Systematic Evaluation and Analysis of Bituminous Road Pavement Failure

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Abstract: Presence of good quality roads and better connectivity to all habitants is counted one of the tool to see the development and development index of any country. In the past 30-40 years, roads were constructed rapidly; hence road length has increased to a greater extent in India. This paper will provide a systematic way of investigation and collection of field data about different types of bituminous pavement failure and their nature. This sample research, quantitative data is collected for the 10 km road stretch of Mumbai-Goa NH-66. This study site is a typical representation of the condition of bituminous pavements in India and most of the parts of the world. However, their nature and magnitude change depends upon their meteorological, geographical parameters, type of road, traffic load etc. The research methodology is framed in four phases. Data is collected by trained engineers and staff working at the field level responsible for the construction and maintenance of bituminous road under the guidance of an experienced highway engineer. Detailed analysis of bituminous pavement distress is carried out systematically. It is also interpreted and represented by the statistical tools to understand it more broadly. The seriousness about type of distress and its effect on the overall failure of asphalt pavement is worked out. Results/findings worked out under this research paper is effective and concentrated the eyes of the researcher towards the root causes of asphalt pavement failure. This will definitely help the present and new researchers to further study and work on these root causes to find out the best possible solutions.

Keywords: Pavement Distress; Pavement Failure; Asphalt; Bituminous Road; Forensic Investigation

1. Introduction
Damaged road surface causes interruption to traffic flow, road structure failure, delay in travel time, rise in expenditure on maintenance cost of road, increase in vehicle maintenance cost, reduced life of the road, the possibility of accidents, defaming the image of the department in public, and above all, criticism from the public and media. It is necessary to maintain the road free of potholes. Good customer service is one of the key objectives of highway maintenance. The number of potholes arising from monsoon damage and It has led to significant criticism from the print, electronic media and public in general about management and repair of potholes by concern authorities. There is a wider cost to the economy arising from potholes/repairs of road, including costs to the road users and
businesses through the disruption caused during repairs. The National Highway and National Highway Authority of India (NH and NHAI), Public Works Department (PWD), Zilla Parishad (ZP), and many Local Bodies (Corporation & Municipalities), among others, have raised concerns over the sustainability of current approaches to dealing with highway pavement failure, particularly potholes. State PWD and ZP have a total road length of about 301267 Kms [5] in Maharashtra State (India). It costs more than Rs. 250 Billions every year in repairing and filling the potholes on roads. Local bodies are also spending billions of rupees for repairing the potholes in the city area under their jurisdiction.

Different kinds of road surface distresses appear on the roads within one to two years after its construction. Therefore, it is essential to design the road pavements perfectly considering the standard of road, traffic volume, type of soil, rainfall, locally available materials, availability of modern machinery and construction equipment, etc. Design of bituminous road pavements should lead to the perfect solution for road surface failures and ultimately elimination of potholes on road to make roads permanently free of potholes. Stagnation of road surface and sub-surface water is also the prominent reason for the failure of road pavements. Therefore, quick drainage of the road surface and subsurface water is essential.

1.1 Types of Bituminous Road Pavement Failures:
The four major categories of common asphalt pavement surface failures and their subcategories are enumerated in Table-1 as follows [10]:

Table-1: Types of Bituminous Road Pavement Failure

| Cracking                  | Surface Deformation | Disintegration | Surface Defects |
|---------------------------|---------------------|----------------|-----------------|
| i) Fatigue cracking       | i) Rutting          | i) Potholes    | i) Ravelling    |
| ii) Longitudinal Cracking | ii) Corrugations    | ii) Patches    | ii) Bleeding    |
| iii) Transverse Cracking  | iii) Shoving        | iii) Polishing | iv) Delamination|
| iv) Block Cracking        | iv) Depressions     |                |                 |
| v) Slippage Cracking      | v) Swell            |                |                 |
| vi) Reflective Cracking   |                     |                |                 |
| vii) Edge Cracking        |                     |                |                 |

1.2 Literature Survey

There are many Books [2, 3, 11,16,20,21], Codes, Guidance Notes [6,7], Specifications [19], National and International Technical Journals, Publications of Indian Roads Congress [8,9,10], findings of National and International Seminars/Conferences, Technical Circulars issued by Highway/Road Authorities, Research works carried out by Research Institutes, Scientists and Engineers, which is published on the research topics.

To know the basics and concepts of bituminous road pavement failure and its branches following work is carried out by researchers:

1. Textbook literature [2,3,11,16,20,21], Guidance Notes [6,7], Codes and Specification [19] covered the types of road surface distresses, general causes of pavement failure, and formation of potholes, maintenance guidelines. Indian Roads Congress [8,9,10] recommended the general method of design of flexible pavements [8].

2. The pavement failure problems are caused due to several factors such as the water stagnation problems, traffic, the condition of the sub grade, climate, the poor-quality material, and problems of compaction. This study classified the type of road pavement damages for the road under the case study. The type of road damages in the case study are depressions, hair cracks, edge cracks, ravelling, alligator cracks, potholes. Road repairs have been done but the damage occurs because of the rain that falls on the surface of road pavement and does not flow into the
A drainage channel in the vicinity due to the elevation of the road. The land next to the road does not allow rainwater to flow into the drainage channels, this leads to flooding of water at the edge of the road and enter through the cracks are beginning to occur and becoming more severe because it is not addressed immediately [4].

3. The problems relating to pavement maintenance are still complex due to the dynamic nature of road pavements, where elements of the pavement are constantly changing, being added or removed. These elements deteriorate with time and therefore to maintain them in the good condition requires substantial expenditure [13,14].

4. The standing water /water stagnation on the road surface has always been a major problem. The stagnant water degrades the surface of the road resulting in the formation of potholes and wears off the surface of the road. The major source of stagnant water is an improper slope provided to the road. The study concentrates on providing an effective way to collect this stagnant water and to modernize the conventional system of drainage [1].

5. General causes of the bituminous road pavement failure and potholes formation, their root cause analysis and solutions for the pothole-free road under case study are explained in detail. Improper road drainage is a prime cause of road surface failure. Study of functional pavement surface failure is carried out & some solutions suggested by researcher [17, 18 & 22].

6. Set of guidance notes is intended to serve as a comprehensive reference for highway practitioners on the design of carriageway pavements in Hong Kong. It lays down the general principles and technical aspects to be considered while designing a pavement for new roads or widening/reconstruction of an existing road. The recommendations given in this set of guidance notes are not intended to be exhaustive. As state-of-the-practice evolves and situation warrants, designers may wish to propose design modifications aiming at a more cost-effective and durable pavement [7].

7. The first-ever porous asphalt pavement in India for rainwater harvesting has been constructed successfully by the Jaipur Development Authority in October 2012. Its design, construction, and performance have been described in this paper. Government should encourage (and mandate in critical areas) construction of porous asphalt pavements in urban areas. [15].

8. Porous asphalt pavement can be used for a parking lot or low-trafficked roads/streets. Water percolates slowly into the underlying soil. The porous parking lot or street can be integrated with a roof rainwater harvesting system in the buildings adjacent to it by diverting the roof water to the stone bed [23].

9. Some work is carried out by researchers to know the fatigue strength of asphalt mixture and fatigue life of asphalt pavement using three point fatigue bending test. This study concentrated for finding the reasons of fatigue failure of bituminous pavements [12, 24].

1.3 Objectives of the Research
As per the present literature survey, many research papers and studies concluded some of the causes of pavement failure and some solutions for them. However, newly constructed roads, existing improved roads show early signs of surface damages at some places within one to two years of its construction or improvement. Therefore, research in investigation and analysis of bituminous road pavement failures in which it will lead to the perfect solution for road surface damages. This study ultimately helps to make the bituminous pavement roads permanently free of potholes. With this gap of study, the following objectives are set for present research work:

1. Collection of asphalt pavement distress data.
2. Systematic evaluation and analysis of asphalt pavement distress,
3. Finding out the root causes of road pavement failure.

2. Methodology
The various phases of the research methodology and techniques to be used are as follows:
Phase I: There would be an extensive literature survey.
Phase II: Survey / Investigation of selected road lengths and Collection of data
To know the bituminous road pavement distresses.
Phase III: Interpretation and analysis of data, cause and effect analysis etc.
Phase IV: Results/Findings/Discussion/Conclusion

2.1 Study Section/ Site

To know the exact type & magnitude of asphalt pavement distress, the road stretch of Mumbai-Goa National Highway No.66 is selected for study. Figure-1 shows the location map of the selected road stretch and details of this stretch are as follows:
i) Geographical Location: Latitude - 17.2468° N to 17.1699° N, Longitude-73.5534° E to 73.5339° E
   ii) Approximate Year of Construction - 1960(1 Lane), 1985(2 Lane), Rehabilitation to 2 Lane (1995) and Rehabilitation to 4 lane - work in progress (2020)
   iii) Kms 251/000 to 261/000 in Sangmeshwar Taluqa of Ratnagiri District in Konkan Region of Maharashtra State
   iv) Type of soil: Mostly murrum and mix with small boulders
   v) Annual Average Rainfall - 4500 mm.
   vi) Period of Data Collection - 17/11/2019 to 16/12/2019
   vii) Type of Pavement - Flexible (Bituminous)
   viii) Formation width - 12m
   ix) Carriageway width - 7m
   x) Type of earlier treatments - WBM-30cm, BM-50mm, BC/OGC- 25/30 mm as per periodical renewals
   xi) Lastly renewed - 2013
   xii) Present condition - pavement failure at many places

Figure 1: Location Map of Road under Study
2.2 Forensic Investigation of selected road stretch

It is decided to carry out the forensic investigation of the selected road stretch in the following ways.

- Data Collection - To know the type & magnitude of distress
- Interview - Interview with people familiar with the road, interview related employees
- Nondestructive Evaluation - Visual Investigation, Detailed Condition Survey, Initial site visit, etc.
- Determination of root cause(s) - Analyze data to find likely failure cause, analyze collected data systematically.

2.3 Data Collection

Proper and accurate collection of data aims to systematic and realistic research. Training is required to choose the proper investigation method at the proper place, to learn how to take care of minimizing the error, to enter the produced data system so that it will be used comfortably during further stages. A team of experienced engineers & field staff working on-site were selected for this work. Special technical training had conducted for this staff before, during and after the work of data collection. A data collection sheet & several questions were framed to get the required information.

Data had collected on the proposed site in November & December 2019. Appointed team worked in different groups with healthy coordination and communication to collect the correct data. These technical groups performed different types of surveys and investigations, studying topographical & meteorological parameters of the proposed study site at a minute level to produce the accurate data. Furlong wise (taking observation/measurements for each 200-meter interval) is quantitative data is collected and recorded. After interaction with local people, team also got some specific qualitative information about the performance of the road surface.

Identifying the distresses on-site shall require high technical skill and knowledge about bituminous pavements. Results of any research work always depends upon accuracy and correctness of data. As per the detailed data collection sheet prepared, measurements are taken on-site for all the 18 types of identified bituminous surface distresses [10]. Abstracted and compiled sample sheets are shown below for fatigue failure (Table-1) and rutting failures (Table-2). Such data is also abstracted and compiled for all observed twelve types of distresses.

Table 2: Abstract - Data Sheet for Fatigue Failure

| Sr. No | Chainage From | Chainage To | No of Locations | Measurement Length | Measurement Width | Area (Sqm) |
|--------|----------------|-------------|----------------|--------------------|------------------|------------|
| 1      | 25100          | 25200       | 4              | 3                  | 1.5              | 18.00      |
| 2      | 25200          | 25300       | 5              | 9                  | 2.5              | 112.50     |
| 3      | 25300          | 25400       | 4              | 6                  | 4.5              | 135.00     |
| 4      | 25400          | 25500       | 5              | 7                  | 3                | 126.00     |
| 5      | 25500          | 25600       | 3              | 15                 | 3.5              | 210.00     |
| 6      | 25600          | 25700       | 4              | 6                  | 2.5              | 45.00      |
| 7      | 25700          | 25800       | 5              | 5                  | 2.5              | 50.00      |
| 8      | 25800          | 25900       | 4              | 6                  | 3.5              | 315.00     |
| 9      | 25900          | 26000       | 3              | 3                  | 2                | 42.00      |
| 10     | 26000          | 26100       | 4              | 3.5                | 2.5              | 35.00      |
| 11     | 26100          | 26200       | 5              | 1.5                | 2.5              | 18.75      |
Table 3: Abstract - Data Sheet for Rutting Failure

| Sr. No | Chainage From | Chainage To | No of Locations | Measurement Length | Measurement Width | Area (Sqm) |
|--------|---------------|-------------|-----------------|--------------------|-------------------|------------|
| 1      | 251000        | 252000      | 6               | 6                  | 3.5               | 126.00     |
| 2      | 252000        | 253000      | 4               | 5                  | 3.5               | 70.00      |
| 3      | 253000        | 254000      | 4               | 7                  | 3.5               | 98.00      |
| 4      | 254000        | 255000      | 2               | 3                  | 3.5               | 21.00      |
| 5      | 255000        | 256000      | 10              | 5                  | 3.5               | 175.00     |
| 6      | 256000        | 257000      | 1               | 30                 | 3.5               | 105.00     |
| 7      | 257000        | 258000      | 2               | 7                  | 3.5               | 49.00      |
| 8      | 258000        | 259000      | 3               | 4                  | 3.5               | 84.00      |
| 9      | 259000        | 260000      | 4               | 3.5                | 3.5               | 49.00      |
| 10     | 257000        | 258000      | 5               | 4                  | 3.5               | 70.00      |
| 11     | 258000        | 259000      | 4               | 5                  | 3.5               | 70.00      |
| 12     | 259000        | 260000      | 0               |                    |                   | 0.00       |
| 13     | 260000        | 261000      | 2               | 6                  | 3.5               | 42.00      |

Total Area of Fatigue Cracking for ch. 251+000 to ch 261+000 (10 Kms) in Sqmt = 2311.25

Total Area of Rutting for ch. 251+000 to ch 261+000 (10 Kms) in Sqmt = 959.00

2.4 Data Analysis
Representation of finding data concerning different parameters also cleared the picture of the considered subject finely. Failure of asphalt pavement is a very vast topic. Hence by studying asphaltic pavement failure with different approaches, one can easily reach to their root causes which indicates the further direction to the researcher to find out the solution. Table-4 shows the main category wise percentage and cumulative percentage of distresses. Figure-2 shows the category wise percentage distresses in the form of a pie chart.
**Table-4:** Main Category Wise Distress Percentage

| Sr. No. | Type              | Percentage Failure | Cumulative Percentage Failure |
|---------|-------------------|--------------------|------------------------------|
| 1       | Cracking          | 44.14              | 44.14                        |
| 2       | Disintegration    | 33.5               | 77.64                        |
| 3       | Surface Deformation | 22.12              | 99.76                        |
| 4       | Surface Defects   | 0.24               | 100                          |

**Figure-2:** Pie Chart showing the Category wise Distresses

**Table-5** shows the type of distress, number of locations, total area of distress, percentage area of distress with respect to total carriageway area of the road under case study and individual weight age percentage concerning the total damaged area.

**Table-5:** Abstract - Distress wise Asphalt Pavement Failure Area & their Percentage

| Sr. No | Type         | No of Locations | Area (Sqm) | Total Carriageway Area (SQM) | % of Individual surface defects | % Individual Weightage on total surface defects |
|--------|--------------|-----------------|------------|-------------------------------|--------------------------------|-----------------------------------------------|
| A      | Cracking     |                 |            |                               |                                |                                               |
| 1      | Fatigue      | 123             | 2111.25    | 70000                         | 3.302                          | 33.75                                         |
| 2      | Transverse   | 72              | 270.61     |                               | 0.387                          | 3.96                                          |
| 3      | Longitudinal | 79              | 403.25     |                               | 0.576                          | 5.89                                          |
| 4      | Edge cracking| 63              | 37.26      |                               | 0.053                          | 0.54                                          |
| **Total A** |           | **4.318**       | **44.14**  |                               |                                |                                               |
| B      | Surface Deformation |       |            |                               |                                |                                               |
| 1      | Rutting      | 50              | 959.00     | 70000                         | 1.370                          | 14                                            |
| 2      | Corrugation  | 38              | 228.75     |                               | 0.327                          | 3.34                                          |
| 3      | Shoving      | 16              | 291.50     |                               | 0.416                          | 4.26                                          |
| 4      | Depressions  | 18              | 35.85      |                               | 0.051                          | 0.52                                          |
| **Total B** |           | **2.164**       | **22.12**  |                               |                                |                                               |
| C      | Disintegration |               |            |                               |                                |                                               |
| 1      | Pot holes    | 181             | 197.88     |                               | 0.257                          | 2.63                                          |
Table 6 shows the sub category wise observed distress percentage & cumulative percentage.

|                | 2 Patches | 2114.00 | 3.020 | 30.87 |
|----------------|-----------|---------|-------|-------|
| **Total C**    |           |         | 3.277 |       |
| **Surface Defects** |         |         | 33.5  |       |
| 1 Ravelling    | 21        | 16.12   | 0.023 | 0.23  |
| 2 Bleeding     | 5         | 0.47    | 0.001 | 0.01  |
| **Total D**    |           |         | 0.024 | 0.24  |
| **Grand Total**| 688.00    | 6847.9  | 9.783 | 100.00|

**Figure-3**: Bar Chart showing the type of Distress & their Percentage in Total Failure

3. Results /Findings / Discussion

3.1 Experiment /Analysis

Innovative data collection system and data collection sheets have been prepared. These sheets designed in such a way that it should not miss any type of distress on the field and give the exact nature of distresses. Visual inspection and interaction with local people gave us the idea about distresses, their nature and the overall performance of the road under study. This qualitative information also supported this work. Many researchers worked on asphalt pavement failure and their solutions. Pavement failure is a very vast topic, so work done by a researcher in that field have the importance of their contribution. This paper emphasizes realistic observation and data collection at the grass-root level in the form of a forensic investigation by conducting non-destructive tests. Conventional matrices are adopted for analyzing the collected data.
3.2 Results/Findings

This work broadly has the following results/findings:

a) Among the four main categories of distresses on the bituminous pavement, three categories have shown their presence viz. cracking, disintegration & surface deformation. Surface defect distresses found to be negligible (refer Table-4 and Figure-2).

b) Out of 18 identified sub categories of distresses of bituminous pavement failure [10], 12 distresses are found on the road under study (Refer Table-5 and Figure-3).

c) Bituminous carriageway under study is 70,000 SqM, out of which 6,847.9 SqM (9.78%) road surface failure by some kind of distress (Refer Table-5).

d) Among 12 distresses found under study road, five distresses i.e., fatigue, patches, rutting, longitudinal cracks and shoving contributed about 90% of total distresses. Other 6 distresses have only 10% contribution (Refer Table-6).

e) Less or more about 50% of total failures fall under the major category - cracking distresses (Refer Table-5).

| Sr. No. | Type          | Individual weight age for surface defect | Cumulative Percentage |
|---------|---------------|-----------------------------------------|-----------------------|
| 1       | C- Fatigue    | 33.75                                   | 33.75                 |
| 2       | D- Patches    | 30.87                                   | 64.62                 |
| 3       | SD- Rutting   | 14.00                                   | 78.62                 |
| 4       | C- Longitudinal | 05.89                                   | 84.51                 |
| 5       | SD- Shoving   | 04.26                                   | 88.77                 |
| 6       | C- Transverse | 03.96                                   | 92.73                 |
| 7       | SD- Corrugation | 03.34                                   | 96.07                 |
| 8       | D- Potholes   | 02.63                                   | 98.70                 |
| 9       | C- Edge cracking | 00.54                                   | 99.24                 |
| 10      | SD- Depression | 00.52                                   | 99.76                 |
| 11      | DF- Ravelling | 00.23                                   | 99.99                 |
| 12      | DF- Bleeding  | 00.01                                   | 100                   |
| Total   |               |                                         | 100                   |

Note: C- Cracking, D- Disintegration, SD- Surface Deformation & DF- Surface Defects

3.3 Discussion

After summarising results and findings as above, it is found that fatigue, patches, rutting, longitudinal cracks, and shoving contribute about 90% of total distresses. Hence the researcher should concentrate on these distresses for construction as well as repairs of bituminous roads. The road under study falls in a heavy rainfall area (average annual rainfall- 4,500mm). It is observed that in other parts of
Maharashtra state where rainfall is less than 1,000 mm, even at these places similar failures are predominant. Therefore the findings of this work are applicable for roads in India and also for the location in the world where the conditions are similar.

To find the proper solution to any problem it is important to know the root causes. To improve the quality of asphalt pavements and to minimize the defects at an early age, it is important to focus on the root causes of these failures. Detailed study, analysis, experiments, laboratory testing, etc. needed to find the optimum solutions to these common distresses. There is a wide scope to research aspirants to work on these burning issues.

If researcher finds the solution on these problems, it will save billions of rupees of government organizations and local bodies every year. It is also widely accepted in the world that conditions of roads in any nation replicate their development status.

As a limitation of this paper, there is scope to work on road drainage. The study, investigation, and analysis of the surface and subsurface drainage of the road is also important. Comparative study of these parameters and their relation with one another is in progress for this road stretch.

4. Conclusion

a) Communication is one of the basic needs of people. Roadway transportation is the mode that handles the highest contribution as compared to railway, airway, and waterway. That is why it is important to construct, maintain the highway in a planned way with optimum cost. Sound research work is needed to take new steps to accept the challenges in this field.

b) Research in the investigation and analysis of bituminous road pavement failures in which it will lead to the perfect solution for road surface damages was the main aim of this research. This study ultimately helps to make the route mark towards making the bituminous pavement roads permanently free of potholes. As per the scheduled research methodology, the whole work is performed smoothly, accurately by studying the field observations meticulously. A detailed study is conducted under pavement failure categories separately. It provided a clear picture of the asphalt pavement distresses. One can study this vast topic of pavement failure category wise and work further for solutions.

c) Pavement distress data is collected by a trained and specialized team. Collected data is again rearranged and abstracted distress-wise such that it will give the answers to the question of the researcher. Data obtained is systematically evaluated, analyzed, and represented with the help of statistical tools to understand the results in a broader aspect. Objectives of the research which were set initially are fully achieved.

d) Results from the above study are clear and impressive. It indicated the concentration of the researcher to emphasize finding out the solutions on important root causes and distresses i.e., fatigue, patches, and rutting. This distress contributed about 80% of the failure of bituminous roads. Counteract against these distresses and minimizing or bringing their contribution to zero is the challenge to researchers in new construction or improvement/overlaying works and in giving solutions in maintaining the existing constructed roads.

e) It is expected to find better conclusion for design of bituminous road pavements for improvement and new construction of roads. It shall give proper bond between metal and bitumen, better fatigue strength and ductility. This will lead to better riding quality, saving in travel time, saving in vehicle maintenance cost to road users. This study direct research aspirants to further concentrate on these important points and work further to obtain better solutions.
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