Economic and environmental benefits of thin bituminous surface pavements over thick bituminous surface pavements

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Abstract. The design of bituminous pavements, using mechanistic-empirical design method, involves the selection of thicknesses of the bituminous layer and the granular layers to keep the strains at critical locations of the pavement structure within the allowable limits arrived from performance equations. The tensile strain under the bituminous layer defines the fatigue life, and compressive strain on top of the subgrade defines the rutting life of the pavement based on the performance equations adopted. It is generally considered that increasing the thickness of the bituminous layer decreases the strain at the bottom of bituminous (binder) layer. So, most of the pavement designers increase the thickness of the bituminous layer to restrict the strains. However, this is not always true. In fact, the tensile strain at the bottom of the bituminous layer increases with the increase in the thickness of bituminous layer up to a critical thickness and then slowly starts decreasing as the thickness further increases. The critical thickness of bituminous layer ranges between 50 mm and 100 mm. In the majority of the cases, the critical tensile strain under the bituminous layer corresponding to the thicknesses of the bituminous layers of 25 mm and 200 mm are very close. Apart from the economy, the problem of mix rutting is greatly minimized in the case of thin bituminous surfacing (TBS). The issues in rehabilitation and recycling of pavement materials are very less as the granular layer can be reused without much processing requirements.

Keywords: critical locations, tensile strain, fatigue, rutting;

1. Introduction
Most of the Indian highways and the majority of the urban roads are bituminous pavements, due to their ease of construction and repair. The urban roads are designed for 10-20 MSA traffic depending on the requirements. The flexible pavement design is done, in India, as per IRC: 37 guidelines [1]. All the revisions of IRC: 37 in the past two decades were based on mechanistic-empirical pavement design principles [1, 2, 3]. In the IRC method, the design of pavement structure involves the selection of thicknesses of different layers to keep the strains at critical locations within the limits as calculated using the performance equations adopted for predicting the fatigue life and rutting life and the failure criteria. However, the selection of thicknesses of different layers can have many possible combinations satisfying the design criteria and hence selecting one combination of layers’ thicknesses by trial and error method is difficult. So, the pavement engineers generally try to fix the thickness of granular layers and vary the thickness of the bituminous layer to match the limiting strains. A similar approach was presented in the design charts given in IRC: 37-2001 onwards, only for the convenience of the pavement engineer. This approach leads to the pavement designs with varying thickness of bituminous layers depending on the traffic levels, keeping the granular layers’ thickness constant.
2. Problem definition
Majority of the pavement designers are giving higher importance to the bituminous layer and lower importance to the granular layer in designing a flexible pavement. This is leading to pavements being designed with the thicker bituminous layer. However, the same pavement performance can be obtained with a thin bituminous layer and thick granular layer at an economical cost of construction. This type of pavement has better qualities in terms of scope for future strengthening and material reusability. The present paper attempts to show that thin bituminous pavements are economical and ideal in places where sufficient quantity of aggregate is available for use. The environmental benefits of the thin bituminous surfacing are also discussed.

3. Methodology
To highlight the advantages of thin bituminous surface pavements, strains at critical locations were calculated for a set of bituminous layer and granular layer thickness combinations, and fatigue and rutting lives were estimated based on these strain values. A subgrade layer’s elastic modulus of 70 MPa and bituminous layer’s elastic modulus of 1700 MPa (corresponding to dense bituminous macadam mix with VG30 binder as per IRC: 37 – 2012 [2]) are considered for the study. The granular layer modulus varies depending on the thickness of the granular layer for a given subgrade modulus. The critical strain locations and the typical pavement structure with dual wheel load are presented in Figure 1 along with the commonly used notations representing the layer thickness and modulus values.

![Diagram](image)

**Figure 1. Critical strain locations considered in flexible pavement design**

The sub grade’s modulus of resilience is considered to be 70MPa (CBR is close to 9%) and elastic modulus of the granular layer is estimated based on the sub grade’s modulus of resilience using Equation 1 given in IRC: 37 [1,2].

\[
E_{\text{granular layer}} = 0.2 \times 10^{0.45} E_{\text{subgrade}} \tag{1}
\]

The thickness values of granular layer considered are 350 mm, 500 mm and 650 mm, and thickness of bituminous layer varied from 25 mm (1 inch) to 200 mm (8 inches) to study the influence of the thickness of these layers on the fatigue and rutting performance of bituminous pavements. For example, the design charts are given in IRC: 37 -2012 [2] for 5 MSA load repetitions for a CBR of 8% show a granular layer thickness of 400 mm and bituminous layer thickness of 75 mm. Similarly, for 10 MSA load repetitions, the suggested granular layer thickness is 450 mm and a bituminous layer thickness of 100 mm for the CBR of 8%.

However, there can be many combinations of the granular layer and bituminous layer thicknesses to satisfy the critical strain criteria for 5 MSA and 10 MSA traffic. This present work is an attempt to show...
different combinations of layer thicknesses which can satisfy the strain criteria and to show that thin bituminous surface pavements have more advantages over thick bituminous layer pavements.

The strains were calculated using the IITPave [2] software with the inputs like elastic moduli of layers, thicknesses and Poisson’s ratio values along with the wheel load configuration and tire pressure. Poisson’s ratio value of 0.35 was considered for all the layers. The strains and deflection values calculated for different combinations of layer thicknesses were represented in a set of graphs to better understand the trends in the variation of values.

4. Observations
4.1 Estimation of strains at critical locations
The tensile strain under the bituminous layer is observed to vary non-linearly with the change in thickness of the bituminous layer. This trend has a peculiar nature. The tensile strain increases with increase in the thickness of bituminous layer up to a critical thickness and then starts decreasing with further increase in thickness. This trend can be seen in Figure 2 for different thicknesses of the granular layer (sub-base and base combined). In all the cases, the tensile strain under the bituminous layer for a bituminous layer thickness of 25 mm is less than that for a 200 mm thick bituminous layer. The reason attributed to this behaviour is how the bituminous layer distributes the loads on to the granular layer in the case of thick bituminous layers. If the flexural rigidity of the bituminous layer is high (in the form of thickness and/or bituminous layer’s modulus) compared to that of the granular layer, the load distribution will be done predominantly by the bituminous layer and hence may lead to higher tensile strains.

Figure 2. Variation of tensile strain under the bituminous layer with its thickness

On the other hand, the variation of compressive strain on top of the subgrade with a thickness of bituminous layer follows a uniform trend. The compressive strain decreases with increase in the thickness of the bituminous layer as shown in Figure 3. The compressive strain on top of subgrade decreases with increase in bituminous layer thickness and also with the increase in the granular layer thickness. However, the effect of an increase in the thickness of the bituminous layer is less for a higher thickness of the granular layer as can be seen in Figure 3. This can be attributed to the ability of a thick granular layer in distributing the vertical load before transmitting them onto the subgrade soil. Though the granular layers cannot be considered for carrying tensile loads, their ability to distribute the load through compression is very effective with aggregate interlocking aiding in the increase of the area of
load distribution on the subgrade. The effect of bituminous layer thickness on compressive strain on subgrade decreases with increase in the thickness of the granular layer.

![Figure 3. Variation of compressive strain on subgrade with the thickness of the bituminous layer](image1)

The variation of surface deflection of the pavement with the thickness of the bituminous layer is similar to the trend followed by the compressive strain on top of subgrade as shown in Figure 4. In the surface deflection, the compressive strain within the top layers also gets compounded along with the compressive strain on top of the subgrade. So, the trends in the variation of surface deflection and vertical compressive strain on top of the subgrade with a thickness of bituminous layer are not the same, though there is a similarity in the trend.

![Figure 4. Variation of surface deflection with a thickness of the bituminous layer](image2)

Though the pavement surface deflection is not considered in the design, it gives a good indication of the pavement structure’s ability to distribute the load. AASHO road tests and the AASHTO’s pavement
design guidelines are based on the pavement surface deflection measurements made with Benkelman beam [4].

4.2 Estimation of pavement service life

The mechanistic-empirical design methods use the mechanistic parameter, like strain at a critical location, to predict the life of a pavement using a performance equation similar to the correlations presented in Equation 2 and Equation 3. Equation 2 is used to predict the fatigue life of the pavement based on the initial tensile strain at the bottom of a bituminous layer as per IRC: 37 – 2018 [3] guidelines published by Indian roads congress (IRC). Similarly, Equation 3 is used to predict the rutting life in terms of the number of standard axle load repetitions the pavement can withstand before undergoing a surface rutting of a predefined magnitude as per IRC: 37 -2018 guidelines [3]. The strains are calculated using the IITPave [1, 2] software which is based on the linear elastic layer analysis, similar to the KENLAYER software [5]. The performance equations proposed in IRC: 37 -2018 are similar to the equations proposed in the asphalt institute method of flexible pavement design. These equations were incorporated into IRC: 37 guidelines from the revision made in the year 2001. Later on, the concept of reliability was associated with the performance equations and the Equations 2&3 were considered for 80% reliability. A new set of coefficients were proposed for designing with 90% reliability. However, for the sake of simplicity only the 80% reliability equations are shown here.

\[
N_{\text{fatigue}} = 2.21 \times 10^{-4} \times \left[ 1/ \varepsilon_t \right]^{3.89} \times \left[ 1/ M_R \right]^{0.854}
\]  
\[
N_{\text{Rutting}} = 4.1656 \times 10^{-8} \times \left[ 1/ \varepsilon_v \right]^{4.5337}
\]

The inputs for the fatigue equation are the tensile strain at the bottom of the bituminous layer (\( \varepsilon_t \)) and resilient modulus (\( M_R \)) of the bituminous layer. For a particular bituminous mix selected, \( M_R \) will be a constant and hence only the tensile strain controls the fatigue life. The only input for the rutting performance equation is the vertical compressive strain on top of subgrade (\( \varepsilon_v \)).

The fatigue life of the bituminous layer can be estimated using the performance equation (Equation 2) when the tensile strain under the bituminous layer is known. The estimated fatigue life values (in number) for different bituminous layer and granular layer thicknesses are presented in the graph shown in Figure 5. This graph indicates the fall in fatigue life by 100 times when the bituminous layer thickness is increased from 25 mm to 50 mm as there is a shift in the load distribution mechanism between the thickness values of 25 mm and 50 mm. The lowest fatigue life value is corresponding to a bituminous layer thickness of approximately 60 mm and from there the fatigue life increased with increase in the thickness of the bituminous layer. This 60 mm thickness associated with the lowest fatigue performance is specific to the combination of subgrade strength and bituminous layer modulus selected in this study.

Figure 5. Variation of estimated fatigue life with a thickness of the bituminous layer
From the figure 5, it can be observed that the design for 50 MSA traffic can have either a bituminous layer thickness of less than 50 mm or greater than 125 mm depending on the thickness of the granular layer to satisfy the fatigue criteria.

The number of repetitions to reach rutting failure or simply rutting life of the pavement can be estimated from the value of vertical compressive strain on top of subgrade using Equation 2 as discussed earlier. Figure 6 shows the variation of rutting life with a thickness of the bituminous layer and it shows a fairly uniform trend of increase in rutting life with an increase in the thickness of bituminous layer for all the granular layer thicknesses considered in the study. Figure 6 also shows the degree of variation in the rutting life with an increase in the thickness of the granular layer and bituminous layer.

![Variation of estimated rutting life with a thickness of the bituminous layer](image)

Figure 6. Variation of estimated rutting life with a thickness of the bituminous layer

Similar to the earlier considered case of design for 50 MSA traffic, the granular layer thickness of 500 mm for 25 mm thick bituminous surface layer and 350 mm for 125 mm thick bituminous layer. Though these two options sound similar, the cost difference will be very high as the cost of bituminous mix is nearly four times the cost of granular material per unit volume (DSR 2018) [6].

The combined plot of variation in fatigue life and rutting life with a thickness of bituminous layer for different thicknesses of granular layers is presented in Figure 7. This plot gives a better understanding of both fatigue and rutting lives of the pavement structure as a whole. The letter ‘R’ indicates ‘Rutting’ and the letter ‘F’ indicates ‘Fatigue’ in the plot. Majority of the pavement designs implemented in the field do not have a balance between the fatigue and rutting lives of the pavement structure and it may lead to an uneconomical pavement section where some material property or geometry of the pavement is under-utilized.

In the places where the aggregate is available in plenty, having a thicker granular layer is economical and also eco-friendly when future overlays and reconstructions are taken into account. The granular layer consists of granular sub-base (GSB) of a minimum thickness of 150 mm and granular base, which is usually, wet mix macadam (WMM), for the remaining thickness. Though the material requirements are different for GSB and WMM materials, the IITPave software considers the thickness of granular layer as a single entity as the modulus of resilience or elastic modulus of the unbound granular base is dependent on the elastic modulus of the underlying soil.
Figure 7. Variation of fatigue and rutting lives with a thickness of the bituminous layer

The data presented in Figure 7 is also shown in tabular format in Table 1, as the exact numbers can be seen in the table data which are not easy to decipher in the graphical representation. The layer combinations suitable for a minimum of 100 MSA traffic are highlighted in the table for different granular layer thicknesses chosen in the study. From the data, it can be seen that a 25 mm bituminous layer and 650 mm granular layer has the best fatigue and rutting life combination.

Table 1. Number of load repetitions for fatigue and rutting failure

| Asphalt layer thickness in mm | Rutting life for 350 mm Granular Layer | Fatigue life for 350 mm Granular Layer | Rutting life for 500 mm Granular Layer | Fatigue life for 500 mm Granular Layer | Rutting life for 650 mm Granular Layer | Fatigue life for 650 mm Granular Layer |
|------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|
| 25                           | 3.87E+06                              | 1.30E+09                              | 4.53E+07                              | 3.80E+09                              | 3.69E+08                              | 7.78E+09                              |
| 50                           | 6.59E+06                              | 1.77E+07                              | 7.19E+07                              | 3.48E+07                              | 5.52E+08                              | 5.57E+07                              |
| 75                           | 1.19E+07                              | 1.17E+07                              | 1.14E+08                              | 2.09E+07                              | 8.02E+08                              | 3.12E+07                              |
| 100                          | 2.22E+07                              | 1.50E+07                              | 1.84E+08                              | 2.52E+07                              | 1.18E+09                              | 3.63E+07                              |
| 125                          | 4.13E+07                              | 2.33E+07                              | 2.99E+08                              | 3.77E+07                              | 1.73E+09                              | 5.29E+07                              |
| 150                          | 7.58E+07                              | 3.84E+07                              | 4.82E+08                              | 6.06E+07                              | 2.55E+09                              | 8.38E+07                              |
| 175                          | 1.36E+08                              | 6.42E+07                              | 7.69E+08                              | 9.94E+07                              | 3.73E+09                              | 1.36E+08                              |
| 200                          | 2.36E+08                              | 1.07E+08                              | 1.21E+09                              | 1.63E+08                              | 5.44E+09                              | 2.22E+08                              |

5. Discussion on results

Based on the fatigue life and rutting life of different combinations of the granular layer and bituminous layer thicknesses, some cost comparisons were presented in this section to highlight the advantages of thin bituminous surface pavements. The cost comparisons and environmental benefits are presented in
this section. However, the environmental benefits are not quantified for consideration in the decision making process.

5.1 Cost comparisons

The costs of material and construction of pavement layers are presented here in Table 2 as per the rates specified in the Delhi schedule of rates (DSR, 2018) [6] published by the CPWD.

Table 2. Rates for construction of different pavement layers as per DSR, 2018

| SL No. | Material description                                      | Cost per cubic meter in Rs. | As per clause |
|-------|-----------------------------------------------------------|----------------------------|--------------|
| 1     | Granular sub-base (GSB) with min. CBR of 30               | 2517.70                    | 16.78, page 284 |
| 2     | Wet mix macadam (WMM)                                    | 2641.60                    | 16.79, page 285 |
| 3     | Dense Bituminous macadam (DBM)                           | 10064.25                   | 16.54, page 279 |

*Rs. was the older symbol used for representing Indian currency of Rupees

For ease of comparison, the cost of both the granular base and sub-base is considered to be Rs. 2,550 and that of dense bituminous macadam material is considered to be Rs. 10,050. Taking into account the data from Table 1 and Table 2, the cost estimate for the selected layer combinations to withstand 100 MSA of traffic is presented in Table 3 per 1 m length and 9 m width of the pavement section. So, a typical volume estimate for pavement layers will be length X width X thickness, where length is considered as 1 m and width as 9 m. Hence, the volume of mix required is 9.h where h is the thickness of the layer in m.

Table 3. Cost estimates for the three alternative pavement compositions

| Combination number | Bituminous layer thickness (m) | Granular layer thickness (m) | Cost of bituminous layer (Rs.) | Cost of granular layer (Rs.) | Total cost (Rs.) |
|--------------------|--------------------------------|-----------------------------|-------------------------------|-----------------------------|-----------------|
| 1                  | 0.2                            | 0.35                        | 18090                         | 8032.5                     | 26122.5         |
| 2                  | 0.175                          | 0.5                         | 15828.75                      | 11475                      | 27303.75        |
| 3                  | 0.025                          | 0.65                        | 2261.25                       | 14917.5                    | 17178.75        |

Alternative 3 has nearly 30 % saving in the cost compared to alternative 1, as can be seen from the data presented in Table 3. The alternative 3, known as thin bituminous surfacing, has environmental benefits along with the cost-saving offered as recycling of the pavement at a later date is easy as the granular layer is an un-bound layer.

AUSTROADS pavement design guide [7] provides the flexible pavement design charts for thin bituminous surfacing and thick bituminous surfacing separately. Hence, this is not a new approach and has been in use for a long time [8].

5.2 Environmental benefits of thin bituminous surfacing

Majority of the flexible pavements, at the end of their service life, are either overlaid or scrapped to construct a new pavement structure. The scrapped bituminous pavement is known as recycled asphalt pavement (RAP) material and it is very difficult to dispose of it or utilize it in the new construction. In case of reconstruction, due to the difficulties in re-heating of RAP material is used only to a limited extent and the remaining material is dumped at a disposal site. The dumping of RAP material is environmentally not acceptable as this does not allow the vegetation to grow there.

On the other hand, disposing or reusing of thin bituminous surfacing is much easier as the quantity of RAP generated is less. The process of overlying to structurally strengthen the pavement is also advantageous in case of thin surfacing, as the existing granular layer provides strong base support. The cost of milling will be less for thinner bituminous surfaces.
6. Concluding remarks
The thin bituminous surface pavements are cost-effective and have a great scope for future strengthening and reusability of aggregate. The cost of construction of thin bituminous surface pavement is only 70% of the cost of a thick bituminous pavement, in addition to the various advantages it has in terms of environmental friendly construction practices. The air pollution due to preparation of hot bituminous mix will also be less in the case of a thin bituminous surface.

The data presented here is for only one subgrade condition and one bituminous mix considered. However, the trends in the variation of fatigue life and rutting life of pavements remain the same with little offsets. The example shown for cost comparison is corresponding to 100 MSA traffic as the numbers are better matched for the combination of layer thicknesses selected for the study.

However, a very thin bituminous layer of the order of 25-30 mm thickness may not offer high shear resistance under heavy axle loads with frequent application of brakes. So, these thin bituminous surface pavements may not be appropriate for highway pavements. However, these pavements are best suited where the traffic is limited in terms of heavier axle loads and frequent brake applications. A binder rich surfacing will have better durability as the modulus of the bituminous layer has little significance on fatigue and rutting lives at thicknesses of the order of 25 – 30 mm.

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