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Modelling of Temperature Effects on Flexible and Rigid Pavements

S. Hariharan[1], S. P. Jeyapriya[2].
[1]*PG Scholar, Geotechnical Engineering, Government College of Technology, Coimbatore*
[2]*Professor, Department of Civil Engineering, Government College of Technology, Coimbatore*

Abstract: One of the most crucial elements impacting the rigid and flexible pavements performance is temperature. This significance necessitates specific care and interest in research to create design and analytical processes that take temperature issues into account. The variation in temperature is modelled using ANSYS v19.2 finite element method software. At any assigned depth in different layers of pavement, the stresses and deformation were obtained using solution of axisymmetric problem for an applied temperature of 45ºC. In flexible pavement the temperature stress variation was found to be 2.512 N/m² at top of bituminous concrete to 0 N/m² to the bottom of compacted subgrade layer, vertical deformation was found to be 0.013m at top of bituminous concrete to 0.0089m bottom of compacted subgrade layer. In the rigid pavement the temperature stress found to be 6.23 N/m² at top of concrete and-1.64 N/m² at bottom of subbase layer and horizontal deformation should be maximum and minimum of 0.0542m-0.0102m.
Keywords: Flexible pavement, Rigid pavement, Temperature, effects, Finite element method, Stresses and Deformation.

I. INTRODUCTION

A. Flexible pavement

In Pavement, that strength and deformation properties strongly depend on temperature. Therefore, in Flexible pavement design process enough attention has to be paid to correct determination of temperature in asphalt concrete layers. As the modern flexible pavement structures represent the multi-layer deformable media. Changes of deformations in asphalt concrete layers lead to change of stresses and deformations in other layers of pavement and subgrade. In practice, change of stresses and deformations in layers of pavement and subgrade, caused by temperature variation in asphalt concrete layers of pavement. It could be essential and should be taken into account at the design stage. Two-dimensional non-stationary problem of heat conduction for calculation of temperature in flexible pavement is solved by finite element method.

B. Rigid pavement

Temperature differential between the top and bottom of concrete pavements causes the concrete slab to curl, giving rise to stresses. The temperature differential is a function of solar radiation received by the pavement surface. As far as possible, temperature differential values estimated realistically for the given site using relevant geographical parameters and material characteristics should be used for analysis. Two-dimensional non-stationary problem of heat conduction for calculation of temperature in rigid pavement is solved by finite element method. If the maximum positive temperature differential during the day time is 20ºC, the temperature differential for stress computation can be taken as 15ºC. However, this 5ºC reduction is generally not made so that the design for bottom-up cracking will be conservative.

C. Ansys Software

This chapter explains about the methodology carried out in this project work. In this project, to determine the temperature stresses and deformation in the flexible and rigid pavement by ANSYS v19.2 finite element analysis software. **John Swanson** developed the initial Ansys software. Ansys develops and markets engineering simulation software for use across the product life cycle. Ansys Mechanical finite element analysis software is used to simulate computer models of structures, electronics, or machine components for analyzing the strength, toughness, elasticity, temperature distribution, electromagnetism, fluid flow, and other attributes. Ansys is used to determine how a product will function with different specifications, without building test products or conducting crash tests. The paper uses transient thermal analysis method in ANSYS software to simulate the distribution of temperature changes between layers of pavement structure based on extreme temperature. Scholars at home and abroad have studied it.

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II. NUMERICAL MODELLING OF FLEXIBLE PAVEMENT

Thus, to investigate this pavement near Hindustan Arts college was taken as reference. The pavement layers have totally 4, they are bituminous concrete, Wet Bound Macadam (WBM), Sub-base course, Subgrade having a thickness and the poisson's ratio is taken from IRC 37:2019 code and the value for heat conductivity coefficient of each layer taken from [3] is shown in below Table 1:

Table 1: Properties of flexible pavement

STRUCTURAL LAYER	THICKNESS (mm)	ELASTIC MODULUS (E) (MPa)	POISSON's RATIO (m)	HEAT CONDUCTIVITY COEFFICIENT (W/m ºC)
Bituminous Concrete	30	2000	0.25	1.0
WBM	50	1800	0.25	1.2
Sub-base Course	150	1200	0.35	1.1
Compacted Subgrade	500	40	0.35	1.0

The complex modulus of asphalt concrete at frequency w is calculated according to the empirical dependencies [1]:

$$E * (\omega) = P c [4200000(1 - (VMA)/100) +3 G b ^ * (\omega)((VFAVMA)/10000)]$$
$$+ (1-P) c [(1 - (VMA)/100)/4200000 + (VMA)/(3VFA*G\_\{b\}(\omega))] ^ - 1 ,$$

$$Pc = ((3+ VFA G i ^ * (\omega) / VMA)^ 0.678))/(2a396+(VFA G i ^ * (\omega)/ VMA)^ 0.678)),$$

where,
E (ω)-Complex modulus of asphalt concrete at frequency ω @; G-Complex shear modulus bitumen at frequency ω; VMA-voids in mineral aggregate; VFA-the fraction of aggregate voids filled with bitumen. The elastic modulus of asphalt concrete at the duration of loading t = 0.1 s is determined on the approximate method [1]:

$$E (t = 0.1s) = E^* (1/ \omega=10 s-1)$$

Poisson's coefficient is determined by empirical dependencies [1]:

$$\mu T=0.15+ \{0.35/ [1+\exp (-1.63 +3.84 *10-6* ET)]\}'$$

where,
- μ- Poisson's coefficient of asphalt concrete at temperature T;
- Er- Elastic modulus of asphalt concrete at temperature T.

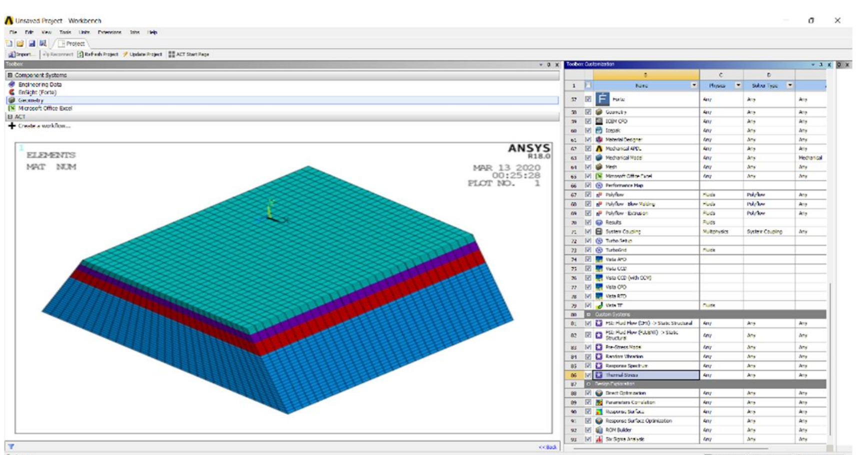

Fig1: FEM Modelling of flexible pavement

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III. NUMERICAL MODELLING OF RIGID PAVEMENT

The pavement layers are concrete slab and sub-base course having a thickness and the Poisson's ratio is taken from IRC 58: 2015 code and the value for heat conductivity coefficient of each layer taken from is shown in below

Table 2: Thickness and Properties of rigid pavement

STRUCTURAL LAYER	THICKNESS (mm)	ELASTIC MODULUS (E) (MPa)	POISSON's RATIO (m)	HEAT CONDUCTIVITY COEFFICIENT (W/m ^oC)
Concrete Slab	125	570	0.15	1.6
Sub-base Course	200	1200	0.35	1.1

The concrete model using finite element software i.e. ANSYS v19.2 is carried out. The figures and tables show the respective parameters of the concrete modeling using ANSYS. The overlay layers are completely continuous and the pavement layers are in close contact. A spatial three- dimensional model is established by simulation. The analysis of model road patch is carried out,

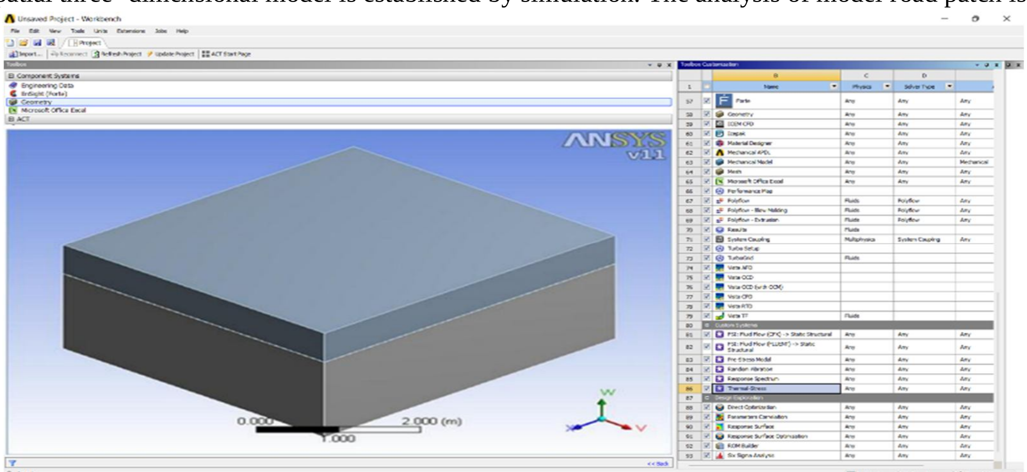


Fig 4: FEM modelling of rigid pavement

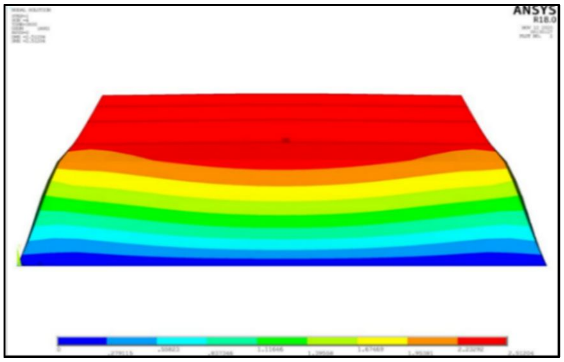
IV. RESULTS AND DISCUSSION

Employed the finite element techniques to model flexible pavement using 3-D dimensional model with appropriate material characterizations and bonding conditions explained earlier in previous sections taking into consideration the effect of thermal loading due to high temperature occurred.

A. *Analysis part of Flexible pavement*

As can be seen from the figure 2, when the pavement temperature reaches 45°C, the heat flow vector direction is upward and the pavement is in an exothermic state. The temperature changes between layers are obvious, and the maximum temperature is at the surface layer. The vertical deformation was found to be 0.013m at 0m depth to 0.0089m at bottom of subgrade. When the pavement temperature is 45^0C, the heat release of pavement structure affects the pavement expansion. The surface temperature is positively correlated with time from 0^0 to 45^0C.

Temperature stress changes at top of bituminous concrete to the bottom of subgrade layer from 0 to 2.51 N/m^2 at 45^{o}C shown in below Fig 5. The greater the change of temperature, the greater the change of stress and deformation of flexible pavement. The optimum thickness keeps the temperature stress within a relatively low range.



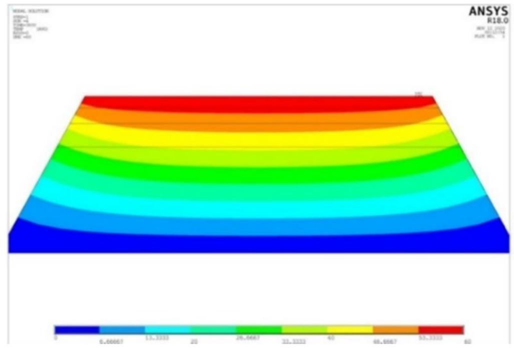


Fig 2 Fig 3

Fig (2) & (3): Temperature stress and deformation variation of pavement layer at 45ºC

B. Analysis Part of Rigid Pavement

Temp 2 is the trend of interlayer node temperature of surface layer (0 cm) changing with time. Temp 3 is the trend of interlayer node temperature of surface layer 15 cm changing with time. Temp 4 is the trend of interlayer node temperature of surface layer 20 cm changing with time. Temp 5 is the trend of interlayer node temperature of surface layer 30 cm changing with time.

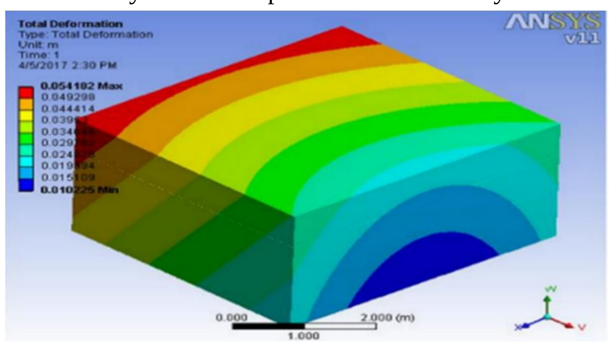
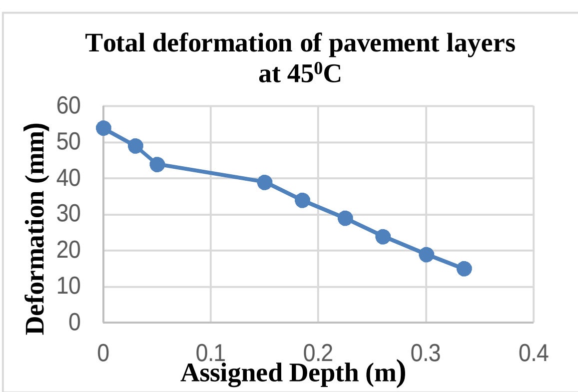


Fig 5: Total deformation of pavement layer at 45ºC

It can be clearly seen that the node temperature is different at different locations and depths. The surface layer temperature is the highest when the temperature is above 0°C, and the lowest when the temperature is below 0°C.



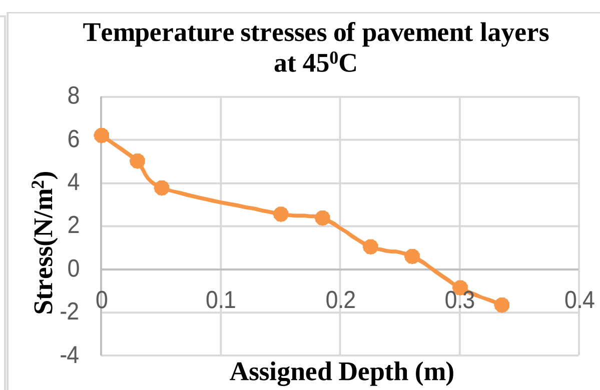


Fig 6 Fig 7

Fig: (6) and (7) is the stresses and vertical deformation of rigid pavement layer at 45°C.

The assigned depth in this temperature analysis part is given to my knowledge of 9 coordinates, as "0 at top of bituminous concrete" and "1.30m at bottom of subgrade layer".

The assigned depths of pavement has no change and the temperature stresses of assigned depths is decreases from bituminous concrete to subgrade layer and the maximum of 55% percent stresses in pavement obtained at assigned depth of 0.03m to 0.08m.

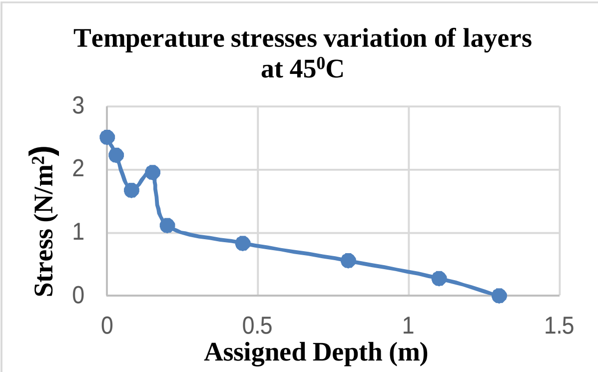


Fig 8

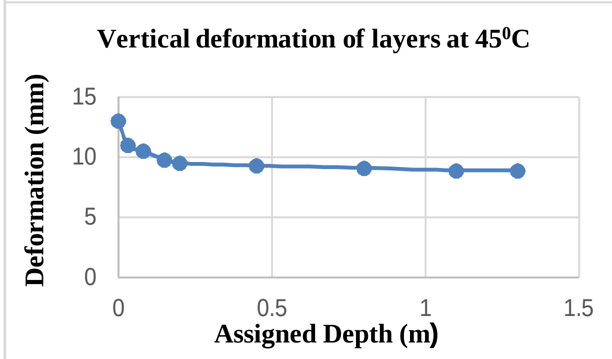


Fig 9

Fig: (8) and (9) is the stresses and vertical deformation of rigid pavement layer at 45°C.

The assigned depth in this temperature analysis part is given to my knowledge of 9 coordinates, as “0 at top of concrete” and “0.335m at bottom of subgrade layer”. In the vertical deformation of the rigid pavement the percentage of all assigned depths deformation obtained at 0.5% and the deformation from the concrete to subgrade layer is 3.9%.

The assigned depths of pavement has no change and the temperature stresses of assigned depths is decreases from concrete layer to subgrade layer and the maximum of 9% percent stresses in pavement obtained at assigned depth of 0m to 0.03m.

V. CONCLUSIONS

In the Modelling of temperature effects in Flexible and Rigid pavement,

The developed finite element model enables to calculate temperature in layered structure of pavement with high accuracy. From the applied of 45º C temperature causes significant change in their elastic modulus of the layered pavement.

In Flexible pavement, stress variation due to temperature of top bituminous concrete to bottom subgrade layer is 2.512-0 N/m². The vertical deformation is 0.013m at top of bituminous concrete and 0.0089m at to bottom subgrade layer.

In Rigid pavement, the temperature stress is distributed all across the model. Stress variation due to temperature of top concrete pavement to bottom sub-base layer is 6.23 N/m² to -1.63 N/m².The Total deformation is maximum of 0.0542m at top of concrete slab while minimum of 0.0102m at 32.5 cm of the sub-base layer.

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