EVALUATION OF LONGITUDINAL AND LATERAL FRICTION OF SRI LANKAN ROADS

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SRILANKA

March 2017

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ACKNOWLEDGEMENT

I would like to express my gratitude to my supervisor Prof.W.K.Mampearachchifor his valuable comments, remarks and engagement through the learning process of this research report. I would like to convey special thanks to Dr.H.R.Pasindu, for his contribution in developing the ideas for the research. My sincere thanks go to the Director General, Road Development Authority for making this study possible by providing the financial assistance to enroll to the Masters Programme. My heartfelt gratitude goes to Eng.D.Ganesan, Director for Highway Designs Division of RDA for the enormous contribution of making the necessary provisions for this study and research related things. Let me thank (Late) Eng. (Ms.) M.M.B.Hasseba (Ex- Deputy Director, Highway Designs Division, RDA) and Eng. M.Ramanasundaran for their contribution in arranging and coordinating the field tests. Furthermore, I would like to thank the participants in the research, who have willingly shared their precious time during their research.

ABSTRACT

The road construction boom in Sri Lanka added new roads and expressways. With the improvement of roads, the exposure to accidents appears to be significant. Though appropriate methods are adopted during the design stage to ensure the road safety and due considerations were taken during the construction stages, it has been noticed significant increase in accidents and it may be purely because of the nature of the new road for road users. Pavement friction contribution is one of the key elements required for ensuring highway safety.

The longitudinal as well as the lateral friction determines the functional performance of the roads. The geometric design is carried out in Sri Lanka is based on Austroads, AASHTO publications and the guideline of RDA publication in the year of 1998, which is also prepared based on Austroads and AASHTO publications. It is a timely decision in local context to test the applicability of these friction parameters and to find out any variations and to provide recommendations. The outcome from this research will be very useful in the geometric design of highways, Pavement Management, construction and maintenance of roads. With limited studies and experiments in local roads for dry and wet conditions recommendations for the longitudinal friction coefficient has been formulated.

Regarding friction measurements, every country has instruments and methods of its own. But in Srilanka, due to the unavailability of new testing instruments, our data collection is limited to a conventional testing.

The information provided, will serve as the basis for further research and recommendations. Most importantly, it presents the case for reconsidering values of adopted for the design manual on a) Coefficient of longitudinal friction for asphalt b) the design of highway improvements with the longitudinal and lateral friction.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

Abbreviation	Description
AASHTO	American Association of State and Highway Transportation Officials
IFI	International Friction Index
MTD	Mean Texture Depth
NMA	Nominal Maximum size of the aggregate
PIARC	Permanent International Association of Road Congress
RDA	Road Development Authority
SSD	Stopping Sight Distance
VMA	Voids in the mineral Aggregate
VTM	Total voids in the mixture

CHAPTER 1

1 INTRODUCTION

1.1 Introduction

The accident rate and crashing rate in Sri Lanka is increasing drastically. Every day we are losing six to seven precious human lives due to road accidents in Sri Lanka. In other words, we are losing more than 2,500 lives every year in Sri Lanka. There are plenty of factors behind the increment of road accidents. These accidents can be related with the driver, the vehicle, the environment, and the roadway infrastructure. Lack of sufficient friction between the tire and pavement is one of the factors that can increase the risk of accidents. Providing sufficient level of friction is an integral factor, in order to ensure the safety of the road users. Every country has their own threshold values for the friction and values less than this could be a potential threat for the increased accidents. Figure 1.1 shows the forces action on a rotation wheel. Friction is act on the tire – road interface against direction of motion.

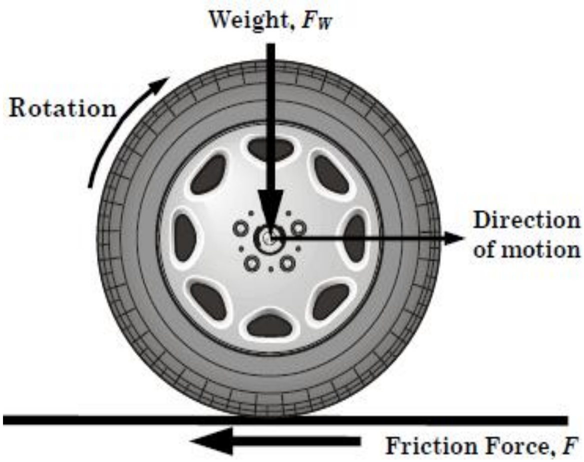

Figure 1-1Simplified diagram of forces acting on a rotating wheel (Hall, 2009)

Pavement friction is the result of a complex interplay between the two principal frictional force components - adhesion and hysteresis. Normally there are two levels of studies to improve surface texture in pavements;

1. **Micro texture**: Direct contact between the tire and pavement surface providing the **adhesion** component of the friction. Friction from the small-scale bonding/interlocking of the vehicle tire rubber and the pavement surface as they come to contact with each other.
2. **Macro texture**: Components of frictional forces results from the energy loss due to bulk deformation of the vehicle tire. This is dependent mostly on macro level surface roughness. This is due to the **hysteresis** component. Figure 1.2 shows the micro and macro texture are the adhesion and hysteresis component of friction.

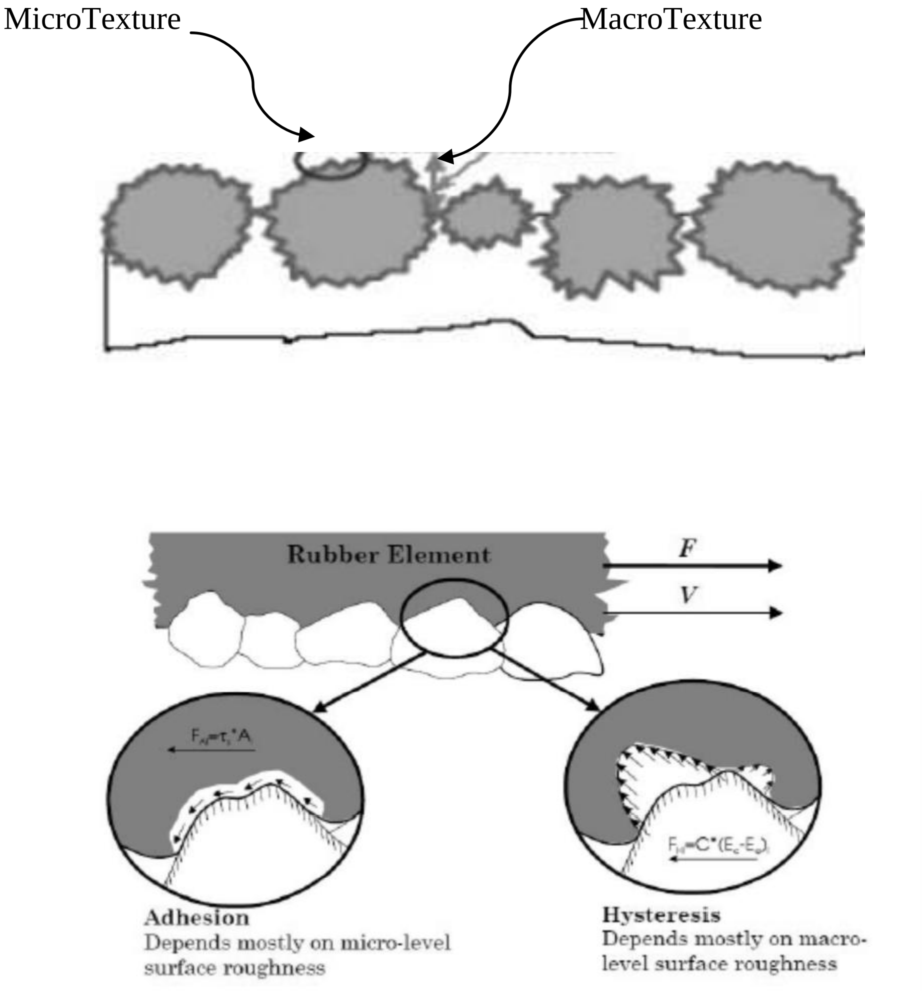

Figure 1-2 Pavement texture (Kummer and Meyer, 1962)

1.2 Background

The coefficient of friction varies with the type of pavement surface characteristics, vehicle operational parameters, tire properties, and environmental factors (NCHRP, 2000).In Sri Lanka, we are currently using the values of geometric guideline standard book of RDA. Which is based on AASHTO, Austroads and adopted for the local conditions. For design of roads, parameter such as minimum curve radius for a required design speed is dependent with coefficient of friction. The values used in RDA standards are based on AASHTO and Austroads standards. Any variations in the coefficient of friction, will affect the aforementioned design parameters. Thus, the values based on the above standards to be verified whether they are appropriate to Sri Lankan conditions, in order to get the suitable design values. Obtaining appropriate values in this regard will play a key role in saving the precious human lives.

The current values that we use seem obsolete to some extent. The coefficient of friction for the corresponding design speed values is available for the design speed values from 30 km/h to 100 km/h. Therefore, the values of this range need to evaluate the coefficient of friction values for the designs. In addition to that, the values are presented only for the bituminous and gravel roads in the RDA design guideline. The values for the coefficient of friction for the bitumen pavements have to be evaluated.

1.3 Objectives

The objective is to gather information about the different friction methods in use. It is obvious that friction between road and tyre and the skidding resistance is interrelated. However, finding the threshold values of the friction that is supposed to guide the maintenance and production of roads is not easy. Thus the validity of the existing coefficient of friction will be verified with the threshold limits.

1.4 Problem statement

The increasing accident rate of Sri Lanka urges the importance of checking the validity of the existing coefficient of friction values. Also, in the designs of curves, that the adequate sight distance needs to be provided, it is important to validate the lateral coefficient of friction to ensure the safe maneuvering of vehicles in the curves.

1.5 Scope of the report

This report will be presenting the experimental studies to determine the actual lateral and longitudinal coefficient of friction values achieved in Sri Lankan Roads. Also this will check for the validation of the existing values. The new values will be recommended and may be implemented subjected to further studies on verification of road friction based on standard friction tests.

CHAPTER 2

2 LITERATURE REVIEW

2.1 Introduction

The literature search focus primarily on information pertains to pavement friction, texture and related surface characteristics. Also the study enhances to review friction effect on user safety, as impacted by deficiencies in pavement friction, and economic considerations in the pavement and geometric design with adequate friction.

2.2 Terminology used in Friction Evaluation

A brief description of the friction related vocabulary used in this report. (Henrik, 2001)

Friction

The resistance an object encounters in moving over another object. Often the force needed to move the object, the frictional force.

Friction value, friction number

This gives the numerical value of the friction given by a specific measuring device corresponds with specific measuring tyre and specific operating conditions.

Friction coefficient (Normalized friction)

The frictional force divided by the normal force.

Skid

Sliding on the slippery ground could be defined as skid. In road circumstances skidding is the sliding of the locked wheel on the pavement.

Skid resistance

The resistance to skidding or the friction for locked wheel tests.

Skid number

The friction value as measured according to ASTM E274 which describes the friction measurement using a locked, smooth or ribbed standard test tyre.

Slip speed

The relative speed between the tyre and the travelled surface at the centre of the contact area is defined as slip speed.

Longitudinal slip, longitudinal slip ratio

The quotient of the slip speed by the operating speed

Slip angle

The angle between the wheel and direction of travel of the centre of tyre contact

Slip resistance

The resistance to slip (to lose one's footing) for pedestrian surfaces

2.3 Models for identifying friction

From these resources the following Modern Tyre-pavement models was identified for the friction (Hall, 2009), those are

- Permanent International Association of Road Congress (PIARC Model)
- Rado model
- Pennsylvania State University model (Penn State model)

2.3.1 PIARC Model

The aim of the PIARC experiment was to make it possible to calculate an international friction index from a friction measurement using any device and a measurement of the road surface MacroTexture (Hall, 2009). This friction index should be independent of the device used

1) Estimate the speed gradient coefficient Sp, using the measured macro texture:

$$Sp = a + (b*TX) \quad (1)$$

Where

TX = macro texture measurement (mm)

A, b = constants for different methods/devices used

2) Obtain the friction measurement from the specified slip speed S for the friction

Instrument used at the standard speed, set at (60 km/h)

$$FR(60) = FR(S) * e^{\frac{(S-60)}{Sp}} \quad (2)$$

Where

FR (60) = Adjusted value of friction

FR(S) = Friction value at recommended slip speed S for devices used

S = Recommended slip speed for each device [km/h]

3) Calculate the IFI friction number F(60) or golden standard estimate, using the Coefficients developed by PIARC for each device:

$$F(60) = A + B*FR(60) + C*TX \quad (3)$$

Where

A, B = calibration constants dependent on friction measuring device

C=calibration constants required for measurement using ribbed tyre

TX = MacroTexture measurement (MTD) (mm)

International Friction Index (IFI) From PIARC model Graph shows Fig 2.1

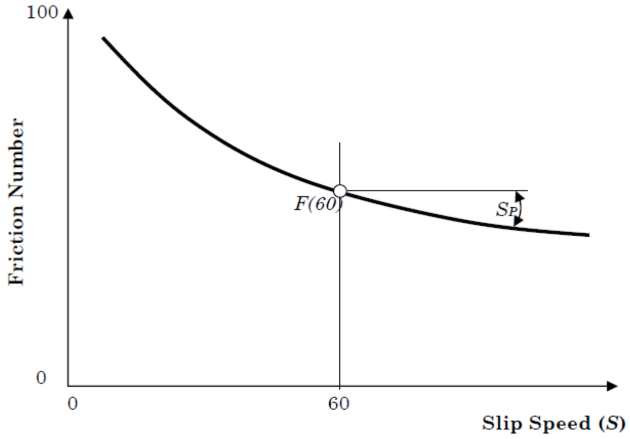

Figure 2-1 IFI friction model by PIARC

2.3.2 Rado Model

This model captures the influences of use of tire or tire uniformed design and material in addition to texture, slip speed and measuring speed. The model is valid for wet pavement also (Hall, 2009).

$$\mu(S) = \mu_{peak} \times e^{-\frac{\left(\ln\left(\frac{S}{Sc}\right)^2\right)}{C^{\wedge 2}}} \quad (4)$$

Where

μ_{peak} Is the maximum or peak friction coefficient value

$S_c$is slip speed at which maximum friction

$C^{\wedge}$is the shape factor   related to texture depth

International Friction Index (IFI) From Rado model Graph shows Fig 2.2

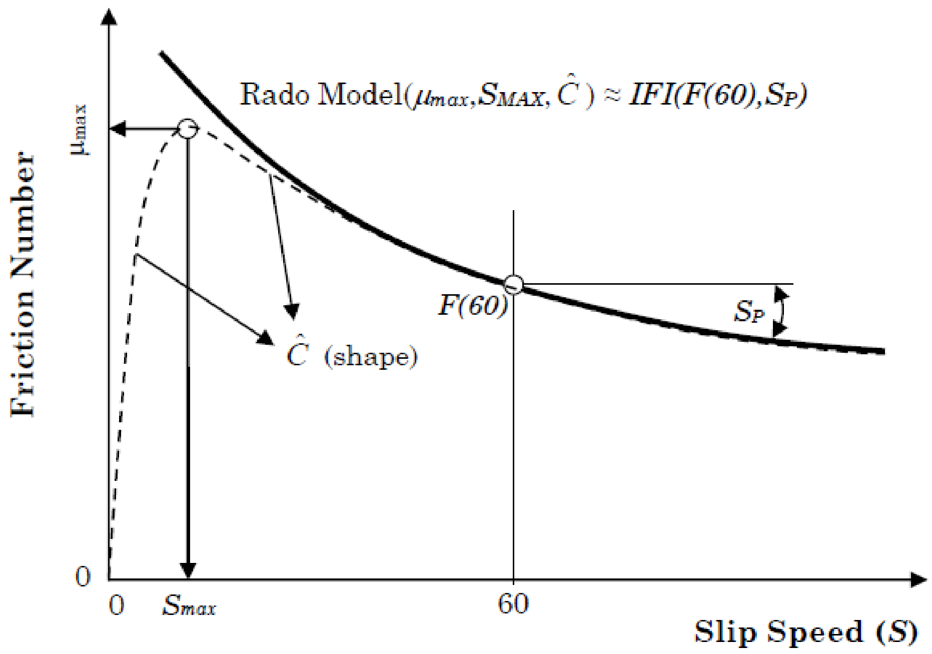

Figure 2-2 The IFI friction model (Rado, 1994)

For Hot Mix Asphalt the following regression equations are using,

Sp = - 270 + (28.3 x NMA) + (6.79 x VMA) (5)

Where NMA – Nominal Maximum size of the aggregate

VMA - Voids in the mineral Aggregate

F_{60} = 0.38189 – (0.02962 x Tyre) + (0.01295 x Binder) + (0.00911 x PP200) + (0.089 x VTM) (6)

Where:

Tyre - Type of tyre using in testing (0, 1)

Binder - Binder code (PG64-22 = -1, PG70-22 = 0, PG76 – 22=1)

PP200 - Percentage passing No 200 Sieve

VTM - Total voids in the mixture

2.3.3 Pennsylvania Model (Penn State Model)

This model mainly depends on the empirically related with MicroTexture and skid resistance measured with static procedures like British Pendulum (Portable Skid Tester) (Henry, 2000)

$$F(S) = Fo * e^{-S/So} \quad (7)$$

Where:

F(S) is the Friction coefficient at speed S

S is the speed of the rubber in contact with the road, relative to pavement

Fo is the static skid number

S_0 is the constant value (unit- km/h) depends mainly on MacroTexture of the pavement

2.4 Measurement of Friction

Out of the friction measurement devices, two common devices commonly used to measure pavement friction characteristics in the laboratory or at low speeds in the field are the British Pendulum Tester (BPT) and the Dynamic Friction Tester (DFT). Both these devices measure frictional properties by determining the loss in kinetic energy of a sliding pendulum or rotating disc when in contact with the pavement surface.

The loss of kinetic energy is converted to a frictional force and thus pavement friction. These two methods are highly portable and easy to handle. The DFT has the added advantage of being able to measure the speed dependency of the pavement friction by measuring friction at various speeds (Saito et al., 1996).

High-speed friction measurements utilize one or two full-scale test tires to measure Pavement friction properties in one of four modes: locked-wheel, side-force, fixed-slip, or variable slip. As noted by Henry (2000) and confirmed by the state survey conducted in this study, the most common method for measuring pavement friction in the U.S. is the locked- wheel method.

This method is meant to test the frictional properties of the surface under emergency braking conditions for a vehicle without anti-lock brakes. Unlike the side-force and fixed-slip methods, the locked-wheel approach tests at a slip speed equal to the vehicle speed, i.e. that the wheel is locked and unable to rotate (Henry, 2000).

The results of the locked-wheel test are reported as a friction number (*FN*, or skid number [*SN*]), which is computed using the following equation:

$$FN\ (V) = 100\mu = 100\times (F/W) \qquad (8)$$

Where:

V = Velocity of the test tire, mi/hr.

μ = Coefficient of friction.

F = Tractive horizontal force applied to the tire, lb.

W = Vertical load applied to the tire, lb.

Locked-wheel friction testers usually operate at speeds between 64 and 96km/hr. Testing can be done using a smooth or ribbed tire. The ribbed tire is insensitive to the pavement surface water film thickness; thus it is insensitive to the pavement macro-texture. The smooth tire, on the other hand, is sensitive to macro-texture.

The Locked –wheel test method systems are user friendly, relatively simple and not time consuming. But it can only be used on straight segments (no curves, T-intersections, or Roundabouts).

Figure 2-3 Locked – Wheel Apparatus

The side-force method measures the ability of vehicles to maintain control incurves and involves maintaining a constant angle, the yaw angle, between the tire and the direction of motion.

The side-force coefficient (*SFC*) is calculated as follows:

$$SFC\ (V, \alpha) = 100\times (FS/W) \qquad (9)$$

Where:

V = Velocity of the test tire, mi/hr.

α = Yaw angle.

FS = Force perpendicular to plane of rotation, lb.

W = Vertical load applied to the tire, lb.

The two most common side-force measuring devices are the Mu-Meter and the Side-Force Coefficient Road Inventory Machine (SCRIM). The primary advantage offered by side-force Measuring devices is the ability for continuous friction measurement throughout a test section (Henry, 2000). This ensures that areas of low friction are not skipped due to a sampling procedure. Fixed-slip devices measure the friction experienced by vehicles with anti-lock brakes. Fixed-slip devices maintain a constant slip, typically between 10 and 20 percent, as a vertical load is applied to the test tire (Henry, 2000). The frictional force in the direction of motion between the tire and pavement is measured, and the percent slip is computed as follows:

$$Percent\ Slip = \frac{(V - r * \omega)}{V} * 100 \qquad (10)$$

Where:

Percent Slip = Ratio of slip speed to test speed, percent.

V = Test speed.

r = Effective tire rolling radius.

ω = Angular velocity of test tire.

These devices are also more sensitive to micro-texture, as the slip speed is low.

Since the aforementioned vehicles and apparatus were not available for the research studies, we carried out the tests in the following conventional methods.

2.4.1 Conventional Methods in Measurement of Friction

1) Stopping Distance Measurement
2) Deceleration Rate measurement

2.4.1.1 Stopping Distance Measurement

Method of the measurement, the pavement surface is sprayed with water until saturated. A vehicle is driven at a constant speed 64 km/hr.specified over the surface. The wheels are locked, and the distance the vehicle travels while reaching a full stop is measured. Alternatively, different speeds and a fully engaged anti-lock braking system(ABS) have been used. Method of calculation describes with the equations in chapter 2.5.1.

This method is the simplest and backward calculation method for determining the pavement surface friction. But the test values obtained are not very repeatable, due to the Visual Acuity, expectancy, behavior and abilities of the driver (Robert Layton, 2012). The physical abilities and psychological limitations impact these criteria. Also the testing area traffic control is required.

2.4.1.2 Deceleration Rate measurement

The measured deceleration force is used to calculate the pavement surface friction coefficient, μ. using the equation:

$$\mu = \frac{\textit{Measured Deceleration}}{g} \qquad (12)$$

Where:

μ = Coefficient of friction.

g = Acceleration due to gravity, (9.81 m/sec^2).

The measured deceleration can be directly measured for the complete stopping operation or determined for a partial stop as the difference between the initial and final deceleration divided by the braking time (Greibe, 2007).

This system is easy, but it requires a sudden braking maneuver to be made, and such maneuvers may not be operationally desirable.

From the proper GPS technology instruments, deceleration rate can be determined during the braking process of test vehicle.

2.5 Experimental Method of Measurement of Friction

2.5.1 Longitudinal Coefficient of Friction Measurement

According to the above conventional methods, Stopping Distance measurement will be the most suitable method compare to the deceleration rate measurement.

From the Geometric Design Standards of Roads Guideline of RDA, the longitudinal friction is calculating according to the stopping sight distance (SSD) Method.

This distance has distance travel during total reaction time and travelled during braking time. Normally RDA has total reaction time is 2.5sec.
The following equation is using for SSD,

$$SSD = \frac{t_R V}{3.6} + \frac{V^2}{254\mu} \qquad (13)$$

Where: V is the design speed of the vehicle (km/h)

t_R is the reaction time (sec)

μ is the coefficient of longitudinal friction

For $\mu$the table 2-1 values are used

Table 2-1 Longitudinal Coefficient of friction in RDA Guidelines

Design Speed / (km/h)	Friction Factor / (μ)
30	0.40
40	0.38
50	0.35
60	0.33
70	0.31
80	0.30
90	0.30
100	0.29

Source: Geometric Design Standards of Roads, RDA (1998)

The values varies with speed, tyre pressure, type of pavement and whether the surface is dry or wet. When present day modern passenger cars are concerned, it has been found that they could consistently achieve longitudinal coefficients in excess of 1.0g. However, values used for design purposes should allow for the degradation of pavement skid resistance, when wet and for reasonable amount of surface polishing (1).

Countries like Sweden, Denmark and Norway are maintaining higher value of coefficient of friction (Greibe, 2007).
Danish standard equation as follows

$$I_{brake} = \frac{V^2}{2g(\mu_{brake} + s) \times 3.6^2} \quad (14)$$

Where:	I_{brake}	-	Braking distance
	V	-	Speed (km/h)
	G	-	Acceleration due to gravity (9.81ms^{-2})
	μ	-	Mean coefficient of braking
	s	-	Roadway grade

2.5.2 Lateral Coefficient of Friction Measurement

Based on the Geometric Design Standards of Roads Guideline of RDA, the lateral coefficient of friction is obtained from the following equation

$$R_{min} = \frac{V^2}{127(e_{max} + f_{max})} \quad (15)$$

Where	R_{min}	- Minimum curve length (m)
	e_{max}	- Maximum Super Elevation
	f_{max}	- Maximum side friction factor
	V	- Design speed (km/h)

According to the equation 15, Rmin value can be determined with maximum values for super elevation and maximum of side friction factor. At low speed, side friction values are high compare to the high design speed values, due the safety of the driving vehicles.

The table 2-2 friction values are using for the above equation

Table 2-2 Values of Side friction in RDA Guidelines

Design Speed (km/h)	**Maximum Design Values of Coefficient of Side Friction**	
	Bituminous Roads	**Gravel roads**
30	0.210	0.14
40	0.190	0.13
50	0.170	0.12
60	0.160	0.11
70	0.150	0.10
80	0.140	0.09
90	0.130	-
100	0.128	-

Source: Geometric Design Standards of Roads, RDA (1998)

For Lateral Coefficient, Chang (2001) proposed the following equations for light vehicle and Heavy vehicles

For Light Vehicles $$R = \frac{V^2}{121(0.5e+f)} \quad (16)$$

For Heavy Vehicles $$R = \frac{V^2}{122.5(0.75e+f)} \quad (17)$$

Where

e - Super elevation value

f - Lateral friction coefficient

For the circular horizontal curve, the supply and demand friction curve (Figure 2-4)concept was developed in 2004 by Echaveguren et al.

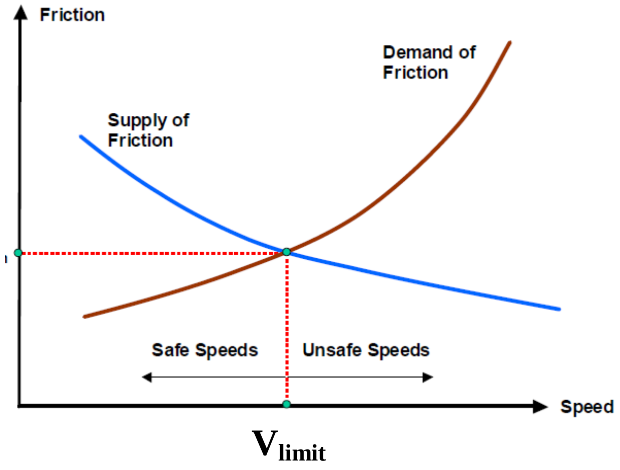

Figure 2-4 Friction Supply vs. Demand (Echaveguren et al, 2004)

For the road surface conditions, the friction can be controlled with the following two methods, those are:

1. Reduction in demand of friction
2. Increase the supply of friction

2.5.2.1 Reduction in Demand of Friction due to increase in super elevation or radius of curve or both

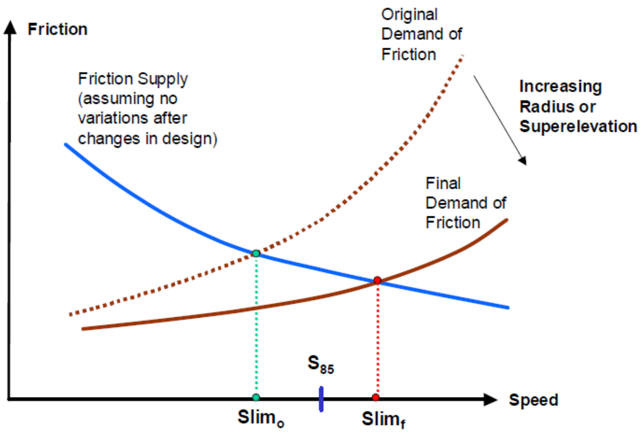

Figure 2-5 Reduction in Demand of Friction(Echaveguren et al, 2004)

For the above condition, the friction between the road surface and vehicle tyre can be reduced with the increase of curve radii and percentage of super elevation(Echaveguren et al, 2004). But some places it cannot possible with the land acquisition and access problems. And also it leads to increase the construction cost drastically.

2.5.2.2 Increase the supply of Friction by changing surface characteristic

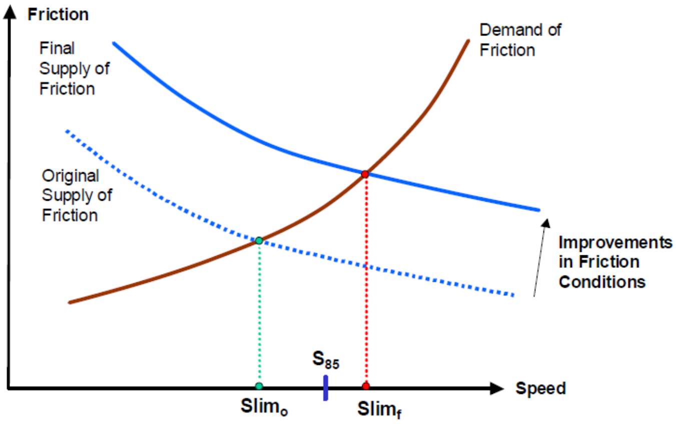

Figure 2-6 Reduction in Supply of Friction(Echaveguren et al, 2004)

The supply of friction can be increased by grooving the road surface or diamond grinding the surface or application of high friction sealing (Echaveguren et al, 2004). But these method leads to increase the construction cost. So these methods are not economical.

CHAPTER 3

3 EVALUATION PROCEDURE

3.1 Methodology

The practical was set up in various locations all around Sri Lanka. However, we have performed most of our field tests related with the Stopping Sight Distance concepts were performed in Katukurunda Airbase, Kalutara, on the recently asphalt overlaid runway. These can be considered as reasonable straight stretches with flat gradient.

A well-trained driver in RDA who drives the car allowed to reach the desired steady velocity drives in constant speed.

Once the flag signal is given the driver applies the brake and the vehicle decelerates and comes to stationary position. The distance between the brake application point and where vehicle stops is measured. The readings were obtained for 12 trials and the values lesser than 90% confidence level were discarded. The values obtained in wet surface condition and dry surface condition with symmetric continuous rib tread pattern tyres (Carl-Gustafwallman,2001). The rib tyre tread depth was around 11/32nds.

a) Location of site

b) Testing

Figure 3-1 Practical location and testing

Similarly in Trincomalee-Pulmoddai Road, Salapaiaru30th km section, we have obtained the SSD for the sea-spraying roads. The hypothesis behind the selection of sea spraying roads is based on reduction of friction due to the salt deposits in the pores/voids of the existing bituminous road. As such we may expect a reduced frictional force. Similar test procedure as explained above adopted for the tests in the sea spraying road.

a) Location of site b) Condition of Site

Figure 3-2 Practical location and condition of site

For the lateral coefficient, the practical speed of the curves in road section, the practical was done in Panandura-Ratnapura Road(A008).Which was constructed for access the Kalutara and Horana people to Ratnapura without the curve improvement with the bituminous road. Along the curve section, the vehicle had driven with the achievable speed without cutting the center and edge thermoplastic lines. The above drive speed was taken from speedometer of the Vehicle and the mobile phones speedometer software (GPS speedometer, version 3.3.4,2016, Australia). The superelevaion percentages are collected from as built drawing.

Figure 3-3 Practical locations

3.2 Calculation of longitudinal Coefficient of Friction

Stopping Sight Distance Test was performed with well-trained RDA driver. For this asphalt roads condition was identified for two types of roads, one is just after the construction and the other 5 years later. Also additional testing was covered for sea spraying roads. In this testing, the reaction time was considered as 1.5sec for known and 2.5sec for unknown hazardous situations.

The equation (18) is used to determine the longitudinal coefficient of friction

$$SSD = \frac{t_R V}{3.6} + \frac{V^2}{254\mu} \qquad (18)$$

Where V is the design speed of the vehicle (km/h)

t_R is the reaction time (sec)

μ is the coefficient of longitudinal friction

Table 3-1 to 3-4 shows the practical values of 5 years old asphalt dry pavement with moderate tyres condition.

Case 1: Asphalt: t=5yrs; Dry Pavement, Tyres in moderate condition

Table 3-1 Case 1, Test 1 Stopping sight distance, Asphalt, t =5yrs, Dry Pavement

V (km/h)	t_r(sec)	Dry Condition		Wet Condition	
		SSD (m)	μ	SSD (m)	μ
30	1.5	16.8	0.83	17.8	0.67
40	1.5	24.6	0.79	26.6	0.63
50	1.5	35.3	0.68	38.9	0.54
60	1.5	50.3	0.56	57.4	0.44
70	1.5	67.0	0.51	78.3	0.39
80	1.5	89.3	0.45	107.0	0.34
90	1.5	118.3	0.39	143.8	0.30
100	1.5	193.2	0.26	238.5	0.20

Case1: Asphalt; t=5yrs; Dry Pavement, Tyres in moderate condition

Table 3-2 Case 1, Test 2, Stopping sight distance, Asphalt, t =5yrs, Dry Pavement

V (km/h)	t_r(sec)	Dry Condition		Wet Condition	
		SSD (m)	µ	SSD (m)	µ
30	1.5	17.0	0.78	18.0	0.64
40	1.5	25.0	0.76	27.0	0.61
50	1.5	34.9	0.70	38.6	0.55
60	1.5	49.0	0.59	55.8	0.46
70	1.5	66.3	0.52	77.4	0.40
80	1.5	88.1	0.46	105.4	0.35
90	1.5	108.8	0.45	131.3	0.34
100	1.5	138.2	0.41	168.7	0.31

Case 1: Asphalt; t=5yrs; Dry Pavement, Tyres in moderate condition

Table 3-3 Case 1, Test 3 Stopping sight distance, Asphalt, t =5yrs, Dry Pavement

V (km/h)	t_r(sec)	Dry Condition		Wet Condition	
		SSD (m)	µ	SSD (m)	µ
30	1.5	16.8	0.83	17.8	0.67
40	1.5	24.7	0.78	26.8	0.62
50	1.5	34.7	0.71	38.6	0.55
60	1.5	49.4	0.58	56.7	0.45
70	1.5	66.3	0.52	76.7	0.41
80	1.5	86.9	0.47	103.9	0.36
90	1.5	122.2	0.38	147.5	0.29
100	1.5	171.8	0.30	212.8	0.23

Case 1: Asphalt; t=5yrs; Dry Pavement, Tyres in moderate condition

Table 3-4 Case 1, Test 4 Stopping sight distance, Asphalt, t =5yrs, Dry Pavement

V (km/h)	**t_r(sec)**	**Dry Condition**		**Wet Condition**	
		SSD (m)	**μ**	**SSD (m)**	**μ**
30	1.5	17.0	0.78	18.1	0.63
40	1.5	25.2	0.74	27.0	0.61
50	1.5	35.1	0.69	38.9	0.55
60	1.5	47.9	0.62	53.6	0.50
70	1.5	64.2	0.55	74.1	0.43
80	1.5	86.9	0.47	103.0	0.36
90	1.5	121.1	0.38	147.5	0.29
100	1.5	191.3	0.26	238.5	0.20

From the above tests, stopping sight distance was measured. And used backward calculation method with the equation 18, the coefficient of longitudinal friction was determined.

From the test no 1 to 4, mean value was calculated and tabulated in table 3-5 for 5 years old asphalt dry pavement with moderate tyres condition.

Case 1: Asphalt; t=5yrs; Dry Pavement, Tyres in moderate condition

Table 3-5Case 1, Mean value, Stopping sight distance, Asphalt, t =5yrs, Dry Pavement

V (km/h)	**t_r(sec)**	**Dry Condition**		**Wet Condition**	
		SSD (m)	**µ**	**SSD (m)**	**µ**
30	1.5	16.9	0.80	17.9	0.65
40	1.5	24.9	0.77	26.9	0.62
50	1.5	35.0	0.69	38.8	0.55
60	1.5	49.2	0.59	55.9	0.46
70	1.5	65.9	0.52	76.6	0.41
80	1.5	87.8	0.46	104.8	0.35
90	1.5	117.6	0.40	142.5	0.30
100	1.5	173.6	0.30	214.6	0.23

Table 3-6 shows the practical values of 1 year old asphalt dry pavement with moderate tyres condition.

Case 2: Asphalt; t=0yr.; Dry Pavement, Tyres in moderate condition

Table 3-6Case 2,Stopping sight distance, Asphalt, t =0yrs, Dry Pavement

V (km/h)	**t_r(sec)**	**Dry Condition**		**Wet Condition**	
		SSD (m)	**µ**	**SSD (m)**	**µ**
30	1.5	16.5	0.88	17.4	0.73
40	1.5	24.5	0.8	26.4	0.65
50	1.5	34.1	0.74	37.4	0.59
60	1.5	45.2	0.7	50.6	0.55
70	1.5	58.8	0.65	67.2	0.51
80	1.5	76	0.59	88.1	0.46
90	1.5	102.1	0.49	121.4	0.38
100	1.5	130.8	0.44	157.5	0.34

Table 3-7 shows the practical values of one year old asphalt sea spraying pavement with moderate tyres condition.

Case 3: Asphalt; t=1yr.; Sea spraying Pavement, Tyres in moderate condition

Table 3-7 Case3 Stopping sight distance, Asphalt, t =1yrs, Sea spraying Pavement

V (km/h)	t_r(sec)	Dry Condition		Wet Condition	
		SSD (m)	μ	SSD (m)	μ
30	1.5	17.7	0.68	18.7	0.57
40	1.5	26.2	0.66	28.4	0.54
50	1.5	36.5	0.63	40.6	0.5
60	1.5	50.3	0.56	57	0.44
70	1.5	67.8	0.5	78.6	0.39
80	1.5	96.3	0.4	110.2	0.33
90	1.5	123.7	0.37	143.8	0.3
100	1.5	157.5	0.34	205.7	0.24

CHAPTER 4

4 ANALYSIS

4.1 Lateral Coefficient of Friction

Different countries uses different friction coefficient values, those are tabulated as in Table 4-1

Table 4-1 Coefficient of Friction values with different standards

V (km/h)	AASHTO, μ_{side}	Australian, μ_{side}	RDA, μ_{side}	Danish, μ_{side}
30	0.17		0.21	
40	0.17	0.3	0.19	
50	0.16	0.3	0.17	0.31
60	0.15	0.24	0.16	0.31
70	0.14	0.19	0.15	0.31
80	0.14	0.16	0.14	0.31
90	0.13	0.13	0.13	0.31
100	0.12	0.12	0.128	0.3
110	0.11	0.12		0.29
120	0.09	0.11		0.28
130		0.11		0.27

From the above different standard values are plotted are shown in Figure 4-1

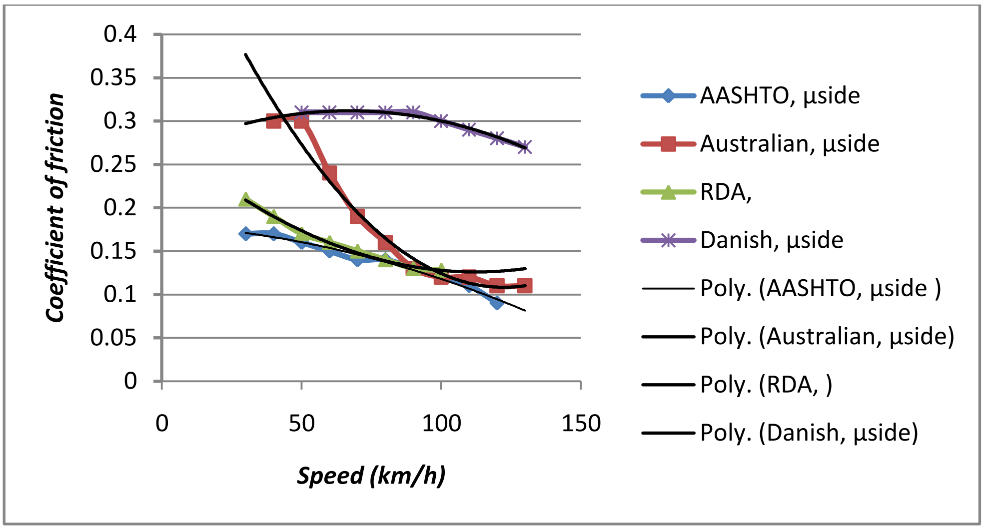

Figure 4-1Speed vs Different standard friction values

From the above graph, Danish standard is the high degree of friction, AASHTO is low. Comparatively RDA design guideline values also have low degree of friction. RDA design guideline values are low at low speed and close to Australian standard value at high speed.

From this values Australian standard value can be adopted for designs, because most of our design concepts are in par with this.

From these Standard lateral Coefficient Friction of Australian and RDA design guideline value, the minimum curve radius for the different speeds and superelevaion percentages are tabulated in Table 4-2.

Due to the unavailability of friction measuring devices (Example: Grip tester, Side force coefficient road inventory machine), the lateral coefficient (µ) analysis was done with the existing values which are practicing by RDA.

Table 4-2 Derivation of Minimum Curve radius for Australian Standards and RDA standard Lateral Friction coefficient values

v (km/h)	**Superelevation, e (%)**																	
	2.5		**3**		**4**		**5**		**6**		**7**		**8**		**9**		**10**	
30		35		30		30		30		30		30		25		25		25
40	40	60	40	60	40	55	40	55	35	55	35	50	35	50	35	45	35	45
50	65	105	60	100	60	95	60	90	55	90	55	85	55	80	55	80	50	75
60	110	155	105	150	105	145	100	135	95	130	95	125	90	120	90	115	85	110
70	180	225	180	215	170	205	165	195	155	185	150	180	145	170	140	165	135	155
80	275	310	270	300	280	280	240	270	230	255	220	240	210	230	205	220	195	210
90	415	415	400	400	380	380	355	355	340	340	320	320	305	305	290	290	280	280
100	545	515	525	500	495	470	445	445	440	420	415	400	395	380	375	365	360	350

Australian Standard Lateral Friction Coefficient Minimum Curve radius values are in Red colour and RDA Standard Lateral Friction Coefficient Minimum Curve radius values are in Black colour.

For Super Elevation of 4% for the above standards analyses, described in Figure 4-2

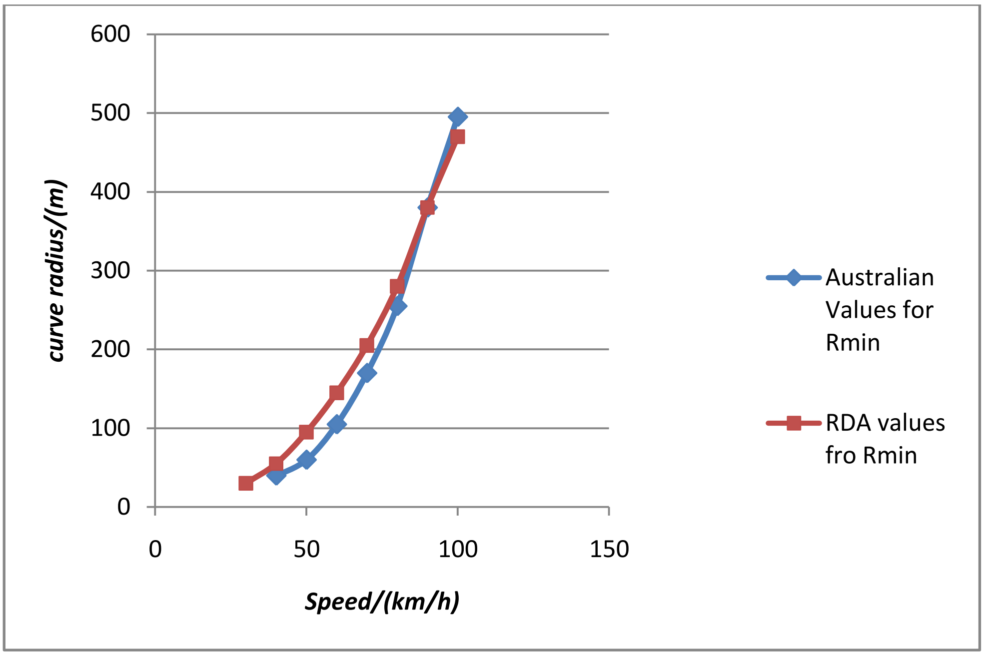

Figure 4-2 Speed vs Different standard friction values

The practically identify the speed of the curves at Panandura – Ratnapura Road (AA008), which was constructed without the curve improvement with the Asphalt surface. The superelevaion percentages was extracted from as built drawing of the road and the travel speeds of the curve from practical. The vehicle movement speed was measured without intercept the centerline thermoplastic marking with the speedometer of vehicle and mobile speedometer software. The values are tabulated in Table 4-3

Table 4-3 Practical speed of the curves

Radius/(m)	Speed/(km/h)	Superelevation/ (%)
15	32	2.5%
20	41	6.0%
30	53	6.0%
35	41	4.0%
50	46	6.0%
60	58	6.0%
80	54	2.5%
95	55	5.0%

4.2 Longitudinal Coefficient of Friction

Different standard longitudinal friction values using, those are tabulated in Table 4-4 and plotted in Figure 4-3

Table 4-4 Coefficient of Friction values with different standards with age of pavement and condition

V (km/h)	RDA existing Values	t = 0 years	t = 5 years	Danish standards	Sea Spray
30	0.40	0.73	0.63		0.57
40	0.38	0.65	0.62		0.53
50	0.35	0.59	0.55	0.38	0.50
60	0.33	0.55	0.46	0.36	0.44
70	0.31	0.51	0.41	0.35	0.39
80	0.30	0.46	0.35	0.34	0.33
90	0.30	0.38	0.30	0.33	0.30
100	0.29	0.34	0.23	0.31	0.24

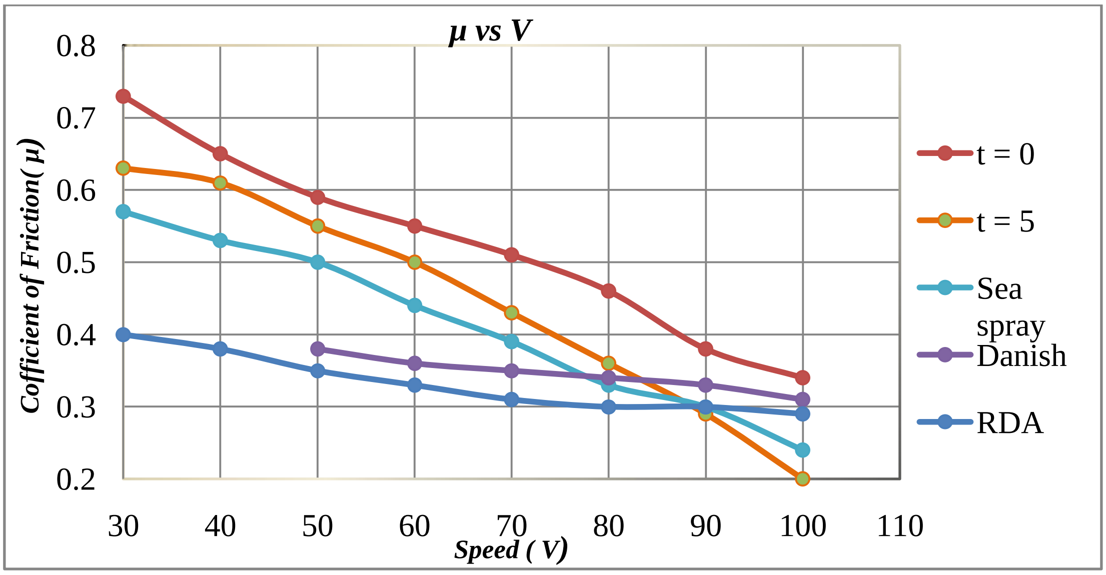

Figure 4-3 Speed vs Different standard and condition friction values

From Figure 4-3, RDA longitudinal coefficient of friction values are comparatively low at low speeds. The Danish standard friction values are almost close to the RDA values. The tested values are high at low speeds. According to the above graph, the longitudinal coefficient decreases with the age of the pavement. But the testing was done with the limited roads within the available resources. It needs to be tested at different climatic and terrain roads with the age of the asphalt pavements.

The stopping sight distances are high for RDA Standard compare to the tested values. Then it will be safety for driving. However the cost of construction may be higher.

CHAPTER 5

5 CONCLUSIONS AND RECOMMENDATIONS

This chapter shall present the conclusions of this study drawn from the works described in the previous chapters and the recommendations for future research based on the limitations of present study.

It is important for Road Development Authority to monitor the Longitudinal and Lateral friction periodical and systematically to support the safety management programs and sustainable economic programs.

The document discusses principle of friction and surface texture. The importance of friction in geometric and safety design of Highways is highlighted. Therefore the values could be developed to the current practice.

5.1 Lateral Coefficient of Friction

The existing RDA lateral friction standard values were introduced in 1998, which is extracted from Austroads and AASHTO publications which suit for the Srilankan conditions. At that time, vehicles which had no advanced technologies. Nowadays most of the present vehicles having advanced technologies and the composition of traffic due to such vehicles is more, accordingly the lateral coefficient of friction of RDA standard to be reviewed. In the design stage, when road need to be improved. The minimum radius of the curve could be relaxed. Due to the relaxation of minimum radius, the acquisition problems can be minimized. Therefore economical curve designs could be provided.

5.2 Longitudinal Coefficient of Friction

The coefficient of longitudinal friction is decreasing with the age of the pavement due to the aggregate polishing. The reason is loss of macro and micro properties. In addition, Friction decreases with dry and wet surface condition. Also friction of sea spraying roads is low. This might be due to presence of the salt deposit in the voids of the pavement. Therefore, the existing values should be recommended for revision.

5.3 Recommendations for Future Research

The following are recommendations for future research:

- Perform additional field testing on the existing and the newly constructed test sections included in this study to allow for an evaluation of friction.
- Conduct a study of the Longitudinal and Lateral friction measurements and level of validation on Srilankan road network with Field devices such as Locked wheel tester.
- Perform additional field testing for low speed conditions with British Pendulum Skid tester and compare the results.
- Conduct a study of the effects of aggregate and bitumen used in the surface.

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