Temperature Effect on Flexible Pavement Responses

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Abstract: *From recent studies in flexible pavement design it is found out that the most sensitive and important part of pavement composition is its top bituminous layer as it tolerates all the load and friction due to load repetitions. Bituminous layer play an important role in the design life of pavements. Many factors like load repetitions, different load groups and contact pressure affects the performance of flexible pavement, besides these factors there is another important factor that is "Temperature" which affects the thick bituminous pavement performance. Temperature affects the material properties like elastic modulus of bituminous layer in pavements. In the present study effect of temperature change is accounted for the pavement responses. With damage analysis the effect temperature variation on design life of pavement is studied. Results show that with the increase in temperature from 20°C and 40°C the design life of flexible pavement decreases by more than 50%. Tensile stains at the bottom of bituminous layer are much more affected due to temperature change than compressive strains at the top of subgrade.*

Key Words: *Temperature, Flexible Pavement, KENLAYER, Design Life.*

1. INTRODUCTION

In India flexible pavement design is governed by IRC: 37 – 2001 "Guidelines for the Design of Flexible Pavements"[5]. Indian Road Congress (IRC) recommends the design of flexible pavement on an average annual pavement temperature (AAPT) of 35°C for whole country. But in actual this AAPT is valid only for some regions of India. India being a large country with varied topography, there is a huge variation in climate/temperature from one region to another. There are regions with AAPT below 20°C therefore for whole India using one AAPT is not recommended. Properties of bituminous mixes being temperature dependent, local atmospheric condition need to be accounted for design of thick bituminous pavements. However IRC: 37 – 2001, recommends the properties of different bituminous mixes i.e. Bituminous Concrete (BC) and Dense Bituminous Macadam (DBM) in the temperature range 20°C to 40°C.

In the present paper a flexible pavement is designed for design traffic of 10 million standard axles (msa) over a subgrade having California Bearing Ratio (CBR) of 5%, as per IRC: 37 – 2001 guidelines. Response of the designed pavement is then analyzed by using mechanistic computer program KENLAYER for different temperatures from 20°C to 40°C.

The objective is to study the effect of temperature on pavement responses i.e. stresses, strains and deformations at the bottom of bituminous layer and at the top of subgrade, and hence on the design life.

The scope and limitations of this research paper are:

1. Mechanistic approach of pavement analysis is used to evaluate the performance of flexible pavement.

2. Only Linear elastic model is used in present study for the analysis.

3. Bituminous mixes properties as is available in IRC: 37 -2001 is used for temperature range 20°C to 40°C. Further analysis can be done for other temperatures.

2. LITERATURE REVIEW

Flexible pavements are pavements constructed with bituminous and granular materials. These types of pavements are so named since the total pavement structure deflects/bends under traffic loading. Flexible pavements are layered systems that can be analysed with Burmister's layer theory [8]. Flexible pavements structure composed of several layers of material which transfers load to the subgrade without failure (Fig. 1). These layered systems have high quality materials on the top where stresses are high and low quality materials at the bottom. The top layer materials which are bituminous mixes are temperature sensitive and their properties i.e. elastic modulus and Poisson's ratio change with the temperature change. Therefore it is important to account for temperature while analysing flexible pavements with thick bituminous mixes.

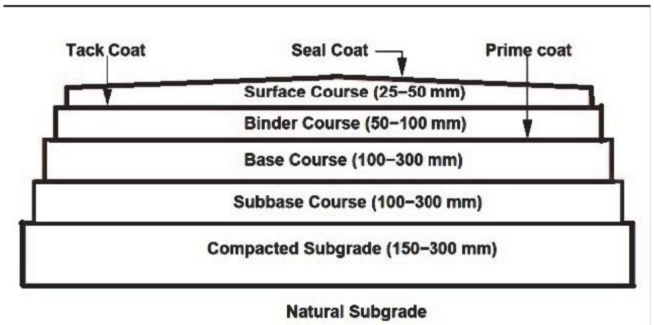

Fig. 1. Typical Flexible Pavement Structure

Indian road designs are semi-empirical, based on load repetitions in terms of standard axle load (msa) and CBR of the subgrade. The temperature considered for pavement design is 35°C as an AAPT for whole country. On the basis of design msa and CBR of subgrade, total pavement thickness and its composition can be obtained from plates 1 and 2 of IRC: 37 – 2001. The thickness of pavement layers provided by IRC: 37 – 2001 are based on computations using linear elastic model FPAVE developed under the MORT&H research scheme 'R– 56' [7]. The equation used in Road Research Scheme 'R-56' for calculating AMPT (average monthly pavement temperature) from average monthly air temperature (AMAT) is given below:

$$AMPT = 1.15\ AMAT + 3.17 \qquad (1)$$

On the basis of results of 'R-56' an uniform AAPT temperature of 35°C is adopted for India. In present study a design is analysed by mechanistic computer program KENLAYER to evaluate the effect of temperature change on the pavement responses and design life. KENLAYER [4] is a part of computer program called KENPAVE developed by Dr. Yang H. Huang, at University of Kentucky and is used for the solution of an elastic multi-layered system under a circular loaded area. KENPAVE is based on the Burmister's multilayered elastic theory. Solutions are superimposed for multiple wheels like dual or dual tandem wheels. The superiority of KENLAYER over the other elastic layer programs is its capability of considering constituting material behaviour as linear-elastic, nonlinear-elastic or visco-elastic [4]. Program also performs damage analysis to evaluate the design life considering the damage caused by fatigue cracking and permanent deformation. The distress models evaluated in KENLAYER are fatigue cracking and permanent deformation or rutting. In flexible pavement critical location and failure causing reason are strains due to fatigue cracking at the bottom of bituminous layer and rutting at the top of subgrade layer. The fatigue cracking is caused by the horizontal tensile strain (ε_t) at the bottom of the bituminous layer and the permanent deformation or rutting is caused by vertical compressive strain (ε_c) on the surface of subgrade. The damage relationships used as input in KENLAYER were developed by the Asphalt Institute as given below:

Fatigue Cracking Model:

N*f*= 0.414 (1/• *t*) 3.291 (1/E) 0.854 (2)

Rutting Model:

N*R* = 1.365 x 10-9 (1/• *c*) 4.477 (3)

Where,

N*f* and N*R* are allowable number of load repetition for fatigue and rutting respectively

ε_t is tensile strain at the bottom of bituminous layer

ε_c is compressive strain at the top of subgrade layer and

E is Elastic Modulus of bituminous layer material

Mechanistic Empirical Methods are also Widely Explored

The main advantage of an ME design method is that the analysis is based on pavement fatigue and deformation characteristics of all layers, rather than only on the pavement's surface performance (ride quality). It is based on the mechanistic of materials that relates traffic load to pavement response, such as stress and strain.

Mechanistic empirical computer program KENLAYER can be used to predict the stresses, strains, and deflections in mechanistic empirical methods. By using this computer program, all the pavement reactions due to the load repetition can be determined more accurately, close to the actual condition.

3. METHODOLOGY

A flexible pavement is designed with the subgrade CBR 5% and design traffic of 10 msa in accordance with IRC: 37- 2001.

3.1 Design of Flexible Pavement

In order to evaluate the effect of temperature on the performance and design life of flexible pavement, a sample pavement is designed by IRC: 37 – 2001, with following input parameters:

1. Initial traffic, P = 169 CVPD
2. Growth rate, r = 7.5%
3. Lane Distribution Factor, D = 1 (single lane road)
4. No. of years b/w last count & year of completion, x = 1
5. Design Period, n = 20 years
6. Vehicle damage factor, F = 3.5
7. Traffic in year of completion of construction,
8. A = P (1+ r) x = 182 CVPD
9. Cumulative Standard axle repetitions during design period, N = 365*A*D*F* [(1 + r) n – 1]/r = 10 msa
10. First Year traffic (msa) = 0.232 msa
11. Design CBR of Subgrade = 5%
12. Flexible Pavement Composition as per IRC: 37 – 2001, plate 2 for 10 msa and CBR 5% is given below:

Table.1. Composition of Sample Pavement [4]

Sr. No.	Layer Type	Thickness (mm)
1.	Bituminous Concrete (BC)	40
2.	Dense Bitumen Macadam (DBM)	70
3.	Granular Base (WMM)	250
4.	Granular Sub – base	300
	Total Pavement Thickness above subgrade	660

To study the effect of temperature on pavement response, AAPT of 20°C, 25°C, 30°C, 35°C and 40°C and corresponding value of elastic modulus of bitumen mixes, with 60/70grade of bitumen, are used for analysis. The analysis is carried out considering linear elastic model using computer program KENLAYER. Damage analysis is also performed to find out the design life of the pavement.

3.2 Material Properties

Material properties used in this study are the modulus elasticity, the Poisson's ratio, and the unit weights of each layer. The 60/70 grade of bitumen is used in the bituminous mixes. The elastic modulus for granular layers and subgrade are calculated using equations given in IRC: 37 – 2001, given in Table 2.

Table 2. Properties of Constituting Pavement Material[4, 5]

Sr. No.	Layer Type and Material	Elastic Modulus (MPa)	Poisson's Ratio	Unit Weight (kN/m3)
1.	BC	1695	0.5	22.8
2.	DBM			
3.	WMM	250	0.4	21.2
4.	Granular Sub-Base	300	0.4	21.2
5.	Subgrade	50	0.4	19.6

The elastic modulus and Poisson's ratio for BC and DBM used at different temperature are given in Table 3.

Table 3. Elastic Modulus and Poisson Ratio of BC and DBM at Different Temperatures[4]

Sr. No.	Temperature (°C)	Mix Type	Elastic Modulus (MPa)	Poisson's Ratio
1.	20		3600	0.35
2.	25		3126	0.35
3.	30	BC and	2579	0.35
4.	35	DBM 60/70	1695	0.50
5.	40		1270	0.50

3.3 KENLAYER Data for Pavement Analysis

The thickness of layers and material properties are taken as recommended by IRC, shown in Table 1, 2 and 3. The load information for analysis is as follows:

Standard single axle dual wheel configuration is considered for the analysis work. Only the outer set of wheels is considered to evaluate the pavement responses. The legal single axle load of 80 KN with dual tires having centre to centre spacing of 31 cm is considered for the study. The tire pressure is assumed as 0.8 MPa [6]. The contact radius is calculated for above load and tire pressure which comes out to be 8.9 cm. The designed pavement is considered as five linear elastic layers as shown in Fig. 1.

3.4 Method of Analysis

Analysis is carried out considering the pavement structure as linear. A computer program KENLAYER is used to analyse the distress in the flexible pavement layers. Key input for linear elastic analysis are traffic loading and temperature dependent material properties, which are keyed in KENLAYER using menu: LAYERINP. The stresses, strains and deformations are obtained at critical locations using KENLAYER. The tensile strains are observed at the bottom of layer of bituminous mix i.e. Bituminous concrete and Dense Bitumen Macadam. Further damage analysis is performed for the fatigue cracking and permanent deformation to predict the design life of pavement. In the analysis DEL (tolerance for numerical integration) is kept as 0.05, which implies an accuracy of 5%.

3.5 Damage Analysis

Damage caused to the pavement in terms of fatigue cracking and permanent deformation with each repetition of load is summed up to evaluate the design life. The damage analysis is based on the horizontal tensile strain at the bottom of a specified bituminous layer and the vertical compressive strain on the surface of a specified layer, usually subgrade. The damage ratio is the ratio between the predicted and allowable number of repetition. It is computed for each load group in each period and summed over the year. The damage ratios for fatigue cracking and permanent deformation are evaluated and the design life of the pavement is estimated as the reciprocal of the damage ratio. In present study the damage analysis is done by Linear and Non-Linear analysis. In the analysis various distresses model constants as recommended by Asphalt Institute are used.

4. ANALYSIS & DISCUSSIONS

As discussed the pavement analysis is carried out by assuming the pavement structure as a linear elastic model. Results of analyses are presented in Table 4 to 6. The stresses shown in Table 4 are found at the bottom of bituminous layer under the centreline of outer tire.

Table 4. Effect of Temperature on Stresses at the Bottom of Bituminous Layers

Sr. No.	Temperature (°C)	Elastic Modulus (MPa)	Mix Type	Stresses (kPa)
1.	20	3600		163.43
2.	25	3126	BC and	174.88
3.	30	2579	DBM	191.36
4.	35	1695	60/70	217.57
5.	40	1270		246.90

The tensile strains shown in Table 5 are calculated at the bottom of bituminous layer and compressive strain at the top of subgrade. From the results it is observed that temperature has more pronounced effect on tensile strain as compared to compressive strain. As a result failure took place in bituminous layer because of fatigue cracking at higher temperatures.

Table 5. Effect of Temperature on Strains

Sr. No.	Temperature (°C)	Elastic Modulus	Tensile Strain (ε_t)	Compressive Strain (ε_f)
1.	20	3600	-2.434E-04	3.429E-04
2.	25	3126 -	2.617E-04	3.501E-04
3.	30	2579	-2.875E-04	3.595E-04
4.	35	1695	-3.434E-04	3.682E-04
5.	40	1270	-3.929E-04	3.801E-04

Table 6 shows decrease in design life with increase in temperature because of early fatigue failure in bituminous layer.

Table 6 Effect of Temperature on Subgrade Deflection and Pavement Design life

Sr. No.	Temperature (°C)	Elastic Modulus (MPa)	Deflection (cm)	Design Life (years)
1.	20	3600	0.03516	3.51
2.	25	3126	0.03551	3.12
3.	30	2579	0.03600	2.69
4.	35	1695	0.03641	2.15
5.	40	1270	0.03709	1.77

In Figure 2, N_f denotes allowable given load repetitions to cause failure in fatigue cracking and N_r denotes allowable given load repetitions to cause failure in rutting.

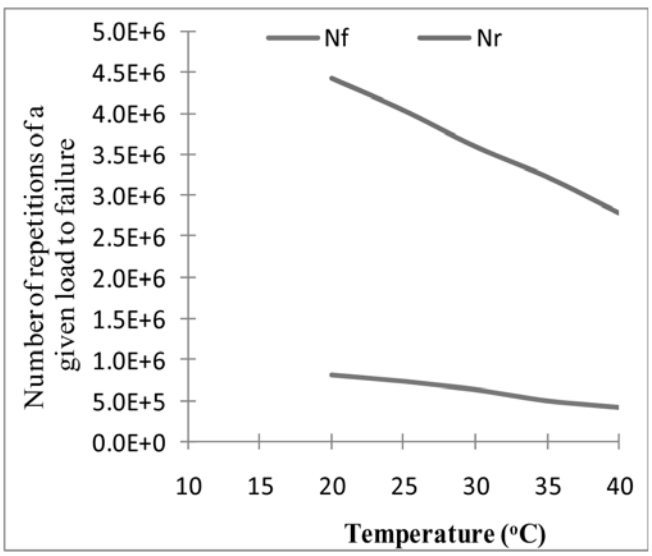

Fig. 2. Allowable Load Repetitions for Fatigue and Rutting at Different Temperature

5. RESULTS AND FUTURE SCOPE

1. Design life decrease by 56 % by increasing the temperature from 20oC to 40oC.
2. Tensile stresses at the Bottom of Bituminous Layers increases with increase in pavement temperature.
3. Subgrade deflection also increases with increase in pavement temperature which may be attributed to decrease in elastic modulus of bituminous layer at higher temperatures.
4. Affect of temperature increase in more predominant in tensile strains of bituminous layer as compared to compressive strains in subgrade.
5. Increase in temperature decreases the allowable number of load repetitions for fatigue (cracking) failure.
6. Here only linear elastic model is considered for analysis, other models like nonlinear, visco-elastic and combination of them can also be used to analyse the pavement at different temperatures.

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