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A Case Study of Pavement Surface Characteristics for the Evaluation of Skid Resistance

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A B S T R A C T:

When maintaining a pavement, skid resistance—a critical component of road safety—should be evaluated. In order to provide the vehicle's tyre with enough friction when it interacts with the pavement when applying brakes, a pavement needs to exhibit a promising degree of skid resistance. In particular, when it's wet, skid resistance is crucial in lowering the number of traffic accidents. This makes it one of the most crucial factors affecting road safety. It is the force generated when a tyre slides across the pavement surface and is stopped from rotating. Tyre-pavement contact results in pavement friction. Skid resistance is the friction force that develops at the point where the tyre and pavement come into contact. It is an important safety measure for driving on the road and helps to lower the number of accidents, particularly in rainy weather.

In this project, the British Pendulum Tester was used for skid resistance testing, and the Sand Patch Tester was used for macrotexture testing. Following that, the International Friction Index was used to calculate the friction values at different slip speeds. These values were then correlated with MTD and BPN values (in both dry and wet conditions).

Keywords: Skid resistance, wet and dry conditions, MTD values, Friction Index, and BPN values.

1. Introduction

The characteristics of the pavement surface are the factors which shows how different surface performance variables, like tyre-pavement noise, friction, smoothness, and acoustic impedance, are affected by different types and configurations of texture. Four features of the road surface are crucial for a safe and pleasurable drive: the friction between the tyres and the road surface, the road's smoothness, the top pavement's attributes for light reflection, and water drainage. In this study, the skid resistance and its relationship to micro- and macro-texture will receive the majority of our attention.

1.1 TYPES OF PAVEMENT SURFACES (SURFACE COURSE)

Basically, there are two types of pavement surfaces: flexible and rigid. Surfaces for flexible pavements are made of bituminous (or asphalt) materials. These can take the form of bituminous surface treatments (BST), which are typically found on lower-traffic roads, or hot mix asphalt (HMA) surface courses, which are typically used on higher volume roads like the Interstate highway network. Since the entire pavement structure "deflects" or "bends" in response to traffic loads, these pavement type are referred to as "flexible". A flexible pavement structure often consists of several layers of materials that can allow this "flexing". Rigid pavements, on the other hand, are made of a PCC surface course. These pavements are noticeably "stiffer" than flexible pavements since the PCC material is having higher elastic modulus. These pavements could also be reinforced with steel, which is normally used to reduce or eliminate joints.

1.1.1 Road Texture

Skid resistance is an important aspect of the surface of the pavement that can give quick insight into how the road surface will affect traffic operations. For determining the role of the pavement to tyre/road friction, it is a measure of friction developed under specific, standard circumstances. It is used to set the values of potential variable components. The combination of two processes, namely molecular adhesion and hysteresis losses, is what causes the friction in between the tyres and the pavement surface.

1.1.2 Microtexture

The asphalt mix's surface characteristics, such as shape and size in addition to the aggregate gradient and the asphalt/bitumen elements used to generate molecular adhesion, all influence microtexture, a fine-scale texture property. The microtexture is based on how rough the surface of the aggregate is. It is among the most significant variables that can affect how skid-resistant the pavement surface is. The microtexture's amplitude ($0.001 < A < 0.5$) and wavelength ($0 < \lambda < 0.5$) (in mm) are used to estimate its texture level

1.1.3 Macrotexture

The existence of gaps between aggregate particles and consideration of the coarse aggregate's greater size, shape, and gradients in the asphalt mix determine macrotexture, which is a larger (coarse) scale texture property. Macrotexture is the main factor for hysteresis loss. Hydroplaning can be decreased by channels in the macrotexture of the surface pavement that allow water to escape. This texture level is assessed using its amplitude ($0.1 < A < 20$) and wavelength ($0.5 < \lambda < 50$) (in mm). Although microtexture and macrotexture have a significant impact on the generation of skid resistance, other pavement surface textures, such as megatexture and roughness (unevenness), are also significant pavement characteristics. These may be explained as follows:

1.1.4 Polished stone value (ASTM 3319 -11)

The polished-stone value measures an aggregate's ability to withstand being polished by tyres of moving vehicles in circumstances that are comparable to those on a road's surface. Since, aggregates make up the majority of a road's surface, one of the significant factors affecting the surface's resistance to skidding will be the polish of the sample. The actual relationship between PSV and skid resistance will change depending on the type of surfacing, traffic circumstances, and other aspects. When formulating regulations for roadworks that include test limits for PSV, all aspects, as well as the test's reliability, should be taken into consideration.

1.2 Literature survey

Jewett Henry et al. (2000) - In a study, the macrotexture of fourteen portland cement concrete pavements and twenty-one asphalt concrete pavements was measured using the CTM. The outcomes were contrasted with those of the sand track and sand patch tests. It was discovered that there was a significant association between the MPD by the CTM and the MTD by the Volumetric Method ("Sand Patch Test"). The research also shows that the IFI may be calculated using the friction coefficient at 20 kmph slip speed, as predicted by the DFT, and the MPD, as determined by the CTM.

Liu et al. (2004) - Many scientists and experts have recognized the British pendulum test's friction measurements as an indirect method for evaluating the microtexture of the road's surface. It is generally accepted that the microtexture of the pavement surface material has a significant influence on the observed friction at low speed. This general viewpoint is not always accurate, as demonstrated by the experimental findings obtained in this study. The two geometric measurements utilized in this study to describe the effects of test surface macrotexture were the magnitude of subcontact regions and the amount of gap available between the subcontact regions. The test findings revealed that the macrotexture of the test surface significantly influenced the friction values at lower speed determined with the help of a British pendulum tester. The results of this study also imply that the British pendulum test's requirement for densely packed aggregate conditions in the lab would not produce an accurate representation of the skid resistance of the actual road surface. Lab studies are likely to overstate a road surface's skid resistance if the aggregate spacing of the road surface is more than the lab prepared sample spacing.

Fuentes and Gunaratne (2010) - A study's findings recommend changing the method for computing the Sp parameter so that it also takes device-specific features into account. The requirement for modification is further emphasized by the need that at any interface the friction's speed gradient should take the characteristics of both the interacting surfaces into consideration- the pavement as well as the device used for assessment. By including vehicular attributes in the computations of Sp parameter, it is possible to resolve a conventional problem with the IFI, namely the inaccurate FR60 (estimated friction at 60 kmph) assessed from the values of friction measurements at 2 distinct slip speeds on the identical surface. This inconsistency makes the device's calibration constants A and B, which are crucial in figuring out the IFI parameters, susceptible to the measurement instrument's slip speed. This study also showed that by modifying the Sp parameter, the dependence on slip speed of the device's calibration constants A and B may be significantly reduced.

Fuentes et al. (2012) - In a study, along with applying IFI techniques to the variation of pavement macrotexture characteristic of runways and highways, the statistical importance of macrotexture of the pavement on the IFI method is evaluated. The results of the analysis showed that the concept put forth by the IFI model did not apply for pavements with high levels of macrotexture, especially since it was known that friction readings on such pavements remained constant under varying slip speeds. The error term employed in linear regression may be able to explain differences in friction measurements with slip speed at high levels of macrotexture. It was also shown that the speed constant utilised in the IFI model was quite sensitive at high levels of macrotexture from a theoretical perspective. The findings limit the application of the IFI model to relatively high levels of macrotexture. An appropriate threshold macrotexture level for the IFI model's efficient application was found.

Rezaei and Masad (2013) - A study aimed to develop a framework that represent skid resistance in terms of traffic volume, texture of aggregate, and gradation of mix. The framework was designed utilizing considerable measurements and research on the skid resistance, texture, and friction of asphalt mix surfaces both in the lab and out in the field. Additionally, aggregates were distinguished utilizing the imaging system of aggregates after different Micro-Deval polishing intervals. The gradation of aggregate was described by the 2-parameter accumulated Weibull distribution function. The proposed model offers a prediction of the field skid number. Therefore, engineers can make various

Mahboob Kanafi et al. (2015) –In order to observe microtexture and macrotexture changes under real-world traffic situations and to validate relations to the values of friction, a study focused on some field experiments which were conducted on actual road surfaces. 3D evaluations of the surface's wearing course of 3 asphalt mixtures were performed during a small period of nine months. A number of photo-simulated pictures of surface height maps, statistical texture indicators, and spectral analysis were employed to examine the evolution of micro-texture and macrotexture and investigate the underlying physical phenomena. Fractal as well as non-fractal characteristics were used, with an emphasis on the Hurst exponent (H), to correlate texture with friction. The findings of texture evolution make it abundantly evident that changes in macro/microscales take place throughout the entire surface profile and not just as a result of the polishing

Phenomenon of a few selected top road surface features. It was demonstrated that H, as a general indicator of road surface specifications, cannot be applied to the studies of pavement texture-friction in real traffic situations.

Wasilewska et al. (2016) - The use of CTM and DFT to assess wearing courses made of AC, SMA, exposed aggregate PCC, and Slurry Seal was covered in a study. 11 assessment sections were considered. Additionally, at test speeds of 30, 60, and 90 kmph with a locked wheel, the SRT-3 equipment was utilized to determine the friction coefficient. At the investigated speeds, a good connection between DFT20 and μ was seen. The SRT-3 instrument was shown to be more responsive to changes in pavement micro- texture than macro-texture. The impacts of the asphalt mix, method of texture, and coarse aggregates resistance against polishing were studied with regard to skid resistance. The IFI values for all testing segments were calculated in accordance with ASTM E1960-07(2011) using the obtained data from the CTM and DFT instruments. Additionally, using IFI, the friction coefficient at various slip speeds was calculated. This was done in order to compare different pavement surfaces in relation to the slip speed. According to the investigation, AC pavements outperformed exposed aggregate PCC and SMA in terms of skid resistance at low speeds. Exposed aggregate PCC and SMA exhibited better skid resistance at high speeds. This knowledge is useful for both the designing stage of a project and for maintaining existing pavements appropriately.

Zhu et al. (2023) To achieve the optimal design and accurate prediction for the long-term skid resistance performance of asphalt pavement, the skid resistance and its evolution trend prediction models of different asphalt mixtures were studied based on the accelerated pavement test using a small accelerated loading device (MLS11). First, three oil-stone ratios, three gradations and four types of coarse aggregates were prepared for different types of asphalt mixes. Second, the long-term skid resistance degradation characteristics and its influencing factors of different asphalt mixtures were studied based on the indoor accelerated pavement test using MLS11. Next, the macro-structure and micro-structure for the evolution prediction models of asphalt pavement were constructed and validated based on the combination of the numerical model and test section. Finally, the design standard and evaluation indexes for skid resistance of high-grade asphalt pavements under heavy traffic conditions were proposed. The results show that dense graded asphalt mixes with a smaller oil-stone ratio have better skid resistance, the type of gradation has less influence on its skid resistance, and the mixture consisting of aggregates with a richer mineral composition type and large difference in mineral hardness has better durability of skid resistance. In addition, the prediction models for the macro-structure and the micro-structure were established, respectively, and the errors of MTD and BPN measured in the test section were controlled within 4% and 5% of the theoretical values. The attenuation rate $|A|\leq 2.15$ is proposed as the design criterion for the skid resistance of asphalt pavements.

1.3 Methodology for Skid Resistance

The measurement of skid resistance is challenging because various natural and man- made factors can either actively or passively alter the friction at the tire- pavement interactions. On wet pavements, the conventional technique for measuring skid resistance is also considered. As a result, the dry and wet pavement conditions have a substantial impact on skid resistance readings. Errors of various forms and magnitudes are typical in data collection. These errors may result from human involvement (such as data classifications, visual assessment, entering or processing of data) or the device or technology used. However, random errors (non-uniform case) and systematic errors (information errors) can both have an impact on data collecting on skid resistance. In some cases, it can be challenging to distinguish between the two types of errors, and several errors involve a combination of random and systematic errors.

1.3.1 Various steps must be taken to better understand skid resistance:

1. Establish a global plan and guidelines for skid resistance;
2. Standardize feasible traffic management process thresholds;
3. Determine measurement methods and parameters;
4. Create a common scale;
5. Implement the procedures that have been created;
6. Evaluate the outcomes in comparison to those attained using additional non-destructive and sensor-based methods;
7. Use more models, data analysis, and machine learning to verify the findings;
8. Utilize cutting-edge technologies to conduct real-time monitoring.

1.4 Norms for skid resistance

1.4.1 International Norms for Skid Resistance

Various test processes and test devices are used to determine a possible skid resistance threshold that can be customised to meet the needs of a certain roadway system. There are so many elements (for example, speed and water film thickness) which have an impact on traffic management practises in terms of skid resistance. For the application in the rehabilitation and maintenance processes, transportation officials strongly advise using a specific approach as a benchmark for the practise of skid resistance measuring in roadway management programs. Thresholds are typically related to existing skid resistance levels and focus on rainy situations. Furthermore, two processes—the investigatory level as well as the intervention level of skid resistance in pavement maintenance systems—are often taken into account for assessment of skid resistance.

1.4.2 National Norms for Skid Resistance

In IRC: SP: 83 -2018 and IRC: 82-2015, few devices have been mentioned for the measurement of skid resistance like British Pendulum Tester and Mu-meter. Pavement skid resistance may easily be measured using a British Pendulum Tester. Testings need to be performed at cautiously chosen sections in order to acquire appropriate readings using this approach.

1.5 EQUIPMENTS USED FOR SKID RESISTANCE

A number of instruments for the evaluation of skid resistance have been evolved and are being used all over world. Some of them have been discussed in the subsequent sections. These instruments have different working fundamentals and work on different speeds.

1.5.1 Mu meter (ASTM E670-09)

A Mu-Meter, which contains 2 testing wheels which rotate independently and tilted in the longitudinal direction, is pulled across the road at a consistent pace whereas the testing wheels are subjected to a consistent loading. This method involves collecting information on side force friction (as well as other information) across the entire section of the testing road to be used. This information is then fed into various computerised methods, that generate results such as rolling average values, friction charts, data in the form of graphs and numerics, and datas in the format accepted by various national aviation regulatory agencies.

1.5.2 Locked wheel Device (ASTM E274)

The measuring of a road surface's skid resistance with a full-scale vehicle tyre is covered by this testing method. In this test method, the frictional force on a lock testing wheel is measured in a uniform condition in which it is being pulled on a wet road surface keeping the loading and speed uniform, with its main plane perpendicular to the road and parallel to the longitudinal direction.

Mu Meter

SCRIM

1.6 Techniques for restoration of Skid resistance

1.6.1 Dense –Graded hot mix asphalt

This category of asphalt concrete is considered as the most typical asphalt pavement, so it serves as the baseline for all comparisons. The compacted mixture have a close-packed curve for aggregate gradation having a minimal quantity of air voids. The initial friction levels are in the range of 60–65 BPN. Data variations are unavoidable due to type of aggregate, size of gradation, and mixing percentage.

1.6.2 Open graded friction course

This category of asphalt mix are unique gap-graded having a massive amount of interconnecting air voids. This volumetric aspect produces high permeability values, with amount of air voids range from fifteen percent to thirty-five percent. In terms of skid resistance, the initial computed readings may vary between fifty and eighty BPN. Furthermore, it performs well in rainy environments since its permeability lowers water spray and splash.

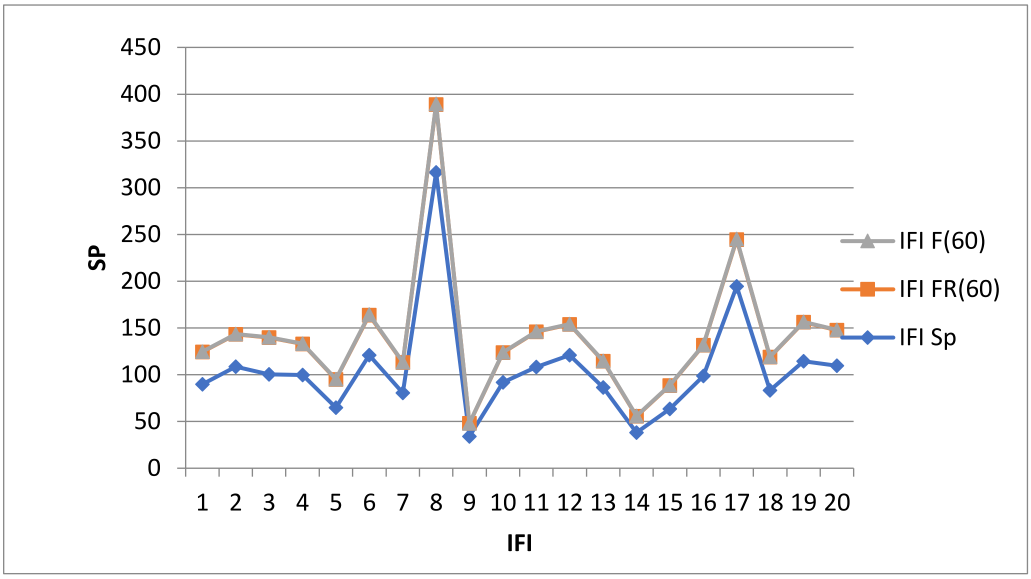
1.7 Data Analysis

The data was analysed using the International Friction Index. At last, the friction values have been correlated with the MTD values and BPN values (both dry and wet conditions).

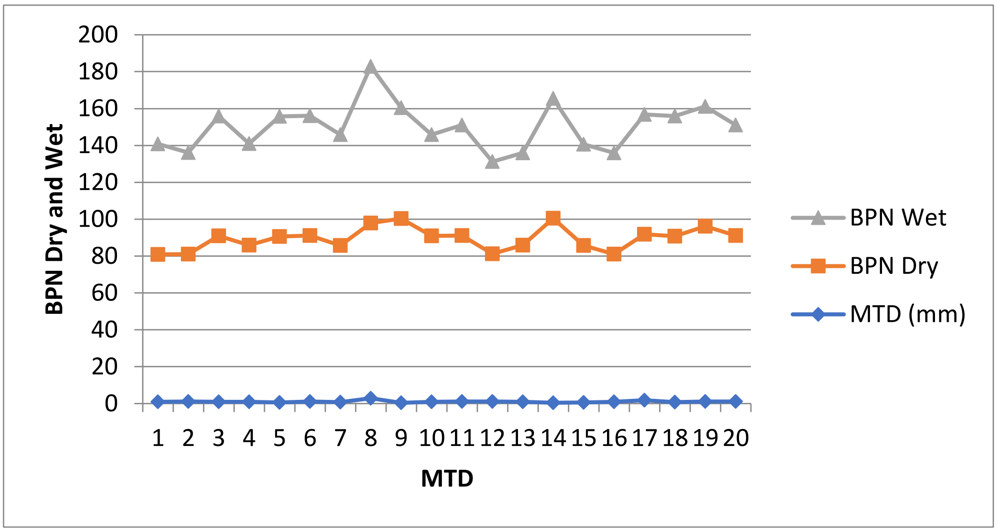
Calculation of IFI

For Wet Condition			**IFI**		
S. No.	**MTD (mm)**	**BPN**	**Sp**	**FR(60)**	**F(60)**
1	0.89	60	89.84	34.39	0.33
2	1.06	55	108.48	34.69	0.33
3	0.99	65	100.30	39.48	0.37
4	0.98	55	99.73	33.31	0.32
5	0.67	65	64.85	30.07	0.30
6	1.17	65	120.86	42.98	0.40
7	0.81	60	80.64	32.28	0.31
8	2.89	85	316.36	72.57	0.64
9	0.40	60	34.07	13.83	0.17
10	0.91	55	91.78	31.90	0.31
11	1.05	60	108.13	37.79	0.36
12	1.17	50	120.86	33.06	0.32
13	0.86	50	86.44	28.04	0.28
14	0.44	65	38.04	17.46	0.20
15	0.66	55	63.49	25.02	0.26
16	0.97	55	98.48	33.10	0.32
17	1.81	65	194.36	50.26	0.46
18	0.84	65	83.26	35.65	0.34
19	1.11	65	114.27	41.96	0.39
20	1.07	60	109.61	38.02	0.36

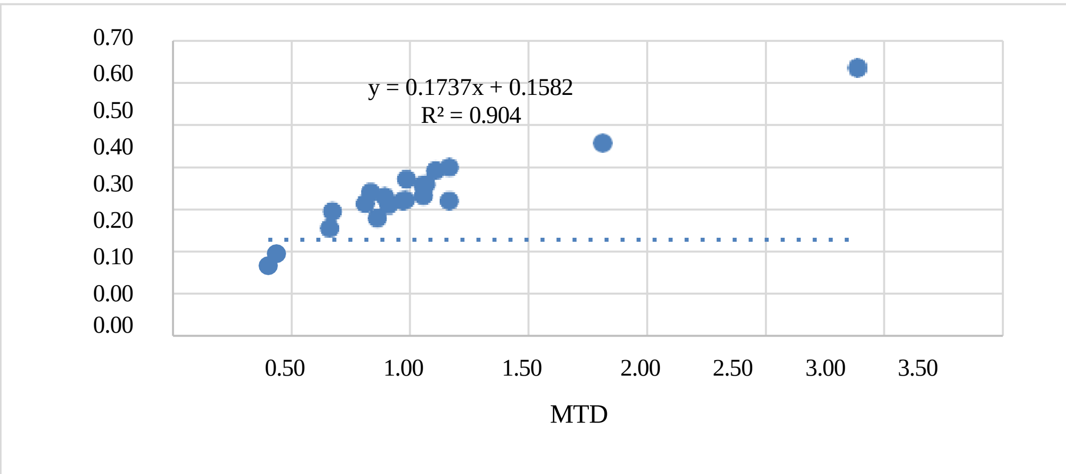
For the International Friction Index (IFI), the MTD and BPN values (in wet condition) have been used for the calculation of speed gradient coefficient Sp, modified values of friction at 60 kmph FR(60) and friction number F(60). The calculations of International Friction Index (IFI)



IFI V/S SP VALUES



MTD V/S BPN VALUES



Correlation between BPN & F60 values

MTD have poor correlation with friction values at lower speeds but for higher speeds it is showing strong correlation with friction values. This verifies that macrotexture contributes to the pavement skid resistance at high speeds. The graph for correlation between MTD and F60

Kosi Minar Road Left Hand Side

MTD		**0.89**
BPN	**Dry**	**80**
	Wet	**60**

Kosi Minar Road (Right Side) 2nd lane

MTD		**0.99**
BPN	**Dry**	**90**
	Wet	**65**

1.8 Conclusion

Macrotexture is a consequence of the qualities of the asphalt mix as well as the manner of placing, while microtexture is a consequence of the mineral composition of the aggregate and the roughness of the aggregates themselves. Numerous researchers looked into the connection of skid resistance and road texture levels and came to the conclusion that while macrotexture contributes to skid resistance when travelling at greater speeds on wet surfaces, microtexture contributes to skid resistance when travelling at lesser speeds on dry surfaces. A key characteristic of macrotexture is the reducing of the hydroplaning phenomena, which happens at greater speeds when the thickness of water film on the road's surface is more than 0.5 millimeters. This suggests that enough macrotexture must be maintained, especially on motorways and other higher-speed roadways.

1. The mean texture depth values have poor correlation with friction values at lower speeds but for higher speeds it is showing strong correlation with friction values. This verifies that macrotexture have influence on the pavement skid resistance at high speeds.
2. The BPN readings in dry condition are closely related to microtexture as the instrument is having low speed while the condition of the road surface is dry. For low speeds, it is showing moderate correlation which is indicating towards the contribution of microtexture in low speed and dry condition.

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