Skid-resistant surfaces are available. They make use of special binders, in most cases epoxy or polyurethane resins, and natural aggregates which either have very good accelerated polishing characteristics and hardness, or artificial aggregates such as bauxite or calcined bauxite.

It has thus been observed that following improvements on these accident-prone areas the percentage of accidents on wet pavements was reduced from 75% to 20% and the annual number of victims was reduced to approximately one fourth with an accompanying reduction in accident severity.

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APPLICATION OF KNOWLEDGE OF PAVEMENT SURFACE PROPERTIES IN GERMANY

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Apart from initial activities before World War II, skid resistance measurements have been carried out in the Federal Republic of Germany since the end of the fifties. Since that time we have used a locked wheel testing machine (Fig. 1). Those members of this audience who participated in the 1962 skid correlation tests at Tappahannock, Virginia, are familiar with this machine which we call the "Stuttgart" apparatus. Since that time the machine and the auxilliary equipment have been much improved. Today five test vehicles with a Stuttgart apparatus are in use, two of them are operated by the Federal Road Institute at Cologne, one each is employed by the Technical Universities of Stuttgart and Berlin, and one is owned by the State of Bavaria.

To provide skid-resistant surfaces there are three principal directions of work:

1. Examination of newly laid surfacings before opening to traffic.
2. Accumulation and application of experience with regionally standardized mix compositions.
3. Systematic evaluation of the accident statistics with regard to wet weather accidents.

I would like to say a few words on each of these points.

Examination Of Newly Laid Surfacings

Most of the difficulties experienced with insufficient skid-resistant highways in recent years occurred with newly laid surfacings. In this case low resistance to skidding is caused primarily by a lack of microtexture rather than a lack of macrotexture. For instance, a newly laid asphaltic concrete surfacing can fail to offer a harsh microtexture due to excess binder accumulated at the top of the layer during rolling. This behavior has been observed primarily with mix compositions rich in binder and mortar which were designed to offer a high resistance to studded tire wear. As another example, newly laid cement concrete pavements offer slippery surfaces when wet due to insufficient treatment of the fresh concrete surface.

In all these cases the characteristic feature of the friction number versus speed relationship is that friction numbers are low even at low speed (Fig. 2). To identify slippery surfaces of this type it is not necessary to use full scale machines which are able to measure at speeds of say 60 or 80 km/h. It is sufficient to use the portable pendulum type skid tester developed in Britain. Pendulum measuring at low speed is comparatively inexpensive and readily available. With these advantages in mind a program was started in the Federal Republic of Germany in 1972 to implement the wide-spread use of the pendulum tester as a first aid in identifying slippery pavements. Under a special scheme the Federal Road Institute at Cologne has taken the responsibility for regularly checking and calibrating the instruments in use throughout the country.

Accumulation Of Experience

Road construction in the southern and western parts of the Federal Republic of Germany relies on the availability of good quality natural road stone, whereas the northern parts must depend upon road stones imported mainly from Scandinavia and Ireland. As a consequence of these regional differences there is much effort placed towards regional standardization of mix compositions with regard to skid resistance as well as with regard to other quality requirements. Among these efforts repeated skid resistance measurements with the locked wheel braking force machine are performed at least twice a year and at speeds up to 120 km/h. This forms a major part of a research program which has been continued since the early sixties. In order to select the most promising alternatives, this program incorporates selected individual pavements of typical mix composition for the region as well as experimental sections with a sequence of 5 to 10 alternatives in mix composition or surface treatment. Much regionally and generally valid experience has been and is still being gathered in this way, and this enables the highway authorities and the road contractors to achieve pavements with long lasting anti-skid properties. In this context limestone has been excluded from the top layers since the mid sixties.

Experimental sections were also devoted to the question of improving the initial skid resistance of asphaltic concrete surfacings. Following practices in Holland and Belgium, spreading of crushed sand onto the hot layer during the rolling process (Figs. 3 and 4) has proved highly successful. Another series of experimental sections of road were devoted to treatment of the fresh concrete pavement surface to obtain a harsh and coarse texture or to enrich the top two millimeters with hard and sharp sand particles. Due to the spreading of crushed stone onto the hot surfacing immediately after laying, no problem of initial skid resistance exists with gussaspahlt surfacings (Fig. 5).

Figure 1.

Figure 2.

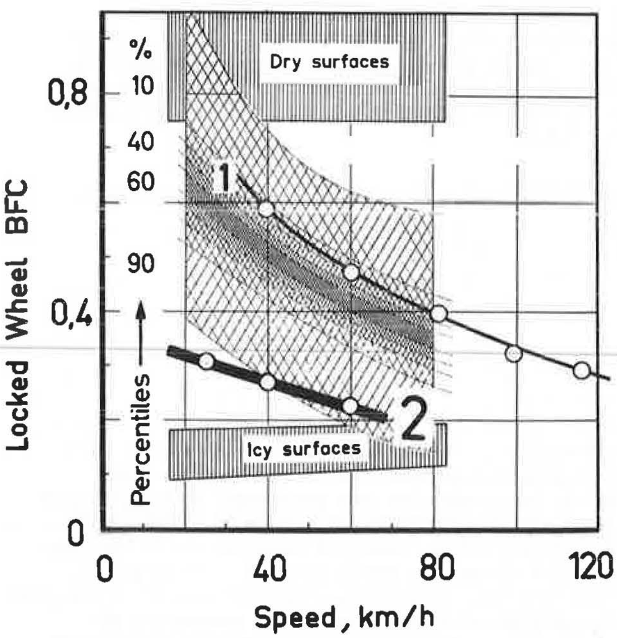

Figure 3.

Figure 4.

Figure 5.

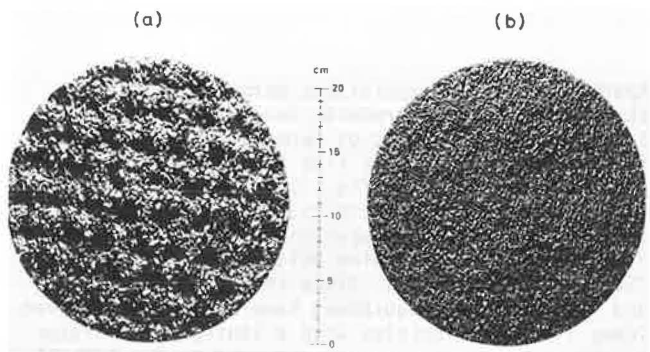

Figure 6.

Accident Statistics

Normally within the road network the percentage of wet road accidents ranges between zero and fifty per cent. If this percentage range is exceeded significantly on a section of road over a period of one or two years, then it is evident that on this section traffic safety during wet weather is reduced. Skid resistance measurements can show whether or not a slippery surface was involved and that some treatment or renewal work would be useful. In many cases however, other factors are also involved. On motorways the main problem arises from water accumulations on the road producing relatively thick water films. The consequence is that the avilable tyre-to-road friction drops significantly with increasing speed.

Two cases of water accumulation on the road can be distinguished:

1. Accumulations due to ruts in the wheel tracks (Fig. 6), and
2. Accumulations due to the geometry of the roadway.

Rutting is caused by winter tyres with studs, no longer permitted in the Federal Republic of Germany, and by irreversible deformations of the pavement system. Critical areas due to roadway geometry are the transition zone between right-hand and left-hand curves when the cross slope passes through zero. Here the water flows very slowly or takes a long path before leaving the roadway. Such transition zones can be avoided by applying a negative crossfall in left-hand curves so that the crossfall of the roadway does not change its direction at all. This is a possible solution for horizontal curves with large radii, say above 5000 m., where crossfall transition zones are unavoidable countermeasures against reduced safety in wet conditions.

The systematic evaluation of accident statistics to identify "black spots" under wet conditions has been carried out in the Federal Republic of Germany since the middle of the sixties. This is now part of an accident evaluation scheme that covers all aspects of accident occurrences and is operated by the Federal Road Institute at Cologne.

In contrast to some other European countries you will not find in German implementation strategies the concept of regularly monitoring the entire network of main rural roads. Indeed, we are not convinced that such surveys performed once or twice a year would help very much in skidding accident prevention. The answer can be given in five steps:

1. Our recommended minimum friction numbers do exclude the most dangerous low friction levels, but for economic reasons they are not high enough to be regarded as definitely "on the safe side".
2. With the exception perhaps of newly laid surfacings, surfaces falling short of the recommended minimum values are relatively rare. Therefore, cost-effectiveness considerations do not favor regular survey tests.
3. Surfaces where friction numbers exceed the recommended minimum can also be the scene of repeated skidding accidents in wet conditions depending on factors other than the measured friction number of the road surface. Such factors include roadway geometry and deep ruts causing water accumulations on the road.
4. Unless the friction numbers measured are extremely low and fall short of the recommended minimum, it is clear that one needs accident figures and the other factors mentioned in interpreting the results of skid resistance measurements with regard to safety.
5. If this is true, then it is more effective in our opinion to make the accident figures and the other factors mentioned the primary input in safety investigations, and make the measuring of friction numbers the secondary input, and not vice versa as in the monitoring concept.

APPLICATION OF KNOWLEDGE OF PAVEMENT SURFACE PROPERTIES IN JAPAN

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Proposed recommendations of friction coefficients in Japan for newly constructed pavement are 0.35 at 80 km/h for expressways and 0.40 at 60 km/h for national roads. The manual for asphalt pavements, which has been the national standard for design and construction of asphalt pavements since in 1950, was revised in 1975 for standard asphalt mixtures applicable both in general and snowy districts. Skid-resistant mixtures used for wearing courses are either open-graded asphalt concrete or gap-graded dense asphalt concrete for general districts, and gap-graded dense asphalt concrete with high filler content for snowy districts. The background of recent revisions is as follows:

1. The effect of open-graded asphalt concrete on pavement skid-resistance has been evaluated mostly through practical uses.
2. In general rubber-asphalt is added to open-graded asphalt concrete. However, the abrasion resistance is not necessarily sufficient compared with gap-graded asphalt concrete.
3. In snowy districts gap-graded asphalt concrete with high filler-asphalt ratio is needed from the point of view of abrasion-resistance against the action of tyre chains and studded tyres.

In Japan, with its many mountainous roadways, there is a growing recognition of the importance of skid-resistant pavements particularly for express highways. Depending on the slope and length of incline some regional highway authorities are considering the adoption of skid-resistant pavements. The Local Road Section of the Ministry of Construction has recommended their use for inclines greater than 6% and total length more than 200 m. At these