INVESTIGATIONS AND PROPOSALS FOR INVESTIGATORY LEVEL REQUIREMENTS FOR SKID RESISTANCE OF SOUTH AFRICA'S ROADS

K NAIDOO[1*], N ZUNGU[1] and T LEWIS[1***]**

[1]ARRB Systems SA, 10 Kyalami Road, Westmead, 3610, KwaZulu-Natal, South Africa
Tel: 031 700 2500; *Email: Kaslyn.Naidoo@arrbsystemssa.com
**Email: Nhlanhla.Zungu@arrbsystemssa.com
***Email: Tony.Lewis@arrbsystemssa.com

ABSTRACT

With South Africa's high incidence of serious road accidents there is a need to provide the country's roads with effective skid resistance characteristics in all weather conditions. Currently there are no skid resistance requirements specific to South Africa, and reliance is placed rather on the Polished Stone Value of the aggregate used in chip seals and asphalts, and to a certain extent on surface macro texture. Recent studies have found these two methods of assessing skid resistance to be highly unreliable at the higher speeds at which a large proportion of road collisions are initiated.

In an attempt to improve the status quo, investigations have been undertaken using a specialised vehicle that measures the sideways force coefficient of the road's surface in both wheel tracks. This vehicle also has the capability of simultaneously carrying out continuous texture measurements and enables large sets of surface friction and texture data to be collected for detailed analysis and identification of sites requiring a more detailed investigation of skid resistance.

This paper presents the methodology of the investigation; the results obtained and discuss proposals for the formal adoption of skid resistance investigatory limits appropriate to South Africa's road conditions.

1. INTRODUCTION

According to the World Health Organisation Global Statistics Report for 2018, road accidents are considered to be the eight-leading cause of deaths in the World, and are expected to be the fifth leading cause by 2030. The number of road accidents occurring across the South African road network over the past few years has been gradually increasing with an overall increase in fatalities of 18.6% over a 5-year period from 2013 to 2017. Statistics, from RTMC (Road Traffic Management Corporation) show that this has resulted in nearly 65 650 road accident fatalities over a five-year period. Figure 1 illustrates this gradual increase in road accident fatalities.

Apart from this increase in fatalities on South African roads, these accidents tend to have a negative impact on the socio-economic development of the country with large sums of government money being spent on associated costs. These disturbing statistics clearly indicate that insufficient attention is being placed on road safety around the country.

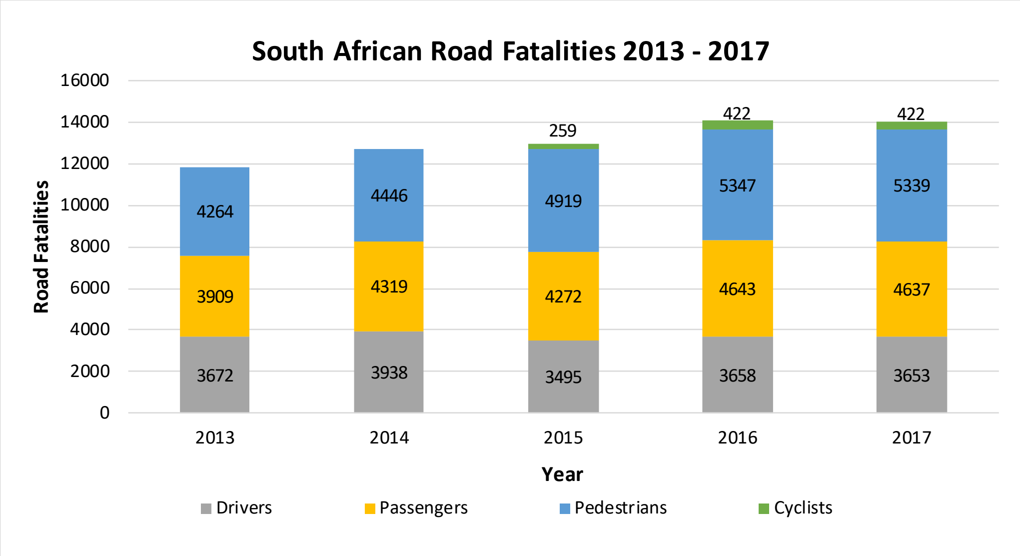

Figure 1: South African Road Fatalities 2013 to 2017

Although it is by no means the only factor influencing road safety, the road's skid resistance is considered to be a significant factor that contributes to road accidents. It has been established that the likelihood of road accidents tends to increase where the skid resistance of the road surface is below a specific threshold. One has only to listen to the radio during rainy conditions following a period of dry weather to hear of the spate of accidents. Clearly some of our roads are prone to skidding-type accidents caused by low surface friction of the wet road surfaces. Figure 2 clearly illustrates that stopping distance is inversely proportional to skidding resistance which implies that a driver will travel a shorter distance on a road of good skid resistance in order to initiate the necessary evasive actions to prevent collision with a harmful object as opposed to the longer distance required on a road of poor skid resistance.

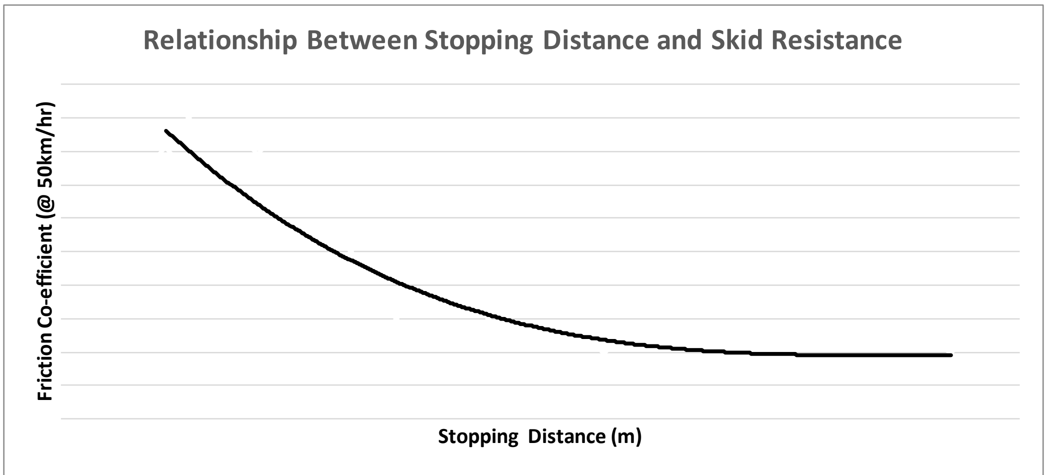

Figure 2: Relationship between Stopping Sight Distance and Friction

Therefore, it is clear that an improvement in the skidding resistance of the South African road network will surely lead to an improvement in road safety and ultimately a reduction in the frequency of road accidents across the country.

South African standards for surface friction are currently (2021) limited to the quality of aggregates used in surfacings in terms of Polished Stone Value (PSV), and to surface texture. Both these parameters are aimed at the construction phase. However, a COTO document, dated December 2008, entitled “Guidelines for Network Level Measurement of Skid Resistance and Texture”, proposes limits for skid resistance and is intended as a tool for Road Asset Management. COTO TMH 13 “Automated Road Condition Assessments” also provides useful information on this topic.

This study covers an assessment of the skid resistance of roads in the Province of KwaZulu Natal where a selection of roads with different types of surfacing and functional conditions were tested. Attention has also been given to areas where braking and turning movements of vehicles can be expected.

A specially designed vehicle with the capability of assessing surface friction using the sideways-force method was used to collect data for this study. Test sections were strategically chosen based on varying factors such as location, traffic volume, age, surfacing type, functional condition and geometrics.

The study compares the friction results obtained from this testing with the investigatory levels used in some other countries. It concludes with preliminary proposals for design and investigatory levels, taking into account the results of the investigation, as well as the levels specified in some other countries. Several recommendations are made to promote the inclusion of skid resistance into Road Asset Management Systems (RAMS).

2. FACTORS INFLUENCING SKID RESISTANCE

Skid resistance is not a consistent measurement throughout a road surface with measurements being influenced by different factors including the speed of a vehicle, tyre characteristics, as well as the thickness of the water film on the road surface during and shortly after a period of rainfall. Other factors that have a large influence on skid resistance include water dispersion from the contact area and elements of surface texture (COTO TMH 13, 2016).

Water Dispersion from The Contact Area refers to the ability of the road as well as the vehicle tyre to rapidly disperse water from the contact area of the road surface and tyre. Road related characteristics which influence this factor include texture depth of the surface as well as geometric features of the road, such as camber and cross fall, which allows the road’s self-drainage ability to be exercised. Vehicle and tyre related factors that influence water dispersion include vehicle speed and thread depth of the tyre.

Surface Texture refers to the elements that produce the friction which has the potential to prevent skidding and slow down a moving vehicle. Skid resistance is influenced by two components, namely; micro texture and macro texture. Micro-texture influences wet and dry skid resistance at all speeds but predominates at low speeds. Macro-texture has more influence on skid resistance at higher speeds. High macro-texture improves the water drainage capacity, enabling the tyre to remove water, thus improving skid resistance.

3. DEVICES THAT MEASURE SKID RESISTANCE

Several devices are suitable for the measurement of skid resistance. Devices such as the British Pendulum Tester (BPT), commonly referred to as the Portable Pendulum Tester are widely used for deriving friction coefficients but are unsuitable for continuous testing of road pavements.

3.1 Locked Wheel Testers

Locked Wheel Testers typically consist of a towing vehicle and the skid testing trailer which contains the test wheel. When testing is carried out, the test wheel is temporarily locked while the survey vehicle remains in motion at a constant speed. The rotating force on the test wheel is measured over the locked period and provides an indication of skid resistance. The test tyre can either be standard smooth or standard ribbed.

3.2 Fixed and Variable Slip Testers

Fixed and Variable Slip Testers take into account the effect of brake forces on friction. In these devices a braking force is applied to such a degree that the test wheel does not lock but rotates continuously over the road surface at a velocity less than that at free-rolling speed.

Fixed Slip Testers carry out skid resistance tests at a fixed brake force and therefore allow the measurement of friction close to critical slip. The main advantages of this device include its compactness, manoeuvrability and the relatively inexpensive operation costs. Studies have, however, found that testing with this device is more suited to targeted sections of road rather than for network level assessments.

Variable Slip Testers apply a range of braking force ratios. Recommended braking ratios can be found in ASTM Standard E1859. The advantages of the Variable Slip Tester include its compactness and manoeuvrability, however, the device is noted to be relatively expensive to purchase and operate and experience with this device is limited.

3.3 Side Force Testers

The investigation work for this study was carried out using a sideways force testing device and has been described in more detail in Section 5 below.

4. HARMONISING SKID RESISTANCE MEASURING DEVICES

It is recognised that devices used to measure surface friction produce different coefficients of friction; this is understandable given the different device configurations, speeds of testing, and water film thickness requirements. For instance, the following equation, which compares the results obtained by a fixed slip device with a device using a sideways force system, is mentioned in NZ Transport Authority's T10 Notes, 2012:

$$SC = 0.85GN \tag{1}$$

Where: SC is the Sideways Force Coefficient and,
GN is the Grip Number

Extensive work has been undertaken in Europe to develop methods for comparing the results of the wide variety of equipment used for surface friction testing. The International Friction Index (IFI) was developed by PIARC and further work has been carried out in the HERMES and Tyrosafe projects. It appears, however, that there are still doubts regarding the precision of these methods to harmonise the various devices. A recommendation from Austroads is that each jurisdiction should carefully choose its most appropriate testing device, and then retain its use over a long period of time. (Austroads, Kym Neaylon, 2010).

5. CONSIDERATIONS FOR CURRENT INVESTIGATION

The aim of this study is to derive appropriate skid resistance investigatory levels that are suited to South Africa's roads, with the intention of building on the existing COTO guidelines.

As mentioned previously, the investigation was carried out using a device measuring sideways force. These test devices are designed to simulate vehicle movement around a curve. A freely rotating test wheel is fitted with a standard smooth test tyre; the smooth tyre eliminates the effects of tyre thread wear. The test wheel is mounted onto the survey vehicle at an angle of typically 20º to the forward motion and is allowed to run freely during the test period. The alignment of the test wheel allows for a continuous sideways force to be measured. The sideways force generated in this way is measured as an indication of the skid resistance of the road's surface.

During the test period, water is sprayed on the surface of the road at a controlled spray rate to achieve a 0.5mm film of water, simulating rainfall and hence enabling the testing to be carried out in a simulated worst-case scenario, i.e. saturated surface condition. The ratio of the force developed at right angles to the plane of the wheel (the sideway force) to the load on the wheel (vertical force) is the Sideways Force Coefficient of Friction (SFC).

The sideways force device used in this investigation, the ARRB System iSAVe, provides a major advancement in measuring skid resistance and inter-related road surface characteristics and has been manufactured in compliance with British Standard (BS) 7941-1:2006. This is a fully integrated survey vehicle capable of simultaneously measuring both frictional and functional pavement conditions at traffic speeds of up to 80km/hr.

The iSAVe is used to measure the wet skid resistance of defined sections of road surface in both wheel paths, with the capability of testing in high demand locations such as the approaches to traffic signals, pedestrian crossings, or around tight curves where vehicles are typically required to brake and accelerate.

During the test a controlled flow of water is sprayed immediately in front of the test wheel to simulate wet conditions. The iSAVe's large water storage tank, enables up to 150 km of continuous data collection in both wheel tracks, making it an ideal device for both project and network level assessments of skid resistance.

A vertical load of 2kN is applied to the angled test wheel and the sideways force generated by this process is directly related to the wet skid resistance of the road surface.

In addition to collecting wet skid resistance measurements, the iSAVe has the capability of collecting roughness (IRI), rutting and macro texture (SMTD or MPD) data. It is also equipped with a Digital Imaging System (DIS) which can be utilised to capture the existing road condition and roadside features, all of which is recorded against the geographical coordinates for each data collection position for ease of reference.

The iSAVe includes features such as the monitoring of the vertical load, a dynamic micro-processor-controlled water spray system, as well as ambient and surface air temperature monitoring. It also monitors tyre pressure. The photograph in Figure 3 provides a general view of the iSAVe, showing the large water tank, testing wheel and laser beam.

Figure 3: General view of the iSAVe showing the large water tank

Figure 4 shows the configuation of the testing wheel, which runs at an angle of 20^o to the vehicle's forward motion, as well as the water spraying unit. Another testing wheel and water spray unit is located on the opposite side of the vehicle.

Figure 4: Showing testing wheel

6. EXISTING STANDARDS

The aim of managing skid resistance is not only attributed to maintaining a high level of skid resistance across a network but rather to take into account specific site characteristics. Such an approach is applied in the UK Standard CS 228 "Skidding Resistance" and has been widely adopted in many countries, and is mentioned in the COTO Guidelines (COTO "Guidelines for Network Level Measurement of Skid Resistance and Texture",dated December 2008).

The CS 228 standards specify skid resistance investigatory levels for different "site categories".

In addition to the UK Standard CS 228, standards for the management of skid resistance in New Zealand as well as some Australian states can be found in the NZTA T10 and VicRoads TN110 standards, respectively. These standards are also based on site categories and are expressed in SFC (sideway force coefficient). The investigatory levels take into account levels of risk such as pedestrian zones, different curve radii, different gradients, junctions and number of carriageways, etc.

A comparison of these different investigatory levels from the above standards with similar site categories is shown in Table 1.

Table 1: Comparison of Investigatory Levels

Site Category	Investigatory Level (SFC50)		
	UK Standard CS 228	**NZTA T10 Specification**	**VicRoads TN110**
Dual carriageway non-event	0.30 - 0.40	0.35 – 0.45	0.30 – 0.40
Single carriageway non-event	0.35 – 0.45	0.35 – 0.45	0.30 – 0.40
Dual/single carriageway with minor junctions & approaches to and across major junctions	0.45 – 0.55	0.40 - 0.50	0.45 – 0.50
Approaches to pedestrian crossings and other high-risk situations	0.50 – 0.55	0.50 – 0.60	0.50 – 0.55
Roundabout	0.45 – 0.50	0.50 - 0.60	0.50 – 0.55
Gradients 5 to 10%	0.45 – 0.50	0.40 – 0.50	0.45 – 0.50
Gradients ≥ 10%	0.45 – 0.55	0.45 – 0.55	0.45 - 0.50
Bend radius < 500m – one-way traffic	0.45 – 0.50	0.40 – 0.55	0.45 – 0.50
Bend radius < 500m – two-way traffic	0.45 – 0.55	0.40 – 0.55	0.45 – 0.50

* Table 1 above tabulates site categories of a similar nature from each country's investigatory levels for comparison purposes only.

As can be seen from Table 1, the investigatory levels of the three standards are fairly similar. It should, however, be noted that skid resistance is not a constant and the measurements are prone to fluctuations throughout the year due to seasonal effects which should be taken into account when determining appropriate levels of skid resistance.

7. NORMALISING SURFACE FRICTION MEASUREMENTS

7.1 Normalising Temperature

The formula used to normalise speed is fairly consistent, however, there are various opinions regarding the normalisation of temperature.

Surface friction is affected by both the speed at which the testing is carried out as well as by the surface temperature of the road. The visco-elastic properties of both the tyres and bituminous surfacing materials cause decreases in surface friction with increases in road surface temperature. (VicRoads Technical Note TN 110, November 2018).

However, there is no general agreement as to how the influence of temperature on surface friction should be taken into account. Some devices are equipped to measure air temperatures while others measure road surface temperature. There is also an opinion that the temperature of the tyre is kept reasonably stable by the cooling effect of the spray water and warming effect of friction that occurs between the tyre and the road's surface.

While the road authorities of the United Kingdom do not require normalisation of temperature (CS228 Skidding resistance, August 2019), temperatures are normalised in some Australian (Ed Baran, 2011) and New Zealand specifications (NZ Transport Authority T10 Notes, 2012).

The reference temperature of 20°C is debatable in countries with warmer climates and higher reference temperatures of 30°C or even 35°C have been proposed. For these reasons it was decided not to take surface temperature into account in this paper. It would, however, be worthwhile to investigate the effect that surface temperature has on surface friction in further work.

7.2 Normalising Speed

Testing is generally carried out at speeds close to 50 km per hour. In some cases, particularly at intersections, the speed is reduced. The speed is then normalised to 50 km per hour.

In this study the following formula from the UK CS 228 Standard has been used to normalise the skid resistance measurements to a speed of 50 km per hour:

$$SR(50) = SR(s) \times \frac{-0.0152 \times s^2 + 4.77 \times s + 799}{1000} \quad (2)$$

Where: SR (50) is the SFC to 50km/hr
SR(s) is the SFC at the test speed s, multiplied by 100.

7.3 Normalising for Seasonal Effects

As already mentioned in this paper a road's skid resistance is not constant, it tends to vary with the seasons. For instance, in New Zealand the skid resistance has been found to be generally lower in the middle of summer than at other times during the year. Friction testing over a period of several years obviously has to be undertaken in order to obtain sufficient data to normalise the results to a mean summer value (MSSC). (NZ Transport Authority's T10 notes, 2012).

Consideration should be given to gather information on the seasonal effects on skid resistance in South African climatic conditions so the surface friction results can be normalised.

8. SELECTION OF TEST SITES

Test sites were strategically selected, mainly to illustrate the performance of different types of surfacing with regard to skid resistance, but also to take other factors into consideration, for instance:

- Binder condition (bleeding).
- Sharp horizontal curvature.
- Steep gradients.
- Vehicle volumes, from light trafficked to heavy trafficked routes.
- Pedestrian activity, such as on sections where schools or dwellings are in close proximity to the road.
- Approximate age of the respective pavement since construction.

The types of surfacing included:

- Concrete.
- Continuously graded asphalt.

- Ultra-thin friction course (UTFC).
- Stone mastic asphalt (SMA).
- Chip seal surface treatment (double seal).

A total of 10 sites within the Province of Kwa-Zulu Natal, South Africa were tested. In each case a 2 km section of road was selected for testing.

As mentioned previously, the skid resistance tests were carried out using the iSAVe, which was built and operated in accordance with the specifications detailed in BS7941-1 (2006).Testing was undertaken along both traffic lanes, with surface friction measurements in both inner and outer wheel paths. Testing was carried out in the outermost traffic lane on roads with auxiliary traffic lanes.

9. DATA ANALYSIS

As a means of assessing the skid resistance of this set of roads the proposed “design” and “investigatory” levels are based on the Sideways Force Coefficient (SFC) levels recommended in Table 2.The “design” level represents the minimum surface friction level of the road’s surface after construction, overlay, or reseal, dependent on the surfacing type. The “investigatory” level represents the minimum surface friction level of the road surface at which a more detailed investigation of skid resistance becomes necessary.

Table 2: Proposed preliminary design and investigatory levels for various site categories

Site Category	Design Level (min)	Investigatory Level (min)
Dual carriageway non-event	0.55	0.35
Single carriageway non-event	0.55	0.35
Dual/single carriageway with minor junctions & approaches to and across major junctions	0.55	0.45
Approaches to pedestrian crossings and other high-risk situations	0.60	0.50
Gradients 5 to 10%	0.55	0.40
Gradients ≥ 10%	0.55	0.45
Bend radius < 500m – one-way traffic	0.55	0.45
Bend radius < 500m – two-way traffic	0.55	0.45

On each of the selected trial sections the following methodology was used to analyse the data:

- The data was initially analysed at 10-metre intervals in each wheel path, with the data being normalised for a speed of 50 kilometres per hour.
- Each wheel path was analysed separately using a four-point rolling average of the 10-metre sub-sections.
- Each of these values was then assigned to a relevant site category, in accordance with Table 2.

The results for the left wheel path (LWP) of the forward direction lane are plotted in Figures 5 to 13. In these figures the SFC values are plotted as the vertical bars. The red horizontal line depicts the proposed investigatory level while the blue horizontal line shows the proposed design level. Salient features of each of the roads on which the testing was carried out are summarised below.

Road A
Surfacing type: Concrete
Approximate age: 30 years
Traffic volume: Very heavy
Surface texture: Transverse tinning
Skid resistance: Satisfactory

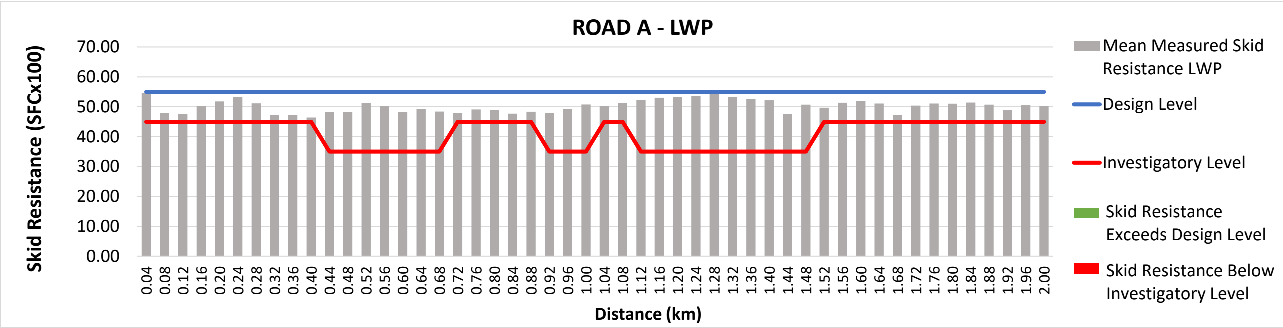

Figure 5: Road A: Concrete pavement

Road B
Surfacing type: Ultra-thin friction course (UTFC)
Approximate age: 2 years
Traffic volume: Very heavy
Skid resistance: Satisfactory

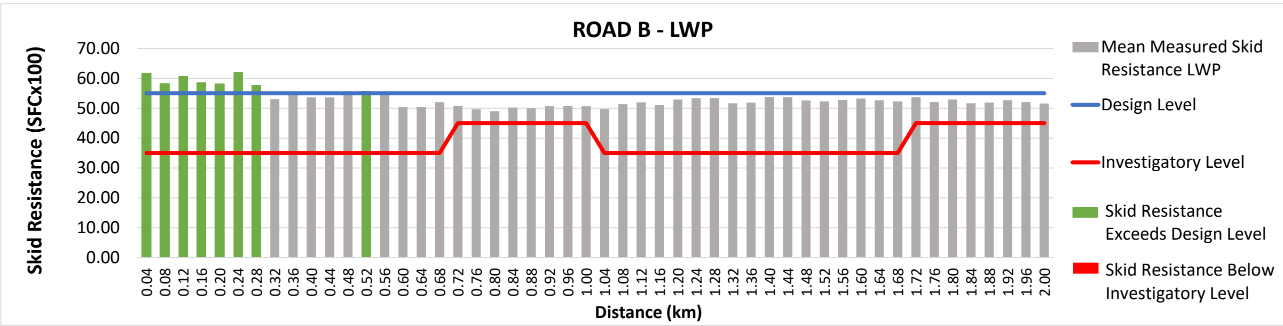

Figure 6: Road B with UTFC

Road C
Surfacing type: Ultra-thin friction course (UTFC)
Approximate age: 6 years
Traffic volume: Very heavy
Skid resistance: Satisfactory

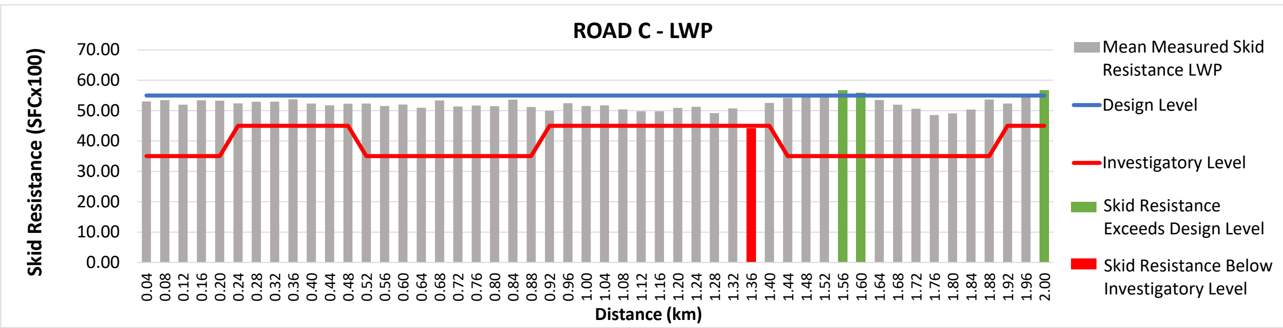

Figure 7: Road C with UTFC

Road D
Surfacing type: Chip seal
Approximate age: 8 years
Traffic volume: Moderate
Grade: Moderate to steep
Skid resistance: Variable, generally poor
Visual condition: Sporadic severe bleeding on steep grades

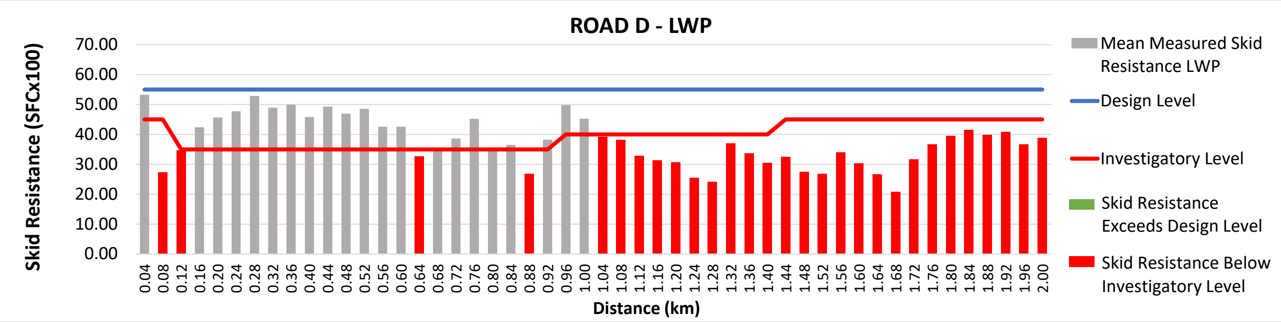

Figure 8: Road D with Chip Seal

Road E
Surfacing type: Chip Seal
Approximate age: 2 years
Traffic Volume: Light/moderate
Skid resistance: Variable, sporadic bleeding

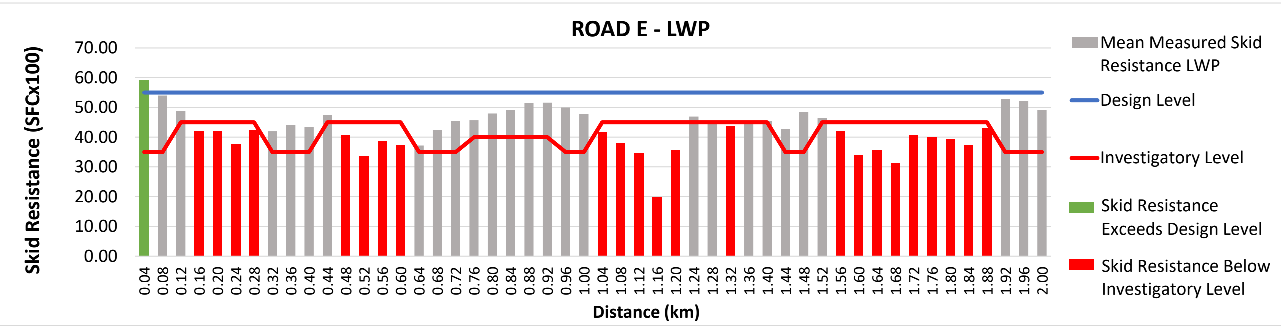

Figure 9: Road E with Chip Seal

Road F
Surfacing type: Continuously graded asphalt
Approximate age: 7 years
Traffic volume: Moderate
Skid resistance: Variable, generally poor
Visual condition: Sporadic bleeding on steep grades and sharp curves

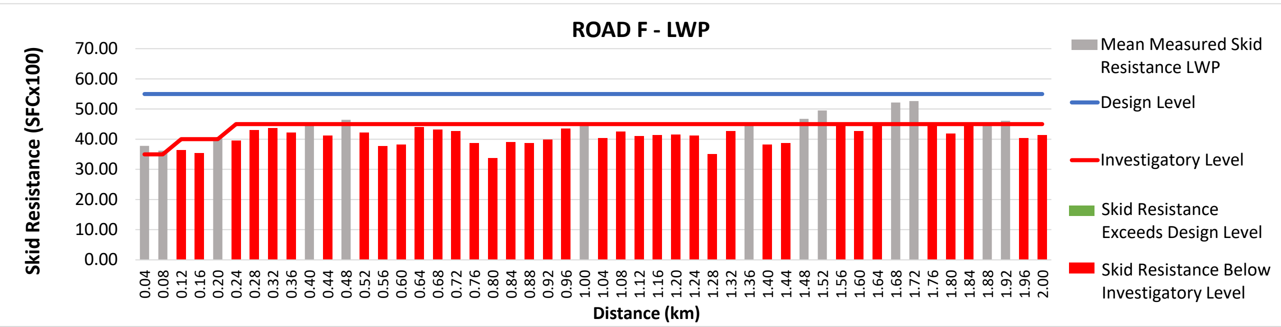

Figure 10: Road F with continuously graded asphalt

Road G
Surfacing type: Continuously graded asphalt
Approximate age: 2 years
Traffic volume: Moderate
Skid resistance: Satisfactory

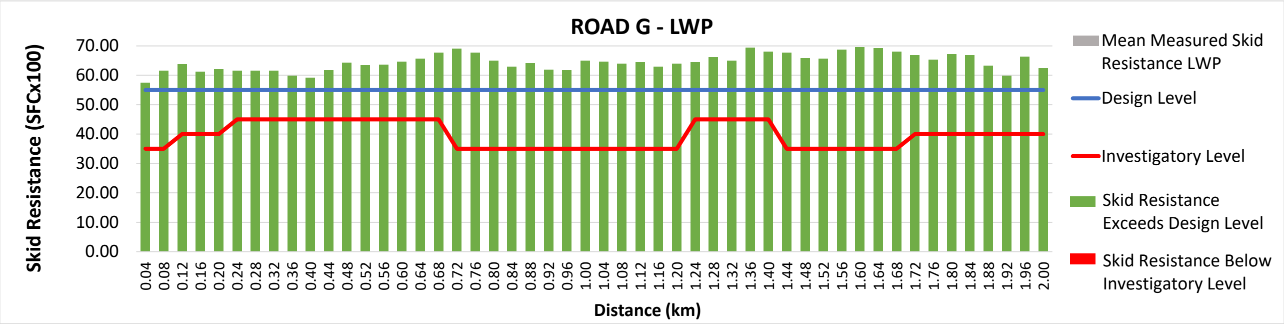

Figure 11: Road G with continuously graded asphalt

Road H
Surfacing type: Continuously graded asphalt
Approximate age: 3 years
Traffic volume: Moderate
Skid resistance: Satisfactory

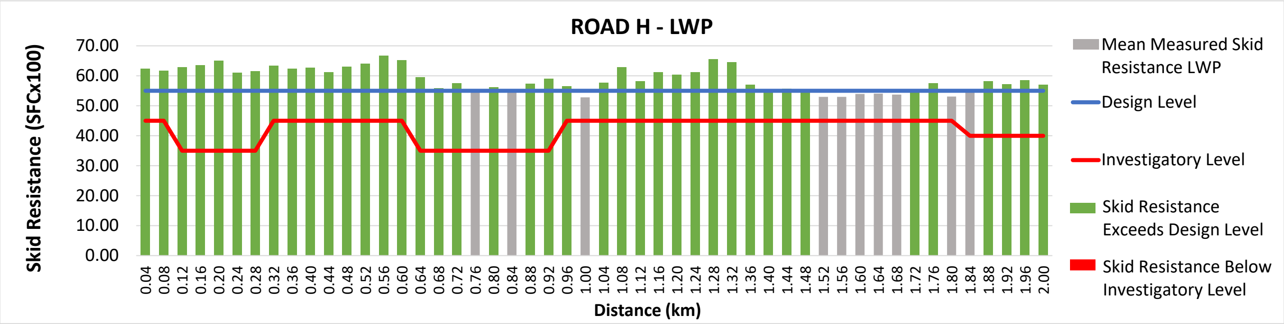

Figure 12: Road H with continuously graded asphalt

Road I
Surfacing type: Stone mastic asphalt (SMA)
Approximate age: 5 years
Traffic volume: Extremely heavy
Skid resistance: Generally poor

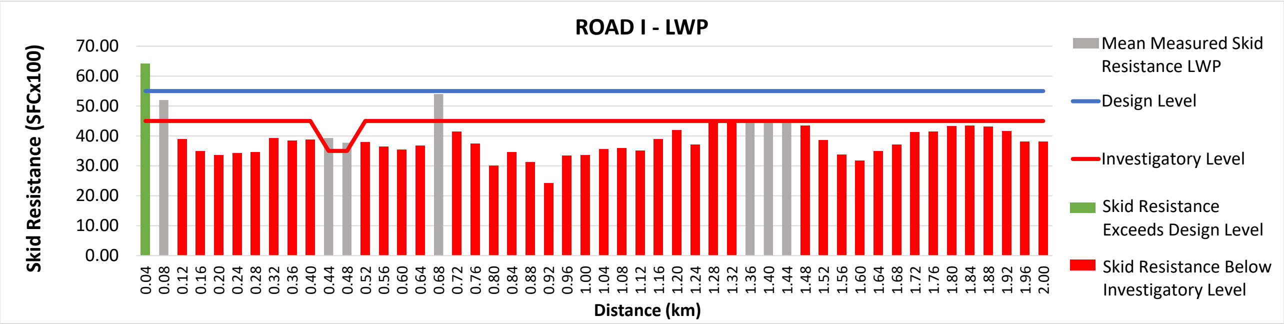

Figure 13: Road I with SMA

Road J
Surfacing type: Stone mastic asphalt (SMA)
Approximate age: 5 years
Traffic volume: Heavy
Skid resistance: Satisfactory

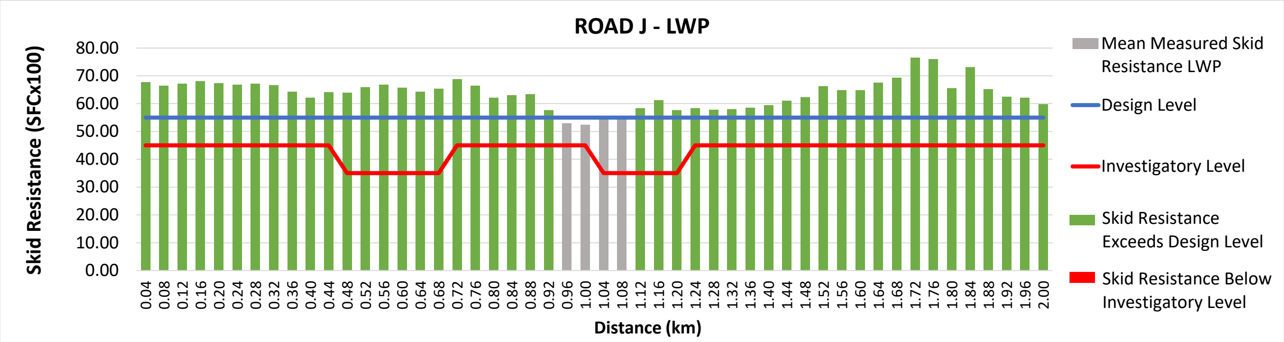

Figure 14: Road J with SMA

In summary it can be seen from these plots that:

- The performance of the concrete pavement is satisfactorily in terms of skid resistance, well over its long-life span.
- The two sections of UTFC surfacing are also performing well under heavy traffic.
- There are two sections with chip seal surfacing, Section D is performing well taking into consideration that it is 8 years old and is situated on a moderate to steep grade. The performance of Section E is unsatisfactory considering that it is only 2 years old.
- The skid resistance of two recently constructed sections with continuously graded asphalt surface (Sections G and H) is good, however, Section F which is located on steep terrain with sharp curves, shows poor skid resistance.
- Two sections with Stone Mastic Asphalt (SMA) surfacing were included in the investigation. The skid resistance of Road I, which carries extremely heavy, channelised traffic is poor, however, that on Section J, which has carried fairly heavy traffic, is good.

10. CONCLUSIONS

The investigation of 2 km sections of several rural and urban roads in the Province of KwaZulu-Natal has enabled useful information to be acquired on typical levels of skid resistance. Sections with poor skid resistance which may contribute to traffic accidents in wet conditions, can be identified.

Design and investigatory levels are proposed which take account these levels of surface friction, as well as those recommended in the UK, Australian and New Zealand standards.

The results show that while the skid resistance of most of the roads in this sample is satisfactory, some fall below the “design” level and in a few cases even below the “investigatory” level where an intervention to improve the skid resistance would be advisable.

11. RECOMMENDATIONS

It should be understood that this study only provides a snap-shot view of surface friction in a limited part of South Africa and it is recommended that the investigation be extended to other regions with different climatic conditions and road surfaces so that a larger sample of data can be obtained. In this way it should be possible to confirm whether the preliminary design and investigatory levels proposed in this paper are appropriate and to amend them where necessary. It may be found expedient to include a third surface friction limit below which the road becomes dangerous for road users and immediate intervention to improve the skid resistance becomes necessary.

Some new site categories that are not included, in particular those which may be peculiar to South Africa, could be included. Examples include the heightened risk along sections of pedestrian concentration, especially where dwellings and schools are built close to the road, as well as other situations such as wildlife crossings and stray domestic animals.

Future work should also consider the need to develop a method to normalise temperature, using appropriate reference temperatures, based on typical South African road surface temperatures. As a longer-term objective data on the seasonal variation of surface friction should be collected so that surface friction data can be normalised to include seasonal variation.

It is suggested that the information obtained from this investigation be utilised in updating the COTO Guidelines (COTO “Guidelines for Network Level Measurement of Skid Resistance and Texture”, dated December 2008).

In the meantime, taking cognisance of the poor skid resistance found on some of the roads, it is strongly recommended that road authorities consider the inclusion of skid resistance into their RAMS as a means of identifying roads that could be a danger to road users, particularly in wet weather conditions. Legislation to enforce minimum levels of skid resistance should be considered.

Skid resistance data also provides essential information into safety assessments as perthe International Road Assessment Programme (iRAP), which was created to alleviate the increasing rate of road crash fatalities globally.

12. REFERENCES

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