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Steel Fibre Reinforced Concrete Pavement Slabs with Contraction Joints

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Abstract—The p**erformance and efficiency of two types of rigid pavements with contraction joints viz. Plain Cement Concrete (PCC) and Steel Fibre Reinforced Concrete (SFRC) are evaluated by nonlinear static analysis using the finite element software ANSYS. The ultimate load carrying capacity, deflection pattern, and load transfer across the joint for the three critical load positions - interior, edge and corner - on rigid pavements are investigated. Results show that there is significant improvement in the ultimate load carrying capacity for the SFRC slabs. Efficiency of joint with respect to load transfer and deflection is also found to be better for SFRC slabs.**

Keywords—**: Rigid pavements, FEM, Nonlinear static analysis, Steel Fibre Reinforced Concrete, Contraction joint**

I. Introduction

Rigid pavements are constructed of cement concrete slabs resting on a prepared sub-base of granular material or directly on a granular subgrade. Here, load is transmitted through the slab to the underlying subgrade by flexure of the slabs. Rigid pavement slabs are generally provided with joints for expansion and contraction during temperature changes and shrinkage. Contraction joints are provided along the transverse direction to serve as prefixed planes of weakness meant for initial cracks to begin. These discontinuities (joints) could be extended to the full or partial depth of the slab. Sometimes iron bars are provided across

The research on Steel Fibre Reinforced Concrete (SFRC) started in early 1960's. Since then a great deal of attention was given to this topic worldwide. The weakness of concrete in the tensile zone can be minimized by the addition of steel fibres. The most important advantages of using steel fibres in concrete is to slow down and finally control crack propagation which usually occurs in tensile zone. One of the most important applications of SFRC nowadays is in pavements where fibres reduce cracking phenomena which is very significant in pavements. Design methods for rigid pavements were traditionally based on the elastic response (Westergaard 1926); however, an elastic approach is not suitable for SFRC pavements since fibres start activating after cracking of the concrete matrix, where the structural behaviour is markedly nonlinear.

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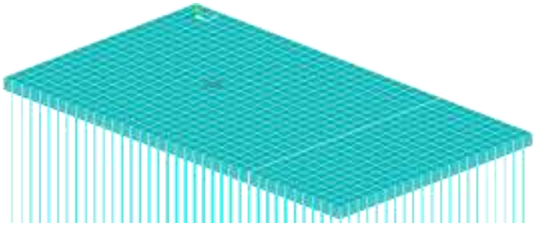
The nonlinear Finite Element (FE) method appears to be the most accurate tool for analyzing SFRC slabs on ground, because it allows a reproduction of the actual collapse mechanism and the development of a new design approach. Hossain et al. [1] performed 3D linear elastic finite element analysis to analyze the highway cement concrete highway pavement-soil system. Davids [2] employed a 3D finite element program for the analysis of jointed plain concrete pavements. Sorelli et al. [3] conducted extensive experimental investigations on full scale slabs with the aim of studying the structural behaviour of SFRC slabs on ground. Belletti et al. [4] conducted a FE analysis of the fracture behaviour of SFRC slabs on subgrade for industrial pavements and validated the results with experiments. Jafarifar et al. [5] experimentally demonstrated that the recycled steel fibres could be used to enhance the mechanical properties of concrete. Patil and Deb [6] proposed FE method as one of the most suitable mathematical tools for analysing rigid pavements under moving loads. It appears from literature that the case of SFRC slabs with contraction joints has not been given due attention. Hence the nonlinear behavior of SFRC slabs with contraction joints is investigated presently.

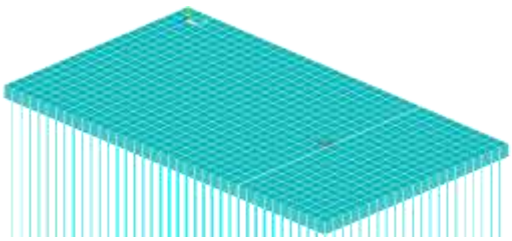
II. Numerical Modelling

FE modelling is done using the elements 'SOLID 65' and 'COMBINE 14'. Material properties of both PCC and SFRC from tests conducted in the concrete lab are input in material modelling. Slab with joint/groove is modelled as three different volumes and finally added to one, which makes the slab under study followed by the groove and a portion of the adjacent slab. The dimensions of the slab are determined by the design procedure for rigid pavements as per IRC: 58 [7]. The dimensions thus obtained are 4.45 m × 3.5 m × 0.27 m and the contraction joint width ranging from 0.01 to 0.02 m, and depth $1/3^{rd}$ to $1/4^{th}$ times depth of the slab throughout the transverse dimension of the slab. In this study, a scaled down model of above mentioned slab is used, which is of dimensions 0.8 m × 0.63 m × 0.05 m with a groove of size 0.003 m × 0.015 m.

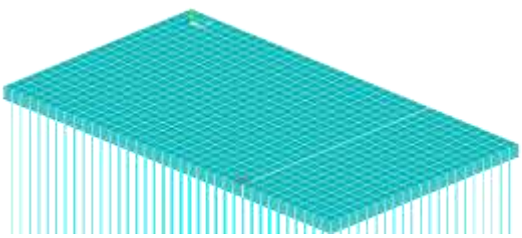
Slab was meshed and the subgrade soil was modelled using translational spring element called 'COMBINE 14' with sufficient stiffness to simulate the required modulus of subgrade reaction (i.e. 8 kg/cm^2/cm). According to IRC: 15 (2002) and IRC: 58 (1988) [8], the modulus of subgrade reaction should be greater than 6 kg/cm^2/cm for rigid pavement subgrade soil. Translational degree of freedom in both x and z direction are arrested in all outer vertical sides of the slab.



(a) Load at Centre



(b) Load at Edge



(c) Load at Corner

Figure 1. FE model showing load positions on slab

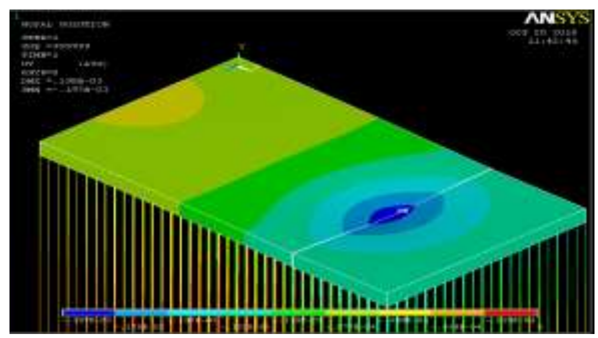
while simulating the boundary conditions. Mesh size control is carried out and the best possible mesh size 3cm × 3 cm is adopted. Modelling, meshing and analysis procedures are checked for its correctness by reproducing with ANSYS both linear and nonlinear analysis results from literature. Details of a validation process consisting of a comparison of stress computations using the Westergaard's method and nonlinear static analysis are presented in Joseph et al. [7]. Results of the validation process indicate the credible behavior of the ANSYS model in predicting performance of rigid pavement slabs with contraction joints. Analysis is done for the three cases of loading, i.e. centre of the slab, edge and the corner nearer to the joint as shown in Fig. 1.

III. Nonlinear Analysis of Slab with Contraction Joint

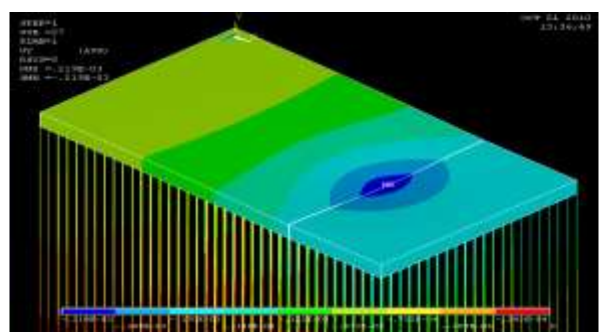
Nonlinearity in terms of material nonlinearity is incorporated in the model by inputting the stress strain curve obtained from the Young's Modulus Test conducted in the lab. Loading is given in smaller increments called 'load steps' and the deflection of the slab under the load point can be obtained for each increment. The failure load is denoted by the drastic increase in deflection for a particular increment in load. The ultimate load (Pu), stress intensity and deflection in the direction of thickness (Δmax) are the main parameters that are taken from the analysis results for further investigation. The efficiency of joint is studied using the load transfer capacity of the joint, which in turn, is obtained from the ratio of maximum deflections in the slab under consideration and the adjacent slab. The ultimate load carried by the slab is computed from the analysis as sum of the reactions in the direction of slab thickness at all nodes on the slab. Ultimate load at failure, deflection at various positions, deflection and stress contours are obtained.

A. *Sample Outputs*

Figs. 2 (a) and 2 (b) depict deflection contours for load at edge of PCC and SFRC slabs respectively.



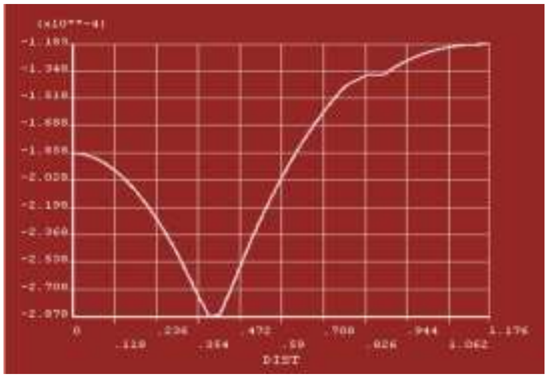
(a) PCC Slab



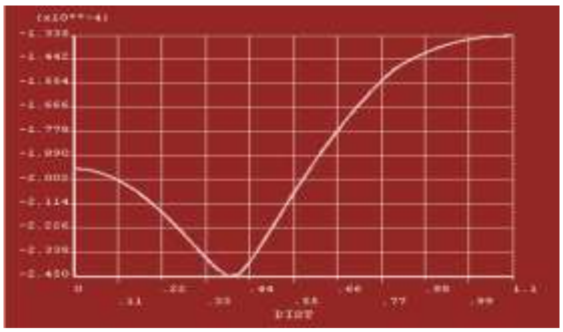
(b) SFRC Slab

Figure 2. Deflection Contour (Edge Load)

The deflection of slab along the longitudinal cross section under central load is illustrated in Figs. 3 (a) and 3 (b) and corner load in Figs. 4 (a) and 4 (b). Stress contours and crack patterns of PCC and SFRC slabs resulting from load at edge are presented in Fig. 5 and Fig. 6 respectively.

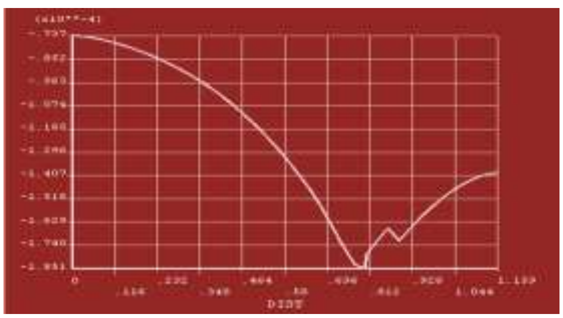


(a) PCC Slab

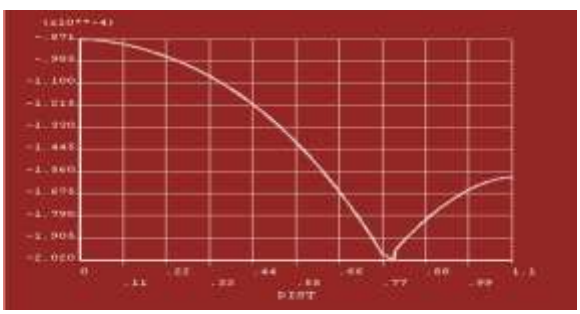


(b) SFRC Slab

Figure 3. Deflection along Length of the Slab (Central load)

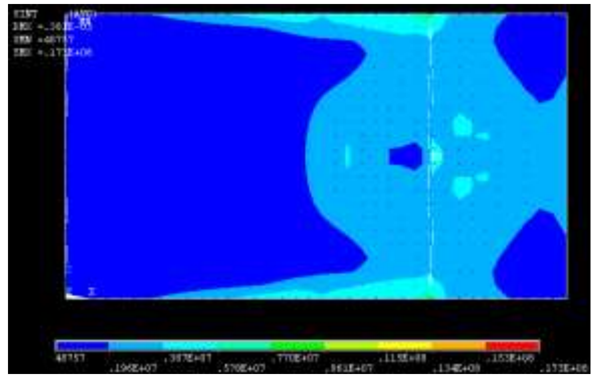


(a) PCC Slab

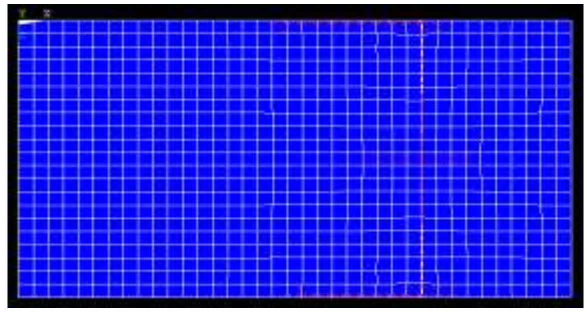


(b) SFRC Slab

Figure 4. Deflection along Length of the Slab (Corner Load)

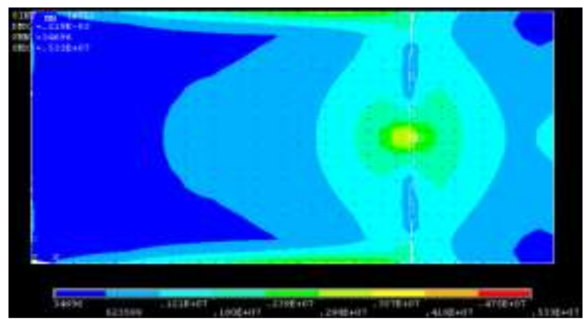


(a) Stress Contours

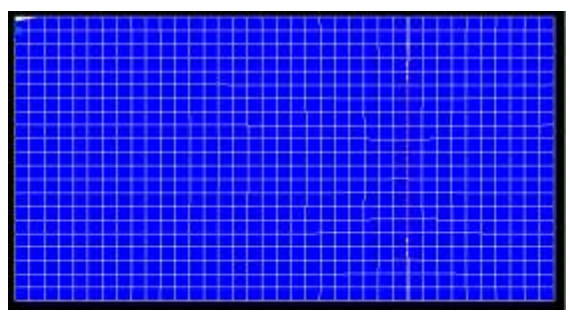


(b) Crack Pattern

Figure 5. PCC Slab (Edge load)



(a) Stress Contours



(b) Crack Pattern

Figure 6. SFRC Slab (Edge load)

B. *Results and Discussion*

The results obtained from the nonlinear static analysis of the FE models are consolidated and presented in Table 1.

TABLE I. RESULT OF FE ANALYSIS

Load Position	Parameters	PCC	SFRC	% increase in SFRC
Centre	Pu (N)	9659	13827	40.69
	Δmax (mm)	0.290	0.408	37.56
	Δmax (adj.slab) (mm)	0.161	0.236	46.58
	Δmax(adj.slab) / Δmax	0.560	0.580	3.60
Edge	Pu (N)	5710	6913.6	21.00
	Δmax (mm)	0.198	0.219	10.60
	Δmax (adj.slab) (mm)	0.198	0.219	10.60
	Δmax(adj.slab) / Δmax	1.000	1.000	1.00
Corner	Pu (N)	4938	5925	19.95
	Δmax (mm)	0.194	0.211	8.70
	Δmax (adj.slab) (mm)	0.194	0.211	8.70
	Δmax(adj.slab) / Δmax	1.000	1.000	-

The ultimate load, stress intensity and deflection in the direction of thickness are the main parameters that are taken from the analysis results for further investigation. The following interpretations can be drawn from them:

- In central concentrated load position, increase in ultimate load in case of SFRC compared to PCC is almost 40 %.
- In edge and corner loading conditions, load carrying capacity increases by nearly 20 % for SFRC.
- In central concentrated loading case, maximum deflection at load point is about 38 % higher for SFRC slabs.
- In edge and corner loading case, it is 9.5% and 15.48% respectively.
- Maximum deflection value in adjacent slabs for PCC and SFRC are 0.161 mm and 0.236 mm respectively which implies the corresponding increase for SFRC is about 47 %.
- Better transfer of load from the loaded slab to the adjacent slab is observed in SFRC model.
- Deflection contour shows smoother variation of deflection in case of SFRC slabs which proves better structural integrity between the loaded and adjacent slab.
- Stress contour shows that addition of fibres facilitates even distribution of load in a larger area of slab.
- Efficiency of joint with respect to load transfer and deflection was found better in case of SFRC slabs.
- Results of the validation process indicate the credible behavior of the ANSYS model in predicting performance of rigid pavement slabs with contraction joints.

In all conditions of loading, the ultimate load of the slab increases significantly on addition of fibres. The deflection contour shows more smooth variation of deflection in case of SFRC slabs. The stress contour also helps in identifying the even distribution of load in a larger area of slab on fibre addition. Also the ratio of deflection in nearer points on the two adjacent slabs are found to be more for SFRC slabs which shows more loads are transferred from one slab to the next in case of SFRC compared to PCC. Thus the efficiency of joint is found to be more in case of SFRC slabs.

IV. Conclusions

- Ultimate Load carrying capacity of concrete slab is increased by 20 to 40 % on incorporating 0.5 % steel fibres into it.
- By the addition of fibres, the deflection-load curve is found to be smoother and flatter.
- The maximum deflection at loaded point in SFRC slab is 37.56 %, 9.5 % and 8.7 % higher than that of PCC for central concentrated load, edge and corner loading case respectively.
- Load transfer across joint studied by checking the deflection at points located in the adjacent slabs show Increase in maximum deflection value in adjacent slab for SFRC as 46.58 % more than that of PCC.
- The addition of steel fibres significantly increases the load transfer across joints.

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