BEHAVIOUR OF PROFILED DECK COMPOSITE SLAB: STATE OF ART REPORT

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ABSTRACT. Profiled deck composite slab is widely used in current construction practice. The virtue of utilizing profiled deck sheet in composite slab have been recognized for lighter, simpler, faster and economical construction. Composite slab consists of concrete, profiled deck sheet, shear transferring devices (shear connector, embossments and indentations) and light mesh reinforcement. In this paper, a review of the research carried out on profiled steel decking is given. Rigorous research is carried out on profiled deck composite slab which can be classified as experimental and analytical methods. Experimental methods include full scale laboratory tests (m-k method, SC method) and small scale tests (pull out test, push out test). Analytical methods focused on different types of mathematical techniques which are used for determine longitudinal shear strength of profiled deck composite slab. Now-a-days to improve load slip characteristics different types of concrete are utilized in composite construction. This study is also focused on different types of concrete used in composite slab.

Keywords: Composite Slab, Shear connector, Slip, Concrete.

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INTRODUCTION

In steel framed buildings composite deck system is economical and efficient floor system. Since, last six decades' composite floor system was considered as optimum solution to High, medium and also for low rise steel framed structure. Composite floor system is created by combining the structural properties of concrete and profiled steel sheet (Figure.1). Here, profiled steel sheet has to play two major roles: It acts as permanent formwork during construction period which creates working platform for workmen, it acts as main reinforcement in composite action. Composite floor act as one-way slab in which concrete and steel sheet are so interconnected that they act together to resist bending in longitudinal direction. For taking care of shrinkage and temperature secondary reinforcement in form of bars/Welded wire mesh is provided.

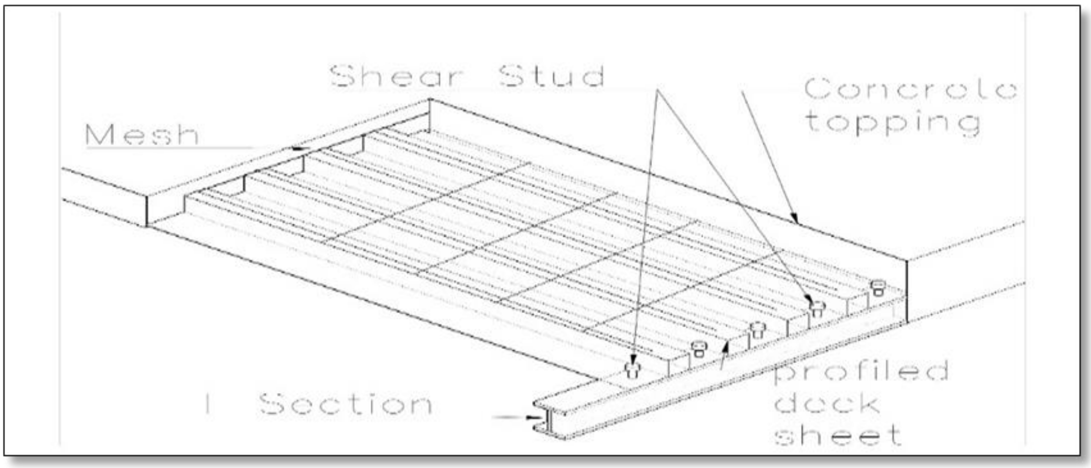

Figure 1 Details of composite slab

TESTS ON COMPOSITE SLAB

To determine the parameters governing the behaviour of the composite slab full scale tests as well as small scale tests are carried out (EC4). Small scale tests are push out, pull out, element bending tests which helps in determining slip, shear action and mainly shear resistance between deck sheet and concrete. Full scale tests are four-point bending, three-point bending which gives ultimate load carrying capacity, deflection, slip. Eurocode 4 recommends two testing methods (m-k method and partial shear connection method) to determine longitudinal shear strength of composite slab which is governing parameter in design. Details of bending tests is shown in figure.2. The common types of failure modes in composite slabs are flexural failure (section 1-1), Shear failure (section 2-2) and longitudinal shear failure (section 3-3) (Figure.2)

FULL SCALE TEST

Most of the researchers have investigated the behaviour of composite slab experimentally and the most of the research work is focused on full scale tests, as the results obtained by full scale tests are more reliable and accurate as compared to small scale tests. Luttrell and

Davison [1] investigated the effect of embossment on the slip resistance of composite slab and they found that vertical embossment is 50% more effective than the horizontal embossment, while horizontal embossment is more effective in resisting vertical separation but it is effective till the existence of chemical bond, addition to that the horizontal embossments adds its little contribution to achieve composite interaction.

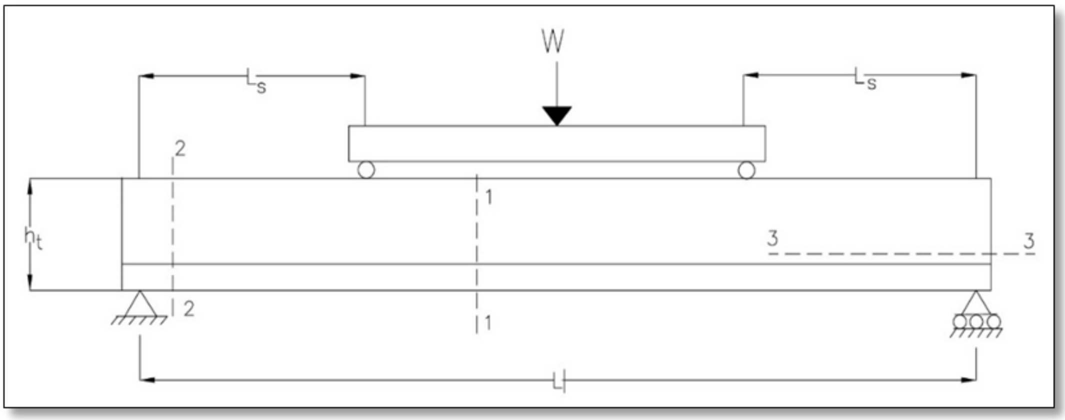

Figure 2 Static Loading

The effect of embossment on bond strength is also studied by Lutrell [6] and they concluded that the failure of profiled decks having embossment is gradual, it can withstand the lad even after initiation of slip, so embossment increases stiffness and load carrying capacity of composite slab. Porter and Ekberg [2] carried out large number of experimental studies on composite slab tested up to failure, and accent is given on ultimate strength design concept. They give design procedure based on ultimate strength concept and concluded that the load carrying capacity is depending on shear bond strength of composite slab. Schuster [3] classified various commercially available profiled steel decks based on type of mechanical interlock and slip resistance offered by steel deck. The classification of deck sheet is into three categories: profiles with mechanical connector, profiles without mechanical connectors and profiles with mechanical interlocks. Stark [4] has experimentally investigated and classified the failure patterns in composite slab as ductile and brittle failure. He also stated that the composite action is dependent on type of profiled deck sheet and depth and density of embossment, on the same line Seleim ,Evan [5,8] assessed results of previous experiments and concluded that compressive strength of concrete does not influence bond strength, [5] they give a new equation to calculate bond strength which is based on the experimental results and deck thickness is one of the major parameter in it.Evan and Wright [8] carried out 200 tests on composite floor and the results obtained are compared with present design methods and concluded that the present design methods are safe. Failure observed is mainly due to loss of shear bond and they proposed the stages of failure. In first stage slab is in composite action, in second stage chemical bond between sheet and concrete breaks and slip initiates and at final stage mechanical bond due to connector/shape of sheet brakes and final collapse takes place. The effect of end anchorage in terms of stud bolt is studied by Calixto [9], test results shows that the studs bolts used as connector gives better results, though failure mode was by shear bond failure. Lee [11] investigated the fatigue and static behaviour of shear stud and the results were compared with EC4 and AASHTO LFRD. The fatigue endurance observed is marginally lower than values obtained from EC4. To simulate actual field condition Chen, Young [12,13] carried out experiments on continuous composite slab.

In all tests load carrying capacity of composite slab is governed by longitudinal shear bond failure [13]

M-K TEST

Porter [14] investigated behaviour of composite slab based on maximum strength concept, also he proposed the design procedure. As per his findings m and k parameter are determined by plot of Vu/bd$\sqrt{f_c}$ ON Y axis and ρd/L$\sqrt{f_c}$ on X axis. M and k parameters provide equation for longitudinal slip resistance. Crisinel and morimon [15] derived the moment curvature relationship using simple calculation model which combines the results from small scale test as well as standard material test. The load carrying capacity of composite slab is determined by using this "New Simplified Method" by considering three stages of moment curvature behaviour. V.marimuthu et.al [16] have carried out m-k test on embossed composite deck slab and they concluded that there is no noteworthy effect of initial cyclic loading as it breaks only chemical bond. For shorted shear span failure is governed by bond failure and for larger shear span failure is governed by flexural failure. Lopes et.al. [17] studied provisions in EC4 and its drawbacks and they concluded that the effect of chemical adherence is not accounted in both the methods i.e. m-k method and partial shear connection method. The author developed a method based on small scale test i.e pull out test and this method is based on determination of moment curvature relation for composite slab at critical section. Swaminathan S. et.al. [18] determined m-k parameters for composite slab having bolted shear connector and headed shear connector. They observed three types of failure. The first type of failure is governed by crushing of concrete, buckling of shear stud connector is second type of failure, the combination of first and second type of is third type of failure.

SMALL SCALE TESTS

In 1970 push out test performed by Schuster [19], this test is carried out to build relationship between maximum push out force and moment capacity of slab. The test results failed to establish correlation with the bond strength for composite slab in flexure.

Detailed procedure of pull out test is given by Daniels [20], the results from tests gives overestimated values of shear resistance. The effect of size shape and location of embossment on profiled sheet is studied by Makelainen and Sun [21], They concluded that the shear strength offered by profiled deck is significantly affected by the depth of embossment [21,22], New block bending test were developed by An to determine interfacial shear stress, those test results were used as input parameters in finite element analysis.

SHEAR CONNECTOR

Maleki et.al. [24] investigated the capacity of channel shear connector used in polypropylene and normal concrete by performing push out test, they proposed nonlinear finite element model to predict the shear capacity of channel shear connectors in polypropylene concrete. Sulong et.al [25] performed push out test on channel shear connectors in plain, lightweight and reinforced concrete with varying length of shear connector, ductile behaviour is observed in lightweight concrete, increased ultimate strength and ductility of channel shear connector is observed in reinforced concrete while plain concrete shows brittle behaviour. Arabnejad K et. al. [26] studied the behaviour of channel shear connector in high strength concrete by performing push out test under low cycle fatigue load and static load. The strength degradation rate observed in high strength concrete is lower than other types of concrete and adequate ductility of channel shear connectors are detected in test. Baran et. al. [27] performed fifteen push out test to understand the behaviour of European type channel shear connector with varying its length and heights, they developed a new equation based on experiments conducted to determine the ultimate resistance of channel shear connectors as the equations proposed by Canadian and American specifications are too conservative.

The behaviour of angel shear connector and channel shear connector is experimentally observed and compared by Shariati et.al. [28], they concluded that shear resistance and ductility offered by angle shear connectors is lesser than of channel shear connectors. Mechanical connectors by means of different reinforcement patterns are developed by Lakshmikanthan et.al [29] and tested under monotonic loading, these concocters modify brittle behaviour of composite slab into ductile

CONCRETE

Carin L. et.al. [30] investigated the influence of secondary reinforcement (which is generally used for minimizing the ill effects due to temperature and shrinkage) on the strength of composite slab. Four types of secondary reinforcements were used in this study: welded wire fabric and three types of fibres. The tests were conducted on 3 span continuous composite slab and they found that there is no noteworthy effect of secondary reinforcement on the strength of composite slab, however slabs with steel fibre has smaller strain and deflection. Mohammad Bahar [31] conducted m-k test on composite slab having crumb rubber concrete topping. They concluded that CRC has reduced unit weight and it absorbs more energy before failure and has comparatively good toughness and slump value. The test results indicate that composite slab with CRC topping achieved the ductile requirements of Eurocode 4 and shear bond strength is also higher as compared to composite slab having NC topping Sarbini N et.al.[32] conducted experiments to determine the shear strength of composite slab having steel fibre concrete topping. Test were carried out on 75 specimens with varying steel fibre volume fraction’s results shows that composite slab having steel fibre concrete topping has more shear strength than of composite slab having welded steel mesh in concrete. The optimum increment in shear strength is observed for SF50 and SF60 started at Vf=0.75% and for SF33 at Vf=0.25%. They concluded that steel fibres are able to arrest cracks which prevents the member from sudden failure.

Gholamhoseini et. al. [33] conducted experimental study on strength and serviceability of reinforced and steel fibre reinforced concrete continuous composite slab to measure the crack width resulting from gravity and shrinkage loading. Sixteen specimens with different bond conditions (greased, standard deck and embossed deck) and different types of reinforcement (steel fibre, WWF reinforcement bars) were casted and tested for serviceability. Test period was 90 days. They concluded that there was no cracking due to shrinkage and creep for composite sab containing mesh and fibre. Hossain et.al. [34] investigated the behaviour of composite slab having high performance concrete (ECC) topping. They carried out m-k test on 30 specimens and test parameters are type of concrete (ECC based concrete and self-consolidating concrete), type of profiled deck and shear span. The behaviour of ECC based composite slab is compared with SCC based composite slab on the basis of failure mode, load displacement results, shear bond strength, strain values in concrete and sheet. ECC based composite slab shown excellent performance in terms of ductility, strength and shear bond strength. Li et.al. [35] conducted four point bending test to observe the behaviour of composite slab with lightweight woodchip concrete topping. Eleven specimens ae tested and accent is given on their failure modes. Shear bond resistance is calculated by conventional methods i.e. m-k method and pcs method, Addition to this method three new methods were also used (slenderness method partial shear connection beam method, force equilibrium method) and results were compared. The experimental results have good agreement with shear bond strength obtained from slenderness method and force equilibrium method. Waldman [36] tested 22 specimens having lightweight woodchip concrete topping. Ductile bond behaviour is observed in all tested specimens. Lightweight woodchip concrete reduces dead load by 50% but also reduces load bearing capacity of slab by 20% as compared to composite slab with NC topping.

FEM

For analysing composite slab Daniels and Crisinel [37] developed finite element procedure employing plane beam element. In this procedure load-slip property of shear connector, nonlinear material properties and positive moment offered by reinforcement are considered. From this model maximum load carrying capacity of composite slab and shear stress distribution are obtained. An [22] in 1993 used 2D nonlinear finite element model for analysis of composite slab using ABAQUS. Spring element is used to model the interaction between concrete and steel deck, for long span slab the finite element results shows good agreement with experimental results. Veljkovic [38] used 3d Finite element model using DIANA to observe the behaviour of composite slab. Nodal interface element was used to model the shear interaction between sheet and concrete also properties obtained from push out tests are also employed to model. Longitudinal slip mechanism of composite slab is simulated using 3D nonlinear FEM by Ferrera et.al. [39] Authors also carried out bending test and small scale tests to validate the results obtained from FEM analysis, they found out that embossing slope and retention angle were important parameters in slip resistance. Abdullah et.al. [40] used explicit model to developed quasi static analysis method to predict ultimate load carrying capacity as well as load-deflection behaviour of composite slab.

CONCLUDING REMARKS

The efficiency of composite slab depends on the composite action between concrete and profiled steel deck sheet. The longitudinal shear failure is the most common type of failure is observed, so further research is needed to improve shear bond strength of composite slab. Finite element analysis requires input parameters of concrete and steel interface interaction for which experimentation is needed. Loading arrangement and slenderness of slab are the key parameters to study the behaviour of composite slab, these parameters are not considered in small scale test. Also, results obtained from small scale tests does not include combined effect of bending and shear. Most of the research is focused on composite slab with normal concrete topping, to improve shear bond strength parameters related to profiled sheet are only considered. Little research has been conducted on behaviour of composite slab with different types of concrete.

REFERENCES

1. Luttrell, L. D. and Davison, J. H. (1973), “Composite Slabs with Steel Deck Panels, proceedings of the Second International Specialty Conference on Cold-Formed Steel Structures, University of Missouri-Rolla, pp. 573-603.

2. Porter, M. and Ekberg, C. (1976). "Design Recommendations for Steel Deck Floor Slabs",ASCE Journal of the Structural Division, Vol. 102, pp. 2121-2136.

3. Schuster, R. M. (1972), "Composite Steel-Deck-Reinforced Concrete Systems Failing in Shear-Bond," Preliminary Report, Ninth Congress of the International Association for Bridge and Structural Engineering, Zurich, Switzerland, pp. 185-191.

4. Stark, J. W. B. (1991), "Design of Composite Steel-Concrete Structures According to Eurocode 4", Proceedings of the International Conference on Steel and Aluminium Structures, ICSAS 91, Singapore, pp. 23-39.

5. Seleim, S. and Schuster, R. (1985), "Shear-Bond Resistance of Composite Deck-Slabs", Canadian Journal of Civil Engineering, National Research Council of Canada, Vol. 12, pp. 316-324.

6. Luttrell, L. D. and Prassanan, S. (1984), “Strength Formulations for Composite Slabs”, Proceedings of the Seventh International Specialty Conference on Cold-Formed Steel Structures, University of Missouri-Rolla, pp. 573-603.

7. Luttrell, L. D., (1987). "Flexural Strength of Composite Slabs," Composite Steel Structures Advances, Design and Construction, Elsevier Science Publishing Co., Inc., pp. 106-116.

8. Wright, H. D., Evans H. R. and Harding, P. W., (1987), “The Use of Profiled Steel Sheeting in Floor Construction”, J. Construct. Steel Research, Vol. 7.

9. Calixto, J. M., Lavall, A. C., Melo, C. B., Pimenta, R. J., and Monteiro, R. C. (1998), “Behaviour and Strength of Composite Slabs with Ribbed Decking”, Journal of Constructional Steel Research, Elsevier Science Ltd, Vol. 46, No. 1-3, Paper No. 110.

10. Eurocode 4 (1992), “Common Unified Rules for Composite Steel and Concrete Structures”, ENV 1994-1-1.

11. Shim C, Lee P, Chang S (2001). Design of shear connection in composite steel and concrete bridges with precast decks. J. Constr. Steel Res., 57: 203-219.

12. Chen, S. (2003), Load carrying capacity of composite slabs with various end constraints‖, Journal of Constructional Steel Research Vol. 59, pp.385–403.
13. Easterling, W. S., and Young, C. Y. (1992), "Strength of Composite Slabs," Journal of Structural Engineering, ASCE, Vol. 118, pp. 2370-2389.

14. Porter, M. and Ekberg, C. (1976). "Design Recommendations for Steel Deck Floor Slabs", ASCE Journal of the Structural Division, Vol. 102, pp. 2121-2136. Sabnis, G. (1979). Handbook of Composite Construction Engineering, Littleton Educational Publishing.

15. Crisinel, M., (1990), Partial-Interaction Analysis of Composite Beams with Profiled Sheeting and Non-welded Shear Connectors, Journal of Construct. Steel Research, Vol. 15, pp.65-98.

16. Marimuthu, V., Seetharaman, S., Arul Jayachandra, S., Chellappana, A., Bandyopadhyay,

17. T. K. and Dutta, D. (2007), Experimental studies on composite deck slabs to determine the shear-bond characteristic (m–k) values of the embossed profiled sheet, Journal of Constructional Steel Research, Vol. 63, pp.791–803.

18. Swaminathan, S., Siva, A., Senthil, R., Prabu, K.: Experimental investigation on shear connectors in steel-concrete composite deck slabs. Indian J. Sci. Technol. 9, 1–8 (2016)

19. Schuster, R. M. (1972), "Composite Steel-Deck-Reinforced Concrete Systems Failing in Shear-Bond," Preliminary Report, Ninth Congress of the International Association for Bridge and Structural Engineering, Zurich, Switzerland, pp. 185-191.

20. Daniels, B. and Crisinel, M. (1993a), "Composite Slab Behavior and Strength Analysis, Part I: Calculation Procedure, Journal of Structural Engineering, ASCE, Vol. 119, No. 1-4, pp. 16-35.

21. Makelainen, P. and Sun, Y., (1998), "Development of a New Profiled Steel Sheeting for Composite Slabs, Journal of Constructional Steel Research, Elsevier Science Ltd, Vol. 46, No. 1-3, Paper No. 240.

22. An, rL., Cederwall, K.: Composite Slabs Analyzed by Block Bending Test. (1992)

23. Akhand, A. M., Badaruzzaman, W. H. W., Wright, H. D., (2004), Combined flexure and web crippling strength of a low-ductility high strength steel decking: experiment and a finite element model, Thin-Walled Structures, Vol. 42, 1067–1082.

24. Maleki, S., Mahoutian, M.: Experimental and analytical study on channel shear

connectors in fiber-reinforced concrete. J. Constr. Steel Res. 65, 1787–1793 (2009). doi:10.1016/j.jcsr.2009.04.008

25. Shariati, M., Ramli Sulong, N.H., Arabnejad Khanouki, M.M.: Experimental assessment of channel shear connectors under monotonic and fully reversed cyclic loading in high strength concrete. Mater. Des. 34, 325–331 (2012).

26. Shariati, M., Sulong, N.H.R., Arabnejad, M.M.K.H., Mahoutian, M.: Shear resistance of channel shear connectors in plain , reinforced and lightweight concrete. 6, 977–983 (2011).

27. Baran, E., Topkaya, C.: An experimental study on channel type shear connectors. J. Constr. Steel Res. 74, 108–117 (2012).

28. Shariati, M., Ramli Sulong, N.H., Shariati, A., Khanouki, M.A.: Behavior of V-shaped angle shear connectors: experimental and parametric study. Mater. Struct. Constr. 49, 3909–3926 (2016).

29. Lakshmikandhan, K.N., Sivakumar, P., Ravichandran, R., Jayachandran, S.A.: Investigations on Efficiently Interfaced Steel Concrete Composite Deck Slabs. J. Struct. 2013, 1–10 (2013).

30. Roberts-Wollmann, C.L., Guirola, M., Easterling, W.S.: Strength and Performance of Fiber-Reinforced Concrete Composite Slabs. J. Struct. Eng. 130, 520–528 (2004).

31. Mohammed, B.S.: Structural behavior and m-k value of composite slab utilizing concrete containing crumb rubber. Constr. Build. Mater. 24, 1214–1221 (2010).

32. Sarbini, N.N., Ibrahim, I.S., Saim, A.A., Abdul Rahman, A.B., Harun, N.F., Hasbullah, N.N.: Shear capacity of composite slab reinforced with steel fibre to that of fabric reinforcement in concrete topping. Mater. Res. Innov. 18, S6-236-S6-240 (2014).

33. Gholamhoseini, A., Khanlou, A., MacRae, G., Scott, A., Hicks, S., Leon, R.: An experimental study on strength and serviceability of reinforced and steel fibre reinforced concrete (SFRC) continuous composite slabs. Eng. Struct. 114, 171–180 (2016).

34. Hossain, K.M.A., Alam, S., Anwar, M.S., Julkarnine, K.M.Y.: High performance composite slabs with profiled steel deck and Engineered Cementitious Composite – Strength and shear bond characteristics. Constr. Build. Mater. 125, 227–240 (2016).

35. Li, X., Zheng, X., Ashraf, M., Li, H.: Experimental study on the longitudinal shear bond behavior of lightweight aggregate concrete – Closed profiled steel sheeting

composite slabs. Constr. Build. Mater. 156, 599–610 (2017).

36. Waldmann, D., May, A., Thapa, V.B.: Influence of the sheet profile design on the composite action of slabs made of lightweight woodchip concrete. Constr. Build. Mater. 148, 887–899 (2017).

37. Daniels, B. and Crisinel, M. (1993b), “Composite Slab Behavior and Strength Analysis, Part II: Comparisons with Test Results and Parametric Analysis, Journal of Structural Engineering, ASCE, Vol. 119, No. 1-4, pp. 36-49.

38. Veljkovic M. (2000), “Behaviour and Design of Shallow Composite Slab, Proceedings of and Engineering Foundation Conference on Composite Construction in Steel and Concrete IV, ASCE, Vol. 1, pp.1-12.

39. Crisinel, M., Marimon, F., (2004), A new simplified method for the design of composite slabs, Journal of Constructional Steel Research, Vol. 60, 481–491.

40. Abdullah, R., Easterling, W. S., (2009), New evaluation and modelling procedure for horizontal shear bond in composite slabs, Journal of Constructional Steel Research, Vol.65, pp. 891-899.