WATER NUISANCE AND ROAD SAFETY

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INTRODUCTION

A road is a succession of straight sectors and level and vertical curves, both horizontally and in gradients. This, and the presence of other road users compel the road user to steer constantly and sometimes very suddenly, and to accelerate or decelerate. Between the times these actions start and end, the road user travels a straight path at constant speed. To make these actions possible, including the last-mentioned, forces have to be transmitted continuously between the vehicle and the road.

These forces are transmitted in the contact area between tyre and road surface. Their extent depends on the required action and the vehicle speed at which it is performed. As long as the required forces do not exceed the available forces there can only be a question of discomfort but not of an unsafe situation due to a risk of skidding, because the path can be followed as planned.

Over a number of years, the State Road Laboratory in The Netherlands has made a constant effort to gather and collate information on the factors influencing the longitudinal and transverse forces transmissible between tyre and road surface. In 1975 and 1976 particular attention was paid to the factor of water. It has always been a known fact that the presence of water on the road increases the risk of skidding. As road accident records became more complete and more detailed, a more quantitative idea was also gained of the influence wet road surfaces have on road safety. First of all, some notes on this.

ROAD SAFETY ON WET ROAD SURFACES

Some data on accidents on wet road surfaces

Table 1 gives the average number of fatalities a year in The Netherlands from 1971 to 1975, as far as concerns drivers and passengers of cars, trucks, delivery vans, buses, coaches and motor cycles. The state of the surface is described as dry or wet. Wet surfaces are subdivided into during rainfall and not during rainfall because a surface may still be wet long after the rain has stopped.

In The Netherlands it rains on average about 6% of the time. It can be estimated that road surfaces are wet on average for about 12% of the time. Based on this percentage, it follows that in the Netherlands from 1971 to 1975 about 2.8 times as many fatalities occurred on wet surfaces as on dry surfaces per unit of time. This figure only illustrates the extent of the problem created by the presence of water on road surfaces.

A better comparison of road safety on wet and dry surfaces only becomes possible if information is available on the traffic volume on such surfaces, i.e. on the number of vehicle-kilometres. Such information can be obtained from the results of research into the statistical relation between road-surface skidding resistance and relative road risk by a Working Group set up by the Netherlands Institute for Road Safety Research SWOV (SCHLÖSSER, 1977). For determining the relative road risk this study uses, inter alia, the concept of the accident rate, the number of accidents per million vehicle-kilometres. The research covered 60,000 accidents recorded by the police.

Figure 1 shows the accident rate per skidding resistance class.

Skidding resistance classes 1 to 8 comprise only vehicle-kilometres and accidents during rainfall. All other vehicle-kilometres and accidents, including those on wet surfaces but not during rainfall, are in class 9. Consequently, the relative road risk for class 9 may have been calculated too high.

Figure 1 shows that each lower skidding-resistance class has a higher accident rate. It will be shown that the transmissible tyre/road-surface forces are generally slighter as the water film on the surface is thicker. The assumption that the relative road risk increases with the thickness of the film therefore seems warranted.

Factors that may contribute to accidents on wet road surfaces

Accident statistics give hardly any indication of the causes of accidents, especially as it is only exceptionally that they can be ascribed to a single cause.

There are a number of things due especially to road-surface rainwater which may help to cause accidents:

A. Reduced general visibility

During precipitation, the falling raindrops, snowflakes or hailstones are a direct source of reduced visibility for road users. Moreover, car windows may steam up when they are cooled off by precipitation. In the dusk and at night this limitation of visibility will be a greater hindrance than in daytime. The traffic itself splashes and sprays part of the precipitation on the road surface up again. The spattering water, often dirtied, makes a heavier demand on the windscreen wipers, especially when one car is overtaken by another. The spray temporarily forms a curtain of fine droplets over the road surface, which may be quite extensive behind heavy truck and trailer combinations. Splashing and spraying from wet surfaces continues even when there is no more precipitation. Road users' visibility will be more affected the thicker the surface water film is.

B. Glare

If an unbroken or partly unbroken film is formed on a road surface, rays of sunshine or beams from oncoming vehicles' headlamps will be reflected from this film. The information the road user then receives about the road pattern may be greatly distorted. There is not only glare, but also a difficult selection from the information presented (visual noise). The result may be a change of path, the consequences of which depend on the traffic situation where it happens.

C. Invisibility of markings

Road markings have an important function as a guide to traffic, especially at night and/or in bad weather conditions. Markings on wet road surfaces will usually still be visible in daytime if they consist of thermoplastic material. At night, headlamp beams may also be reflected by the water film on the markings. Road users cannot see them properly, or not at all and an item of information necessary for guiding the vehicle along the road has been obscured.

D. Reduction of tyre/road-surface forces

This brief enumeration of possible contributory factors in accidents on wet surfaces shows that dealing with the interplay of tyre/road-surface forces is only one aspect of the risks, though an important one as Figure 1 shows.

The following sections will deal principally with this aspect.

FORCES IN THE TYRE/ROAD-SURFACE CONTACT AREA

When brakes are applied a longitudinal shearing force occurs between tyre and road surface parallel to the direction of travel. If this force is divided by the vertical wheel load, a dimensionless reference value μ_x is obtained, which we shall call the coefficient of longitudinal force.

The terms coefficient of friction or braking force coefficient are also used. This is not the place to discuss all the factors influencing the longitudinal force coefficient. But it should be noted that it is built up of three components: adhesion, hysteresis and cohesion.

Besides the tyre characteristics, which are disregarded for present purposes, the size of these components is determined mainly by the following factors: roughness of the pavement surface, water-film thickness and vehicle speed. To determine their influence on μ_x, the coefficient of longitudinal force, measurements were made on five test sectors.

Longitudinal forces as a function of vehicle speed and water-film thickness measured on five different pavement surfaces

The measurements were made with the Dutch State Road Laboratory's standard skidding resistance measuring truck which performs measurements with a retarded wheel with an 86% slip (SCHLÖSSER, 1977).

Measurements were made at speeds varying between 50 and 120 km p.h.

Water films of various thicknesses (0-20 mm) were applied by utilising the transverse gradient of the road surface (this thickness is in all cases that of the unbroken water film over the topmost points of the surface texture).

The five pavement surfaces varied both in texture depth, TD, and in the form of the mineral aggregate on the surface.

The five surfaces were:

1. A layer of epoxy bitumen not gritted with mineral aggregate. This provides a hard-wearing but very smooth surface with a negligible texture depth ($TD \approx 0$).

2. A surface treatment consisting of epoxy bitumen gritted with crushed gravel 5/8 mm. This provided a very deep-textured surface ($TD \approx 4.3$ mm).

3. A surface treatment consisting of epoxy bitumen gritted with round gravel 5/8 mm ($TD \approx 4.1$ mm).

4. A layer of porous asphaltic concrete with over 16% voids. In interpreting the results of measurements on this pavement, then just laid,

the thin bitumen film still on the surface must be taken into account. The texture depth of this material can not be determined.

5. A layer of open-textured asphaltic concrete (TD = 0.7 - 0.9 mm).

The S.R.T. values of these pavements are given in Table 2.

ii) Presentation of results

The measured longitudinal force coefficients are given in Figure 2(a) to (e) in a stylised form. Each figure gives the results for one measured speed. This presentation is acceptable because the spread of the individual values was unexpectedly slight in all cases. An example of this spread is given in Figure 2(a) for the results on open-textured asphalt at nearly 50 km p.h.

ii) Interpretation of results

Influence of roughness of pavement surface

The longitudinal transmissible tyre/road-surface forces increase with texture depth at all speeds and with practically all water-film thicknesses. But there is no clear-cut correlation. There are not enough different texture depths for this. The existence of a minimum in some of the curves in Figure 2 is suggestive of aquaplaning.

The fact that pavement roughness influences this is apparent from the position of these minima. For untextured Epoxy Bitumen (EB) there is already a minimum μ_x at 66 km p.h. and a water-film of about 0.5 mm. For open-textured asphaltic concrete (OAC) the minima are about 4 to 5 mm at 88 km p.h. and 2 mm at 102 km p.h. Porous asphaltic concrete (PAC) with an apparent texture depth of 2 to 3 mm has a minimum μ_x at 5 to 6 mm at 120 km p.h. The gritted epoxy surface treatments reveal no minimum.

There is no point in ascertaining the precise speed and water-film thickness at which aquaplaning will occur. Long before this point the available longitudinal forces are so low that the road user is already in a dangerous situation.

With the above information the importance of good texture depth can be indicated (as a standard of macro roughness). The fact that micro-roughness is also important is evident from the difference between the longitudinal force coefficients measured on the epoxy bitumen gritted with crushed gravel 5/8 and with round gravel 5/8 (See Figure 2). The former layer has a rather rougher micro-roughness (See Table 2), which results in a higher μ_x at low speeds.

Influence of vehicle speed

On a dry surface, speed has no demonstrable influence on μ_x (See Figure 3(a)). In this situation, not only adhesion and hysteresis but other factors play a part: for instance tyre wear (cohesion) and heat generation. It has always been a known fact that on a wet road the available longitudinal forces decrease as speed increases. The decrease is greater as the macro texture is smaller (SABEY et al., 1970).

The measurements by the Dutch State Road Laboratory confirm this tendency for nearly all water-film thicknesses. Figure 3(b) is an example, in which μ_x is plotted against speed for a 4 mm film.

The surfaces treated with epoxy bitumen as binder and porous asphaltic concrete have a much coarser macro-roughness than open-textured asphaltic concrete. The decrease in longitudinal forces with speed is therefore quicker with open-textured asphalt.

Many people apparently believe that only fast and very fast drivers get involved in skidding accidents. It is true that this category have slighter forces available and are therefore more likely to skid than slower drivers. The values of μ_x given in Figures 2 and 3 are braking force coefficients which may occur in emergency braking. These diagrams show that minima occur for open-textured asphalt at 100 km p.h. if the water-film is 2 mm thick, and even at about 85 km p.h. if it is 4 mm. These speeds are regularly exceeded by many drivers, also when it is raining.

The film thicknesses mentioned are quite substantial, but do occur.

Influence of water-film thickness

Figure 2 shows that the thickness of the water-film hardly affects measured longitudinal forces if the 2 to 3 mm level is exceeded. This roughly applies to all speeds and to all of the five pavement surfaces investigated. In concrete terms this means that measures aimed at avoiding low longitudinal force coefficients will only serve any purpose if they reduce the water-film thickness to less than the 2 to 3 mm limit.

MEASURES FOR COUNTERACTING WATER NUISANCE

Factors affecting water-film thickness

As the thickness of the water film has so much influence on the transmissible tyre/road-surface forces and is also a nuisance to drivers in other ways and hence interferes with their driving (by reducing visibility, causing glare, obscuring road markings), it may be as well to establish what factors influence water-film thickness. The principal ones, also emphasised in the literature on this problem (GALLAWAY et al, 1971; HÖCKER, 1971; KALENDER, 1971), are:

- intensity of rainfall; there is no way of influencing this.
- the resultant of transverse and longitudinal gradients of the pavement surface; if the local road geometry requires a slight transverse gradient it will have to be compensated for in the longitudinal gradient or else special measures will have to be taken.
- the afflux length; the more water flows over a greater distance over the pavement surface, the thicker the film will be.
- texture depth; the greater the texture depth, the more water can be retained between the topmost points of the surface texture and the longer it will take for an unbroken film to form on the surface.

Comparison of the results of a number of formulae (WELLEMAN, 1977) for calculating water-film thickness gives a preference for that of a number of American research workers (GALLAWAY et al, 1971). The value of such a formula should not be overrated. Its use is based on conditions only achievable in a laboratory. It should be borne in mind that differences are likely as regards traffic intensity and composition, wind effects and the existence of (thermoplastic) markings or rutting.

In assessing road situations, therefore, formulae will merely yield an idea of the water-film thicknesses actually occurring in such situations.

Road situations requiring special attention

Financial limitations are often the reason why action cannot be taken immediately after an undesirable situation is noted. It is therefore important for every road controlling authority to set the proper priorities for maintenance and reconstruction.

As to water nuisance, the priorities should ensure that thick films of water are obviated especially where regular demands are made on the transmissible longitudinal and/or transverse tyre/road-surface forces.

A number of situations deserving of special attention may be mentioned:

- At places where drivers have to apply their brakes thick water films should be avoided or the pavement should be made so that even if there are thick films sufficient braking forces can still be transmitted between tyre and road surface. This applies for instance to exit lanes, road sectors ahead of signal-controlled intersections and exits at grade-separated intersections of motorways with lower ranking roads. Road sectors often having queues of cars are also important in this context.

- In sharp bends it is important for an ample transverse force coefficient to be available. "Sharp" can be widely interpreted and depends on the design speed of the road.

In this connection, thought should be given to road intersection areas. These will be more difficult to drain the bigger they are, and will encourage pools to form. Vehicles turning left or right can be particularly troubled by this and are liable to skid.

- Applying the brakes hard in bends should be avoided wherever possible. Exit lanes in bends should therefore be discouraged, but if they are unavoidable, good drainage is essential.

The same applies to roundabouts.

- Where there are transition curves the great afflux length and the slight transverse gradient of the pavement surface will fairly frequently cause thick water films.

- Where gusts of wind are likely owing to discontinuities in building or roadside vegetation (for instance near bridges), sudden steering adjustments will have to be made. This puts demands on tyre/road-surface forces.

- On all road sectors puddles and pools should be obviated wherever possible. Thick, localised water films apply a sudden rolling resistance to the wheels owing to the horizontal component of the force representing the resistance of water to displacement (the mass effect). If the rolling resistance is unevenly distributed between the left and right wheels, a sudden steering manoeuvre is needed to correct the path. Failing this, the situation is liable to become dangerous. Regular inspection by the road controlling authorities during heavy rainfalls is imperative to ascertain where pools occur.

The above-mentioned situations call for attention where film thickness have to be watched; it should also be avoided that rutting occurs in those situations.

Possible road engineering measures

If, in spite of all the road and pavement designers' efforts, substantial localised water-film thicknesses prove unavoidable, a number of special engineering methods exist. As regards the Dutch main roads system, largely having an asphaltic concrete top layer, the following special measures may be mentioned.

A. Cutting longitudinal or transverse grooves

Grooves cut into the pavement surface increase its macro-roughness, as it were; this has a favourable effect on the transmissible tyre/road-surface forces especially when the surface is wet. Owing to the composition of the mix, the grooves do not last long in The Netherlands; no longer than about two or three years, depending on traffic intensity and the number of large pieces of gravel in the asphalt-concrete mix.

B. Small transverse discharge channels

If the afflux length is indicated as the main cause of thick films of water (transition curves, bridge and tunnel approaches and exits), it might be considered making small discharge channels in the pavement surface. Their function is to collect rainwater running over the road surface where long flow paths are intersected, and to guide it to the verge via the shortest route. The Dutch State Road Laboratory has made succesfull experiments with transverse channels. A steel U-channel, 50 x 50 x 5, packed into the pavement with a slurry of synthetic resin works well without any inconvenience to drivers.

C. Synthetic resin surface treatment

Where heavy demands are made on the available longitudinal and/or transverse tyre/road-surface forces (for instance on intersection pavements) it may be advisable to pay more attention to surface quality. Synthetic resin surface treatment, provided it is gritted with coarse mineral aggregate, still guarantees substantial available tyre/road-surface forces even with thick water films (See Figure 2). The explanation is the great texture-depth. Such measures will only be taken occasionally because of the high cost.

D. Porous asphaltic concrete

A top layer of porous asphaltic concrete can be an excellent means of counteracting water nuisance on road surfaces. The Dutch State Road Laboratory has examined some aspects of this material, including that of water nuisance. Mr. Elsenaar will be reporting on this during the present Session.

CONCLUSIONS AND RECOMMENDATIONS

There are relatively more accidents on wet road surfaces than on dry ones in The Netherlands. Per unit of time, nearly three times as many fatalities occur on wet surfaces as on dry ones.

Research shows that the accident rate per million vehicle-kilometres increases considerably when the transmissible tyre/road-surface forces are smaller.

Measurements have proved that available forces decrease as the vehicle's speed increases, as the pavement-surface roughness decreases and the road-surface water-film is thicker. The water-film thickness hardly has any more influence on the measured longitudinal forces once the 2 to 3 mm level is exceeded. This means that measures to limit water-film thicknesses can only have a favourable influence on transmissible tyre/road-surface forces if they reduce the water-film thickness beyond 2 to 3 mm. This finding can be used, for instance, in determing the permissible rutting depth. In counteracting water nuisance, road and pavement designers are becoming less and less empty-handed. Putting available measures into practice, however, often means facing objections of a financial nature.

Table 1. Average number of fatalities a year in The Netherlands from 1971 to 1975, as far as concerns drivers and passengers of cars, trucks, delivery vans, buses, coaches and motor cycles.

Drivers of/ passengers in:	Passenger cars	Trucks, delivery vans, buses and coaches	Motor cycles	Total
Dry road surface	851	46	78	975
Wet surface and raining	167	11	7	186
Wet surface: not raining	171	8	11	190
Total	1189	65	96	1351

Table 2. SRT-values of the pavement surfaces investigated.

		SRT-value	Standard deviation	Number of Measurements
Epoxy bitumen	(EB)	33		
Epoxy bitumen + crushed gravel 5/8	(EB + CG 5/8)	85	4.9	51
Epoxy bitumen + round gravel 5/8	(EB + G 5/8)	73	4.7	38
Porous asphaltic concrete	(PAC)	74	3.2	37
Open-textured asphaltic concrete	(OAC)	74	3.2	45

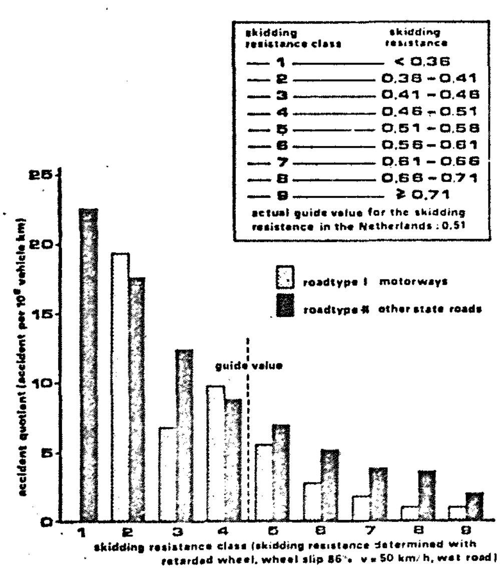
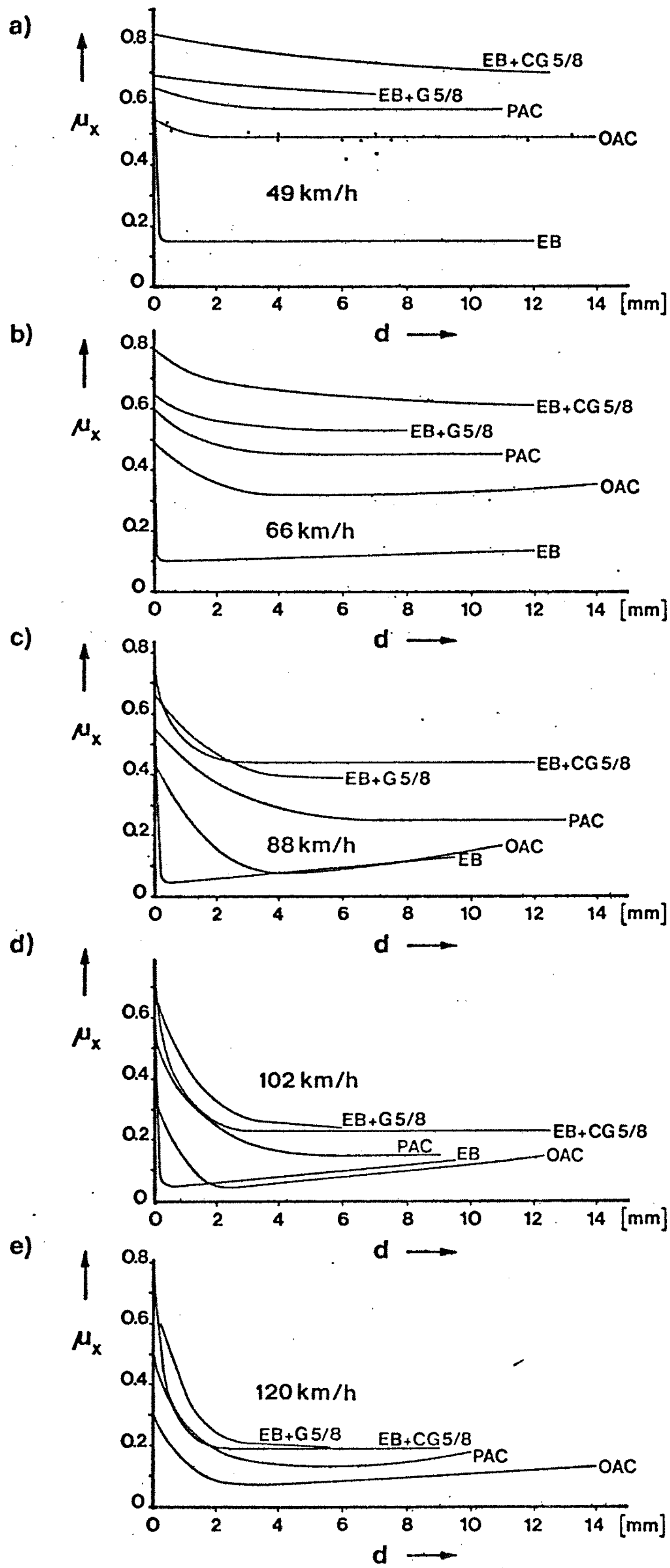


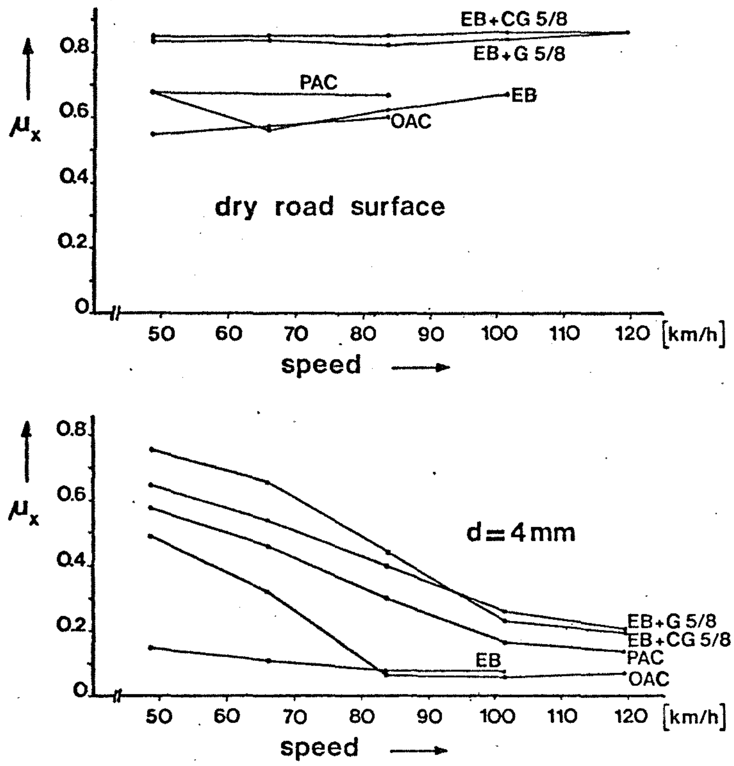
Figure 1

Relation between skidding resistance and accident rate on Dutch national highways in 1965 and 1966.



Figures 2 (a) to 2 (e)

Coefficient of longitudinal force, μ_x, as a function of water-film thickness, d, at various speeds.



Figures 3 (a) and (b)

Coefficient of longitudinal force μ_x as a function of speed (86% slip)
(a) with dry road surface
(b) with 4 mm water-film.

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