

A Study of Static Response of Concrete Pavement Resting on Elastic Foundation

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ABSTRACT: Present study includes the stress and deflection response analysis of a concrete pavement resting on elastic foundation (spring foundation) subjected to static circular wheel loads at interior, edge and corner part of concrete pavement by using Westergaard's closed form solution and compare the results with A3D-FE modelling in ANSYS. The study reveals that Finite Element Method can be applicable and reliable tool for concrete pavement analysis.

KEYWORDS: Concrete pavement, Elastic foundation, Westergaard's closed form solution, 3D-FE modelling

I. INTRODUCTION

Pavements are an essential feature of the urban communication system and provide an efficient means of transportation of goods and services. Depending on its rigidity compared to the subsoil, pavements are classified as flexible, rigid and semi-flexible. The Rigid concrete pavements are now a day becoming more popular in India because of steep rise in the cost of bituminous construction. Rigid pavement is the technical term for any road surface made of concrete. Concrete roads are called rigid. The largest advantages to using concrete pavement are in its durability and ability to hold a shape. The conventional methods of rigid pavement Analysis and design are based on the closed-form solutions obtained from the static analysis of infinitely long plates resting on an elastic foundation. But three Dimensional finite-element programs have been employed in the past two decades for analysing road pavement response. In recent years three dimensional finite-element (3DFE) analysis emerged as a powerful tool which is capable of capturing pavement response. Then the study of the effect vehicle load response on road pavement using ANSYS software was presented. ANSYS is a finite element method based on software. Analysis for deformation stresses-strain state have been done using both linear and non-linear material properties between top and bottom of pavement structures by Melaku, S.et. al [1]

II. RELATED WORK

Three methods can be used to determine the stresses and deflections in concrete pavements closed-form formulas, influence charts, and finite-element computer programs. The formulas originally developed by Westergaard can be applied only to a single -wheel load with a circular, semicircular, elliptical, or semielliptical contact area. The influence Charts developed by Pickett and Ray (1951) can be applied to multiple-wheel loads of any configuration. Both methods are applicable only to a large slab on a liquid foundation. If the loads are applied to multiple slabs on a liquid, solid, or layer foundation with load transfer across the joints, the finite-element method should be used. The liquid foundation assumes the subgrade to be a set of independent springs. Deflection at any given point is proportional to the force at that point and independent of the forces at all other points. The liquid foundation is also called a Winkler foundation, with the force-deflection relationship characterized by an elastic spring. The term "liquid" does not mean that the foundation is a liquid with no shear strength, but simply implies that the deformation of the foundation under a slab is

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similar to that of water under boat. According to Archimedes' principle, the weight of the boat is equal to the weight of water displaced. This is similar to the case where a slab is placed on an infinite number of springs and the total volume of displacement is proportional to the total load applied. The stiffness of a liquid foundation is defined by $k = P/w$

III. PROBLEM STATEMENT

A concrete Pavement is of size $4.5\text{m} \times 3.5\text{m}$ having thickness $h=0.25\text{m}$, load is having circular contact area of radius $=0.15\text{m}$ and load applied on a circular contact area $P= 44500\text{ N}$, foundation stiffness $k=27.2\text{ MN/m}^3$ and modulus of elasticity and Poisson's ratio is $E=27.6\text{ GPA}$ and $\mu=0.15$ respectively and radius of relative stiffness $l=1.07\text{m}$, a pavement is analysed by using Westergaard's closed form solution and by 3D-FE modelling in ANSYS

IV. 3D-FE MODELLING IN ANSYS

Concrete Plate is of size $4.5\text{m} \times 3.5\text{m}$ having thickness 0.25m is created in static structure analysis in ANSYS. A load of 44500 N having circular contact area of radius $a=0.15\text{m}$ applied on a plate, foundation for plate is modelled as liquid foundation i.e Spring foundation having foundation stiffness $k=7.2\text{ MN/m}^3$ and modulus of elasticity and Poisson's ratio is 27.6 GPA and 0.15 respectively. All the edges of pavement are infinite edges due to Westergaard theory assumptions. 4 noded tetrahedron element is used to model the pavement with 100 mm mesh size.

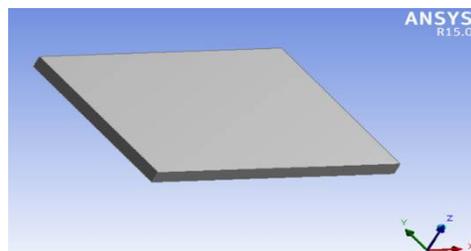


Fig.1 Pavement model of size $4.5 \times 3.5\text{ m}$

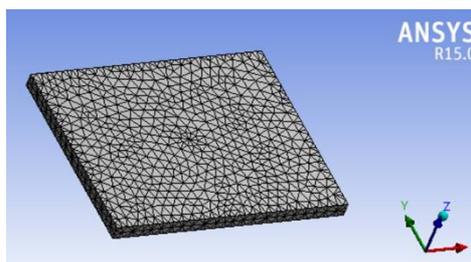


Fig.2 Meshing of pavement model

V. ANALYSIS RESULTS

1. Interior loading condition

1.1. Westergaard's closed form solution

Stresses developed due to interior loading,

$$\sigma_i = \frac{0.316 Pd}{h^2} \left[4 \log \left(\frac{l}{b} \right) + 1.069 \right]$$

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$$= \frac{0.316 \times 44500}{0.25^2} \left[4 \log \left(\frac{1.0}{0.146} \right) + 1.069 \right]$$

$$\sigma_i = 0.992 \text{ MPA}$$

Deflection due to interior loading,

$$\delta_i = \frac{p}{8kl^2} \left\{ 1 + \frac{1}{2\pi} \left[\ln \left(\frac{a}{2l} \right) - 0.673 \right] \left(\frac{a}{l} \right)^2 \right\}$$

$$= \frac{44500}{8 \times 2.72 \times 10^7 \times 1.07^2} \left\{ 1 + \frac{1}{2\pi} \left[\ln \left(\frac{0.15}{2 \times 1.07} \right) - 0.673 \right] \left(\frac{0.15}{1.07} \right)^2 \right\}$$

$$\delta_i = 1.74 \times 10^{-4} \text{ m} = 0.174 \text{ mm}$$

1.2. ANSYS solution

Fig 3 (a) shows interior loading position where load is applied. (b) shows stresses developed in the pavement due to interior loading, stresses under the load are higher than that of the edges. (c) deflection occurred in the pavement and maximum deflection is under the load patch.

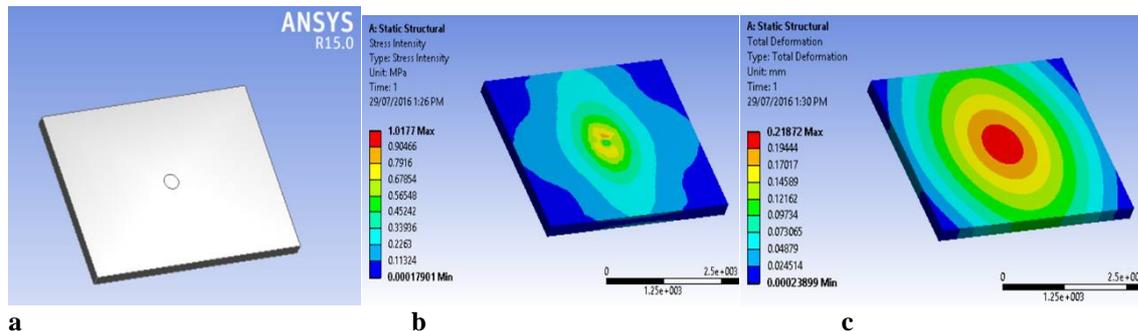


Fig.3 a,b,c shows interior loading position, stresses and deflection due to interior loading condition respectively

Table 1. Interior Loading Results

Interior Loading	Analytical Solution	By ANSYS
Stresses (MPA)	0.99	1.01
Deflection (mm)	0.17	0.21

2. Edge loading condition

2.1. Westergaard's closed form solution

Stresses due to edge loading,

$$\sigma_e = \frac{0.803 \times P}{h^2} \left[4 \log \left(\frac{l}{a} \right) + 0.666 \left(\frac{a}{l} \right) - 0.034 \right]$$

$$= \frac{0.803 \times 44500}{0.25^2} \left[4 \log \left(\frac{1.07}{0.15} \right) + 0.666 \left(\frac{0.15}{1.07} \right) - 0.034 \right]$$

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$$\sigma_e = 1.93 \text{ MPA}$$

Deflection due to edge loading,

$$\delta_e = \frac{0.431p}{kl^2} \left[1 - 0.82 \left(\frac{a}{l} \right) \right]$$

$$\delta_e = \frac{0.431 \times 44500}{2.76 \times 10^7 \times 1.07^2} \left[1 - 0.82 \left(\frac{0.15}{1.07} \right) \right]$$

$$\delta_e = 5.37 \times 10^{-4} \text{ m} = 0.537 \text{ mm}$$

2.2. ANSYS solution

Fig.4 (a) shows edge loading position on the pavement. (b) shows stresses developed at the edge of pavement, stress intensity is higher at the loading edge of a pavement & shows deflection shown at the edge is higher than other locations on the pavement.

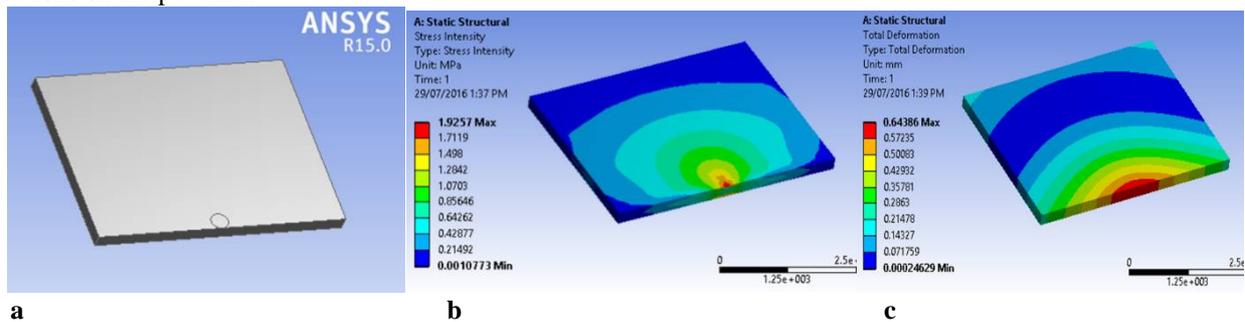


Fig.4 a.b.c shows edge loading position, stresses and deflection due to edge loading condition respectively

Table 1. Edge Loading Results

Edge Loading	Analytical Solution	By ANSYS
Stresses (MPA)	1.93	1.92
Deflection (mm)	0.53	0.64

3. Corner loading condition

3.1. Westergaard's closed form solution

Stresses due to corner loading,

$$\sigma_c = \frac{3P}{h^2} \left[1 - \left(\frac{a\sqrt{2}}{l} \right)^{0.6} \right]$$

$$= \frac{3 \times 44500}{0.25^2} \left[1 - \left(\frac{0.15\sqrt{2}}{1.07} \right)^{0.6} \right]$$

$$\sigma_c = 1.32 \text{ MPA}$$

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Deflection due to interior loading,

$$\delta_c = \frac{p}{kl^2} \left[1.1 - 0.88 \left(\frac{a\sqrt{2}}{l} \right) \right]$$

$$= \frac{44500}{2.76 \times 10^7 \times 1.07^2} \left[1.1 - 0.88 \left(\frac{0.15\sqrt{2}}{1.07} \right) \right]$$

$$\delta_c = 1.303 \times 10^{-3} = 1.3 \text{ mm}$$

3.2. ANSYS solution

Fig.5 (a) shows corner loading position on the pavement. (b) shows stresses developed at the loading position are higher than other locations on the pavement. (c) deflection at the loading position is higher than other locations.

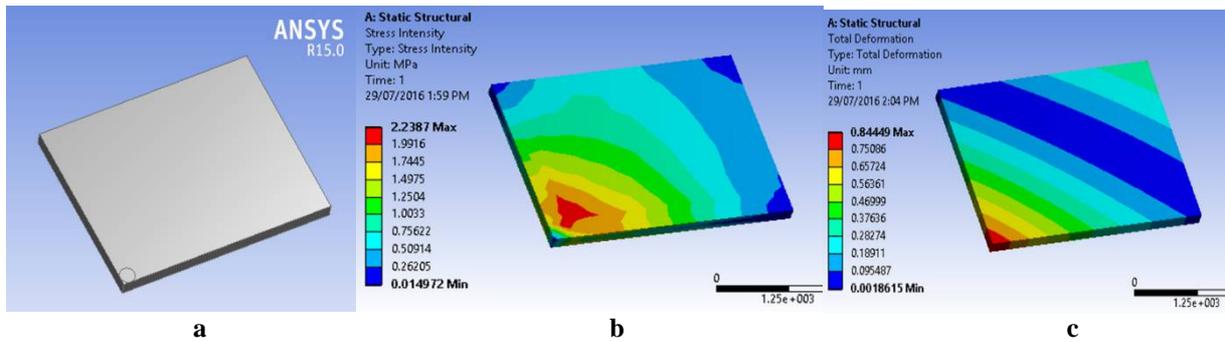


Fig.5.a,b,c shows corner loading position, stresses and deflection due to corner loading condition respectively

Table.3. Corner Loading Results

Corner Loading	Analytical Solution	By ANSYS
Stresses (MPA)	1.32	2.23
Deflection (mm)	1.37	0.84

Fig 6 shows the stress comparison between analytical and ANSYS solution for three different loading positions. The results interior loading and edge loading are very close to each other for analytical and ANSYS solution but at corner loading stresses calculated by ANSYS are very higher than by analytical solution.

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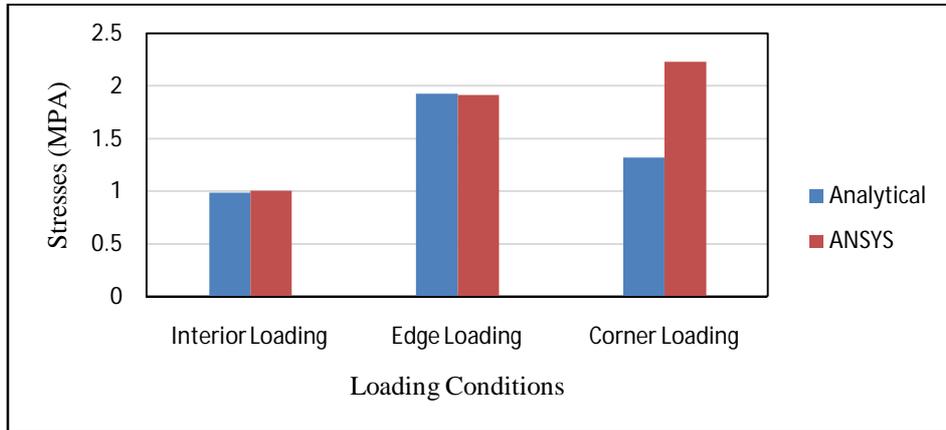


Fig.6 Comparison of stresses developed in pavement between analytical and ANSYS Solution

Fig 7 shows the deflection comparison between analytical and ANSYS solution for three different loading positions. The results interior loading and edge loading are very close to each other for analytical and ANSYS solution but at corner loading deflections calculated by analytical solution are very higher than by ANSYS solution.

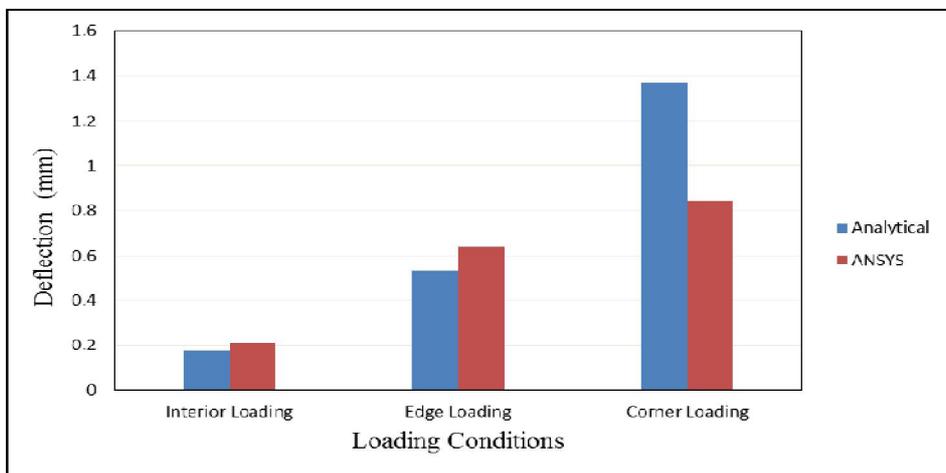


Fig.7 Comparison of deflection developed in pavement between analytical and ANSYS solution

VI. CONCLUSION

1. Results obtained from 3D-FE analysis by using ANSYS are very close to Westergaard's closed form solution for interior and edge loading condition.
2. The stresses and deflection developed in the concrete pavement by Westergaard's theory do not match with FEM analysis because we used infinite boundaries for all four edges but the fact that the Westergaard's theory assume the two ends at the corner where load is applied is fixed and other two edges are infinite for corner loading condition and ANSYS cannot give deflection response if the two ends are fixed.
3. Finite Element Method can be applicable and reliable tool for analysis of concrete pavement.

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