TYRES AND ROAD SURFACES

Experimental multifactor investigation of the factors affecting the brake and side way forces between car tyres and wet road surfaces.

Summary, Conclusions and Recommendations from the study by Sub-Committee I of the Working Group on "Tyres, Road Surfaces and Skidding Accidents".

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CONTENTS

PREFACE

At the request of the Dutch Minister of Transport and Waterways, the Institute for Road Safety Research SWOV has conducted a study on the phenomenon of skidding. For this purpose, the Board of SWOV has set up a Working Group on "Tyres, Road Surfaces and Skidding Accidents". This Group consists of representatives of the authorities, research institutes and industry.

Among the duties of sub-committee I of the Working Group was the determination of the road surface and tyre factors and also the other factors affecting the brake and side way forces between a car tyre and a wet road surface.

The basic assumption of the study was that skidding accidents arise from human behaviour in traffic as the result of incorrect, excessive expectations regarding the available brake and side way forces. A major factor involved is a local and/or temporary decrease of the brake and side way forces. This decrease is in particular attributable to the presence of water on the road surface. The study is therefore mainly concerned with wet road surface conditions.

Following the above train of thought, it would be possible to reduce the number of skidding accidents by preventing incorrect expectations of the road user. This could be achieved through making the local and/or temporary brake and side way forces decrease as little as possible. The road user must have the greatest possible brake and side way forces under all circumstances.

In braking and steering cars a distinction should be made between minimum brake and side way forces required for the movements of the vehicle, and the available forces between tyre and road surface. In order to achieve forces greater than the minimum required, the size of such forces must be known.

In view of this, the need arose to find out, under possibly most realistic conditions, what factors actually affect the size of the brake and side way forces. According to the relevant literature, many of the studies conducted so far had been single-factor investigations, in which the influence of one single variable on the size of the brake and side way forces was investigated.

An experimental multifactor investigation to supplement the existing knowledge was therefore considered necessary for a sound study schedule. This would have to make it possible to measure the effect of each variable as well as the interaction.

The investigation consisted of three phases. The first served to determine the factors and interactions of primary importance to the forces in the contact face between car, tyre and road. In the second phase the numerical influence on these factors had to be determined for the above factors. The third phase concentrated on truck tyres.

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The Foundation for Film and Science, Utrecht, has made a film of the study with the title "Tyres and Road Surfaces".

E. Asmussen
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SUMMARY

The study concerning the contact between a tyre and the road surface was conducted in three phases. In each of these it was attempted not only to determine the effect of variables such as type of road surface and speed on the skid resistance but also interaction effects such as tread depth - speed or tyre type - water depth - tread depth.

In the first phase the first and second-order factors were separated. The factors type of road surface, tyre type, tread depth, water depth, tyre pressure and tyre load were included in an experimental multi-factor investigation. Each of them appeared to affect the brake and side way forces. Only the influence of the tyre pressure and load was found to be insignificant or very small.

The second phase served to determine the numerical influence of the road surface characteristics and the speed on the size of the brake and side way forces. It was found possible to compile a mathematical relation incorporating the contribution of the macro-roughness and micro-roughness of the road surface and also of the speed to the brake and side way forces.

In the third phase a similar mathematical relation was drawn up for truck tyres.

Car and truck tyres were compared by reference to the results. A main feature is that with car tyres the values of the available brake forces are about a factor two lower than with car tyres.

Among the characteristics of the road surface, the micro-roughness has mostly considerable influence on the skid resistance. This applies to all tyre types, at all speeds and all degrees of macro-roughness. The influence of the macro-roughness of the road surface counts heavily almost exclusively at high speeds.

Finally, recommendations are made for official measures, with emphasis on standards to be met by the macro-roughness and micro-roughness of road surfaces.

1. CRITERIA OF THE INVESTIGATION

The object of the study of the available forces arising between a tyre and a wet road surface is to determine the influence of the variables on the size of the brake and side way forces. For comparison, dimensionless brake and side way coefficients are used, defined as follows [1]:

μ_{xm}: the quotient of the maximum value of the brake force and the momentary vertical tyre load

μ_{xb}: the quotient of the brake force and the momentary vertical tyre load of the wheel is locked

μ_{y}: the quotient of the maximum side way force and the momentary vertical tyre load.

These three coefficients define the skid resistance.
Each of them is important under certain conditions. A high μ_{xm} value means that braking hard is possible without the wheels of the vehicle blocking. This permits of high deceleration whilst maintaining stability and controllability. In an emergency situation a driver will usually brake as hard as he can, which may cause the wheels to block. Under these circumstances, the shortest possible braking distance depends on a high μ_{xb} value. A high μ_{y} value is desirable if the driver wishes to change direction, run through a bend or attempts to perform an evasive manoeuvre.

Measuring method

Car tyre measurements were carried out with the tyre measuring vehicle of the Vehicle Research Laboratory of the Delft University of Technology. In a special measuring tower the vertical tyre load and the brake and side way forces were measured with the aid of a measuring hub. The resulting brake and side way force coefficients are all averages of four observations. The vehicle used for the measurements is exhaustively described in an article by A. Dijks [2].
Measurements with truck tyres were made with the single-wheel measuring trailer of the Vehicle Research Laboratory of the Delft

University of Technology. This vehicle permits measuring only brake force coefficients. The measuring criteria for truck tyres were therefore the maximum brake force coefficient μ_{xm} and locking value μ_{xb}.

2. INFLUENCE VARIABLES

Initially, the relevant literature was consulted to list the important factors influencing the contact between the tyre and the road surface. As these factors are undoubtedly known a brief description should suffice, dealing especially with the measuring method.

1. Road surface factors

The nature and composition of the road surface, and in particular the surface texture have much effect on the brake and side way force coefficients [3, 4, 5]. The main characteristics important to the skid resistance are the macro-roughness and the micro-roughness. The macro-roughness (uneven portions of 10^{-3} to 10^{-2}m) serves for quick disposal of water from the zone of contact between the tyre and the road surface. The micro-roughness (10^{-4} to 5.10^{-4}m) is meant to break the remaining water film and thus to allow adhesion between the rubber of the tyre and the road surface.
In the present study, the macro-roughness was measured by determination of the average texture depth $\overline{TD}$ according to the sand-patch method [6]. A standard volume of fine sand is spread in a circle on the road surface to be measured. The diameter of the sand patch is a measure of the average texture depth $\overline{TD}$. The micro-roughness was determined by means of the SRT device (British Portable Skid Resistance Tester), an instrument developed by the British Road Research Laboratory [7]. A pendulum, with a small block of rubber attached to its end, slides along a wetted surface. The swing height, expressed in values between 0 and 100, is a measure of the micro-roughness.
The planeness ($10^{-2}$to 1 m) is important for the skid resistance in connection with puddles on the road surface and the occurrence of dynamic changes in wheel load. The planeness is measured with the aid of the bump integrator.
Other characteristics of the road surface such as longitudinal and transverse profile affect the removal of water to the roadsides

(static drainage) and may therefore be important for the brake and side way forces. This aspect will not be enlarged upon.

2. Tyre factors

Tyres display characteristics connected with their design, tread profile and composition of the rubber.
Tyre design usually relates to the make-up of the carcass. Of the radial, bias-ply and bias-belted types the latter is very rare in Europe. The stiff carcass of radial tyres allows more latitude as regards the shape of the tread. The grooves are hardly closed at the contact face [8]. Grooves across in radial tyres present fewer problems than in bias-ply tyres, and radial tyres therefore nearly always display such grooves. They provide local reduction of the hydrodynamic pressure and therefore have favourable effect on the brake forces.
Among the characteristics of the carcass, it is probably only the cornering stiffness which is important for the side way force coefficient. The cornering stiffness is the side way force coefficient per degree of skid angle between +1 and -1 degree of skid angle. Within this, the side way force can be assumed to be linear.
The tread profile of the tyre serves to force away and take up water from the face of contact between the tyre and the road surface. Some of the water will be taken up in a groove or a sipe (small incision). The take-up capacity can be related to the air ratio. This is the quotient of the total area of the grooves and sipes, and the total contact surface. The water which cannot be taken up will have to be removed from the contact face. For the time being it is not possible to calculate the removal capacity and this was therefore determined by experiment. Water is forced through a slot into the tyre profile. Tread shapes can be compared with the aid of characteristic values [9].
The tread compound of car tyres consists of a mixture of synthetic rubber, carbon, oil and other additives. Truck tyres are still often made of natural rubber. The composition is difficult to analyse chemically. A number of derived characteristics was

therefore determined for this aspect. The hardness was measured by means of a shore hardness meter, and the resilience with a modified Lübke meter. Finally, the glass transition temperature was determined. The temperature at which the specific heat of the rubber changes, is referred to as glass transition temperature [10].

Under practical conditions, the effects of tyre load, pressure and size on the skid resistance of car tyres is probably small. With greater water depths, the tyre pressure may carry some effect with regard to aquaplanning.

3. Tread depth

The influence of the explicit tyre characteristic tread depth has been exhaustively covered by a single-factor investigation [11]. On the whole, the brake force coefficient will decline fairly gradually with the tread depth decreasing. At less than 2 - 3 mm tread depth, the brake force coefficient will be reduced very progressively. This effect is most pronounced at relatively high speeds and on slippery roads. The influence of the tread depth on the side way coefficient appears to be smaller than on the brake force coefficient.

4. Speed

The influence of the speed on the skid resistance is very much dependent on the properties of the tyre and the road surface. This means that the results of single-factor studies should be approached with caution. Generally speaking, the skid resistance will become less as the speed increases.

5. Water depth

Measures in road construction such as edging, planeness and transition to the verges, and also effective maintenance, bigger water depths on the roads can be largely prevented. On a plane, normally edged road a value of 1 mm after a heavy shower is already extreme [5, 12]. At depths of a few millimetres and more the risk of aquaplaning arises.

3. QUALIFICATION STUDY

Object

First of all, the study served to determine what factors and interactions were of primary importance to the skid resistance. To this end, an experimental multi-factor investigation [13, 14] was arranged for. The number of measurements to be taken is partly determined by the number of levels of the factors. According as the extent of the experiment increases along with the number of required measurements, unintended heterogeneity may grow in the results. With a view to eliminating this heterogeneity, the measurements can be divided into "blocks". For the purpose of the qualification study the unit day was chosen as block. As it was not feasible to measure within one block, i.e. one day, with all combinations of factors, it was decided to confound some factors with blocks. The result of confounding a factor with blocks has the result of the effect of that factor not being distinguishable from the block effect.

In this experiment, the factor road surface type and the factor units of one tyre type have been confounded with blocks to cause any differences existing between the various tyres within the type to coincide with the differences between days.

To confound effectively, it was desirable to select a large number of factors at the same levels.

It was therefore decided to set the factors speed, water depth, tyre load and tread depth at two levels. For each of the other two factors, viz. road surface type and tyre type, four levels were included in the test. The levels of the factors are set out in Appendix 1.

In addition to these variables, there are a number of conditions which had to vary during the measurements. They include the outside air temperature, the temperature of the road surface and of the spray water, and also such weather conditions as air humidity, air speed, cloudiness, etc. All these variables were recorded as consistently as possible throughout the measurements.

Results of the qualification study

The results of the main effects and interactions are shown in Appendix 2. The results of 32 repetitive measurements warrant the conclusion that the reprocibility is very high, owing to which small differences in brake and side way force coefficients can be significant. It may also be concluded that none other than the main influence factors have varied.

The conclusions from the qualification study can relate only to the area within which the levels of the factors were chosen. The choice aimed at involving the entire area which was important for practice. First-order factors important for the contact between the tyre and road surface are: the type of road surface, the tyre type, the speed, the tread depth and the water depth. Tyre load and pressure appear to carry little effect. The influence of the water depth is very small, but significant within the levels chosen.

4. FUNCTIONAL REQUIREMENTS

Object

After the qualification study it was considered necessary to investigate further because in principle only quantitative findings have value for policy decisions. This phase concentrated on the road characteristics. It had moreover appeared from the first phase that these characteristics had the greatest influence on the skid resistance.
For the second phase, it was assumed that all main effects, two-factor and three-factor interactions had to be determinable. The result was that measurements had to be taken for any setting of factors. Again, a grouping was made into blocks, with the unit day as block. Twelve measurements were carried out each day. As it was again impossible to conduct all measurements within one block, it was decided to confound, and conduct the experiment in two measuring series.
In the first series, the factors road surface type and tread depth were confounded with the blocks. In the second the factors tyre type and speed. In view of the emphasis on road characteristics, six levels of road surface types were used in this phase. Furthermore, the factor tyre type was varied at four levels, the speed at three levels and the tread depth at two. All other variables, including the water depth, were kept at constant level. One reason was that the water depth is a rather intangible aspect in policy decisions because the amount of precipitation per unit of time is a given value. Another reason is that the influence of the water depth, though significant, was yet rather small. The variables are set out in Appendix 3. As road surfaces displaying the required characteristics were not available in practice or not suitable for carrying out measurements, test sections were laid on a test road.

Brief description of the results (see Appendix 4)

As could be expected, the road surfaces with very high macro-texture (B and C) yielded extremely high values, which occasionally even well exceeded the value 1 for the maximum brake force coefficient. The high values measured on section C (macro high, micro low) can be attributed to the micro-roughness which was still rather much in evidence. Section F (no macro, no micro) displays very low values under all conditions.
The differences between tyres are very slight compared with the other main effects. There is a clear difference between new and worn tyres. The effect of speed is less for new than for worn tyres.
As the speed increases, the coefficients decrease practically linearly on all road surfaces. According as the macro structure increases the effect of the speed declines and is hardly noticeable on very macro-rough road surfaces. Very considerable interaction with the speed is found on a road with micro-texture only.

Mathematical relation

The variables and their levels have been so chosen that it must have been possible to obtain a quantitative relation between the brake and side way force coefficients on the one hand and the road characteristics, tyre characteristics, the speed and the tread depth on the other hand. A formula was drawn up to form a model representing this relation.
The model was based on the following considerations:
- Difficulties arose in attempting to incorporate tyre characteristics in the model. The differences between the tyre types as main effect are but slight. For proper distinction between the effect of each tyre characteristic more tyres would have to be available. This study was conducted by the Vehicle Research Laboratory of the Delft University of Technology. The investigations and the results are described by A. Dijks [15].

Roughly, the characteristics glass transition temperature and air ratio are of importance for μ_{xm}, the characteristics air ratio and resilience for μ_{xb} and the characteristics glass transition temperature and cornering stiffness for μ_y.

- Difficulties were likewise met with incorporating the tread depth in the model. For a good insight, the tread depth would have to be varied at more than the chosen two levels. This study was likewise carried out by the Vehicle Research Laboratory of the Delft University of Technology, and is also described by A. Dijks [15].
- The $\overline{TD}$ and SRT values are a reasonable indication for the macro-roughness and micro-roughness of the road surface. These values can therefore reasonably serve to represent the road characteristics in the model.
- The formulas are actually valid only within the range covered by the variables. With regard to the road surfaces the fact that no road surfaces from practice were available was considered a drawback. To remove part of this drawback, a series of additional measurements were carried out on road sections used by normal traffic. This was done on a number of trial sections of the Department of Roads and Waterways on State Highway 12. These sections display some diversity and their properties had been known for a number of years. The road characteristics and the measuring results are set out in Appendices 5 and 6.

For the model, it was assumed that the brake and side way force coefficients can be explained from an adhesion term and a hydrodynamic term. The adhesion term is related to the SRT value, and the hydrodynamic term to speed and texture depth. The relation will therefore take the following form:

$$\mu = \left[1 - f\left(\frac{v}{TD}, v\right)\right]\left[f(SRT)\right].$$

Out of a number of different ways of approach, this form yielded the best results. If linear relations are assumed, the following formula is obtained:

$$\mu = a_1 + a_2 \frac{v}{TD} + a_3 v + a_4\ SRT + a_5 v * SRT + a_6 \frac{v}{TD} * SRT.$$

Coefficients a_1, a_2, etc. have to be determined from the measuring results. Terms with two or more variables display interaction effects.

With the aid of a forward stepped multiple regression analysis, the coefficients were calculated, which produced the following formulas:

$$\mu_{xm} = 0{,}397 + 0{,}94 \frac{SRT}{100} - \frac{v}{100} \left(0{,}0017 \frac{SRT}{TD} - \frac{0{,}028}{TD}\right)$$

$R = 0{,}990 \qquad s = 0{,}038$

$$\mu_{xb} = 0{,}133 + 0{,}95 \frac{SRT}{100} - \frac{v}{100} \left(0{,}0017 \frac{SRT}{TD} - \frac{0{,}035}{TD} + 0{,}0010 \times SRT\right)$$

$R = 0{,}985 \qquad s = 0{,}038$

$$\mu_{y} = 0{,}520 + 0{,}58 \frac{SRT}{100} - \frac{v}{100} \left(0{,}0010 \frac{SRT}{TD}\right)$$

$R = 0{,}985 \qquad s = 0{,}034$

v in km/h

SRT dimensionless

TD in mm

R is the multiple correlation coefficient and s is the standard deviation. The multiple correlation coefficient is very high. This means that the make-up of the μ-values is approx. 0,04, in the order of magnitude of the scatter of the measurements.

5. TRUCK TYRES

Before the results were evaluated, it was considered necessary also to subject truck tyres to measurements. The object was to prevent that recommendations for car tyres would not apply where truck tyres were used.
In the production of truck tyres, large-scale use is made of natural rubber. The resulting brake and side way force coefficients are much lower than those obtained with car tyres. As a rule, the tyre load, and also the tyre pressure, are much higher. Important for the contact between tyre and road surface is the high surface pressure in the contact face.
It can be safely assumed that on account of the specific working conditions of truck tyres, the road surface would have to meet different requirements than if it were used for car tyres. The object of the third phase was therefore to see if conclusions from the study on car tyres would also apply to truck tyres. The study schedule therefore did not have to be so exhaustive.

Scope

For a similar mathematical relation as with car tyres, at least twenty observations are required. This was achieved by measuring on normal roads as well as on the test sections. On the latter, the measurements were again carried out twice. Again, groups of blocks were made with the unit day as block. It appeared not feasible to change a wheel during the measurements, so that the measurements were conducted with only one tyre a day. This means confounding tyres with days. The road sections and the levels of the other factors are listed in Appendix 7.

Results

The measuring results are shown in Appendix 8. The four tyres did not differ much between themselves. In all cases, the bias-ply tyre reaches slightly lower values than the radial tyres. A feature is that the level of the brake and side way force

coefficients are up to a factor 2 lower than those of car tyres. The effect of the speed is likewise virtually absent.
A formula was drawn up for truck tyres in the same way as for car tyres, for which the same model was used. In view of the limited scope of the tests the formulas can only be roughly indicative of the size and the sequence in which the factors and the interactions account for the brake force coefficients. The formulas are:

$$\mu_{xm} = 34{,}8230 - 0{,}0666 \frac{v}{TD} + 0{,}4384 \; SRT$$

$$R = 92{,}2$$

$$\mu_{xb} = 46{,}2222 - 0{,}0417 \frac{v}{TD} - 0{,}4559 \; v + 0{,}0048 \; v \times SRT$$

$$R = 90{,}1$$

6. DISCUSSION OF THE RESULTS

Tyre type

As the various tyres differed very little among themselves, further considerations have been simplified by working with averages for car and truck tyres. The measurements with the various tyres are then considered to have been taken with the same tyre in several observations.

Comparison of car and truck tyres (Appendix 9) shows a consistent large difference between the two types. On public roads (passing lanes of state highways) the ratio between truck tyres and car tyres is 71% for μ_{xm} and 58% for μ_{xb}. These are averages calculated for all speeds. The test strips show roughly the same picture: 57% for μ_{xm} and 49% for μ_{xb}.

The definition of the measuring criteria (Chapter 1) already enlarged upon the importance of each of the three coefficients μ_{xm}, μ_{xb} and μ_y. For normal braking, a high μ_{xm} is favourable, but for an emergency stop, μ_{xb} is very important. Not only are the absolute values of μ lower for truck tyres. It appears also that the ratio μ_{xb}/μ_{xm} is more unfavourable for truck tyres than for car tyres. This means that trucks will not only find their wheels locking at relatively low deceleration, but that the available brake force also decreases progressively more compared with cars.

Tread depth

As the tread depth as separate factor was already exhaustively discussed elsewhere [11] the approach is again simplified. Direct comparison between car and truck tyres was always made with full treads. In the discussion of the road surface characteristics and speed an average value for car tyres was determined from the measuring values of a new tyre and one worn to 1 mm. For the truck tyres the full tread was used again.

Road surface type and speed

By reference to the formulas developed in Chapters 4 and 5 the variables carrying the greatest effect can be calculated for a practical situation. The road surface characteristics considered are the micro-roughness with the SRT values as criterion, the macro-roughness with the average texture depth $\overline{TD}$ as criterion, and the speed v.

On present state highways, the SRT values vary between 50 and 80; the $\overline{TD}$ varies between 0.4 and 1. As to speed, the limits of 50 and 100 km/h can reasonably serve to delineate the speed interval for the practical situation.

The numerical influences of the variables within the practical area are set out in Appendix 10.

Influence of $\overline{TD}$

According to the tables, the influence of $\overline{TD}$ can be rather considerable. It is biggest for μ_{xm}, followed by μ_{xb} and then for μ_y. In an absolute sense, the influence of $\overline{TD}$ is greater for car tyres than for truck tyres. As could be expected, the influence of $\overline{TD}$ is greater at higher than at lower speeds.

Influence of SRT

The SRT has mostly considerable influence. It is greatest for μ_{xm}, followed by μ_{xb} and then for μ_y. The influence of the SRT is greater for car tyres than for truck tyres. For car tyres, a high SRT value combined with a high $\overline{TD}$ value has an particularly favourable effect (interaction). With truck tyres, the influence of SRT is practically independent of $\overline{TD}$.

Influence of speed

The speed can carry relatively much effect, which is greatest for μ_{xb}, then for μ_{xm} and then for μ_y. It is greater for car tyres than for truck tyres at a high SRT value, but the reverse at a low SRT value.

Summarising, it can be said that at the chosen peripheral conditions the micro-roughness of the road surface has much influence on the skid resistance. This applies to any type of tyre, at any speed and at any level of macro-roughness. The macro-roughness of the road surface has much influence practically only at high speeds. Reversely, there is much influence from the speed only on roads with little texture depth.

7. CONCLUSIONS AND RECOMMENDATIONS

Conclusions relative to the method followed

The study has added much to the knowledge concerning the factors affecting the brake and side way forces working in the plane of contact between a tyre and a road surface. Being planned as a multi-factor investigation, it has made it possible to study the factors not only separately, but also interrelatedly as regards their influence on the skid resistance.
This required very many measurements. The planned measuring schedule required that a certain number often had to be carried out within one day. As this is hardly practicable on public roads, a test road has to be available. Its drawback, however, is that normal traffic never uses this.

First-order factors important to the skid resistance

The following factors are important with regard to the size of the brake and side way forces between car tyres and a wet road surface: the type of surface, the tyre type, the speed of the vehicle, the tread depth of the tyre and the water depth on the road. The type of road surface and the speed have much effect, the tread depth and the water depth (disregarding extremes in case of ruts, etc.) moderately so and the tyre type has little influence. Tyre load and pressure can be regarded as second-order factors for the skid resistance. Their influence is so slight that it can be further disregarded.
Factors other than those mentioned had no demonstrable effect on the skid resistance. Particularly, no relationship was found between temperature and skid resistance.

Characteristics important for ensuring the greatest possible brake and side way forces

With a view to achieving the greatest possible brake and side way forces, the conclusion regarding the characteristics studied is:

a high SRT value is favourable on all roads. On roads where vehicles travel at high speeds (100 km/h and over), increasing the average texture depth results in higher skid resistance, particularly with car tyres. Reducing the speed always increases the skid resistance, the least on roads with great micro-roughness and macro-roughness, the most on those without these two features. Large tread depth is favourable, also at moderate speeds and on rough roads. Normal commercial-grade tyres display little difference among themselves, and this applies to both car tyres and truck tyres.

Recommendations for official measures

In order to ensure the highest possible skid resistance through official measures, the conclusions give rise to the following recommendations:

A recommendation can be made with regard to a highest possible minimum requirement for the micro-roughness of road surfaces, expressed in an SRT value. Depending on the type of road and in connection with the customary speeds a minimum requirement may be added for the average texture depth $\overline{TD}$, i.e. particularly for motorways. The level of the minimum values can be decided on partly by reference to socio-economic considerations (funds) and aspects of environment (noise nuisance). Basically, however, the study can only recommend the highest possible minimum values.

With a view to countering temporary and/or local reduction of the available brake and side way forces, speed limits might be considered. As it is not realistic to introduce general speed limits on the grounds of the degree of skid resistance of the road surface alone, such limits should only relate to situations in which the road is wet. Combination with moistness indicators would then be required.

Although no value as regards tread depth can be directly derived from this study, setting a minimum is recommended.

There is as yet no sufficient knowledge of tyre characteristics important to the skid resistance to warrant recommending official measures. This applies to both car and truck tyres.

In an absolute sense, there is considerable difference between truck tyres and car tyres. The former moreover display a relatively big difference between the maximum brake force coefficient and the locking value (ratio μ_{xm} / μ_{xb}). Everything should therefore be done to ensure optimum use of the available brake forces. Such measures would relate to distribution of the brake force, with an anti-blocking device supplementing it.

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APPENDICES

APPENDIX 1. Level of variables in the first test programme (car tyres)

1. Type of road surface

Normal highways

	Testsite Kesteren	Testsite Leiden	Testsite Raamsdonkveer	Testsite Gorinchem
Macro texture $\overline{TD}$	0.3	0.6	0.8	0.7
Micro texture SRT	69	74	77	79

2. Type of tyre

	Uniroyal Rallye 180		Michelin 2 x		Vredestein Sprint		Goodyear 9800	
Tread depth	7 mm	2 mm	7 mm	2 mm	7 mm	2 mm	7 mm	2 mm
Type	Radial steel belted		Radial steel belted		Radial textile belted		Radial textile belted	
Cornering stiffness kg/deg	76		80		65		63	
Air ratio %	29.7	26.3	23.4	16.2	30.6	28.4	30.6	27.6
Resilience rebound %	36	36	39	38	42	42	31	33
Hardness Skore A	59		62		59		64	

3. Speed: 50 and 100 km/h

4. Water depth: 0.3 and 0.6 mm

5. Tread depth: new tyre 7 à 8 mm; worn tyre: 2 mm

6. Tyre load: 250 and 400 kg

7. Tyre pressure: 1.4 and 2.0 kg/cm^2

APPENDIX 2.1. Results of the main effects of factors in the first test programme

Type of road surface

KES = Testsite Kesteren
LEI = Testsite Leiden
RAA = Testsite Raamsdonkveer
GOR = Testsite Gorinchem

Type of tyre

UNI = Uniroyal Rallye 180
MIC = Michelin z X
VRE = Vredestein Sprint
GOO = Goodyear G 800

Main effects

Table 1. Type of road surface

Average μ_{xm} 84,3				Average μ_{xb} 50,6				Average μ_y 78,7			
KES	LEI	RAA	GOR	KES	LEI	RAA	GOR	KES	LEI	RAA	GOR
-13,9	+0,3	+4,5	+9,1	-6,0	+0,2	+0,4	+5,4	-9,7	+1,8	+1,0	+6,9

Table 2. Type of tyre

μ_{xm}				μ_{xb}				μ_y			
UNI	MIC	VRE	GOO	UNI	MIC	VRE	GOO	UNI	MIC	VRE	GOO
-2,3	-1,9	+1,5	+2,7	-2,0	-2,5	-0,3	+0,3	+2,1	0,3	-0,9	-1,5

Table 3. Other factors

				μ_{xm}		μ_{xb}		μ_y	
Speed	km/h	50	100	+6,3	-6,3	+9,6	-9,6	+4,2	-4,2
Tread depth	mm	2	7	-2,8	+2,8	-3,6	+3,6	+1,0	-1,0
Water depth	mm	0,3	0,6	+1,7	-1,7	+0,5	-0,5	+0,5	-0,5
Tyre load	kg	250	400			+0,7	-0,7	+1,2	-1,2
Tyre pressure	kg/cm^2	1,4	2,0			+0,5	-0,5		

APPENDIX 2.2. Results of the significant interactions of factors in the first test programme

Two-factor interactions

Following the order of magnitude, the significant interactions are:

μ_{xm}:

1.	road surface type	-	tyre type
2.	tyre type	-	tread depth
3.	speed	-	tread depth
4.	road surface type	-	tread depth
5.	road surface type	-	speed
6.	speed	-	tyre type
7.	tread depth	-	water depth

μ_{xb}:

1.	tyre type	-	tread depth
2.	road surface type	-	tyre type
3.	speed	-	tread depth
4.	road surface type	-	speed
5.	road surface type	-	tyre type
6.	road surface type	-	tyre type
7.	tread depth	-	tyre pressure

μ_{y}:

1.	road surface type	-	tyre type
2.	road surface type	-	tread depth
3.	tyre type	-	tread depth
4.	road surface type	-	speed
5.	speed	-	tyre type
6.	road surface type	-	tyre load
7.	tyre type	-	tyre load
8.	tread depth	-	tyre load
9.	speed	-	water depth

Three-factor interactions

μ_{y} :

1.	road surface type	- speed	- tread depth
2.	tyre type	- speed	- tread depth
3.	tyre type	- tread depth	- tyre load

APPENDIX 3. Level of variables in the second test programme (car tyres)

1. Type of road surface

Specially constructed road surfaces

	A	B	C	D	E	F
$\overline{TD}$	1.2	3.2	3.6	2.0	0.5	0.1
SRT	82	92	72	68	92	34

2. Type of tyre

	Pirelli Cinturato CN53		Michelin X as		Vredestein Sprint		Uniroyal Rallye 180	
Tread depth	1 mm	new	1 mm	new	1 mm	new	1 mm	new
Type	Radial textile belted		Radial steel belted		Radial textile belted		Radial steel belted	
Glass transition temperature ^{o}K	199		215		227		223	
Hardness Skore A	72	71	65	62	63	63	62	60
Cornering stiffness kg/deg	61	57.5	72.5	71.5	62	57.5	73	70.5
Air ratio %	17	30	101	31	25	31	21	30
Resilience rebound %	37	34	36	35	42	41	36	35

3. Speed: 50, 75 and 100 km/h

4. Tread depth: new 7 à 8 mm; worn: 1 mm

5. Water depth: 0,6 mm

6. Tyre pressure: 1,8 ato

7. Tyre load: 330 kg

Road surface		A			B			C			D			E			F		
Speed	km/h	50	75	100	50	75	100	50	75	100	50	75	100	50	75	100	50	75	100
Vredestein	new	112	110	109	121	127	127	102	104	108	105	107	106	115	113	108	59	40	57
		115	116	106	133	127	120	98	101	101	101	98	100	116	110	108	53	48	38
	1 mm	115	116	104	110	113	122	91	95	90	101	106	101	101	70	48	38	33	16
		116	99	97	120	125	115	88	91	91	99	89	86	97	51	38	58	35	19
Uniroyal	new	129	122	109	130	128	131	98	101	103	113	111	106	107	108	98	65	36	29
		117	111	109	128	137	128	101	111	109	105	113	105	110	106	98	56	49	42
	1 mm	127	115	103	123	111	114	106	92	101	114	112	105	82	51	41	41	26	14
		128	102	95	134	123	124	93	104	92	103	106	86	79	48	35	41	24	15
Pirelli	new	113	112	109	109	125	124	91	101	98	104	104	101	105	104	104	50	48	43
		112	110	98	120	124	120	103	102	101	101	97	94	108	106	99	69	55	47
	1 mm	105	107	99	102	112	119	78	92	88	98	94	92	111	98	65	35	29	30
		122	107	102	116	121	121	90	88	88	91	94	92	122	102	78	57	30	22
Michelin	new	118	111	114	124	126	116	97	102	98	100	109	104	106	102	101	46	57	34
		113	108	103	123	125	122	99	99	101	103	106	96	108	100	94	59	50	46
	1 mm	132	99	107	114	107	115	89	97	91	99	103	95	80	50	35	47	23	17
		118	107	95	119	123	119	88	87	85	98	89	79	79	57	33	59	38	24

APPENDIX 4.1. Results μ_{xm} in the second test programme

Road surface		A			B			C			D			E			F		
Speed	km/h	50	75	100	50	75	100	50	75	100	50	75	100	50	75	100	50	75	100
Vredestein	new	84	76	71	99	102	95	79	76	81	78	71	70	93	84	73	30	22	25
		79	72	69	95	92	92	75	75	72	68	65	59	92	80	77	31	25	18
	1 mm	76	66	58	91	89	87	66	65	63	69	61	57	60	45	34	23	16	10
		66	60	50	90	84	72	61	60	56	64	51	46	75	38	26	25	19	10
Uniroyal	new	82	80	66	92	95	88	79	79	82	72	74	69	78	79	67	39	17	13
		79	71	65	92	89	84	78	77	74	70	67	61	80	79	64	34	28	22
	1 mm	71	68	51	89	92	87	68	70	66	66	66	58	47	35	24	21	22	9
		71	57	48	92	83	75	63	63	59	62	50	44	55	34	24	20	14	8
Pirelli	new	85	80	71	91	98	93	80	79	79	83	73	71	92	82	70	24	21	17
		81	78	66	94	90	88	80	77	75	74	68	65	91	82	72	34	30	21
	1 mm	71	69	60	88	89	87	68	68	64	75	65	56	79	62	34	21	12	12
		82	65	60	89	85	75	62	59	59	66	62	55	87	69	49	26	16	11
Michelin	new	76	74	70	103	90	95	82	78	73	71	71	67	75	73	62	30	28	15
		65	66	66	91	80	77	75	74	73	66	64	60	71	66	55	36	30	20
	1 mm	72	59	59	95	88	78	69	66	65	74	63	57	56	35	24	26	13	10
		75	61	52	88	83	74	60	57	58	61	54	45	60	36	20	30	22	14

APPENDIX 4.2. Results μ_{xb} in the second test programme

Road surface		A			B			C			D			E			F		
Speed	km/h	50	75	100	50	75	100	50	75	100	50	75	100	50	75	100	50	75	100
Vredestein	new	92	93	92	100	102	100	89	86	90	91	87	87	88	86	84	51	40	41
		95	90	85	111	96	94	91	89	89	88	86	89	89	84	87	51	49	40
	1 mm	76	97	96	101	94	100	83	83	81	88	88	90	101	96	52	35	34	8
		106	104	101	105	107	109	80	79	82	88	85	87	107	85	53	47	30	13
Uniroyal	new	109	99	95	108	102	106	94	90	94	98	94	92	93	93	84	68	32	25
		103	99	101	114	112	111	96	96	93	93	95	90	92	104	85	59	54	43
	1 mm	122	111	101	112	103	106	90	83	87	97	97	89	112	99	52	38	17	8
		119	118	104	115	106	113	84	85	85	95	94	87	131	104	60	46	22	10
Pirelli	new	99	98	74	99	102	97	86	88	81	91	92	87	100	96	73	43	49	37
		102	94	94	109	107	106	88	89	89	91	87	86	101	97	95	61	55	47
	1 mm	99	97	92	96	99	98	80	81	76	87	87	85	105	101	69	23	27	19
		107	103	94	107	110	108	79	81	78	85	82	82	111	101	80	37	33	14
Michelin	new	100	98	91	105	105	102	91	89	84	94	92	85	95	93	83	39	54	27
		96	92	95	112	109	107	90	88	89	87	87	86	92	89	82	57	49	37
	1 mm	116	103	93	100	96	93	85	83	77	89	90	83	107	93	38	47	25	10
		112	103	99	106	107	105	78	72	79	84	84	84	120	87	41	54	37	17

APPENDIX 4.3. Results μ_y in the second test programme

APPENDIX 5. Level of variables of the additional measurements in the second test programme

1. Type of road

Normal highways

	Test site 1		Test site 4		Test site 7		Test site 9	
	Traffic lane	Passing lane	Traffic lane	Passing lane	Traffic lane	Passing lane	Traffic lane	Passing lane
SRT	70	70	66	71	71	73	69	70
$\overline{TD}$	1.3	1.0	0.5	0.6	1.5	1.4	0.5	0.7

2. Type of tyre: Vredestein Sprint

3. Speed: 50 and 100 km/h

4. Water depth: 0.6 mm

5. Tyre pressure: 1.8 ato

6. Tyre load: 33 kg

7. Tread depth: new

APPENDIX 6. Results of the additional measurements in the second test programme

Testsite	Speed	Traffic lane			Passing lane		
	km/h	μ_{xm}	μ_{xb}	μ_{y}	μ_{xm}	μ_{xb}	μ_{y}
1	50	.93	.58	.71	1.01	.63	.74
1	100	.90	.57	.69	.92	.49	.73
4	50	1.00	.60	.67	1.08	.66	.71
4	100	.84	.44	.64	.94	.49	.71
7	50	.96	.63	.75	.98	.67	.77
7	100	.88	.49	.69	.93	.52	.74
9	50	.96	.67	.68	1.03	.64	.72
9	100	.91	.50	.65	.95	.53	.71

APPENDIX 7. Level of variables in the third test programme (truck tyres)

1. Type of road

	Specially constructed road surfaces					Normal highways				
	A	B	D	E	F	Go	Ze	Wo	Br	Wi
SRT	74	87	67	89	84	70	70	67	68	77
$\overline{TD}$	1.2	3.0	1.8	0.4	<0.1	0.7	1.1	0.8	0.8	0.6

2. Type of tyre

Pirelli Cinturato SN 55	radial
Michelin D 20 X	radial
UBO WPX	cover tyre on Carcass Michelin D 20 X
Vredestein Special	diagonal

3. Speed: 50, 75 en 100 km/h
4. Tyre load: 2500 kg
5. Tyre pressure: 6,25 bar
6. Tread depth: new
7. Water depth: 1 mm at 100 km/h   2 mm at 50 km/h

APPENDIX 8.1. Results μ_{xm} *100 in the third test programme

μ_{xm} *100		Specially constructed road surfaces					Normal highways				
		A	C	D	E	F	Wi	Ze	Wo	Br	Go
100 km/h	Mich	63 66	61 58	61 55	57 58	13 19	58	56	48	59	55
	Pire	70 75	63 60	66 60	57 60	11 15	63	61	57	61	
	UBO	68 63	61 59	58 58	59 52	21 15	55	53	53	54	54
	Vred	54 63	54 57	59 60	50 48	6 11	58	55	55	47	48
75 km/h	Mich	67 64	60 58	58 54	60 62	20 20	62	62	53	62	62
	Pire	70 71	62 62	61 64	76 68	21 19	67	70	66	66	65
	UBO	66 69	59 62	61 65	60 56	21 19	61	60	56	60	60
	Vred	70 70	56 59	58 63	52 58	16 15	64	63	54	64	58
50 km/h	Mich	72 69	58 56	63 62	70 71	28 25	66	69	57	63	65
	Pire	71 71	68 60	64 66	75 71	20 22	68	69	63	65	70
	UBO	68 70	61 57	64 61	67 66	24 27	61	62	58	60	61
	Vred	67 68	56 57	58 62	72 69	17 19	68	67	59	62	65

APPENDIX 8.2. Results μ_{xb} ×100 in the third test programme

μ_{xb} ×100		Specially constructed road surfaces					Normal highways				
		A	C	D	E	F	Wi	Ze	Wo	Br	Go
100 km/h	Mich	32 32	39 34	31 28	31 30	9 8	32	29	22	29	26
	Pire	34 34	40 36	33 31	26 24	7 7	28	27	19	25	22
	UBO	34 36	41 40	33 33	36 30	9 7	31	29	23	28	27
	Vred	31 32	36 37	29 29	21 26	4 7	27	28	19	24	20
75 km/h	Mich	39 36	36 37	32 32	38 38	10 8	36	36	27	36	34
	Pire	39 39	39 37	33 33	39 35	10 8	35	35	25	35	30
	UBO	39 42	40 38	34 36	39 37	13 9	38	38	29	37	34
	Vred	39 39	35 39	33 33	28 32	6 9	37	35	25	35	31
50 km/h	Mich	42 44	37 37	36 37	45 46	15 13	43	43	36	39	39
	Pire	48 41	44 38	42 36	46 43	13 12	42	41	33	38	38
	UBO	45 41	38 37	39 36	44 45	13 11	44	41	36	40	40
	Vred	43 43	34 39	37 37	42 41	10 11	44	43	32	38	41

	Speed km/h	Car tyres specially constructed road surfaces					Truck tyres					Truck tyres / Car tyres				
		A	C	D	E	F	A	C	D	E	F	A	C	D	E	F
μ_{xm} (*100)	100	108	101	104	100	38	66	60	60	56	14	61	59	58	56	37
	75	114	103	109	107	45	69	60	61	62	19	61	58	56	58	42
	50	119	100	108	111	56	70	59	63	71	23	59	59	58	64	41
μ_{xb} (*100)	100	68	76	67	66	15	33	38	31	28	8	49	50	46	42	53
	75	75	77	71	77	21	39	38	33	36	9	52	49	46	47	43
	50	81	79	75	84	30	44	38	38	45	13	54	48	51	54	43
$\frac{\mu_{xb}}{\mu_{xm}}$ %	100	63	75	64	66	39	50	63	52	50	57					
	75	66	75	65	72	47	57	63	54	58	47					
	50	68	79	69	76	54	63	64	60	63	57					

APPENDIX 9.1. Comparison car tyres - truck tyres on the specially constructed road surfaces

APPENDIX 9.2. Comparison car tyres - truck tyres on normal highways

		Truck tyre 25000 N; 6.25 bar		Car tyre 3300 N; 1.8 bar		
Road surface	Speed km/h	μ_{xm}	μ_{xb}	μ_{xm}	μ_{xb}	μ_y
Go	50	65	40	81	60	73
	75	61	32	84	56	72
	100	54	24	85	48	70
Ze	50	67	42	86	62	82
	75	64	36	82	53	75
	100	56	28	81	49	75
Wo	50	59	34	71	52	68
	75	57	27	67	44	65
	100	53	21	70	39	61
Br	50	63	39	79	57	67
	75	63	36	81	52	68
	100	55	27	78	47	67
Wi	50	66	43	83	62	76
	75	64	37	81	58	74
	100	59	30	83	50	72
Average	50	60	37	80	59	73
	75	58	32	79	53	71
	100	53	27	79	47	69
Truck/Car		72%	60%			
μ_{xb}/μ_{xm}		56%		67%		

APPENDIX 10.1. Calculation of the numerical influence of SRT and TD

		Car tyre				Truck tyre				
V (km/h)		50		100		50		100		
$\overline{TD}$ (mm)		0,4	1,0	0,4	1,0	0,4	1,0	0,4	1,0	
SRT	50	79,6	83,9	72,5	81,0	48,6	53,7	40,3	50,3	μ_{xm}
	80	101,4	109,5	87,9	104,1	61,8	66,9	53,5	63,5	(x100)
SRT	50	52,1	55,8	43,3	50,8	29,8	32,9	13,3	19,8	μ_{xb}
	80	72,7	80,3	56,1	71,2	37,0	40,1	27,9	34,2	(x100)
SRT	50	74,8	78,5	68,5	76,0	-				μ_y
	80	88,4	94,4	78,4	90,4					(x100)

			Car tyres μ_{xm}	Car tyres μ_{xb}	Car tyres μ_y	Truck tyres μ_{xm}	Truck tyres μ_{xb}
Effect $\overline{TD}$							
$\mu_{\overline{TD}=1} - \mu_{\overline{TD}=0,4}$	at 50 km/h	SRT = 50	4,3	3,7	3,7	5,1	3,1
		SRT = 80	8,1	7,6	6,0	5,1	3,1
	at 100 km/h	SRT = 50	8,5	7,5	7,5	10,0	6,5
		SRT = 80	16,2	15,1	12,0	10,0	6,3
$\mu_{\overline{TD}=1} - \mu_{\overline{TD}=0,4}$	av. at 50 km/h		6,2	5,6	4,8	5,1	3,1
	av. at 100 km/h		12,4	11,3	9,8	10,0	6,4
	av. at SRT = 50		6,4	5,6	5,6	7,6	4,8
	av. at SRT = 80		12,2	11,3	9,0	7,6	4,7
$\mu_{\overline{TD}=1} - \mu_{\overline{TD}=0,4}$	total average		9,3	8,5	7,3	7,6	4,8
Effect SRT							
$\mu_{SRT=80} - \mu_{SRT=50}$	at 50 km/h	$\overline{TD}$ = 0,4	21,8	20,6	13,6	13,2	7,2
		$\overline{TD}$ = 1	25,6	24,5	15,9	13,2	7,2
	at 100 km/h	$\overline{TD}$ = 0,4	15,4	12,8	9,9	13,2	14,6
		$\overline{TD}$ = 1	23,1	20,4	14,4	13,2	14,4
$\mu_{SRT=80} - \mu_{SRT=50}$	av. at 50 km/h		23,7	22,6	14,8	13,2	7,2
	av. at 100 km/h		19,2	16,6	12,2	13,2	14,5
	av. at TD = 0,4		18,6	16,7	11,8	13,2	10,9
	av. at TD = 1		24,4	22,4	15,2	13,2	10,8
$\mu_{SRT=80} - \mu_{SRT=50}$	total average		21,5	19,6	13,4	13,2	10,8

APPENDIX 10.2. Calculation of the numerical effect on μ , using the formulas

			Car tyres			Truck tyres	
			μ_{xm}	μ_{xb}	μ_y	μ_{xm}	μ_{xb}
Effect speed							
$\mu_{50\ km} - \mu_{100\ km}$	$\overline{TD} = 0,4$	SRT = 50	7,1	8,8	6,3	8,3	16,5
		SRT = 80	13,5	16,6	10,0	8,3	9,1
	$\overline{TD} = 1$	SRT = 50	2,9	5,0	2,5	3,4	13,1
		SRT = 80	5,4	9,1	4,0	3,4	5,9
$\mu_{50\ km} - \mu_{100\ km}$	av. $\overline{TD} = 0,4$		10,3	12,7	8,2	8,3	12,8
	av. $\overline{TD} = 1$		4,2	7,0	3,2	3,4	8,5
	av. SRT = 50		5,0	6,9	4,4	5,8	14,8
	av. SRT = 80		9,4	12,8	7,0	5,8	7,5
$\mu_{50\ km} - \mu_{100\ km}$	total average		7,2	9,9	5,7	5,8	11,2

APPENDIX 10.2. Calculation of the numerical effect on μ , using the formulas

			Car tyres			Truck tyres	
			μ_{xm}	μ_{xb}	μ_{y}	μ_{xm}	μ_{xb}
Effect TD							
$\mu_{\overline{TD}=1} - \mu_{\overline{TD}=0,4}$	at 50 km/h	SRT = 50	5,1	6,6	4,7	9,5	9,4
		SRT = 80	7,4	9,5	6,4	7,6	7,5
	at 100 km/h	SRT = 50	10,5	14,8	9,9	19,9	32,8
		SRT = 80	15,6	21,2	13,3	15,8	18,4
$\mu_{\overline{TD}=1} - \mu_{\overline{TD}=0,4}$	av. at 50 km/h		6,4	8,2	5,6	8,5	8,5
	av. at 100 km/h		13,2	18,5	11,8	17,6	23,7
	av. at SRT = 50		7,7	10,5	7,3	14,6	18,2
	av. at SRT = 80		11,4	14,9	9,7	11,7	12,7
$\mu_{\overline{TD}=1} - \mu_{\overline{TD}=0,4}$	total average		9,8	13,2	8,6	12,9	15,1
Effect SRT							
$\mu_{SRT=80} - \mu_{SRT=50}$	at 50 km/h	$\overline{TD}$ = 0,4	21,5	28,3	15,4	21,4	19,5
		$\overline{TD}$ = 1	23,4	30,5	16,9	19,8	18,0
	at 100 km/h	$\overline{TD}$ = 0,4	17,5	22,8	12,6	24,7	52,4
		$\overline{TD}$ = 1	22,2	28,6	15,9	20,8	42,1
$\mu_{SRT=80} - \mu_{SRT=50}$	av. at 50 km/h		22,4	28,6	16,2	20,5	18,7
	av. at 100 km/h		20,0	26,1	14,5	22,6	46,6
	av. at $\overline{TD}$ = 0,4		19,6	26,0	14,2	21,1	33,6
	av. at $\overline{TD}$ = 1		22,8	29,6	16,4	20,2	29,1
$\mu_{SRT=80} - \mu_{SRT=50}$	total average		21,4	27,9	15,3	20,7	31,0

APPENDIX 10.3. Calculation of the procential effect on μ , using the formulas

			Car tyres			Truck tyres	
			μ_{xm}	μ_{xb}	μ_y	μ_{xm}	μ_{xb}
Effect speed							
$\mu_{50\ km} - \mu_{100\ km}$	$\overline{TD} = 0,4$	SRT = 50	8,9	16,9	8,4	17,1	55,4
		SRT = 80	13,3	22,9	11,3	13,4	24,6
	$\overline{TD} = 1$	SRT = 50	3,5	9,0	3,2	6,3	39,8
		SRT = 80	4,9	11,2	4,2	5,1	14,7
$\mu_{50\ km} - \mu_{100\ km}$	av. at $\overline{TD} = 0,4$		11,4	20,4	10,0	15,0	38,4
	av. at $\overline{TD} = 1$		4,3	10,3	3,7	5,6	23,3
	av. at SRT = 50		6,1	12,8	5,7	11,3	47,3
	av. at SRT = 80		8,9	16,7	7,7	9,0	19,5
$\mu_{50\ km} - \mu_{100\ km}$	total average		7,7	15,2	6,8	10,0	32,1

APPENDIX 10.3. Calculation of the procential effect on μ , using the formulas