Paper No. 554
COMPARATIVE STUDY OF FLEXIBLE AND RIGID PAVEMENTS FOR DIFFERENT SOIL AND TRAFFIC CONDITIONS†
Atakilti Gidelew Bezabih* & Satish Chandra**

ABSTRACT
Flexible pavements are widely used despite some doubts regarding their economics under different conditions. Two most important parameters that govern the pavement design are soil sub-grade and traffic loading. The Indian guidelines for the design of flexible pavements use soil sub-grade strength in terms of California Bearing Ratio (CBR) and traffic loading in terms of million standard axles (msa). For the design of rigid pavements, IRC: 58 - 2002 uses the same parameters in terms of modulus of sub-grade reaction, k, and axle load distribution (ALD). To compare the cost of two types of pavements, it is necessary to ensure that they are designed for the same traffic loading. Therefore, a study was done to convert the traffic load given in msa into ALD and vice-versa. Mathematical models are developed to estimate the ALD from individual vehicle counts.

A total of 90 flexible pavements and 63 rigid pavements are designed and their costs computed. The costs include the construction cost and a fixed maintenance cost. Mathematical expressions are developed to relate the cost of pavements with soil CBR and traffic in msa. The critical line of equal costs on the plane of CBR versus msa is also identified. This is a swing line which delineates the economic feasibility of two types of pavements.

1 INTRODUCTION
The two most important factors that govern pavement design are soil sub-grade strength and traffic loading. Depending on the strength of sub-grade soil, the layer thicknesses of flexible as well as rigid pavements are affected. IRC:37 - 2001 uses soil sub-grade strength in terms of CBR; whereas IRC: 58 - 2002 uses the same in terms of modulus of sub-grade reaction (k). The traffic load is generally estimated from 3-day axle load survey. In the design of flexible pavements, traffic load is expressed in terms of million standard axles (msa); whereas it is expressed in terms of axle load distribution (ALD) in design of rigid pavements.

The accurate determination of axle load spectra is crucial in the effective design as well as damage investigation of pavements. The Motor Vehicles Act, 1988 stipulates axle load limits for the different axle configurations (that is single, tandem, and multi axles). However, these limits are seldom followed in actual practice as per the prevailing regulatory system and consequently a large number of commercial vehicles are overloaded. The Indian Roads Congress (IRC) method of flexible pavement design (IRC:37-2001) uses the concept of vehicle damage factor (VDF), to account for the effect of overloading in the design. Load equivalency factors suggested by AASHTO are used to change the individual axle loads in to Equivalent Single Axle Loads (ESAL); and then the sum of ESAL is divided by the number of vehicles to get the VDF.

The present study was undertaken in two parts. In the first part, mathematical models are developed to obtain the ALD on a highway from its vehicle volume count. The ability to convert the soil sub-grade strength given in terms of CBR into modulus of subgrade reaction (k), and a traffic load given in terms of msa into ALD makes it possible to design the two types of pavements for the same soil and traffic conditions expressed differently. In the second part, flexible and rigid pavements are designed for similar soil and traffic conditions and their costs are compared.

2 ESTIMATION OF ALD FROM INDIVIDUAL VEHICLE COUNTS
2.1 Background
Although the types of commercial vehicles that are available for use in India are very few, the goods that are transported daily are very large. On the other hand,
due to prevailing structure of regulatory system, the overloading of vehicles is very common. There are generally two types of axles (single and tandem) which dominate the axle load spectra on all roads in India. The axle load configuration of the different vehicle classes that are widely used in India is shown in Fig. 1.

<table>
<thead>
<tr>
<th>Axle Configuration</th>
<th>Vehicle Class</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Axle Configuration Diagram" /></td>
<td>vc&lt;sub&gt;1&lt;/sub&gt;</td>
<td>LCV- 2 Axle, Light Goods Carrier</td>
</tr>
<tr>
<td><img src="image" alt="Axle Configuration Diagram" /></td>
<td>vc&lt;sub&gt;2&lt;/sub&gt;</td>
<td>2 Axle Truck</td>
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<tr>
<td><img src="image" alt="Axle Configuration Diagram" /></td>
<td>vc&lt;sub&gt;3&lt;/sub&gt;</td>
<td>3 Axle Truck</td>
</tr>
<tr>
<td><img src="image" alt="Axle Configuration Diagram" /></td>
<td>vc&lt;sub&gt;4&lt;/sub&gt;</td>
<td>Bus, 2 Axle</td>
</tr>
<tr>
<td><img src="image" alt="Axle Configuration Diagram" /></td>
<td>vc&lt;sub&gt;5&lt;/sub&gt;</td>
<td>Tractor Trailer</td>
</tr>
<tr>
<td><img src="image" alt="Axle Configuration Diagram" /></td>
<td>vc&lt;sub&gt;6&lt;/sub&gt;</td>
<td>Truck Trailers*</td>
</tr>
</tbody>
</table>

* Truck Trailers are grouped under one class because their number in Indian traffic is very small.

The present practice of computing axle-load distribution is based on 3-day axle load survey. However, relying on 3-day axle load survey data has many limitations. The use of a model which is found by integrating the different sub models developed for each vehicle class based on field data collected in different areas and at different times would be much better in determining the ALD of the traffic mixture.

The proportions of the different vehicle classes in the traffic stream vary from place to place across a country. Mintis et al. have shown the variation in vehicular proportions at different places. Sriramula et al. found that the different vehicle classes have different growth rates and these growth rates are dependent on economic condition of the country. Various researchers have tried to represent the ALD using different mathematical models. The limitations to these works are summarized by Timm et al. who combined two theoretical distributions (normal and lognormal) with different weights to address the bi-modal characteristics of axle load distribution for different axle load configurations (single and tandem). However, the effect of variation in vehicle classes was not considered in their study.

Haider and Harichandran used a similar technique to model the axle load distribution. They related axle load distribution to gross vehicle weight (GVW) and volume. Two normal distributions with different weights p<sub>1</sub> and p<sub>2</sub> were used to model the axle load distributions. The means, standard deviations and weights corresponding to these distributions were then related to those corresponding to the different vehicle classes’ gross vehicle weights data and volume using multiple regression analysis. Five parameters were estimated for each axle configuration (single or tandem) coming from the traffic mixture. However, the model efficiency for some of the parameters was not very high. Since these parameters are to be used in the ALD model, the error that would occur in using these parameters will increase substantially. Therefore, it would be better to develop a model that directly considers the proportions of different vehicle classes to estimate the axle load distribution of mixed traffic.

2.2 Data

Data for this study were taken from the different reports available at Central Road Research Institute (CRRI) New Delhi and Department of Civil Engineering, Indian Institute of Technology (IIT) Roorkee, India. The CRRI report contained the data collected on different National Highways in the years from 1988 to 1992 in different states of the country. The IIT Roorkee reports provided axle load survey data collected in the states of Uttar Pradesh and Bihar in 2004 and 2007. A total of 12 sites were selected from these reports depending on the extensiveness of the data, covering 9 states of the country.

2.3 Methodology

Preliminary analysis of the data revealed that there is no significant variation in ALD of a particular vehicle class with place and time. The fact that the different vehicle classes follow typical axle load distribution regardless of time and space enables us to have control over the ALD of the traffic mix by integrating the individual ALD. A single model cannot describe the axle load distribution for the entire traffic stream as the proportions of different vehicle classes vary from place to place. However, it is possible to develop a mathematical model to represent the average ALD of each vehicle class. The different vehicle types have different peak values and the peaks occur at different values of axle load group along the x-axis. Parametric study was carried out to represent...
these distributions. Gaussian distribution was found to be convenient to represent multi-modal distributions of all vehicle classes. As an exception, however, exponential and power distributions were found to give better results for vehicles class 1 and 5. The combination of exponential and Gaussian distributions was also used to represent the tandem axle load distribution (TALD) of vehicle class 3 (vc3) as an alternative to the Gaussian model.

2.3.1 Mathematical Models

The parameters of Gaussian model were used to represent the peak values, their location along x-axis with a parameter related to the width of the peak. The model efficiency ($R^2$ value) was computed for all the equations, and goodness of fit was judged by using the Kolmogorov Smirnov (K-S) test. The algorithm used is given in Equation (1):

$$[Y]_i = \sum_{j=1}^{m} \left[ \frac{V_j}{A} f_j(x_i) \right]$$

where

- $[Y]_i$ = 1 x n matrix of ALD for the traffic mix for each type of axle configuration;
- $[Y]_j$ = 1 x n matrix of ALD for vehicle class j;
- $x$ = axle load groups (in 1000 kg);
- $i$ = $i^{th}$ group on the x-axis; $i=1, 2, ..., n$ for single axles and 5, 7, 9, ..., $n$ for tandem axles.
- $n$ = 25 for single axles and 39 for tandem axles. The maximum values of $n$ correspond to the maximum possible values of single and tandem axle loads with reference to the data recorded.
- $j$ = vehicle class;
- $m$ = number of vehicle classes;
- $V_j$ = the volume of vehicle class $j$ in the traffic stream;
- $A$ = any number for which the formula is developed (1000 in the present study);
- $f(x)$ = function representing ALD of vehicle class $j$.

The general Gaussian model is given in Equation (3):

$$[Y]_i = \sum_{k=1}^{z} a_k e^{-\left(\frac{x_i-b_k}{c_k}\right)^2}$$

where

- $a_k$ = a parameter representing the $k^{th}$ peak value;
- $b_k$ = the axle load group for which the maximum frequency is observed;
- $c_k$ = a parameter that is related to the width of the peak;
- $z$ = number of peaks.

In cases where Gaussian model did not provide a good fit, other forms of mathematical models like the exponential and power and their combinations were attempted. The exponential and power models are given in Equations (4) and (5) respectively.

$$[Y]_i = a \cdot e^{b \cdot x_i}$$

$$[Y]_i = a \cdot x_i^b + c$$

where $a$, $b$ and $c$ are constants.

2.3.2 Modelling of ALD of Vehicles Class 2, 3 and 4

The ALD of these vehicle classes were best represented by Gaussian distribution with two peaks. The parameters for each vehicle class are presented in Table 1. Fig. 2 shows ALD for six of the 12 sites and the average of all sites for vehicle class 2. The number of lines were reduced for the purpose of clarity. The load pattern here has two peaks, one high peak at lesser axle load group (ALG 3-5) and another relatively low peak around 12,000 kg axle load (ALG 11-12). Therefore, a general Gauss model with two peaks $a_1$ and $a_2$ was used to fit the axle load spectra for this category of vehicle. Fig. 3 shows the model fitted to the average loading condition. Similar analysis was done for other vehicle classes also. All the models were found statistically sound through K-S test at $\alpha = 0.05$. The individual average vehicle damage factors for vehicles class 2, 3 and 4 are found to be 7.1, 3.8 and 0.78 respectively.
Table 1 Parameters for Models Fitted to the ALD of Vehicles Class 2, 3 and 4

<table>
<thead>
<tr>
<th>Vehicle class</th>
<th>Model used</th>
<th>Parameters</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Gaussian</td>
<td>$a_1$ 354.4 $b_1$ 4.514 $c_1$ 1.738 $a_2$ 88.18 $b_2$ 11.41 $c_2$ 5.883</td>
<td>0.996</td>
</tr>
<tr>
<td>3 (FA)*</td>
<td>Gaussian</td>
<td>$a_1$ 182.2 $b_1$ 6.239 $c_1$ 2.179 $a_2$ 119.4 $b_2$ 10.1 $c_2$ 1.352</td>
<td>0.992</td>
</tr>
<tr>
<td>3 (TA)**</td>
<td>Gaussian</td>
<td>$a_1$ 82.16 $b_1$ 23.49 $c_1$ 6.508 $a_2$ 133.8 $b_2$ -8.2 $c_2$ 21.39</td>
<td>0.982</td>
</tr>
<tr>
<td>4</td>
<td>Gaussian</td>
<td>$a_1$ 396.1 $b_1$ 4.075 $c_1$ 1.401 $a_2$ 211.9 $b_2$ 6.416 $c_2$ 2.689</td>
<td>0.995</td>
</tr>
</tbody>
</table>

* Front Axle  **Tandem Axle

No axle load was recorded exceeding 16,000 kg at any location for vehicle class 4. Vehicle class 3 has front single axle and rear tandem axle. Therefore, separate equations were developed for single and tandem axles. Table 1 shows the second peak parameters for tandem ALD of vehicle class 3 also. It does not have any physical significance as the value of $b_2$ is negative. However, it helped in getting an excellent fit to the data for the values of the TALG5 and above. Hence, it was also considered in the model.

Fig. 2 shows the axle load distribution of vehicle class 1 at different sites. There is only one peak at axle load group 2 ($x = 2$). Exponential distribution was used to model the data starting at axle load group 2. Since axle load group 1 (500 to 1500 kg) has negligible damaging effect on the pavement, it was removed from the data for convenience. No axle load greater than 12,000 kg was recorded at any location. Fig. 3 shows the model fitted to the data for an average condition from all the sites. The data for vehicle class 5 was fitted to a power distribution as shown in Fig. 6. No axle load exceeding 14,000 kg was recorded at any site for this vehicle class.

The parameters of the models fitted to ALD of vehicles class 1 and 5 are given in Table 2. The individual average vehicle damage factors for vehicles class 1 and 5 are 0.08 and 0.89 respectively.

Table 2 Parameters for Models Fitted to ALD of Vehicles Class 1 and 5

<table>
<thead>
<tr>
<th>Vehicle class</th>
<th>Model used</th>
<th>Parameters</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Exponential</td>
<td>$a$ 3690 $b$ -0.7412 $c$ ---</td>
<td>0.995</td>
</tr>
<tr>
<td>5</td>
<td>Power</td>
<td>$a$ 1203 $b$ -0.8037 $c$ -136.3</td>
<td>0.993</td>
</tr>
</tbody>
</table>

2.3.3 Modelling of ALD of Vehicle Classes 1 and 5

Vehicle class 1 and 5 were best represented by exponential and power distributions, respectively.
3 DESIGN AND COST OF FLEXIBLE PAVEMENTS

The structural capacity of flexible pavements is attained by combined action of the different layers of the pavement. The load is directly applied on the wearing course and it gets dispersed with depth in the base, sub-base and sub-grade layers and then ultimately to the ground. Since the stress induced by traffic load is highest at the top, the quality of top and upper layer materials is better. The sub-grade layer is responsible for transferring the load from above layers to the ground. Flexible pavements are designed in such a way that the load transmitted to the sub-grade does not exceed its bearing capacity. Consequently, the thickness of layers would vary with CBR of soil and it would affect the cost of the pavement.

The Indian Roads Congress method of flexible pavement design uses the concept of ESAL for the purpose of flexible pavement design and the same has been used in this study also.

The variation in the cost of pavements designed with varying soil and traffic conditions results in an array. Nine subgrade soil conditions (CBR 2% to 10 %) and ten design lane traffic conditions (1 msa to 150 msa) have been considered in this study. Therefore, a total of 90 pavements were designed and the costs of construction and maintenance were computed. The above ranges of soil and traffic values are assumed to cover almost all possible combinations of soil CBR and traffic loadings. Exceptional cases of climatic or rainy conditions have not been considered.

3.1 Design Strategy

A design life of 20 years is considered in this study. These 20 years are divided into two 10 years life for stage construction. The traffic growth rate is assumed to be 7.5 per cent. Let,

\[ A_0 = \text{Present traffic (that is traffic after completion of construction)} \]

\[ N_{10}^1 = \text{Traffic load repetitions in msa in the first 10 years period} \]

\[ N_{10}^2 = \text{Traffic load repetitions in msa in the second 10 years period} \]

\[ N_{20} = \text{Total traffic load repetitions in 20 years design life} \]

The relationships between \( N_{10}^1, N_{10}^2 \) and \( N_{20} \) are established as below:

\[ N_{10}^1 = \frac{365 \times \left[ (1 + r)^{10} - 1 \right]}{r} \times A_o \times D \times VDF \] \( \ldots(6) \)

\[ N_{20} = \frac{365 \times \left[ (1 + r)^{20} - 1 \right]}{r} \times A_o \times D \times VDF \] \( \ldots(7) \)

\[ N_{20} = N_{10}^2 - N_{10}^1 \] \( \ldots(8) \)

\[ \frac{N_{10}^1}{N_{20}} = \frac{(1 + r)^{10} - 1}{(1 + r)^{20} - 1} \] \( \ldots(9) \)
Substituting a value of $r = 0.075$ in Equation (10),

$$N_{10}^1 = \frac{(1 + r)^{10} - 1}{(1 + r)^{20} - 1} \times N_{20} \quad \ldots(10)$$

The following steps are used in design of flexible pavements for stage construction.

i) Provide design thicknesses of subbase and base courses for 20 years.

ii) Provide bituminous surfacing course for traffic of $N_{10}^1$ msa.

iii) Provide a shoulder of thickness equal to that of the sum of the layers in steps (i) and (ii) on both sides.

iv) Provide bituminous surfacing course for traffic of $N_{10}^2$ msa after 10 years.

v) Provide shoulder thickness equal to the thickness calculated in step (iv) at the same time.

### 3.2 Volume and Cost Computations

A typical pavement section used in this study is shown in Fig. 7. The section is of two-lane road with 7.0 m carriageway and 1.2 m shoulder on either side. A length of 1 km road is considered for computation of the cost. The thicknesses of the different layers that are obtained from the design are used to compute the cross sectional areas of the layers by multiplying with the pavement width. The materials used for constructing the different layers are Granular sub-base (GSB), Water Bound Macadam (WBM), Premix Carpet (PC), Bituminous Macadam (BM), Dense Bituminous Macadam (DBM), Semi-dense Bituminous Concrete (SDBC) and Bituminous Concrete (BC), which are currently recommended in IRC:37-2001.

![Fig. 7 Typical Cross-section of a flexible pavement](image)

The costs of different pavements are obtained by multiplying the volumes of materials by their respective costs. The costs of the different materials were calculated using 2006 schedule of rates for Dehradun district. Bageshwar Prasad\(^2\) used a maintenance cost of Rs 1.5 million for flexible pavements and the same was uniformly added to all the pavements in this study. Therefore, the costs computed in this study include both construction and maintenance costs. Table 3 gives the costs of flexible pavements designed for different combinations of soil CBR and traffic conditions. Fig. 8 shows the variation in cost of flexible pavements with respect to traffic loading. Equation (13) relates the cost of flexible pavements with soil CBR and traffic loading.

$$\text{Cost} = -16.98 + 12.136 \times \text{CBR}^{-0.3} + 15.476 \times \text{msa}^{0.10} \quad \ldots(13)$$

$$R^2 = 0.98$$

### Table 3 Cost of Flexible Pavements in Million Rupees for Different Combinations of Soil and Traffic

<table>
<thead>
<tr>
<th>Soil CBR (%)</th>
<th>Traffic Load (msa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>7.12</td>
</tr>
<tr>
<td>4</td>
<td>5.80</td>
</tr>
<tr>
<td>5</td>
<td>5.45</td>
</tr>
<tr>
<td>6</td>
<td>5.17</td>
</tr>
<tr>
<td>7</td>
<td>5.07</td>
</tr>
</tbody>
</table>

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4 DESIGN AND COST OF RIGID PAVEMENTS

Rigid pavements are named so because of the high flexural rigidity of the concrete slab. The concrete slab is capable of distributing the traffic load into a large area with small depth which minimizes the need for a number of layers to help reduce the stress. Generally, depending on the strength of soil, a layer of dry lean concrete (DLC) is provided as base/sub-base immediately above the sub-grade. Fig. 9 shows a typical cross section of a rigid pavement considered in this study.

4.1 Factors Governing Design

The factors that affect the thickness design of rigid pavements are traffic loading, sub-grade soil, moisture and temperature differential. Being the most important parameters, sub-grade soil and traffic loading are considered in this study.

4.1.1 Sub-grade Soil

IRC method of rigid pavement design stipulates that cement concrete layer should not be laid directly over a sub-grade with modulus of sub-grade reaction \( k \), less than 6 kg/cm\(^3\). However, the equivalent value of modulus of sub-grade reaction for a soil sub-grade with CBR value of 10% is 5.5 kg/cm\(^3\). In this study, a DLC (of M10 grade) sub-base layer of 100 mm thickness was used except for soil sub-grade with CBR value of 2%, for which a DLC sub-base of 150 mm is considered.

4.1.2 Traffic Loading

Traffic loading is used as an input in the design of rigid pavements in the form of axle load distribution. To be able to compare flexible and rigid pavements, they should be designed for the same traffic loading. Therefore, the same traffic loadings that were used in the design of flexible pavements were converted into ALD for their use in the design of rigid pavements. A typical proportion of different vehicular classes in the traffic stream was found from the average of classified traffic volume counts at nine sites in the state of Utter Pradesh in 2004. The percentages of the different vehicular classes assumed in this study are 33, 30, 15, 16 and 6 for vehicle classes 1, 2, 3, 4 and 5 respectively.

4.2 Design

The thickness of rigid pavement is designed for fatigue failure and then checked for the critical combination of load stresses and temperature stresses. The traffic loadings are same as used in the design of flexible pavements in the earlier Section. The effective values of \( k \) as mentioned in IRC :58-2002 are used for the purpose of design. Dowel bars and tie bars were designed for all the pavements as per IRC guidelines.

4.3 Computation of Costs

The cost of construction and maintenance are considered in this study. The cost of sub-grade, dry lean concrete sub-base, pavement quality concrete slab, shoulders, dowel bars, and tie bars were computed as per 2006
schedule of rates for Dehradun district. Maintenance cost is adopted from a study made by Bageshwar Prasad\(^2\). The total cost of construction and maintenance costs for all the pavements are shown in Table 4. Fig. 10 shows the cost of rigid pavements against traffic loading for different values of sub-grade CBR. Equation 14 was developed using multiple regression analysis.

\[
Cost = 8.284 + 4.719 \times CBR^{-0.9} + 20.83 \times msa^{0.15}
\]

\[\ldots \text{(14)}\]

\[R^2 = 0.95\]

Table 4 Cost (in Million Rupees) of Rigid Pavements for Different Soil and Traffic Conditions

<table>
<thead>
<tr>
<th>Soil CBR (%)</th>
<th>Traffic Load (msa)</th>
<th>7</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>50</th>
<th>100</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td></td>
<td>13.32</td>
<td>13.92</td>
<td>13.92</td>
<td>14.54</td>
<td>14.85</td>
<td>15.15</td>
<td>15.15</td>
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<td>4</td>
<td></td>
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<td>12.74</td>
<td>12.74</td>
<td>13.36</td>
<td>13.36</td>
<td>13.66</td>
<td>13.96</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>11.87</td>
<td>12.46</td>
<td>12.46</td>
<td>13.07</td>
<td>13.37</td>
<td>13.37</td>
<td>13.69</td>
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<td>7</td>
<td></td>
<td>11.90</td>
<td>12.19</td>
<td>12.50</td>
<td>12.80</td>
<td>13.09</td>
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<tr>
<td>8</td>
<td></td>
<td>11.61</td>
<td>12.21</td>
<td>12.21</td>
<td>12.82</td>
<td>12.82</td>
<td>13.11</td>
<td>13.41</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>11.64</td>
<td>11.92</td>
<td>12.24</td>
<td>12.53</td>
<td>12.82</td>
<td>13.13</td>
<td>13.13</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>11.36</td>
<td>11.95</td>
<td>11.95</td>
<td>12.53</td>
<td>12.53</td>
<td>12.84</td>
<td>13.13</td>
</tr>
</tbody>
</table>

5 DISCUSSION

The cost of flexible pavement changes rapidly in the lower range of traffic load, especially up to 20 msa, beyond that the variation is less. Similarly, the change in the cost of flexible pavement with respect to CBR reduces with increase in the value of CBR. The partial derivatives of cost with respect to CBR and msa are found from Equation 13 and are given below.

\[
\frac{\partial C_f}{\partial CBR} = -3.641 \times CBR^{-1.3}
\]

\[\ldots \text{(15)}\]

\[
\frac{\partial C_f}{\partial msa} = 1.548 \times msa^{-0.9}
\]

\[\ldots \text{(16)}\]

The cost of flexible pavements generally varies from Rs 5.07 million to Rs 18.85 million depending upon the soil CBR and traffic conditions.

The cost of rigid pavements, on the other hand, does not show much variation with respect to CBR as well as traffic conditions. The reason is the extreme sensitivity of fatigue life to differential change in the stress ratio. Rigid pavements have shorter life in higher axle load ranges. The occurrence of few axle loads of high magnitude consumes the entire fatigue life of the pavement because higher axle loads will result in higher stress ratio which in turn will reduce the fatigue life considerably. Equations 17 and 18 show the change in rigid pavement costs with respect to soil CBR and traffic loading.

\[
\frac{\partial C_r}{\partial CBR} = -3.761 \times CBR^{-1.9}
\]

\[\ldots \text{(17)}\]

\[
\frac{\partial C_r}{\partial msa} = 0.3125 \times msa^{-0.85}
\]

\[\ldots \text{(18)}\]

The thickness of the slab designed in this study varies from 24 cm to 34 cm. The cost of rigid pavements varies from Rs 11.36 million to 15.15 million, a narrow range of Rs 3.79 million only, against Rs 13.78 million in the case of flexible pavements. The narrow range of variation in
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Cost for rigid pavements shows that poor response of rigid pavement cost to the design parameters.

Moreover, the assumed proportions of the different vehicular classes were found not to affect the design thickness of rigid pavements. This is due to the rapid deterioration of fatigue life in the larger axle load groups. However, the effect is reflected on the value of cumulative damage, D. Table 5 shows the variation in the value of D for the design traffic of 50 msa and CBR of 5% for different assumed proportions.

<table>
<thead>
<tr>
<th>Assumed Proportion (%)</th>
<th>Vehicle Classes</th>
<th>Design Thickness (mm)</th>
<th>Cumulative Damage, D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>33</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>35</td>
<td>15</td>
</tr>
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6 COMPARISON

The design and cost computations for flexible and rigid pavements are discussed in Sections 3 and 4 respectively. The initial aim of this study was to determine the threshold values of CBR and msa beyond which one of the pavements becomes economical in its combined construction and maintenance cost. The points of equal cost on the CBR vs msa graph were determined using Equations 13 and 14 and these are plotted in Fig.11. Rigid pavements are found to be economical in the upper portion of the graph and flexible pavements are economical in the lower portion of the graph. Mathematically:

If \( msa < 12.48 + 6.05 \times CBR \), flexible pavement will be economical;

If \( msa > 12.48 + 6.05 \times CBR \), rigid pavement will be economical;

If \( msa = 12.48 + 6.05 \times CBR \), both pavements will have the same cost.

The above mathematical equation is developed by fitting a straight line to the points of equal costs. It has an \( R^2 \) value of 0.998. The equation is valid for soil CBR values ranging from 2 percent to 10 percent.

7 CONCLUSIONS

The following conclusions are drawn from this study:

The data collected on the different highways in the different parts of the country and at different times were used for developing mathematical models relating axle load distribution to the vehicular count. These models can be used to predict axle load distribution on a highway from its classified volume count. This approach has three major advantages. One, it considers the average axle load distribution of all the sites which were spread all over the country and therefore the results are geographically transferable. Two, it provides an economic way of determining ALD without actually going for axle load survey in field. Three, it allows for the use of actual growth rates of different vehicle classes in determining the design traffic loading for a highway.

Flexible pavements show wider range of variation in cost with respect to design parameters of traffic and soil CBR. The overall variation in cost of rigid pavements is comparatively small. The design of a rigid pavement is highly influenced by the occurrence of small number of heavy axle loads. The fatigue life of a rigid pavement is prone to small changes in the stress ratio which can happen with a small increase of the loading along the axle load axis. It is observed that flexible pavements are more economical for lesser volume of traffic. Fig.11 shows a swing line in the CBR vs msa graph which indicates the region of feasibility for choosing the type of a pavement. The flexible pavements are economical in...
the lower region of the graph, whereas rigid pavements are economical on the upper portion. Any point on the line is the point of equal cost.

REFERENCES


