
Steel Fiber Reinforced Concrete as Sustainable Material for Construction of Slab on Grade - Review

^{*1}Sumit S. Geete, ²Manoj S. Tiwari, ³Mahendra S. Kadu

^{1,2,3}Civil Engineering Dept., Shri Ramdeobaba College of Engineering and Management, Nagpur, India
Email: ¹sumit.geete@gmail.com, ²tiwarims@rknec.edu, ³kadums@rknec.edu

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Abstract

Slab on grade is a slab directly supported on the soil. Slab on grade is used for construction of industrial floor and rigid pavement. For construction of slab on grade, fibers mainly steel fibers are used with specified doses. Addition of the fiber in the slab on grade improved the ductility and post cracking nature of the load versus deflection curve. Area under load deflection curve is called toughness. Peak load of SFRC is higher than the plain cement concrete. Steel fibers are more appropriate to used in slab on grade that synthetic and polypropylene fiber. Non linear fracture mechanics of concrete between cracks is evaluated to understand the performance of the SFRC. Parametric study carried out to evaluate the effect of type of steel fiber, dose of steel fiber and load – deflection curve on the depth of the slab on grade. Some equations and charts are proposed for the calculation of dose of fibers based on loading criteria and minimum depth of slab on grade. Plastic method, yield line analysis and non linear fracture mechanics methods consider for analysis and design of slab on grade. Slab on grade should be sustainable to perform satisfactorily intended use and economical. To design slab on grade with minimum slab thickness and optimum dose of fiber based on serviceability criteria reflects sustainability construction approach.

Keywords

Fiber Reinforced Concrete (FRC), Slab on Grade, Steel Fiber, Collapse Load, Yield Line, Non Linear Fracture Mechanic (NLFM)

Introduction

The demands for an industrial floor have increased tremendously over the last few years. The main objectives for an industrial floor are to transfer the loads to the sub-base and to provide a hard and even surface to work. Industrial floor should sustained the all the types of load imposed over. Industrial floor is necessary to be sustainable based on performance and economy. Slab on grade means slab supported on the foundation soil beneath. In industrial floor slab on grade, use of steel fiber instead of steel reinforcement more preferred. From the literature, use of steel fibers in the slab on grade is more economical, durable than the conventional steel reinforcement concrete. The mechanical properties and cracking behaviour are improved by adding steel fibers to the concrete mix. The thickness of the floor is function of the loading, modulus of sub grade and flexural strength of the concrete. Flexural strength of the concrete depends on the types of fiber, dose of fiber and post cracking nature of the load- deflection curve.

Literature Review

Collapse mechanism method of yield line analysis suggested for slab on grade. A yield – line analysis technique is developed to determine collapse loads by equating the internal and external work done for reinforced concrete slab on grade with evaluating three load cases separately namely load in the central, free edge and free corner region of a large slab. [1] Developed collapse load equation of concrete slab on ground with load transmitted through circular contact at interior, near the edge, at the edge and at corner through lower bound analysis. [2] Proposed work analysed the effect of steel fibers inclusion on fresh and hardened properties of concrete. Workability of FRC concrete could not affect by use of hooked end steel fiber dose up to 1.5% by volume of concrete. Fibers restrained the crack propagation of the cracks originated within the body of the concrete. Ductility and post cracking load carrying capacity of the concrete increase by addition of the fiber. Fiber merely increases the compressive strength of the concrete. Increment in the split tensile strength flexural strength and impact strength is reported about 57%, 67% and 25% respectively. [3] Load – deflection curve of SFRC slabs under a concentrated load exhibits four distinct regions initial elastic un-cracked region, crack development region, post yielding region and post peak region. The critical perimeter of punching failure is 4.5 times of effective depth measured from perimeter of loading platen with inclination of 20^o-60^o to plane of slab. With increment of dose of fibers in SFRC, cracking load is also increases. Cracks initiated mainly in radial direction and partly in circumferential direction. [4]

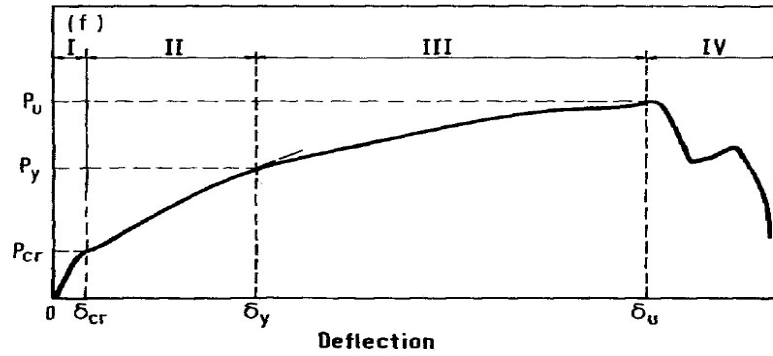


Fig. 1: Load – Deflection Curve for FRC

Finite-element analysis predicted behaviour of slab on grade for the collapse load and the load-settlement analysis. Nature of initiation of the circumferential and radial direction of cracks analysed through testing of the circular slab. The proposed equations to evaluate the load-carrying capacity of a slab on grade are found to be simple and practical. [5] Shrinkage cracks are mainly responsible for the durability of the slab on grade. Shrinkage of the concrete is reduced by using Shrinkage reducing admixtures (SAR). SAR delayed the cracking which reflected in to cracks of smaller crack width in unrestrained slab on grade. [6] Behaviour of concrete slab supported on the concrete studied by generating a numerical model of material non-linear analysis. The behaviour of concrete between the cracks is simulated using conventional theory of the plasticity and studied crack properties of concrete. The influence of simulating the loss of contact between the slab and the soil and the influence of the soil constitutive law in a material non-linear analysis of a slab supported on soil are discussed. [7]

On the basis of energy absorption capacity of SFRC, a constitutive model is developed for material non-linear analysis for slab on grade. Model is created slab resting on the soil and concrete cracking behaviour. [8] Slab on grade loss the contact between soil and slab surface because of effect of curling. Curling of slab on grade generated because of differential strain within the slab thickness due to variation in the humidity. Protective measures suggested to reduced the curling effect of slab on grade. [9]

Deviation of the levels of the slab on grade was studied by collecting the data of levels of concrete after immediate placement of the concrete. Average and maximum deviation are 1/334 and 1/101. These deviations should be fall within the specified limit as per ACI 117-90 otherwise angular rotation exceed threshold value. [10] Behaviour of slab on grade under concentrated load had investigates for varying types and dosage of fiber typically used in slab construction. Test results of the SFRC are comparable with slab on grade casted with welded wire mesh. Polypropylene fiber reinforced concrete (PFRC) is not at par with the load carrying capacity requirement of slab on grade. PFRC reduced the plastic shrinkage cracks and improved long term performance of the slab for intended use. [11]

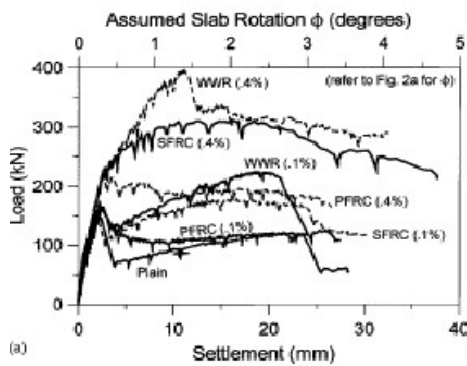


Fig. 2: Load Vs. Settlement of Slab with Variation of Types of Fibers

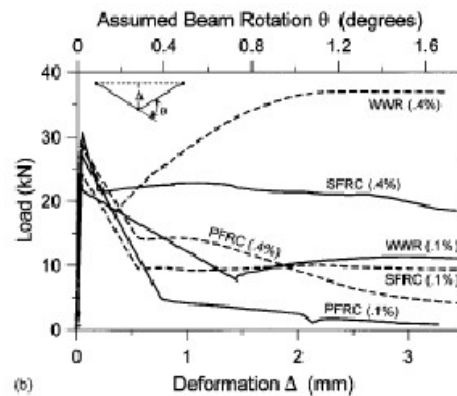


Fig. 3: Load Vs. Deflection of Slab with Variation of Types of Fibers

Comparative experimental investigation reported between plain cement concrete and SFRC for slab on grade. Load – carrying capacity of the slab on ground increase with the use of SFRC. Flexural toughness is the area under stress- strain graph. Flexural toughness of the SFRC is more than the plain cement concrete slab. It is

proposed that friction between surface of slab of grade and the sub-grade is negligible effect on the load-carrying capacity. [12] Fiber improved the load- deflection property of the plain cement concrete. Tensile cracks in the FRC slab initiated at the same load irrespective of dose and type of fiber but well below the flexural cracking load. Slab flexural strength of slab is 1.8-2.2 times higher than flexural strength of beam. Flexural strength of the FRC is around 1.4 times flexural strength of the plain cement concrete. The flexural cracking load of the fiber reinforced slabs was 25 -55% higher than the plain concrete slab. Optimum doses of the various types of fibers are proposed for slab on grade. [13] Failure pattern of slab on grade similar is to all types of slab failed under uniform load. As the dose of the steel fiber increase then ultimate load carrying capacity increases. [14] Effect of fiber content and diameter of steel fiber studied on the SFRC slab on grade. Modulus of elasticity tend to decrease with the increment with fiber content. Toughness of the concrete is mainly depends on the dose of the fibers. [15] Required thickness of the slab on grade depends on the magnitude of loading, modulus of sub-grade, reinforcement and grade of concrete. [16]

Ultimate load carrying capacity of the FRC slab on grade is not only function of the Modulus of rupture (MOR). Load – deflection curve of the FRC after post crack failure influence the peak load associated with cracking. Structural designing of the slab on grade with fibers should take into account of post cracking behaviour of the FRC mainly strain softening and plasticity. So it is proposed to used plastic analysis or yield line theory for designing of the slab on grade. [17] From the experimental investigation executed for assessment of structural behaviour of slabs on ground casted with SFRC. Full scale slab with varying proportions of dose of steel fibers are casted and tested with concentrated point load at centre. From the experimentation results, it is concluded that load carrying capacity and ductility of the slab increases with addition of the steel fibers.

Non linear behaviour of the SFRC evaluated through non linear fracture mechanics (NLFM) and constitutive models formed. Proposed the equation for minimum depth of SFRC slab on grade with loading conditions. [18] A numerical study in ABAQUS based on the design aspects of SFRC slabs on grade considering contribution of fibers to the toughness, serviceability and ultimate load carrying capacity. Comparisons with experimental results of full-scale tests validated the proposed model and provided evidence of the usefulness of NLFM to analyze SFRC structures. Ultimate load of the slab on grade is function of the point of application of the load, location of construction joints, boundary conditions and dose of the steel fibers. [19] Polymeric micro fibers (PMF) increased the toughness of the FRC slab on grade. PMF also nullify the chances of corrosion of the steel fibers. PMF reduced the performance of the fresh concrete. Low dose of PMF in slab on grade is ineffective as compared to the control mix slab on grade without PMF.[20] Behaviour of short term and long term performance of slab on grade depends on the properties of the sub-grade soil, workmanship, differential settlement soil. [21] SFRC improved the performance of slab reinforced with steel because it increases the load carrying capacity of the slab. Flexural strength capacity increase with applying layer of FRC in tension side of the slab. [22] Non linear behaviour of the slab on grade of SFRC is studied. Parametric investigation executed to study the effect of influence of grade of concrete, dose of steel fiber and sub-grade coefficient on the load displacement curve of SFRC of slab on grade. [23] As compared to steel fibers, synthetic fibers provide more pronounce post cracking behaviour of the FRC. The requirement of dose of the synthetic fiber is less than the dose of steel fiber. Synthetic fibers create balling effect in the production of concrete. Method of addition of synthetic fibers in dry mix state rather than wet mix state to reduced the balling effect. [24] Performance of slab on grade for application of load at centre, edge and corner are evaluated to study formation and pattern of the cracks. Non linear finite element analysis done to check the effect of application of load on assessment of tensile strength of the slab on grade. [25]

Results and Discussion

From the literature it is concluded that

1. The behaviour of slab of grade depends of the dose of the fibers and type of fiber. Slab on grade reported improvement in the performance of load – deflection curve by addition of steel fibers.
2. Area under load – deflection curve (denotes toughness of concrete) more for SFRC than plain cement concrete, this indicates that strain energy of the SFRC is more than plain cement concrete.
3. Post cracking region of the SFRC is more pronounce than the plain cement concrete. Post cracking deflection increment enhances the peak load capacity of the SFRC.
4. Steel fiber is effective to use in slab on grade as compared to polypropylene and synthetic fibers. Polypropylene and synthetic fibers mainly exhibit balling effect to reduced workability of FRC.
5. Some charts and equations are available in the literature based on type of fiber, dose of fiber, grade of concrete and modulus of sub grade to calculate the minimum thickness of the slab.
6. The existing design methods could not be applied to fiber reinforced concrete floor slabs as Fibers represent a diffused reinforcement and are not localised in defined planes.

Conclusion

Steel fiber is effectively used in slab on grade construction. Load – deflection behaviour of the FRC slab on grade is indicated the increment of peak load capacity because of increment of strain energy due to addition of steel fiber. Durability of steel FRC is more the welded wire mesh reinforcement slab on grade. Steel fiber is more effective rather polypropylene fiber for constriction of slab on grade. Design of thickness steel FRC slab on grade is basically depends on the loading condition, grade of concrete, type off fiber and dose of fiber. It is necessary to develop the methodology for design of FRC slab on grade.

Future Scope

Based on extensive literature review, it was found that slab length, slab width, slab thickness, sub-grade modulus, loading are considered to be important in the design of an industrial floor slab on grade. So, in order to develop a rational design or analysis procedure, it was proposed to conduct a parametric study involving determine the deflection curve at centre, edge and corner of slab on grade by centre point loading, thickness of slab on grade, fiber content, type of fiber sub-grade modulus of soil, grade of concrete and loading parameters to study their influence on deflections, stresses, modulus of rupture, bending moments, and punching shear forces occurring in the slab.

References

- [1] B. Robert and F. E. Weisgerber, "Yield-line analysis of slabs-on-grade," *J. Struct. Eng. (United States)*, vol. 111, no. 2, p. 481, 1983.
- [2] B. Kanakapua, S. S. Rao, and S. Singh, "CONCENTRATED LOAD-CARRYING CAPACITY deflections of the slab can be computed , as for an elastic and infinite slab on an elastic subgrade (Westergaard 1948). They will all be functions involving a characteristic length or radius of relative stiffness giv," vol. 112, no. 12, pp. 2628–2645, 1987.
- [3] A. Faisal Fouda Wafa, "Properties and Applications of Fiber Reinforced Concrete," *JKAU Eng. Sci.*, vol. 2, pp. 49–63, 1990.
- [4] Kiang-Hwee Tan and P. Paramasivam, "Punching Shear Strength of Steel Fiber Reinforced Concrete Slabs," *J. Mater. Civ. Eng.*, vol. 6, no. 2, pp. 240–253, 1994.
- [5] Longmei Shentu; Dahua Jiang and Cheng-Tzu Thomas Hsu, "LOAD-CARRYING CAPACITY FOR CONCRETE SLABS ON GRADE," *J. Struct. Eng.*, vol. 123, no. January, pp. 95–103, 1997.
- [6] W. W. Weiss, W. Yang, and S. P. Shah, "By W . Jason Weiss , l Student Member , ASCE , Wei Yang , 2 and Surendra P . Shah , 3 Members , ASCE," *J. Eng. Mech.*, vol. 124, no. 7, pp. 765–774, 1998.
- [7] J. Barros, "Analysis of concrete slabs supported on soil," *Metod. Numer. En Ing.*, pp. 1–21, 1999.
- [8] J. A. O. Barros and J. A. Figueiras, "Model for the analysis of steel fibre reinforced concrete slabs on grade," *Comput. Struct.*, vol. 79, no. 1, pp. 97–106, 2001.
- [9] and D. A. T. Noel P. Mailvaganam, John Springfield, Wellington L. Repette, "CURLING OF CONCRETE FLOOR SLABS ON GRADE - CAUSES AND REPAIR," *J. Perform. Constr. Facil. Facil.*, vol. 15, no. January, pp. 11–16, 2000.
- [10] B. and B. Walsh, "STATE OF PRACTICE OF RESIDENTIAL FLOOR SLAB FLATNESS," *J. Perform. Constr. Facil.*, vol. 15, no. November, pp. 127–134, 2001.
- [11] P. H. Bischoff, A. J. Valsangkar, and J. Irving, "Use of fibers and welded-wire reinforcement in construction of slabs on ground," *Pract. Period. Struct. Des. Constr.*, vol. 8, no. 1, pp. 41–46, 2003.
- [12] S. Chen, "Strength of steel fibre reinforced concrete ground slabs," *Proc. Inst. Civ. Eng. Struct. Build.*, vol. 157, no. 2, pp. 157–163, 2004.
- [13] J. R. Roesler, D. A. Lange, S. A. Altoubat, K. A. Rieder, and G. R. Ulreich, "Fracture of plain and fiber-reinforced concrete slabs under monotonic loading," *J. Mater. Civ. Eng.*, vol. 16, no. 5, pp. 452–460, 2004.
- [14] C. L. Roberts-Wollmann, M. Guirola, and W. Samuel Easterlina, "Strength and performance of fiber-reinforced concrete composite slabs," *J. Struct. Eng.*, vol. 130, no. 3, pp. 520–528, 2004.
- [15] R. D. Neves and J. C. O. Fernandes de Almeida, "Compressive behaviour of steel fibre reinforced concrete," *Struct. Concr.*, vol. 6, no. 1, pp. 1–8, 2005.
- [16] V. Zlogas and S. Juocnas, "Design and installation peculiarities of monolithic concrete floor," *J. Civ. Eng. Manag.*, vol. 11, no. 2, pp. 153–162, 2005.
- [17] E. S. Bernard, "Influence of toughness on the apparent cracking load of fiber-reinforced concrete slabs," *J. Struct. Eng.*, vol. 132, no. 12, pp. 1976–1983, 2006.
- [18] L. G. Sorelli, A. Meda, and G. A. Plizzari, "Steel fiber concrete slabs on ground: A structural matter," *ACI Struct. J.*, vol. 103, no. 4, pp. 551–558, 2006.
- [19] B. Belletti, R. Cerioni, A. Meda, and G. Plizzari, "Design aspects on steel fiber-reinforced concrete pavements," *J. Mater. Civ. Eng.*, vol. 20, no. 9, pp. 599–607, 2008.

- [20] F. Azhari, S. Talukdar, and N. Banthia, "A performance comparison between FRC and WWM reinforced slabs on grade," *Struct. Heal. Monit. Intell. Infrastruct. - Proc. 4th Int. Conf. Struct. Heal. Monit. Intell. Infrastructure, SHMII 2009*, no. July, pp. 1–12, 2009.
- [21] M. S. Seniwongse, "Slab-on-grade versus framed slab," *J. Archit. Eng.*, vol. 16, no. 4, pp. 164–169, 2010.
- [22] M. J. Radik, E. Erdogmus, and T. Schafer, "Strengthening two-way reinforced concrete floor slabs using polypropylene fiber reinforcement," *J. Mater. Civ. Eng.*, vol. 23, no. 5, pp. 562–571, 2011.
- [23] W. A. Elsaigh, E. P. Kearsley, and J. M. Robberts, "Modeling the Behavior of Steel-Fiber Reinforced Concrete Ground Slabs. II: Development of Slab Model," *J. Transp. Eng.*, vol. 137, no. 12, pp. 889–896, 2012.
- [24] A. M. Alani and D. Beckett, "Mechanical properties of a large scale synthetic fibre reinforced concrete ground slab," *Constr. Build. Mater.*, vol. 41, pp. 335–344, 2013.
- [25] J. Overli, "Experimental and numerical investigation of slabs on ground subjected to concentrated loads," *Cent. Eur. J. Eng.*, vol. 4, no. 3, pp. 210–225, 2014.