© 2017 IJSRST | Volume 3 | Issue 7 | Print ISSN: 2395-6011 | Online ISSN: 2395-602X
Themed Section: Science and Technology

An Experimental Study and Evaluation of Thermal Stresses in Rigid Pavements using FE Method

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ABSTRACT

In the present investigation, an experimental study was conducted to evaluate the thermal stresses in rigid pavement. In pavements design, temperature differential is having dominant role across the depth at critical locations. Seasonal climate changes influences the characteristic of pavement track. The study influences the behavior of the pavement slab in a nonlinear manner. The critical stresses are developed during the combined effect of load and temperature differential. Three different mix proportion were used in the present study using different mix proportion of N-sand and M-sand. (N) cast with N-sand, (M) cast with M-sand and (NM) with equal proportion of M-sand and N-sand. Temperature variations across the depth were being observed and recorded at three critical locations for all the three different mix proportions using thermocouples. The experimental results obtained were being analyzed using FE method. The result obtained from the study clearly shows that the actual temperature differentials are Non-linear. The finding confirmed the importance and the need to account the nonlinear temperature differential in the design of concrete pavements. Also, 3DFE technique using ANSYS proved to be a versatile technique in analyzing concrete slab for thermal and load stresses. The results arrived from this study shows that stresses due to the nonlinear temperature differential are greater than the linear temperature differential hence it is necessary to take care while designing the rigid pavements.

Keywords : Rigid pavement, FE Method, Critical Stress, Natural And Manufactured Sand.

I. INTRODUCTION

Climate change is expected to pose many challenges to the road design, construction and maintenance. Temperature variations cause curling and thermal-expansion stresses within the concrete. Curling stresses result from temperature gradients through the slab depth and thermal-expansion stresses are induced due to uniform changes in temperature that cause the slab to expand. Rigid or concrete pavements are impacted by temperature changes through alterations in expansion and contraction movements and subsequently cracks form. Distortion of the slab due to both upward and downward curling occurs respectively when the top surface of the slab is cooler than the base course and also when there is a higher temperature on the top surface respectively, as illustrated in figure 1.

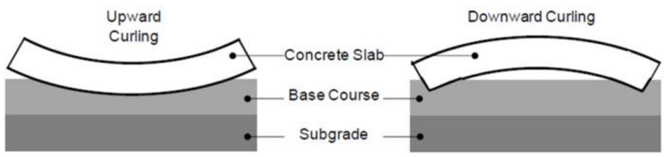

Figure 1. Curling of concrete slab

Curling Stress

Westergaard (1926) was one of the first researchers to investigate slab curling by looking into the effect of temperature differentials on PCC pavement without traffic loads. Westergaard (1927) also assumed that the temperature distribution was linear throughout the concrete depth. Authour derived numerical equations for calculating curling stresses by accounting for the positive and negative temperature gradients (Westergaard 1927). However, a study conducted by Teller and Sutherland (1935) extended Westergaard's work and revealed that temperature is, in fact, nonlinearly distributed within PCC slabs. Further extending Westergaard's study, Bradbury (1938) derived an approximate solution to calculate the maximum stress in a finite concrete slab with all edges free. He developed a simplified chart to estimate curling stresses by applying the ratio of the slab length to the radius of relative stiffness.

The PCC curling phenomenon did not receive much attention until later researchers found proof of the significance of curling stresses from field data and finite element (FE) analysis (Choubane and Tia 1992, Kuo 1991, 1998). Nevertheless, most of those numerical analysis methods still relied on Westergaard's and Bradbury's work, including the assumption of linear temperature distribution, even though it had already been realized that the true temperature profile is highly nonlinear in realistic conditions (Liang and Niu 1998). In the later part of the 20th century, two-dimensional (2D) FE methods were used for curling analysis, which were limited to linear temperature distribution (Haril et al. 1994). Compared to the three-dimensional (3D) FE methods used later, the traditional 2D plate elements' analysis did not require as much input and execution time (Harik et al. 1994, Smith et al. 1991), but these methods had limitations with respect to predictive accuracy and visualization.

Warping Stresses

Hansen et al. (2008) constructed a model for warping stresses using a FE solution, which can compute concrete properties by analyzing varying environmental conditions. The model used both surface drying at the top of the slab and wetting exposure at the bottom to predict warping. The authors found that wetting of the slab bottom could significantly increase the equivalent temperature gradient and consequently warping deformations.

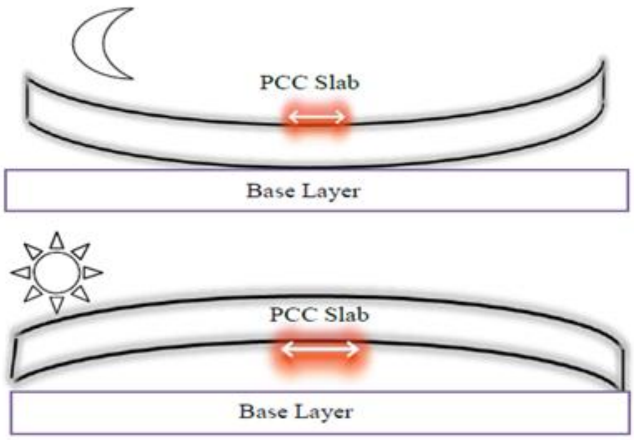

Figure 2. Stresses exerted due to PCC curling and warping

II. MATERIALS AND METHODOLOGY

Cement: Ordinary Portland cement of 43 grade is used. The properties of cement are determined by conducting tests as per IS 4031-1968. 43 grade cement conforming to IS: 8112-1976 was used.

Fine aggregates: N-sand: Locally available natural river sand is used in the present project. Properties of N-Sand are determined by various tests as per IS:2386-Part3. The results conforms to Zone II of IS:383-1970.

M-Sand: M-sand nearby available is used in the present investigation. The properties of the M-sand are determined by various tests as per IS:2386-Part3. The results confirms M-sand selected to Zone-I

Coarse aggregates: Aggregates are retained on IS sieve size 4.75mm are called coarser aggregates. Locally available crushed granite coarse aggregates are used in this study. The tests for physical properties on these are conducted as per IS: 383-1970. Proper grading of aggregates is essential to make the mix dense so as to get the required strength and to provide good interlocking between the aggregates.

Water: Water is a very Essential ingredient in the concrete. As it is necessary for Hydration Process. Potable water free from impurities and other substances is used for mixing and curing purpose. Water should meet the requirements stipulated in IS456:2000. Mix proportions in the present study, IS 10262:2000methodof mix design is used for arriving at the mix proportions. Three mix proportions for conventional M30 grade concrete are arrived.

Methodology:

General: Pavement Slabs of different material properties are considered for study and the effect of temperature and load are analyzed. Difference in temperature between top and bottom of slab, causes to warp or bending, giving rise to stresses. The variation in temperature across the depth of the pavement slab is caused by daily variation where as an overall increase in slab temperature is caused by seasonal variation in the temperature. The stress developed in the pavement slab due to the temperature is obtained. Finally, the total stresses due to the effect of temperature, and load are obtained by algebraically adding the individual stresses induced by the, temperature and load.

Analysis of temperature stresses

Stresses induced by temperature differential are divided in to three components: Axial, linear and nonlinear (Figure 3). The stresses occurring due to the various components are calculated every hour and the peak stress developed in the pavement slab due to the combination of the above temperature components are found every day. The realistic stresses developed in the pavement due to the various temperature components are obtained.

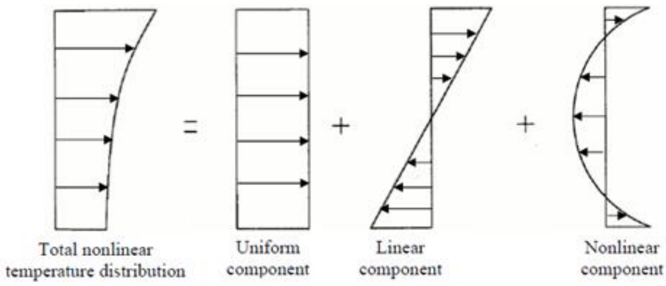

Figure 3. Typical temperature distribution throughout concrete slab depth

Thermal Stress using FE ANSYS Software

With the recorded temperatures and material properties, thermal stresses in the pavement slabs are evaluated using ANSYS software. All parameters of slabs such as temperature variation, Modulus of Elasticity, slab dimensions, density of concrete, poisons ratio (μ) and Thermal expansion coefficient are fed in to software. Here our model is symmetrical about X and Z axis hence we are considered quarter portion for modeling and analysis. The aspect ratio for meshing is checked, if the aspect ratio is greater than five, the meshing is refined so that aspect ratio will have a value less than five. The problem is solved on the solve menu.

The results are visualized and the stresses at any point on the slab are displayed in result for points on the visualization menu. The thermal stresses obtained using ANSYS software. Structural analysis deals with stresses strains deformation and thermal analysis deals with thermal stresses and temperature variation across the thickness.

Steps involved in structural and thermal analysis:

- Problem specification
- Problem Description
- Prepare for a specified analysis
- Creating Geometry
- Defining Materials
- Generating Mesh
- Apply Loads
- Obtain Solution
- Review Results

III. RESULTS AND DISCUSSION

Stresses due to axial temperature component (frictional Stresses) Due to the uniform temperature rise and fall in the cement concrete pavement slab, there is overall expansion and contraction of the slab. Day time, as the mean temperature of the slab increases, pavement slab expands. Due to the frictional resistance at

- Frictional stresses are maximum during day time.
- The frictional stresses are compressive during day time whereas they are tensile during night time. This is because during day the slab will tend to expand whereas during night the slab will tend to contract. the interface, compressive stress is developed at the bottom of the pavement slab as it tends to expand. Similarly, during night time, the pavement slab contracts causing tension at bottom of slab.

Stresses due to nonlinear temperature differential

To evaluate stresses due to nonlinear temperature differential, a model developed and analyzed also warping stresses in concrete pavement slabs is used.

- The peak stress due to nonlinear temperature differential occurred during the noon. This is due to the higher ambient temperature during noon time (12-3pm).

- The average of peak stress due to the nonlinear temperature differential at the edge region in slab S3 is 40% and 27% more than slab N and slab M respectively.
- In all the slabs, peak stresses occur at the edge region. The high stresses obtained in the slab cast with partially NM-sand.

The ANSYS software input for a 200 mm thick slab are given below

Preference menu: In this menu the analysis method is preferred like thermal for thermal analysis or structural for structural analysis. Main menu > Preferences
Preprocessor menu: Element type : In this menu the element type is preferred
Material models menu: In this menu we have to define materials models and material properties.
Material Properties (Pavement Slab):

i. E (Young's modulus) Mpa = 29.383x103
ii. μ (Poisson's ratio) = 0.15
iii. Thermal expansion of concrete (per °C) = 1x10-5/ °C
iv. Density (kg/m3) = 2400
v. Thermal Conductivity of Concrete = 1.68

Modeling menu: In this menu we have to create models by selecting create-Nodes-In active CS
Slab Geometry:
i. Column length (x mm) = 1200
ii. Row width (ymm) = 600
iii. Slab thickness (z mm) = 200
Meshing menu: In this menu we have to mesh the created models by selecting the model. Here we have to consider the Aspect Ratio was used

i. Number of elements along x in column1 = 10
ii. Number of elements along y in row1 = 18
iii. Number of elements along z in the slab = 3
i. Aspect ratio 2.50 < 5

Loading menu: Here temperature values are used as loads and is given in Figure 4

Figure 4. Loading Menu

Loading Parameters: thermal are given in Table 1

	Interior	Edge	Corner
Temperature at 25mm	50.00	48.40	52.30
Temperature at 100mm	48.10	48.50	52.50
Temperature at 175mm	44.44	47.50	52.00

Solve menu: After applying loads the next step is to get solution done is given in Figure 5.


Figure 5. Solve Menu

Evaluation of load stresses using ANSYS

Load stresses are evaluated by using ANSYS
Where,
P = Load, kN
h = thickness of the slab, mm
μ = Poisson's ratio = 0.15
E = Modulus of elasticity, N/mm2
Steps are similar to thermal analysis like modeling, meshing etc.. Here in the loading menu
the structural loading is defined by using IS :875 Part-II

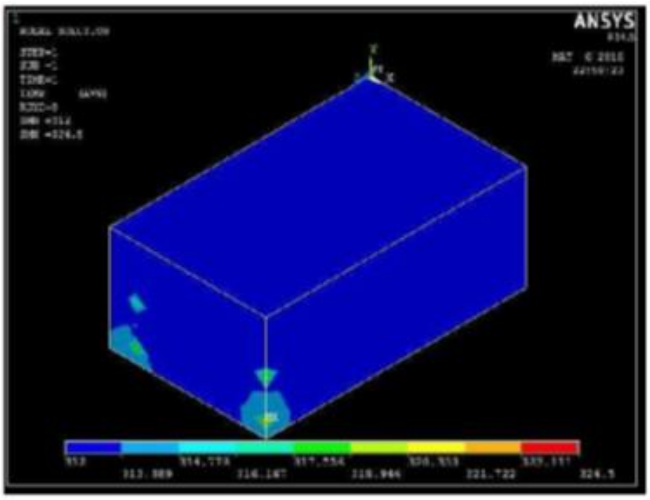

Figure 6. Temperature Distribution

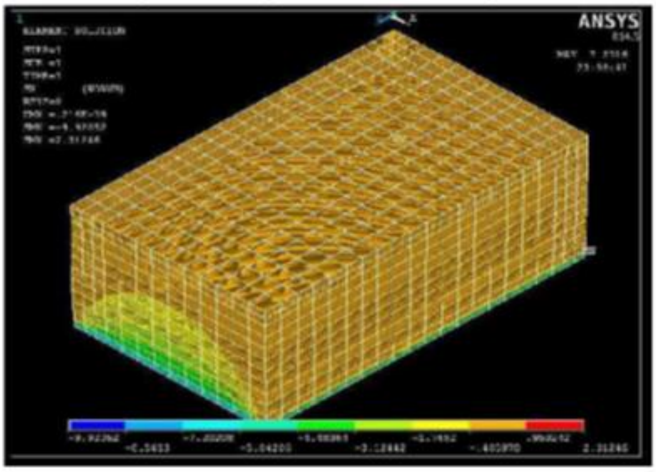

Figure 7. Stress along X gradient

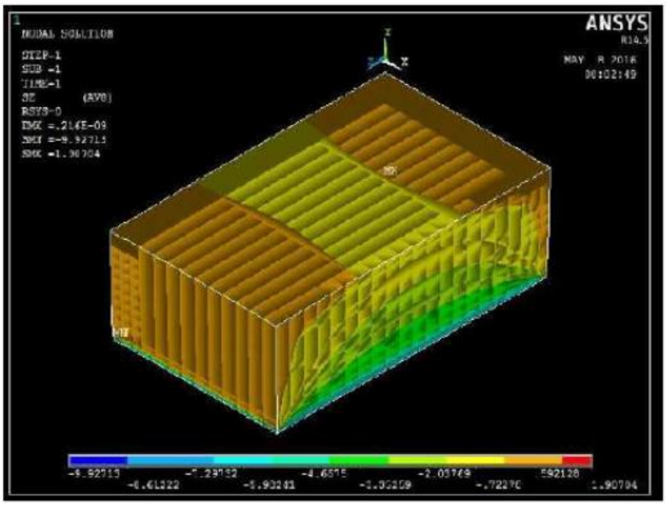

Figure 8. Stress along Y gradient

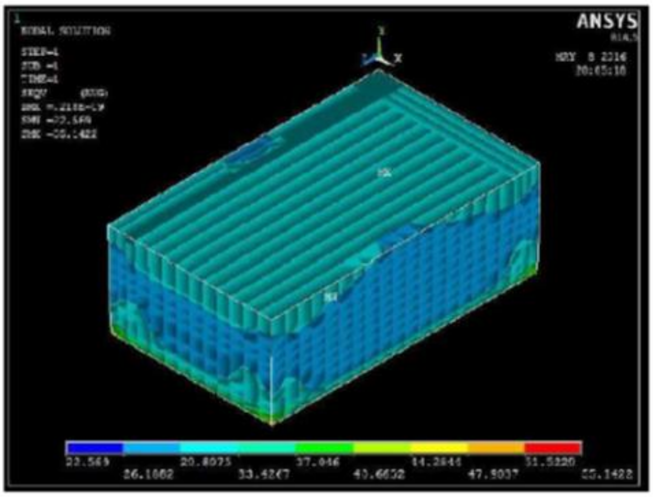

Figure 9. Von Mises stresses of N –Slab

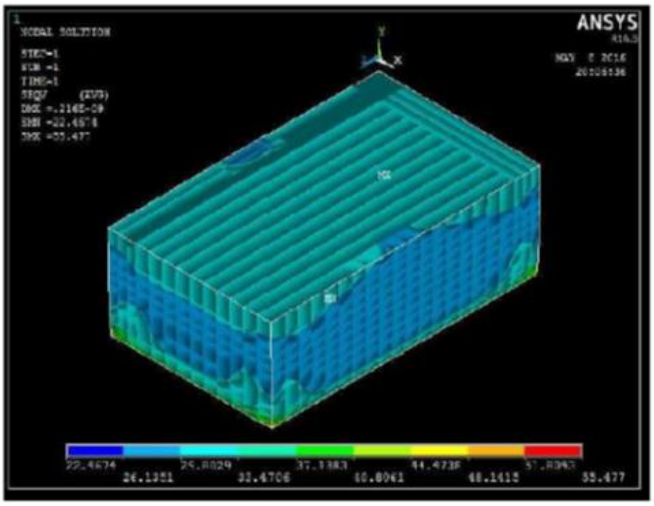

Figure 10. Von Mises stresses of M –Slab

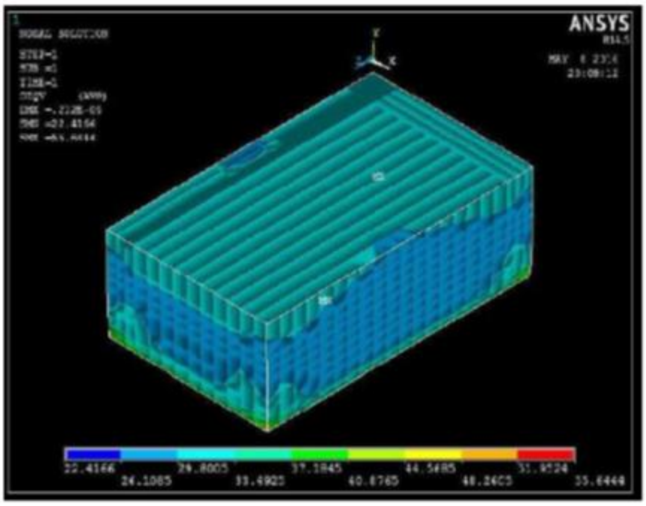

Figure 11. Von Mises stresses of NM –Slab

Table 2 Von mises stress Value N/mm^2

Von mises stress Value N/mm^2	N	M	NM
Maximum	55.47	55.48	55.65
Minimum	22.46	22.47	22.41

Discussions

- From the Table 2, it is observed that the peak stress due to the load occurred at the corner region.
- Stresses are independent of the length and breadth of the slabs.
- Maximum stresses occurred in NM - Slab.

Thermal Analysis

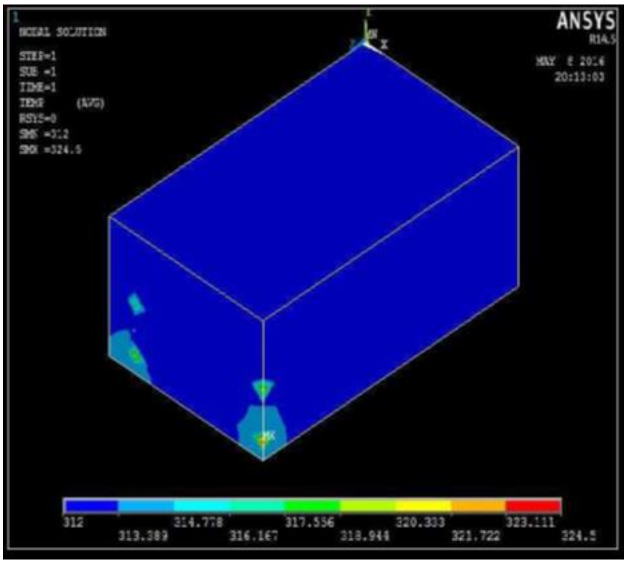

Figure 12. Thermal distribution of Slab N

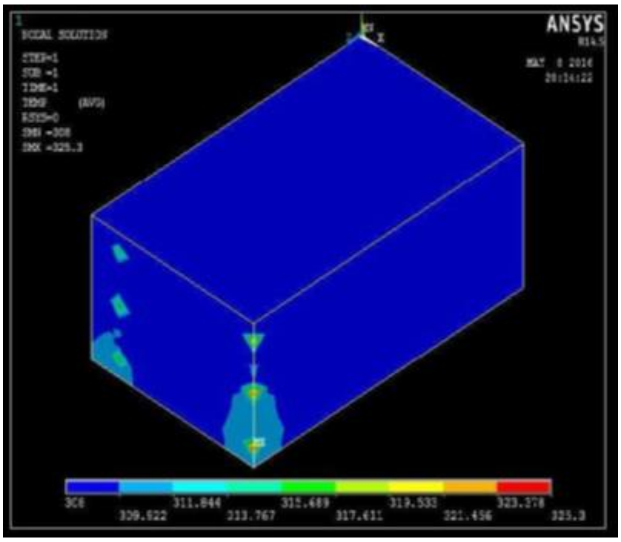

Figure 13. Thermal distribution of Slab M

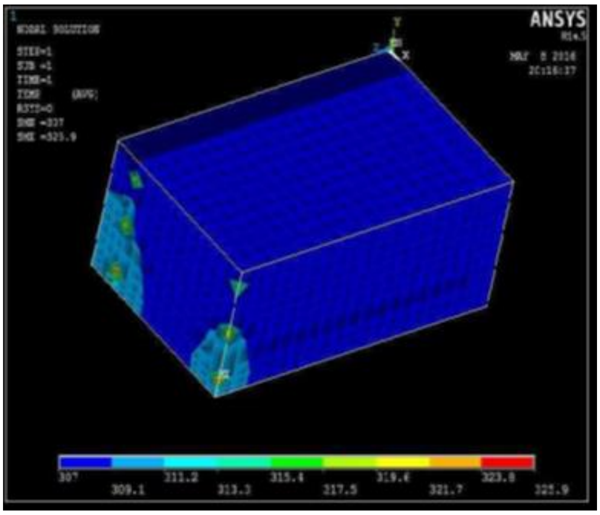

Figure 14. Thermal distribution of Slab NM

IV. CONCLUSIONS

Compressive strength of concrete is more when it is cast with M-sand. The high stresses occur at corner regions of the slabs. ANSYS is preferable for evaluation of temperature stresses and Load stresses to get good results. By observing the obtained temperature data results in the morning 8am-9am and in evening 5pm-6pm slabs may subjected to negative temperature differentials it means it warp upwards. It is necessary to consider temperature differential effect for pavement slabs exposed to Temperature subjected to high stresses compare to normal stresses. The peak stress occur in slab cast with partially M-sand and partially N-sand in comparison with other two slabs, due to non-linear temperature differential in slab NM is 28% and 35% more than slab N and slab M respectively. The peak total nonlinear stress in slab NM is 38% and 44% more than slab N and slab M respectively. Nonlinear temperature stresses evaluated using ANSYS are up to 30% more than the linear temperature stresses. The peak stresses due to load occurred in slab at corner region. 3DFE technique using ANSYS provides a versatile technique in analysing slab for thermal and load stresses due to different temperature profiles and load. The results arrived from this study shows that stresses due to the nonlinear temperature differential are greater than the linear temperature differential hence it is necessary to incorporate this effect while designing the slabs. For evaluating realistic stresses in a concrete slabs, nonlinear temperature differential should be adopted instead of assuming the linear temperature differential for the design of pavement slabs while designing for Thermal loadings.

V. REFERENCES

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