Stress Strain Analysis for Prediction of Fatigue Cracking and Rutting in Flexible Pavements

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Abstract— Many studies in the past have been focusing on the behavior of asphalt pavement systems through stress strain approach. This approach has been mainly adopted to arrive at optimum pavement design and to improve its lifespan. This study has focused on the stress strain analysis of flexible pavements using KENPAVETM software. The stress and strain values have been used further to obtain number of repetitions for permanent deformation and fatigue cracking considering the criteria given in IRC: 37-2018. This study has been performed for a three-layered asphalt pavement system subjected to Type-3 vehicle given in IRC: 3-1983. This study may help to arrive at cost effective pavement maintenance strategies and increase the service life of asphalt pavements.

Keywords: Stress Strain, Fatigue Cracking and Rutting

I. Introduction

Flexible pavement systems are subjected to continuous effect of vehicular loads. These vehicular loads cause considerable stress and strains in pavements, which further leads to permanent deformation, fatigue cracking, potholes, raveling, bleeding, shoving etc [1, 2]. There is a need to account for these mentioned distresses to increase the lifespan of flexible pavements and to minimize their maintenance and rehabilitation cost. Various studies have been conducted to analyze the effect of traffic on flexible pavement systems. The analysis from these studies have been performed using various software interfaces such as ANSYS®, ABAQUS®, IITPAVE®, KENPAVE™, BISAR, WESLEA etc. The various distresses have been studied by observing the behavior of different layers of flexible pavement with the help of mechanistic parameters.

The study performed in this paper mainly focus on the stress strain analysis of flexible pavements subjected to vehicular load. The vehicle considered is Type-3 as per IRC: 3-1983 and the analysis is performed in KENPAVE™ software. This analysis will help in determination of number of repetitions pertaining to permanent deformation and fatigue cracking as per IRC: 37-2018.

II. Analysis and Results for Flexible Pavement

The stress strain analysis in KENPAVE™ has been performed for a three-layered asphalt pavement system subjected to a Type-3 vehicle. The asphalt pavement system considered for this study comprises of subgrade (bottom layer), base course (middle layer) and asphalt wearing course (top layer) and the thickness are 200 cm, 25 cm and 10 cm respectively. The material properties for the considered pavement system have been described using elastic modulus and Poisson's ratio and are given in Table 1.The values given in Table 1 are adopted from literature [3].

Sr. No.	Layer	Elastic modulus MPa	Poisson's ratio
1.	Subgrade	52	0.45
2.	Base course	415	0.4
3.	Asphalt wearing course	2175	0.35

Table 1: Material properties of flexible pavement system

The loading for Type-3 vehicle has been considered as per its legal axle limit given in IRC: 3-1983, which is 24 tonnes. The vehicular load has been assumed to be acted on a circular contact area with contact pressure of 0.67 MPa and radius of 23.64 cm and 28.96 cm for front and rear tires respectively. The analysis is performed at selected locations along the depth of pavement, which are 5 cm, 9.999 cm, 10.001 cm, 34.999 cm, 35.001cm and 50cm. The loading is applied separately considering the loading due to front (6 tonnes) and rear (18 tonnes) axle of Type-3 vehicle.
The considered asphalt pavement system has shown certain mechanistic parameter values in the form of stress and strain due to the applied load. The stress and strain values obtained at top of subgrade are tabulated in Table 2.

Load Group	Maximum Stress in Subgrade	Maximum Strain in Subgrade
Single axle	100.919	1.738E-03
Tandem axle	146.621	2.323E-03

Table 2: Maximum and minimum stress-strain in subgrade due to Type-3 vehicle

For the calculation of number of repetitions for fatigue cracking and rutting, the maximum horizontal tensile strain (ε_t) at the bottom of bituminous layer and maximum vertical compressive strain (ε_v) at the top of subgrade are obtained from the calculations performed in KENPAVE™. The fatigue cracking and rutting performance is determined as per the equations given in IRC: 37-2018.

For load group 1 (Front axle of Type 3- single axle with single wheels on both sides):
For 80% reliability:

$$N_f = 1.6064 * C * 10^{-4} * (\frac{1}{\varepsilon_t})^{3.89} * \left(\frac{1}{M_{Rm}}\right)^{0.854} \qquad (2.1)$$

For 90% reliability:

$$N_f = 0.5161 * C * 10^{-4} * (\frac{1}{\varepsilon_t})^{3.89} * \left(\frac{1}{M_{Rm}}\right)^{0.854} \qquad (2.2)$$

In the above equation, the value of $\boldsymbol{\varepsilon_t}$ is 2.764*E-04 (as per KENPAVE™ results) and M_{Rm} =4523 MPa [4], C=$\mathbf{10^{M}}$, M= 4.84*($\frac{V_{be}}{V_a+V_{be}}$ $\mathbf{- 0.69}$), $\boldsymbol{V_a}$ ***and*** $\boldsymbol{V_{be}}$ are assumed as 3% and 8.5% respectively (MS-2, 2014).
Therefore,
$N_f = 14.56\ msa$ (80% reliability)
$N_f = 4.67\ msa$ (90% reliability)

For 80% reliability:

$$N_R = 4.1656 * 10^{-8} \left(\frac{1}{\varepsilon_v}\right)^{4.5337} \quad (2.3)$$

For 90% reliability:

$$N_R = 1.4100 * 10^{-8} \left(\frac{1}{\varepsilon_v}\right)^{4.5337} \quad (2.4)$$

In the above equation, the value of ε_v is 1.738*E-03 (as per KENPAVE™ results)

Therefore, N_R= 0.13 msa (80% $reliability$)

N_R=0.045msa 90% $reliability$)

For load group 2 (Rear axle - Tandem axle):

For 80% reliability:

$$N_f = 1.6064 * C * 10^{-4} * (\frac{1}{\varepsilon_t})^{3.89} * \left(\frac{1}{M_{Rm}}\right)^{0.854} \quad (2.5)$$

For 90% reliability:

$$N_f = 0.5161 * C * 10^{-4} * (\frac{1}{\varepsilon_t})^{3.89} * \left(\frac{1}{M_{Rm}}\right)^{0.854} \quad (2.6)$$

In the above equation, the value of ε_t is 4.222*E-04 (as per KENPAVE™ results) and C=10^M, M= 4.84* $(\frac{V_{be}}{V_a+V_{be}} - 0.69)$, V_a and V_{be} are assumed as 3% and 8.5% respectively [5].

Therefore,

$N_f = 2.8\ msa$ (80% reliability)

$N_f = 0.9\ msa$ (90% reliability)

For 80% *reliability*:

$$N_R = 4.1656 * 10^{-8} \left(\frac{1}{\varepsilon_v}\right)^{4.5337} \quad (2.7)$$

For 90% *reliability*:

$$N_R = 1.4100 * 10^{-8} \left(\frac{1}{\varepsilon_v}\right)^{4.5337} \quad (2.8)$$

In the above equation, the value of ε_v is 2.323*E-03 (as per KENPAVE™ results)

Therefore, N_R = 0.36 msa (80% $reliability$)

N_R=0.012 msa (90% $reliability$)

For predicting the performance of asphalt pavement, the obtained N_f and N_R must be compared to the design traffic. The design traffic is given as follows:

$$N_{Des} = \frac{365*[(1+r)^n - 1]}{r} * A * D * F \quad (2.9)$$

Where,

N_{Des} = Cumulative number of standard axles to be catered for during the design period of ‘n’ years.

A = Initial traffic in the year of completion of construction,

D = Lateral distribution factor,

F = Vehicle damage factor,

n = Design period in years,

r = Annual growth rate of commercial vehicles in decimal.

For determination of N_{Des}, the traffic growth rate is assumed as 7.5%, design period is 20 years, lateral distribution factor is 0.5 (for two lane two way traffic), the present traffic is taken as 10 vehicles per day, the initial traffic is calculated as follows:

$$A = P(1 + r)^x \quad (2.10)$$

Where,

P = number of commercial vehicles per day as per last count.

x = number of years between the last count and the year of completion of construction.

Let x = 2 years, therefore A= 11.55 CVPD

For the calculated initial traffic, the vehicle damage factor is taken as 1.7 from Table 4.2 of IRC: 37-2018. Hence, from the above calculations the design traffic is obtained as 0.155 msa. From the comparison between N_{Des} and N_f, N_R it is observed that for the given pavement design, the number of repetition due to fatigue for load 1 and load 2 exceeds the value of design traffic for 80% reliability. On contrary, the numbers of repetitions for rutting are less than design traffic for load group 1 at both 80 and 90 % reliability. While N_R for load group 2 exceeds design traffic for 80 % reliability but is less than design traffic for 90% reliability.

From the above calculations and discussion, it is inferred that the given pavement should be designed for 90% reliability to arrest rutting. Also it is found that the pavement design is vulnerable to fatigue cracking over its design life.

III. Conclusion

The analysis performed in this study is completely based on assumed values. The motive of this study is to present a methodology for prediction of fatigue cracking and rutting for a given pavement design subjected to a particular type of vehicular load. Hence, it is suggested to perform such analysis with the realistic values obtained from the field data and laboratory experiments.

From the stress strain analysis performed in this study it has been observed that the permanent deformation and fatigue cracking in asphalt pavements needs to be monitored based on N_f and N_R values. These values may help further for the pavement design engineers to arrive at a optimum thickness of asphalt pavements, which may sustain the vehicular loads due to Type-3 and also from another vehicles. This may form the basis to reduce the permanent deformation and fatigue cracking in asphalt pavements in an effective manner. The decrease in these distresses will lead to maintenance of pavement systems in a cost effective manner.

References

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