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Analysis of Pavement Using Finite Element Techniques

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Abstract: The importance of highways are getting increased with modernization. It should satisfy structural aspects apart from geometric design. A finite element programmed for analysis of pavements. Finite-element analysis is not new to the pavement design. Two-dimensional finite-element programs have been in use for the past two decades to analyze pavement response. In recent years three dimensional finite-element (3DFE) analyses emerged as a powerful tool capable of capturing pavement response.

The study based on design of rigid pavement using ANSYS software. ANSYS is FEM based software. The results obtained from the model has reasonable agreement with those obtained from AASHTO method. Design of pavement done for various thickness and various loads of pavement. It gives values less than that obtained form AASHTO method.

Temperature gradient was also obtained by model to check the distribution across the slab form top to bottom

Keywords: Finite Element Techniques, Rigid Pavement, ANSYS

1. Introduction

In recent years, cement concrete pavements are being adopted in many new road projects in India in view of their longer services lives, lesser maintenance requirements and smoother riding surface. The current practice of constructing concrete pavement on Indian highways is to provide a granular sub-base over the sub-grade to be followed by a Dry lean concrete base with the concrete slab on top which is called rigid pavement. Rigid pavements are those which possess flexural strength & flexural rigidity. The stresses are not transferred from grain to grain to the lower layer as in the case of flexible pavement layers. The rigid pavement are made of Portland cement concrete either plain, reinforced or prestressed concrete. Rigid pavement consists of three components a)soil sub-grade b)base course c)cement concrete slab.

1.1 Types of Rigid Pavement

Rigid pavements are differentiated into three major categories by their means of crack control.

- **Jointed Plain Concrete Pavement (JPCP):**

This is the must common type of rigid pavement. JPCP controls cracks by dividing the pavement up into individual slabs separated by contraction joint slabs are typically one lane wide. JPCP does not use any reinforcing steel but does use dowel bars and tie bars.

- **Jointed Reinforced Concrete Pavements (JRCP):**

As with JPCP, JRCP controls cracks by dividing the pavement up into individual slabs separated by contraction joints. JRCP uses reinforcing steel with in each slab to control with in slab cracking. This pavement type is no longer constructed due to some long term performance problems.

- **Continuously Reinforced Concrete Pavements (CRCP)**

This type of rigid pavement uses reinforcing steel rather than contraction joints for crack control. Transverse cracks are allowed to form but are held tightly together with continuously reinforcing steel. Research has shown that the maximum allowable design crack width is about 0.5mm.

1.2 Foundation Strength of Concrete Pavement

Foundation strength of pavement is expressed as subgrade modulus **'K'** which is defined as load per unit deflection of pavement.

The subgrade soil strength and strength of foundations whole is affected by moisture content. The ideal period for testing foundation strength would be after the monsoons as foundation attains adequate moisture content.

In case, test have to be constructed at some other time, allowance for increase in strength due to increase in moisture must be made. CBR test has been done in laboratory on subgrade soil samples before and after saturation to overcome this issue. Approximate value of **K** has been taken directly from CBR value. According to IRC, **K** value should not be less than 5 kg/cm^3 for rocky subgrade.

2. Literature review

V.A.Patil (1) presented solution algorithm based on 3D finite element analysis. This analysis focused on dynamic response of pavement under the moving loads. The pavement is discretized by 20-node iso parametric brick element. The moving vehicle is modeled by mass supported over linear spring. The effect of vehicle pavement interaction on pavement thickness, soil subgrade are investigated through parametric study-

(1) Considering vehicle pavement interaction(Moving Mass)- Max deflection increases initiatlly and attains peak value with velocity.
(2) Without considering Vehicle pavement interaction(Moving Force)- Subgrade modulus affects deflection of slab.

This study gives only response of slab under moving load(speed of vehicle). This study does not show about stresses developed and their impact on slab under various position of moving load?

K. P. Goerge (2) used elastic layer model of pavement for calculating both static and dynamic deflection. This study shows about serveacibility requirements(deflection, cracking and vibration) of pavement slab. Deflection equations are developed based on series of various loads.

Study consider only impact load of vehicle(not considered moving load). Cracking locations are not fully modeled in developing prediction equations so deflections are not fully correct. Falling weight deflectometer is used in this analysis that has greater impact on failure under mid slab. Effect of load on corner and edge region is not defined in this analysis.

I. E. Harik (3) developed model (considered as thin plate) for study for temperature loading. It is considered in the study that temperature is linear, uniform through slab from top to bottom surface. In is observed that temperature vary across thickness of pavement slab.Temperature stresses are not considered in this study so there is linear distribution of temperature across thickness of slab.

S. K. Saxena (4) presented the development of rational method of analysis. A physical model represents the slab. A physical model of heavy liquid or bed of springs is introduced as subgrade soil. A computer based method(Matrix Method) has been used for this analysis.

From the model of subgrade and slab, deflection are obtained at various points for various loads and their positions. This deflection obtained is used for calculating stresses(Corner and Interior stress) and bending moments at various load positions. Finally these two stresses are used for design of pavement. Edge stress has not been considered for design (Edge stress is more predominant as compared to corner stress).

E. J. Yoder (5) presented the factors such as pavement thickness, slab dimensions, base course, slab reinforcement. This study present the design by westergaard method.

Study introduce design only for airfield pavement. No procedure has been introduced for the highway pavement design. Such pavements are designed for heavy loads and tyre pressures rather than no of repititions of loads.

S.K.Sharma (6) proposed the design of rigid pavement for the highway experimental procedures. Rigid airfield pavements have been designed by PCA (Portland Association Method). External forces has been studied for design.

G Rao (7) used IRC (Indian Road Congress) method for rigid pavement design. Design stresses are carried out by Westergaard's Method. The design involves checking of load and temperature stresses at edge region. Modulus of subgrade reaction is used for design. Flexural strength of pavement concrete is 40 kg/cm^2, modulus of elasticity is 3×10^5 kg/cm^2, poission's ratio is 0.15 coefficient of thermal expansion is 10×10^{-6} has been taken.

3. Introduction To Ansys

Finite Element Analysis: 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 element method is a numerical procedure that can be applied to obtain approximate solutions to a variety of problems in engineering. Development of model, stress analysis, steady, transient, linear, or nonlinear problems in stress analysis, heat transfer, fluid flow, and electromagnetism problems may be analyzed with the finite element method the idea of representing a given domain as a collection of discrete parts is not unique to the finite element method. It was recorded that ancient mathematicians estimated the value of π by noting that the perimeter of a polygon inscribed in the circle approximates the circumference of the latter. They predicted the value of π to accuracies of almost 40 significant digits by representing the circle as a polygon of a finitely large number of sides. 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 notwithstanding, 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 types, and boundary conditions. These expert analysts 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.

4. Finite Element Modeling

4.1 Model Description for Pavement Design

In this study, a 3-dimensional finite element model for concrete pavement system (concrete slab and base course) has been developed. For this, the structural analysis package „ANSYS‟ (Version 14.0) has been used. A 3-D brick element SOLID 65, having 8 nodes with three degrees of freedom per node translations in the nodal x, y and z directions, were used to model the concrete slab as well as the base.

For all models, it was assumed that the concrete slab is 5.0m long, 5.0m wide which has density of 2314 kg/m^3, young’s modulus of 1.96×10^{10} N/mm^2, poission’s ratio is of 0.2 and bulk modulus of 8.17×10^9 N/mm^2. For all models it was assumed that base course is 5.0m long, 5.0m wide and 0.5m thick which has Young’s modulus of 6.45×10^{07} N/mm^2, poission’s ratio of 0.3 and density of 2070 kg/m^3. Five different slab thickness of 10cm, 15cm, 20cm, 25cm & 30cm were used.

There are two types of loads are considered in the model development- (1) Static Structural Load, used for calculation of stresses at corner and edge region for different loads, (2) Transient Thermal. Real constants are considered. Boundary conditions are applied.

A comparison was conducted between the results obtained by the finite-element model developed in the ANSYS and AASHTO method.

4.2 Model Description for Parametric Study

A parametric study has been conducted to study the effect of various loads on differenet slab thickness. A 3-D brick element SOLID 65, 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 various parameters used in the study were

Modulus of elasticity E = 15 x 10^3 Mpa,
Slab length – L=5m
Slab width = 5m
Slab thickness – H1 = 10cm, H2 = 15cm, H3 = 20 cm, H4=25cm, & H5=30cm
Ground unit weight = 21 KN/m^3 Concrete properties: Modulus of elasticity = 1.96 x10^{10} N/mm^2, poison‟s ratio = 0.2 and unit weight = 24 KN/m^3

4.3 Transient Thermal Analysis

The temperature values are introduced to the model using the ANSYS software package. For solid elements used in this model, only one temperature value is needed at each node. Heat flux of 1000 W/m^2 is generated. Figure shows temperature values at different time across the slab.

For time cycle of 1 sec, there are two lines shown in the graph. Black line indicate the increase in temperature whereas red line shows indicate decrease in temperature. This model overcome previous work done by researcher that temperature is constant throughout the slab.

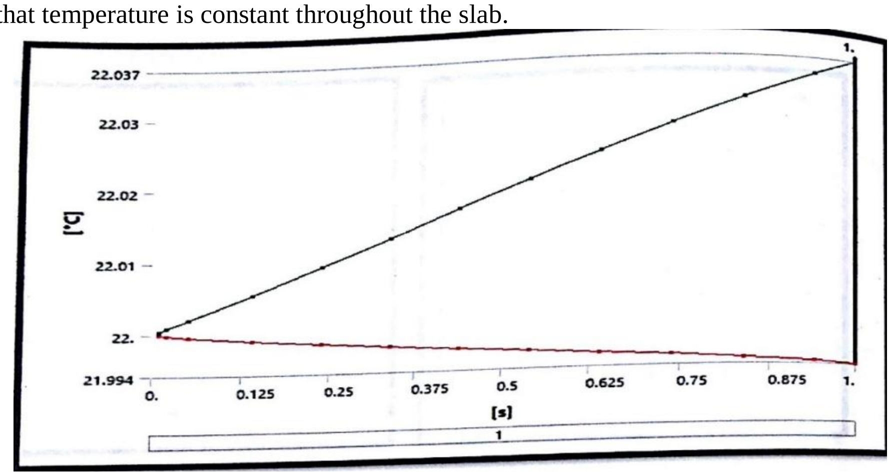

Figure1 Variation of temperature with time

Below figure shows the temperature distribution from top to bottom of slab by colour. Top layer shows the red colour that have high value of temperature. It decreases towards the bottom as shown by different colour.

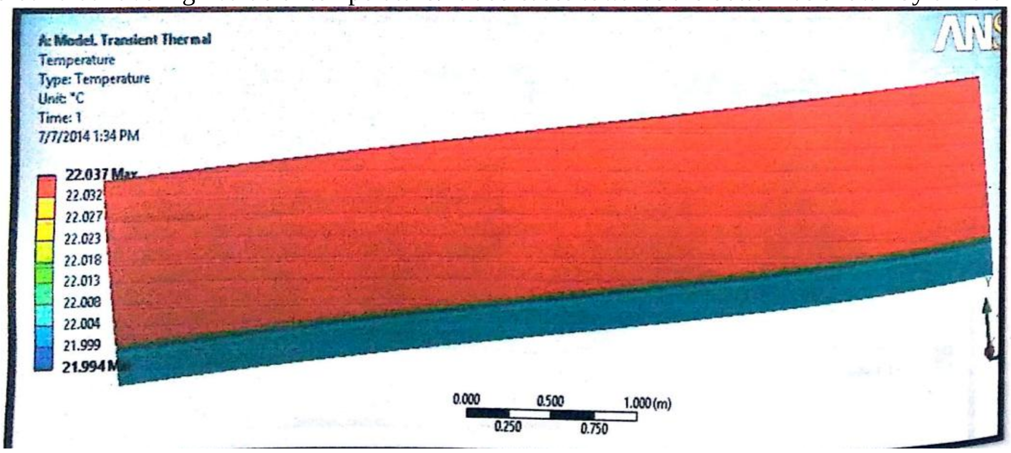

Figure2 Temperature distribution across slab

5. Results & Discussion

5.1 Effect of loads on slab thickness in terms of Stress produced

Below table shows the corner stress developed by ANSYS for different loads and different thicknesses. There is large variation in stress produced by ANSYS tool with particular thickness under different load. Stresses so produced are dependent not only on thickness but also on vehicular load. Edge stresses are much lower than corner stresses.

There are only two types of stresses are obtained as these are the critical locations, there has greater tendency fail under load as nearer to the joints. Vehicle changes one slab to another slab highly affected these places, so it is necessary to design the pavement only corner and edge.

There is less change in stress for particular load over thickness. It means vehicle has less impact on bottom slab as compared to top most. Edge stresses are very less as compared to corner stress due to greater area of loading.

Table1 Corner Stress

CORNER STRESS (Kg/cm2)								
THICKNESS(CM)	LOAD(TONNE)							
	1	2	3	4	5	6	7	8
10	20.29	40.59	60.89	81.19	100.47	121.79	142.08	162.38
15	14.8	29.61	44.41	59.22	74.02	88.82	103.62	118.42
20	11.76	23.52	35.28	47.04	58.8	70.56	82.32	94.09
25	9.86	19.71	29.56	39.42	49.27	59.132	68.98	78.84
30	8.56	17.11	25.67	34.22	42.78	51.33	59.89	68.44

Table2 Edge Stress

EDGE STRESS (Kg/cm2)								
THICKNESS(CM)	LOAD(TONNE)							
	1	2	3	4	5	6	7	8
10	9.06	18.12	27.18	36.24	45.24	54.3	63.36	72.42
15	5.76	11.58	17.34	23.1	28.92	34.68	40.5	46.265
20	4.26	8.46	12.66	16.92	21.12	25.32	29.58	33.78
25	3.24	6.48	9.72	12.96	16.2	19.44	22.68	25.98
30	2.58	5.22	7.86	10.5	13.08	15.72	18.36	20.94

Temperature stresses are shows according to region and slab thickness. Due to this there is temperature differential between top and bottom of slab which can be used for checking daily and seasonal variation between the slab.

Table3 Temperature Stress

Thickness of Pavement	Temperature Differential of slab(0C)	Temperature Stresses(kg/cm2)
10	10.2	42.605
15	12.5	29.855
20	13.1	20.731
25	14.3	11.044
30	15.9	7.315

There are two models given in reference to above values(one for corner and one for edge) shows the stress produced from top to bottom of model and its values at different layers by different colours.

Figure3 Corner stress for 5000 kg load for 200mm thickness

At most corner point, there is max stress continuously decreasing towards bottom as well as along the surface. Effect of stress is seen upto that point where color of corner is different from other slab. Stress is negative on the surface of slab as there is very less impact of load so that more tendency to move upward. Only that much area is affected where load is applied and rest of slab has less impact of load.

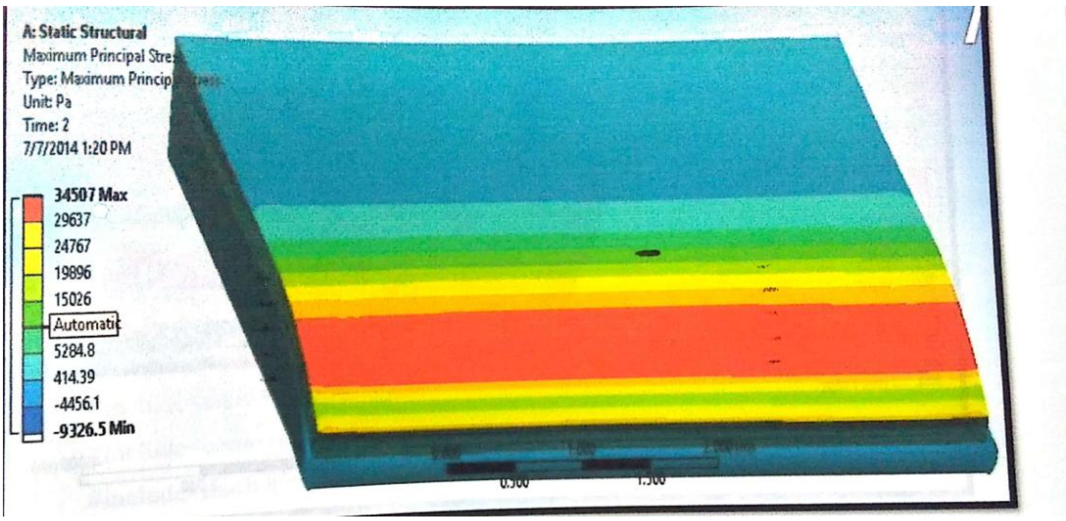

Figure3 Edge stress for 5000 kg load for 200mm thickness

At between the affected area, there is large stress produced and at edges of slab, stress values are continuously decreasing. At most edge line, stress produced is less as compared to between the edges. It is due to the load moving from inner edge to at most edge line so that impact of load greater at inner edge.

5.2 Comparative Study with AASHTO Method

Stress obtained in the Table 1 and Table 2 are used to check factor of safety by C programming and final values of slab thickness are obtained as given in table no4. These values are based on grade of concrete. Slab thickness so obtained shows large variation with respect to loads.

AASHTO Method shows the less variation in the thickness as obtained. Also design thickness obtained are higher (almost double) than that of values obtained from this model. For higher loads, there is no such difference between these values.

ANSYS Method followed by IRC

DESIGN DETAILS OF SALB THICKNESS								
GRADE OF CONCRETE	LOAD(TONNE)							
	1	2	3	4	5	6	7	8
M25	15.5	17.5	19.8	21	22.2	23.5	25.5	27
M30	14.7	16.5	18.5	20	21	22.5	24.3	25.5
M35	13.5	15.3	17	18.8	20	21.5	23	24.3
M40	12.5	14.5	16.2	18	19.2	20.5	22	23.5

AASHTO Method

DESIGN DETAILS OF SALB THICKNESS								
GRADE OF CONCRETE	LOAD(TONNE)							
	1	2	3	4	5	6	7	8
M25	30.4	33	35	36.8	38.1	39.9	40.6	41.1
M30	28.4	31.2	34	35.6	36.8	37.6	38.6	39.1
M35	27.4	30.2	32	33.5	35	36.8	37	37.6
M40	27.2	29.9	31.8	32.5	33.5	35	35.6	36

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Author Profile

Naynish Pandey awarded degree of M.Tech in 2014 with 8.32 CGPA on 10 point scale. He did his B.Tech from U.P.T.U. Lucknow U.P. with 69.67 % marks. He is rewarded by Mayor for his performance at school level. Interesting topic of researches are traffic engineering, mathematical modeling, finite element analysis.