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Scientific Study of Asphalt Road Surface Distress and their Role in the Design of Flexible Pavements

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Abstract *- Identifying the various locations, magnitude, and frequency of pavement distresses on the highway stretch under study. Examining the total pavement failure, distress, and individual weightage percentage, analyzing and reviewing the role of pavement distress in the design of asphalt pavement were the main objectives of the study. The forensic investigation of the selected road stretch was carried out through the experienced engineers engaged in the road construction and maintenance activity by data collection, interaction with the public, and employees familiar with the road, non-destructive evaluation by a primary site visit, condition Survey, visual investigations, etc. As per the present study of National Highway No.61, India, longitudinal cracking, ravelling, rutting, patches, and fatigue cracking are predominant, with their distress percentage as 32.71, 21.5, 19.82, 19.15, and 4.23, respectively. These five distress accounted for 97.41% of the weightage in bituminous pavement failure. Longitudinal cracking and ravelling are found to be predominant and such type of failure is the most common kind of pavement deterioration along with fatigue cracking and rutting on many roads for specific road segments. As a result, it must be taken into account along with other major pavement distress for effective solutions on them while designing the flexible pavements.*

Keywords - *Asphalt Pavement Distress, Pavement Design, Rutting, Fatigue Cracking, Longitudinal Cracking*

I. INTRODUCTION

Pavement design is a method of determining the most cost-effective mix of the layers of pavement (in terms of the type of materials and thickness) to fit the total expected traffic over the design life and soil foundation. Pavement structure design differs from bridges and building design because pavement design is still reliant on the empirical or the semi-empirical approaches and is no logical technique. Indian Roads Congress (IRC) Code, IRC-37: 2018 [1] is used in India for the design of flexible pavements. The design of pavement is divided into two elements:

• Material mixture design, i.e. job mix or gradation of different materials that are used in each single element layer of the pavement

• Structure design of the pavement.

The key reasons to be measured in the design of pavement are soil, climate, position and road geometry, traffic, and drainage. One of the critical characteristics of the complete road system is road maintenance [2]. Even if the National Highways are properly constructed and designed, they necessitate maintenance, the level of which is determined by a variety of criteria, including the type of pavement. A flexible failure of the pavement is defined by cracks, potholes, formation of ruts, settlements, localized depressions, etc. Heaving in the area is usually followed by a localized depression. A wavy pavement surface is developed by the sequence [3]. Failure of one or more components of the flexible pavement occurs due to shoving and longitudinal ruts, waves, and corrugations on the surface of the pavement[4]. When pavement unevenness is extreme, it can be considered a failure. Pavement distress/failure is a complicated topic since many variables contribute to its failure and deterioration [5]. The deterioration of the flexible pavement is caused by the oxidation and ageing of bituminous layers[6]. When surplus water is trapped in the vacant pavement’s spaces, detrimental activities are swiftly enhanced [7].

At the outset of its design life, a brand-new pavement is supposed to be free of any unattractive aspects or “distress”. The shorter the life of the pavement, the more distress is there, and at some point, the distress is so severe (for example, if 75 per cent or more of the pavement surface has cracks) that the road or pavement is referred to as “failed” or “at the end of its design life and rebuilt action is needed”. Blacktopping (flexible pavement) is used to create 90 per cent of road structures in Indian states (including Arunachal Pradesh). Arunachal Pradesh is a state in India where the atmospheric changes depending on elevation. The pavement composition material is completed via proper mix design, ensuring that the material's desired levels of different assets are met [8]. However, with the fluctuation of a mixed element, a pair of desirable traits show opposing tendencies. For example, increasing the content of the bitumen binder in the asphalt mix improves the functioning of fatigue while decreasing the modulus stiffness value[9]. Both a high modulus rigorousness of the asphalt mix and good performance of fatigue are desirable in terms of the design of the pavement [10].

As a result, appropriate mix design for each of these materials, pavement material selection for specific layers of the pavement, and engineering property estimation are all important aspects of the pavement design process. Variation in moisture and temperature conditions (including thawing and freezing circumstances) during the service cycle of the pavement is the most important environmental characteristic utilized in pavement design. Such discrepancies are reported in the design guidelines by taking into consideration the expected/equilibrium moisture and temperature content throughout the design period or by splitting the overall design period into different intervals of time. The asphalt layer stiffness is thought to be affected by temperature, while the stiffness of the subgrade and the unbound granular layer is thought to be affected by moisture content. It should also be noted that a moisture content profile and a temperature profile are always present in the variation of the pavement along with the depth. A representative value of moisture and temperature content is established for design purposes, which carries the corresponding effects of such fluctuations down the depth. Traffic parameters include things like axle load spectrum, traffic volume, tire contact pressure, axle and wheel arrangement, traffic growth rate, lateral wheel path wander, etc.

Guidelines offer a variety of empirical elements or computational methodologies to take into account when converting the expected cumulative volume of the traffic (over the design phase) to the corresponding number of standard load axle repetitions [11]. Damage caused by specific axle load categories is sometimes calculated independently. The following part goes through the fundamental asphalt pavement design principles and is used by various guides to develop design suggestions.

Fatigue cracking happens when the asphalt binders become rigid and the pavement reaches its end. Long-term aged asphalt binders are used during this time. It's a type of load-related cracking that occurs because of repeated loading. The horizontal strains of tensile at the pavement's bottom layer surpassed the tensile property strength of pavement, resulting in microcracks[12,13]. These cracks develop into macrocracks that grow in width and length, resulting in alligator cracking or fatigue cracking. Thermogravimetric analysis (TGA) is a technique for determining the percentage change in weight material as the function of time or temperature[14]. Materials characterization, corrosion studies, thermal characteristics, kinetic studies, and compositional analysis are some of the uses [15]. It can be used to distinguish between the various components of multicomponent products such as rubber crumb modifiers. The material is warmed towards high temperatures, and the loss of mass from breakdown is plotted as the temperature function, creating a thermograph [16]. The derivative of thermograph (DTG) depicts the link among sample breakdown rates and temperature as indicated in the weight-to-temperature derivative [d(Weight) / d(T)].

Hence scientific study regarding different types of surface distress, their nature, and magnitude is essential to know the exact reasons for bituminous pavement failures. Therefore it can be considered in the design of flexible pavements. It may reduce pavement failure to some extent.

II. Types of Major Asphalt Surface Failures

Localized settlement of the flexible pavement component layers structure could be sufficient to induce the failure of the pavement. This necessitates that each layer is meticulously developed and placed out. As a result, to preserve the overall pavement structure stability, every layer must be balanced within itself, allowing the complete pavement to remain stable. One of the most difficult tasks for pavement engineers is determining the best repair plan for a flexible pavement that is ageing and showing signs of degradation. Only practising engineers in road construction and maintenance can only recognize and identify it. The different forms of failure/distress in the flexible pavement are enumerated in Table 1.

Table 1. Types of Failure in Flexible Pavement

Sr. No	Types of Failure	Description
1.	Edge cracking	The pavement is divided into rectangular blocks by interconnected cracks (approx. 0.1 to 9 m^2).
2.	Slipping Cracking	Cracks in the shape of a half-moon or a crescent, with the ends pointing in the traffic direction.
3.	Polished aggregate	Areas with either a very small fraction of extending aggregate above the binder asphalt or no angular or rough aggregate particles.
4.	Raveling	The fragmentation of the Hot Mix Asphalt (HMA) layer from the downward surface is due to aggregate particle dislodgement.
5.	Corrugation and shoving	Abrupt waves (shoving) or ripples (corrugation) across the surface pavement characterize this type of plastic movement.
6.	Depression	Surface sections of the pavement are slightly lower in height than the pavement surrounding.
7.	Longitudinal cracking	Cracks that run parallel to the centerline or the laydown direction of the pavement
8.	Patching	A section of pavement was repaired by replacing it with new material.
9.	Potholes	Small, bowl-shaped formations on the surface of the pavement. These potholes

		reach all the down way to the base course through the Hot Mix Asphalt (HMA) layer
10.	Rutting	In-wheel path, there is a depression on the surface.
11.	Transverse (thermal) cracking	Thermal cracking is defined as the kind of cracks that run vertically to the laydown direction or pavement's centerline.
12.	Water bleeding and pumping	Water percolates out of fissures or joints through HMA porous layer, causing bleeding. Under moving loads, fine material and water are discharged from the underlying layers through HMA layer cracks, resulting in pumping.
13.	Bleeding	On the pavement surface, there is an asphalt binder film.
14.	Joint reflection cracking	Cracks in a rigid pavement's flexible overlay form directly over the rigid pavement joints.
15.	Fatigue (alligator) cracking	Under repeated traffic loads, fatigue failure results in a network of interconnected cracks.

A. Fatigue (Alligator) Cracking

Alligator or fatigue cracking is the most frequent structural distress in asphalt pavements with granular and poorly maintained bases, and it is produced by fatigue degradation, as shown in Figure 1. Alligator cracking starts as parallel longitudinal fractures in wheel paths and evolves to a network of interconnected cracks that looks like alligator skin or chicken wire.

Fig. 1 Fatigue (alligator) cracking

The magnitude and number of applied loads, the design structure of the pavement (thicknesses and layer-wise materials), the consistency of the asphalt cement, the uniformity and quality of sub-base support, the percentage of bitumen content, the aggregate, and air voids characteristics of the concrete mix asphalt. The life of the fatigue cracking of the mixes should be assessed using constant-strain testing. In an asphalt-overlaid concrete pavement, longitudinal or alligator-type cracking implies one of the following unusual circumstances:

- An unstable mix of asphalt-concrete with a deterioration of the link between the concrete layers and asphalt,
- Total concrete deterioration, e.g., extensive and severe "D" cracking. Where the wheel paths cross these places, the concrete breakdown is likely to be focused in limited areas around fractures and joints, resulting in localized collapses [17].

B. Rutting

Rutting is a production of the longitudinal recessions in the wheel paths, which is usually affected by material movement or consolidation in the subgrade and base, as well as the asphalt concrete layer. Abrasion by studded tires and tire chains is another independent cause of rutting.

Fig. 2 Rutting

Consolidation or plastic flow is the cause of deformation that occurs only later in the asphalt concrete. After construction, traffic loads continue to compact the asphalt concrete, resulting in consolidation, as shown in Figure 2. Consolidation can cause severe rutting in very thick asphalt layers that are compacted to initial air void contents that are significantly greater than the air void long-term contents for which the blends were designed. The stiffness of cement asphalt is thought to play a minimal role in the resistance rutting of asphalt mixes containing angular, rough-textured, well-graded particles. Rutting occurs in overlays asphalt on concrete pavements because of shear stress caused by applied stresses causing the mix to flow laterally away from the wheel paths. Asphalt shear stress is maximum for thicknesses overlay of 4 to 6 inches when the asphalt and concrete are not connected [16]. Premature rutting, which happens in an insufficiently designed mix because of shear failure, develops abnormally quickly and reaches a critical level within one or two years.

C. Longitudinal Cracking

Longitudinal cracking is an asphalt pavement that is caused by insufficient compaction at the borders of longitudinal paving lanes, or it might be caused by the edges of the old underlying pavement or the cracks and edges in a stabilized base, as shown in Figure 3. When conducting condition surveys, it is critical to differentiate between longitudinal cracking of non-wheel path and wheel path, only the longitudinal wheel path cracking, along with alligator cracking, should be considered when determining the level of load-related damage to the pavement.

Longitudinal cracking has occurred in concrete highway and street pavements; however, it is rarely caused by fatigue. The longitudinal cracks can also emerge to join diagonal or transverse cracks that already exist [18].

Fig. 3 Longitudinal cracking

D. Ravelling

Ravelling is the gradual deterioration of the concrete asphalt surface instigated by the loss of aggregate and bitumen binder particles from the downward surface. This can be caused by the dust on the aggregate interfering with adhesion asphalt, asphalt cement hardening, isolated pockets of segregation in the concrete mix asphalt where fine aggregate particles are missing, or a low in-place mix density due to poor compaction.

Fig. 4 Ravelling

Ravelling also includes aggregate dislodging and surface softening as a result of oil spillage, as shown in Figure 4. Ravelling and weathering can be dangerous if water collects in degraded portions of the surface, causing hydroplaning or wheel-spray. A potential safety issue is a loose material on the pavement surface that could be scooped up by vehicle tires [19].

E. Edge Cracking

The cracking of the asphalt pavement into the rectangular chunks ranging in size from 1 to 10 feet on a side is known as edge cracking. Edge cracking occurs on large paved surfaces such as parking spaces and streets, particularly in places that are not subjected to the traffic loads, but it can also occur in heavily trafficked locations, as shown in Figure 5.

Fig. 5. Edge cracking

The use of asphalt cement that has grown too strong for the climate causes both thermal cracking and edge cracking. The key to minimizing thermal and edge cracking is to choose the asphalt cement with a low stiffness that is not sensitive to temperature [20].

F. Slippage Cracking

In regions where vehicles do not run smoothly, i.e., use of breaks, slippage cracking happens because of the low-strength asphalt mix in the surface layer and/or a poor link between the underlying layer and the surface layer, as shown in Figure 6. As a result, slippage cracking is unusual on highway pavements, but it is frequent on streets and local roads, especially near the intersections [21].

Fig. 6. Slippage cracking

G. Shoving and Corrugation

These are the phrases used to describe the longitudinal displacement of the asphalt concrete in the specific location, as shown in Figure 7. Traffic loading causes shoving and corrugation, which are signs of an unstable liquid asphalt mix (e.g., emulsion or cutback) [5].

Fig. 7. Shoving

H. Pot-hole

A pot-hole is a bowl-shaped form that appears in the layers of pavement asphalt surface or structure, ranging in diameter from 6 inches to 3 feet, as shown in Figure 8. When traffic wheels displace fragments of asphalt concrete, such as in alligator-cracked areas, potholes emerge. Like water gathers in the hole and seeps into base and subgrade, potholes expand in size and depth, decreasing stability in the area [5].

Fig. 8 Pot-hole

III. MATERIALS AND METHODS

A. Research Objectives

The key objective is to carry out the analysis on the distressed pavement present in Kalyan Nirmal National Highway (NH)-61, Thane, Maharashtra, India. The objectives of the research are:

• To identify the various locations of pavement distresses in the stretch under study.

• The frequency and magnitude of distress pavement present on the highway stretch. Causes of pavement distress. Pavement performance study about impact on safety and impact on comfort

• To examine the total pavement failure percentage, distress per cent, and percentage individual weightage of distress.

• To see and review the role of pavement distress in the design of flexible pavement.

B. Related Works

This section shows the several related works of many authors in the area of flexible pavement.

Ud Din et al. [21] stated that the physical and engineering qualities of asphalt pavement could be seriously harmed by freezing and thawing. Compressive strength, fatigue cracking, air gaps, and rutting are all common signs of the change. Rutting and fatigue are problems linked with the flexible pavement that is more susceptible to weather. Warm mix asphalt technology and natural asphalt can enable bituminous mixes that are subjected to freeze-thaw cycles to enhance their technical features. For optimum pavement performance, choosing the right void content is critical.

Oshone et al. [22] investigated the effect of fracture energy and proposed crust or overlay stiffness of the bituminous mixture on overlay field cracking performance. The study looked at 15 different pavement segments in Minnesota, where disk-shape efficient tension testing is done on overlays field cores. Different performance cracking metrics, such as maximum, average transverse cracking rate, and the transverse cracking performance index (TC Total), were determined because of the differences in overlay lifetimes. The results of the investigation revealed that TC Total is affected by both overlay stiffness and fracture energy.

Hamzah et al. [23] stated that the most common causes of pavement distress are moisture-induced degradation, which results in stripping, ravelling, fatigue damage, permanent deformation, and loss of strength. To describe the process of moisture deterioration in asphalt pavements, a variety of approaches have been used. The moisture damage mechanism, on the other hand, is the outcome of the interplay of many processes. For a wide range of materials and settings, a single test approach for measuring moisture damage is impractical. As a result, a new laboratory-based analytical technique and testing process are required to account for the effects of both traffic and moisture degradation at the same time.

Already published work of Salim G. Shaikh & Abhijeet P. Wadekar. [24] has systematically evaluated and analyzed the bituminous pavement failure, developed the methodology to find the nature and magnitude of asphalt pavement distress. Luo et al. [25] stated that cracking is a common type of asphalt pavement distress, particularly from the top of the surface to down that has been discovered all over the world. The article's major goal is to give a road map for developing a mechanism and related design tools for top to down approach cracking in asphalt pavements, as well as a thorough review of previous work.

Norouzi et al. [26] investigated the accomplishment of pavement asphalt of the Korea Expressway Corporation Road test using typical design pavement parameters such as surface base layer thickness, base layer type, mixture type, anti-frost layer, and subbase layer thickness. As a consequence of the realistic traffic and environmental conditions, a road test is often regarded as the most realistic technique for studying the effects of various aspects. The impacts of changes in the above-mentioned factors on the number of rut depths and cracking were captured using the newly created 'layered viscoelastic pavement analysis for critical distresses' (LVECD) tool. However, to obtain a more precise performance of field predictions, a model is developed, which is known as a laboratory-to-field transfer.

Zhang et al. [27] investigated that cracking is one of the predominant problems for asphalt surfaces. However, a variety of laboratory tests have been performed and established to assess the cracking performance of the asphalt materials. The research's main purpose is to investigate the relationships between distinct real-world pavement cracking performance and laboratory-measured binder/mixture characteristics (both thermal and fatigue cracking) while also taking into account crucial asphalt pavement and mix design factors. Data on field performance pavement was obtained from different 23 project locations, each of which had one control Hot Mix Asphalt (HMA) portion and at least one Warm Mix Asphalt (WMA) portion.

Many factors affect the serviceability and performance of asphalt pavement, including severe temperatures, traffic loads, water, execution errors, design, and lack of maintenance [28]. These factors cause the pavement to deteriorate quickly over time. Rapid emergence and intensification of deformation due to a lack of routine maintenance in the surface pavement, increased subgrade weakness, traffic in weights and repetition, drainage system deficiencies, and poor asphaltic mixture design are the main causes of highway network failure in the middle of Iraq. Karim et al. [29] define the causes of distress on two main roads in Hilla city as the poor design of road layers and site execution, poor excellence of wearing asphaltic course to withstand loads, temperature, traffic, reduction in thickness, bad adhesive, and the inadequate compaction. Laboratory results of units with Poor polymerase chain reaction show a higher discrepancy with specifications. According to Kadhim & Mahdi [28], road pavements require rehabilitation and ongoing maintenance to avoid deterioration due to repeated environmental conditions and traffic loading. Rutting in high proportions, bleeding due to block and transverse cracks, weather and high traffic loads, ravelling, and potholes in lower proportions, corrugation in high proportions, a minimal percentage of rutting, and ravelling in lower percentages were the distress that appeared in the middle of Iraq[30]. Sarsam [31] stated that a high percentage of alligator cracks followed by depression and potholes in lower percentages. According to the state commission for roads and bridges, more than 70 per cent of the current road network is in a poor situation and needs maintenance [32]. Mohamed [33] concluded that every year, the Ministry of Housing and Construction develops a strategy for road maintenance around the country, however owing to a shortage of resources, the strategy is not implemented in a prioritized manner. The road maintenance managing system has been enhanced to save time and money [34]. The Pavement Management System depends significantly on pavement distress surveys at the network level. It also gives information for assessing the serviceability of pavements, anticipating protection and repair priorities and needs, and distributing funding [35]. Pavement distress is one of the factors to consider when determining the necessity for pavement restoration [32]. The Pavement Distress Rating is a tool for determining the state of the pavement. It considers current and future pavement issues, as well as aspirations, to help preserve the structural capabilities of the pavement [31].

C. Causes, Technique, and Solution

Inflexible pavement, different types of failures under cracking such as fatigue, longitudinal and transverse, edge, block, and reflection are all types of distress that occur in the pavement. Except for alligator cracking, which is produced by weight, and slippage cracking, which is caused by traffic, most of them are connected to climatic reasons.

Inadequate structural support, which can be caused by several things, is the possible cause of Fatigue cracking. A few of the more common ones are enlisted here; Loss of base, sub-base, or sub-grade support (e.g. improper drainage or spring thaw resulting in poor stiff base), Construction flaws (e.g. Inadequate compaction), Decrease in pavement load support characteristics, Loading increase (more than design load), and Stripping on the HMA's bottom layer (surface layer) (the stripped portion contributes little to the pavement strength, so effective HMA thickness decreases).

In longitudinal cracking, shoulder settlement, poor drainage, weak connections between the contiguous spread of pavement layers, or differential frost heave are all possible reasons. The treatment options are determined by how stable the asphalt is. Cracks should be sealed with a slurry seal or fog seal. Unsound cracking pavements would require reinforcement or restoration.

The numerous reasons for rutting may be summarized as follows: The coarse aggregate, sub-base, granular base, lower layers, or any composite of such pavement layers is not stable enough. The subgrade or any of the pavement structures have not been adequately compacted and Improper design creating substantial vertical stress on the subgrade. The channelized flow of large wheel loads causes significant vertical stress. Raveling is more common on older pavements that have already deteriorated. Raveling can be hastened by traffic and other factors in the surroundings. A wearing course or an overlay can be used to restore a ravelled pavement.

In Edge cracking filling low-severity fractures is one of the restorative procedures. Patches and repair of distressed regions may be required as the severity of the condition worsens. In all circumstances, excessive moisture should be removed, and the shoulders should be rebuilt using high-quality materials.

Excessive recurrent traffic on an aged pavement system causes polishing, which is a failure mechanism of the pavement surface consisting of abrasive exposed particles which are probably treated by a thin bituminous overlay.

The earlier isolated asphalt deterioration, which was removed and patched, as well as the utility cuts along the pavement, are all contributing factors. Patches are a repair activity in and of themselves, but the only other method to get them off the pavement is to use a structural or non-structural overlay.

Distress in the flexible pavement can be caused by a variety of factors, and their possible techniques for resolving these failures are classified below. Possible causes and probable treatments of major surface failures are based upon the time-tested practical experience of Highway Engineers of different organizations engaged in road construction and maintenance activities. Table 2 depicts the various possible root causes and their respective treatments of the different types of failures.

Table 2. Possible causes and treatments of the different pavement distress

Type of Failure	Possible Causes	Probable Treatment
Fatigue cracking	Poor drainage base	Recover the drainage and reconstruct
	Low modulus base	Strengthen the base or reconstruct
	Inadequate pavement thickness	Strengthen the pavement or reconstruction
	Brittle course wearing	Treat or replace wearing course
	Brittle base	Base reconstruction or recycling
Longitudinal Cracking	The different settlement between the fill and the cut.	Crushed reconstruction or overlay aggregate of joints
	Poorly erected paving lane in	Replace the bituminous

	the bituminous surfacing	surfacing
	Reflection of shrinkage cracks	Patch and cut
	Displacement of the joints at pavement expanding	Joints reconstruction
Raveling	Inadequate construction or compaction during wet weather	Thin overlay bituminous
	Poor bitumen adhesion binder to aggregate particles because of wet aggregate.	Thin overlay bituminous
	Insufficient bitumen content	Thin overlay bituminous
	Deterioration of aggregate and/or binder	Thin overlay bituminous
Rutting	Unstable bituminous mixes	Recycle or use the stiffer mix or replace bituminous surfacing
	Inadequate compaction of structural layers.	Reconstruction
	Inadequate pavement thickness	Strengthening overlay or reconstruction
	Excessive and permanently deformed sub-grade	Reconstruction
	Unstable and deformed bases or subbases granular.	Base or subbase strengthening
	Weak shoulder material that does not provide appropriate lateral	Shoulder repair and bituminous paving over rutted areas
	resistance.	
Edge Cracking	Heavy rainfall and seepage	Efficient and proper drainage
	Alignment promotes drivers to travel on the asphalt edge pavement.	Pavement widening and realignment
	Inadequate pavement width	Widen the pavement
	Inadequate edge support	Shoulder strengthening
Potholes	Load associated disintegration of base	Base reconstruction
	Moisture seeps into the base course from a fracture in the pavement.	Patch and cut
	Loss of surface course due to heavy rainfall.	Patching
Traverse (thermal) cracking	Shrinkage bituminous crack surfacing	Replace or seal cracks of bituminous surfacing
	Construction joint in the bituminous surfacing.	Crack sealant
	Reflection of shrinkage cracks	Cut and patch
	Reflection of joints in the underlying base	Reconstruction of joints or crushed aggregate overlay
	Structural failure of Portland Cement	Reconstruction of base
Polished Aggregates	Use of naturally smooth uncrushed aggregates.	Thin bituminous overlay

	Surface aggregates have insufficient resistance to polishing, especially in places with heavyweight traffic or where high tensions emerge among the surface and the tire.	The bituminous overlay of use of a stiffer mix
Patching	Water leakage through asphalt, particularly in cracks, affects the link between the underlying and top layers to be broken.	Replace wearing course or thin bituminous overlay
	Insufficient washing or tack coat before the application of the upper layers.	Relay upper layers and mill off
	The loose, weak layer immediately.	Reconstruction of weak layers

D. Materials

Kalyan-Nirmal National Highway (NH) - 61, which is located in the Thane district of Maharashtra, India, has been chosen for the scientific study of asphalt pavement distress. Present Kalyan-Nirmal NH 61 was initially a single-lane road that was constructed in the year 1965. It was then converted to two lanes in the 1981-2001 Road Development Plan and upgraded to State Highway standard. It was declared as NH in 2004. The traffic intensity on this highway, on average, is around 25614 PCU (Passenger Car Units). The formation width of the highway is 12m, whereas the carriageway width of the highway is 7m. The chainage from km 36/000 to 43/000 (7 km) is selected for this study. The average annual rainfall that is recorded in the study area is 2800 mm. The soil strata are mostly murram and mixed with boulders. The data that is used in this study were collected between 20/11/2020 to 04/12/2020.

a) Forensic Investigation of the Road under Study

The forensic investigation of the road under study was carried out through the experienced engineers engaged in the road construction and maintenance activity of this road stretch working under the National Highway Division, Thane, Maharashtra, India, as follows:

- Data Collection - To know the type, magnitude, and nature of distress, pavement performance study about impact on safety and impact on comfort
- Interview - Interaction with public, politicians, and employees familiar with the road
- Non-destructive Evaluation - Primary site visit, Condition Survey, Visual Investigations, etc.
- Determination of failure/root cause(s) - Data analysis to find and know the likely failure cause

b) Data Collection

Perfect and proper data collection aims for scientific and realistic research. A team of dedicated and experienced highway engineers and field staff working on-site were selected for this work. To improve their skill, special training related to proposed research work had conducted before starting and during the work of data collection. It helped to choose the proper research method at the proper place, to learn and take care of minimizing the error, to enter the collected data system so that it will be used comfortably during analysis and finding stages. A data collection sheet and questionary were designed to get the required information.

c) Flexible Pavement Material

The primary concept of flexible pavement (FP) material is a compact and jointless wearing course made of an open-graded asphalt mixture (with 20–30 per cent porosity) filled with a particular cement grouting material. It outperforms dense-graded asphalt concretes in terms of rutting resistance. At the same time, it can handle heavily loaded traffic. FP has the potential to be used in heavy-load pavements, junctions, bus stops, and other specific sections as traffic flows and loads rise. Cracking, on the other hand, is the fundamental issue impeding the promotion and implementation of FP. Despite much research on the macroscopic features of FP, the damage mechanism, as well as the damage process at the macro, remain unknown. It is owing to the unpredictability of diverse backfilling concrete virtues and grouting saturation, as well as resources, are designed of three-phase disparities (material properties vary in space) and structural features of interlocking concrete (interaction between aggregates, e.g., friction, extrusion).

E. Methods

a) Fatigue

It occurs in locations that are subjected to heavy traffic loads regularly (wheel paths). In the early phases of growth, there may be a sequence of interconnecting cracks. Later stages develop into many-sided, sharp-angled fragments with a chicken alligator/wire pattern, usually shorter than 300 millimetres (mm) on the far-seeing side.

1) Severity Levels

• Low: Cracks area with a few linking cracks, pumping is not evident, and cracks are not sealed or spalled.

• Moderate: Interconnected cracks area creating the complete pattern, cracks are spalled slightly, pumping is not evident, and cracks may be sealed.

• High: Area of severely or moderately spalled interlocked forming cracks a complete piece, patterns may move when subjected to traffic, pumping may be evident, and cracks may be sealed.

2) Measure

In square meters, record the impacted area for every single level of severity. If distinct severity concentrations within an area can't be recognized, assign the highest severity level to the entire region. Both fatigue and edge cracking should be graded when they coexist in the same location. Fatigue cracking is defined as an area of close, small spaced (< 300 mm) cracks transverse in a wheel path. The result in per cent of surface faults in terms of total failed bituminous pavement area of 347.98 square meters (sqm) is 4.23 per cent while assessing fatigue cracking at 36 different places (Refer Table 3).

b) Longitudinal Cracking

The majority of the cracks run parallel to the centerline of the pavement. It's important to know where you are in the lane (wheel path vs non-wheel path).

1) Severity Levels

• Low: The crack having a mean width of equal to or less than 6 mm or the sealed crumble with a useful sealant substance but an unknown width.

Table 3. Distress-wise failure area, and their individual weightage

Sr. No.	Type	No. of locations	Area (Sqm)	% of individual surface defects to total pavement area	% Individual weightage to total surface defects
Cracking					
1.	Longitudinal	29	2691.79	5.493	32.71
2.	Fatigue	36	347.98	0.710	4.23
3.	Transverse	3	57.11	0.117	0.69
4.	Edge cracking	27	25.05	0.051	0.3
5.	Slippage	6	0.84	0.002	0.01
	Total	**101**	**3122.77**	**6.373**	**37.94**
Surface Deformation					
1.	Rutting	13	1631	3.328	19.82
2.	Depressions	19	29.01	0.059	0.35
3.	Shoving	1	15	0.031	0.18
	Total	**33**	**1675.01**	**3.418**	**20.35**
Disintegration					
1.	Patches	47	1575.3	3.215	19.15
2.	Potholes	20	77.82	0.159	0.94
	Total	**67**	**1653.12**	**3.374**	**20.09**
Surface Defects					

1.	Ravelling	24	1769.6	3.666	21.5
2.	Bleeding	45	9.05	0.018	0.11
3.	Delamination	6	0.91	0.002	0.01
	Total	**75**	**1779.56**	**3.632**	**21.62**
	Grand Total	**688**	**8230.46**	**16.797**	**100**

• Moderate: Any fracture with a mean depth larger than 5 mm but a little less than 19 mm, or any fissure with a mean breadth less than 19 mm but persistent less moderate random cracking. Random cracking should be regarded adjoining if it occurs within 300 mm of its primary source of distress.

• High: Any fissure with a mean size greater than 19 mm, or any crack with a mean dimension greater than 19 mm with a continuous random snapping of moderate to high sensitivity. Random cracking that is within 300 mm of the main distress must be considered adjacent.

2) Measure

The longitudinal cracking has been measured in two different parts:

• Wheel Path longitudinal cracking: The length of the longitudinal cracking records in meters inside the indicated wheel tracks at every single level of severity.

• Non-Wheel Path longitudinal cracking: Record the length in meters of longitudinal cracking that is not located in the authorized wheel routes at each degree of severity.

The total area for detection in longitudinal cracking ranges from km 36.000 to Km 43.000 (7kms) at 29 locations, totalling 2691.79 sqm which is 32.71 per cent of total surface failure (Refer Table 3).

c) Rutting

A longitudinal planar depression is seen in the rutting. It could be linked to a transverse displacement.

1) Severity Levels

The severity levels of the measurements might be determined by categorizing them. A record of the measures made is far more desirable than severity levels since it is more accurate and repeatable.

2) Measure

SPS-3 (Specific Pavement Studies): For every wheel path, measure the maximum rut depth towards the closest millimetre at an interval of 15.25-m with a straight edge of 1.2-m. The detection was carried out at 13 places, ranging in chainage from 36.000 to 37.000, with a total rutting area of 1631.00 sqm, which is 19.82 per cent of total surface failure (Refer Table 3).

d) Ravelling

The displacing of aggregate particles and the loss of asphalt binder affect the surfaces pavement to wear out. Raveling ranges from the loss of the fine to the loss of aggregate coarse, and finally to the pitted and very rocky surface with apparent aggregate loss.

1) Severity Levels

The presence of ravelling indicates possible performance issues with the blend. To observe any progression, the extent is adequate.

2) Measure

Ravelling measures the affected area in square meters. Chip seals should not be used to rate ravelling. The entire area covered up for surface defects ravelling at 24 locations is 1769.6 sqm which is 21.50 per cent of total surface failure (Refer Table 3).

IV. RESULTS AND DISCUSSION

The primary cause of distresses pavement along the highway, as well as flexible pavement, is inadequate mix design and construction, followed by a lack of timely maintenance.

A. Type, Magnitude, and Weightage of Distress

This study analyzes the different types of pavement distress and finds out which is the commonly occurred pavement distress on the highway. Table 3 summarizes the distresses discovered, their analysis for individual weightage along Kalyan-Nirmal NH 61, Taluka -Murbad, Thane. The total bituminous pavement area for 7km length and 7.0 m width works out to be 49000 sqm. Out of which 8230.46 sqm, i.e. 16.797 per cent area is damaged due to some kind of pavement surface distress.

The study shows that cracking is predominant in the national highway. While the surface deformation is in the second position and the surface defects are the type of pavement deterioration that occurs in a minimum amount in the Kalyan-Nirmal National Highway. This distress includes different types of cracking, surface deformation, disintegration, and surface defects for a variety of locations and areas in sqm, including surface defects measured as a percentage of total bituminous pavement area. The findings are based on pavement distresses such as longitudinal cracking, ravelling, rutting, fatigue cracking, and others.

B. Predominant Pavement Distresses

According to this data, longitudinal pavement distress has the largest weightage of pavement distress on the National Highway, accounting for about 32.71 per cent. Ravelling, rutting, patches, and fatigue cracking has pavement distress of 21.5, 19.82,19.15, and 4.23 per cent, respectively. These five distresses accounted for 97.41% of the weightage in bituminous pavement failure.

Figure 9 Pie Chart shows the pictorial representation of category-wise pavement distress.

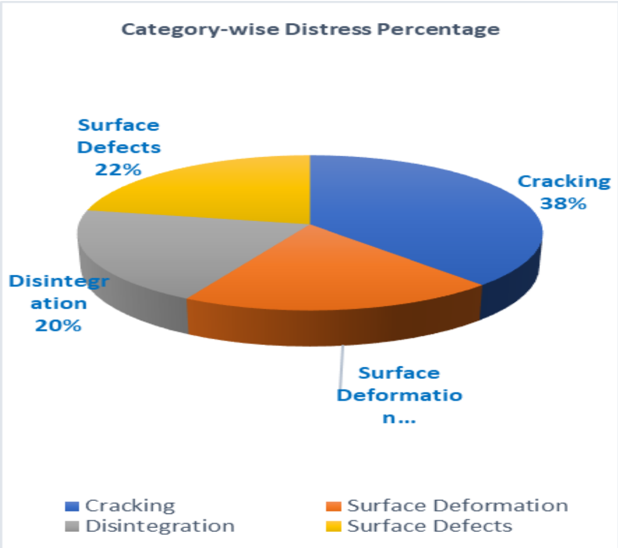

Fig. 9. Category-wise distress percentage

As a graphical representation of the analysis, Figure 10 presents a Pareto Chart, which represents individual percentages of different distresses with sky blue bars and cumulative percentage distresses by an orange line. It is easily analyzed that longitudinal cracking, ravelling, rutting, patches, and fatigue cracking have a major contribution (97.41percent) in the failure of bituminous road pavements.

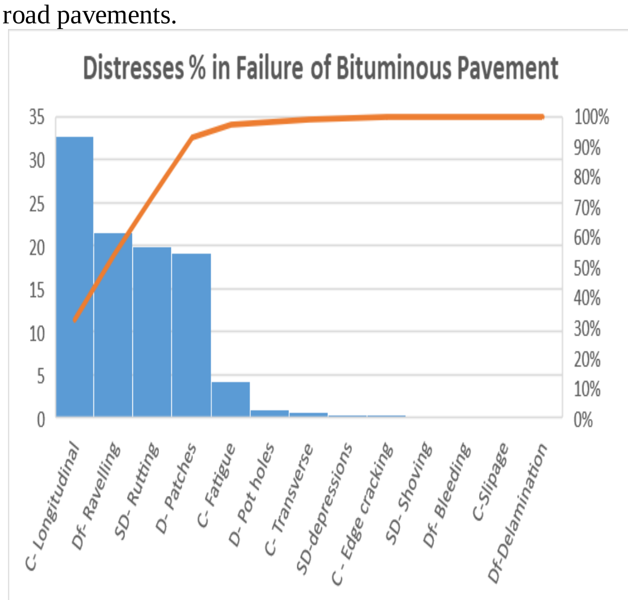

Fig. 10. Pareto Chart- Weightage of different pavement distress

C. Predominant Distress Classification to Safety and Comfort Criteria

Table 4 shows the distress categorization (fatigue cracking, longitudinal cracking, rutting, and ravelling) and their analysis based on both safety and comfort criteria. The severity is shown in three different levels Low, Medium, and High. At the same time, the safety and comfort impact is rated on a scale between 0-2 [0 (low), 1 (Medium), 2 (high)].

Table 4 - Safety and comfort criteria based on Severity of Distress

Distress	Severity	Impact on safety	Impact on comfort
Fatigue cracking	Low	0	0
	Medium	0	1
	High	1	2
Longitudinal cracking	Low	0	0
	Medium	0	1
	High	1	2
Rutting	Low	0	1
	Medium	0	1
	High	1	2
Ravelling	Low	1	0
	Medium	1	0
	High	2	0

D. Role of Surface Distress in the Pavement Design

Pavement design is a procedure of determining the cost-effective combination of different layers of pavement, is primarily concerned with the design of the material combinations and the pavement layer thicknesses. Pavement design, which is primarily concerned with the design of material combinations and pavement layer thicknesses, is a technique for identifying the most cost-effective combination of different layers of pavement. Even though highway pavements are properly constructed, they may require regular maintenance. If sufficient maintenance is not given, numerous distress such as fatigue, longitudinal cracking, rutting, patches, etc., develops in the pavement, which is a complicated occurrence owing to the multiple components involved (like rainfall, traffic, etc.). The processes for executing the structural design of pavements are explained in several design guidelines. The goal of this research paper is to provide a quick overview of several pavement distress guidelines for the structural design of asphalt pavements, as well as the design ideas that were used for the importance of asphalt pavement distress in pavement design and the various types of distress found on the road.

a) IRC 37-2018 guidelines are used in India for the design of flexible pavements. Highway engineers are supposed to use their experience, technical skills, time tested engineering judgment and took into consideration the traffic, cost, and availability of local materials, their durability, local climatic conditions, and past pavement performance in their respective areas for selecting a suitable pavement composition. Therefore the study and detailed analysis of asphalt pavement surface failure are important to know the current pavement performance. It is useful in pavement design for the restoration/rehabilitation of existing pavements and also for new construction.

b) It is observed that fatigue cracking, longitudinal cracking, rutting, patches are predominant in most of the bituminous pavement failure cases. The present study concentrated the attention of researchers towards road failure due to longitudinal cracking (32.71%) and Ravelling (21.5%).

c) The mechanistic-empirical design approach is used in the IRC: 37 2018. The theory selected for the analysis of pavements is 'linear elastic layered theory' in which the pavement is modelled as a multi-layer system. This code has been taken into consideration the performance criteria for

- Subgrade rutting criteria
- Fatigue cracking criteria for bituminous layer
- Fatigue performance models for Cement Treated Base (CTB)

d) Most of the codes of the developed countries have been considered the above parameters in the design of flexible pavements. As per the present study, methodology and research for taking into account the Performance Criteria against longitudinal cracking, Ravelling, and transverse cracking are essential in the design of flexible pavements.

V. CONCLUSIONS

a) This study analyzes the asphalt pavement distress of around 7 km, mostly damaged road length of the Kalyan-Nirmal National Highway. The relationship between cracking performance, overlay thickness, and fracture energy of overlays in the area is investigated in this study using related fracture energy measurements and pavement performance data by forensic investigations.

b) In the analysis, cracking pavement deterioration is present maximum in the road under study. At the same time, longitudinal cracking is among the highest weightage of pavement distress. Longitudinal cracking, ravelling, rutting, patches, and fatigue are the most common pavement distress found on the National Highway.

c) Pavement performance study also gave the idea about impact on safety and impact on comfort against major and predominant pavement distress.

d) Furthermore, according to the IRC 37- 2018, the major concern is given towards the repeated application of high temperature, traffic load, and heavy load on the pavement are the main cause of the pavement distress. Therefore, while designing the pavements, magnitude and nature of distress shall be taken into account to avoid damages to the pavement after its construction. Performance criteria against longitudinal cracking and ravelling need to be designed along with the already considered performance criteria against fatigue cracking and rutting.

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