Experiences with Porous Asphalt in Switzerland

THOMAS ISENRING, HARALD KÖSTER, AND IVAN SCAZZIGA

Since 1982 a research program observing the long-term behavior of porous asphalts under normal traffic conditions has been carried out at the Institute for Transportation, Traffic, Highway and Railway Engineering IVT of the Swiss Federal Institute of Technology in Zurich. In a first phase, an observation program measured skid resistance, permeability, rolling tire noise, and deformation once or twice a year on a selection of porous asphalt pavements already in service. The general appearance and behavior under winter conditions were also recorded. In a second phase, the research was extended to include the study of material properties such as aging of the binder, performance of the mix, and so forth. The emphasis in this paper is given to results from the first phase of the research program. Particular attention is devoted to the problems of skid resistance, permeability, noise reduction, and behavior under winter road conditions of porous asphalt pavements. For these parameters, the methods of measurement, results, and general conclusions are presented. Conclusions are provided separately for two potential areas of application of porous asphalt: motorways and other roads with fast traffic, and urban roads with slower traffic. Taking into account the different advantages and disadvantages of porous asphalt, experiences obtained so far are generally very positive about the application of porous asphalt to roads with high-speed traffic. When applied in urban areas, different problems appear and initial advantages may be lost within a short time. Also applications in an urban environment cannot take full advantage of the noise-reducing potential when traffic travels at lower speeds. Results from this research project also indicate that a number of conventional surface layers can have favorable acoustic properties; in this field there is potential for further development. Under winter road conditions, porous asphalt surfaces can present the same range of variation of skidding properties as conventional surface layers. However, at a particular moment, there is a difference in the behavior of the two pavement types along the road at the site where the type of surface changes.

The first porous asphalt in Switzerland was placed on an airport runway in 1972. On road pavements, porous asphalts have been used since the late 1970s and early 1980s. Since 1982 a research program has been carried out at the Institute for Transportation, Traffic, Highway and Railway Engineering IVT of the Swiss Federal Institute of Technology in Zurich to observe the long-term behavior of porous asphalts under normal traffic conditions. Using these observations, it should be possible to collect data on all material properties of porous asphalt concrete with a view to its future use. The work described here is mainly limited to experiences in Switzerland. Some studies from other countries were also considered in certain cases; otherwise they cannot be compared because of different conditions such as climate, winter maintenance, type of bitumen, test procedures, and so forth.

Swiss Federal Institute of Technology, ETH Hönggerberg, Zurich, Switzerland CH-8093.

In a first phase, porous asphalt pavements already in service in 1982 were selected and an observation program measured skid resistance, permeability, rolling tire noise, and deformation once or twice a year. The pavement's general appearance and the behavior under winter conditions were also recorded. The research program was enlarged in a second phase and now also includes material properties such as aging of the binder, performance of the mix, and so forth. Results from the first phase of the research program are emphasized here.

TEST PAVEMENTS

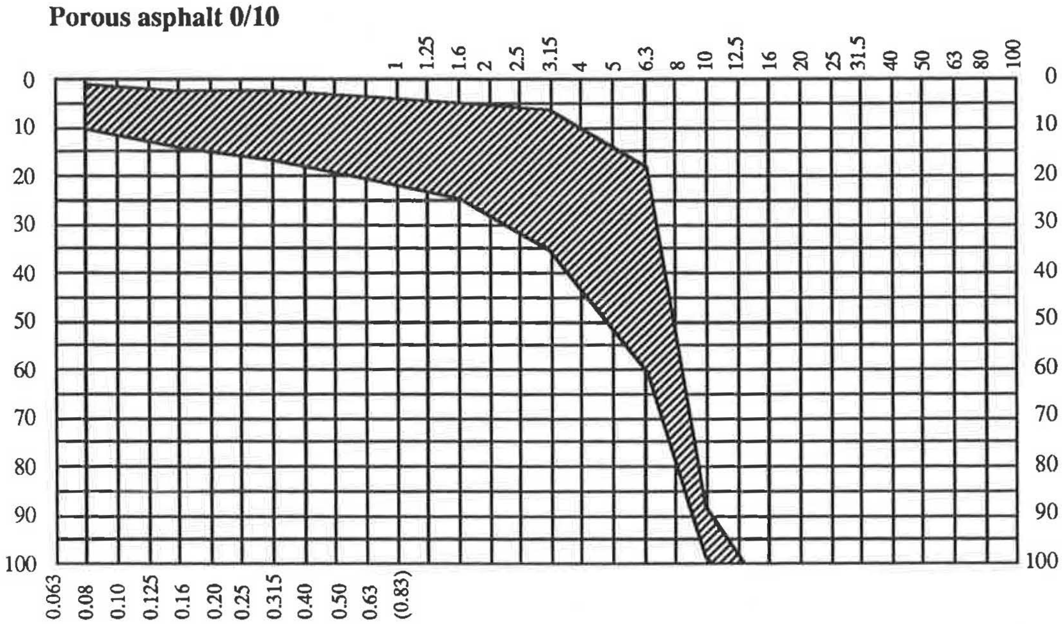
The research program now comprises 17 sections located on motorways, interurban, and urban roads with a section length between 150 m and 2.2 km. The oldest section was placed in 1979; the majority were constructed in 1985 and 1986. Reasons for choosing porous asphalt on these sections were general material testing, traffic safety, or traffic noise reduction. (A polymer-modified bitumen is generally used as a binder for the porous asphalt.) General data on the materials used are given in Figure 1 and as follows:

	Porous Asphalt (0/10)	*Porous Asphalt (0/16)*
Max. aggregate size (mm) (round sieve)	10	16
Layer thickness (mm)	28–42	43–50
Binder content (% by mass)	4.65–5.82	4.23–4.99
Void content (%) (Marshall specimens)	10.9–22.5	14.9–17.0
Void content (%) (cores)	14.6–21.1	14.6–19.6

SKID PROPERTIES

Test Procedures

Skidding properties were measured once or twice a year with the Skiddometer BV8. This skid trailer makes it possible to determine the coefficient of friction with either a locked wheel or a braked wheel (slip ratio of 14 percent, normally on a theoretical water film of 0.5 mm thickness). Measurements were carried out with the PIARC skid test tire of dimension 165 R15 with four longitudinal grooves. Tire pressure is 1.5 bar and tire load 3.5 kN. The initial conditions of each section were measured within two months of the opening to traffic, in any case before the first winter.



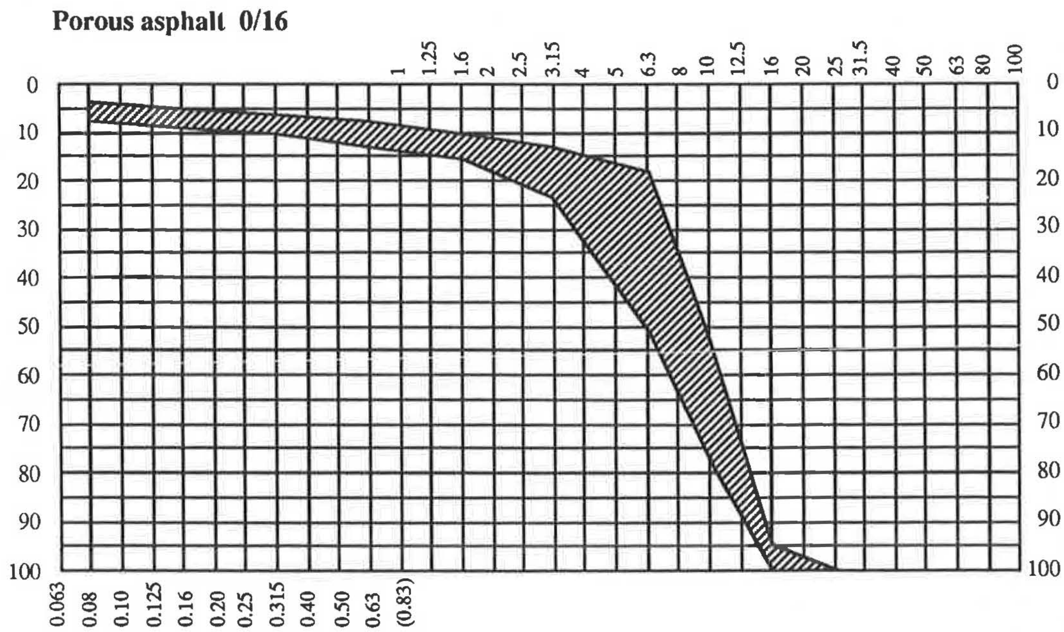


FIGURE 1 Gradation curves for porous asphalt (size in mm).

Other measurements of skid properties such as the SRT pendulum or the sand patch method were not considered suitable for this type of material. Also the Moore outflow meter (SN 640 510b) cannot be used for porous asphalt, where water outflow occurs through the pavement. Therefore, it is not possible to characterize of the pavement texture.

Results

Skidding properties of porous asphalt pavements (measured with the locked wheel) are usually in the range of values measured on conventional asphalt mixes. However, values for porous asphalt are hardly speed dependent. The curves in Figure 2 are flatter than the general shape of the frequency distribution used as the evaluation background. This means that porous asphalt has exceptionally good skidding properties at higher speeds where macro-texture is very important. At lower speeds, where micro-texture is more relevant, porous asphalt has, on the contrary, rather poorer skid properties than a conventional mix, as can also be seen in particular in Figure 3 with the results of the measurements with the braked wheel (slip ratio of 14 percent).

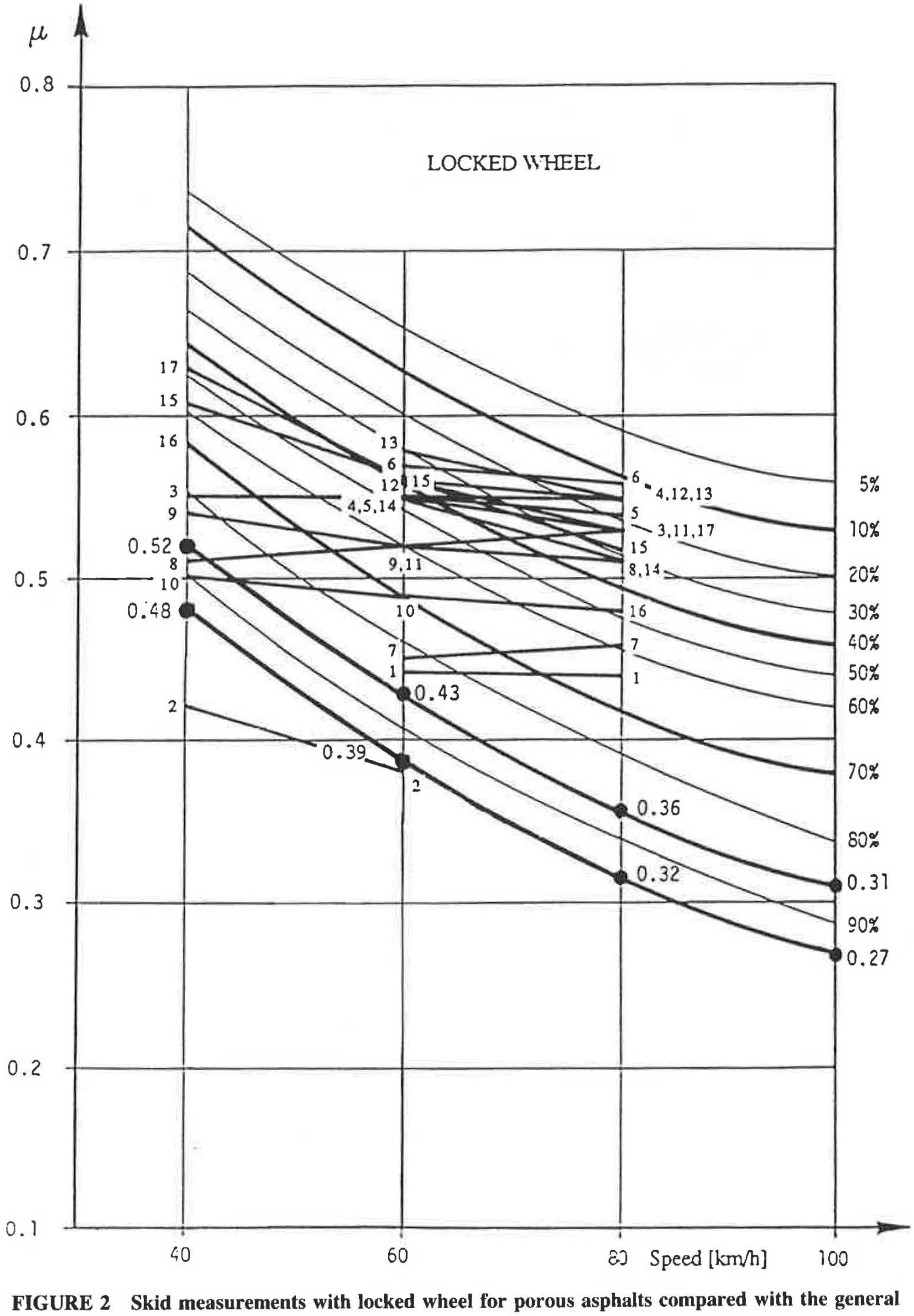


FIGURE 2 Skid measurements with locked wheel for porous asphalts compared with the general evaluation backround.

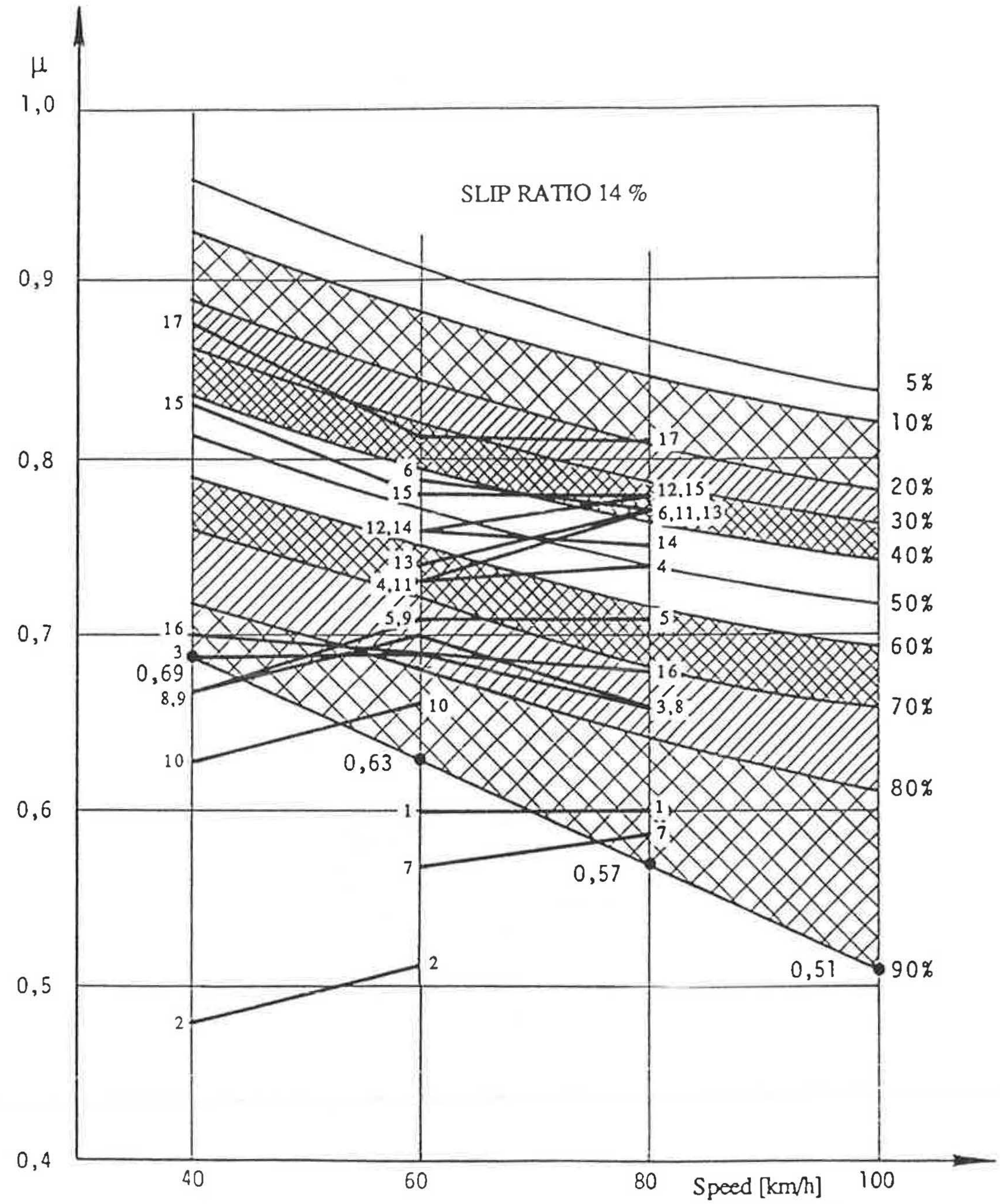


FIGURE 3 Skid measurements with braked wheel (14 percent slip ratio) for porous asphalts compared with the general evaluation background.

Skidding properties of porous asphalt in the initial stage after construction (Figure 4) are frequently lower than the values obtained on the same pavement after a certain usage time. This can best be seen in the results with the locked wheel, where skid values normally clearly increased after the first winter.

Skid Resistance: Conclusions

Skidding properties of porous asphalt are generally in the same range as conventional pavement mixes. Because of the high macro-texture, results for porous asphalt are generally above average at higher speed. However, a lack of microtexture can often be observed. This leads to lower skid values with the locked wheel at low speeds.

Because of the particular surface structure of porous asphalt, the aggregates used must meet more severe requirements. In particular, it is important for skid properties to use high quality aggregates with good resistance to polishing and with sharp edges. In fact, in the case of porous asphalt, all the contacts between tire and pavement occur on the single surface aggregates, which also by themselves alone contribute to the surface "sharpness." Normally good skid properties may be obtained

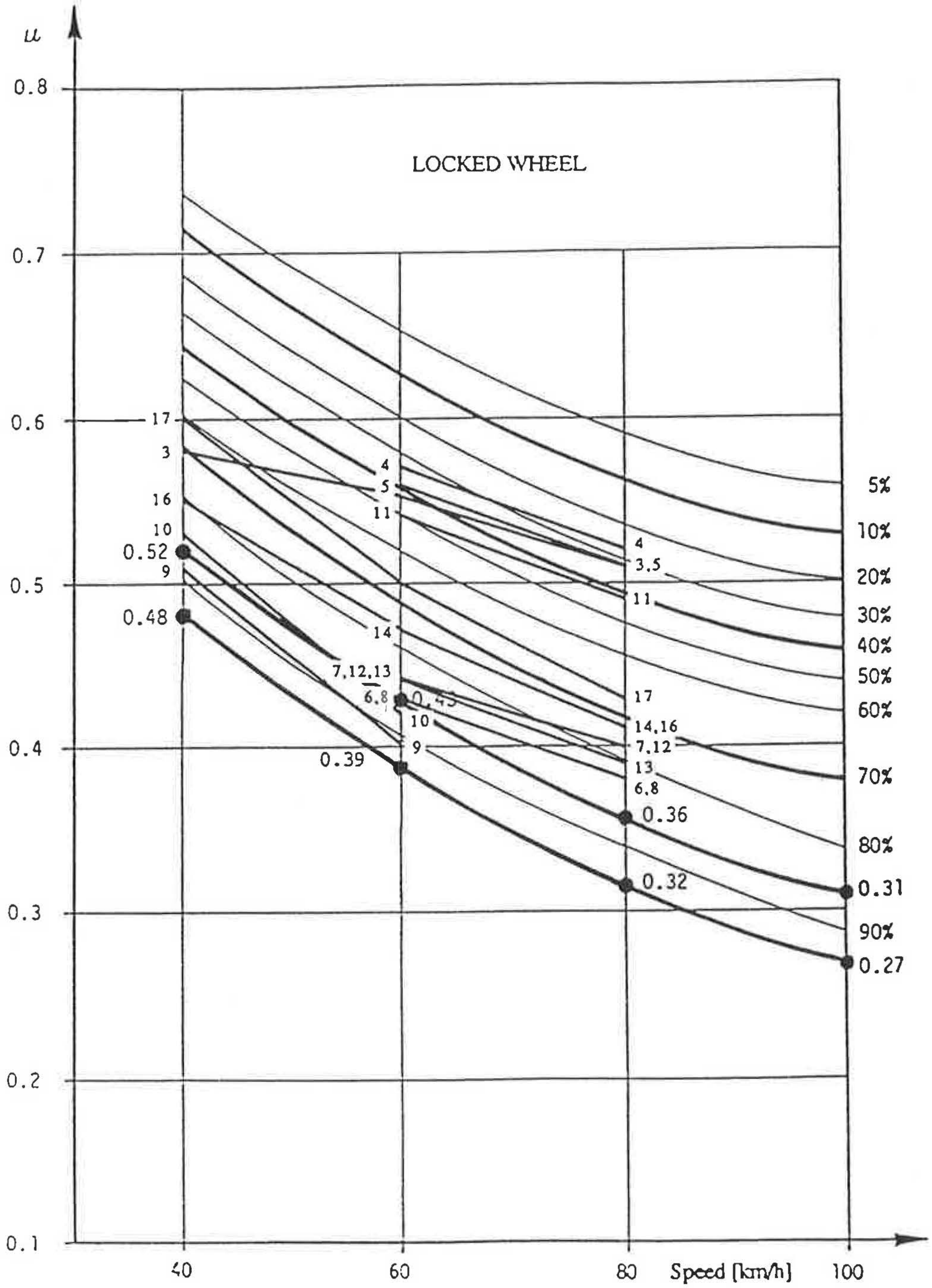


FIGURE 4 Initial skid values with locked wheel for porous asphalts compared with the general evaluation background.

with the available aggregates. However, the general shortcomings at lower speed must be considered when using porous asphalt in urban areas or in critical curves.

The occurrence of reduced skid properties shortly after construction is similar to the experience with conventional mixes. But with porous asphalt, there is a bigger problem because generally microtexture is poorer and normal repair methods (such as spreading of chippings) cannot be used. The situation improves after a certain time when the binder coating of the single surface aggregates has worn off.

PERMEABILITY

Permeability to water is one of the characteristic properties of porous asphalt. This is also the main difference with conventional asphalt mixes and the reason for the great advantages of porous asphalt (e.g., strong reduction in the risk of hydroplaning). New solutions had to be developed for measuring drainage potential. An objective methods to quantify this property is essential for evaluating these mixes.

Test Procedure

Within the research project, one of the first tasks involved the search for an appropriate methodology to measure permeability. Devices such as Moore's outflow meter could not be considered, as already mentioned. Other devices developed for this purpose were considered to be either insufficiently precise or too complicated for practical use. Therefore, the Institute chose to develop a new methodology which has now been used successfully in practice in Switzerland for about seven years.

The IVT permeameter shown in Figure 5, is made of a plexiglass cylinder with an interior diameter of 190 mm and a height of 250 mm. The cylinder has five engraved markings 20 mm apart from each other, with the "zero-marking" 120 mm above the bottom of the cylinder. A special putty is placed as a 30 mm wide ring on the pavement surface in order to cover the highest aggregates and fill voids at the surface. Thus the contact zone between the cylinder and the pavement is sealed, and the water is forced to flow through the interior voids of the porous asphalt layer. Permeability of the layer is expressed by the time elapsed between the 0 and the 80 mm line. This downward movement of the water surface corresponds to an outflow quantity of 2.27 L. In cases when the time needed to pass the 40 mm line is greater than 300 sec, the permeability and thus also the functional quality of the porous asphalt is considered to be insufficient.

This method, a "single point measurement," is a disadvantage, recognizing the inhomogeneity of the porous mixes. A sufficient number of measuring points must be considered for a good characterization of the layer. Three sampling areas were therefore selected on each section, and in each sampling area, two measurements were made in the wheel track and two others outside of it. In order to follow with precision the development of permeability, measurements were always repeated at the same spots. measured values for a water level decrease of 80 mm range between 10 sec for a very permeable mix to almost ∞ for a dense mix (conventional mix or a porous asphalt with filled voids). Measurements within the research

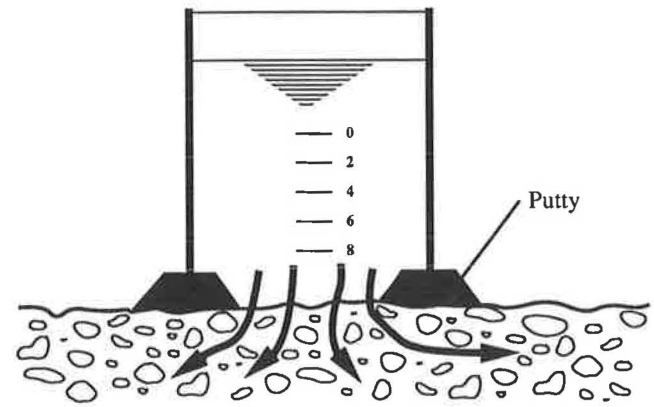


FIGURE 5 IVT permeameter (schematic, not to scale).

program had two purposes: to determine the permeability of new mixes and develop permeability with the increasing age of the porous asphalt.

Permeability of New Porous Asphalt Mixes

Initial permeability values for a water level decrease of 80 mm on new porous asphalt layers ranged between about 23 and 105 sec. These are the mean values for the different sections (determined on the sampling basis mentioned earlier). Single values can be outside of this range. The mean value for the initial permeability of all the observed pavements is 3.4 L/min, corresponding to an outflow time of about 40 sec. An influence of the maximum aggregate size on the initial permeability has not been observed with certainty.

Large differences can be observed not only between different mixes but also within the same section, already in an initial stage after construction. Standard deviations on the order of magnitude of 30 to 50 percent of the mean value are not rare, demonstrating the problems of getting good homogeneity during construction. Results from laboratory tests on material specimens (cores) also show this tendency. Under the assumption that a porous asphalt layer can be qualified as being homogeneous when the standard deviation of the permeability values is below 30 percent, about one half of the pavements observed fell in this category.

Development of Permeability

Permeability of porous asphalt layers decreases with higher or lower progression with the age of the mix (Figure 6). All kinds of dirt on the pavement and the consequent filling of the voids in the layer account for this progression. In single cases postcompaction of the layer can also lead to reduced permeability. Normally conditions remain better in the wheel tracks than in the center of a lane or on emergency lanes because of the "cleaning" suction effect of rolling tires. Therefore, postcompaction cannot be considered a major cause of reduced permeability.

The rate of reduction of permeability depends on a number of factors such as the environment, traffic loadings, type of mix, construction, and so forth. Some sections still show satisfactory values of permeability even after 5 years of traffic; others have become almost completely dense within 1 year

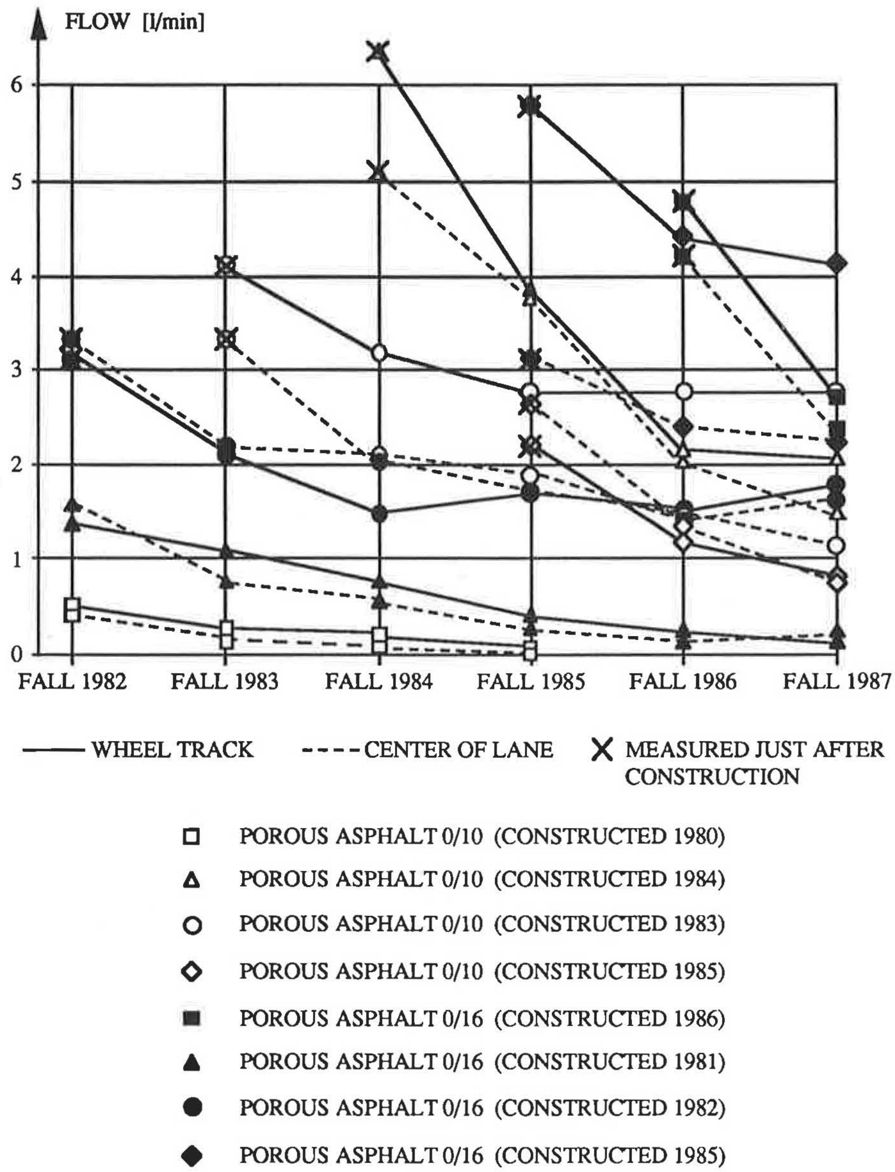


FIGURE 6 Development of permeability with time.

(Figure 6). Although just after construction no significant differences were measured for mixes with maximum aggregate sizes of 16 and 10 mm, those with 16 mm maximum aggregate generally show a much more favorable situation in the last series of measurements considered for this paper (fall 1987) than the mixes with 10 mm maximum aggregate. However, this result may not stem from the difference in maximum aggregate size but from generally more favorable service conditions for the sections having the 16 mm mixes (mostly on motorways).

Favorable conditions for maintaining a sufficient permeability are: reduced amount of dirt, good drainage (in particular, free water outflow at the edge of the layer and sufficient crossfall of the supporting layer), a layer structure with large voids and high void content, and finally the cleaning action of rapid and intense traffic. The use of porous asphalt layers on motorways can be seen very positively from the viewpoint of the developing permeability. On the contrary, more dirt and a reduced cleaning action by traffic are not favorable to an intense use of these materials in agricultural areas, nearby stone and aggregate pits, or urban areas. In the latter case generally, the influence of poorer drainage conditions for the layer must be considered. Porous asphalt overlays with a free edge usually are not recommended in urban areas for traffic safety reasons (cyclists and pedestrians). Ramps for lateral access also limit the lateral flow of the water from the porous layer. This leads, as experience shows, to deposits of dirt in the layer that tend to increase with time, which can considerably reduce the permeability of the layer.

Cleaning porous asphalt layers with filled voids could be very difficult if not completely impossible. First tests with water under high pressure and subsequent suction of the dirt have shown the capability of clearly cleaning the surface. However, permeability of the layer was not improved by this measure. Periodic cleaning of pavements with still sufficient permeability might have a positive influence on its development.

Effects of Permeability

The use of porous asphalt layers on motorway sections that had a concentration of hydroplaning accidents considerably reduced the number of accidents, even on sections deficient in surface drainage. Moreover, poorly drained porous asphalt layers can accumulate large quantities of water within the layer. Porous asphalt layers remain wet longer after rain than conventional, dense pavement layers because the water within the layer is pressured out by the tires. As long as the surface remains wet, this will also have an unfavorable influence on rolling tire noise.

Reducing permeability, except with very heavy rain, generally will have less influence on traffic safety than on the acoustical properties of the porous asphalt layer. In fact, a porous asphalt layer with filled voids can also be considered to be favorable from the viewpoint of safety on a wet surface because of its high macrotexture, if skidding properties are satisfactory. However, acoustical properties of these coarse, but unpermeable mixes are usually no longer positive, because the surface is no longer capable of noise absorption.

TRAFFIC NOISE

Methodology for Measurement

A 1986 environmental law fixed limit values for noise emission in order to reduce the nuisance to the population based on the general principle that noise should be reduced at the source. In view of this law, there is great interest in porous asphalt, because traffic noise derives from engine noise and, at higher speeds, from rolling tire noise.

For evaluating road pavements, three different measurement methods can be adopted:

- Measurement of rolling tire noise with a special trailer (LMA),
- Measurement with a microphone at the roadside (coasting or traffic noise) or sound level L_{eq}, and
- Measurement of the absorption qualities of a pavement surface.

Measurements on fixed facilities, such as the drums used for tire testing, are not suitable for investigating pavement surfaces under realistic conditions. Because the problem is complex, the three methodologies just mentioned have been used in this research project. The following values have been used to characterize the noise:

- Degree of reflection: the amount of sound reflected by the pavement surface and the quantity of sound absorbed by the pavement respectively,
- LMA-value: determinant of rolling tire noise level in the noise-measuring trailer LMA,
- Coasting noise: maximum sound level of a passenger car rolling by with engine turned off,
- Traffic noise: maximum sound level of a passenger car passing at constant speed, and
- Traffic noise (L_{eq}): the energy-equivalent continuous sound level for total "normal" traffic (including trucks).

Measurement of Absorption

Measurement of the absorption or reflection of sound can be done either in the laboratory on cores or other suitable samples with the impedance tube, or in the field with special instrumentation. The principle is the measurement of a known emitted sound and the sound signal reflected by the pavement. The degree of reflection of sound is determined by comparing the signals; it is then possible to calculate die absorption (1 − degree of reflection). Conventional, dense-graded asphalt pavements are very hard and lead to almost total noise reflection. Porous asphalt layers, however, can absorb part of the sound. A porous asphalt layer in good functional condition can therefore reduce the nuisance deriving from traffic noise. Because it can be assumed that the absorption potential depends on the permeability of a porous asphalt, the IVT permeameter was also used in conjunction with all noise measurements. The program of measurements was carried out only on select pavements, because the primary purpose was only to study general relationships.

The study of absorption characteristics has shown porous asphalt pavements in good functional condition capable to absorb sound. Figure 7 shows some typical curves for different pavement materials. However, on the basis of acoustical theory, high absorption effects are not expected for the layer thickness (30 to 50 mm) used today for porous asphalt. The lowest mean reflection value measured in this study was 0.79 (corresponding to an absorption factor of 0.21). This means that a maximum of about 20 percent of the sound was absorbed.

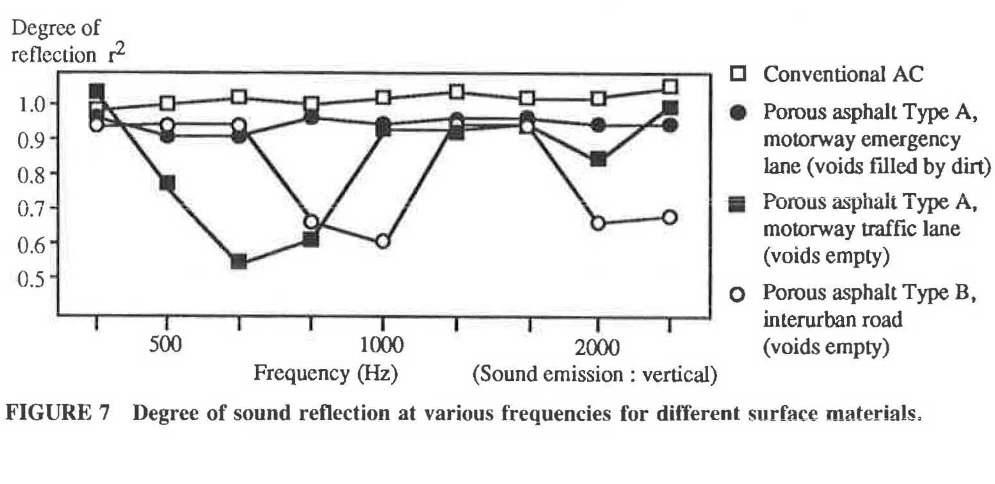


FIGURE 7 Degree of sound reflection at various frequencies for different surface materials.

Analyzing some parts of the spectrum of frequencies, one can find absorption factors of up to about 40 percent.

A correlation between reflection and absorption has been determined (Figure 8). (Figure was based on 21 pairs of values for 4 porous asphalt sections. Permeability was determined by IVT permeameter. Measurement was of the degree of reflection on the road. Mean value of reflection values in the octave volumes 500 Hz, 1,000 Hz, and 2,000 Hz. Sound absorption, $\alpha = 1 - r^2$.) In order to obtain a noticeable absorption of at least 10 percent, permeability should not be above 130 to 140 seconds, or the flow value not below 1 L/min. Mean flow quantities for many of the sections with porous asphalt are below this limit.

Rolling Tire Noise Measurement with the Measurement Trailer LMA

The trailer for noise measurement (LMA) has been developed and built by the Institute based on a scheme adopted by the Technical University of Stuttgart. It is a one-wheel trailer meant to determine the rolling noise of tires on different road surfaces at different speeds. Two microphones are used to register the sound immediately adjacent to the wheel. The body is fitted with sound insulation that prevents almost any outside influence. Therefore it is possible to obtain a precision of ±1 dB on homogeneous surfaces and without larger disturbing effects from the outside.

The two microphones register two parts of the noise creation and diffusion mechanism. A laterally placed microphone registers sound emitted from the tire side due to the vibrations of the rolling wheel. A microphone on the rear side of the tire is used to determine the sound-increasing influence of the "funnel-effect" between tire and surface or the absence of this effect on porous asphalt surfaces. The mean value from both microphones is used as the determinant value. Frequency analysis was carried out by the acoustics department of the Swiss Federal Laboratory for Testing of Materials (EMPA). The results are shown in Figure 9 and are discussed next.

Standard conditions of measurement include the use of the European PIARC test tire 165 R15 with 4 longitudinal grooves, which is normally used for skid testing. Earlier comparisons of different tires have shown that the PIARC tire is in the same range as modern standard production tires as far as rolling noise is concerned, but has the advantage that it best differentiates among road surfaces. The use of the noise measurement trailer has proven to be a simple method, which under normal traffic conditions precludes disturbances from other noise sources. This method is therefore particularly well suited for comparing pavement surfaces.

The use of two microphones in the trailer allows differentiating between sound propagation from the tire and from the texture of the pavement surface. Values measured from the recordings on the rear microphone are usually greater than for the lateral position on conventional, dense asphalts because of the "funnel effect." In the case of porous asphalt, both recordings lead generally to the same values and in certain cases the higher value is even recorded for the lateral microphone, because of the high absorption behind the tire. The lateral microphone is not influenced by the absorption characteristics of the surface and, moreover, the coarse surface may even increase lateral reflection.

For porous asphalt layers in good functional condition, values recorded on the rear microphone are lower than for conventional pavement surface layers at speeds above 50 to 60 km/hr. The difference increases with higher speed. At speeds below 60 km/hr, it is possible to measure the same level of rolling noise at the rear microphone for certain "acoustically favorable" conventional materials.

Values obtained from the lateral microphone for porous asphalt are in the range of values obtained with other surfacings. This could happen because of the generally coarse

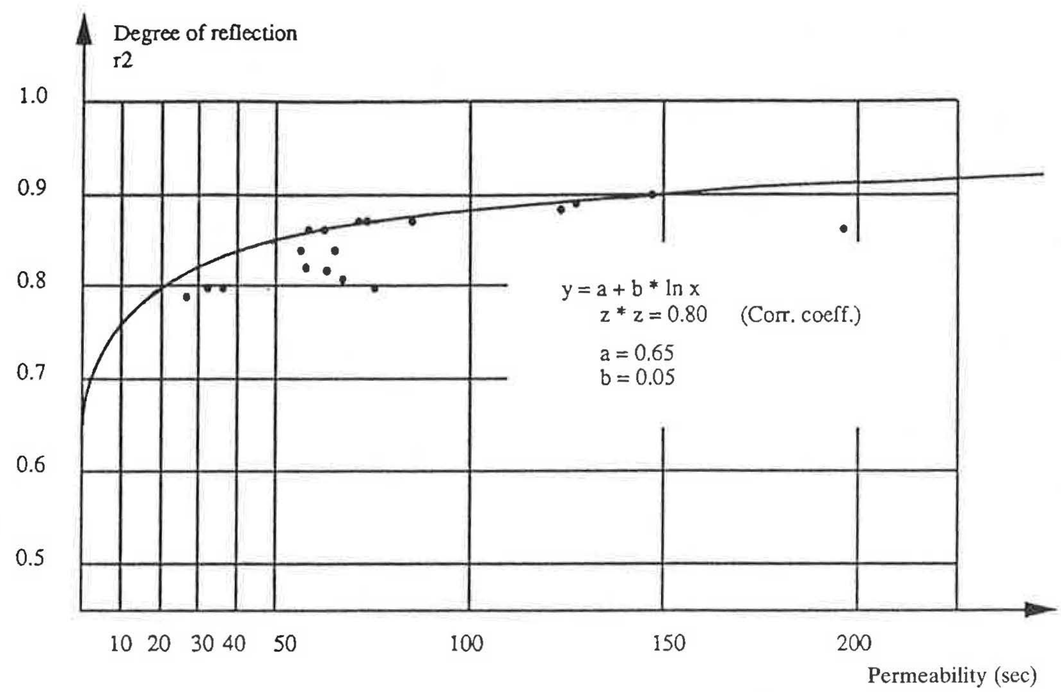


FIGURE 8 Relation between permeability and degree of sound reflection.

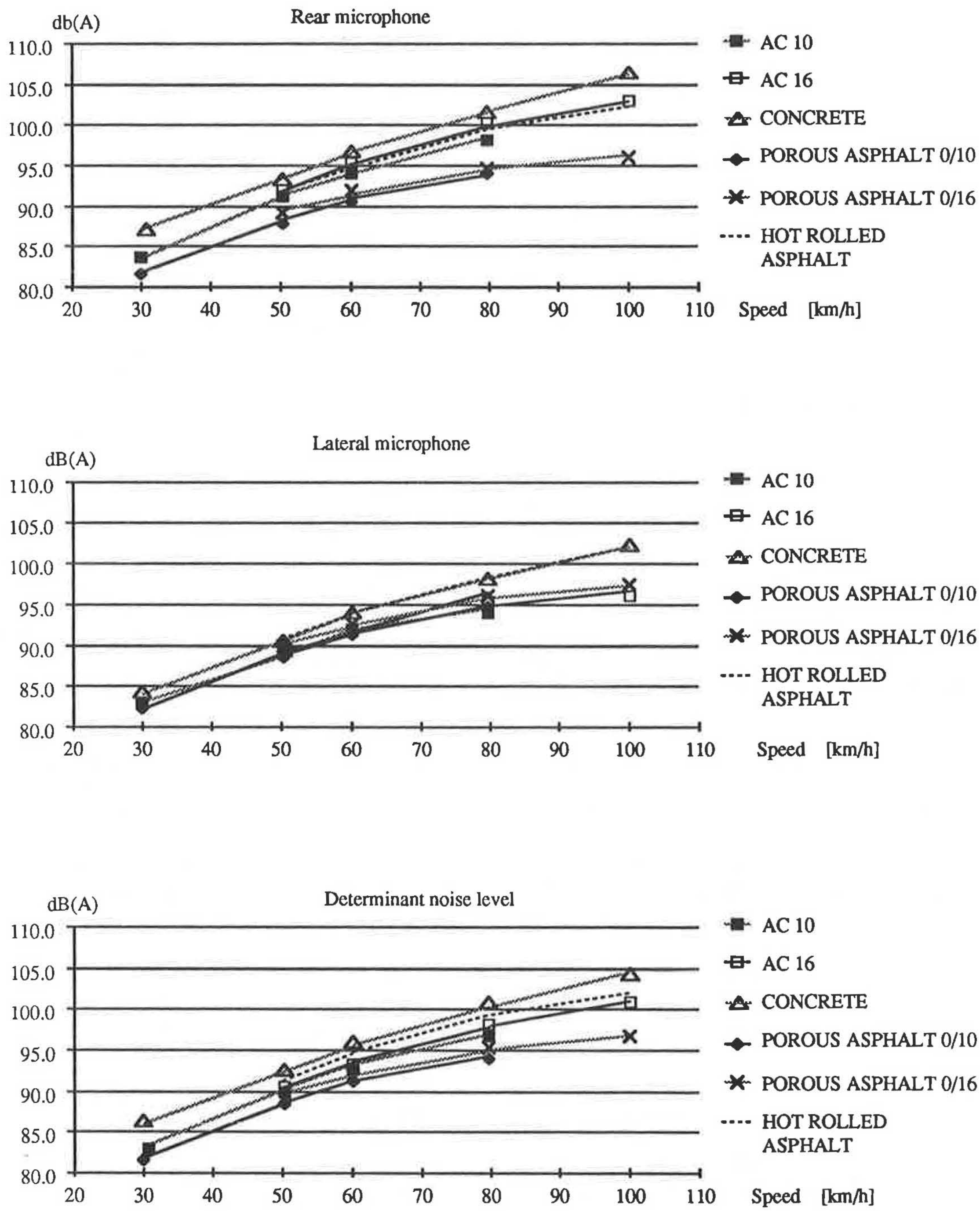


FIGURE 9 Mean values for rolling tire noise (LMA trailer) for selected pavement surfaces.

texture of porous asphalts used in Switzerland. The "acoustical optimization" or a porous asphalt leads to a finer texture of the surface.

The determinant LMA value gives an overall characterization of acoustical conditions. The difference in sound level for the porous asphalt with the lowest value and the corresponding conventional surface depends on the speed. Based on the results obtained so far, this difference is 1.5 dB(A) at 50 km/hr, 3.5 dB(A) at 60 km/hr, and 5.0 dB(A) at 80 km/hr. This shows that a reduction of rolling noise by the use of porous asphalt can be obtained primarily at a higher speed level. Similar results should be obtained in the comparison between porous asphalt and conventional materials when the mean values of rolling noise are considered.

A low noise level is not necessarily typical for all porous asphalts. The difference in noise level between all sections lies between 7 and 9 dB(A), a value corresponding to the difference between porous asphalts and dense-graded layers. A binder film at the surface seems to have a noise-reducing effect. Indeed, also on dense-graded asphalts, noise measurements carried out immediately after construction of the pavement had lower noise levels than for the same pavement at

a later time. No influence was found in relation to the material (concrete or asphalt) of the pavement layer beneath the porous asphalt.

The noise level is influenced by aggregate size, size distribution, permeability, and the condition of the layer. Porous asphalts with smaller maximum aggregate size or a more continuous gradation have a lower noise level than coarse porous asphalt layers. Permeability also has a positive effect on the noise. However, the influence of texture seems to be more important because some pavements in the study still had low noise levels despite having filled voids and very reduced permeability. This again is particularly true for fine-textured porous asphalts, whereas coarse layers are generally noisy when their voids have been filled completely with dirt.

The observation that some porous asphalts still exhibit low noise volumes, even when the voids are filled, leads to the conclusion that the comparatively low noise level, of fine-textured porous asphalt layers in particular, is caused by a reduced rolling noise emission rather than the absorption effect of the pavement surface. Therefore, it should be possible, in attempting to achieve an "acoustical optimization" of conventional pavement surface layers, to obtain equal or even better rolling noise values than with porous asphalts, in particular when their permeability is reduced. A dense asphalt layer with a surface similar to that of a fine-textured porous asphalt therefore should perform quite will in respect to rolling tire noise.

Measurements with Roadside Microphone

Measurements with a roadside microphone were used to directly determine the effects of the construction of a porous asphalt on the noise nuisance at the roadside and to verify a possible relationship between values measured with the noise trailer LMA and roadside noise levels. This type of measurement involves considerable effort and gives valid results only in an acoustically appropriate environment (including traffic conditions). Therefore, such measurements were conducted only on selected sections.

Measurements would usually be carried out in the zone of a change in pavement type. A microphone was installed at a distance of about 30 m on both sides of the surface change at a distance of 6 m from the road edge and at a height of 1.7 m. Normally, the traffic noise of individual passenger cars driving at constant speed was measured and also the general traffic noise (L_{eq}). The value for traffic noise of individual cars was determined taking the mean value of 60 to 80 recordings of cars driving by at constant speed. Traffic noise, L_{eq} was determined from a number of short-time recordings of the total traffic (including trucks).

For traffic noise (maximum value) of individual cars, a level reduction between 1 and 5 dB(A) was measured for porous asphalt in good functional condition compared to conventional, dense layers. The magnitude of the reduction depends on the acoustical properties of the porous asphalt and the compared material. Traffic noise levels L_{eq} could be reduced with a porous asphalt in good functional condition between 0 and 3.5 dB(A) compared to the conventional material, depending on the type of porous asphalt, the compared material, and the traffic. In the case of two "before and after" comparisons with a microphone at a longer distance from the road edge (25 m, 75 m, and 140 m) on roads which previously had a concrete pavement traffic noise (L_{eq}), reductions of 3 to 5 dB(A) have been measured. But on older, coarse porous asphalts with filled voids, too, the noise values measured were higher than on the adjacent, conventional surface.

Noise Frequencies

Besides generally reducing noise level, porous asphalt often can also lead to a reduction of particularly disturbing higher sound frequencies. The remaining noise is then comparatively acceptable to human perception. For this reason, it has been possible to register positive reactions from road neighbors, even if the measurable difference in noise level would not justify such a reaction.

Traffic Noise: Conclusions

The noise-reducing effect of porous asphalt results from the following factors:

- Lower rolling noise at the source, particularly on fine-textured surfaces and at higher speeds,
- Absorption effect of the pavement surface. However, the absorption effect is rather limited on today's thin porous asphalt layers. In addition, this quality is not permanent because porous asphalts with a reduced or disturbed permeability show few or no signs of absorption, and
- "Pleasant" noise from a change in frequencies stemming from a rolling noise of lower sound frequency and the absorption "cutting off" higher frequencies.

Porous asphalts in good functional condition can potentially reduce the traffic noise level (L_{eq}) by 0 to 4 dB(A), compared to dense-graded asphalt layers and by 3 to 7 dB(A) compared to old concrete pavements. Porous asphalts with fine-textured surface generally are acoustically more favorable than coarse-graded ones.

Regarding the relatively low reduction in rolling noise compared to the more "silent" characteristics of the conventional dense-graded layers and the fact that the absorption effect is often limited in time, it would not seem appropriate generally to consider porous asphalt as the real alternative to other noise-reducing means such as noise barriers (walls) or sound-insulated windows, and so forth. This is particularly true in urban areas, where direct accumulation and the drainability of porous asphalt layers are a more serious problem and where engine noise is generally more relevant than rolling tire noise.

BEHAVIOR UNDER WINTER CONDITIONS

Problem Description

Despite the advantages mentioned so far, generally unfavorable behavior under winter road conditions is said to be a major disadvantage of porous asphalt. To investigate this problem in more detail, it was decided to run a series of skid

measurements with the Skiddometer under winter road conditions on some sections, in addition to visual inspections and contacts with the road maintenance departments. Measurements were carried out with the test wheel brake only (slip ratio of 14 percent at a speed of 60 km/hr on motorways and of 40 km/hr on other roads). This choice was made because of very inhomogenous road surface conditions on one side and of the possible formation of a snow or slush wedge in front of a blocked wheel. The purpose of these measurements was to determine relative values as the basis for comparing porous asphalt and other surface materials. More than 160 measurement runs were made under winter road conditions in the winters 1981 to 1982, 1983 to 1984, 1984 to 1985, and 1985 to 1986.

Results of Skid Resistance Measurements for Winter Road Conditions

Road conditions in winter are very variable and can change rapidly with time. Therefore the results of skid measurements also show a large degree of variation. Generally, it can be said that skid values on porous asphalt are in the same range as those measured on conventional, dense asphalt layers. In the winters 1981 to 1982 and 1984 to 1985, porous asphalts were rather better, and in the winters 1983 to 1984 and 1985 to 1986, rather below compared materials, but this depended on the situation at the moment the measurements were carried out (Table 1).

It also was found that the influence of other factors is generally more important than the type of pavement surface. Such other factor are microclimate, side vegetation, wind exposure, width of the roadway, and so forth. In comparing different sections under winter road conditions, differences concerning the factors mentioned above must be considered. It also was observed that porous asphalt with filled voids and a permeability of less than 1 L/min behaved in almost the same manner as conventional, dense asphalt layers with similar surface texture. Differences in the behavior of porous asphalt show up mainly on heavily trafficked roads in areas not directly covered by traffic (center of a lane, center, and edges of the road).

Winter Conditions: Conclusions

Porous asphalt surfaces generally do not behave worse than conventional pavement materials under winter road conditions. The differences in behavior could, in areas of the change of surface material, lead to increased traffic hazards due to inhomogeneity. However, it should not be forgotten that road surface conditions are very inhomogeneous in winter. Their variability depends strongly on time and location (shaded areas, altitude, wind, winter maintenance, etc.). Variations in skid values for porous asphalt layers lie overall within the variations observed for conventional pavement materials.

The main differences in behavior of porous asphalt under winter road conditions can be summarized as follows:

- Advantages of porous asphalt: Ice formation on a wet surface is generally prevented because of good surface drainage and a good macrotexture. This good macrotexture is also an advantage for porous asphalt on snow and slush. The tendency for ice formation in the wheel tracks on roads covered with snow is reduced again by macrotexture, water absorption within the layer, and limited thaw.
- Disadvantages of porous asphalt: Winter maintenance on porous asphalt surfaces requires the use of deicing salts and other thawing products. The use of sand and small aggregates is not possible because of the negative effect on the void structure. Snow has a tendency to stick sooner on a porous asphalt surface because of its generally colder surface (about 0.5°C). Snow and icing rain can also form earlier on porous asphalts because deicing salts do not remain on the surface. Preventive salting does not make great sense, because the salt sinks into the voids or is blown away. If the drainage within the porous asphalt layer is bad, ice can build up within the layer and expand later on the surface. In this case, preventive salting may be appropriate. The absence of a salt solution on the surface outside the wheel tracks can also keep the snow on the surface longer. With reduced traffic and winter maintenance, this problem can also appear in the wheel tracks. It also has been observed that some icing problems can occur in the initial part of the following road section with a conventional surface, which does not receive salt, by transportation through road traffic from the preceding porous asphalt section.

TABLE 1 GENERAL DATA ON POROUS ASPHALTS IN SWITZERLAND

	1981/82	1983/84	1984/85	1985/86	
AC 1	0.67	0.57	0.36	0.58	
Porous asphalt 1	0.62	0.48	0.48	0.58	voids filled
Surface treatment	0.63	0.64	0.58	0.65	since 1984/85
Hot rolled asphalt			0.51	0.61	
Porous asphalt 2			0.52	0.54	
AC 2			0.51	0.57	
Mean value	0.63	0.56	0.49	0.59	

Measurements carried out with braked wheel (slip ratio 14%), speed = 40 km/h

The disadvantages of porous asphalt in winter can be controlled by intensive winter maintenance. The reduced effect of salting porous asphalt surfaces must be compensated by more intensive salting. Critical times are the beginning of snowfall and, in certain cases, the thaw period.

SUMMARY AND CONCLUSIONS

The experiences so far with porous asphalt layers on motorways and similar roads can be qualified as good. Their excellent quality in surface drainage reduces the risk of hydroplaning and sight-disturbing spray. Porous asphalt layers can also be used for dealing with drainage deficiencies in zones of change in crossfall, even if this use of porous asphalt is not optimal in view of the accumulation of water within the pavement and its consequences for the qualities of the layer. Skid properties of porous asphalt are adequate for motorway requirements.

On motorways, too, the durability of a good permeability can be expected. Drainage at the edges of the layer normally does not cause any problems and winter maintenance can be controlled. At higher speeds, traffic noise is also significantly reduced and the remaining noise is experienced as more pleasant.

Results are not quite so positive in urban areas. Major problems are the drainage of the layer at the edge and frequently a rapid reduction in permeability. Skid properties of porous asphalt are often inadequate for the needs of urban traffic. The use of deicing salts, generally tending to be used increasingly less often in residential areas, is imperative for porous asphalt. Pavement repair work, frequently in conjunction with the utility work in the roadway, is also a specific problem for urban conditions. At lower speeds, the measurable effects in noise reduction are well below certain expectations. And many porous asphalts soon lose their noise advantage with decreasing permeability. At lower traffic speeds, then, porous asphalts are not different from conventional pavement materials. Thus, the noise problem in urban areas generally cannot be solved with the use of porous asphalt. Rather, this problem might be solved by developments in vehicle technology, traffic management, passive means of noise protection, and eventually by the development of new noise-reducing road surfaces.

Advantages and Disadvantages of Porous Asphalt

Advantages

- Reduction of hydroplaning on motorways,
- Spray reduction generally, particularly on motorways,
- Good skid properties at higher speeds on motorways,
- Noise reduction, generally, particularly on motorways,
- Reduced glare at night and on wet surfaces generally, and
- Good resistance to permanent deformation generally, particularly on motorways.

Disadvantages

- Poor durability of good qualities by loss of permeability, generally, particularly in urban areas,
- Unknown durability (oldest porous asphalts of the new generation only 5 to 6 years old) generally, particularly on motorways,
- Special requirements for (lateral) drainage in urban areas,
- Unfavorable skid properties at low speed in urban areas,
- Different behavior for winter road conditions, use of salt, generally, particularly in urban areas,
- Repairs, utilities in urban areas, and
- Costs, particularly in urban areas (special drainage).

Before using porous asphalt layers on a large scale, some open questions should be answered. The principal problem is durability; others include quality requirements and control, the study of possible ways to improve the development of permeability, and more experiences are needed. Research on the acoustic properties of road surfaces should also be intensified. In the future, it might be useful to differentiate between porous asphalts used as a safe surface with good drainage on the one hand and those used as noise-reducing surfaces on the other hand. In this second group, porous asphalts are not necessarily the only surface. Optimal texture can already reduce rolling tire noise; in addition, a porous structure can also produce a sound absorption effect. Today's porous asphalts are not yet satisfactory for urban situations. The use of porous asphalts is very interesting on motorways and other roads with constant, fast traffic and little dirt accumulation, where they improve traffic safety and also contribute to reducing traffic noise.