CONCRETE COMPOSITE SLAB CONSTRUCTION: STATE OF THE ART

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Abstract

In the recent trends emerging day by day in the construction industry, composite construction method has gained its popularity for its economical usage of materials and providing higher sustainability than conventional concrete construction system. Several factors that affect the degree of slippage deterioration in composite slab, e.g. embossments, shape of profiled sheeting and shear connector types. The common types of failure modes in composite slabs are flexural failure, shear failure and combination of flexural-shear failure mechanism. Small scale test helps to determine the shear resistance capacity, slip and shear action between the corrugated steel and harden concrete. Small scale tests usually used Push out, Pull out, Pull over or elemental bending tests. The reduction in the size of the structural components, thereby decreasing the dead loads which results in the construction of more floors (i.e.) increasing the service living area. The shear action between the sheet and the concrete can be achieved by providing frictional interlock (shape of the profiled sheeting), mechanical interlock (embossments on the sheet) and end anchorage interlock (studs on the profiled sheeting). The advantages of composite construction over steel reinforced concrete construction are reducing the thickness of the floor slab with a simultaneous proving in the load bearing capacity of the slab. This paper also discusses an attempts on quantifying the slippage in terms of m-k method. Finally, the areas that need further research are highlighted and the need for incorporating composite slab contribution into building design guidelines is emphasized.

***Keywords**: Composite Slab, Shear Failure, Slip and Deflection*

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1. INTRODUCTION

Composite construction method is a widely used diaphragm strengthening method where two different materials performing a composite action. The composite action of the composite slab depends upon shear action between the corrugated steel sheeting on the hardened concrete. The shear action between the sheet and the concrete can be achieved by providing frictional interlock (shape of the profiled sheeting), mechanical interlock (embossments on the sheet) and end anchorage interlock (studs on the profiled sheeting). Depending upon the transfer of shear stress various types of profiled sheeting such as rectangular trapezoidal and dovetail re-entrant profiled sheeting are generally selected. In recent years the composite slabs have gained popularity in various residential, commercial, industrial and institutional constructions. The advantages of composite construction over steel reinforced concrete construction are reducing the thickness of the floor slab with a simultaneous proving in the load bearing capacity of the slab. Decreasing the indirect cost involved in construction due to which faster construction or installation progress. The reduction in the size of the structural components, thereby decreasing the dead loads which results in the construction of more floors (i.e.) increasing the service living area. The steel decking itself act as an external reinforcement and eliminate the need for formworks. Figure1, 2 and 3 represents the different type of embossment and different profile geometry.

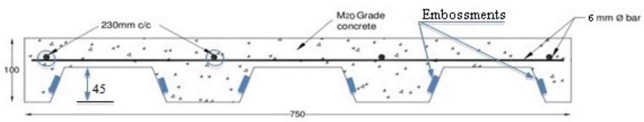

Fig 1. Trapezoidal profile with embossments

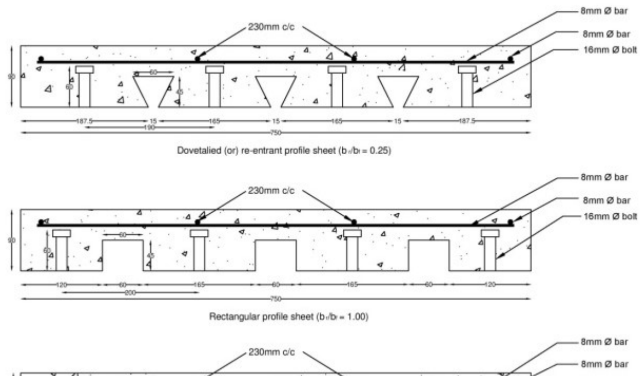

Fig 2. Different profile geometry with stud shear connector

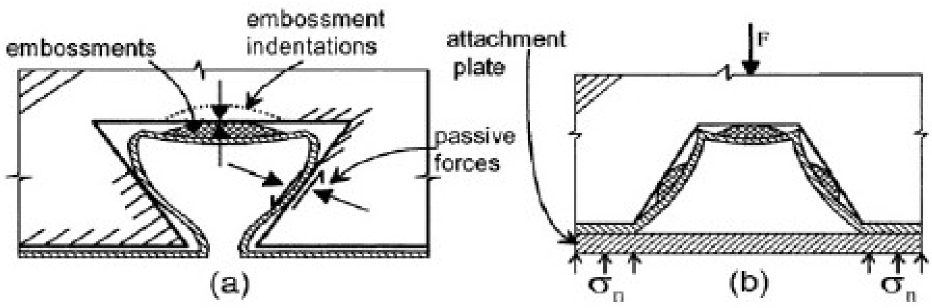

Fig 3. Type of punching (Embossment or Indentation)

2. TEST ON COMPOSITE SLABS

To determine the parameters governing the behaviour of the composite slab small scale and full scale tests are carried out, in the last three decades. Small scale test helps to determine the shear resistance capacity, slip and shear action between the corrugated steel and harden concrete. Small scale tests usually used Push out, Pull out, Pull over or elemental bending tests. The slip, curvature slip and the longitudinal shear capacity are determined by small scale tests. On the other hand, full scale tests are focused on the flexural strength, deflection and the delamination of profiled steel sheeting. Euro Code 4 recommends two testing methods to determine the behaviour of composite slab. As per Euro Code 4 standards, the slab is considered to be ductile, if the maximum load is 10 percent greater than that of the loads causing 0.5 mm end slip. Based on the results of the full scale tests the slabs are marked as ductile or brittle. The common types of failure modes in composite slabs are flexural failure, shear failure and combination of flexural-shear failure mechanism.

2.1 Flexure Failure Mode

The flexural failure depends upon the shear span. The shear span is the distance between the point of application of the load and the nearest support. The composite slab with longer shear spans is prone to fail easily by flexural failure.

2.2 Shear Failure Mode

The shear failure is characterized by the sliding of the hardened concrete over the steel sheeting, when the load is increased. As the load is increased, the diagonal cracks are formed adjacent or below the applied load. When the load reaches its threshold, shear bond failure occurs.

2.3 Combination of Flexural-Shear Failure Mode

The shear failure is characterized by the sliding of the hardened concrete over the steel sheeting with the flexural failure at the same time, Figure 4 different type of failure in composite deck slabs.

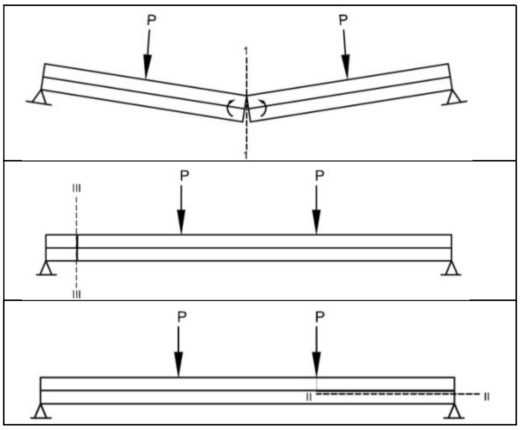

Fig 4. Different type of failure in composite deck slabs

3. LOADING SCHEME

3.1 Static Loading

In static loading, the concentrated load is applied over the composite slab. The deflection is measured simultaneously as the load is progressively increased; the load is applied until the specimen fails. Thus, the load-deflection behaviour and the end-slip behaviour are measured. The load-deflection behaviour is the relationship between the loading and the deflection which results in the formation and propagation of cracks from the bottom of the slab to the point of application of load. The end-slip is stated as the horizontal movement of concrete over the steel. When there is a progressive application of load, end-slip occurs followed by the delamination of composite slab.

3.2 Cyclic Loading

In cyclic loading, the load is applied in a cyclic pattern over the composite slab. The main advantage in this type of loading is the energy absorbed or dissipated per cycle load which can be measured.
Table.1 summarizes the researches which were carried out by various authors and main outcome results.

4. CONCLUSION

In this paper, an attempt on quantify the performance of composite concrete floor slabs in steel framed which made by various researchers are discussed and highlighted. However, the area needs further studies to better understanding the complex behaviour of composite concrete slab under both static and dynamic loading. An asses for exact composite slab behaviour can contribute for the industry and enhancing the growth of development.

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BIOGRAPHIES

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Table: 1 Experimental investigation by various authors for the composite slab elements.

S.I	**Author**	**Country**	**Year**	**Shape of the section**	**Type of loading**	***A/E/N**	**Number of tests specimen**	**Variable study**	**Remarks**
1	Porter and Eleberg	USA	1975	Rectangular	Static and cyclic loading	A & E	353 samples	i) The shear bond End slip behaviour was used in this journal. ii) predicting the maximum load for shear bond by using the linear regression relationship	For simple span slab element the test gives linear regression relationship and the load deflection data. Recommendation design equations for shear-bond which provide a consistent margin of safety is suggested
2	Ong and Mansurt	Singapore	1986	Rectangular	Static and live loading	E	10 samples	The regression analysis for the slab is done by shear tests	i) Two linear regression plots was obtained ii) The slabs without shear devices tends to fail in shear bond mode under third point load location.
3	Lutterll	USA	1986	Trapezoidal	Static loading	A	Over 75 samples	Three types of slip resistances were adopted i) Adhesive bond ii) Mechanical bond from embossments, and iii) Shear connectors	The two broad categories of deck types were identified by providing embossments in a vertical manner in the web and lugs running horizontally. Then formulae were derived to describe the flexural strength of the slab.
4	Wright, Harding and Evans	UK	1987	Rectangular & trapezoidal profiles	Static loading	E & N	40 samples	Determination the load deflection characteristics	There is a need for an efficient structural design for the slabs where economy plays a major role.

5	Wright and Evans	UK	1987	Trapezoidal	Static loading	A & N	Over 200 samples	i)Lapped joints and crimped joints were provided. ii) Analysis were made by fold plate analysis, and iii) The effective thickness for the composite element was derived.	Accurate and versatile results were obtained using fold plate analysis.
6	Wright	UK	1990	Trapezoidal	Dynamic loading	A & E	3 samples	i)Welding reinforcement bars with the sheets. ii) Dummy shear elements connecting the steel plates and concrete plates.	i) Analysis by folded plate method found to be useful, ii) Horizontal plates take major longitudinal forces due to bending, and iii) In composite slab behaviour the presence of slip between the two materials causes non-linear behaviour
7	Stark and Brekelmans	Netherland	1990	Trapezoidal	Static and cyclic loading	E & N	8 samples	i) Plastic analysis on the composite slab, ii) A simplified calculation method is adopted for the ultimate moment which is obtained from the moment curvature relation	i) The reinforcement is the critical for the rotation capacity of the slab, and ii) The non linear analysis predicts the moment curvature for the position of negative bending moment.
8	Poh and Atlard	Australia	1992	Trapezoidal	Symmetric concentrated load	N	12 samples tested by Abdel-Sayed et al.	i) The deflection and the interface slips are calculated from the integration of the cross sections curvatures, and ii)The slab is considered to fail when any cross section along its length reaches a maximum value for moment.	The numerical presentation was given to calculate the interface slip, the load-deflection and the strength of the composite slab under symmetrical loading.
9	Daniels and Chrisinel	Switzer-land	1993	Rectangular, Trapezoidal and Re-entrant	Concentrated or line loading	A & E	6samples (single span-type of decking)+18 samples (spacing of loading) +17 samples (emboss	The construction, decking, concreting, positive moment reinforcement, slab length and load locations are studied	i) The contribution of each internal moment resistance element is non- linear as a function of the applied load, and ii) The concrete slab is the most important internal moment carrying element at service load levels.

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10	Andrade, Vellasco, Silva and Takey	Brazil	2004	Trapezoidal, rectangular and Reentrant	Static loading	A & E	8 samples	The experiment is divided into two: i) Development of a wide-rib composite steel deck and ii) Parametric design study of the steel deck profile.	i) Do not require standard scaffolding and propping systems and the intrinsic construction speed, ii) High associated stiffness allowing the achievement of longer spans.
11	Abdullah and Easterling	Malaysia	2004	Trapezoidal	Static loading	A & E	24 samples	(i) Elemental behaviour was determined of each of the 24 slab elements. (ii) Three concrete thickness were considered (i.e) 125 mm, 165 mm and 190 mm iii) Three span conditions were adopted(i.e)560 mm, 660 mm & 760 mm	i) The elemental tests were found comparable with the full scale testing. ii) Edge web curling, end anchorage details, and type of support have significant influence on the slab specimen strength and behaviour.
12	Lams and Qureshi	Singapore	2008	Trapezoidal	Static and cyclic loading	E	12 samples	i) Two long specimens were used (i.e) 5.0 m and 3.0 m. ii) For the m-k test two types of loading were adopted (i.e) static and cyclic loading	i) The testing and evaluation of the slabs were done in accordance to the Euro code 4. ii) Failure in short-span specimens was accompanied by horizontal slip at the ends, vertical separation between the steel and the concrete and local buckling of the profiled sheeting near the supports.
13	Jeong, Kim and Koo	Korea	2009	Trapezoidal	Static loading	E	16 samples for full scale loading test & 6 nos. of push out test sample	The perfobond rib connector was used as a shear connector for which the push out test was carried out to determine the shear bond strength	i) The longitudinal shear resistances were analysed using m-k method ii) The longitudinal shear resistances have led to over estimation.
14	Irwan, Hanizah and Azmi	Malaysia	2009	Trapezoidal	Static loading-push out test	A & E	68 samples	Bent up shear transfer enhancement mechanism.	BTTST enhancement is a viable alternative for a shear connector40% increase in concrete

									strength.
15	Chen, Shi and Qiu	China	2011	Rectangular	Static loading	A & E	13 samples	i) The strain gauges and the LVTDs are employed to capture the strain distribution and variation. ii) The longitudinal shear force deduced are proportional to the vertical shear force in terms of shear bond strength in m-k method.	i) The shear bond failure occurs by crack in bottom concrete initiates ii) The shear bond slip and separation occurs by the loss of shear bond strength. iii) The longitudinal shear bond stress among shear span contributes to the longitudinal shear bond strength
16	Bouchair, Bujnak, Duratna and Lachal	France	2012	Conventional rectangular slab	Static loading (push out test)	A & E	4 samples	The behaviour of studs was stimulated by a three-dimensional quarter scale finite element model using ATENA software.	A finite element model has been developed to stimulate the load slip characteristics of headed shear stud in a solid reinforced concrete slab
17	Pires, Rodrigues and Silva	Portugal, Brazil	2013	Trapezoidal	Static loading	E		Restrained thermal elongation	Reduction in load level and slenderness of columns enhance performance of columns in fire.
18	Gilbert	Australia	2013	Trapezoidal	Sustained loading	A	10 composite samples + 12 RCC slab samples	The deflections were calculated on the basis of long term sustained loading over the slab acting along with its self weight.	For composite slabs carrying superimposed loads typical of the magnitudes applied to the floors of most buildings, the shrinkage deflection is often more than 50% of the total deflection.
19	Lakshminathan, Sivakumar, Ravichandran and Jeyachandran	India	2013	Trapezoidal and Reentrant	Static loading	E	3sample (without shear connectors)+3 samples (with shear connectors)+3 samples (with shear connectors and continuous rods	i)Different embossment type shear connector was used. ii) Minimum reinforcement was provided to avoid shrinkage	i) The composite slab without shear connectors fail early. ii) The minimum reinforcements in the form of mesh were found to resist temperature and shrinkage effects.

20	Abdullah, Bailey and Wu	UK	2013	Rectangular	Cyclic loading	E	5 samples	The structural response of the strengthened specimen was compared with the non strengthened specimen in terms of punching shear strength, strain and deflection profile.	The flexural strength of the composite slab connections using FRP increased the load bearing capacity by 43% over the non strengthened slab specimen
21	A. Gholamhosini, R.I. Gilbert, M.A. Bradford and Z.T. Chang	Australia	2014	Trapezoidal and Reentrant	Static Line loading	E	2 samples with trapezoidal + 2 reentrant samples	i) Two shear spans were studied at ($\frac{L}{4}$and $\frac{L}{6}$) and the end slips at both the roller and pin supports were recorded. ii) Two cases were considered 1. While there is no slip 2. When there is a partial connection allowing slip.	The ultimate shear stress of the slab for $\frac{L}{6}$ was greater than $\frac{L}{4}$. Then the Finite element model utilizing interface elements to model the bond properties between the steel decking and the concrete slab was described and used to investigate the behaviour of the slab throughout the full range loading.
22	A.Siva, R.Senthil and Saddam M Ahmed	India	2016	Trapezoidal	Static Line loading	E	6 samples with trapezoidal	Short & Long shear span	Experimental investigations are needed for each type of embossed profiled sheet to verify the 'm' and 'k' values. Short shear slab with rectangular embossments showed greater shear bond capacity as compared to the long shear span specimens.
23	Swaminathan.S, A. Siva, R. Senthil and Kinson Prabu	India	2016	Trapezoidal	Static Line loading	E	6 samples with trapezoidal	Bolted shear connector, Headed stud shear connector	Three major types of failure were detected. The first failure is crushing of concrete and shear, second type of failure is buckling of shear stud connector and combining of both shear connector and concrete is third type of failure.
24	A.Siva, S.Swaminathan, K.Prasanth &R.Senthil	Switzerland	2016	Trapezoidal	Static Line loading	E	6 samples with trapezoidal	Varying Shear Spans	Depending upon the loading given at various shear spans the behavior of the composite slab varies accordingly

25	A.Siva, R.Senthil and S.Swaminathan	Morocco	2016	Trapezoidal	Static Line loading	E	6 samples with trapezoidal	Varies embossments and Varying Shear Spans	The longitudinal shear capacity of the specimen can be increased by depth of the embossment and orientation of the embossment.

*N, E and A are Numerical Investigation, Experimental Investigation and Analytical Investigation respectively.