SKID RESISTANCE AND WATER FILM THICKNESS

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Summary

Problems of safety are closely linked to the state of the wearing course. In view of the imperious necessity to insure the best tyre-road adhesion possible, the researches undertaken in this fiel by the Laboratories of the french highways Administration have been directed towards the study of the reasons of rapid decreasing of friction which may lead to aquaplanning of the vehicles.

The precise study of these friction coefficients on damp pavement must be accompanied by measurements of water film thickness which covers these pavements. These measurements are particularly difficult, for the surfacing of a pavement is not perfectly even at all scale.

This paper describes a measurement method of the water film thickness which uses a device based on the principle of rapid neutron deceleration by hydrogen nuclei. This method is very advantageous for it allows to make a "point" measurement with respect to the whole pavement and to obtain a mean water film thickness which takes into account the pavement asperities.

The research now goes towards the study of a simulation computer model. The data of output surfaces function are obtained on a miniature model in laboratory.

The geometrical data are measured on the road. A car with a gyroscopic machine gives the gradient and the ruled surfaces of pavement (Scale of lie) treatment gives and automatical method to find water accumulation zones on an itinerary (highway principaly). The local investigation using gradient variation on the pavement (Scale of evenness and inferior, but superior to roughness) allows the river system of drainage the flashes of water and accumulation, to be simulated during any intensity storm.

1 - INTRODUCTION

1.1. Problems of safety are very closely linked with the condition of the pavement surface, and the imperative necessity of ensuring the best possible grip has slanted research towards a knowledge of the origins of sharp reductions in coefficients of friction which occur espacially with the phenomenon of aquaplaning of vehicles on the thin film of water covering the pavement.

1.2. Grip decreases rapidly as the thickness of the film increases, and the smoother the surface the more marked is the variation. Consequently a precise study of coefficients of friction must be accompanied by measurements of the thicknesses of water covering the pavement. But a pavement surface is not perfectly smooth ; it has a succession of very slight irregularities, in the form of crests separated by troughs. So when the pavement is wet, account must be taken not only of the thickness of water above the crests, but also of the water in the troughs, so as to measure the mean thickness of the film of water covering a given surface.

2 - DRAWBACKS OF THE VARIOUS EXISTING METHODS OF MEASURING WATER FILM THICKNESSES

2.1. Among the familiar methods employed, mention may be made of the one consisting of a wedge in the shape of a right-angled triangle, one side of which is laid on the pavement (1). This wedge rests entirely on the crests of the irregularities, and hence can only enable the meam thickness of water above the crests to be measured. Moreover, its accuracy is no more than about 6/10 mm. Furthermore, the measurement can only be made when the thickness of the film covering the zone in question is equal to or greater than 2.5 mm.

2.2. Another well-known method is the point water level gauge (2). This consists of a fine needle which is lowered on to the water-covered pavement. During the lowering, a high-precision micrometer measures the position of the point of the needle between the moment it comes into contact with the surface of the film and the moment it touches the surface of the pavement. Though the measurements are very accurate, they are difficult to interpret statistically in order to determine the mean thickness ; very many measurements have to be made, because the needle can only give the minimum or maximum thickness of water according to whether it is in contact with a crest or a trough.

2.3. These considerations led the L.C.P.C. to design and apparatus for measuring water film thicknesses on pavements with does not possess these drawbacks.

3 - PRINCIPLE OF THE PROPOSED METHODS OF MEASUREMENT AND DESCRIPTION OF THE APPARATUS

3.1. Our attention very soon turned to the use of nuclear methods, which a priori are quite promising and more elegant. They offered two possibilities :

§ Using the principle of beta-ray retrodiffusion on the surface.

§ Using the slowing down and diffusion of neutrons, since the hydrogen present in the water is one of the elements with the highest coefficient of slowing down.

3.2. Beta-ray retrodiffusion measurements are very local, and may be considered as point measurements in relation to the scale of the pavement. This has drawbacks, as we have seen in the case of the water level gauge. Consequently research was conducted on the principle of the second method.

3.3. The principle of the slowing down and diffusion of neutrons has already been used for determining the water content of pavement materials. Modifications were made so that the slowing down of high speed neutrons could be strongly influenced by the water present on the surface of the pavement

3.4. For this purpose the measuring instrument (Fig. 1) has two sources of high-speed Americium Beryllium neutrons, embedded in the mass of a solid moderator containing many hydrogen nuclei (polyethylene). Such a system slows down the neutrons as soon as they are emitted, and the geometry is such that the neutron flow in the direction of the water film contains a high proportion of neutrons whose energy is slightly above the thermal threshold. Thus the slowing down is completed mainly in the water film.

3.5. Four boron trifluoride detectors are placed on the lower surface of the moderator unit. They detect thermal neutrons. A metering instrument connected to these detectors gives information on the intensity of the flow of thermal neutrons above the water film, over a surface of about 400 cm^2. This is very advantageous, because it gives us point measurements which are integrated with variations in the height of water due to surface irregularities.

Fig. 1. Schematic cross-section of the system of emission, primary slowing down and detection of neutrons.

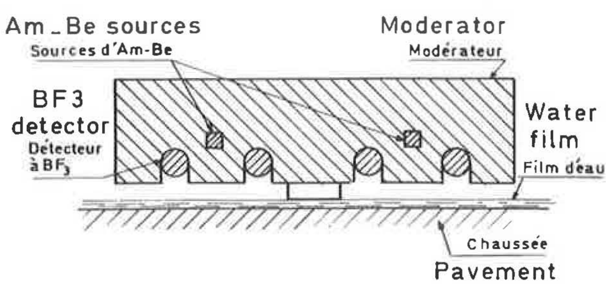
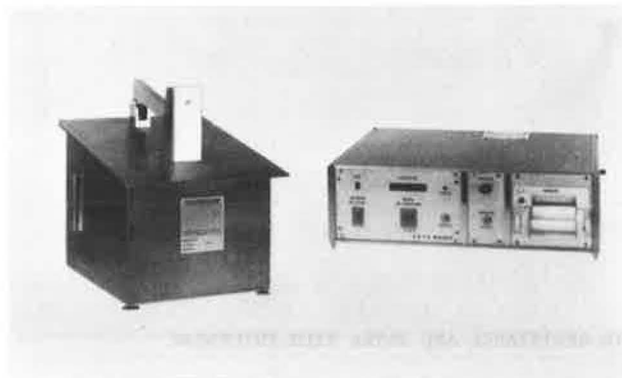


Fig. 2. General view of the instrument. Left, impervious housing containing the moderator unit ; right, the measuring system and print-out.



4 - MEASUREMENT PROCEDURE

4.1. The moderator, sources and detector are contained in an impervious housing fitted with a handle. The lower surface of the housing rests on three legs, arranged in triangular pattern. The upper surface is inclined so as to allow water to flow off when measurements are made in rainy weather (Fig. 2). The four detectors are connected in parallel to the input of a preamplifier located in the measuring instrument. The signals detected are conveyed through a very long cable connected to a measuring system comprising a metering scale and a print-out.

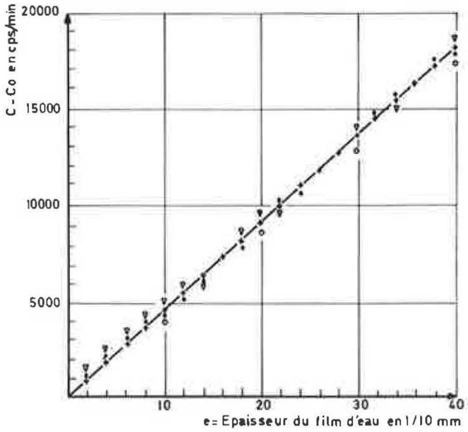
4.2. For a given pavement, the rate of metering depends on the thickness of the water film covering it, and consequently it is necessary to determine the rate of metering Co on the dry pavement and the rate of metering C on the wet pavement, with the bottom of the housing 10 mm above the pavement.

4.3. Numerous tests carried out with this apparatus showed that the thickness of the water film is uniquely a linear function of the difference between C and Co, whatever the nature of the underlying surface, though the rate of metering Co depends on this nature. These results are very important, because it is not necessary to calibrate the apparatus for each type of pavement. At each spot where measurements are made, it suffices to determine the rate of metering Co on the dry pavement. Figure 3 shows all the calibrations made under four different conditions.

4.4. Examination of the mean curve C - Co =f(e) shows that the calibrations are identical whatever the composition of the surface under the water film (coated material or concrete), watever its roughness, and watever the calibration procedure (with glass plate or direct coated material).

4.5. In view of the sensitivity of calibration (slope of the straight line in figure 3) and the statistical error for a metering period of one minute, we consider that the instrument makes it possible to determine mean water film thicknesses between 0 and 8 mm to an accuracy of $\pm$ 1/10 mm.

Fig. 3. Calibration curve of the instrument, valid for different surfaces under lying the water film.



Water film thickness in 1/10mm

+ glass plate placed on slab of coated material
△ glass plate placed on cement concrete slab
. slab of smooth coated material
o very rough slab of coated material

5 - APPLICATIONS

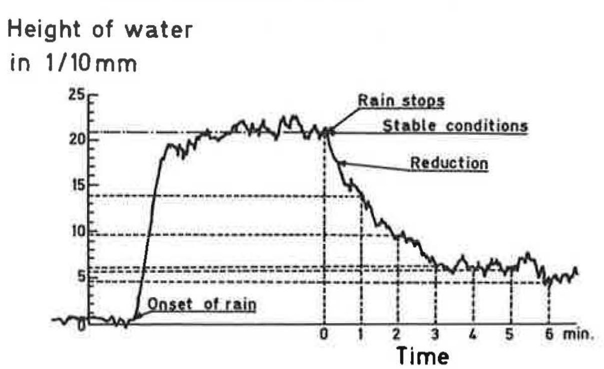
5.1. The instrument was designed and built for measuring water film thicknesses and their drainage (i.e. how the thickness changes over a period of time) on a very wide range of pavement surfaces.

5.2. To achieve satisfactory reproductibility in the determination of the drainage characteristics of the surfaces studied, various instruments simulating "standardized" rainfalls were used in conjunction with the neutron probe. The whole formed and autonomous system which could be used on various pavements. We shall briefly give some examples.

5.3. Figure 4 shows the recording of the height of water on a pavement. This makes it possible to keep track of the evolution of water films. In an experimental procedure, we may distinguish successively :

§ The dry pavement.

Fig. 4. Formation and disappearance of a water film under artificial rain.



§ The more or less rapid increase in the water film thickness after the onset of a so-called "concentrated" fall of rain.

§ The achievement of equilibrium which can be prolonged to improve the accuracy of measurement.

§ A "recession" after the rain ceases.

§ A Stabilisation or very slow drainage corresponding to an interception of the water by the pavement surface ; the water is eliminated mainly by evaporation.

5.4. As we have said, we were mainly interested in determining water thicknesses and their evolution over a period of time. In figure 6 the periods of stabilization during and after rainfall give interesting values, but the intermediate period of reduction in thickness depends on the drainage propensities of the pavement surface ; we shall deal with this at greater length.

5.5. For instance, figure 5 shows measurements obtained on various pavements with gradients varying by a few per cent. Bilogarithmic coordinates were used here, for we noted that during a large part of the drainage they enable the drainage curves to be validly represented by straight lines.

5.6. These curves indicate that a pavement may present marked differences in drainage, but in particular drainage may last quite a long time, up to one hour after rain ceases. Hence the importance of ensuring the most rapid possible run-off of surface water (since the slopes depend on external requirements of alignment, or simply on the symmetry of traffic). Thus the drainage of pavement 2 is markedly more rapid than that of pavement 5, though the slope is the same.

5.7. The second example is taken from comparative measurements made on a motorway whose concrete was either smoothed with burlap or grooved transversaly with a metal brush (worn in the slow lane),

Fig. 5. Comparative drainages of various roads.

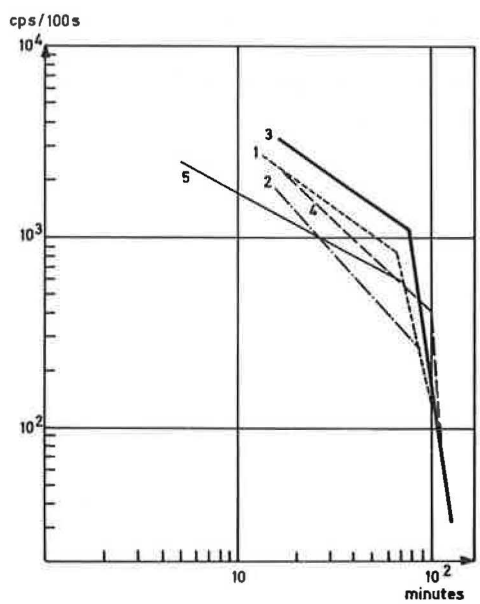
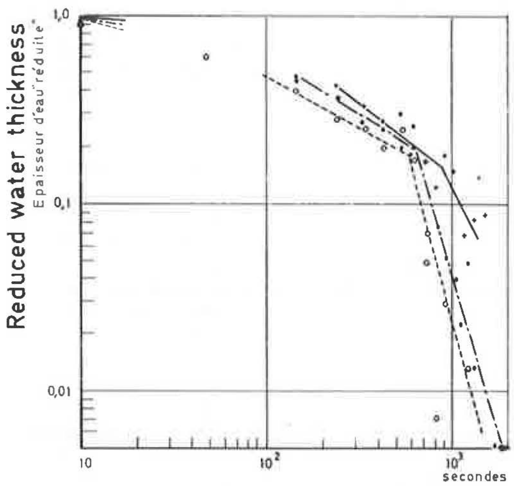


Fig. 6. Comparison of drainage propensities of three surface textures on the same motorway

——— concrete smoothed with burlap
- · - · worn grooved concrete, slow lane
----- grooved concrete in good condition, fast lane.



in good condition in the fast lane). Thus only the surface states differed. In figure 6 we have brought each drainage curve to its equilibrium value, so that at the outset all the drainages start from 1 and comparison is easier. Let us examine the beam of lines in detail.

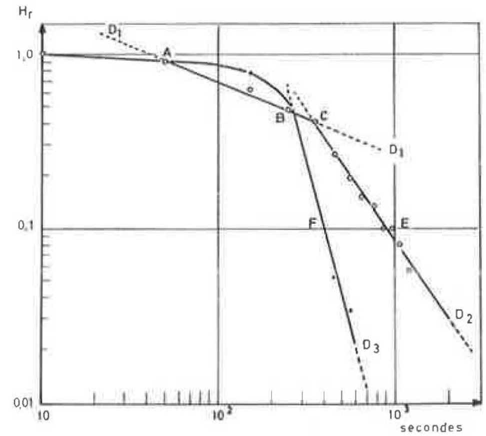
5.8. Leaving aside the first phase of transition (10 to 100 s), we see that the shape of the lines indicates that from 10^2 to 10^3 s the smoothed concrete has a relatively greater thickness of water and its rate of drainage is greater than that of the grooved concrete.

5.9. On the other hand, after about 10^3 s conditions change ; drainage slows down, and the thicknesses of water remaining on the pavement are about 10 % of their initial value ; while for grooved concrete, whose curves are below and which also undergoes a change of conditions, the thicknesses are reduced to 1 % of the initial value. Thus the advantage of grooving is that the quantity of water remaining on the pavement is reduced by nine tenths after 20 minutes.

5.10. A grooved concrete pavement, even worn, is therefore always better from the drainage point of view, even though it becomes less effective under traffic wear.

5.11. The following example is taken from an experiment conducted on a concrete pavement where there were two very different textures practically in justaposition. One was a surface smoothed with burlap, the other a surface grooved transversaly with a grooving saw to a depth of about 5 mm, the grooves being 10 cm apart. The care taken with the experimental conditions made it possible to obtain figure 7, sufficiently accurate to calculate the different parameters. But some important points should first be noted : between 50 and 300 seconds, the drainage of the smoothed concrete is linear, and more rapid than that of the grooved concrete is linear, and more rapid than that of the grooved concrete. Beyond this point, however, two linear conditions are initiated, giving a much more effective drainage in the case of the grooved concrete.

Fig. 7. Variation in H_r in function of time on a concrete smoothed with burlap (o) and a grooved concrete (+)



5.12. The variation of the film thickness with time is given by :

$$H_r = a.\ t^{-b}$$

where H_r = height of water brought to its maximum value at equilibrium

t = time in seconds

a and b = two coefficients affecting drainage, and probably depending on texture, gradient, etc..

The various parameters of drainage are given in the table below.

	D 1	D 2	D 3
a	4.9	3.1×10^3	5.2×10^8
b	0.42	1.52	3.74

The field covered by these coefficients is thus quite wide, and clearly distinguishes the different hydrodynamic conditions which arise.

5.13. Thus grooving reduces the time during which water remains on the pavement surface following a fall of rain lasting several dozen minutes. This is all the more important in that drivers are less careful in their driving after the rain has stopped than while it is falling.

6 - FURTHER RESEARCH

6.1. We have observed that real drainage conditions on pavements have previously been assessed very imperfectly. Apart from extreme cases of zones of transition between left hand curves and right hand curves on motorways (zones which favour the accumulation of water because of the change of banked corner at the point of inversion) there is no quick method of determining the real conditions of water run-off on a given pavement.

6.2. We therefore consider that these problems are to be studied from two angles :

§ From the angle that pavements are ruled surfaces. This makes it possible to select zones on a given itinerary where important accumulations of water are more likely.

§ From the angle that local variations in gradient due to defects in laying and riding quality and rutting due to wear create particular drainage networks the rivers on the pavement surface may then be greatly above the average, and this average is then meaningful only in relation to the pavement as a whole, or to a zone.

These two angles are dealt with in the following practical descriptions.

7 - DETECTING ZONES FAVOURING THE ACCUMULATION OF WATER

7.1. This is done with a vehicle called the Gyros.

A gyroscopic unit mounted on an ID 20 station wagon permanently gives the three angles of direction, roll and pitch at 25 Km/h. This basic information is recorded on magnetic tape. After being processed in a computer, it makes it possible to reconstitute the geometric characteristics of the road : plane alignment, longitudinal profile, and hauted corner. Different combinations of the results extend the field of application of the apparatus to other problems (Fig. 8).

7.2. To detect points at which water accumulates on the pavement surface, we may determine at each point of measurement the line of greatest slope in the transverse profile or in the longitudinal profile by driving the Gyros once along each traffic lane. Driving the Gyros twice along each traffic lane gives transverse reverse slopes if need be. The graphic representation of these results (Fig. 9) enables us to visualize the points favouring accumulation. To rate these points in order of importance, the width and surface of the pavement have to be considered. An Automatic research for a Water accumulation coefficient is performed by a computer program. The most dangerous sites can be drawn with this method and a limit of this coefficient. (Fig. 10 et 11).

Fig. 8. Banked curves in relation to plane alignment.

Scales

Plane 0,8 cm = 50 m
Bank 0,8 cm = 2 %

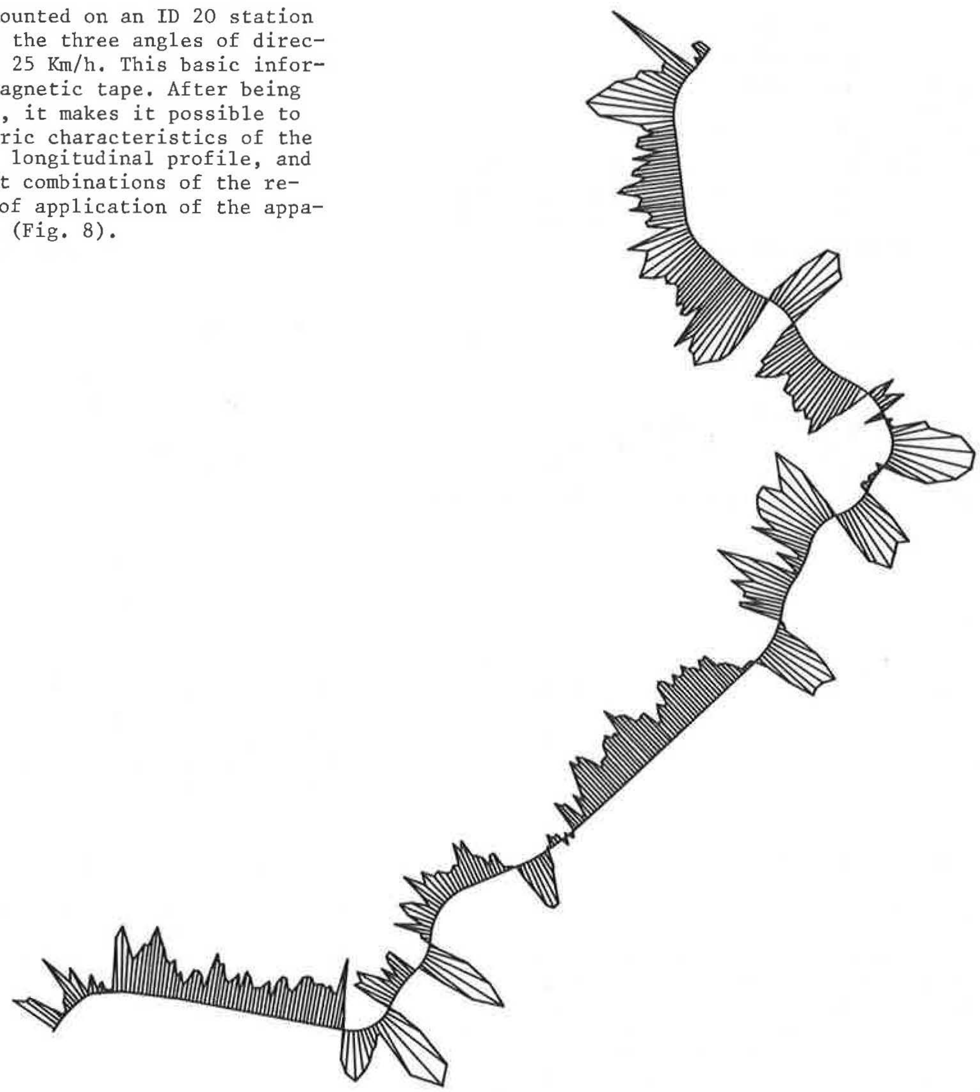


Fig. 9. Sloping section with curves : water run-off

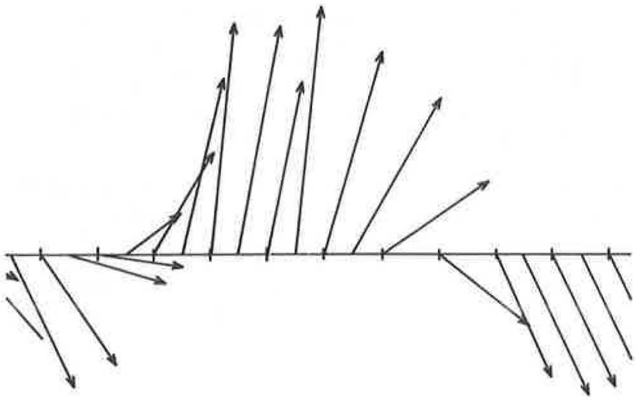


Fig. 10. Flat section with curves : accumulation of water.

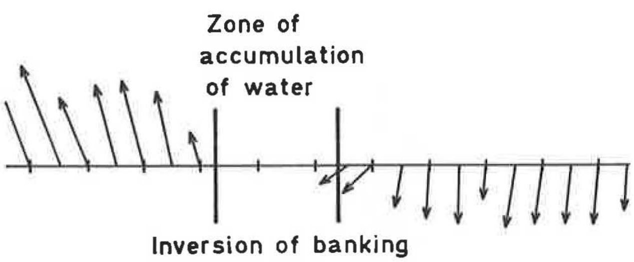
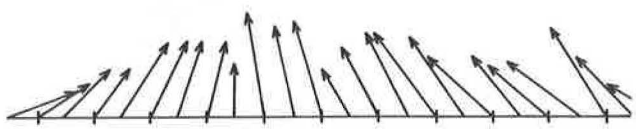


Fig. 11. Straight section with low point : preferentiel run-off.



8 - RUN-OFF SIMULATION MODEL

8.1. This model, now being developed, is intended to reproduce in a computer the evolution of the height of water at each point of a pavement during a rainstorm. Its operation calls for the gathering of a certain amount of data :

§ Geometric data.

§ Drainage transfer functions.

§ The rain function.

8.2. The geometric data are characterized by the gradients of the elementary units of surface covered. The square or rectangular unit may very from 10 cm to 3.5 metres ; it is generally 50 cm.
This data may be gathered by the Gyros vehicle in the course of several passages, or by a pendulum tripod at specific points in a zone of investigation.

8.3. The drainage transfer functions are basic data gathered in advance on a model in the laboratory, with surfaces of 1 m^2 of different geometric rugosities on which the gradient and the flow of water can be varied. Measuring the height of water in equilibrium with a neutron probe placed underneath enables us to obtain the data matrix :

§ The flow rate or transfer function.

§ The gradient.

§ The height of water.

In a second stage we shall introduce the effect of wind.

8.4. The rain function can be standardized in respect of intensity and duration, or can be the result of a real recording with all its variations.

8.5. Numeral simulation will use these data to calculate the height of water at each point in function of time. The system cannot be divergent, but only oscillatory in function of the time-interval adopted.

8.6. A knowledge of this height along the paths followed by vehicles will give an accurate indication of the amount of water which the tyres have to remove. The grip of vehicles depends on the extent to which they can adapt to variations in this height.

8.7. In situ verifications of the results obtained with the model are planned, under real or artificial rainfall conditions.

9 - CONCLUSIONS

9.1. The development of the neutron probe for the purpose of accurately measuring heights of water has met the objective set. The apparatus makes it possible to measure water film thicknesses on the pavement surface, and keep track of them.

9.2. Very varied applications may be envisaged for example, the detection of critical levels on airport runways using a series of instruments embedded under the runway, facing upwards.

9.3. Further development seems particularly interesting in respect of a knowledge of all phenomena of run-off. This involves continuous measurement embracing localized accumulations. The rate of measurement would, however, be slower. A prototype is actually tested.

9.4. Measurement at specific points nevetheless makes it possible to create a model or a computerized simulation of run-off over the whole pavement, taking account of geometric data relating to gradients and surface structure. The former can be obtained by specialized high-yield instruments in situ, and the latter by laboratory measurements on models. Research is continuing along these lines.

BIBLIOGRAPHIC REFERENCES

1. NASA - Pavement Grooving and Tractor Studies. SPP 5073,1968.
2. ROSS N.F. - Road Research Laboratory, An Investigation of the hydraulics of run off from road surface, Technical Note n° 79, third report 1966.
3. JP. BARON, J. LEFRANC - Mesure des épaisseurs des films d'eau à l'aide d'une méthode neutronique - Bulletin de Liaison des Laboratoires des Ponts et Chaussées n° 59 (p. 49) 55).
4. J. BERTHIER - Bulletin Liaison des Laboratoires des Ponts et Chaussées n° 26 (réf. 369-1967).
5. ROME - XII° Congrès A.I.P.C.R. Comité Glissance 1964.
6. L.H. WATKINS - R.R.L. note LN/418/LHW,B.P.964 - 1963
7. L.H. WATKINS - R.R.L. note LN/699.LHW,B.P.1036 - 1964.
8. KALENDER,U. Einflussfsktoren auf die Wasserfilmdicke. In : Strassenbautagung Berlin 1970.
9. Forschungsgesellschaft fur das Strassenwesen e.V. Koln 162/168.
10. KALENDER, U. Abfluss das Regenwassen von idealebenen Fahrbahnoberflachen.
11. Doct.Thesis, Technisch Universitat Berlin D. 83.1972.