RES MILITARIS
REVUE EUROPEENNE D ETUDES EUROPEAN JOURNAL OF MILITARY STUDIES
Social Science Journal

EFFECT OF GRADATION TOLERANCES ON RUTTING PERFORMANCE OF BITUMINOUS CONCRETE MIX

Dhruva Singh, Vaibhav Dubey

Faculty of Engineering & Technology/Rama University Uttar Pradesh, Kanpur

Abstract

Bituminous Pavements are designed to carry design traffic load under prevailing conditions. As every material deteriorates with time, distress may occur within the design period. Rutting and Cracking (fatigue and thermal cracking) are the significant distress in flexible pavement. Several aspects in the design of flexible pavement are considered following rutting and fatigue performance. Rutting is observed as significant distress, primarily in thick bituminous pavements and pavements subjected to high temperatures, high traffic volumes and overloading. Mix rutting would be significant distress if any pavement failed prematurely. In India, Flexible pavements are designed based on the mechanistic-empirical pavement design philosophy outlined in IRC 37-2018. At the same time, bituminous mixes are designed based on specifications mentioned in MoRTH 2013. MoRTH 2013 provides a gradation band for different design layer thicknesses and minimum bitumen content. As target gradation is challenging to achieve in the field, tolerance limits for each sieve size are also recommended in MoRTH 2013.

The study aimed to evaluate the effect of aggregate gradation tolerances on the rutting performance of mix and to find probable causes for premature rutting failure of the NH-353C highway section. In this study, a forensic investigation was carried including a pavement assessment survey, thicknesses of layers and laboratory testing on materials. From the test pit opening, it was observed that rutting is confined to the bituminous layer only. Field cores were taken to examine the cause of failure of mix rutting. Collected cores were tested for volumetric bituminous mix and white rock gradations. Higher binder content was observed in bituminous mixes used in the field. Very Low air voids were observed wearing course cores taken from the wheel path. Mix instability is observed in the binder course as air voids range from low to high. A laboratory study was conducted to evaluate the effect of aggregate gradation tolerance on the rutting performance of the mix. MoRTH gradation for BC-1 was selected. A total of 21 gradations were considered. Rutting Performance of selected gradations was evaluated by using a wheel tracking test. The data analysis was carried out to identify the relationship between rut depth and gradation parameters and to evaluate variability in rutting performance concerning gradations using baileys ratio and change in deformation rate with repeated load cycles.

Keywords: Rutting, Forensic investigation, Gradation, variability

I. INTRODUCTION

India possesses the world's second-largest road network, spanning approximately 5.898 million kilometers, and it continues to expand at a rate of roughly 27 kilometers per day. Given the substantial costs involved in road construction, it is imperative to economically design roadways that can effectively serve their intended purpose throughout their designated lifespan.

Pavement design is a pivotal aspect of road construction, encompassing the selection of suitable materials and strict adherence to quality construction standards to create a structure capable of efficiently distributing the loads imposed by vehicles onto the underlying subgrade.

There are two primary types of pavements in use: concrete and bituminous. However, bituminous pavements are favored by designers due to their cost-effectiveness, phased construction feasibility, and quicker road accessibility to traffic.

Over time, pavements undergo deterioration, resulting in various forms of distress, with rutting and cracking (fatigue and thermal cracking) being notable concerns in flexible pavements.

Rutting, specifically, is characterized by the longitudinal depressions formed in wheel paths on bituminous pavements, primarily attributed to excessive consolidation and permanent deformations caused by repeated loads.

Rutting can be categorized into two main types: subgrade rutting and mix rutting. Subgrade rutting occurs due to inadequate subgrade strength and affects all pavement layers. Mix rutting, conversely, impacts only the bituminous layer and can be caused by factors such as heavy loads, high tire pressures, improper aggregate type and gradation,

and high binder content.
An illustrative instance of premature rutting failure can be observed on National Highway (NH-353C) in Telangana, India.
In essence, the text underscores the significance of economically designing durable road pavements, particularly focusing on bituminous pavements for their inherent advantages. It also highlights the necessity of addressing rutting and cracking as significant sources of distress and the diverse causes and manifestations of rutting failures in flexible pavements. The utilization of high-quality construction materials and adherence to construction standards are critical in ensuring the longevity and functionality of India's extensive road network.

Objective of the study-

Examine Premature Rutting Failure Causes:
Evaluate Gradation Tolerance Impact on Rutting Performance:
Analyze how gradation tolerances influence the rutting performance of bituminous concrete mixtures.
These objectives highlight the study's primary focus on understanding the reasons behind pavement failure and exploring the relationship between gradation tolerances and rutting performance in bituminous concrete mixes.

Mechanism of Rutting

The cumulative effect of densification, lateral plastic flow and loss of materials within the wheel path due to repeated loading resulted in the accumulation of permanent deformation called rutting. (Chaturabong and Bahia, 2017) Among these, the material loss causes raveling but is not
significantly contribute to rut depth, while the amount of densification and plastic flow governs rut depth. Densification is one-dimensional in-elastic displacement, while plastic flow refers to two-dimensional in-elastic displacements. These two types of rutting mechanisms are illustrated in Figure 2.1.
Figure 2.1 Mechanism of Rutting (NCHRP Report 1-37A, 2004)

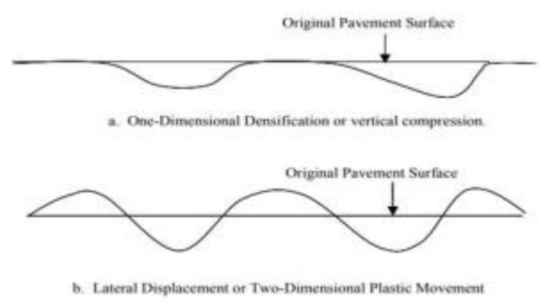

Figure 2.1 Mechanism of Rutting (NCHRP Report 1-37A, 2004)

4

Densification significantly contributes to rutting at the very early stage of opening bituminous pavement to traffic. Pavement is more susceptible to additional densification at high pavement temperature and excessive compressive stresses from traffic loading. Plastic flow of lateral distortion of the bituminous mix is caused by the formation of a shear failure plane due to the overloading of mixtures. The localized shear failure of mixes depends on factors such as high tire pressure, inadequate binder content, mix design, etc. In this kind of rutting, humps on either side of the depression bowl were observed. This kind of rutting can result in moderate to high severity rutting.

Elliott et al. (2016) examined six mixes for the effect of variation in the aggregate gradation on bituminous mix properties. They considered gradation by giving tolerance to the job mix formula. The five gradations were considered; (1) job mix formula (JMF) gradation, (2) a fine gradation, (3) coarse gradation, (4) a coarse-fine gradation, and (5) a fine-coarse gradation. They investigated several properties: creep stiffness, split tensile strength, resilient modulus, Marshall stability, Marshall flow, air voids and voids in mineral aggregate (VMA). Rutting performance was measured in terms of creep behavior. The creep stiffness was calculated by equation 2.1 for each interval of 5sec, 30 sec, 2min, 30min and 60 min.

(2.1)

$$Sx = l * \frac{h}{d}$$

Where,

Sx = creep stiffness at time x;l = creep loading stress (15psi),h = original height of specimen; andd = vertical specimen deformation at time x.

Quan et al. (2020) studied the rutting potential of mixes concerning gradation and binder content variation. The study considered four key variables; 4.75 mm key sieve passing, Coarse particle gradation (>4.75 mm), Fine Particle gradation (< 4.75 mm) and binder content. Hamburg Wheel Tracking Test was used to determine rutting potential. The results showed that rut depth increases with an increase in 4.75 mm sieve passing percentage, and after a specific limit, the mix exhibits a significantly high amount of rutting. Skeletons composed of 13.2-9.5 mm aggregates outperformed 9.5-4.75 mm aggregates. Finer gradation in fine fractions improves the mix rutting resistance.

Radhakrishnan et al. (2018) evaluated the rutting performance and moisture resistance of asphalt mixes concerning gradation and design air void content. The different gradations provided by different agencies as shown in Figure 2.3. From those, a total of five gradations were considered. These gradations were designed for 3%, 4% and 5% air voids. As a result, they found that compared to design air voids, the aggregate gradation significantly affects the rutting performance of mixes. In contrast, both gradation and design air voids have a similar effect on the moisture resistance of mixes. Comparing the Marshall parameter and Rut Depth suggested that the current specification of 9kN stability and 4 mm maximum flow values are inadequate even for 10 msa traffic.

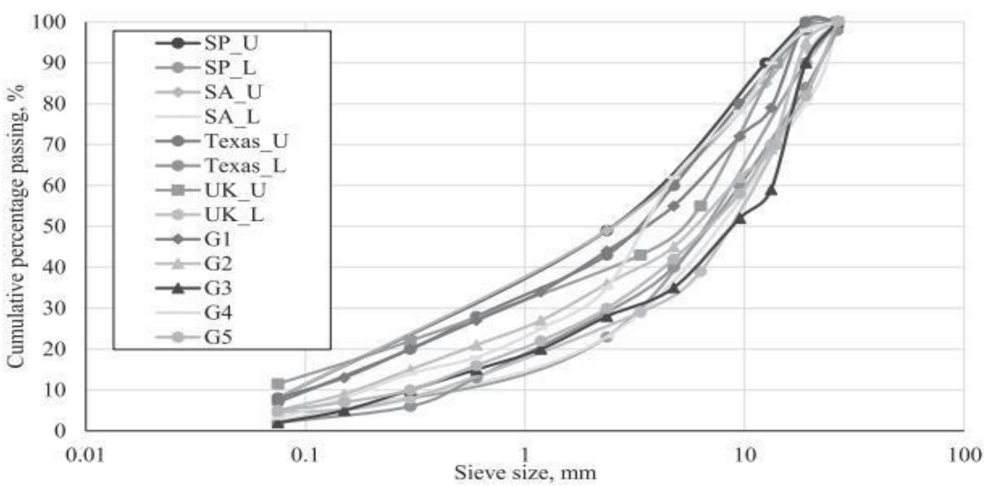

Figure 2.3 Different Gradation Provided by Researchers (Radhakrishnan et al. 2018)

1) Forensic Investigation of Premature Failure of Rutting

Button and Perdom(1990) investigated causes of rutting in bituminous pavements. and performance of bituminous mixes wtih increasing natural sand percentage in Texas, US. The carries out detail survey included test pits opening, axle load survey and core sample were taken. The pits are opened at location where rut depth is greater than 25 mm. The five cores were taken in tranverse direction. 25 cores were taken in 5 locations Field cores were tested for Bulk and Maximum Specific Gravity, Air Voids,Resilient Modulus At Five Temperatures, Marshall Stability,Tensile Properties – ITS,Resistance to Moisture, Binder Content, Aggregate Characteristic. The study found that air voids at each location were slightly low, particularly in binder coarse;Both surface and binder coarse indicated severe moisture susceptibility; Mixes used in Field have mixture deficiencies (excessive asphalt content, excessive fine aggregate and round shaped and smooth textured coarse aggregate).

Summary of Literature Review

From the literature review, it can be summarized that

- Rutting and deformation in selected locations mentioned in the papers were mainly due to heavily loaded trucks, steep gradients and high temperatures, and mixes used in the field have mixture deficiencies.
- Deep ruts are associated with pavements having fewer air voids and slow-moving and channelized traffic.
- The aggregate contact action composed of interlocking force and friction was enlarged by the enlargement of NMAS of the asphalt mixture.
-
- The values of VMA decrease first and then increase with the increase of the passing percentage of the 2.36 mm sieve, while the values of percentage air voids decrease monotonically and tend to be constant. Further, the 13.2-9.5 mm aggregates fraction affects more in the rutting performance of the mix than the 9.5-4.75 mm aggregates.

Pavement Condition Survey

A pavement condition survey is carried out to measure the extent and types of distress. This gives us an idea about pavement surface conditions concerning different chainages of the concern section. From the pavement condition survey data analysis, the locations which need to be addressed have been identified and based on those, further steps in evaluation are planned. In this study Network Survey Vehicle (NSV) was used to assess pavement condition. NSV, used in this study. The Network Survey vehicle has video cameras, a laser, a global positioning system, and video image processing techniques. From the NSV survey, rut depth, percentage cracking and variation in the International Roughness Index (IRI) along the stretch length can be obtained.

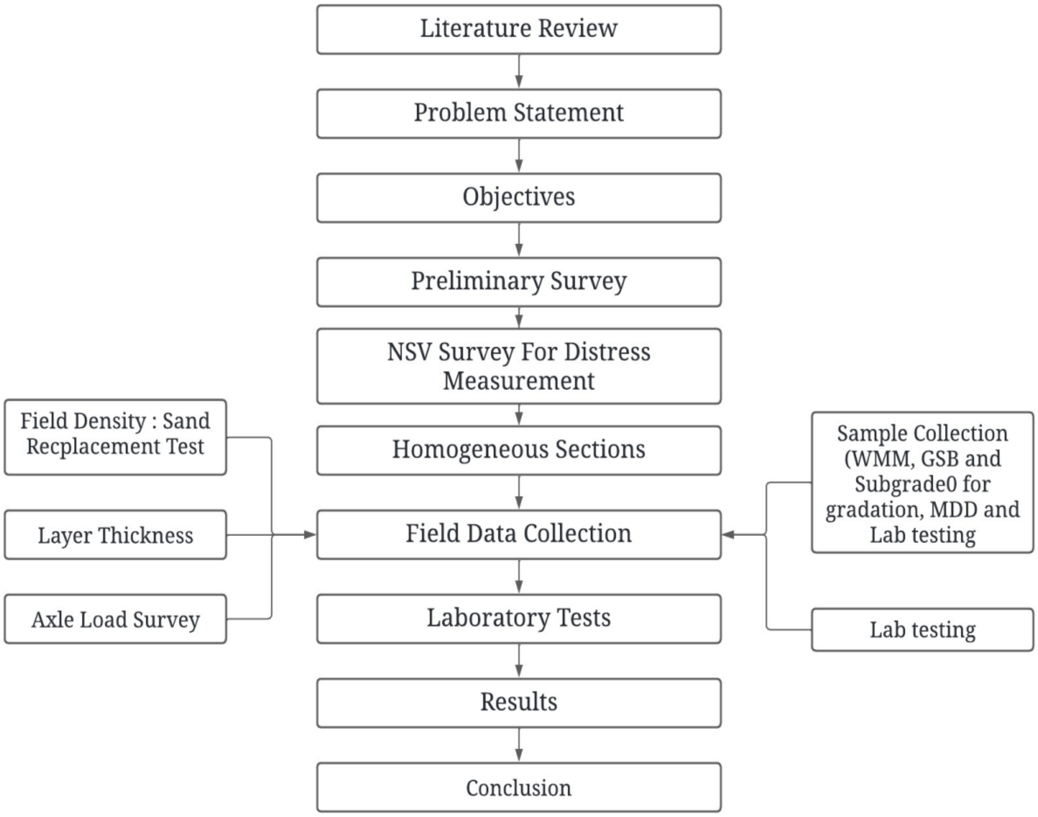

Figure 3.1 Flowchart for Forensic investigation of Premature Failure of Pavement

Wheel tracking test

The most common distress in bituminous pavements is rutting. This distress can be explained as a depression of material due to repeated wheel load on different pavement layers. Rutting is a depression in the longitudinal direction along with the wheels on the pavement. The rutting behavior of the bituminous mix is affected by gradation, aggregate type, type and quantity of binder content, air voids in the bituminous mixture, the surrounding temperature, and the loading on the pavement surface. The bituminous specimen's rutting can be analyzed per AASHTO T 324. According to AASHTO T 324, the rutting of the specimen can be tested using a wheel tracking machine. The Wheel tracking test was carried out using a dry wheel tracker. Figure 3.6 shows the test setup used for the wheel tracking test. It consisted of an arrangement for applying a normal load of 700±10 N on the specimens. The entire test setup was closed in an environmental chamber, where a constant test temperature could be maintained.

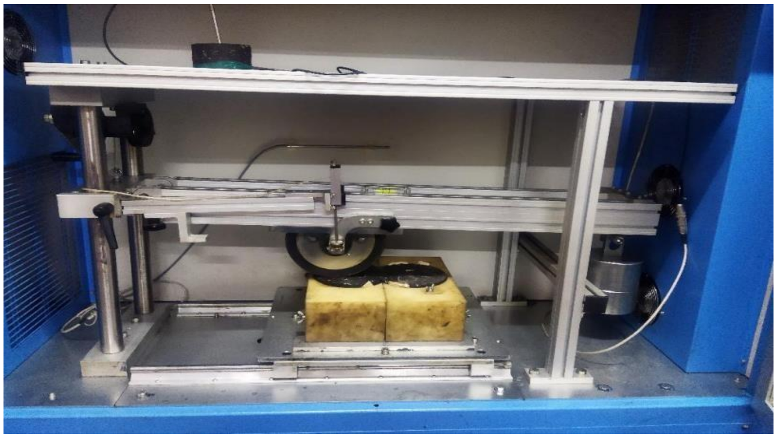

Figure 3.7 Wheel Tracking Apparatus

The specimens for the wheel tracking test were prepared to have an air void content of 7±0.5%. The mix was then short-term aged for 2 h, and cylindrical cast samples of 150 mm diameter specimens of 115 mm height were prepared using a Superpave gyratory compactor to achieve the target air void. Then the specimens were cut in D shape using a cutting machine. The specimen and the mold were placed in the wheel tracking device. The specimen was kept for 2 h to attain a temperature of 60°C. After 2 h, the computer was connected to the wheel tracking machine with the help of Hypertherm software. The input data related to the wheel tracking machines, such as temperature, number of cycles, maximum rut depth, and number of passes, were entered to record the rut depth at every 10-cycle interval, and the test was started. The test was automatically terminated as the number of passes reached 10,000 or rut depth reached 15 mm.

Conclusion

Excessive Binder Content (BC-1): The wearing course of the highway had a binder content ranging from 5.63% to 6.28%, which was higher than ideal. This excessive binder content led to increased lubrication effect and shear deformation under load. It was identified as the primary reason for mix instability, resulting in high densification and low air voids in the mixes.

Non-Uniform Air Voids in DBM-2 Mixes: The air voids in the DBM-2 mixes varied between 1.8% to 6.38%, indicating non-uniform compaction. This non-uniformity in air voids contributed to densification and shear deformation of the DBM-2 mixes.

Dry Aggregate Air Voids (DAAV) and Film Thickness: The study found a strong correlation between DAAV and film thickness with rut depth. Mixes with higher DAAV and thicker binder films exhibited greater rutting potential.

Gradation Impact: Relative coarser gradations showed a faster secondary stage of deformation compared to finer gradations. This was attributed to the aggregate packing characteristics and binder film thickness around the aggregates.