# Optimization of Bituminous Pavement Thickness using Mechanistic-Empirical Strain-Based Design Approach

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## Abstract

The pavement in this paper has been considered as a three layered system with the top layer of bituminous mix followed by unbound granular layer which rests on soil subgrade. The objective of the paper is to develop an optimization method based on mechanistic –empirical approach for estimation of bituminous and granular layer thickness. Two major modes of failure as rutting and fatigue have been considered for structural design of bituminous road section on strain based criteria. The vertical compressive strain on the top of subgrade and radial tensile strain at the bottom of bituminous layer have been determined by Boussinesq's theory after transforming the three layered system in to a homogeneous system by Odemark's method. The findings from the present study reveals that only one typical combination of bituminous and granular layer thickness is possible to save the pavement both against rutting and fatigue. The result of layer thickness obtained using present methodology was compared with other international published data and was found in good agreement. The pavement deflection as a performance indicator for the optimized pavement section thus obtained have been determined by Odemark's-Boussinesq's approach and compared with the deflection obtained using IITPAVE and KENPAVE software, which show reasonable good convergence.

*Keywords:* Bituminous Layer; Boussinesq's; Compressive Strain; Granular Layer; Odemark; Radial Strain.

## 1. Introduction

Most of the roads in India are flexible pavement which carries lion's share of cargo and passenger traffic of the country. Therefore, the durability of pavement becomes an important issue to reduce the life cycle cost of the pavement. In this backdrop, formulation of a reliable method for estimation of crust thickness in a multilayered bituminous pavement is of primary importance to get a durable structure. So, the reliability of the method of pavement design is important to predict the required thickness of constituent layers in a pavement which can protect it from failure under rutting as well as cracking. It is relevant to mention that the bituminous layer either as a binder or wearing course can be replaced easily by putting an overlay on an existing road but the inadequacy in terms of thickness and strength of the granular layer cannot easily be corrected after the construction of full depth of granular layers during its service life. Keeping this in view, the present paper deals with the formulation of a methodology based on the mechanistic-empirical approach to determine the thickness of the bituminous and granular layer in a flexible road pavement. The cost of construction of granular and bituminous layers in a flexible road pavement is different. Therefore, it is important to predict a choice of optimum thickness of bituminous and granular layer required to protect the pavement against rutting and cracking both for high volume and low volume roads with weak as well as

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the strong subgrade. In this context , the present paper deals with the development of an optimization model of thickness design for conventional flexible road pavement using Odemark's and Boussinesq's method [1, 2] often referred to as a Method of the Equivalent Thickness (MET).

## 2. Literature Review

Ghanizadeh (2016) [3] reported an optimization technique of flexible pavement thickness considering economical and functional requirements. The study reveals that the use of asphalt layer in pavement should be kept as minimum as possible from the cost aspect, whereas sub-base layer may be avoided in the optimum section of pavement if the subgrade strength is reasonably high. Saridee et al. [4] established a reliability-based thickness design optimization process to incorporate rutting and cracking as a failure mode. A sensitivity analysis shows the effect of thickness and resilient modulus of the bituminous layer is significant on fatigue failure whereas the same has little significance on rutting. Rajbongshi et al. [5] presented a typical pavement design approach for optimal pavement design thickness, which is cost-effective and safe from reliability considerations. Maji et al. [6] proposed a simulation and analytical-based methodology on the variability of pavement design input parameters with different reliability levels for various failure definitions of a given pavement. The study depicts that the thickness of the bituminous surface layer is the most sensitive parameter both under fatigue and rutting failure. Li et al. [7] performed a sensitivity analysis of performance for flexible pavement, which can be used for the optimization of design and performance evaluation of the pavement structure. Peddinti et al. [8] studied the accuracy of the reliability-based design optimization technique using the appropriate probability density function for design parameters associated with flexible pavement design and to optimize the reliability index. Tsiknas et al. [9] carried out a study to propose a cost-optimal design method by comparing the Asphalt Institute method, British method, and EgnatiaOdos (EO) methods.

Narasimham et al. [10] developed an optimization technique to find structurally as well as cost-wise optimum flexible pavement section using the principle of elastic layered analysis based developed software FPAVE using direct search method and a gradient method. Dalla Valle and Thom [11] suggested an alternative model to improve the accuracy of Odemark's (MET) method through a comparative analysis of a three-layer pavement system analyzed by BISAR software and MET method which shows that the rutting strain is in good agreement with BISAR whereas the fatigue strain varied ±10%. Huang et al. [12] developed an analytical tool for modern pavement evaluation and design, by providing realistic data in the long-term planning of pavement based on the two-dimensional (2D) axisymmetric Finite Element Method (FEM). The proposed method also eliminates the constraint of a different kind of assumption related to pavement design by incorporating material characteristics layer-wise including cross anisotropic behavior, elastic behavior of unbound aggregate layers, subgrade soils, and viscoelastic behavior of hot mix asphalt. Eberhardsteiner and Blab [13] developed a mechanistic approach for the design of bituminous pavements in Austria to resolve the limitations like the inclusion of performance-related material characteristics or detailed traffic load. The proposed approach ensures a modern, performance-based and economic pavement design. Sabbagh Moghadam and Hadiani [14] studied the effect of lime and cement on compressive strength and CBR values of construction demolition and excavated materials and found appreciable improvement on the said properties. A plate load test has also been carried out on the bed constructed with demolition material. The enhanced CBR value may be used for the optimization of granular unbound layers to be used for flexible pavement construction and thereby proper recycled material can be made. Torio-Kaimo [15] presented a method based on the ME-PDG guide for pavement design used in the Philippines.

This method was initially analyzed based on AASHTO 1993 design and all the results were then compared and adjusted as evaluated with the proposed ME-PDG method. The study concluded that the ME-PDG yielded results found to be more realistic and conservative in comparison with AASHTO 1993 design guide. Luo et al. [16] reported a robust pavement design approach that includes the influence of uncertainties of pavement material to predict the fatigue and rutting life through a rational adjustment of the design parameters. The developed method makes uses of a genetic algorithm and a marginal function to meet the requirements of safety, robustness, and cost and is demonstrated through a case study. Bueno et al. [17] carried out a study on the characterization and verification of fatigue behavior of four test sites with dense asphalt in Santa Maria, Brazil using field monitoring, linear viscoelastic characterization, uniaxial cyclic fatigue testing, the simplified VECD (S-VECD) model and Flex PAVE and fatigue damage transfer function. The study revealed that the proposed methodology can predict fatigue damage by identifying early cracking which could be minimized by using increased asphalt thickness. An improved cost/ benefit ratio considering fatigue criteria was also realized applying the adopted methodology. Santos and Ferreira [18] presented an optimum pavement design method namely OPTIPAV considering performance, construction costs, maintenance and rehabilitation costs, user costs, the residual value of the pavement at the end of the project analysis period along with preventive maintenance and rehabilitation interventions. Obtained results show that it may be a valuable addition to the road engineer's toolbox. Ameri and Khavandi [19] developed a Mechanistic-Empirical (M-E) design procedure based on the KENLAYER software algorithm considering Iran's climatic and traffic conditions. The study also revealed the relationships and diagrams based on an effective variable that facilitates the design process of flexible pavement

design. AASHTOWare [20] are is a comprehensive ME pavement design software based on NCHRP mechanistic-empirical pavement design guide. It calculates pavement responses (stresses, strains, and deflections) based on traffic, climate, and materials parameters to predict the progression of key pavement distresses and smoothness loss over time for asphalt concrete (AC) and Portland cement concrete (PCC) pavements. This state-of-the-practice tool represents the current advancements in pavement design which provides tools to optimize pavement designs based on given requirements allowing the user to evaluate and fine-tune the design. Moreover, the database utility allows facilitates to reuse and save of final designs along with individual input pavement design parameters, which can be used for future designs as well as detection of distress, performance analysis, and pavement management in long term.

## 3. Proposed Model of Pavement Design

In this paper, the pavement has been characterized as a three-layer system as shown in Figure 1. The top layer of the pavement consists of a bituminous mix with thickness h1 and resilient modulus $E_1$, followed by an unbound granular layer of thickness $h_2$ and elastic modulus $E_2$, which are resting on a subgrade with an elastic modulus of $E_3$. Mechanistic- empirical design of flexible road pavement is based on limiting the radial tensile strain at the bottom of the bituminous layer to resist fatigue failure and vertical compressive strain at the top of the subgrade layer to resist rutting. It is to be noted in Figure 1 that, the radial tensile strain at the bottom of the bituminous layer at point A or the vertical compressive strain at the top of the subgrade layer at point B will depend on the thickness and modulus of constituent layers in flexible road pavement. Therefore, multiple combinations of the thickness of the bituminous layer ($h_1$) and granular layer ($h_2$) are theoretically possible for an allowable radial tensile strain or the vertical compressive strain. So, an increase in resilient modulus and thickness of constituent layers in a flexible road pavement reduces the critical strains in the bituminous layer and subgrade. Mechanistic –empirical design guidelines (IRC -37-2012) [21] show that the allowable radial strain depends on the resilient modulus of the bituminous mix and the axle load repetitions on the pavement (Equation 1) whereas the allowable vertical compressive strain depends only on the axle load repetitions before failure (Equation 2 ). Therefore, attempts are made in this paper to determine the variation of $h_1$ and $h_2$ by limiting the radial tensile strain at the bottom of the bituminous layer and the vertical compressive strain at the top of the subgrade layer. The point of intersection of the line diagrams showing the variation of $h_1$ and $h_2$ from fatigue as well as rutting criteria will indicate the optimum thickness of the pavement from both failure criteria.
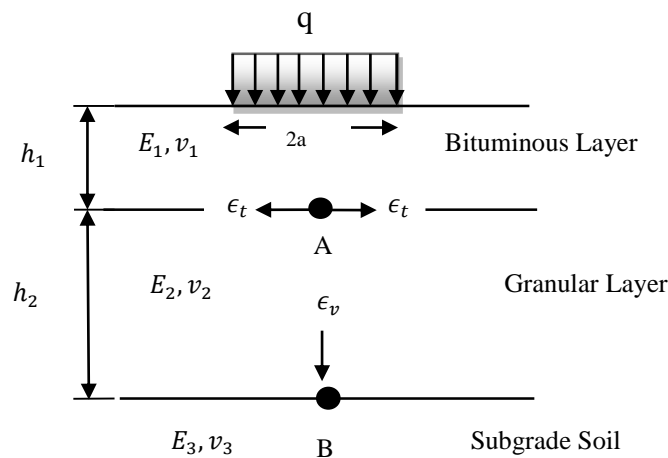


**Figure 1. Typical bituminous pavement section in a three-layer system**

$$N_f = 2.21 \times 10^{-04} \times \left[\frac{1}{\varepsilon_t}\right]^{3.89} \times \left[\frac{1}{M_R}\right]^{0.854} \tag{1}$$

Where; $N_f$ = Fatigue life in the number of cumulative standard axles, $\epsilon_t$= Maximum tensile strain at the bottom of the bituminous layer, and $M_R$= Resilient modulus of the bituminous layer (MPa).

$$N_r = 1.41 \times 10^{-08} \times [\epsilon_v]^{-4.5337} \tag{2}$$

Where $N_r$ = Number of cumulative standard axles before rutting failure, and $\epsilon_v$= Maximum vertical compressive strain on the top of the subgrade.

However, to determine the strains at critical locations in pavement using Boussinesq's approach, the multi-layered system of pavement needs to be transformed using Odemark's method. The critical strains thus obtained using Boussinesq's theory at different layer interfaces for a standard axle load have been made equal to the allowable strain obtained from M-E design criteria to establish the correlation between $h_1$ and $h_2$. The methodology followed in this

paper to estimate the layer thickness in bituminous road pavement has been illustrated in Figure 2.

### 3.1. Indicative Flow Chart of Proposed Methodology

The methodology followed for design and optimization of pavement section have been illustrated below by a flow diagram.
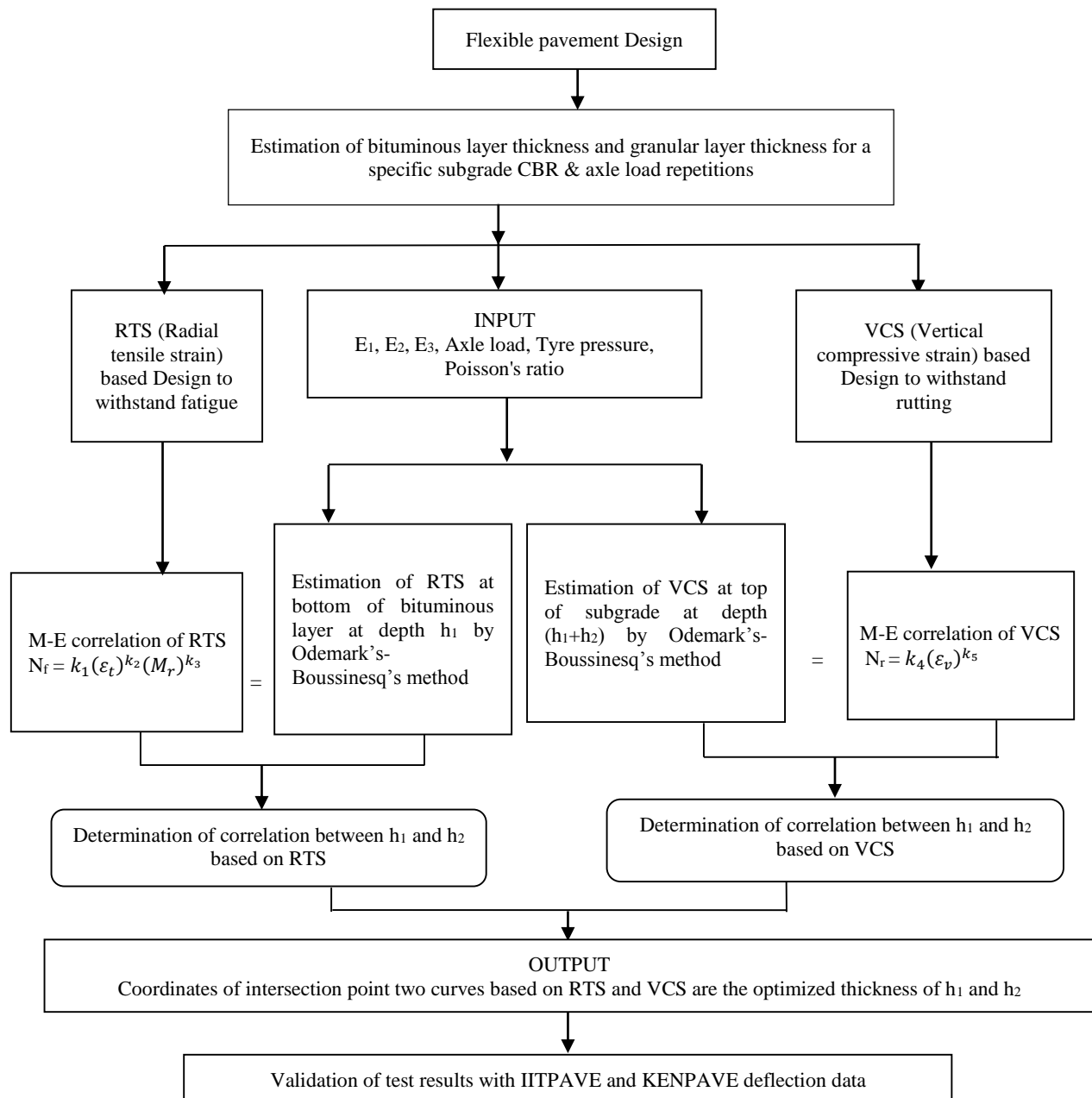
Flexible pavement Design

Estimation of bituminous layer thickness and granular layer thickness for a specific subgrade CBR & axle load repetitions

RTS (Radial tensile strain) based Design to withstand fatigue

INPUT
$E_1$, $E_2$, $E_3$, Axle load, Tyre pressure, Poisson's ratio

VCS (Vertical compressive strain) based Design to withstand rutting

M-E correlation of RTS
$N_f = k_1(\varepsilon_t)^{k_2}(M_r)^{k_3}$

Estimation of RTS at bottom of bituminous layer at depth $h_1$ by Odemark's-Boussinesq's method

Estimation of VCS at top of subgrade at depth $(h_1+h_2)$ by Odemark's-Boussinesq's method

M-E correlation of VCS
$N_r = k_4(\varepsilon_v)^{k_5}$

Determination of correlation between $h_1$ and $h_2$ based on RTS

Determination of correlation between $h_1$ and $h_2$ based on VCS

OUTPUT
Coordinates of intersection point two curves based on RTS and VCS are the optimized thickness of $h_1$ and $h_2$

Validation of test results with IITPAVE and KENPAVE deflection data

**Figure 2. Flow diagram of the adopted methodology**

### 3.2. Odemark's Transformation

It has to be noted that Odemark's method of equivalent layer thickness (MET) has been widely used for pavement response analysis and FWD back-calculation. Ullidtz (1998) [29] reported pavement responses in terms of stress, strain, and deflection calculated by the method of equivalent thickness using Boussinesq's Equations are in good agreement with the results obtained using CHEVRON (Elsym5) [22] computer program. Zhang and Macdonald [23] concluded that the horizontal strains at the bottom of the asphalt layer when calculated with Odemark's method (MET), the linear elastic method [24-28] (LET) and the Finite Element Method (FEM) could be seen to match the measured values. Therefore, the concept of MET used in this paper is effective to predict the strains and stresses in pavement layers. In the present work, the three-layer system has been transformed into a homogeneous system by application of Odemark's method [1] which assumes that the stress or strain below a layer depends on the stiffness of

that layer only. If the thickness, modulus, and poisons ratio of layers is changed but the stiffness remains unchanged the stress and strains below the layer should also remain unchanged. The transformation of a two-layered system into a homogeneous system can be done in the manner shown in Figure 3.
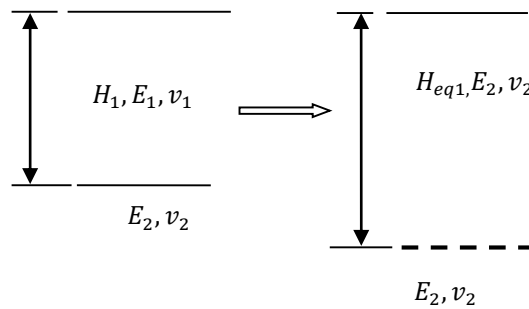


**Figure 3. Transformation of a two-layered system by Odemark's method**

The two-layer system with the modulus of $E_1$ with thickness $h_1$ and Poisson's ratio $v_1$ as top layer resting on the bottom layer with the modulus of $E_2$ and Poisson ratio of $v_2$. Transformation of such a two-layered system may be done with the concept of an equivalent thickness ($H_{eq1}$) with an elastic modulus ($E_2$) and can be expressed as:

$$H_{eq1} = f H_1 \sqrt[3]{\frac{E_1}{E_2} \times \frac{(1-v_2^2)}{(1-v_1^2)}} \qquad (3)$$

Where $H_{eq1}$ is termed as equivalent thickness and f = Odemark's correction factor, which ranges from 0.8 to 1.0.

### 3.3. Model-based on Fatigue Failure

In the present analysis, to determine the radial tensile strain at point A in Figure 1, the top bituminous layer and the second layer consists of unbound granular materials have to be transformed using Odemark's method. Considering the poisons ratio of all the layers are 0.35, the equivalent layer thickness (heq1) for the top two layers may be expressed as:

$$z_1 = h_{eq1} = f h_1 \sqrt[3]{\frac{E_1}{E_2}} \qquad (4)$$

In the present paper, the value of elastic modulus of the granular layer ($E_2$) has been obtained using Equation 5 as recommended by Powell et al (1984) and the elastic modulus ($E_3$) of subgrade soil has been estimated by the formulation recommended by (Brown et al.1990, Lister and Powel 1987) [30] in Equations 2 and 3:

$$E_2 = 0.2(h_2)^{0.45} E_3 \quad (MPa) \qquad (5)$$

Where $h_2$ = thickness of the granular layer in mm.

$E_3$= 10 * CBR in MPa for CBR ≤ 5%. $\qquad (6)$

$E_3$= 17.6 * (CBR) $^{0.64}$ in MPa if CBR > 5% $\qquad (7)$

Where CBR is the California bearing ratio of subgrade.

The resilient modulus of the bituminous mix ($E_1$) has been considered in this analysis as 1700 MPa which has been recommended in IRC: 37-2012 [21] for use of Bituminous Concrete (BC) and Dense Bituminous Macadam (DBM) as binder course with VG30 bitumen at 35°C.In this paper, a tire pressure (q) as 0.56 MPa has been assumed to act on pavement surface with a circular contact area with radius (a) of 155 mm corresponding to a standard axle load of 80 kN. However, using the value of E2 as explained in Eq. and considering the value of f as 1.0 for the bituminous and granular layer interface, Equation 4 may further be modified as in Equation 8:

$$z_1 = h_{eq1} = h_1 \sqrt[3]{\frac{E_1}{0.2 \times h_2^{0.45} \times E_3}} \qquad (7)$$

Where $z_1$ = Equivalent depth of the pavement layer in a two-layered system.

However, according to Boussinesq's theory, the radial strain at a depth (z) in a homogenous, elastic, and isotropic medium due to a uniform circular load at the surface with contact radius (a) and uniform load intensity (q) has been expressed Equation 9.

$$\varepsilon_t = \frac{(1+v) \times q}{2E_2} \times \left[ \frac{-\frac{z_1}{a}}{\left\{ \sqrt{1+\left(\frac{z_1}{a}\right)^2} \right\}^3} - (1-2v) \times \left\{ \frac{\frac{z_1}{a}}{\sqrt{1+\left(\frac{z_1}{a}\right)^2}} - 1 \right\} \right] \tag{8}$$

The radial tensile strain thus obtained from Equation 9 should not be more than the allowable strain recommended in Equation 1. Therefore, solving Equations 1 and 9, the correlation between $h_1$ and $h_2$ can be established. The combination of the thickness of the bituminous layer ($h_1$) and granular layer ($h_2$) thus obtained from the present analysis characterizes the thickness against fatigue failure. In the present analysis, the axle load repetitions are considered from 2-150 msa whereas the subgrade CBR of 3, 5 and 10% have been considered. Similarly, another set of combinations of $h_1$ and $h_2$ can be determined from a failure of pavement under rutting criteria and has been illustrated in the next section.

### 3.4. Model-based on Rutting Failure

To determine the vertical compressive strain on the top of the subgrade, the principle of transformation of the two-layer system recommended by Odemark can further be used to transform the multilayer system into a homogeneous medium by successive transformation. The transformation of the three-layer system has been shown in Figure 4 by the successive transformation of pavement layers starting from the bituminous layer at the top to the subgrade at the bottom.

In the present analysis, the top two layers with the respective elastic modulus of $E_1$ and $E_2$ have primarily been transformed by an equivalent thickness of $h_{eq1}$ as shown in Figure 4(b). Similarly, the transformation of layers with an elastic modulus of $E_2$ and $E_3$ have been made in this analysis by an equivalent thickness of $h_{eq2}$ with an elastic modulus of $E_3$ which characterizes a homogeneous system as shown in Figure 4(c).
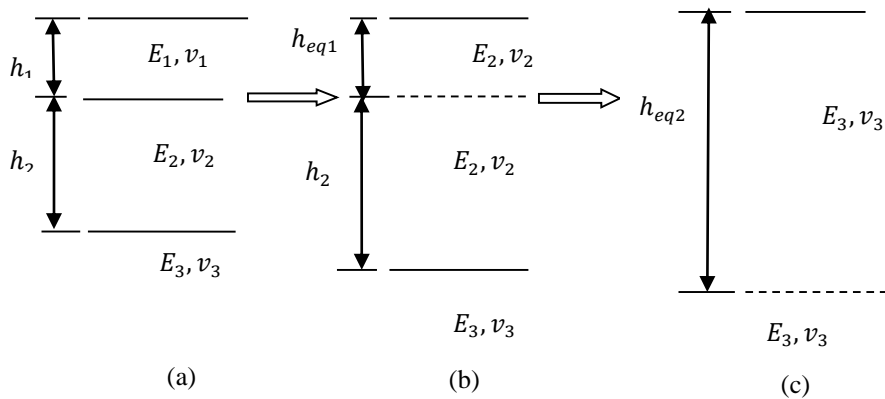


**Figure 4. Successive transformation of a three-layered system using Odemark's method**

The equivalent thickness of $h_{eq2}$ thus explained may be expressed in Equation 10 by using Odemark's method.

$$z_2 = h_{eq2} = f_1 \left[ fh_1 \sqrt[3]{\frac{E_1}{0.2 * h_2^{0.45} * E_3}} + h_2 \right] \times \sqrt[3]{\frac{E_3}{0.2 * h_2^{0.45} * E_3}} \tag{10}$$

Where $f_1$ is the Odemark's correction factor for subgrade–base interface, which has been considered as 0.8 as recommended by El-Badawy and Kamel [31].

According to Boussinesq's theory, the vertical compressive strain at a depth (z) in a homogenous, elastic, and isotropic medium due to a uniform circular load at the surface with contact radius (a) and uniform load intensity (q) has been expressed in Equation 11.

$$\varepsilon_t = \frac{(1+v) \times q}{E_3} \times \left[ \frac{\frac{z_2}{a}}{\left\{ \sqrt{1+\left(\frac{z_2}{a}\right)^2} \right\}^3} - (1-2v) \times \left\{ \frac{\frac{z_2}{a}}{\sqrt{1+\left(\frac{z_2}{a}\right)^2}} - 1 \right\} \right] \tag{11}$$

If the vertical compressive strain on the top of the subgrade calculated using Equation 11 is made equal to the allowable compressive strain as shown in Equation 2, the solution of two simultaneous equations will establish the correlation between $h_1$ and $h_2$. The correlation thus obtained for variation of bituminous layer thickness ($h_1$) and granular layer thickness ($h_2$) characterizes the constituent layer thickness against rutting. In the present section of the analysis, the range of axle load repetitions and the subgrade CBR have been kept the same as those used in the estimation of pavement thickness using fatigue criteria.

### 3.5. Optimization of Bituminous and Granular Layer Thickness

The correlations between $h_1$ and $h_2$ obtained against fatigue as well as rutting have been presented in Figure 5 to Figure 7. Those figures represent the variation of bituminous layer thickness ($h_1$) and granular layer thickness ($h_2$) corresponding to indicative subgrade CBR of 3, 5, and 10% to study the effect of low, medium, and high strength of subgrade on pavement thickness. The range of variation of bituminous layer thickness ($h_1$) has been considered in between 0-350 mm whereas the range of variation of granular layer thickness ($h_2$) has been considered in between 0-1000 mm. It is evident from those figures that an increase in granular layer thickness ($h_2$) reduces the requirement of bituminous layer thickness ($h_1$) and vice versa. However, the rate of change of $h_1$ concerning $h_2$ was found higher in rutting than fatigue. The curves representing a differential rate of change of $h_1$ and $h_2$ both under rutting and fatigue were found to intersect each other. The intersection point thus obtained emphasizes the rationality of optimization of pavement thickness both from rutting and fatigue failure of the pavement. Therefore, the coordinates of the intersection point of two curves thus obtained characterize the thickness of the bituminous layer ($h_1$) and granular layer ($h_2$), which are safe for both in terms of fatigue and rutting. The thickness of the bituminous layer and granular layer thus obtained have been termed in this paper as optimized pavement thickness and are reported in Table 1.0 to Table 3.0. The tables under consideration represent the optimized pavement thickness in terms of bituminous and granular layers for axle load repetitions ranging from 2 to 150 msa.

## 4. Results and Discussion

It has been found from the present analytical study that the thickness of the granular layer required against rutting and fatigue increases with the decrease in bituminous layer thickness and vice versa. It has been observed in Figures 8 to 10 that the gradient of variation of bituminous layer thickness is much higher in rutting than fatigue. However, the rate of change of bituminous layer thickness was significantly less with the increase in thickness of granular layer under fatigue failure. The correlation between the bituminous layer and granular layer under fatigue shows that the change in the thickness of the bituminous layer becomes less significant after exceeding the granular layer thickness of 150 mm. The trend of variation of the curve thus emphasizes the granular layer thickness as a more sensitive parameter than the thickness of a bituminous layer on pavement performance under rutting. Therefore, the optimum thickness of the pavement section in terms of the bituminous and granular layer will be the coordinates of the intersection point of the curves shown in Figure 5 to Figure 7. The bituminous and granular layer thickness thus obtained using the present approach corresponding to different subgrade strength (CBR) and axle load repetitions have been presented in Figures 8 to 10. Such variation of pavement thickness against axle load repetitions was found significant up to 50 msa load.

Pavement deflection is often considered an indicator of pavement performance. Therefore, attempts are made in this paper to validate the thickness of pavement obtained from the present analytical method with other comparable formulations using deflection data. The deflection in all the layers of the pavement has been determined by the theory of elasticity and plasticity after transformation of respective layers into a homogeneous section by application of Boussinesq's - Odemark's method as explained earlier in this paper. The deflections on pavement obtained from different models were estimated with a dual wheel load of 40 kN and tire pressure of 0.56 MPa. The deflection estimated for the optimized pavement section obtained using the present approach were compared with the deflection obtained using IITPAVE and KENPAVE software and are presented in Table1 to Table 3 for comparative study. The axle load repetitions in this paper was ranged between 2-150 msa for estimation of pavement deflection on subgrade CBR of 3, 5, and 10%. It is evident from the data presented in Tables 1 to 3, that, there is a significant level of convergence of deflection data obtained from different methods under consideration with different axle loads and different subgrade strength.

Narasimham et al. [10] developed an optimization technique to determine an optimum thickness of structurally safe and cost-effective pavement section based on the principle of elastic layered analysis using FPAVE software. In this backdrop, the result obtained from the present analytical approach was compared with the results obtained by Narasimham et al. (2001) [10] and Ghosh [32] in Table 4. The limited data available for comparison from those references further reveal the convergence of deflection data with the present pavement design method for different axle loads on the different subgrade.

It is to be noted that, the present method assumes the elastic modulus of constituent layers in a pavement remains unchanged till the failure of the pavement. Moreover, the material behaviour in the present model has been considered linear elastic in nature which is not the real characteristics of granular bound or unbound materials. Therefore, the incremental variation in the modulus of pavement under its service life need to be considered in the future for a more accurate estimation of pavement thickness.

**Table 1. Comparison of deflection value obtained from Present analysis, IITPAVE and KENPAVE for 3% subgrade CBR**

| Axle Load repetition (msa) | Bituminous layer thickness ($h_1$) (mm) | Granular layer thickness ($h_2$) (mm) | Deflection for 3% subgrade CBR | | |
|---|---|---|---|---|---|
| | | | Present analysis (mm) | IIT PAVE (mm) | KENPAVE (mm) |
| 2 | 129 | 360 | 1.12 | 1.15 | 1.09 |
| 5 | 150 | 378 | 0.99 | 1.03 | 0.98 |
| 10 | 162 | 410 | 0.92 | 0.95 | 0.91 |
| 20 | 183 | 420 | 0.84 | 0.88 | 0.81 |
| 30 | 193 | 425 | 0.81 | 0.84 | 0.78 |
| 50 | 205 | 451 | 0.77 | 0.80 | 0.74 |
| 100 | 229 | 470 | 0.69 | 0.73 | 0.65 |
| 150 | 238 | 490 | 0.66 | 0.70 | 0.62 |

**Table 2. Comparison of deflection value obtained from Present analysis, IITPAVE and KENPAVE for 5% subgrade CBR**

| Axle Load repetition (msa) | Bituminous layer thickness ($h_1$) (mm) | Granular layer thickness ($h_2$) (mm) | Deflection for 5% subgrade CBR | | |
|---|---|---|---|---|---|
| | | | Present analysis (mm) | IIT PAVE (mm) | KENPAVE (mm) |
| 2 | 104 | 315 | 0.90 | 0.91 | 0.87 |
| 5 | 128 | 315 | 0.80 | 0.81 | 0.76 |
| 10 | 145 | 330 | 0.73 | 0.74 | 0.70 |
| 20 | 160 | 348 | 0.67 | 0.69 | 0.65 |
| 30 | 170 | 350 | 0.65 | 0.66 | 0.62 |
| 50 | 188 | 360 | 0.60 | 0.62 | 0.58 |
| 100 | 204 | 386 | 0.56 | 0.57 | 0.54 |
| 150 | 218 | 390 | 0.54 | 0.55 | 0.50 |

**Table 3. Comparison of deflection value obtained from Present analysis, IITPAVE and KENPAVE for 10% subgrade CBR**

| Axle Load repetition (msa) | Bituminous layer thickness ($h_1$) (mm) | Granular layer thickness ($h_2$) (mm) | Deflection for 10% subgrade CBR | | |
|---|---|---|---|---|---|
| | | | Present analysis (mm) | IIT PAVE (mm) | KENPAVE (mm) |
| 2 | NA | NA | NA | NA | NA |
| 5 | 98 | 290 | 0.68 | 0.68 | 0.65 |
| 10 | 120 | 290 | 0.62 | 0.61 | 0.59 |
| 20 | 142 | 290 | 0.56 | 0.56 | 0.54 |
| 30 | 151 | 300 | 0.53 | 0.54 | 0.51 |
| 50 | 165 | 310 | 0.50 | 0.51 | 0.47 |
| 100 | 186 | 320 | 0.46 | 0.47 | 0.44 |
| 150 | 197 | 328 | 0.44 | 0.45 | 0.42 |

**Table 4. Comparison of pavement depth obtained from different design approaches**

| ESAL (msa) = 30 | Pavement thickness | | ESAL (msa) = 50 | Pavement thickness | |
|---|---|---|---|---|---|
| Subgrade modulus (MPa) = 50 | Bituminous layer (mm) | Granular layer (mm) | Subgrade Modulus (MPa) = 30 | Bituminous layer (mm) | Granular layer (mm) |
| Narasimham, K.V. et al (2001) | 180 | 370 | Ghosh (2005) | 210 | 410 |
| Present analysis | 200 | 355 | Present analysis | 205 | 451 |

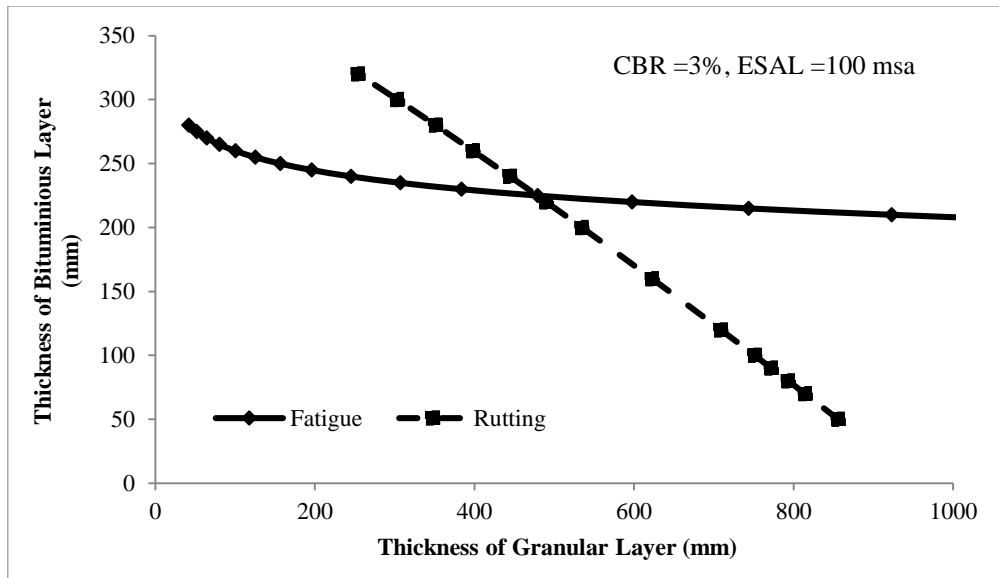msa** =Million standard axle

**Figure 5. Variation of bituminous and granular layer thickness under fatigue and rutting**
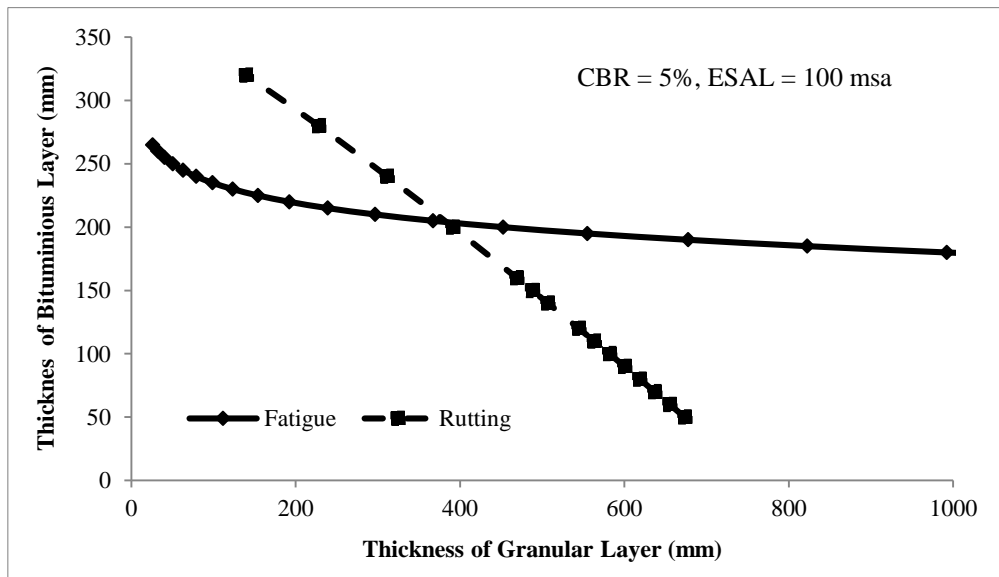


**Figure 6. Variation of bituminous and granular layer thickness under fatigue and rutting**
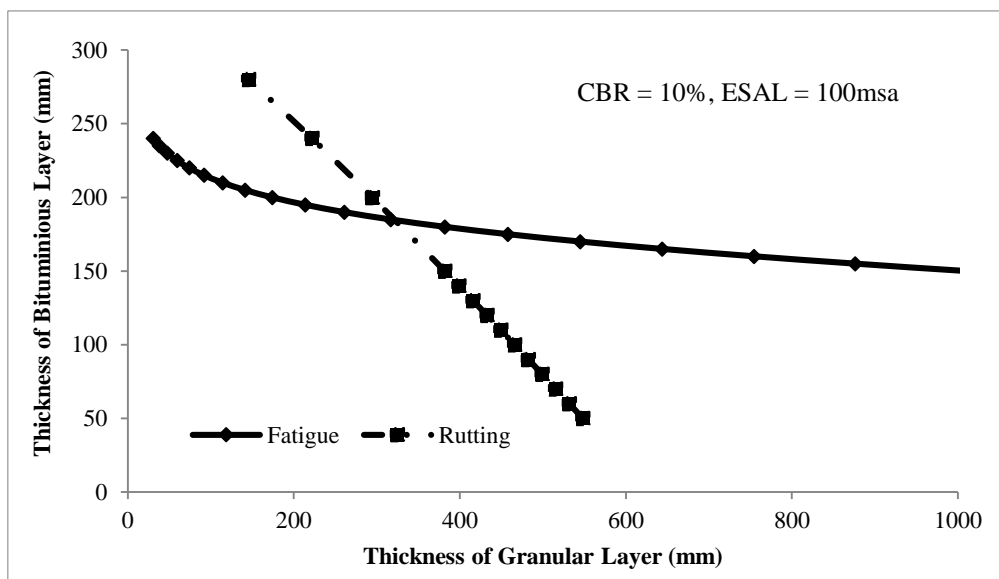


**Figure 7. Variation of bituminous and granular layer thickness under fatigue and rutting**
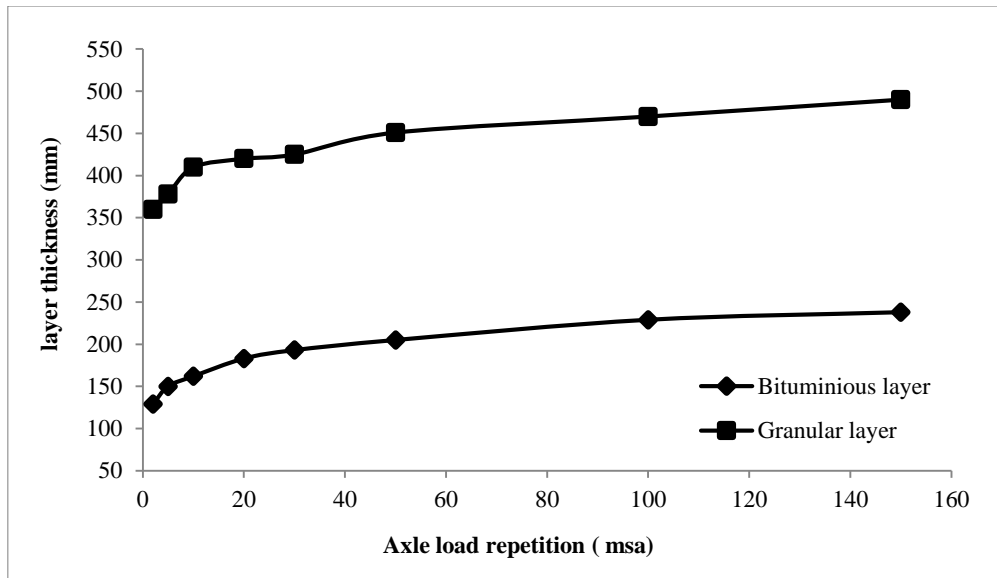
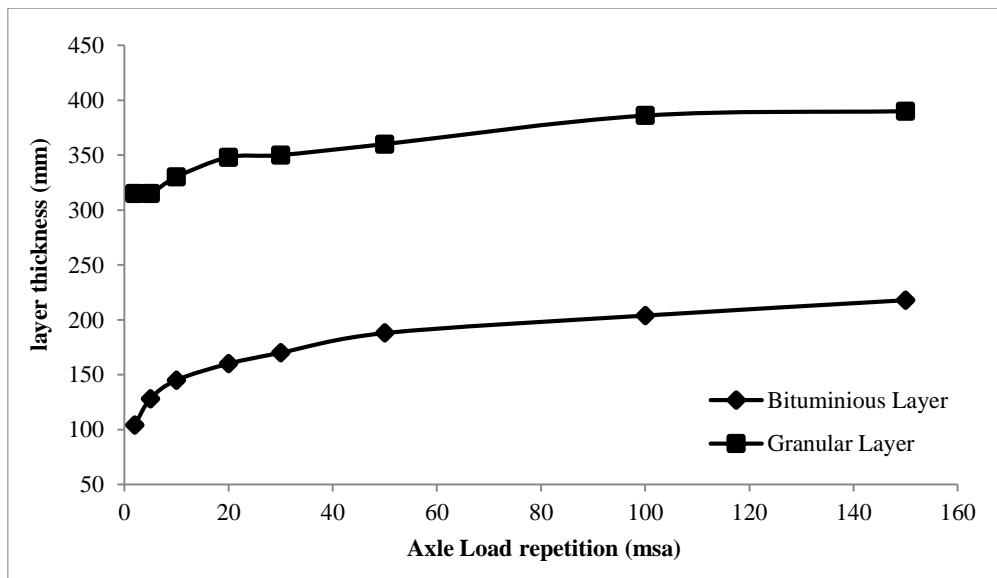**Figure 8. Variation of layer thickness with axle load for 3% Subgrade CBR**



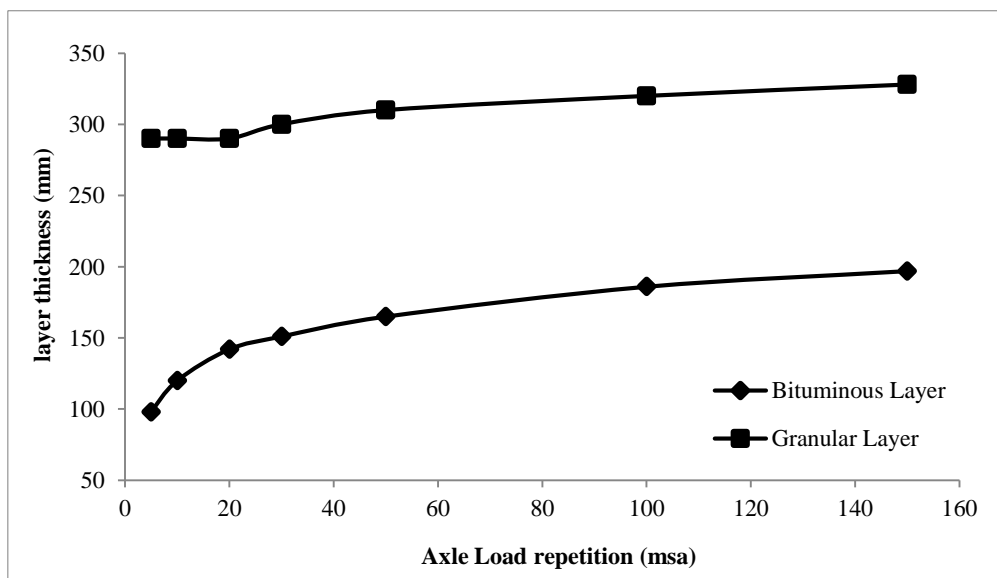**Figure 9. Variation of layer thickness with axle load for 5% Subgrade CBR**



**Figure 10. Variation of layer thickness with axle load for 10% Subgrade CBR**

## 5. Conclusion

In this paper, two major modes of failure as rutting and fatigue have been considered for structural design of bituminous road pavement on strain based criteria. So, different combinations of bituminous and granular layer are possible against fatigue or rutting in a bituminous road pavement for a specified axle load repetitions. But the findings from the present study reveals that only a typical single combination of bituminous and granular layer thickness is possible to save the pavement section both against rutting and fatigue for a specified axle load repetitions.

It has been found in this study that the variation of granular layer thickness is more sensitive than the bituminous layer thickness on pavement performance in terms of rutting than cracking. The rate of increase in bituminous layer thickness was found to be less with the changes in axle load repetitions beyond 50 msa. However, the variation of granular layer thickness with axle load repetitions was found reasonably higher for lower subgrade CBR than the subgrade with higher CBR. But the variation of bituminous layer thickness was found to increase significantly with increase in axle load repetitions for subgrades with lower to higher CBR.

The comparative analysis of pavement thickness thus obtained using present methodology with other findings based on mechanistic-empirical approach show a reasonable degree of convergence. Moreover, the methodology presented in this paper may further be used to estimate the thickness of wearing course, binder base, granular base and sub base with different mix and modulus. The deflection of the pavement section determined using present method were compared with results obtained for similar sections using KENPAVE and IITPAVE software have been found good in agreement , which in other way establishes better reliability of present method of pavement design.

## 6. Declarations

### 6.1. Author Contributions

Conceptualization, M.K.S. and P.P.B.; methodology, M.K.S. and P.P.B.; formal analysis, M.K.S. and P.P.B.; writing—original draft preparation, M.K.S. and P.P.B.; writing—review and editing, M.K.S. and P.P.B. All authors have read and agreed to the published version of the manuscript.

### 6.2. Data Availability Statement

The data presented in this study are available in article.

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The authors received no financial support for the research, authorship, and/or publication of this article.

### 6.4. Conflicts of Interest

The authors declare no conflict of interest.

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