Case Study

A FIELD STUDY ON CAUSES OF FAILURE OF BITUMINOUS PAVEMENTS

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Roads are pavements specifically designed to carry men and material to various destinations and should last for the period for which they have been designed. A field case study is presented in the present article to illustrate the failure of flexible pavement. Traffic study was conducted along with other tests to find out various causes of failure of the road chosen in the case study. A comparative study was made between the design of the road at the time of construction of the road and present traffic and other design factors. A design of flexible pavement is also given for the present traffic and soil characteristics as per IRC 37-2001 specifications.

Keywords: Pavement failure, Bituminous Roads, Traffic Study, Pavement Design, IRC 37: 2001

INTRODUCTION

Roads are pavements specifically designed to carry men and material to various destinations and should last for the period for which they have been designed. Rigid or Flexible pavements are constructed to fulfill the need of transport and the bitumen roads belong to the category of flexible pavements whereas cement concrete roads belong to the category of rigid pavement.

Failure of bitumen roads is a very common problem and has been drawing the attention of the state and central government authorities like NHAI, RDC, and RRDA, PMGSY etc. The phenomenon of failure has been observed to occur in national highways, state highways, rural roads and even internal roads of the metros.

There are multiple reasons for failure of bitumen roads and a variety of known and unknown factors responsible for such failures. More important factor is the error in following instructions given in the manuals for every stage of road construction, may it be raising of a new road or improvement of existing road in all the cases the guidelines given in the manuals in respect of materials to be used, quality control measures to be strictly adhered to and number of checks and rechecks by different agencies engaged in the task of constructing quality bitumen roads.

It has been observed that frequent damage to the bitumen roads immediately after the construction of roads takes place.

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Typical Layers of a Flexible Pavement

Typical layers of a conventional flexible pavement includes seal coat, surface course, tack coat, binder course, prime coat, base course, sub-base course, compacted sub-grade, and natural sub-grade (Figure 1).

Seal Coat
Seal coat is a thin surface treatment used to water-proof the surface and to provide skid resistance.

Tack Coat
Tack coat is a very light application of bitumen, usually bitumen emulsion diluted with water. It provides proper bonding between two layer of binder course and must be thin, uniformly cover the entire surface, and set very fast.

Prime Coat
Prime coat is an application of low viscous cutback bitumen to an absorbent surface like granular bases on which binder layer is placed. It provides bonding between two layers. Unlike tack coat, prime coat penetrates into the layer below, plugs the voids, and forms a water tight surface.

Surface course is the layer directly in contact with traffic loads and generally contains superior quality materials. They are usually constructed with dense graded bitumen concrete (AC). The functions and requirements of this layer are:

- It provides characteristics such as friction, smoothness, drainage, etc. Also it will prevent the entrance of excessive quantities of surface water into the underlying base, sub-base and sub-grade,
- It must be tough to resist the distortion under traffic and provide a smooth and skid-resistant riding surface,
- It must be water proof to protect the entire base and sub-grade from the weakening effect of water.

Binder Course
This layer provides the bulk of the bitumen concrete structure. Its chief purpose is to distribute load to the base course The binder course generally consists of aggregates having less bitumen and doesn’t require quality as high as the surface course, so replacing a part of the
surface course by the binder course results in more economical design.

**Base Course**
The base course is the layer of material immediately beneath the surface of binder course and it provides additional load distribution and contributes to the sub-surface drainage. It may be composed of crushed stone, crushed slag, and other untreated or stabilized materials.

**Sub-Base Course**
The sub-base course is the layer of material beneath the base course and the primary functions are to provide structural support, improve drainage, and reduce the intrusion of fines from the sub-grade in the pavement structure. If the base course is open graded, then the sub-base course with more fines can serve as a filler between sub-grade and the base course. A sub-base course is not always needed or used. For example, a pavement constructed over a high-quality, stiff sub-grade may not need the additional features offered by a sub-base course. In such situations, sub-base course may not be provided.

**Sub-grade**
The top soil or sub-grade is a layer of natural soil prepared to receive the stresses from the layers above. It is essential that at no time soil sub-grade is overstressed. It should be compacted to the desirable density, near the optimum moisture content.

**PAVEMENT FAILURE**
Common features indicating pavement failures:

1. Rutting
2. Cracking

### A. Longitudinal
a) Fatigue cracking
b) Single crack in the wheel path
c) Alligator cracking
d) Seasonal (frost heave) cracks
e) Joint construction cracking
f) Edge (verge) cracking

### B. Transversal (thermal) cracking

### C. Pattern cracks
a) Block Cracking
b) Joint Reflection Cracking
3. Potholes
4. Bleeding
5. Ravelling
6. Stripping
7. Corrugation and shoving
8. Segregation
9. Patching
10. Polishing
11. Depressions
12. Slippage cracking

If any one of the above features are observed on any bituminous surfaces (Flexible Pavement) its known as the failure of that pavement. If these failures occur either immediately after construction or during the design life of that road its commonly known as failure of flexible pavement.

**Photographs of Different Types of Distress in Flexible Pavement**
<table>
<thead>
<tr>
<th>Photo No. 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.jpg" alt="Photo 1" /></td>
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</table>

<table>
<thead>
<tr>
<th>Photo No. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image2.jpg" alt="Photo 2" /></td>
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</tbody>
</table>

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CAUSES OF DISTRESS
Common Reasons for Failures:

1. Instability of bituminous mixes (coarse or fine aggregate too rounded or smooth textured)
2. Low modulus base course
3. Thin wearing course
4. Dragging of pavers during laying when bituminous mix temperatures were low
5. High stress due to braking and acceleration movements
6. Inadequate stability of bituminous surface (excessive moisture)
7. Compaction of base in wave form
8. Faulty paver behaviour with some mixes (contamination caused by oil spillage)
9. Heavy traffic on steep downgrade or upgrade
10. Stopping at intersection stop lights or roundabout
11. Inadequate stability of base course
12. Inadequate pavement thickness
13. Inadequate compaction of structural layers
14. Unstable bituminous mixes
15. Unstable shoulder material which does not provide adequate lateral support
16. Overstressed subgrade which deforms permanently
17. Unstable granular bases or subbases
18. Differential settlement of subgrade or base materials
19. Settlement of services and / or widening of trenches
20. Volume change of subgrade due to environmental influences
21. Settlement due to instability of embankment
22. Excessive bitumen in the surface layer. On hot days the binder expands into air voids; if the volume of air voids is too low, continued expansion results in lower stability of the mix with the consequence that traffic will force out excess binder to the surface.
23. Paving over flushed surfaces. The excess bitumen on the old surface may be pumped up through the new paving over period of time.
24. Paving over excessively primed surfaces
25. Lack of proper rolling during placement on hot bituminous mix.
26. Failure to protect a newly constructed surface from traffic until the bitumen cured sufficiently.
27. Insufficient bitumen content
28. Poor adhesion of bitumen binder to aggregate particles due to wet aggregate
29. Inadequate compaction or construction during wet weather
30. Deterioration of binder and/or aggregate
31. Inadequate resistance to polishing of surface aggregates particularly in areas of heavy traffic movements or where high stresses are developed between surface and tyres
32. Use of naturally smooth uncrushed aggregates
33. Inadequate cleaning or inadequate tack cot before placement of upper layers
34. Seepage of water through bitumen, especially in cracks, to break the bond between surface and lower layers.

35. Weak, loose layer immediately underlying seal

36. Adhesion of surface binder to vehicle tyres.

FAILURE OF BITUMINOUS PAVEMENT – A CASE STUDY

Jabalpur to Patan road is a typical example of failure of bituminous roads. Most of the common features mentioned in above paragraphs were evident on this very important road.

A detailed field study was conducted by the authors to find out the various causes of the failure of the road.

The study was carried out in following stages:

1. Preliminary Survey or Reconnaissance

2. Detailed Field Study and Sample Collection

3. Laboratory Tests

After the study the data was analyzed to find the causes of the failure of the study road. Conclusions were drawn based on the data obtained from the field study and laboratory tests and recommendations were put forward to prevent such types of failures.

This road was constructed in the year 2007 by state public works department (PWD) of Madhya Pradesh. The design of the crust and the pavement was as follows:

The above design was done as per the Indian Road Congress (IRC) standards.

The code used was IRC: 37-2001 for the design of the above mention pavement.

The design data which was used is as follows:

- Number of commercial vehicles per day (CVPD) = 270
- The California Bearing Ratio (CBR) of the subgrade = 5.0 %

The design procedure adopted for the study road was as follows:

Design Traffic Calculation

1. No. of commercial vehicles per day = 270

2. Expected No. of vehicles at the time of completion of the construction

\[ A = P(1+r)^t \]

\[ A = \text{Expected No. of vehicles at the time of completion of the construction} \]

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Pavement Layer</th>
<th>Thickness of layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Semi Dense Bituminous Carpet (SDBC)</td>
<td>25 mm</td>
</tr>
<tr>
<td>2</td>
<td>Bituminous Macadam (BM)</td>
<td>50 mm</td>
</tr>
<tr>
<td>3</td>
<td>Water Bound Macadam (Grade III)</td>
<td>75 mm</td>
</tr>
<tr>
<td>4</td>
<td>Water Bound Macadam (Grade II)</td>
<td>75 mm</td>
</tr>
<tr>
<td>5</td>
<td>Water Bound Macadam (Grade I)</td>
<td>100 mm</td>
</tr>
<tr>
<td>6</td>
<td>Granular Sub Base</td>
<td>180 mm</td>
</tr>
<tr>
<td>7</td>
<td>Subgrade</td>
<td>300 mm</td>
</tr>
</tbody>
</table>

Table 1: The Design of the Existing Crust

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Table 2: Traffic Volume Count Details at the time of Design of the Road

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>Average No. of Pass/ day</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCV Goods</td>
<td>84</td>
</tr>
<tr>
<td>LCV Bus</td>
<td>29</td>
</tr>
<tr>
<td>MCV</td>
<td>4</td>
</tr>
<tr>
<td>HCV, Bus</td>
<td>26</td>
</tr>
<tr>
<td>Tractor with Laden Trolley</td>
<td>43</td>
</tr>
<tr>
<td>HCV, 2- Axle Trucks</td>
<td>53</td>
</tr>
<tr>
<td>HCV, 3- Axle Trucks</td>
<td>27</td>
</tr>
<tr>
<td>HCV, Multi - Axle Trucks</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total Number of Commercial Vehicles</strong></td>
<td><strong>270</strong></td>
</tr>
</tbody>
</table>

Total number of Commercial Vehicles Per Day (CVPD) = 270

\[ A = P(1+r)^t \]
\[ A = 270 (1+ 0.075)^3 = 335 \text{ CVPD} \]

Design Traffic (N)

\[ N = \frac{365 \times [(1+r)^n - 1]}{r} \times A \times D \times F \]

where,

- \( N \) = The cumulative number of Standard Axles to be catered for the design in terms of million standard axles (MSA)
- \( A \) = Initial traffic in the year of completion of road construction in terms of the number of the commercial vehicles per day (CVPD)
- \( D \) = Lane distribution factor (Taken as 1.0)
- \( F \) = Vehicle Damage factor (Taken as 1.5)
- \( n \) = Design life in years (Taken as 15 yrs)
- \( r \) = Annual growth rate of commercial vehicles (Taken as 7.5% or 0.075)

\[ N = 365 \times [(1+ 0.075)^3 - 1] \times 335 \times 1 \times 1.5 / 0.075 \text{ msa} \]
\[ N = 4.7 \text{ msa} \]

Design MSA = 5

Existing Crust Design as per IRC 37-2001

For above Design Traffic \( N = 5 \text{ msa} \) and CBR = 7% of Subgrade

The total thickness of the crust = 505 mm

Table 3: Variation in Designed and Actual Thickness in the Pavement Layers

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Designation</th>
<th>Design Thickness (in mm)</th>
<th>Actual Average Thickness (in mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wearing Course</td>
<td>SDBC</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>BM</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>Base Course</td>
<td>WBM GIII</td>
<td>75</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>WBM GI</td>
<td>75</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>WBM GI</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>Sub- base Course</td>
<td>GSB</td>
<td>180</td>
</tr>
<tr>
<td>7</td>
<td>Total Crust Thickness</td>
<td>505 mm</td>
<td>22</td>
</tr>
</tbody>
</table>

Total Crust Thickness = 505 mm
### Table 4: Traffic Volume Count Details at the time of Beginning of the Study

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>No. of Pass/ day</th>
<th>Date</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>07/11/2012</td>
<td>09/11/2012</td>
</tr>
<tr>
<td>LCV Goods</td>
<td></td>
<td>181</td>
<td>177</td>
</tr>
<tr>
<td>LCV Bus</td>
<td></td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>MCV</td>
<td></td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Standard Bus</td>
<td></td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Tractor/Trolley</td>
<td></td>
<td>98</td>
<td>97</td>
</tr>
<tr>
<td>2- Axle Trucks</td>
<td></td>
<td>100</td>
<td>96</td>
</tr>
<tr>
<td>3- Axle Trucks</td>
<td></td>
<td>78</td>
<td>85</td>
</tr>
<tr>
<td>Multi- Axle Trucks</td>
<td></td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Total Number of Commercial Vehicles</td>
<td></td>
<td>542</td>
<td>543</td>
</tr>
</tbody>
</table>

Photographs Showing Heavy Traffic on the Study Road

**Photo No. 11**
Photo No. 12

Photo No. 13

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Total number of Commercial Vehicles Per Day (CVPD) = 540

Traffic Calculation

1. No. of commercial vehicles per day = 540
2. Expected No. of vehicles at the time of completion of the construction
   \[ A = P(1+r)^t \]
   \[ A = \text{Expected No. of vehicles at the time of completion of the construction} \]
   \[ P = \text{No. of vehicles at the time of count} \]
   \[ r = \text{Annual rate of increase of heavy vehicles (7.5\%)} \]
   \[ t = \text{Time to complete the construction of road (3 YRS)} \]
   \[ A = P(1+r)^t \]
   \[ A = 540 \times (1+0.075)^3 = 670 \text{ CVPD} \]

\[
\text{Traffic } N = \frac{365 \times ((1+r)^n - 1)}{r} \times A \times D \times F
\]

where,

\[ N = \text{The cumulative number of Standard Axles to be catered for the design in terms of million standard axles (MSA)} \]

\[ A = \text{Initial traffic in the year of completion of road construction in terms of the number of the commercial vehicles per day (CVPD)} \]

\[ D = \text{Lane distribution factor (Taken as 1.0)} \]

\[ F = \text{Vehicle Damage factor (Taken as 1.5)} \]

\[ n = \text{Design life in years (Taken as 15 yrs)} \]

\[ r = \text{Annual growth rate of commercial vehicles (Taken as 7.5 \% or 0.075)} \]

\[ N = 365 \times [(1+0.075)^{15} - 1] \times 670 \times 1 \times 1.5/0.075 \times \text{msa} \]
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\[ N = 9.58 \text{ msa} \]

Design MSA = 10

Crust Design as per present traffic spectrum, IRC 37-2001

For above Design Traffic \( N = 10 \text{ msa} \) and CBR = 7\% of Subgrade

The total thickness of the crust = 580 mm

**CONCLUSION**

The daily traffic volume has increased considerably on the study road. It has increased by more than 100\% as per the traffic study done during the study in the year 2012. This increase in the traffic took place in a very short span of time. The increment in the design traffic is phenomenal in terms of commercial vehicles per day.

Prior to the design of the road, the average traffic volume was around 270 commercial vehicles per day in the year 2003 which got increased to around 543 commercial vehicles per day.

The increase of traffic volume on the road was due to the construction of Jabalpur- Damoh road via Katangi. All the commercial vehicles started taking Jabalpur- Damoh route via Patan and traffic volume was suddenly shoot up.

The road was not at all able to bear such a heavy traffic load which caused the failure of the study road.

There were some other reasons identified for the failure of the study road:

1. The CBR values of the subgrade, determined in the laboratory were below the designed CBR value of 7\%. Low CBR values cause uneven settlement of the different pavement layers causes rutting and undulations on the top surface of the pavement.

2. The width of the carriageway was kept 3.75 m in the study road with unpaved shoulders on both sides of the carriageway. The crossing of heavy vehicles became a big problem which further damage and scarify the sides of the bituminous layer.

3. The soil below the subgrade was found to be the Black Cotton soil, which exhibits the characteristics of the excessive swelling in presence of moisture and shrinkage in the absence of moisture. The soil also exerted heavy swelling pressure on the subgrade and made it vulnerable and susceptible to failure.

4. The shoulders were found not properly compacted due to which rain water started accumulating in the ruts created on the
shoulders and the slowly entered the pavement layers caused damages to it.

5. The relative compaction of various layers was also found less than 98% in some cases which is not desirable from the point of view of road construction.

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