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"Mechanistic Analysis of Rigid Pavement for Wheel Load Stresses By Finite Element Method Considering Different Sub-Grade with Different Percentage of Metal Fibre"

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***Abstract:** In the present work, analysis of concrete pavements using ANSYS software has been attempted. ANSYS is a finite element method-based software. The concrete slab has been modeled with solid 45 brick element and spring elements for soil. Analysis was carried out for a wide range of load and slab soil combination. The soil as "Winkler type" represented by elastic springs and their stiffness was derived from modulus of sub-grade reaction. The influence of any particular base or sub base on edge stresses was not studied here. The model will be then subjected to number of varying input parameters like the change in the thickness of pavement slab, sub-grade material to winkler foundation, modulus of elasticity by adding metal chips in different percentage like 10%, 20%, 30% and also intensity of loads. It is aimed to compare the stresses of the model study with classical approach of Westergaards and IRC 58-2002 method. Westergaards equation under estimate edge wheel load stresses when compared with those obtained from ANSYS. For generating the charts, edge loading condition was considered which is critical case for wheel load stresses. Also, it was aimed to compare the results with those given by IRC 58 – 2002 design charts. Design charts were developed in thesis work yield the same value of pavement thickness as that of IRC 58 – 2002 method.*

***Keywords:** Concrete slab, winkler foundation, Interface, Contact, Finite Element Model.*

I. INTRODUCTION

Finite element analysis (FEA) was first developed in 1943 by R. courant, who utilized the Ritz method of numerical analysis and variation calculus to obtain approximate solutions to vibration systems. The finite elements method is a numerical procedure that can be applied to be Obtain approximate solutions to a variety of problems in engineering. Steady, transient, heat transfer, fluid flow, and electromagnetism problems may be analyzed with the finite elements method the idea of representing a given domain as a collection of discrete parts is not unique to the finite elements methods.

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FEA systems now have powerful graphics, capabilities, automated functionality, and advanced user interfaces that make the technology considerably, faster and easier to use. These improvements not with standing, however, full-blown advanced FEA still requires considerable time and the expertise of a dedicated analyst with the knowledge necessary to apply proper mesh densities, element type, and boundary conditions. These expert analyst also must know how to go about translating cad geometry into proper format for building the FEA model as well as correctly interpreting plots and other output information in the current research work, the model has been generated and also engineering analysis was carried out using the commercially available package ANSYS.

ANYSY finite element analysis software enables engineers to perform the following tasks.

- Products, components, or system
- Apply operating loads or other design performance conditions.
- Study physical response, such as stress levels, temperature distributions, or electromagnetic fields.
- Optimize a design early in the development process to reduce production costs.
- Do prototype testing in environments where it otherwise would be undesirable or impossible (for example, biomedical application)

The ANSYS program has a comprehensive graphical user interface (GUI) that gives users easy, interactive access to program functions, commands, documents, and reference material. An intuitive menu system helps users navigate through the ANSYS program. Users can input data using a mouse, a keyboard, or a combination of both.

II. LITERATURE REVIEW

Chin-ping et al. [2], Studied dynamic response of concrete pavement subjected to moving loads by using the three-dimensional(3D) finite –element method in conjunction with Newmark integration scheme. The dynamic vehicle-pavement foundation interaction effects are considered in the 3D finite element algorithm. The moving vehicle loads are modelled as lumped masses each supported by a spring dashpot suspension system and having a specified horizontal velocity and acceleration.

Concrete pavements are considered to respond elastically and are represented by a series of brick elements.

The present formulation considers a linear viscoelastic foundation model (Kelvin model) consisting of a system of discrete linear springs and dashpots. The interaction between concrete pavements and under lying soil foundation was considered.

In the early days of highway engineering rigid – pavement slabs were constructed directly upon the subgrade without giving consideration to subgrade type and drainage conditions. Slabs as little as 150 mm uniform thickness were commonly built. With increasing truck traffic, particularly just before the Second World War, it became evident that subgrade type played an important role in the performance of the pavements. In fact, pavement pumping was described as early as 1932.

In the between 1930 and 1940, it was not uncommon to build thickened- edge sections, for example, 8-6, which indicates centre thickness of 6 inches and the edge thickened to 8 inches. Thickened- edge section were constructed to offer increased resistance to high stress conditions at the edge of the pavements. At about that time, pavements 6264mm wide were not uncommon, with the result that heavy trucks travelled very close to the pavement edge.

K. Bhattacharya [3], Has reported studies on edge stresses of plain concrete pavements. Edge stresses of plain concrete slabs-on-grade were computed by finite element methods using 3-dimensioal (3D) brick element and spring elements for slab and soil, respectively, analysis was carried out for a wide range of load and slab-soil combinations, with an aim to derive a unified expression on edges stresses. The soil as 'Winkler type' represented by elastic spring and their stiffness was derived from modulus of sub-grade reaction. The influence of any particular base or sub-base on edge stresses was not studied here. The expression was validated with both experiment and theoretical result obtained from literature.

Shunanfa Chen et al [10], Have done the finite elements stress analysis of concrete pavement wit sub-base voids, cracks at the corners and along the edges of concrete slabs appear frequently on Portland cement concrete pavement this study analyzes the relationship between the loss of support underneath pavement slabs and the premature failures of pavement slabs. The combined effects of the size of sub- base void and the magnitude of vehicle loading on pavement stress were examined through three-dimensional finite element analysis. This paper presented the values of flexural tensile stresses at the corner and along the longitudinal and transverse joint edges of concrete slabs under different loading and the changing patterns of the stresses with various sizes of sub-base voids.

S. Santosh Kumar et al [11] Have studied on mechanistic design of concrete pavement, they described examples of thickness design of various types of concrete pavement considering the combined action of axle loads of commercial vehicles and non-linear temperature distribution. Finite element method was adopted foe the analysis's of stresses. The possibility of top-down cracking due to axle loads during the night hours had also been examined. It is found that the slabs may undergo top-down cracking when the front and rear axles lie within the transverse joints of slabs. They concluded that less thickness of slabs is required if there is a tied concrete shoulder or when the slab has a widened outer lane. Thickness of the pavement slab can be reduced substantially if it is bonded to the cemented sub-base. Higher modulus of sub-grade reaction causes higher flexural stresses due to combined action of axle load and warping during the day time as compared to those sub grades with lower modulus of sub-grade reaction.

III. DETAILS OF THE RIGID PAVEMENT MODEL

Finite Element Modelling. In the present study, a 3-dimensional finite element model for concrete pavement system has been developed. Fir this, the structural analysis package 'ANSYS' (version 10.0) has been used. 3-D brick element SOLID45 having 8 nodes with three degrees of freedom per node translations in the nodal x, y and z directions, are used to model the concrete slab as well as the base. The sub-grade is modelled as Winkler foundation that consists of a bed of closely spaced, independent, linear springs. Each spring deforms in response to the vertical load applied directly to that spring and is independent of any shear force transmitted from adjacent areas in the foundation. Spring elements namely COMBIN 14 are used to represent the Winkler foundation which has three degrees of freedom at each node-translations in the nodal x, y, and z directions the effective normal stiffness of the element is obtained by multiplying the modulus of sub-grade reaction with the influencing area of that element.

Single axel loading 80 KN (Metal chip 10%):

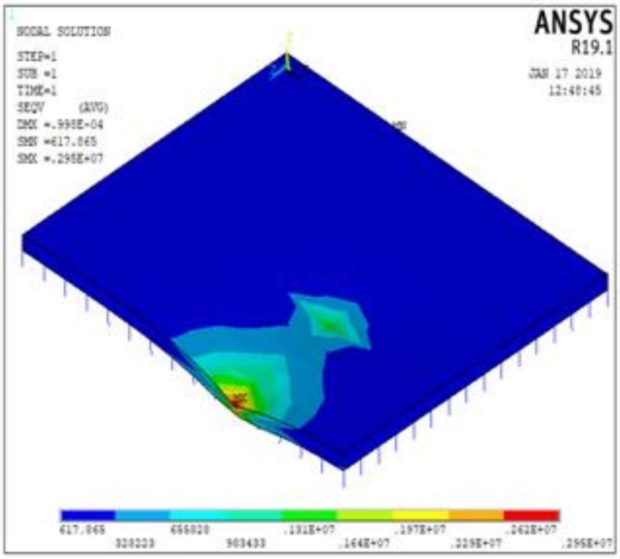

Fig 5.4.1: Contour for thickness of 160mm deformation and k = 0.06 N/mm³

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Single axel loading 80 KN (Metal chip 20%):

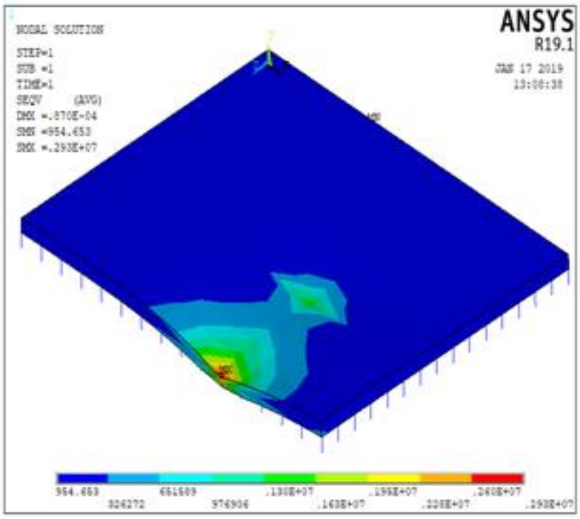

Fig 5.5: Contour for thickness of 160mm von mises stresses and k = 0.06 N/mm³

Single axel loading 80 KN (Metal chip 30%):

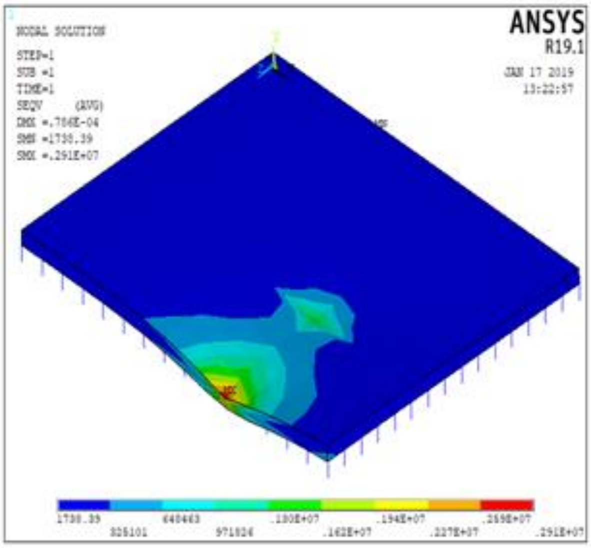

Fig 5.6: Contour for thickness of 160mm von mises stresses and k = 0.06 N/mm³

IV. RESULTS & DISCUSSION

Charts for different thickness of slab and Various % metal chips:

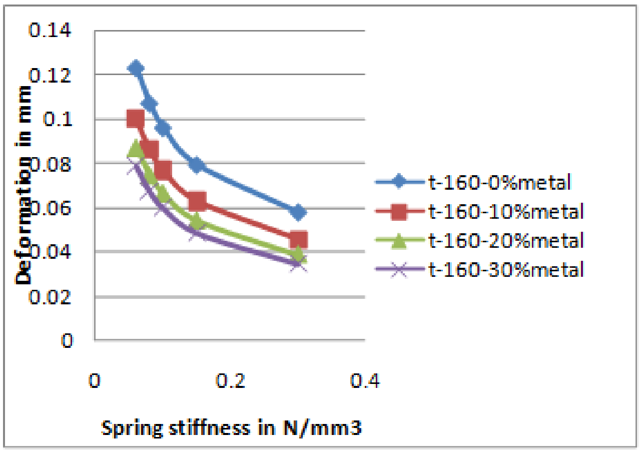

Fig. 6.12: Stiffness Vs deformation for various metal % of 160 mm thick slab (single axle load = 80 KN)

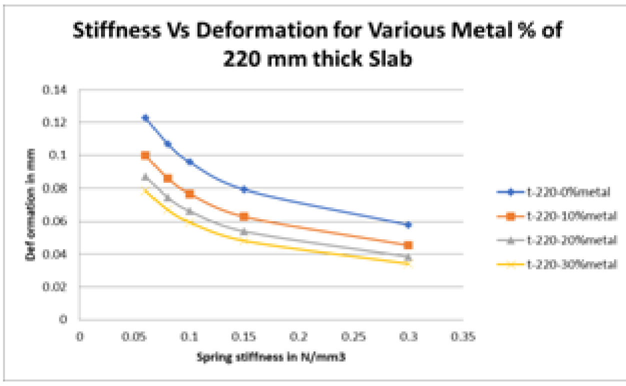

Fig. 6.13: Stiffness Vs deformation for various metal % of 220 mm thick slab (single axle load = 80 KN)

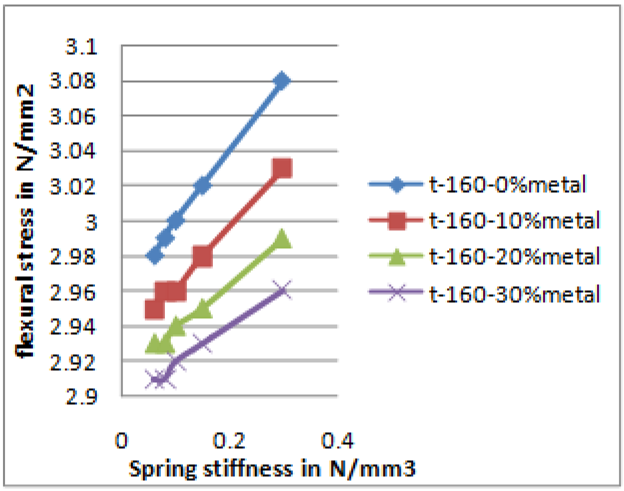

Fig. 6.17: Stiffness Vs flexural stress for various metal % of 160 mm thick slab (single axle load = 80 KN)

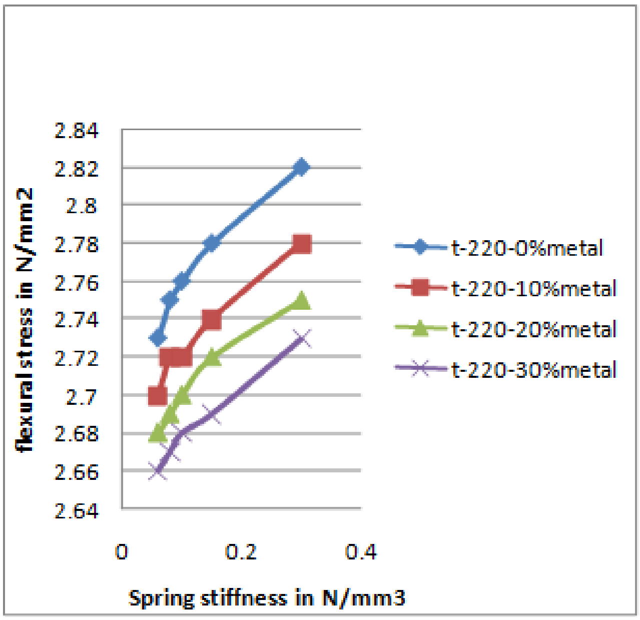

Fig. 6.18: Stiffness Vs flexural stress for various metal % of 220 mm thick slab (single axle load = 80 KN)

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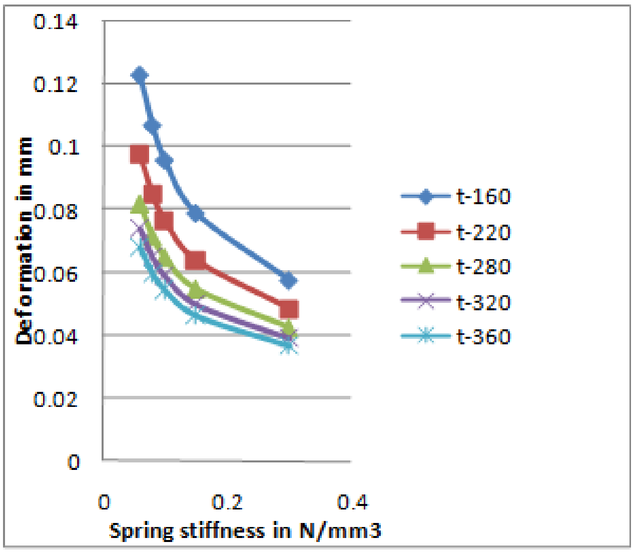

Fig. 6.22: Stiffness Vs deformation for different slab thickness of 0 % metal chip (single axle load = 80 KN)

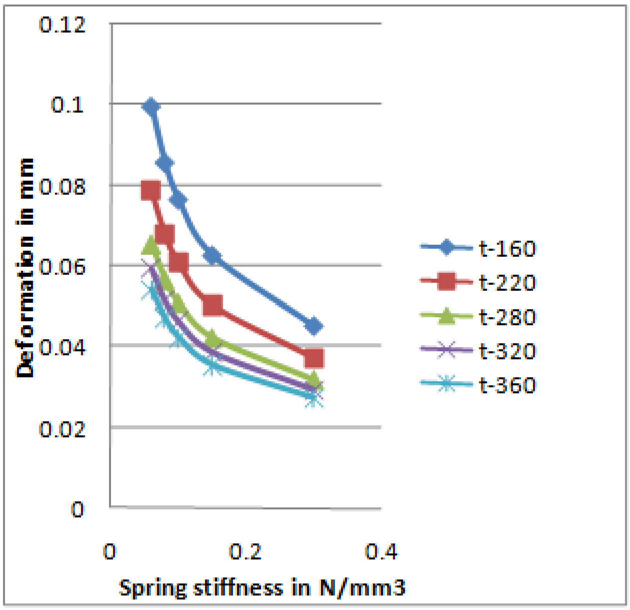

Fig. 6.23: Stiffness Vs deformation for different slab thickness of 10 % metal chip (single axle load = 80 KN)

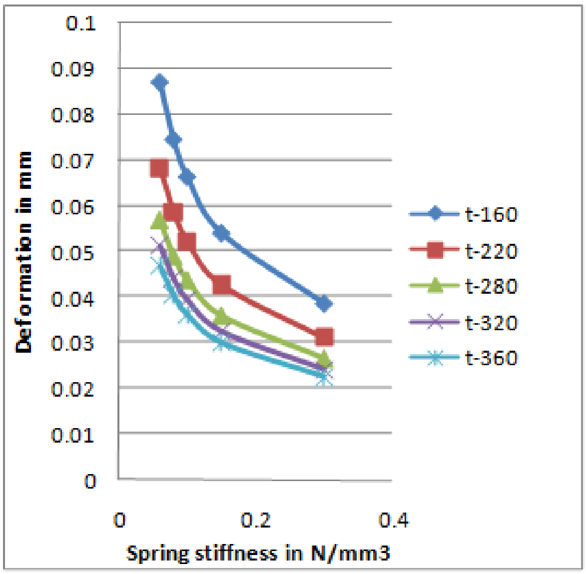

Fig. 6.24: Stiffness Vs deformation for different slab thickness of 20 % metal chip (single axle load = 80 KN)

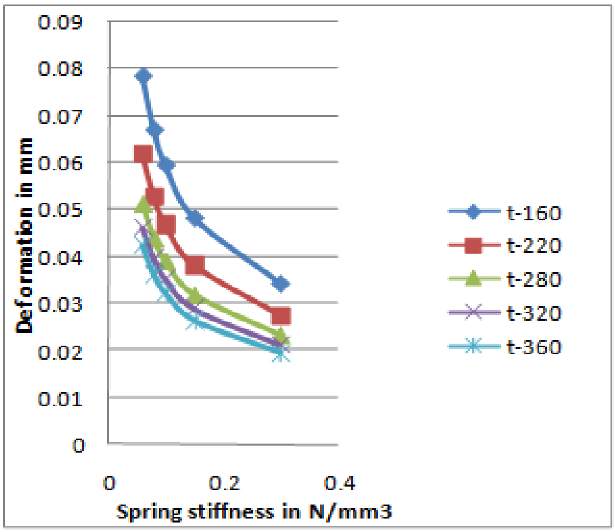

Fig. 6.25: Stiffness Vs deformation for different slab thickness of 30 % metal chip (single axle load = 80 KN)

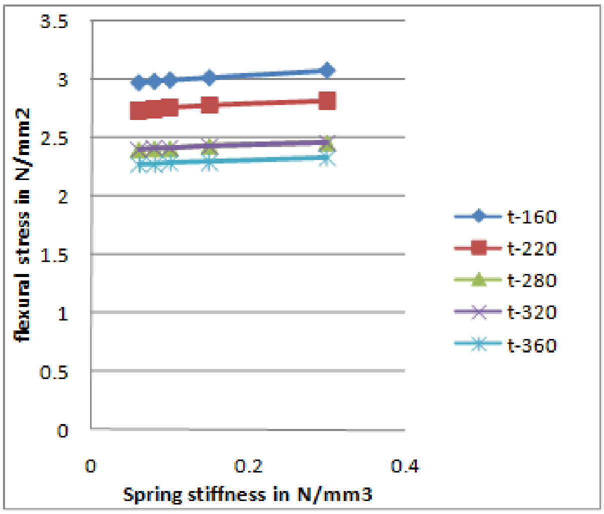

Fig. 6.26: Stiffness Vs flexural stress for different slab thickness of 0 % metal chip (single axle load = 80 KN)

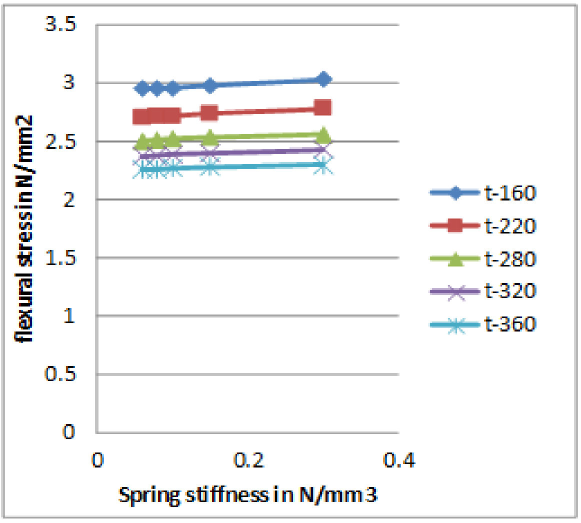

Fig. 6.27: Stiffness Vs flexural stress for different slab thickness of 10 % metal chip (single axle load = 80 KN)

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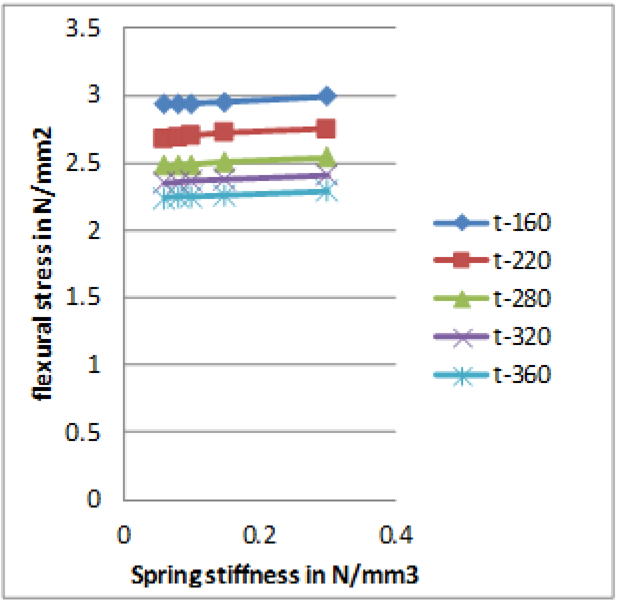

Fig. 6.28: Stiffness Vs flexural stress for different slab thickness of 20 % metal chip (single axle load = 80 KN)

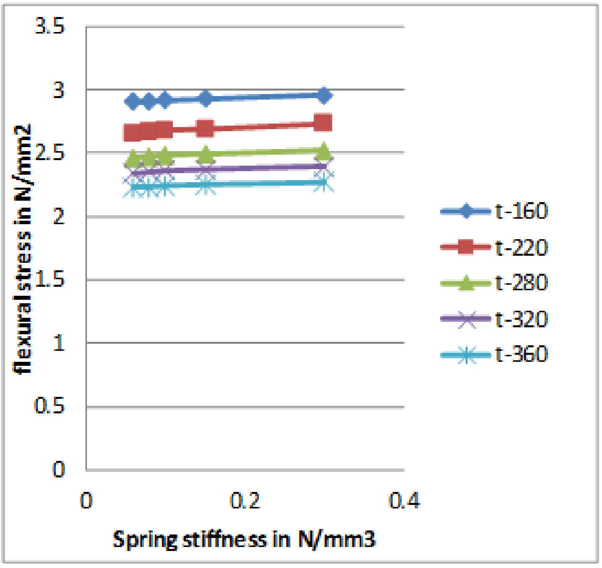

Fig. 6.29: Stiffness Vs flexural stress for different slab thickness of 30 % metal chip (single axle load = 80 KN)

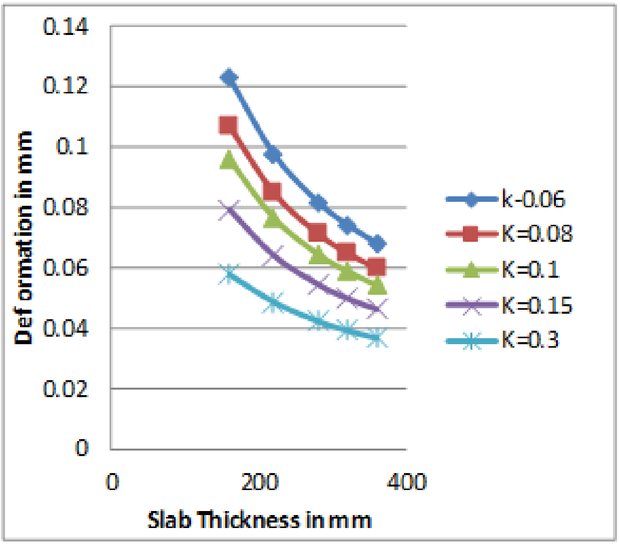

Fig. 6.30: Slab thickness Vs deformation for various stiffness of 0% metal chip (single axle load = 80 KN)

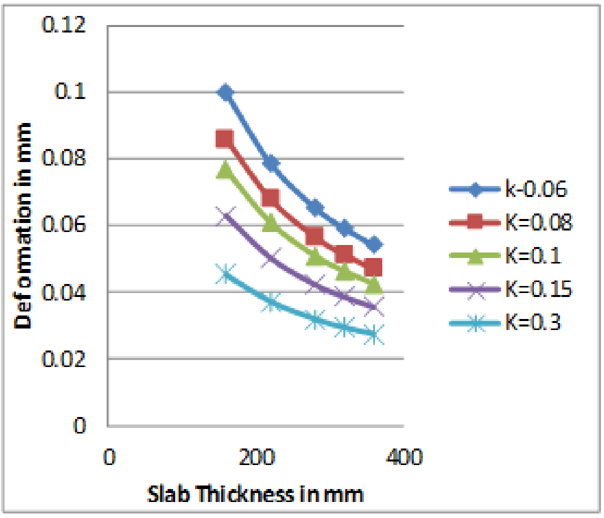

Fig. 6.31: Slab thickness Vs deformation for various stiffness of 10% metal chip (single axle load = 80 KN)

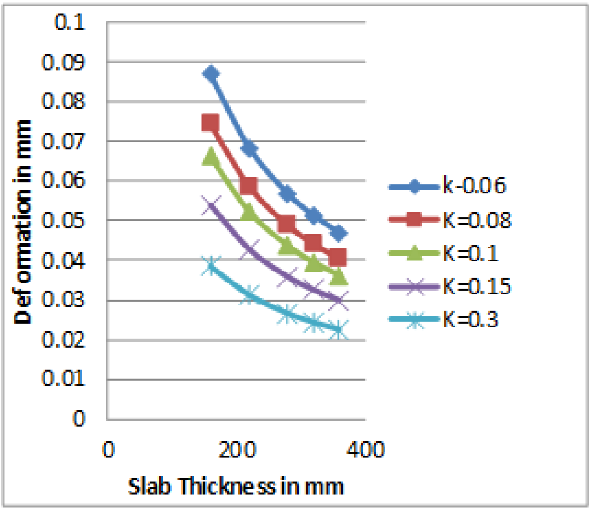

Fig. 6.32: Slab thickness Vs deformation for various stiffness of 20% metal chip (single axle load = 80 KN)

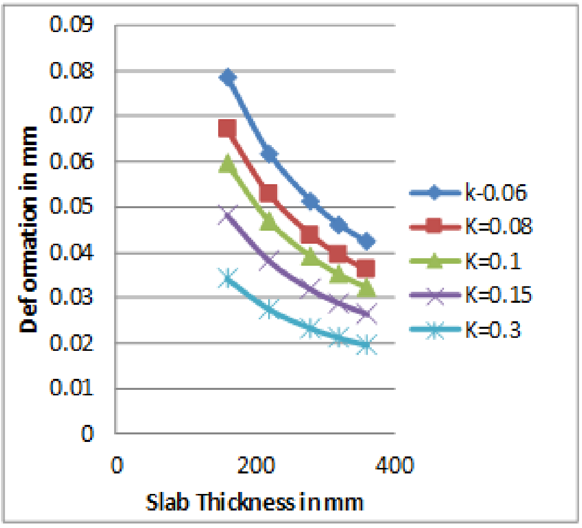

Fig. 6.33: Slab thickness Vs deformation for various stiffness of 30% metal chip (single axle load = 80 KN)

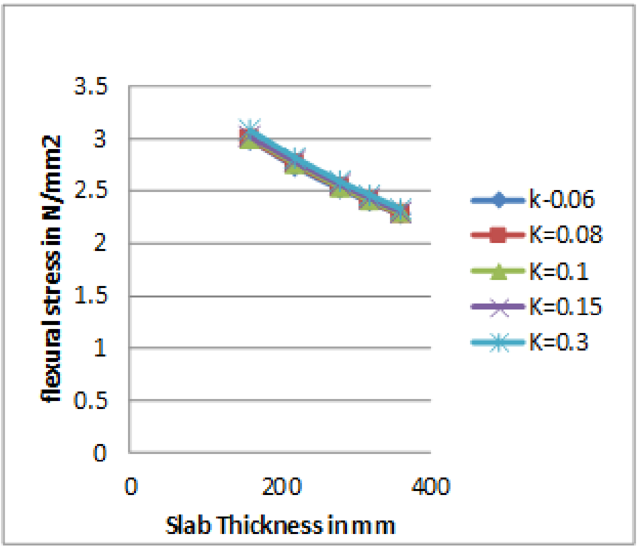

Fig. 6.34: Slab thickness Vs flexural stress for various stiffness of 0% metal chip (single axle load = 80 KN)

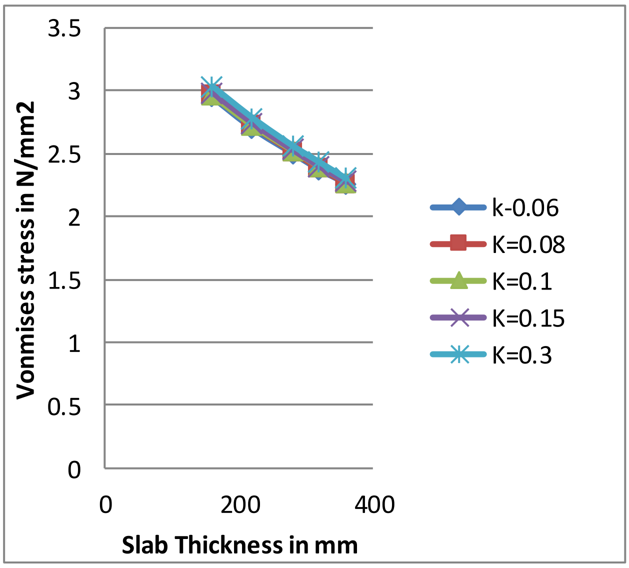

Fig. 6.35: Slab thickness Vs flexural stress for various stiffness of 10% metal chip (single axle load = 80 KN)

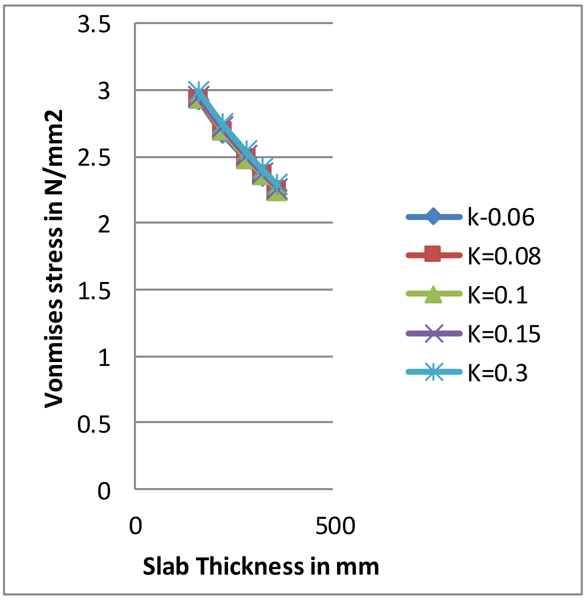

Fig. 6.36: Slab thickness Vs flexural stress for various stiffness of 20% metal chip (single axle load = 80 KN)

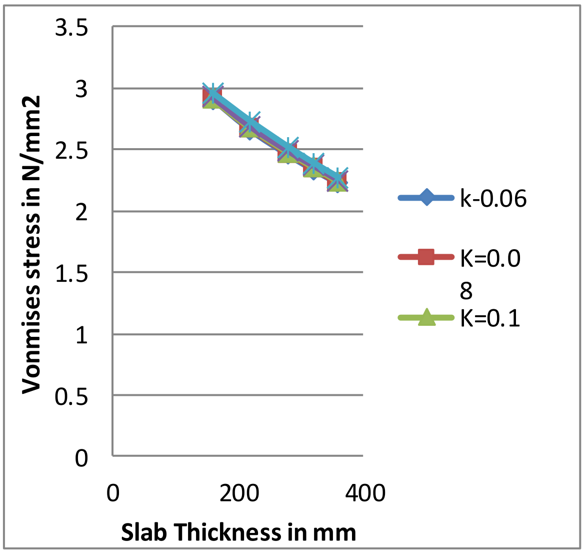

Fig. 6.37: Slab thickness Vs flexural stress for various stiffness of 30% metal chip (single axle load = 80 KN)

Comparison of ANSYS results with Westergaard's(Single axle load = 80KN, 0% Metal Chip)

Table 6.12: For Various slab thickness

Sl. No.	Stress in N/mm² by analysis results	Stress in N/mm² by Westergaard's	Axle load in KN	Slab thickness in mm	K in N/mm³
1.	2.96	3.21	80	160	0.06
2.	2.97	3.10	80	160	0.08
3	2.83	2.65	80	180	0.06
4	2.84	2.56	80	180	0.08
5	2.58	2.22	80	200	0.06
6	2.59	2.15	80	200	0.08
7	2.34	1.82	80	220	0.06

8	2.36	1.72	80	220	0.08
9	2.02	1.58	80	240	0.06
10	2.04	1.52	80	240	0.08
11	1.72	1.38	80	260	0.06
12	1.73	1.33	80	260	0.08
13	1.45	1.17	80	280	0.06
14	1.46	1.13	80	280	0.08
15	1.22	1.04	80	300	0.06
16	1.24	1.01	80	300	0.08
17	1.19	0.904	80	320	0.06
18	1.21	0.894	80	320	0.08
19	0.994	0.817	80	340	0.06
20	1.004	0.791	80	340	0.08
21	0.982	0.718	80	360	0.06
22	0.983	0.696	80	360	0.08

Comparison of ANSYS results with Westergaard's(Single axle load = 80KN,10% Metal Chip)
Table 6.13: For Various slab thickness

Sl. No.	Stress in N/mm² by analysis results	Stress in N/mm² by Westergaard's	Axle load in KN	Slab thickness in mm	K in N/mm³
1.	2.95	3.31	80	160	0.06
2.	2.96	3.20	80	160	0.08
3	2.7	1.89	80	220	0.06
4	2.72	1.83	80	220	0.08
5	2.5	1.21	80	280	0.06
6	2.51	1.17	80	280	0.08
7	2.35	0.969	80	320	0.06
8	2.36	0.941	80	320	0.08
9	2.26	0.751	80	360	0.06
10	2.26	0.731	80	360	0.08

Comparison of ANSYS results with Westergaard's (Single axle load = 80KN, 20% Metal Chip
Table 6.28: For Various slab thickness

Sl. No.	Stress in N/mm² by analysis results	Stress in N/mm² by Westergaard's	Axle load in KN	Slab thickness in mm	K in N/mm³
1	2.91	3.53	80	160	0.06
2	2.91	3.42	80	160	0.08
3	2.66	1.87	80	220	0.06
4	2.67	1.81	80	220	0.08
5	2.46	1.28	80	280	0.06
6	2.47	1.23	80	280	0.08
7	2.34	0.993	80	320	0.06
8	2.35	0.958	80	320	0.08
9	2.23	0.796	80	360	0.06
10	2.23	0.771	80	360	0.08

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Comparison of Ansys results with Westergaard's
(Single axle load = 80KN, 30% Metal Chip)Table 6.33: For Various slab thickness

Sl. No.	Stress in N/mm² by analysis results	Stress in N/mm² by Westergaard's	Axle load in KN	Slab thickness in mm	K in N/mm³
1	2.93	3.44	80	160	0.06
2	2.93	3.32	80	160	0.08
3	2.68	1.95	80	220	0.06
4	2.69	1.89	80	220	0.08
5	2.48	1.25	80	280	0.06
6	2.49	1.21	80	280	0.08
7	2.35	0.969	80	320	0.06
8	2.36	0.941	80	320	0.08
9	2.24	0.777	80	360	0.06
10	2.25	0.755	80	360	0.08

V. CONCLUSION

Based on the result of the research work, following conclusions were drawn:

The pavement slab has been analysed for different axle loads and sub-grade using finite element method. And result is compared with westergaard's analysis.

FEM techniques is more versatile in determining wheel load stresses.

A curve has been drawn between spring stiffness in N/mm^2 on (x axis) and deformation in mm (y axis) for various metal percentage. It has been observed as spring stiffness increases when deformation decreases and deformation is maximum when metal percentage is zero. When increasing the percentage of metal then deformation reduces for the same spring stiffness. It can be observed that deformation is minimum when metal % 30. Similar observation has been observed from thickness 220 mm, 280mm, 320mm, 360mm slab (refer fig 6.12 to 6.13).

A curve has been drawn between spring stiffness in N/mm^3 on (x axis) and flexural stress in N/mm^2 on (y axis) for various metal percentage. It has been observed that flexural stress increases with spring stiffness increases. Almost a linear relation observed for the same spring stiffness, the flexural stress decreases with increase of metal percentage. Flexural stress for the same spring stiffness is maximum for zero metal % and is minimum for 30% metal. These figures have been drawn for various thickness of slab 220mm, 280mm, 320mm, 360mm, and similar trends have been observed, (refer fig 6.17 to 6.18).

A curve has been drawn between spring stiffness in N/mm^3 on (x axis) and deformation in mm on (y axis) for different slab thickness. For the same spring stiffness, the deformation decreases with the thickness of slab, and for zero % of metal chips for the same spring stiffness the deformation is maximum for slab thickness of 160mm, and it decreases to minimum for slab thickness of 360mm. It can be said that if reduce deformation thickness of slab helps. Similar result has been drawn for metal chips 10%, 20%, 30% and similar trends have been observed, (refer fig 6.22 to 6.23).

A curve has been drawn between spring stiffness in N/mm^3 on (x axis) and flexural stress in N/mm^2 on (y axis) for different slab thickness. It has been observed that flexural stress increases with increases in spring stiffness, again for same spring stiffness the flexural stresses are maximum for thickness of 160 mm. While it is minimum for thickness of 360 mm. On a very narrow band flexural stress decreases with increase in stiffness for the same slab thickness. Almost linear relationship has been observed, similar curve has been drawn for different % of metal chips i.e., 10%, 20%, 30%. Similar trend has been observed. (refer fig 6.26 to 6.27).

A curve has been drawn between slab thickness in mm on (x axis) and deformation in mm on (y axis) for various spring stiffness. From figure it is observed that as the spring stiffness increases deformation increases but if the slab thickness increases deformation decreases. For the same spring stiffness, the deformation decreases with the thickness of slab increases, and for 10 % of metal chips for the same spring stiffness the deformation is maximum for slab thickness of 160mm, and it decreases to minimum for slab thickness of 360mm. It can be said that if reduce deformation thickness of slab helps and also metal chips. (refer fig 6.30 to 6.31)

A curve has been drawn between slab thickness in mm on (x axis) and flexural stresses in mm on (y axis) for various spring stiffness. From figure it is observed that as the spring stiffness increases flexural stresses increases but if the slab thickness increases flexural stresses decreases. For the same spring stiffness, the flexural stresses decrease with the thickness of slab increases, and for 0 % of metal chips for the same spring stiffness the flexural stresses are maximum for slab thickness of 160mm, and it decreases to minimum for slab thickness of 360mm. It can be said that if reduce flexural stresses thickness of slab helps and also metal chips. (refer fig 6.34 to 6.35).

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