Test, Bond slip behaviour

1 Introduction

In Steel Framed Building systems, a composite slab with profiled steel decking is commonly used nowadays as the construction is simpler, faster, lighter and economical. The profiled steel deck serves as a tensile reinforcement for the slab when it is in service as well as a shuttering for the concrete during building. The profiled decking sheet provides resistance to vertical separation and horizontal slippage between the concrete surface and the decking sheet. Additionally, it allows shear forces to be transferred from the concrete slab to the steel deck. Shear connectors placed at the point where the two materials meet also help to glue the materials together. The horizontal slippage is mainly because of the longitudinal shear stress developed at ultimate shear force. In order to reduce the slippage steel deck should be properly connected to concrete and also to each other. Mechanical shear connectors including all the types and their combinations are widely adopted in effective way. Mechanical shear connectors like studs, perfobond ribs, combination of perfobond ribs and studs are used. Different profiled sheet like re-entrant type and trapezoidal type are also used for steel decking.

Hyeong-Yeol Kim *et al.* [1] studied by evaluating the final behaviour of a steel concrete composite deck slab system with profiled steel sheeting and perfobond rib shear connectors, the perfobond rib was found to be a potential substitute for shear connectors in a composite deck slab system with sheeting Namdeo Adkuji Hedaoo *et al.*[2]. The load carrying capacity of the composite slabs is sufficiently good comparing the experimental results and analytical results of behavior of concrete slabs with profiled steel decking by full scale test and by m-k method and PSC method. Wang Yu Hang *et al.* [3] an analytical model was developed in order to predict the ultimate loading capacity of continuous composite slabs with profiled steel sheet, and the test verification carried out, in order to investigate the solution precision of the analytical model. Qingtian Su [4], as an effective structural part to lessen fatigue damage on the orthotropic metal deck and the pavement, the combined concrete slab with the shear connectors helps to limit the stress attention

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caused by vehicles at the orthotropic steel concrete composite bridge deck. Rebecca J. Gravina *et al.* [5] studied the bond characteristics of corrugated steel deck and concrete is studied with Push and pull tests on small-scale composite specimens.

In this paper a parametric study on the effect of shear connectors like headed stud shear connectors, perfobond rib shear connectors, and their combinations on slab panel under push test is done by comparing the bond slip and ultimate load.

2 Validation of Journal

The journal selected for validation was entitled as" Push and pull out bond behavior of CRC composite slabs – An experimental investigation" by Rebecca J. Gravina *et al.* [5] published in 2021. The software used for the validation of the journal is ANSYS 2021 Workbench.

2.1 Composite Slab Panel

Eight small-scale composite slab specimens were built and examined to decide the remaining bond strength and the burden wearing potential of normal concrete and crumb rubber concrete. Direct shear tests on eight sets of small-scale composite slab specimens using each push and pull out load were conducted as part of this magazine's experimental software to examine the bond characteristics between concrete and a 0.75 mm-thick reentrant profiled metal deck with a focused compressive power of 25 MPa. Right here for the validation best push test on ordinary concrete is taken into consideration.

2.2 Profiled Steel Deck Properties

The profiled steel deck which was used in this study is shown in figure 1. The Tensile Yield strength is 550 MPa . The steel deck was of thickness 0.75 mm and area of cross-sectional was 1259 mm^2.

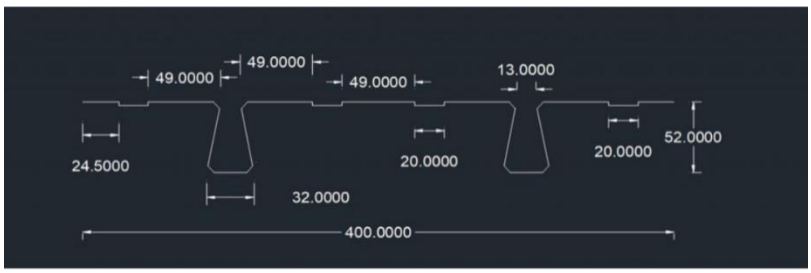

Figure 1: *Profiled steel deck details*

2.3 Concrete Properties

Concrete used was of grade 25 MPa. Six cylinder specimens of 100 x 200 mm size were casted for compressive strength and modulus of elasticity. Coarse aggregate of 20 mm size was used. The proportion of concrete used in the mixture is 1:1.42:3.49 with water cement ratio 0.71.

2.4 Modelling

A small-scale composite slab specimens with the dimensions shown in the figure 2 was used. The thickness profiled steel deck 0.75 mm. was modeled using ANSYS Workbench. Surface extension was done on four side. Using M16 bolts the steel deck plate was mounted above steel plate at the base. Dimension details and model used for study are given in figures 2 and 3.

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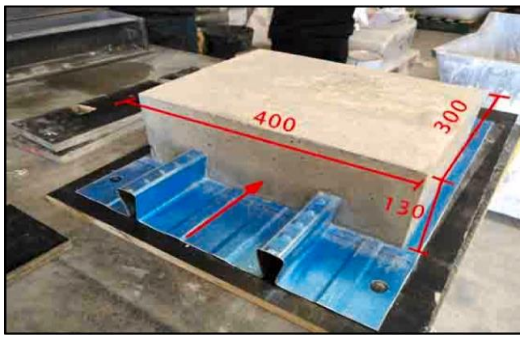

Figure 2: *Slab dimension*

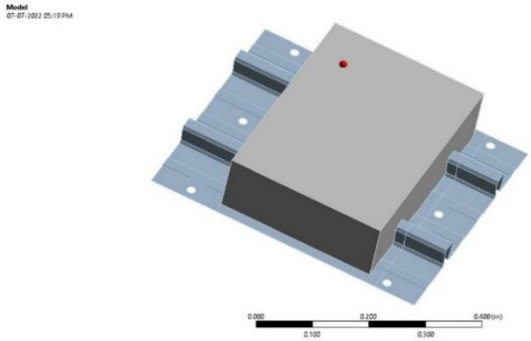

Figure 3: *Model for Study*

2.5 Support and Loading Conditions

To measure the longitudinal shear bond between the concrete and the profiled steel at the interference a push off load was applied. The shear devices resisted the load. This resistance is due to the corrugation and embossments. The transfer of the shear bond to the base plate was due to the embossments. The horizontal load was applied as a single point load. The load was given at the centre of the steel deck. Load was given 15.3 mm above the bottom of the steel sheet.

2.6 Results and Comparison

The bond slip graph is prepared on the basis of bond stress calculated by dividing total force reaction (N) by contact area of two ribs and end slip (mm).The obtained graph from the analytical study were compared with the bond stress end slip graphs in the journal corresponding to τ1 (maximum chemical bond), τu (ultimate bond) and S1 (end slip @ ultimate chemical bond), Su (end slip @ ultimate bond) which is obtained from experimental study. The bond slip curve is shown in figure 4 and Deformation of slab under push test is shown in figure 5. Both graphs are in good well with each other as follows.

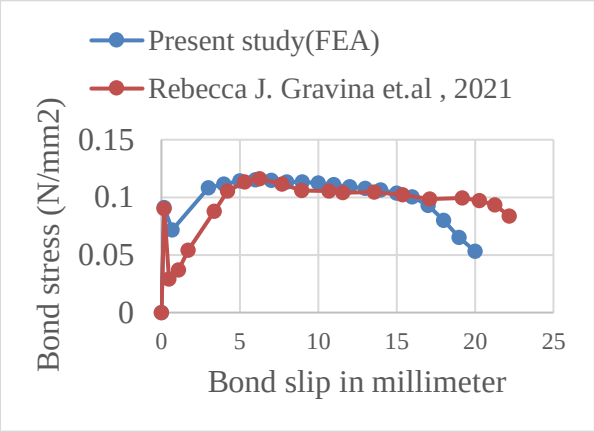

Figure 4: *Bond Slip Variation Curve*

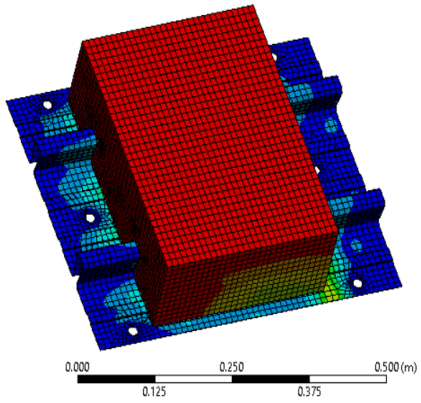

Figure 5: *Deformation of slab*

Bond-slip relationship consist of 2 levels. During the level I before the start of the end slip, there was a linear increase in the bond strength up to the maximum capacity due to chemical adhesion was reached. At this stage the bond stress is τ1 and corresponding slip is S1. At the starting of the end slip, it increase with the decrease in bond strength linearly. Chemical adhesion is due to the bond between the cement paste and steel deck surface. When the adhesion suddenly breaks, the behaviour is not consistent. The strength that was partially lost in level I due to end slip is suddenly gained in level II and is known as the residual bond, or τr. The ultimate bond, denoted by the symbol τu, and Su is the matching slip, are then reached. Following this, the bond strength increases together with the end slip growth until it reaches its maximum strength at

point. The interaction between the mechanical effect and frictional binding is what leads to this rise in strength. The specimen begins to lose bond strength as the end slip grows once it achieves its maximum frictional capacity and ultimate interlock. Bond slip evaluated is shown in table 1.

Table 1: *Bond slip Evaluated.*

Bond stress (N/mm^2)	Result from journal (Slip in mm)	Analytical result (Slip in mm)
τ_1= 0.090	S_1 = 0.18	S_1 = 0.19
τ_u = 0.117	S_u = 5.98	S_u = 6.01

From Table 1 it is clear that variation between the values from journal and analytical study are within the limit. Thus, the model can be used for further studies where various profiled steel deck slabs with different shear connector configuration could be investigated.

3 Parametric Study on Shear Connectors

In this study, about 4 types of shear connector configurations are chosen and their ultimate bond stress and end slip values are compared. The steel stud and steel bars provided is of modulus of elasticity 2.1x105 MPa and Poisson's ratio 0.3. Following are the type of shear connectors used. First one is Slab with 5 stud bolts as shear connector (SW5BSC), here the composite slab is modeled with 5 shear connectors in each soffit line as 10 mm diameter bolts at 60 mm c/c distance which is of length 50 mm. Secondly, Slab with 7 stud bolts as shear connectors (SW7BSC) here, the composite slab is modeled with 7 shear connectors in each soffit line as 10 mm diameter bolts at 40 mm c/c distance which is of length 50 mm. Third type was Slab with perfobond rib shear connector (SWPRSC) here, the slab is modeled with perfobond shear connectors. The perfobond shear connector includes a plate which consists of circular holes or gaps of 25 mm diameter at regular intervals of 60 mm c\c throughout the span direction. These plates are placed in every trough portion along the span direction. Plates are placed in such a way that the circular holes of every plates are in the same alignment in the width direction and also a 10 mm diameter bar is able to pass through the circular hole of every plate in width direction of slab. And lastly slab with perfobond rib and stud bolts as shear connector (SWPRBSC),here perfobond shear connector along 10 mm diameter bolts are placed through the soffit portion of steel deck at 60 mm c/c distance as shown in figure 10.

4 Analysis of Composite Slab

The Analysis of each combination of shear connectors are explained as follows. Bond slip variation is also discussed.

4.1 Composite Slab with Five Stud Bolted Shear Connector (SW5BSC)

The composite slab with five number of 10 mm diameter bolt as shear connector modeled successfully in the geometrical part and it is loaded to the model. Material properties are properly assigned to the solid and surface elements of the model. Meshing was done with element size of 10 mm for both concrete and structural steel elements as shown in figure 6. The analysis of composite slab with shear connector was done corresponding to the support and loading conditions as given. The analysis settings were properly fixed for the analysis. Material failure was allowed in the analysis. The analysis was time controlled including maximum of 20 sub steps later fixed supports were assigned to the solid parts by selecting each faces and to the five M16 bolt holes. The slip between the steel deck and concrete in the span direction was determined using "deformation probe" in the Ansys workbench. After selecting the deformation probe (Figure.7), the face of steel deck was selected and corresponding span direction, i.e., along X-axis was selected for results. The force and end slip tabular values are taken from Ansys and loaded to excel to get the bond slip curve preparation. The bond slip curve was obtained as shown in the Figure 8. The ultimate

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bond stress value was found to be 0.1847 N/mm² and 8 mm being the ultimate slip value.

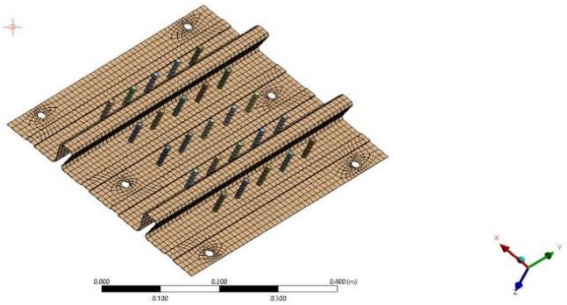

Figure 6: *Meshed model of composite slab with five studded shear connector (SW5BSC)*

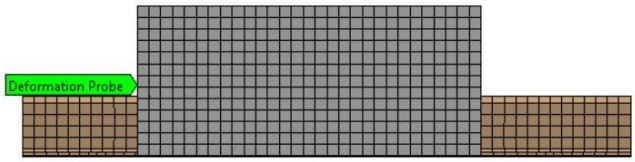

Figure 7: *Deformation probe or slip of SW5BSC.*

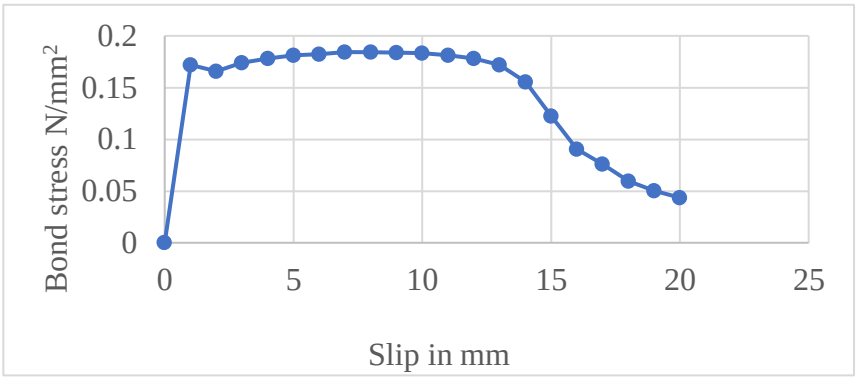

Figure 8: *Bond slip curve of SW5BSC*

4.2 Composite Slab with Seven Stud Bolted Shear Connector (SW7BSC)

The composite slab with seven number of 10 mm diameter bolt as shear connector was modeled in the geometry and material properties are given to both surface and solid elements as structural steel Fe 415 and concrete M25 grade with proper stress strain properties. And thus, model was loaded into the model section and later meshing was done for element size of 10 mm as shown in figure 9. Later analysis settings were done properly with maximum of 20 sub steps. The fixed support was assigned to both the edges and loading was done and thus solved until it get the green tick mark i.e., solution get done. To determine the final bond stress value, the total force reaction was calculated and divided by the cross sectional area between two ribs. The ultimate bond stress value was obtained as 0.227 N/mm² and corresponding slip as 7.36 mm as shown in figure 10.

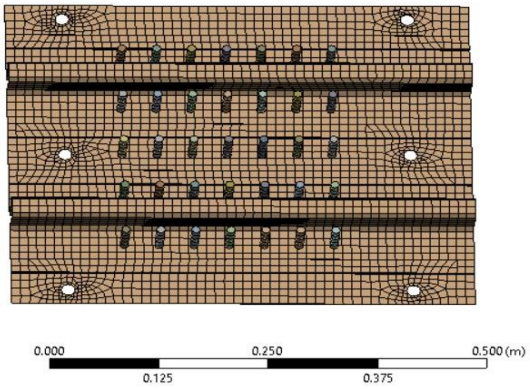

Figure 9: *Meshed model of SW7BSC*

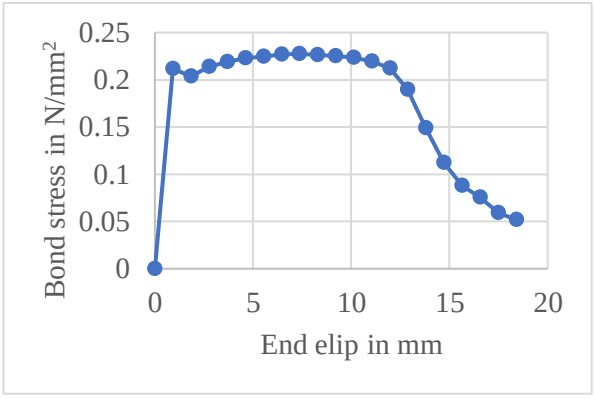

Figure 10: *Bond slip curve of SW7BSC*

4.3 Composite slab with perfobond rib shear connector (SWPRSC)

The third type of shear connector was modeled using composite slab with perfobond rib shear connector is found to be another type of shear connector scheme. This slab was properly modeled using perfobond ribs which include circular openings placed at an interval of 60 mm center to center along span direction and these ribs were placed in the soffit portion in the span direction is such a way that holes of every ribs are along same line in width. After completing the analysis, bond slip curve (Figure.12) was plotted using the values obtained from the analysis results. The ultimate bond stress and slip value was obtained as 0.279 N/mm² and 5 mm.

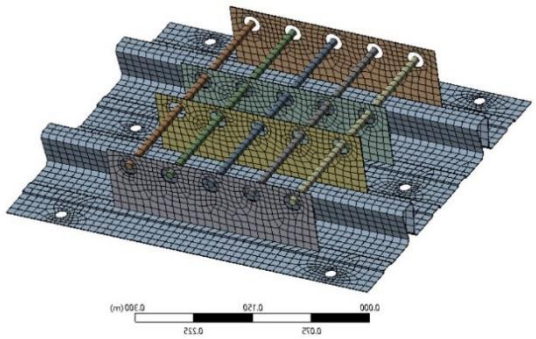

Figure 11: *Meshed model of SWPRSC*

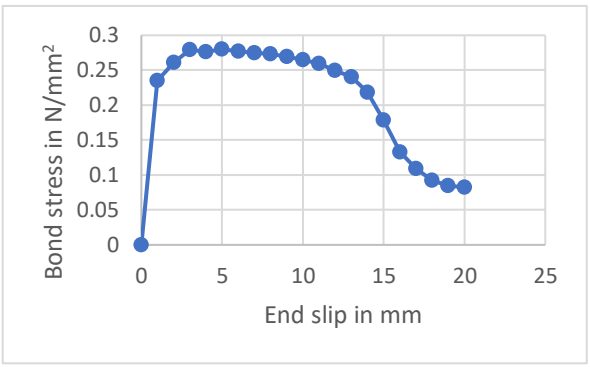

Figure 12: *Bond slip curve of SWPRSC*

4.4 Composite slab with perfobond rib and studded bolts as shear connector (SWPRBSC)

This composite slab was modeled using perfobond rib shear connector same as in the previous one and added to that 10 mm diameter bolts are placed through the soffit portion of steel deck at 60 mm c/c distance. The supports and loading points were given as same as that of previous cases. The meshing and analysis were done to obtain the total bond stress and slip on the composite slab (Figure.13). After the analysis, bond slip curve were plotted using the values obtained as result from solution part. The ultimate bond stress and end slip was obtained as 0.2940 N/mm² and 4.667 mm. as shown in fig 14.

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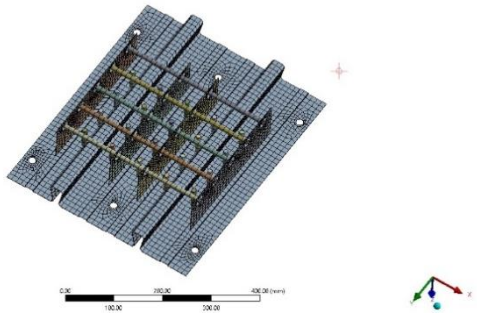

Figure 13: *Meshed model of SWPRBSC*

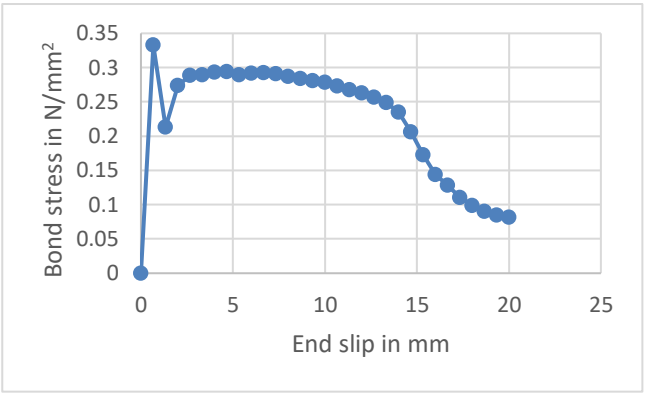

Figure 14: *Bond slip curve of SWPRBSC*

4.5 Comparison of Results and Determination of Effective Slab Configuration

The Comparison of the Ultimate Bond strength obtained after the analysis of the four type of composite slabs with different shear connectors are shown in table 2 and bond slip curve is also shown in figure 15.

Table 2: *Comparison table of ultimate bond stress and end slip*

Type of shear connector in composite slab	Ultimate bond stress (N/mm^2)	End Slip in (mm)
SW5BSC	0.1847	8
SW7BSC	0.227	7.36
SWPRSC	0.279	5
SWPRBSC	0.294	4.667

The four different type of composite slab with different shear connector configurations were analyzed and obtained ultimate bond stress end slip. After comparing and studying these features, it was obtained that the slab with shear connector scheme SWPRBSC (with both perfobond ribs and 10 mm diameter bolts) is the effective way to be used. Thus, SWPRBSC is the composite slab with effective shear connector configurations.

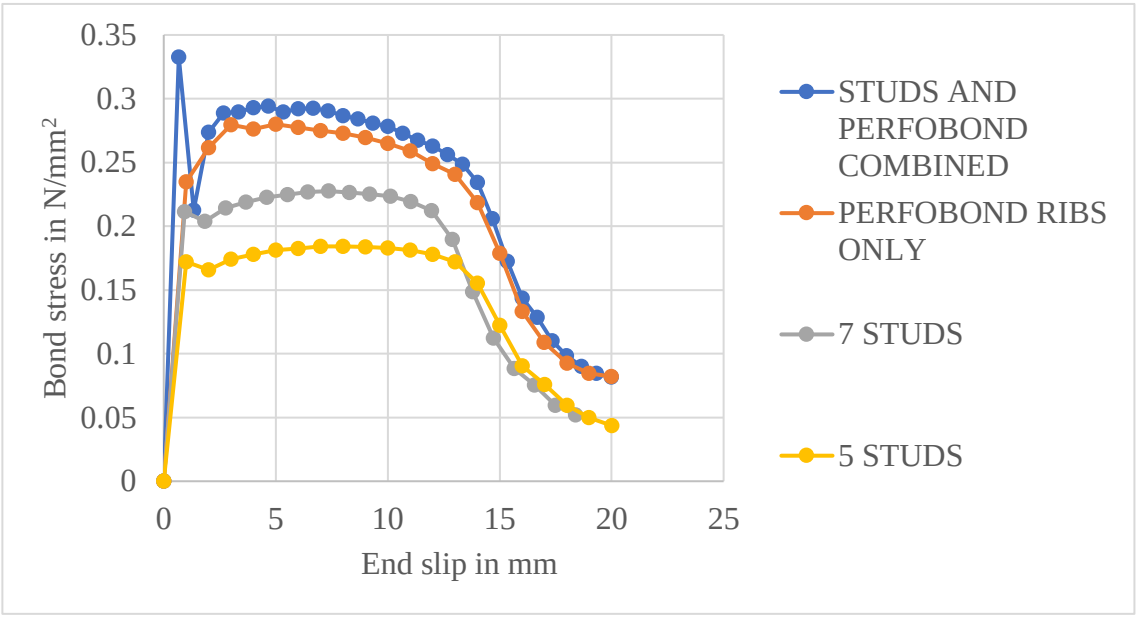

Figure 15: *Comparison graph of Bond slip for different shear connector configuration*

5 Conclusions

The analysis of the composite deck slab with various shear connectors and combinations were done using

Ansys. The comparison of the results were based on the ultimate bond stress value and end slip values. From the results ,the slab incorporated both perfobond shear ribs and bolt (SWPRBSC) is the effective slab. This result is based on its higher ultimate bond stress value and lower end slip values among the other cases. And also, from the parametric study of it is found that as number of shear studs increases the ultimate bond stress value increases and end slip value decreases. So, more studies can be done with different combinations of shear connectors to increase the shear capacity of composite deck slab.

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