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VARIATION OF PAVEMENT DESIGN WITH ENVIRONMENTAL TEMPERATURE VARIATION

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Abstract: Indian Roads Congress (IRC): 37-2012 is the main guideline for design of flexible pavement. This guideline developed several pavement design charts ready for use based on Average Annual Pavement Temperature (AAPT) which varies from 200 C to 400 C. Environmental condition pertaining to the monthly variation of temperatures have not been considered in the pavement design. This paper presents pavement design considering variation of resilient / elastic modulus value at different time periods throughout the year (month wise) using Indian Institute of Technology(IIT) Pave software and compare conventional pavement design as proposed in IRC: 37 – 2012. A different temperature model has been used to determine pavement temperature month wise. Different resilient moduli (E) values of Bituminous Concrete (BC) and Dense Bituminous Macadam (DBM) have been considered based on air temperatures and design life based on monthly pavement temperature is calculated for each month and average value is adopted for final pavement design life. It has been found that conventional pavement design is underestimated when pavement design is conducted using monthly variation of pavement temperature at design tire pressure of 0.56× 106 N/m2 and below and is overestimated at higher tire pressure. Design life with variation of temperature is found 3 times approximately obtained from conventional method of pavement design. It is also found that rut and fatigue life varies with tire pressure.

Keywords: *IIT Pave, average annual pavement temperature, AASHTO, pavement temperature model.*

1.0 Introduction

There are several methods for design of flexible pavement. Several countries proposed pavement design taking a single average annual pavement temperature. American Association of State Highway Transportation Official (AASHTO) 1993 proposed pavement design considering environmental variation i.e., seasonal effects.

Indian Roads Congress (IRC): 37-2012 proposes pavement design based on average annual pavement temperature which varies from 20 to 350 C for use in different regional zones. However, charts have been developed for 35 0C representative of the general climate in various regions of India. E value of asphalt mix has been tested in the laboratory at different temperatures and different values have been observed which are presented in Table 7.1 of IRC: 37-2012. The same is presented in Table 1.

Table 1: E Value of Bituminous Mix (MPa) Using Viscosity Grade (VG 30) Bitumen

Temperature (^0C)	*E Value(MPa)*
20	3500
25	3000
30	2500
35	1700
40	1250

A linear relationship has been found for Viscosity Grade (VG) 30 which is presented in Figure1.

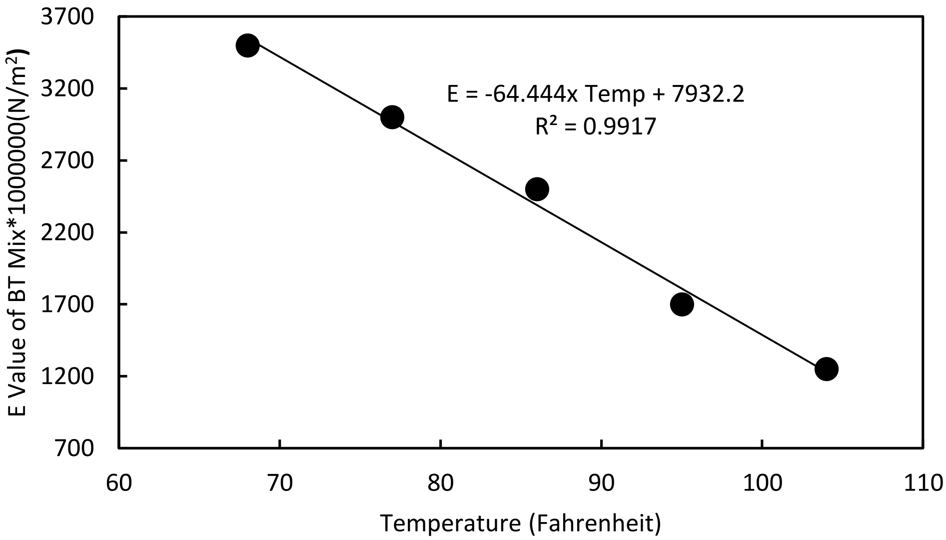

Figure 1: Variation of E value with Temperature

Regression equation may be used to interpolate / extrapolate the E Value to other temperatures. This paper presents pavement design based on seasonal variation and determines design life for different months and compares with conventional pavement design life. A temperature model has been proposed for evaluation of air and pavement temperature for a particular location.

2.0 Pavement Temperature Model

The design pavement temperatures can be calculated from design air temperatures using analytical models and regression equations. In the analytical models, the heat equation is solved and the pavement temperature is calculated knowing the weather parameters such as solar radiation, absorptivity and emissivity of the surface and air temperature. Regression equation developed from the measured pavement temperature database relating air temperature and latitude can also be used and the pavement temperature for the required time period can be calculated. Due to the complexity in measuring the material parameters required for use in the analytical models, most of the attempts related to pavement temperature have focused on regression models. The various factors influencing the pavement temperature are air temperature, latitude, solar radiation, wind speed and rainfall (Nivihta and Krishnan, 2014).

Among these factors, air temperature and latitude are reflected as the sole factors influencing the pavement temperature. To formulate a regression equation using this database, a linear regression equation with two variables has been assumed considering the effect of latitude and air temperature on the pavement temperature (Wahhab *et al.*, 1998).

The effect of temperature on asphalt pavements is different from that of concrete pavements. Temperature reduces the resilient modulus of asphalt layers, while it induces curling of concrete slab. In rigid pavements, due to difference in temperatures of top and bottom of slab, temperature stresses or frictional stresses are developed. While in flexible pavement, dynamic modulus of asphaltic concrete varies with temperature. Frost heave causes deferential settlements and pavement roughness. Most detrimental effect of frost penetration occurs during the spring break up period when the ice melts and subgrade is a saturated condition

Pavement temperature prediction has been extensively investigated by many researchers all over the world. The Enhanced Integrated Climatic Model (EICM) (NCHRP 1 -37A [Dempsey 1970]) is used in the mechanistic empirical pavement design guide (MEPDG) for pavement temperature prediction. The EICM consists of three parts: the CMS (Climatic -Materials-Structural) model originally developed at the University of Illinois (Dempsey, 2006), the CRREL Frost Heave and Thaw Settlement Model and the Infiltration and Drainage Model (NCHRP 1 - 37A). The CMS is a forward finite difference one -dimensional heat transfer model that determines the temperature distribution and the frost penetration within the pavement. The model considers radiation, convection, conduction and latent heat. Heat fluxes due to transpiration, condensation and precipitation are neglected in this model (Dempsey, 2006). The inputs used in this model include heat capacity and thermal conductivity of the asphalt mixture, pavement surface absorptivity, air temperature, wind speed and incoming solar radiation. Some of these input parameters were not measured directly but were estimated using empirical correlations. Several empirical models based on linear regression analysis have been developed to predict maximum and minimum temperatures in the pavement. Dempsey 2006 developed monographs to predict pavement temperatures at the surface and at a depth of 50mm. The collected data included pavement temperature and hourly solar radiation. A simulation model based on the theory of heat transfer and energy balance at the pavement surface was later developed. Until the initiation of the Long-Term Pavement Performance (LTPP) program, there was little information present in the general literature on this topic.

The Strategic Highway Research Program (SHRP) established the LTPP program in 1987 as a 20-year study to better characterize the in-situ performance of pavements. Approximately 2,500 sites throughout North America were selected to represent a broad range of pavement types and climatic conditions. To specifically deal with the challenges of studying climatic conditions, 61 LTPP sites were selected to become part of the Seasonal Monitoring Program (SMP). The 1994 SMP research was designed to measure and evaluate the effects of temperature and moisture variations on pavement performance; thus making it possible to monitor the appropriateness of the varying Super pave mixture designs (NCHRP 1 -37A, 2004).From the initial SHRP testing and the more recent SMP data, pavement temperature models were developed to assist with the selection of the proper asphalt binder performance grade for usage in a particular location (NCHRP 1 -37A, 2004).

Pavement temperature prediction using energy balance equations include studies performed by Hermansson (2004) and Christison and Anderson (1972). Several empirical models based on linear regression analysis have been developed to predict maximum and minimum temperatures in the pavement. Barber 1957 was among the first researchers to discuss the calculation of maximum pavement temperatures based on weather reports. He observed that the changes in pavement temperature measured in Hybla Valley (Virginia, USA) roughly followed a sine curve with a period of one day. The analyses showed that when solar radiation and air temperature was included, the sine approximation provided reasonable estimates of surface temperatures. However, his model incorporates a total daily radiation factor instead of a more accurate measure such as hourly radiation and he proposed a model to correlate pavement surface temperatures and temperatures at 3.5 in. depth with weather station information.

Solaimanian (1993) developed a quadratic model that determines the maximum and minimum surface pavement temperature based on the latitude of the location of the pavement.

Mainly, flexible pavement performance depend on pavement structure, applied load, pavement conditions and environmental factors, such as asphalt mix temperature and moisture content in unbound materials. The temperature of an asphalt mix is a determining factor of its performance. Asphalt mix properties change depending on temperature; thereby its response to traffic loads will also be different (Antonio and Maria, 2011)

The bearing capacity and the performance of flexible pavement are clearly affected by variation of modulus of asphalt mixture which significantly affected by pavement temperature. Thus temperature can influence the structural bearing capacity of Flexible pavement in the following sides (Bayomy *et al*., 2012):

- The modulus of asphalt mixture reduces with increasing the pavement temperature. Thus the structural bearing capacity reduces.

- Higher stress is transmitted to under layers according to the reduction of asphalt mixture modulus. However, material properties of base are relevant to stress level. Granular material of base course will be consolidated under the high stress level; however, cohesive soil will be more debility. Thence the temperature of asphalt mixture will straightway influences material properties of base and sub base.

- Stress induced by temperature variation: according to microscopic mechanical model, in the case of temperature increase, the contact force among the granules of granular base will be bigger, leading to the increase of volume stress.

The design pavement temperatures can be calculated from design air temperatures using analytical models and regression equations. In the analytical models, the heat equation is solved and the pavement temperature is calculated knowing the weather parameters such as solar radiation, absorptivity and emissivity of the surface and air temperature. Regression equation developed from the measured pavement temperature database relating air temperature and latitude can also be used and the pavement temperature for the required time period can be calculated. Due to the complexity in measuring the material parameters required for use in the analytical models, most of the attempts related to pavement temperature have focused on regression models. The various factors influencing the pavement temperature are air temperature, latitude, solar radiation, wind speed and rainfall (Nivihta and Krishnan, 2014). Among these factors, air temperature and latitude are reflected as the sole factors influencing the pavement temperature. To formulate a regression equation using this database, a linear regression equation with two variables has been assumed considering the effect of latitude and air temperature on the pavement temperature (Wahhab *et al.*, 1998).

The coefficients of the equation are determined by the in-built linear regression function in MATLAB and given as follows (Wahhab *et al.,* 1998):

$$Pt = 0.7147 + 1.3023At + 0.1103L \tag{1}$$

where, Pt = pavement temperature (^{0} C),At = air temperature (^{0} C), and L = latitude of the selected location.

This regression model developed is used to calculate pavement temperature for the entire country. This has been proven with other established method and satisfactory results are obtained.

2.1 Validation of Adopted Equation

The development of regression models require considerable amount of data and since such data was not available for India, the air temperature and the corresponding pavement temperatures data collected as part of the Long Term Pavement Performance Program (LTPP) of USA was used to develop the regression model. As there was no pavement temperature information available to validate the regression model, a comparison was performed with the data points extracted from the highways research station at Chennai data (IRC:37-2012). This study was carried out in the year 1969–1971. The highways research station at Chennai constructed an experimental bituminous concrete section and collected pavement temperature at the surface of the pavement as well as at different depths. From this report, 48 data points were extracted to validate the regression model developed as a part of this study. Among these, 24 data points were hourly pavement temperature measurements on a single day, 8th June, 1969 and the other 24 points were monthly average pavement temperatures for two years, 1970 and 1971. It is seen that the present model (Equ. 1) can predict the pavement temperature to a reasonable accuracy (Nivihta and Krishnan, 2014).

The design maximum and minimum pavement temperatures were calculated for all the selected 37 locations. The reliability considered in this case is of the order of 99.6 % as the maximum of seven day average maximum air temperature was used in calculating the pavement temperature and similarly the one day minimum air temperature for the design minimum case (Nivihta and Krishnan, 2014).

3.0 Pavement Design

3.1 Pavement Failure

Structural deterioration, and ultimately failure of a flexible pavement, is generally “defined” by the development of cracks in the bituminous surfacing and ruts in the wheel paths. Cracking and rutting are, in turn, indicated by elastic strains at critical locations within the pavement system. Horizontal tensile strains at the bottom of the bituminous surfacing ultimately result in fatigue cracking in response to repeated flexural stress, or excessive vertical compressive strains at the top of the subgrade causing rutting (Yoder and Witczak, 1975). When a pavement structure is designed, these strains are commonly limited to prevent cracking and rutting.

3.2 Model for Pavement Design

The resilient modulus of the subgrade is estimated from its respective California Bearing Ratio(CBR)-value which is based on the following empirical relationship (IRC:37-2012):

The relation between resilient modulus and the CBR is given as:

$$E\ (MPa^*) \quad \left.\begin{aligned} &= 10\times CBR \quad \text{for } CBR < 5 \\ &= 17.6\times(CBR)^{0.64} \quad \text{for } CBR > 5 \end{aligned}\right\} \qquad (2)$$

Where, E= Resilient modulus of subgrade soil in MPa

Resilient Modulus (MR) of the untreated Granular Sub Base (GSB) above the subgrade of modulus,

$MR_{subgrade}$ is given as(IRC:37-2012):

$$MR_{gsb} = 0.2h^{0.45} \times MR_{subgrade} \qquad (3)$$

Where h=thickness of sub base layer in millimeter.

Fatigue life of a bituminous mixture for bottom up cracking at a reliability level of 80% is given as:

$$N_f = 2.21 \times 10^{-04} \text{ x } [1/\varepsilon_t]^{3.89} \times [1/E]^{0.854} \qquad (4)$$

N_f = fatigue life, ε_t = Maximum Tensile strain at the bottom of the bituminous layer, E= Elastic modulus of the bituminous layer

Note:*Conversion Factor: 1 MPa=10^6 N/m^2

3.3 Subgrade Rutting Criteria

The equation for rutting is given as (MOST, 1999):

$$N= 4.1656 \times 10^{-08} [1/\varepsilon_v]^{4.5337} \quad (5)$$

Where, ε_v= Subgrade strain at the top of subgrade.

4.0 Case Study

A hypothetical case study has been considered. Following pavement compositions for a road with latitude of 31 degree with following values:

Design CBR: 10%,
Pavement Compositions: BC=40 mm, DBM=80 mm. WMM=250 mm, GSB=200 mm and Bitumen used: V G 30

Latitude of a place is assumed 31 degree. Pavement temperature has been determined using Equation 1 and presented in Table 2.

Table 2: Relationship between Air and Pavement Temperature (Nivihta and Krishnan, 2014).

Month	*Air *Temp(^0C)*	*Pavement* Temp(^0C)*
Jan	12	18
Feb	15	22
March	22	31
April	28	39
May	33	46
June	34	47
July	30	42
Aug	27	38
Sep	26	37
Oct	24	34
Nov	18	26
Dec	15	22

*Note: F=1.8*C+32*

Elastic modulus (*E*) of bituminous mix varies with temperature. It decreases with increasing pavement temperature. IRC: 37-2012 recommended *E* value mix at different temperature for using VG 30 bitumen. Based on these *E* values as reported in IRC: 37-2012, a graph *E* Vs. temperature has been plotted and regression equation has been developed and same has been presented in Figure 1.

VG 30 has been proposed for the case study and E values of mix at different months have been determined from Figure.1 and presented in Table 3.

Table 3: Variation of *E* throughout Year

Month	*E Value×106(N/m^2)*
Jan	3745
Feb	3300
March	2250
April	1340
May	585
June	427
July	1035
Aug	1490
Sep	1635
Oct	1940
Nov	2850
Dec	3295

Pavement design is carried out taking *E* values as mentioned in Table 3 and varying tire pressure from 0.3×10^6 N/m^2 to 1.0×10^6 N/m^2 MPa Fatigue and rut life are calculated and presented in Table 4.

Table 4: Fatigue Life and Rut Life

Month	*Design MSA* for tire Pressure 0.56 MPa*		*Design MSA for tire Pressure 0.3 10^6 N/m^2*		*Design MSA for tire Pressure 0. 10^6 N/m^2*		*Design MSA for tire Pressure 1. 10^6 N/m^2*	
	Fatigue	Rut	Fatigue	Rut	Fatigue	Rut	Fatigue	Rut
January	83.3	417.9	133.1	455	63.6	408.4	43.1	402.2
February	64.1	374.7	104.4	409	48	367.5	32.1	358.3
March	28.6	279.9	51.8	307.9	20.6	274.1	13.3	267.7
April	308	202.2	22.8	226	7.5	199	4.54	194
May	3.1	140.9	8.6	157.4	1.95	136.8	1.04	133.6
June	2.1	126.7	6.7	142.4	1.32	123.7	0.7	120.2
July	7	178.7	16.1	198.6	4.7	173.7	2.8	169.4
August	13.1	216.7	26.8	239.8	9.2	196.5	5.6	204.4
September	15.6	229.1	31	253.3	11.1	224.2	6.8	218.3
October	21.4	254	40.1	279.1	15.4	249.9	9.7	241.8
November	46.2	333.4	78.6	364.7	34.3	326.6	22.8	317.3
December	63.1	373.5	104.4	409	48	367.5	32.1	358.3
Average	54.6	260.6	52.0	286.9	22.1	254.0	14.5	248.8

Note: MSA-Million Standard Axle.*

Latitude of some important places in India is presented in Table 5.Some typical pavement temperature calculations month wise are also presented in Table 5.

Table 5: Average Pavement Temperature Month wise in ^{0}C and Latitude of Places

Month	Important Places(^{0}C)*				
	New Delhi	Lucknow	Srinagar	Jaipur	Guwahati
Jan	21.3	21.1	6.3	22.4	25.0
Feb	24.6	25.7	7.6	26.3	26.9
Mar	31.1	32.8	14.1	33.5	32.1
April	40.2	40.6	21.9	40.6	35.4
May	44.7	44.5	26.5	45.2	36.7
June	46.0	45.2	32.3	45.8	39.3
July	42.8	41.3	34.3	41.3	39.3
Aug	41.5	40.6	34.3	39.3	39.3
Sep	40.8	39.3	28.4	39.3	38.0

Table 5 (con't): Average Pavement Temperature Month wise in ^{0}C and Latitude of Places

Month	Important Places(^{0}C)*				
	New Delhi	Lucknow	Srinagar	Jaipur	Guwahati
Oct	36.9	36.1	21.3	36.7	36.0
Nov	29.1	28.9	13.5	30.2	31.5
Dec	23.3	23.1	7.0	24.4	25.6
Latitude					
Latitude	28.37	26.55	34.08	26.53	26.11

Note: F=1.8×C+32*

5.0 Analysis of Results

From Table 2, it is observed that both air and pavement temperatures increase gradually from January to June and then decrease from June to December. E value of the bituminous mix is reverse in nature of air / pavement temperature as obtained from Table 3. From Figure 1, it is found that E value of mix with VG 30 bitumen decreases with increasing temperature of mix. Behavior of fatigue strain is similar to that of air/ pavement temperature. Behaviour of Fatigue / rut life of the mixture is similar to E value of mixture. Pavement Life is least value during the month June.

IRC: 37-2012 recommended pavement design at tire pressure 0.560 10^6 N/m^2 with axle load of 80 KN. The proposed compositions carry design traffic of 20 MSA.
When the design is checked with temperature variation of per wise throughout the year, it has been found that the same compositions is capable of sustaining traffic up to 54.6 MSA. Therefore, pavement design has been underestimated or on the other hand a factor of safety 2.7 has been provided in the pavement design. This factor may be checked for other parts of India.

DBM thickness may be reduced to 50 mm for design life of 20 MSA.BC thickness may also be reduced to 30 mm. Following pavement compositions may be proposed for design traffic 20 MSA with subgrade CBR of 10%.

BC=30 mm (Original 40 mm), DBM=50 mm (Original 80 mm), WMM=250 mm

GSB=200 mm

Further study is required for consideration of environmental variation of temperature in Indian condition.

Table 5 may be used to determine pavement thickness for other places of India knowing latitude of the project road. Latest average monthly temperature may be collected from metrological department located near to the project road location. Similar table may be developed for other locations in India and other countries.

6.0 Conclusions

The analysis of the present paper is limited to the particular case study. Therefore, conclusions are very limited and specific and applicable for this case study only. It may be varied for other case studies. On the particular case study, following conclusions may be drawn from the present research work and presented here in:

- Fatigue and rut strain of pavement are varying parabolic shape. Maximum values are found at the month of June.

- Rut / Fatigue life is found parabolic nature and it is minimum at the month of June and highest at December and January.

- *E* value BC / DBM mix decreases with increasing temperature linearly with negative slope.

- The regression equations for the estimations of E Value of bituminous mix, allow the calculation of the required E value for flexible pavements to be made in practical applications with sufficient accuracy within the range of the available data including extrapolation.

- Fatigue life and rut life decrease with increasing tire pressure. Therefore, tire pressure should be minimized as practicable to prevent damage of road. But lower tire pressure damage tire life rapidly.

- Design life with variation of temperature is found 2.7 times more than the design life obtained from conventional method of pavement design.

- Trucks operating with conventional tire pressures can cause significant damage, particularly in the form of cracking and damage can be reduced substantially with reduced tire pressures.

- The reduction in damage by using reduced tire pressures would increase pavement life and reduce maintenance costs significantly and economic benefits may be obtained.

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