Analysis of Design of a Flexible Pavement with Cemented Base and Granular Subbase

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Abstract
The Major District Road are the secondary road in India. They carry most of India's freight and passenger traffic. Major District Road presently totalling to a length of about 4,67,763 km, MDR & SH both combine carry nearly 40 per cent of the traffic, and are the most important category of roads. Flexible pavements are those, which on the whole have low or negligible flexural strength and are rather flexible in their structural action under the load. The service life of a flexible pavement is typically designed in the range of 10 to 20 years. Required thicknesses of each layer of a flexible pavement varies widely depending on the materials used, magnitude and number of repetitions of traffic loads, environmental conditions and the desired service life of the pavement. The latest design method of IRC: 37-2012 is mechanistic approach of design and incorporates the use of non conventional & conventional kinds of materials in the base but in sub-base only conventional kind of material is used. The stretch of MDR-108 between Tosham to Bhiwani is taken for the study. The required data are collected from PWD B&R Bhiwani which include traffic data, CBR value and VDF. Using the data, the cumulative design traffic in standard axles is calculated for the design life. Finally using the cumulative standard axles and effective CBR value, the pavement has been designed for period of 20 years, using IRC 37:2012 guidelines of flexible pavement design.

Keywords: Design; Flexible pavement; traffic; cumulative standard axles; CBR; VDF; thickness of pavement.

I. INTRODUCTION
Flexible pavements are so named because the total pavement structure deflects under loading. Each layer receives the loads from the above layer, spreads them out, and then passes on these loads to the next layer below. The purpose of design is to provide a pavement structure which is capable of withstanding the traffic loads which would be coming onto it during the design life of a pavement. The design involves determining the thickness of component layers based on the strength characteristics of the pavement materials. Now in India, a total road length is about 33 lakh km. It requires not only adequate resources but also proper planning and innovative way of maintenance. Major District Road (MDR) & State Highway (SH) presently totalling to a length of about 4,67,763 km, carry nearly 40 per cent of the traffic, and are the most important category of roads. MDR 108 is a Major District Road in South western Haryana in India that links the Hisar (Haryana) to Bhiwani(Haryana). It runs for a distance of 59.83 km. This stretch comes under the south western Haryana i.e. Tosham to Bhiwani (MDR 108), driving distance from Tosham to Bhiwani is 24.2 kms. The total travel time is approximately 32 min(s); which may vary depending upon the road and traffic conditions.

II. OBJECTIVES OF STUDY
a) Collecting traffic data for the study stretch which would be used in design.
b) Finding pavement composition by CBR value & \( N_3 \) cumulative number of standard axles to be catered for in the design in terms of MSA from available data based on the IRC: 37-2012 guidelines [1].
c) Finding cost of pavement composition from data which is obtained in step (b) based on MORTH Data Book (2003)
III. METHODOLOGY

Indian Roads Congress Method: Indian Roads Congress Method is based on an empirical method where the thickness value of a pavement used was read from the CBR value of the sub-grade. From the design chart the total pavement thickness could be read for a given CBR value and cumulative standard axle load. The design procedure of the pavements based IRC: 37-2012 guidelines [1].
I. Selection of a trial pavement including the number of layers and thicknesses of all layers overlying the sub-grade.
II. Selection of design loading (traffic) and determination of vertical stress (i.e., tire contact pressure) and radius of the tire contact area.
III. Determination of the elastic parameters of Asphalt which include flexural modulus and Poisson's ratio.
IV. Determination of the cemented base and granular sub base elastic parameters of the sub-grade elastic modulus and Poisson's ratio.
V. Determination of the elastic parameters of the granular sub-layer as mentioned in step IV and which include elastic modulus and Poisson's ratio.
VI. Using the IITPAVE software to calculate the Actual Horizontal Tensile Strain in Bituminous layer and Actual Vertical Compressive Strain on sub-grade.

IV. TRAFFIC GROWTH RATE (r)

As per Clause 5.5.4 of 2 laning Manual of Specifications and Standards IRC SP 84 - 2009 (Published by Planning Commission of India) [2], it is said to adopt a realistic value of growth rate for pavement design provided that the annual growth rate of commercial vehicles shall not be less than 5%. Considering this clause 5% growth rate is adopted for calculating the design traffic as given in [1].

V. VEHICLE DAMAGE FACTORS (F)

The Vehicle Damage Factor is a multiplier to convert the number of commercial vehicle of different axle loads and axle configuration into the number of repetitions of standard axle load of magnitude 80 KN. It is defined as equivalent number of standard axle per commercial vehicle. The VDF varies with the vehicle axle configuration and axle loading. The equations for computing equivalency factor for single, tandem and tridem axles given below should be used for converting different axle load repetitions into equivalent standard load repetitions. Since the VDF values in AASHO Road test for flexible and rigid pavement are not much different, for heavy duty pavements, the computed VDF value are assumed to be same for bituminous pavements with cemented base and granular subbase.

Single axle with single wheel on either = (axle load in KN/65)^4
Single axle with dual wheels on either = (axle load in KN/80)^4
Tandem axle with dual wheels on either side = (axle load in KN/148)^4
Tridem axle with dual wheels on either side = (axle load in KN/224)^4
Indicative VDF value according to IRC: 37-2012 VDF value according to IRC: 37-2012 is 6.32 .

VI. LANE DISTRIBUTION (D)

The Lane distribution is a realistic assessment of distribution of commercial traffic by direction as it affects the total equivalent standard axle load. Distribution of commercial traffic in each direction and in each lane is required for determining the total equivalent standard axle load applications to be considered in the design.

a) Single-lane carriageway road

Traffic tends to be more channelized on single-lane roads than two-lane road and to allow for this concentration of wheel load repetitions, the design should be based on total number of commercial vehicles in both directions.

b) Two-Lane single carriageway road

The design should be based on 50 per cent of the total number of commercial vehicle in both directions. If the VDF is one direction is higher, the traffic in the direction of the higher VDF is recommended for design.

c) Four-Lane single carriageway roads

The design should be based on 40 per cent of the total number of commercial vehicle in both directions.

d) Dual carriageway roads

The design of dual two lane carriageway roads should be based on 75 per cent of the number of commercial vehicles in each direction. For dual three-lane carriageway and dual four lane carriageway, the distribution factor will be 60 per cent and 45 per cent respectively.

It is taken as 0.75 from clause 4.5.1 of IRC 37-2012.

VII. DAILY TRAFFIC VOLUME

The initial traffic survey data was available for the year 2015. Estimate of initial daily average traffic flow for any road should normally be based on at least 7 days, 24 hour classified traffic counts. Table 1 & 2 shows the daily traffic count observed at the
Dang Adda in the year 2015. For this study only the counts for bus, Trucks (1,2 and 3 axles), canter and tractor were considered.

Table 1: Traffic Data Single Axle Load Vehicles given below:

<table>
<thead>
<tr>
<th>SR NO.</th>
<th>NAME OF VEHICLES</th>
<th>TOTAL LOAD(T)</th>
<th>AXLE LOAD CLASS (T)</th>
<th>MEDIAN LOAD (T)</th>
<th>NO. OF VEHICLE(N)</th>
<th>(VDF) VEHICLE DAMAGE FACTOR</th>
<th>VDF*N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Truck 6 tyres</td>
<td>30</td>
<td>18-20</td>
<td>19</td>
<td>22</td>
<td>31.36</td>
<td>689.92</td>
</tr>
<tr>
<td>2</td>
<td>Truck 6 tyres</td>
<td>28</td>
<td>17-19</td>
<td>18</td>
<td>28</td>
<td>25.26</td>
<td>707.28</td>
</tr>
<tr>
<td>3</td>
<td>Truck 6 tyres</td>
<td>26</td>
<td>16-18</td>
<td>17</td>
<td>32</td>
<td>20.098</td>
<td>643.136</td>
</tr>
<tr>
<td>4</td>
<td>Truck 6 tyres</td>
<td>25</td>
<td>15-17</td>
<td>16</td>
<td>67</td>
<td>15.77</td>
<td>1056.59</td>
</tr>
<tr>
<td>5</td>
<td>Loaded canter</td>
<td>21</td>
<td>14-16</td>
<td>15</td>
<td>21</td>
<td>12.18</td>
<td>255.78</td>
</tr>
<tr>
<td>6</td>
<td>Loaded canter</td>
<td>20</td>
<td>13-15</td>
<td>14</td>
<td>35</td>
<td>9.24</td>
<td>323.40</td>
</tr>
<tr>
<td>7</td>
<td>Loaded canter</td>
<td>20</td>
<td>12-14</td>
<td>13</td>
<td>35</td>
<td>6.87</td>
<td>247.32</td>
</tr>
<tr>
<td>8</td>
<td>Loaded canter</td>
<td>18</td>
<td>11-13</td>
<td>12</td>
<td>64</td>
<td>4.99</td>
<td>319.36</td>
</tr>
<tr>
<td>9</td>
<td>Loaded canter</td>
<td>16</td>
<td>9-11</td>
<td>10</td>
<td>81</td>
<td>2.406</td>
<td>194.886</td>
</tr>
<tr>
<td>10</td>
<td>Loaded bus</td>
<td>14</td>
<td>8-10</td>
<td>9</td>
<td>83</td>
<td>1.578</td>
<td>130.974</td>
</tr>
<tr>
<td>11</td>
<td>Loaded bus</td>
<td>12</td>
<td>7-9</td>
<td>8</td>
<td>71</td>
<td>0.985</td>
<td>69.935</td>
</tr>
<tr>
<td>12</td>
<td>Unloaded bus &amp; truck</td>
<td>8</td>
<td>4-6</td>
<td>5</td>
<td>53</td>
<td>0.15</td>
<td>7.95</td>
</tr>
<tr>
<td>13</td>
<td>Unloaded canter</td>
<td>4.5</td>
<td>2-4</td>
<td>3</td>
<td>76</td>
<td>0.0195</td>
<td>1.482</td>
</tr>
<tr>
<td>14</td>
<td>Loaded tractor trolley</td>
<td>9.3</td>
<td>5-7</td>
<td>6</td>
<td>87</td>
<td>0.312</td>
<td>27.144</td>
</tr>
<tr>
<td>15</td>
<td>Unloaded tractor trolley &amp; other</td>
<td>3</td>
<td>1-3</td>
<td>2</td>
<td>22</td>
<td>0.0038</td>
<td>0.0836</td>
</tr>
</tbody>
</table>

\[ \sum=778 \quad \sum=4675.2406 \]

Table 2: Traffic Data Multiple Axle Load Vehicles given below:

<table>
<thead>
<tr>
<th>SR NO.</th>
<th>NAME OF VEHICLE</th>
<th>TOTAL LOAD(T)</th>
<th>AXLE LOAD (T)</th>
<th>MEDIA N LOAD (T)</th>
<th>NO. OF VEHICLE(N)</th>
<th>(VDF) VEHICLE DAMAGE FACTOR</th>
<th>VDF*N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Truck (18 tyres with 3 rear axle)</td>
<td>80</td>
<td>54-57</td>
<td>56</td>
<td>14</td>
<td>38.50</td>
<td>539.00</td>
</tr>
<tr>
<td>2</td>
<td>Truck (18 tyres with 3 rear axle)</td>
<td>78</td>
<td>51-54</td>
<td>53</td>
<td>18</td>
<td>30.89</td>
<td>556.02</td>
</tr>
<tr>
<td>3</td>
<td>Truck (18 tyres with 3 rear axle)</td>
<td>76</td>
<td>48-51</td>
<td>50</td>
<td>26</td>
<td>24.47</td>
<td>636.22</td>
</tr>
<tr>
<td>4</td>
<td>Truck (18 tyres with 3 rear axle)</td>
<td>74</td>
<td>44-48</td>
<td>46</td>
<td>42</td>
<td>17.53</td>
<td>736.26</td>
</tr>
<tr>
<td>5</td>
<td>Truck (14 tyres with 3 rear axle)</td>
<td>70</td>
<td>40-44</td>
<td>42</td>
<td>52</td>
<td>12.18</td>
<td>633.36</td>
</tr>
<tr>
<td>6</td>
<td>Truck (14 tyres with 3 rear axle)</td>
<td>63</td>
<td>38-42</td>
<td>40</td>
<td>62</td>
<td>10.02</td>
<td>621.24</td>
</tr>
<tr>
<td>7</td>
<td>Loaded Truck (10 tyress with 2 rear axle)</td>
<td>48</td>
<td>34-38</td>
<td>36</td>
<td>28</td>
<td>34.50</td>
<td>966.00</td>
</tr>
<tr>
<td>8</td>
<td>Loaded Truck (10 tyress with 2 rear axle)</td>
<td>50</td>
<td>30-34</td>
<td>32</td>
<td>43</td>
<td>21.54</td>
<td>926.22</td>
</tr>
<tr>
<td>9</td>
<td>Loaded Truck (10 tyress with 2 rear axle)</td>
<td>48</td>
<td>27-30</td>
<td>29</td>
<td>38</td>
<td>14.53</td>
<td>552.14</td>
</tr>
<tr>
<td>10</td>
<td>Unloaded Truck ( 2 rear axle)</td>
<td>10</td>
<td>7-9</td>
<td>8</td>
<td>212</td>
<td>0.084</td>
<td>17.808</td>
</tr>
<tr>
<td>11</td>
<td>Unloaded Truck ( 3 rear axle)</td>
<td>12</td>
<td>8-10</td>
<td>9</td>
<td>408</td>
<td>0.0256</td>
<td>10.48</td>
</tr>
</tbody>
</table>

\[ \sum=943 \quad \sum=194.713 \]

Indicative VDF value according to IRC: 37-2012

- Single axle with dual wheels on either side = (axle load in KN/80)\(^4\)
- Tandem axle with dual wheels on either side = (axle load in KN/148)\(^4\)
- Tridem axle with dual wheels on either side = (axle load in KN/224)\(^4\)

VDF is calculated from equation

For Truck (6 Tyre) VDF = \([(19*9.9640)/80]^4 = 31.36\)
So for 20 Truck VDF = 22*31.36 = 689.94
Similarly we can calculate VDF for other vehicles also.
Total sum of (VDF*N) = 4675.2406 + 6194.713 = 10869.9536
Total Number of Vehicles = 778 + 943 = 1721

7.1 Design Traffic – Cumulative Million Standard Axles
Based on the above said parameters the design traffic in terms of CMSA is computed for a design period (n) of 15 years.
\[ N_s = \frac{365 \times [(1+r)^n-1] \times A \times D \times F}{r} \]

\( N_s \): The cumulative number of standard axles to be catered for in the design in terms of MSA
\( A \): Initial traffic in the year of completion of construction in terms of number of commercial vehicles per day.
\( D \): Lane distribution factor.
\( F \): Vehicle Damage Factor (VDF).

\( n \): Design life in years.
\( r \): Annual growth rate of commercial vehicles (for 5% annual growth rate \( r=0.05 \)).

For \( n = 20 \) years
\[ N_s = \left[ 365 \times (1+0.05)^20 - 1 \right] \times 1721 \times 0.75 \times 6.32 \] / 0.05
\[ N_s = 98.45 \text{ msa.} \]

7.2 Design Thickness of Conventional Layer
A subgrade effective CBR of 7.1 % is adopted for design. If soil having an effective CBR of 7.1 % is not available, suitable soil stabilization techniques shall be adopted to improve the sub-grade strength. Crust Composition is obtained from Pavement Design Catalogue of IRC: 37-2012 for 7.1% CBR and for Design Traffic in MSA.

<table>
<thead>
<tr>
<th>Design Period</th>
<th>20 Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective CBR</td>
<td>7.1%</td>
</tr>
<tr>
<td>BC (mm)</td>
<td>49</td>
</tr>
<tr>
<td>DBM (mm)</td>
<td>119</td>
</tr>
<tr>
<td>WMM (mm)</td>
<td>250</td>
</tr>
<tr>
<td>GSB (mm)</td>
<td>227</td>
</tr>
<tr>
<td>TOTAL (mm)</td>
<td>645</td>
</tr>
</tbody>
</table>

7.3 Cross Check for Safety
The actual values of strain as calculated using IITPAVE software. The comparison of these values is tabulated below:

<table>
<thead>
<tr>
<th>Location/ Type of Strain</th>
<th>Allowable Strain</th>
<th>Actual Strain From IITPAVE</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Tensile Strain in Bituminous Layer</td>
<td>( \epsilon_t = 170.65 \times 10^{-6} )</td>
<td>167.2 \times 10^{-6}</td>
<td>Safe</td>
</tr>
<tr>
<td>Vertical Compressive Strain on Subgrade</td>
<td>( \epsilon_v = 320.09 \times 10^{-6} )</td>
<td>276.4 \times 10^{-6}</td>
<td>Safe</td>
</tr>
</tbody>
</table>

7.4 Design Thickness of Non-Conventional With Conventional Layer
In place of conventional layers of WBM/WMM base course of the pavement, cement treated base layers can be provided. A crack relief layer of wet mix macadam of thickness 100 mm sandwiched between the bituminous layer and cement treated layer is much more effective in arresting the propagation of cracks from the cementitious base to the bituminous layer, given in Table 5.

<table>
<thead>
<tr>
<th>Design Period</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective CBR</td>
<td>7.1%</td>
</tr>
<tr>
<td>BC (mm)</td>
<td>50</td>
</tr>
<tr>
<td>DBM (mm)</td>
<td>50</td>
</tr>
<tr>
<td>Aggregate Inter- Layer (mm)</td>
<td>100</td>
</tr>
<tr>
<td>CT Base (mm)</td>
<td>190</td>
</tr>
<tr>
<td>GSB (mm)</td>
<td>250</td>
</tr>
<tr>
<td>TOTAL (mm)</td>
<td>640</td>
</tr>
</tbody>
</table>

7.5 Cross Check for Safety
The actual values of strain as calculated using IITPAVE software. The comparison of these values is tabulated below:
<table>
<thead>
<tr>
<th>Location/ Type of Strain</th>
<th>Allowable Strain</th>
<th>Actual Strain From IITPAVE</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal Tensile Strain in Bituminous Layer</td>
<td>170.65*10^{-6}</td>
<td>129.20*10^{-6}</td>
<td>Safe</td>
</tr>
<tr>
<td>Vertical Compressive Strain on Subgrade</td>
<td>320.09*10^{-6}</td>
<td>179.00*10^{-6}</td>
<td>Safe</td>
</tr>
<tr>
<td>Horizontal Tensile Strain in Cementitious Layer</td>
<td>71.07*10^{-6}</td>
<td>62.04*10^{-6}</td>
<td>Safe</td>
</tr>
</tbody>
</table>

### VIII. COST ANALYSIS OF THE PAVEMENTS

The rates have been taken from rate analysis given in Specification of Road and Bridge MORT&H PWD Haryana & Haryana Schedule Rate

**Table 7 Cost Analysis of the pavement with Conventional material**

<table>
<thead>
<tr>
<th>Design Life (Years)</th>
<th>Crust Material</th>
<th>Road Pavement Dimension</th>
<th>Total Quantity (m³)</th>
<th>Rate par m³ (Lacs)</th>
<th>Total Cost of Material Rupees per m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>GSB</td>
<td>7.0 0.227 1000</td>
<td>1589</td>
<td>904</td>
<td>14.37/-</td>
</tr>
<tr>
<td></td>
<td>WMM</td>
<td>7.0 0.250 1000</td>
<td>1750</td>
<td>1068</td>
<td>18.69/-</td>
</tr>
<tr>
<td></td>
<td>DBM</td>
<td>7.0 0.119 1000</td>
<td>833</td>
<td>7205</td>
<td>60.02/-</td>
</tr>
<tr>
<td></td>
<td>BC</td>
<td>7.0 0.049 1000</td>
<td>343</td>
<td>9111</td>
<td>31.25/-</td>
</tr>
</tbody>
</table>

TOTAL COST 1 KM OF ROAD PAVEMENT 124.33/-

**Table 8 Cost Analysis of the pavement with Non-Conventional with conventional material**

<table>
<thead>
<tr>
<th>Design Life (Years)</th>
<th>Crust Material</th>
<th>Road Pavement Dimension</th>
<th>Total Quantity (m³)</th>
<th>Rate par m³ (Lacs)</th>
<th>Total Cost of Material Rupees per m³ (Lacs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>GSB</td>
<td>7.0 0.250 1000</td>
<td>1750</td>
<td>904</td>
<td>15.82/-</td>
</tr>
<tr>
<td></td>
<td>CT Base</td>
<td>7.0 0.190 1000</td>
<td>1330</td>
<td>1961</td>
<td>25.97/-</td>
</tr>
<tr>
<td></td>
<td>AGG. Layer</td>
<td>7.0 0.100 1000</td>
<td>700</td>
<td>1068</td>
<td>07.47/-</td>
</tr>
<tr>
<td></td>
<td>DBM</td>
<td>7.0 0.050 1000</td>
<td>350</td>
<td>7205</td>
<td>07.47/-</td>
</tr>
<tr>
<td></td>
<td>BC</td>
<td>7.0 0.050 1000</td>
<td>350</td>
<td>9111</td>
<td>31.88/-</td>
</tr>
</tbody>
</table>

TOTAL COST 1 KM OF ROAD PAVEMENT 106.35/-

### IX. CONCLUSION

We can conclude that the design of Flexible Pavement using non-conventional with conventional layer requires equal/ less thickness of pavement and less quantity of bitumen (which is one of costlier material of pavements, saving of bitumen layer up to 40 %) which leads to less usage of material specially the bitumen. Saving of bitumen and more usage of cement is a better practice as cement is abundantly available which bitumen depends on the imports. The traffic and sub-grade soil characteristics are necessary in order to design a pavement. The IRC method of design can be used to find the total pavement thickness due to its simple approach. The material rates have been taken from rate analysis given in Specification of Road and Bridge MORT&H PWD Haryana & Haryana Schedule Rate, it conclude that non-conventional with conventional layer pavement is require less cost than conventional layer flexible pavement (saving 14 % of cost).

**REFERENCES**
