DOCUMENTATION SUR LES MELANGES OUVERTS DRAINANTS (OFC)

Gouvernement du Québec
Ministère des Transports
Direction générale du génie
Direction des sols et matériaux

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Documentation sur les mélanges ouverts drainants (OFC)

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Extraits du compte rendu de Richard Langlois
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Selon le Texas, une couche d'usure antidérapante à granulométrie ouverte (Open-Graded Friction Course) doit avoir 8 à 10% passant le 2 mm, 2 à 3% passant le 80 µm et un vide d'environ 15%. Pour évaluer les caractéristiques de surface de l'OFC l'essai au sable n'est pas valable, c'est l'essai du mastic (putty) qui est le meilleur. L'OFC est très antidérapant à toute vitesse à condition qu'il ne soit pas recouvert d'eau car alors il devient glissant s'il est recouvert de 1.8 mm d'eau et plus. L'ajout de silicone aide à placer ce genre de mélange. La vie normale d'un OFC est de 6 à 12 ans selon le trafic (100 à 200 millions de passages).

La Californie utilise les OFC depuis 40 ans. On ne peut poser un OFC sur un vieil OFC, il faut l'enlever par fraisage à froid avant. C'est un grade plus dur de bitume qui est utilisé pour les OFC par rapport aux mélanges denses. La grosseur maximale de la pierre est de 12.5 mm, le maximum passant le 80 µm est le 3% et ce revêtement ne se pose jamais à des températures inférieures à 21 ^{o}C.

Quant à la Georgie, elle a posé plus de 3000 Km de OFC depuis 1970. En 1982, elle a débuté l'ajout de chaux hydratée pour empêcher le désenrobage. Le taux de pose utilisé est de 33 Kg/m^2.

Le Nouveau-Mexique utilise les OFC depuis la fin des années 50. La granulométrie est de 90 à 100% passant le 10 mm, 0 à 10% passant le 2 mm. La température du mélange est en moyenne $115^{\circ}C$ et se pose jamais à une température ambiante inférieure à $15^{\circ}C$. Pour empêcher l'arrachement, il est préférable d'utiliser un bitume polymère comme le Styrelf.

Le Michigan pose des OFC depuis 1973 au taux de 55 Kg/m^2.

Le Montana en pose depuis 1975 (encore en service) avec la granulométrie suivante: 10 µm - 100%, 5 µm - 30 à 40%, 2.25 µm -5 à 15%, 80 µm - 2 à 5% passant. La chaux hydratée est incorporée et un liant d'accrochage est utilisé.

L'Ontario en pose depuis 1976 et a remarqué une diminution des accidents sous la pluie de 40%.

B

USE OF FRICTION COURSE MIXES
IN
ONTARIO

by

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ABSTRACT

The dramatic increase in the volume and speed of automotive vehicles in the 50s and 60s in Ontario resulted in the need for safer and better quality highways. The increased traffic also created rapid deterioration of frictional and durability characteristics of the road system that was originally designed for lighter traffic. The need to up-grade the urban freeways and to rehabilitate other highways lead to the development of the friction course mixes.

In the process of formulating policy for safer and better quality highways, in 1974 a major installation of 18 test sections of bituminous overlays on one of the heaviest trafficked roads in Ontario was undertaken, and a task force was also set up to review the performance of friction course as well as to make recommendations on their use.

This paper outlines the developments leading to the adoption of a policy of using friction course mixes in Ontario. It discusses the design, construction and results of the experimental sections and the findings of the task force on friction course mixes. The experience gained and the annual program of friction courses are also discussed.

One important finding of the experiment is that the most effective way to improve the level of friction on a wearing course is by using harsh, angular fine aggregates such as traprock or slag screenings and a sufficient proportion of crushed good quality coarse aggregate in the bituminous mixes to maintain the micro- and macrotexture of a surface. These characteristics can best be provided by Open Friction Course (OFC) and Dense Friction Course (DFC) mixtures.

Friction courses are accepted by the Ontario Ministry of Transportation and Communications as the most suitable surface course mixtures for freeways and accident "black-spots". The steady volume of friction course mixes each year verifies this commitment.

CONTENTS

1. INTRODUCTION

The advances in the automobile technology in the 50's resulted in the need for safer and better riding quality roads to accommodate for the high speed transportation. The dramatic increase in the volume of traffic on the roads that was brought about by the increase in the post-war ownership of automobiles and the change to the surface transportation of goods and commodities by trucking contributed to greater challange for the highway engineer to construct and maintain better highways.

Such need was clearly felt on a major multi-lane urban commuter freeway in metropolitan Toronto - the Hwy. 401 Toronto By-pass. The rehabilitation and upgrading of this section of freeway opened up the search for better techniques to improve the driving qualities, as well as for a hot mix resurfacing system that will produce a long wearing surface with good friction properties which will withstand the high volumes of traffic.

This paper outlines the developments leading to the use of open friction course (OFC) and dense friction course (DFC) involving a major installation of 18 test sections, and the findings of a task force on the performance of these friction courses. In addition, the annual OFC and DFC program and the rehabilitation techniques are discussed.

2. BACKGROUND

The implementation of the use of OFC and DFC was sparked by the need to rehabilitate Hwy. 401. Planned, constructed and reconstructed in stages over the past 40 years, Hwy. 401 (Fig. 1), or The MacDonald-Cartier Freeway as it is also called, has become the main artery across Southern Ontario. It runs from the Ontario-Quebec boundary on the east to the Ontario-Michigan boundary on the west, for a total distance of 820 km (510 miles). Commencing in 1947 sections of this major route were constructed to by-pass major centres. In its 50+ km (30 miles.) path through Metropolitan Toronto it combines with Hyw. 427 to become the main commuter east-west route serving a population of three million people. The AADT (average annual daily traffic) for the busiest location is 238,400, with 1800 vehicles per lane, per hour at peak periods over several sections.

2.1 Construction of Hwy. 401 into an Urban Freeway

In the vicinity of Toronto, Hwy. 401 was first constructed as a four-lane divided rural freeway through largely agricultural land. Construction began in 1952, and by 1958 the basic four lane divided controlled-access highway was completed. It was built as a conventional flexible pavement with gravel shoulders, core type construction and a wide depressed median.

By 1960 the by-pass was being taxed beyond capacity due to the fact that, within a relatively short period of time after completion, numerous residential sub-divisions and industrial areas were constructed adjacent to the freeway which resulted in a major increase in car and traffic volume (Table 1).

The reconstruction of the original facility to a multi-lane, urban commuter, concrete pavement in the vicinity of Toronto took place between 1963 and 1973 when the original four lane asphalt pavement was widened to a twelve lane system of collector and express lanes. Concrete pavement was chosen for the highway since it was assumed to have the best potential for providing a long service life under the anticipated heavy traffic conditions.

2.2 Performance of the Concrete Pavement

It was originally expected that the Portland cement concrete pavement would be maintenance free for 25 years. However, within less than 10 years of construction it was evident that rehabilitation would be required sooner than expected because of emerging problems. The main and earliest problem to develop was the marked increase in the multi car wet weather accident rate. The Ministry tried grooving the existing concrete pavements to improve the frictional properties. That technique, although somewhat effective for a while, created excessive tire noise which was unacceptable to both the driving public and nearby residents. Problems were also encountered with the performance of the joints and transverse cracking began to show up between the, joints and spalled areas of varying depth developed at quite a number of joints and cracks.

During the ten year period after the construction of the first section of concrete pavement there was a marked increase in traffic volume over that anticipated as well as a dramatic increase in allowable truck weights and axle loadings (Table 1).

3. DEVELOPMENT OF POLICY FOR SURFACE COURSE MIXES

The low friction condition was created because of the original burlap drag and broom textured concrete pavement surface was severely polished by the heavy traffic and studded tires (banned after 1971). The texture depth was reduced to about one tenth of what is desirable. The friction value as determined by the ASTM Brake Force Trailer at 100 km/h (62 mph) varied between 19 and 22.

3.1 Bituminous Mix Test Sections

In an effort to determine the best rehabilitation methods for future programs to restore the driving qualities of the concrete pavement, the Ministry designed and placed 18 bituminous overlay test sections in 1974, involving the use of dense and open graded hot mixes, sand asphalt mixes and mastic mixes both with and without asbestos. The emphasis in the evaluation of the test sections was on long term frictional characteristics and improvement of the ride. The other consideration was that the rehabilitation method chosen should be of low cost. The following describes the main points of the experiment:

(a) Test Location and Traffic:
The location for the test sections was on the westbound core lane between Allen Expressway and Jane Street (Fig. 1). The traffic count had increased dramatically from 111,000 AADT in 1967 to 179,000 in 1974 and 260,600 in 1985. The percent truck traffic averaged about 17%.

(b) Layout of Test Sections:
The 18 test sections were placed each 137 m (448 ft.) long and 11.3 m (37 ft.) wide. Sections 1 to 10 and 17 were 38 mm (1-1/2 in.) thick overlays whereas Sections 11 to 16 were only 25 mm (1 in.) and Section 18 consisted of two lifts of 38 mm (1-1/2 in.) each.

(c) Mix Design and Composition:
Recognizing the fact that a surface with good frictional properties must possess sufficient microtexture or harshness (evaluated by PSV per ASTM D3319) and suitable macrotexture or stone projections (measured by ASTM E770 method, ref.1) , the mixtures were so designed to have various degree of micro- and macrotextures. The test sections included both dense and open graded types of mixes with a variety of coarse and fine aggregate types including traprock, steel slag and blast furnace slag (Table 2).

Test sections 1 to 10 consisted of HL-1 mixes in which the coarse aggregate content was progressively increased to obtain a greater macrotexture i.e. more stone particles at the surface (Fig. 2). The standard HL-1 mix is a dense graded mixture with good quality coarse aggregate (50% retained 4.75 mm sieve) and local fine aggregate. The modified HL-1 mixes tested are mixtures with good quality fine aggregate (i.e. DFC by definition), or a blend thereof, rather than only the local natural sand.

Mixes in Sections 11 and 12 were sand asphalt mixes using traprock screenings containing small percentages of coarse aggregates and asbestos fiber filler for greater flexibility and impermeability.

Sections 13 and 14 were open graded mixes designed to have high permeability (e.g. > 10^{-5} cm^2, test method ref. 6) characteristics that facilitate rapid drainage of surface water into, and laterally through the surface course layer, i.e. O.F.C. mixes. The mixes used a large proportion (67%) of single size coarse aggregate and a small amount of washed fine aggregate (Fig. 2).

Sections 15 and 16 were also considered as OFC mixes but with 30% coarse aggregate and washed fine aggregate as in mixes 13 and 14. Section 17 was a mix called "Mastiphalt" which is a kind of mastic asphalt derived from the German "Gussasphalt" technology and modified so that the material could be mixed and placed with conventional equipment.

(d) Construction:

Night paving was necessary due to the heavy traffic. The core lanes at the contract location were closed and traffic diverted to the collector lanes via a transfer lane. The construction was problem free, except that normal mixing time was extended for mixes with asbestos due to lumps of asbestos appearing in the mix.

(e) Frictional Performance of Test Sections:

The frictional characteristics were measured using the ASTM brake-force trailer. A previous report by Ryell et al(1) detailed the results obtained up to 1978. Since then, some sections had physically deteriorated to the degree that complete resurfacing of all the test sections was warranted in 1985. Prior to this work, a final evaluation was carried out on the sections and a report is being prepared on the evaluation of the performance of these test sections after 11 years of service. The up-dated results to 1985 (Fig. 3) are summarized below :

(i) HL-1 and Modified HL-1 Mixes - Sections 7 (Fig. 4) and 9, which are considered DFC mixes (i.e. consisting of steel slag or blast furnace slag coarse and fine aggregates respectively), had maintained a F.N. (friction number, formerly skid number) in excess of 31. In comparison, section 8 containing steel slag coarse aggregate and a

blend of natural sand and limestone screenings as the fine aggregate, and section 10 with similar fine aggregate and blast furnace slag coarse aggregate exhibited significantly lower F.N.. This fine aggregates had a similar effect on the frictional properties of the HL-1 mixes containing traprock coarse aggregate particularly in the driving lane (e.g. Section 3 versus 1).
Test Sections 3 and 6 that utilized traprock screenings as the fine aggregate have F.N. just on the 31 level.

(ii) Open Graded Mixes - Test Sections 13 and 14 had maintained the high F.N. with good macrotexture appearance (Fig. 5). However, Sections 15 and 16 containing a reduced proportion of coarse aggregate had a reasonable initial F.N. but the level had declined to below the 30 value. The interconnected voids in mixes 13 and 14 appeared very efficient in removing water away from the tire to road contact area and thus enhancing the frictional characteristics as well as reducing splash and spray in wet weather. However, these voids tend to clog up after 4 to 5 years of service but the permeability is still relatively higher than the other mixes (Table 4, see also sub-section g); it appears that the pumping action of the tires helps to clean out some of the debris.

(iii) Other Mixes - The two sand mixes (11 and 12) have maintained at the level of about F.N.= 30, but these mixes are considered not quite suitable for high speed traffic due to the lack of macrotexture on the surface; the lower initial F.N. value for section 12 is because of the higher AC content used (Table 2). The mastic mix (17) had a lowest initial friction value of all the test sections and after 3 years, the values are approaching 20.

(iv) Friction Number (FN) versus speed - Fig. 6 shows that the OFC (section 13) has less drop in the FN than all the mixes compared, especially the sand mix (section 11). It is clear that the two DFC mixes consisting of slag materials (sections 7 and 9) yield the highest FN of all the mixes altough they maintain a similar friction-speed gradient as the traprock DFC mix (section 3). The dense graded mixes (sections 1 and 4) and mastic asphalt (section 17) seem to have a similar FN-speed gradient as the DFC mixes. An increase in stone content by 10% (e.g. section 4 versus 1) of the same type of aggregate tends to reduce the FN-speed gradient. The graph clearly suggests that, while the FN-speed gradient is governed by the macrotexture, the level of FN achievable at a given speed is a function of the types of aggregate used which determines the level of microtexture available in a mix.

(v) General - Almost all the mixes provided substantially better friction characteristics than the existing concrete. The mixes seem to have reached their equilibrium friction level after two or three years of service (Figs. 3 and 7). Also mixes which have a high initial friction value tend to take longer to arrive at their equilibrium (e.g. sections 7,13,and 3 versus 1). In the driving lane carrying 3700 c.v. per day, the mixes that provide F.N. above the value of 30 are :

- dense graded mixes with both coarse and fine aggregates consisting of traprock, steel slag or blast furnace slag (named Dense Friction Course, DFC).
- open graded mixes using traprock coarse and fine aggregates with high stone contents (named Open Friction Course OFC).

(f) Durability:

The durability of the sections is compared by using the "overall rating" derived from multiplying the length or the area of the appropriate distresses by the weighing factors assigned for the severity and type of distress as outlined in the " Manual for Condition Rating of Flexible Pavements " (4). Table 3 shows that sections 1, 9 and 17 have an overall rating of 57, 54 and 58 respectively whereas the other sections have an overall rating of between 25 and 37. The friction course mixes (e.g. sections 3,7,9 and 13) performed well relative to the dense graded mixes, except the section 9 which consisted of all blast furnance slag aggregate. The deterioration of section 9 was in the form of ravelling and delamination. It is because of the highly absorptive nature of the blast furnance slag aggregate that absorbs the A.C. and reduces the effective A.C. available for holding the aggregate in place as well as for adhering the mat to the existing pavement surface. The transverse crackings were reflection crackings from the underlying concrete pavement.

(g) Permeability:

Permeability tests were performed on the driving lane wheel path of each test section using the John Manville outflow permeameter (1). However, at the 11th year, the wheel track matrix of all the sections was closed up to the extend that it required much longer time (>1 hr.) to obtain a water permeability reading. Hence, cores taken from the test sections were tested in the laboratory for permeability using the air permeability method as described in the ASTM D3637.

The results (Table 4) indicate that the OFC test section (13 and 14) had a very high initial permeability but the voids closed up after 7 years of traffic compaction, reducing the permeability to about 10 ml/min (and DFC to zero ,Fig. 8). However, the air permeability of the OFC at the 11th year on the driving lane is still relatively higher than the other mixes e.g. 10^{-8} cm versus < 10^{-9} cm respectively. In general,the lower air permeability in the driving lane confirms the believe that the traffic compaction in the driving lane wheel tracks is more than the passing lanes due to heavier traffic volume.

3.2 Policy on use of Friction Course Mixes

Based on the performance of these test mixes, a new Ministry policy was introduced in 1978 governing the selection of surface course mixes for main highway facilities. The new policy specifies the use of Open Friction Course (OFC) mixes as the surface layer for urban freeways and Dense Friction Course (DFC) mixes for other heavily trafficked main highways carrying traffic in excess of 5,000 AADT per lane. The DFC mixes are also used in accident " black-spots " with lower traffic volumes. Other factors to be considered are:

-projected traffic volumes
-type and percentage of trucks -accident rate
-highway classification

Special provisions were drawn up for both the OFC (SP 311) and DFC (SP 321) mixes as illustrated in the appendix. The OFC consists of 65 to 70% coarse aggregate (retained on 4.75 mm sieve) with 30 to 35% washed screenings. Both the coarse and fine aggregates have to be obtained from the same source of traprock or steel slag.

The DFC mix consists of 55% of retained 4.75 mm sieve coarse aggregate and both coarse and fine aggregates have to be selected from the ' List of Designated Sources ' but do not have to be from the same source. The fine aggregate is unwashed screenings.

3.3 Task Force on Performance of Bituminous Friction Course

The commitment of the Ministry to construct more friction course pavements made it essential that the field performance of the new mixes be evaluated and necessary changes be made to optimize the performance. A Task Force was therefore set up with a mandate to review, determine and recommend the most suitable driving qualities of pavement, with specific emphasis on improving frictional characteristics. The Task Force activities covered the following:

- general performance
- winter performance
- frictional characteristics
- safety
- riding quality
- noise levels
- performance of zone paint
- open friction mixes in other jurisdictions
- observations
- recommendations

The Task Force evaluated eleven contracts consisting of five OFC and six DFC mixes, over a period between Feb. 1979 and July, 1981.

The following summarizes the findings of the Task Force (3) under each of the above topics:-

(a) General Performance :

On review of the contracts and observations, the pavements were considered performing satisfactorily. The OFC mix that had been placed over concrete pavement without sawing and sealing over the concrete joints showed reflection cracks that were ravelling extensively. All these cracks were routed and sealed. The reflection cracks on some of the DFC pavements on the other hand were not ravelled.

(b) Winter Performance :

Visual observations made during the 1978-79 winter showed:

-The OFC mixes seemed to provide the best frictional characteristics.

-There were no problems observed in clearing the OFC surfaces. The 'broadcasting' technique of salt application has worked quite effectively to clear up the OFC pavements.

-Ice buildup in the DFC mixes has been reported. This problem can be related to the method of spreading the deicing salt, i.e. windrowing versus a recommended 'broadcasting' application. The permeable nature of the DFC mix permits the brine solution to penetrate the pavement before the windrowed deicing salt has a chance to be spread by the traffic. It is recommended that both OFC and DFC mixes require the 'broadcasting' of deicing salts and a slightly higher application rate for winter snow and ice control.

(c) Friction Characteristics :

The Task Force monitored some 48 sites laid with the DFC and HL-1 mixes in southern Ontario. A friction survey in 1976 showed that mixes with fine aggregate consisting predominantly of natural sand do not provide as good a friction number as mixes with screenings as fine aggregate (i.e. DFC, Fig. 9).

(d) Safety :

The wet pavement collisions before and after rehabilitation showed a reduction in accidents ranging between 42% and 81%. However, together with the improved surface texture, alignment improvement, additional lanes, longer lane change tapers, etc, have also been installed on some of these locations which would also contribute to the reduction of wet pavement accidents. In general, the use of improved friction surface has improved the accidents experienced.

(e) Riding Quality :

The results of the Mays meter readings (in inches of roughness per mile) indicate that the majority of the friction courses fall in the fair ride criteria of 80-100. Two of the contracts are in the good to excellent ride of less than 80 inches per mile.

(f) Noise Levels :

The OFC was found to be 2.1 dB(A) quieter than standard HL-1 mix based on roadside noise measurements.

(g) Performance of Zone Paint :

Monitoring of test sections in the core lane of Hwy. 401 indicates that normal mixes and open and dense friction course mixes have to receive a build-up of traffic paint in order to have a durable appearance. The traffic paint on the bituminous pavements had a minimum of 25% remaining with an average of 70%, whereas the concrete pavement adjacent to the test sections was in the order of 15% remaining, and this was mainly in the grooves. Zone paint on fresh OFC and DFC pavements appears to require the same amount of repainting as with standard surface course mixes.

Problems were encountered with adhesive backed plastic strips not sticking to the OFC mix. It would appear that this material must be placed on the hot mix prior to compaction so that both the mix and plastic strip can be rolled as one.

(h) Observations :

The contracts monitored have not shown any major problems. In addition to the above discussion, small over-asphalted areas were observed on some OFC pavements. They were caused by asphalt draining down in the mix that was mixed too hot. This problem was eliminated by reducing the mix temperature to below 135^{0}C at discharge.

(i) Recommendations on the use of Friction Course Mixes :
The Task Force recommended that

- The Ministry should continue the policy of using the OFC and DFC mixes in surfacing urban freeways and main highways.
- Late fall paving should be avoided for OFC and DFC mixes and DFC mix should be placed in depths not less than 30 mm (1.2 in). Resurfacing should include a levelling course (particularly for DFC mixes) to reduce the chance of thin lifts and subsequent ravelling.
- OFC shoulder mix could consist of cheaper local aggregates.
- Mix temperatures as discharged into the truck at the plant between 122^{0}C (250^{0}F) and 135^{0}C (275^{0}F) (present specification has a maximum of 140^{0}C and placement within one hour of discharge) in order to avoid asphalt drainage.
- Tandem paving on multi-lane facilities should be used wherever practical to reduce joint ravelling.
- Dump boxes should be cleared after each discharge onto the paver.
- Maintenance patrolers should be informed of the whereabout and the need to broadcast deicing salts on OFC and DFC surface course mixes.

4. RESURFACING PROGRAM

Based on the performance of the Hwy. 401 test sections a hot mix overlay system consisting of a binder course 40 mm (1-1/2") in thickness followed by a surface course of 25 mm (1") in thickness of OFC was selected as the best method of rehabilitating the freeway.

The Ministry embarked on a program in 1976 to rehabilitate the 50 km bypass around Toronto, planning to have the program completed by 1995. A budget of three to five million dollars has been allowed annually for this program. The rehabilitation involves five main areas, namely:

- additional capacity
- repairs to structures
- environmental improvements
- pavement and shoulder rehabilitation
- construction staging or scheduling of the resurfacing

On other concrete pavements carrying high volume traffic, the normal resurfacing design has been as follows:

25 mm (1") Sand levelling course
50 mm (2") Open graded (porous) binder course
40 mm (1-1/2") Binder course
40 mm (1-1/2") Surface course

These concrete pavements however have been allowed to deteriorate to a point where they required more substantial treatment, whereas the rehabilitation treatment, by comparison, on the Toronto by-pass consists only of:

40 mm (1-1/2") Binder course
25 mm (1") OFC mix surface course

It can be seen that the challenge of a high volume road with many overhead clearance problems, etc., has been met with an overlay system that is far less expensive than the normal approach.

4.1 Performance of the Rehabilitation System

(a) Pavement Ride :

The placing of the new binder and OFC surface course mixes on the two contracts indicate an initial improvement in ride as determined by the Mays Meter (Table 5). It is felt that the roughness figures may be improved even more by the use of automatic screed controls with skiis on both sides of the paver when laying the hot mix binder course in the future.

(b) Surface Durability :

The surface course OFC shows a very small number of flushed areas due to over asphalting (drain down in truck boxes) and some minor winter snow plough scuffing at grade points such as crown and shoulders but, all things considered, the durability of the OFC has been exceptionally good to date.

4.2 Annual Friction Course Resurfacing Program

The general effect of the OFC mix overlay on improving the driving qualities of the Toronto by-pass has been substantial. In addition to the commitment to the overlay program on the bypass, there has been a gradual increase in tonnage being laid on freeways from 1978 to 1981 (Table 6). The steady volume of OFC and DFC mixes constructed each year confirms the commitment. The OFC and DFC mixes are specified for use on some 1500 km of main highway across the province (MTC total = 21,500 km) with most of it in Southern Ontario. However,the tonnage is relatively small, with less than 20,000 tonnes for OFC and 100,000 tonnes for DFC, comparing to the average total hot mix of about 2.5 million tonnes used by the Ministry annually.

Generally there is a misconception of the perceived high cost due to the special single size (-3/8") washed coarse aggregate and washed screenings. Also, on the supplier's side, high stone content in the mix posts the problem of having to find an outlet for the surplus screenings. In fact, based on coverage per square metre the cost of OFC (laid at 25 mm thickness, 24 kg/m^2/10 mm) turns out to be about the same as or slightly less than the standard dense surface mix (HL-1) for medium-high traffic. When it is compared with DFC, its cost is about 35% lower (Table 7).

The aggregate used prior to 1982 for the OFC and DFC was mainly traprock. However, factors such as availaibility and good frictional characteristics of the slag aggregates (both steel and blast furnance slag) have lead to the increasing use of the slag mixes in future constructions.

5. CONCLUSIONS

OFC and DFC mixes are accepted by the Ministry as the most suitable mixtures for treatment of urban freeways and accident "black-spots" where heavy traffic volumes and a large number of commercial vehicles prevail.

The sequence of events that lead to the use of open graded friction course (OFC) and dense friction course (DFC) is as follows:

1947 - Construction of sections of Hwy. 401 By-pass
1952 - Initial construction as a four-lane divided
1963 - Reconstruction of original facility to multi-lane facility
- Widened to a twelve lane system of collector and express lanes
- Experienced marked increase in multi car wet weather accidents

1974 - Placement of 18 bituminous overlay test sections
1976 - Embarked on use of OFC and DFC in various contracts
1978 - Task Force set up to review and recommend the use of friction course mixes for future construction
- Formalize policy on use of OFC and DFC

The Task Force 's findings on friction courses are:-

a) General performance - satisfactory with ravelled joints at reflection cracks.

b) Winter performance - OFC provides the best friction properties.
- 'broadcasting' of salt should be used.

c) Friction characteristic - superior than standard dense mixes.

d) Safty -over 40% reduction in accidents before and after rehabilitation.

e) Riding quality - rated good to excellent.

f) Noise level - 2.1 dB (A) quieter than standard dense mixes.

g) Zone painting - requires the same quantity as standard dense mixes but adhesive backed strips must be rolled in when mix is hot.

h) Construction - avoid late fall paving.
- OFC shoulder mix could use cheaper local aggregates.
- discharge temperature at the plant be between 122^{0}C (250^{0}F) and 135^{0}C (275^{0}F).
- tendem paving to reduce joint ravelling.
- clear dump boxes after each discharge.

In order to be effective in improving the levels of friction, bituminous friction course mixes must contain harsh, angular fine aggregate such as traprock or slag fines and a sufficient proportion of crushed good quality coarse aggregate (50 to 70% retained 4.75 mm) to maintain the micro- and macrotexture on the travelled surface. These characteristics can be provided by the open friction course (OFC) and the dense friction course (DFC).

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TABLE 1: TRAFFIC VOLUMES AND TRUCK WEIGHTS

YEAR	AADT	G.V.W. TONNES	LEGAL AXLE WEIGHT TONNES
1963	77,000	32.0	8.6
1976	199,000	63.5	10.6

TABLE 2: BITUMINOUS MIXES, COMPOSITION AND DESIGN DATA(1)

		Mix Composition % Wt. of Aggregate Plus Filler			*	Mix Characteristics					
Test Section Number	Mix Type	Coarse Agg. Ret. No. 4	Fine Agg. Pass No. 4	Filler Material	% Ret #4	Asphalt % Wt. of Mix	Marshall Stability	Marshall Flow	V.M.A % Vol.	Voids % Vol.	
1	HL1	45TR	41NS		43.8	5.4	1625	10.3	16.9	2.8	L
			14LS			5.4	2614	11.6	17.5	3.7	F
2	HL1	45TR	41NS		48.2	5.4	1625	10.3	17.2	3.0	L
			14TRS			5.3	2870	13.4	15.0	0.8	F
3	HL1	45TR	55TRS		47.5	4.1	3185	16.5	12.9	1.2	L
						4.0	3407	15.3	13.5	2.0	F
4	HL1	55TR	34NS		54.1	4.8	1730	10.2	16.0	2.7	L
			11LS			4.8	3027	12.3	14.2	1.2	F
5	HL1	60TR	28NS	2ASB	58.1	5.6	1800	15.0	14.2	1.0	L
			10LS			5.7	1903	22.5	16.0	0.9	F
6	HL1	60TR	38TRS	2ASB	62.3	5.3	2190	22.7	15.2	1.0	L
						5.4	2570	18.7	18.6	3.4	F
7	Mod. HL1	45SL	55SLS		46.8	5.3	3520	16.0	18.5	2.7	L
						5.2	3640	13.2	18.7	3.3	F
8	Mod. HL1	50SL	38NS		47.1	5.7	2160	12.9	17.3	2.3	L
			12LS			5.7	2990	13.7	17.7	1.9	F
9	Mod. HL1	45BF	55BFS		43.2	8.0	2830	12.8	24.0	6.9	L
						7.8	3326	14.9	23.1	6.1	F
10	Mod HL1	40BF	45NS		40.5	6.8	1975	10.4	17.9	2.9	L
			15LS			6.5	3155	9.7	17.0	2.2	F
11	Sand Mix	14TR	84TRS	2ASB	5.4	7.1	2084	27.2	17.7	0	L
						7.0	2175	40.2	19.5	0.2	F
12	Sand Mix	9TR	89TRS	2ASB	6.9	7.0	2650	19.2	16.8	0	L
						7.2	1885	45.1	20.7	1.1	F
13	Open Graded	67TR	33TRS		60.5	5.9	1458	12.7	20.6	4.7	F
14	Open Graded	67TR	31TRS	2ASB	71.7	5.8	1691	11.9	19.6	4.0	F
15	Open Graded	30TR	70TRS		29.3	5.6	2678	19.2	16.3	0.7	F
16	Open Graded	30TR	68TRS	2ASB	31.4	6.6	2116	30.5	18.6	0.2	F
17	Mastic	70TR	19TRS	9MF 2ASB	75.2	7.5	1887	56.7	21.0	1.0	F
**1-19	HL1	45TR	41NS		47.4	5.4	1625	10.3	16.9	2.8	L
			14LS			5.4	2825	14.5	14.6	0.4	F

* Based on field laboratory extraction tests.
** As Test Section 1 but constructed over a 38 mm (1½") thick bituminous base course layer.

LEGEND

Coarse Aggregate
TR - Traprock
SL - Steel Slag
BF - Blast furnace Slag

Fine Aggregate
SLS - Steel Slag Screenings
LS - Limestone Screenings
TRS - Traprock Screenings
BFS - Blast Furnace Screenings
NS - Natural Sand (Glacial Deposit)

Filler Material
ASB - Short Fiber Asbestos
MF - Mineral Filler (Finely Crushed Limestone)
L - Laboratory Mix Designs
F - Field Laboratory Tests

Table 3: Durability Performance of Test Sections

Section	Cracks Tr.	Cracks Lg.	Rav.	Patc.	Del.	Rut	Overall Rating
1	4	44	6	0	0	3	57
3	0	1	18	6	4	3	32
4	12	4	6	0	0	3	25
7	16	2	6	9	1	3	37
9	5	7	18	6	14	5	54
11	34	0	0	0	2	0	36
13	6	2	6	14	5	0	33
17	26	5	18	8	2	0	58

Table 4: Permeability Results

Section	Water Permeability (ml/min) Age (year) 0	2	5	7	Air Permeability @ 11 yr.(cm) Passing Lane	Centre Lane	Driving Lane
1	-	1.1	0	0	.imp	.imp	8.6E-12
2	-	1.7	-	0	.imp	.imp	2.2E-11
3	70	3.2	2.5	0	6.6E-10	1.3E-9	1.9E-9
4	-	1.2	-	0	.imp	.imp	.imp
5	-	1.9	-	0	6.4E-10	.imp	.imp
6	-	50	-	3	3.0E-9	6.0E-9	1.3E-9
7	-	4	0	0	10.0E-10	2.6E-10	3.2E-11
8	-	4	-	0	.imp	.imp	.imp
9	vh	30	5.5	0	1.9E-9	2.4E-9	1.5E-10
10	22	2	-	0	.imp	.imp	.imp
11	-	2.8	-	0	1.6E-9	.imp	7.1E-11
12	-	2.4	-	0	6.6E-11	3.1E-11	-.-----
13	vh	78	20	7	1.3E-9	1.3E-10	-.-----
14	vh	150	-	13.5	6.6E-9	1.2E-9	1.0E-8
15	6	3	-	0	6.7E-12	.imp	.imp
16	22	2.5	-	0	1.4E-10	.imp	.imp
17	-	4.3	-	0	.imp	.imp	1.0E-9
18	-	2.4	-	0	3.4E-11	.imp	.imp

- = results not available, vh = very high permeability,
imp = impermeable, E = x10⁻

Table 5: Roughness Measurement By Mays Ride Meter

Contract Number	Original			New			Change		
	$\bar{X}$	σ	n	$\bar{X}$	σ	n	$\bar{X}$	σ	n
1	110	24	5	73	3	5	-38	17	5
2	141	19	7	72	14	7	-70	14	7

Table 6: Annual Volume of Friction Course Mixes (tonnes)

YEAR	OFC	DFC
1976	5,080	27,400
1977	40,130	104,800
1978	11,098	104,800
1979	8,147	129,271
1980	7,357	113,698
1981	50,108	112,708
1982	10,531	73,096
1983	18,371	43,829
1984	36,213	76,488
1985	11,138	95,186
Total	198,173	881,276

Table 7: Comparative Cost (1983) of Friction Course Mixes (OFC and DFC) and Standard Mix (HL-1) (1986 cost about $1.50 /tonne higher)

Unit	Cost ($CN)				% above/below HL-1		
	HL-1	DFC	OFC	OFC	DFC	OFC	OFC
cm	40	40	40	25	40	40	25
Tonne	34.00	42.00	50.00	50.00	24	47	47
m^2	3.50	4.30	5.15	3.20	23	47	-9

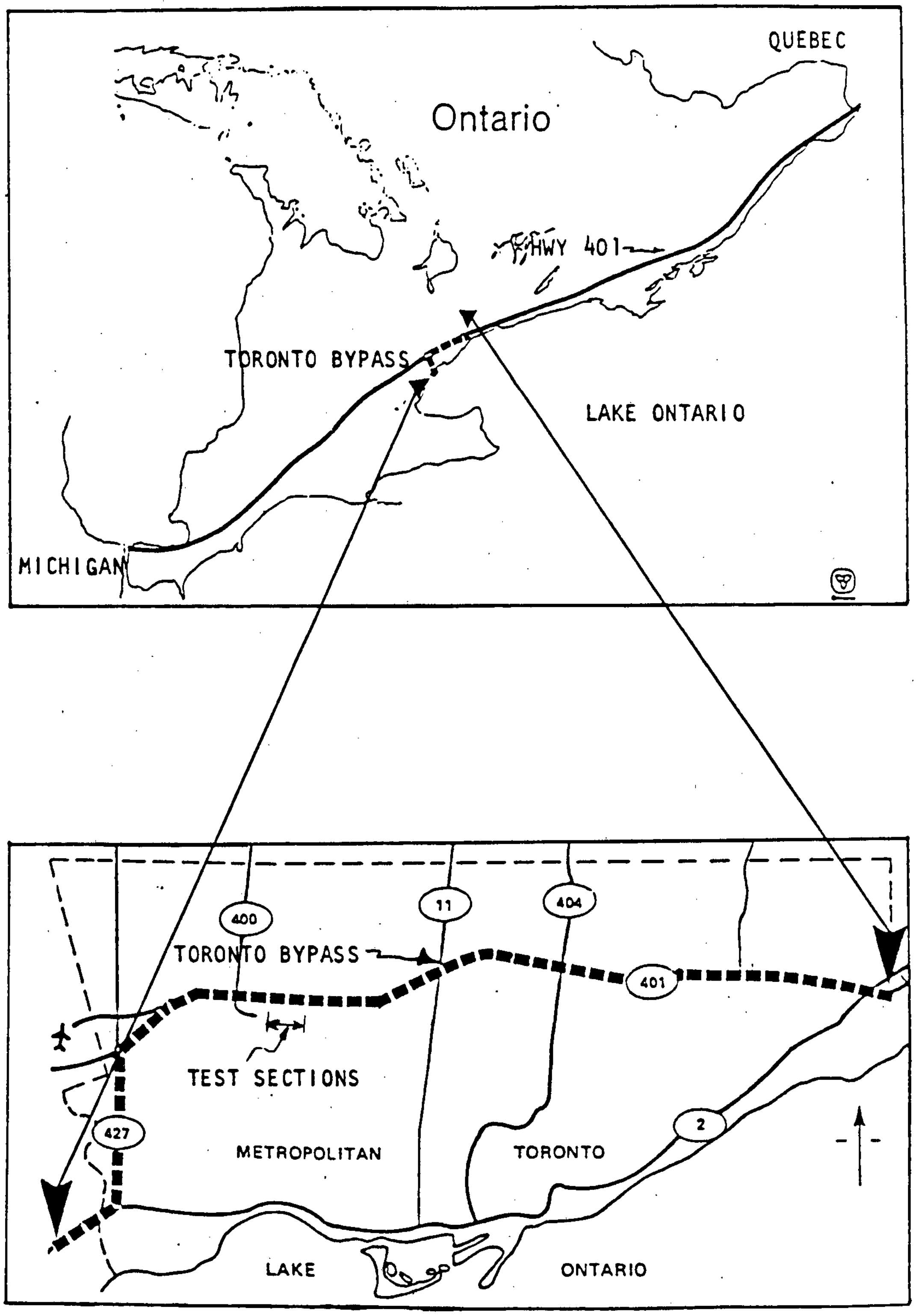
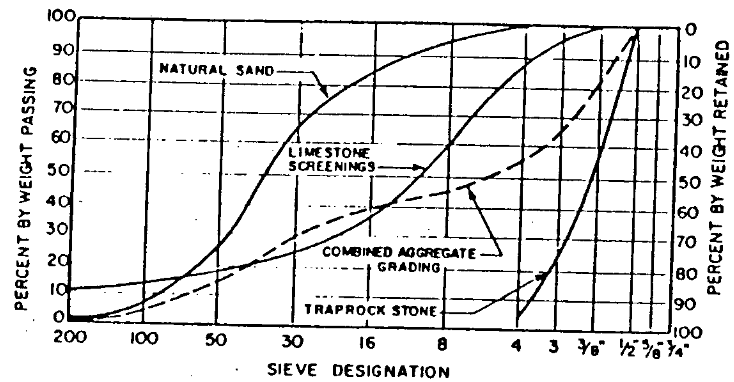
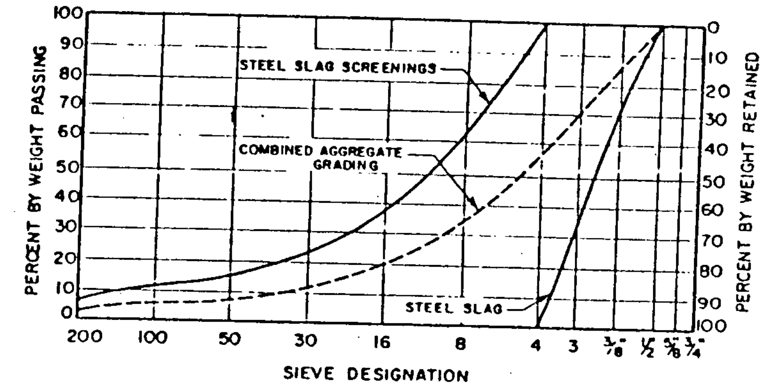


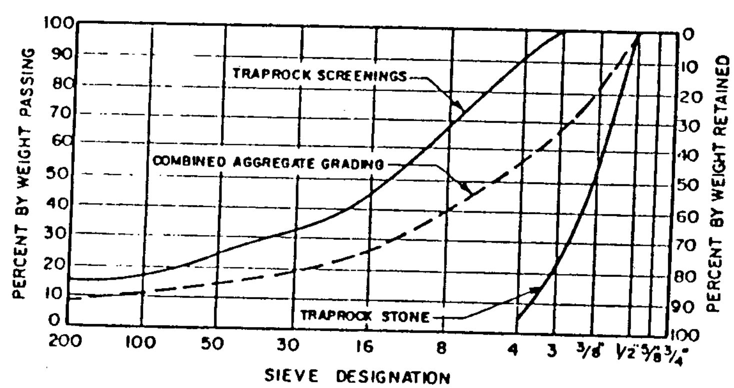
FIG. 1: THE TORONTO BY-PASS, HWY. 401 AND LOCATION OF TEST SECTIONS



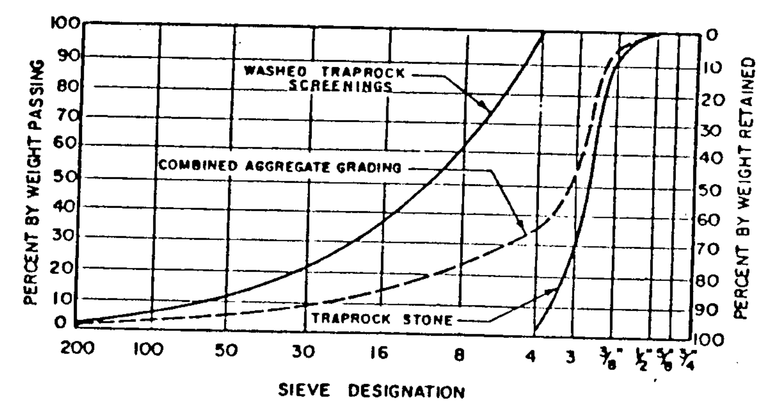
Aggregate Gradations, Test Section No. 1



Aggregate Gradations, Test Section No. 7



Aggregate Gradations, Test Section No. 3



Aggregate Gradations, Test Section No. 13

FIG. 2: GRADATIONS OF FOUR OF THE TRIAL MIXES (1)

FIG. 3: FRICTION NUMBER (AT 100 KM/H) OF DIFFERENT TEST SECTIONS ON THE DRIVING LANE

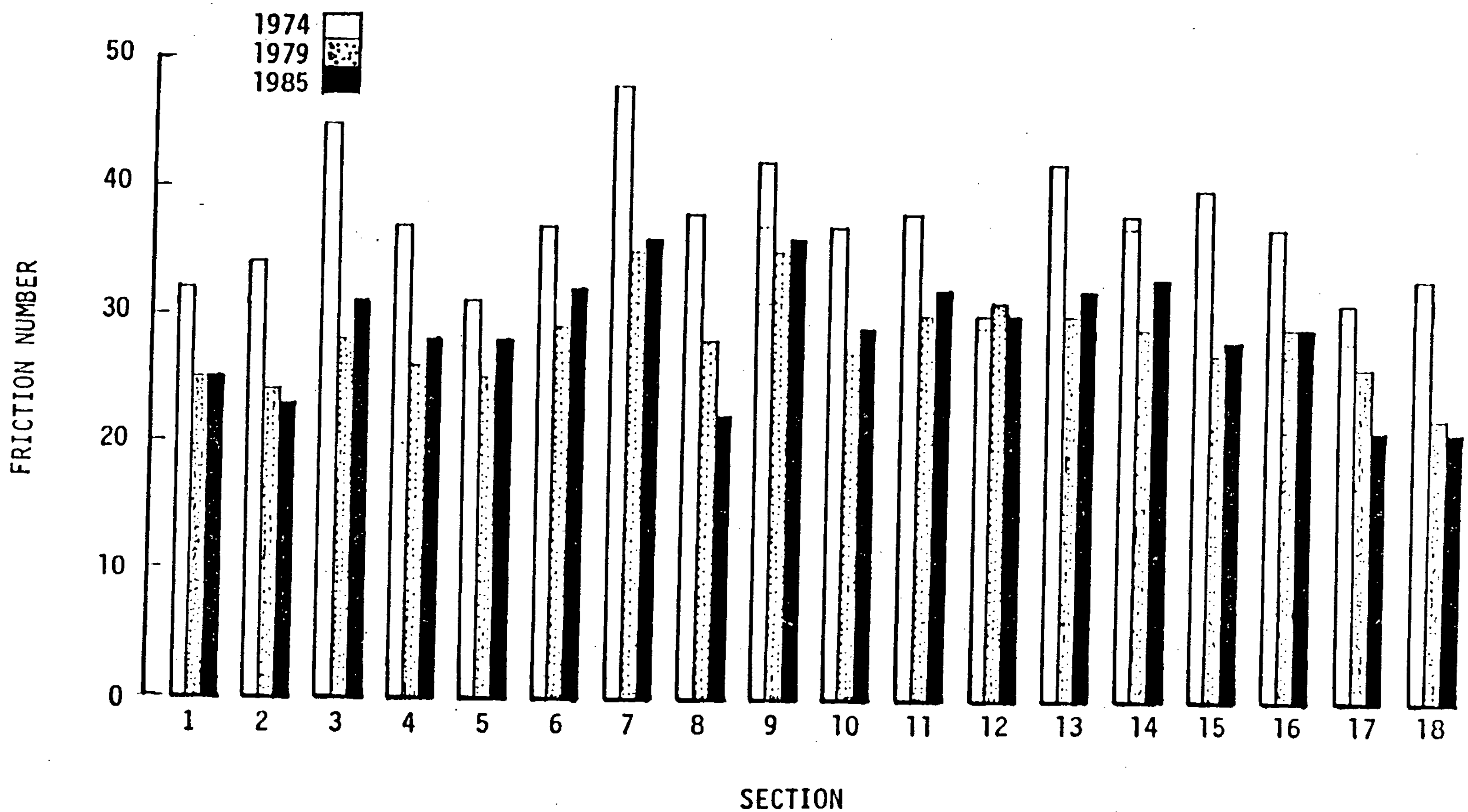


Fig. 4: Close-up of Test Section No. 7, Wheel Path, Driving Lane, After 11 Years Service

Friction Excellent, Good Macrotexture and Microtexture

Steel Slag Coarse Aggregate
Steel Slag Screenings Fine Aggregate

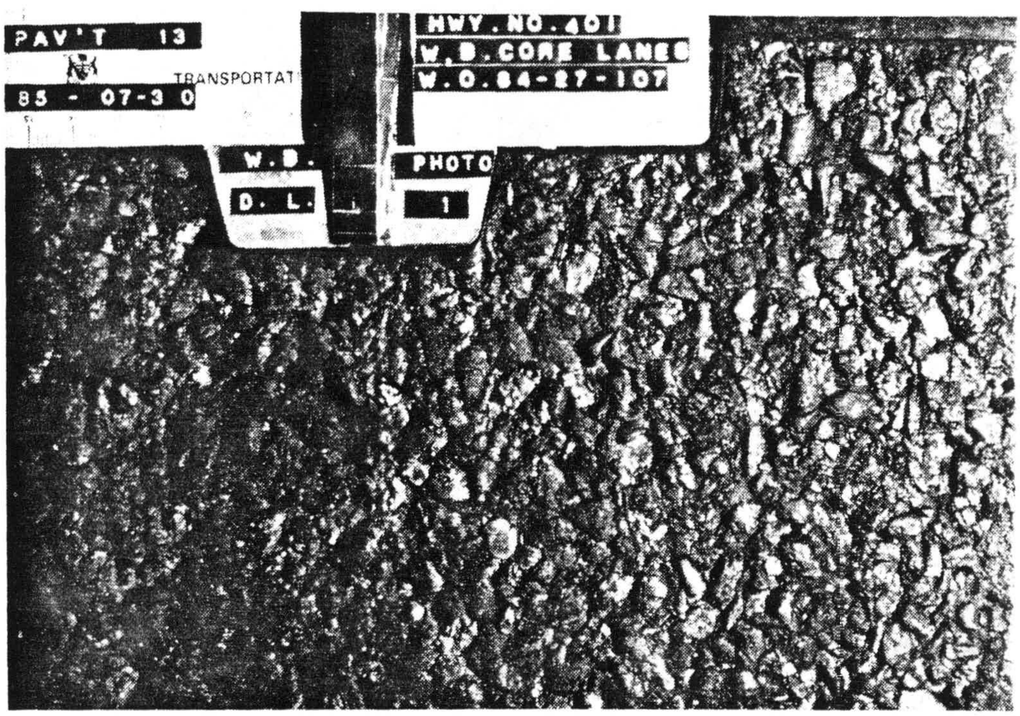


Fig. 5: Close-up of Test Section No. 13, Wheel Path, Driving Lane, After 11 Years Service

Friction Excellent,
Well Developed Macrotexture

Traprock Stone Coarse Aggregate
Traprock Screenings Fine Aggregate

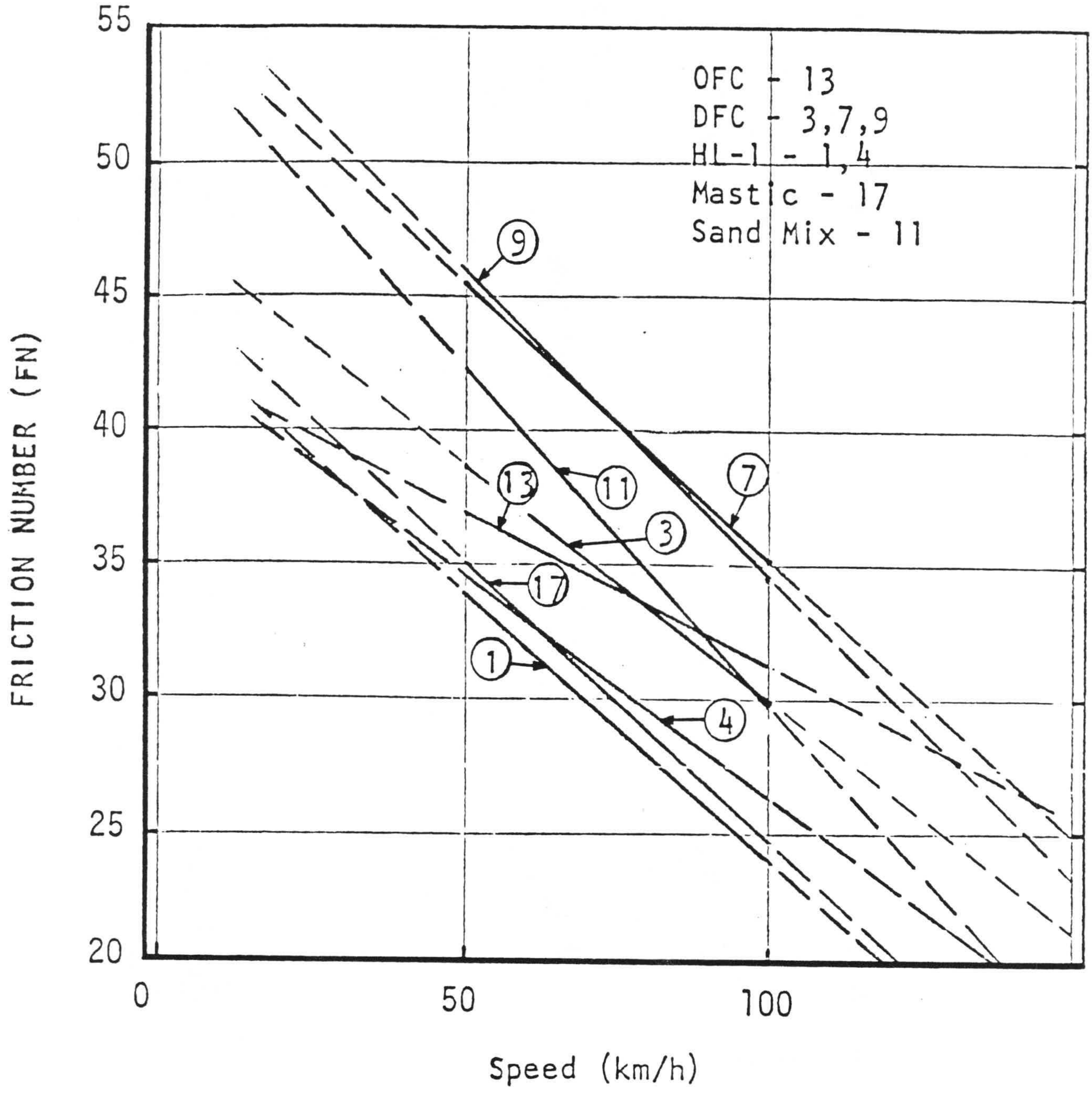


FIG. 6: INFLUENCE OF SPEED ON THE FRICTION NUMBER FOR DIFFERENT MIXES WITH VARIOUS DEGREES OF MACROTEXTURE (AFTER 11 YEARS OF SERVICE)

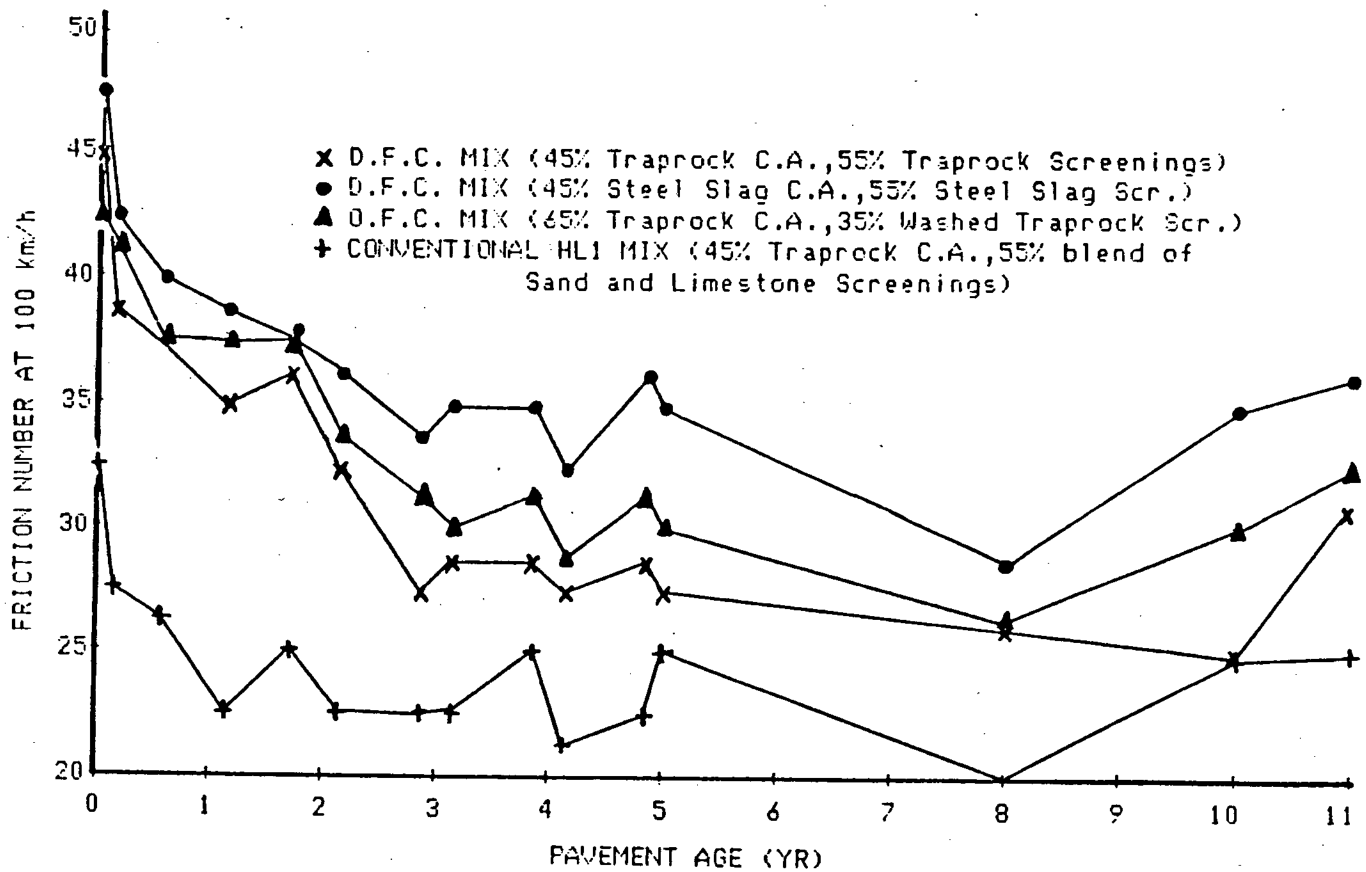
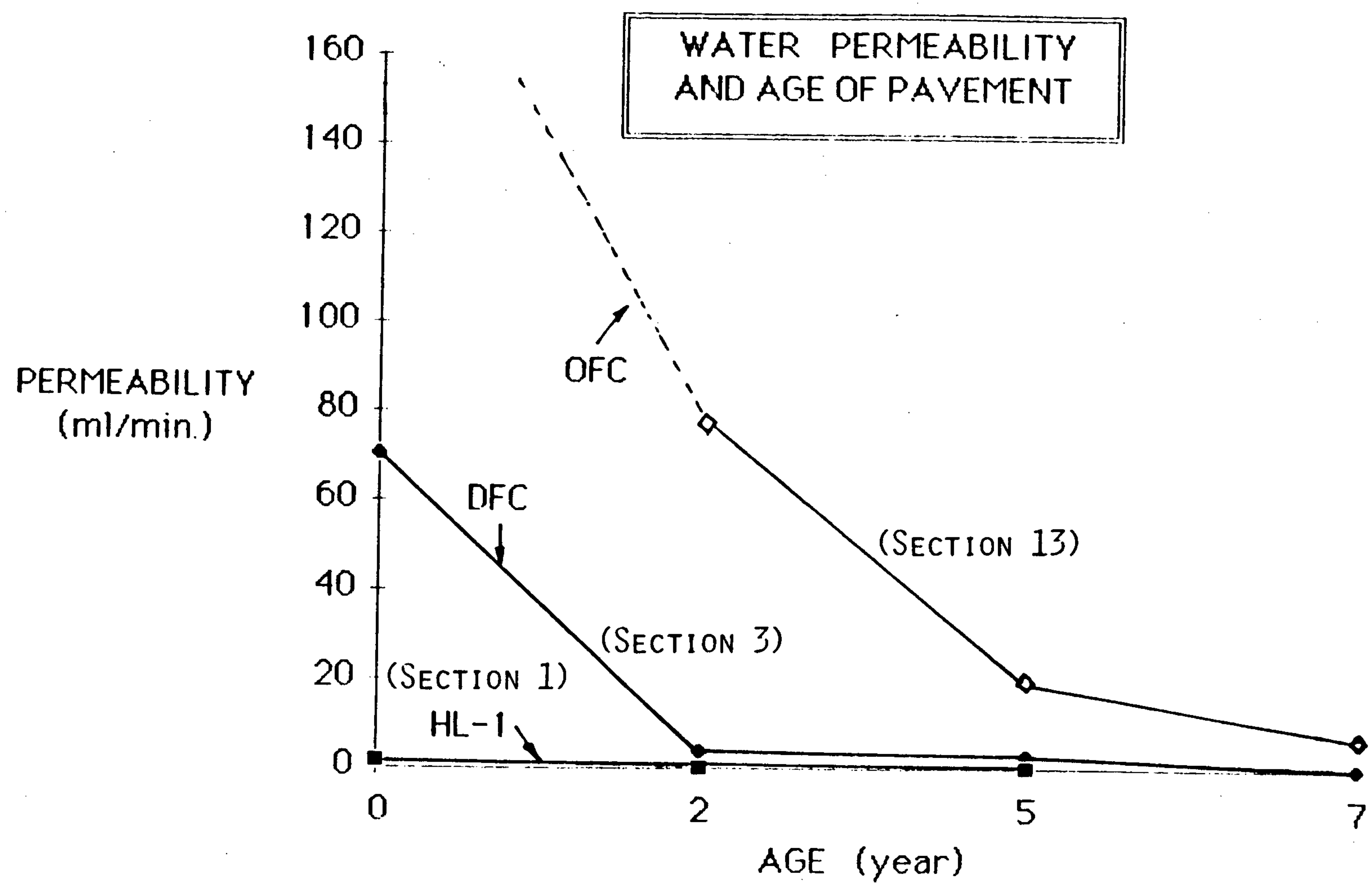


FIG. 7: CHANGE IN FRICTION NUMBER WITH TIME FOR SELECTED TEST SECTIONS

FIG. 8


WATER PERMEABILITY
AND AGE OF PAVEMENT
160
140
120
100
80
60
40
20
0
PERMEABILITY
(ml/min.)
OFC
DFC
(SECTION 13)
(SECTION 3)
(SECTION 1)
HL-1
0
2
5
7
AGE (year)

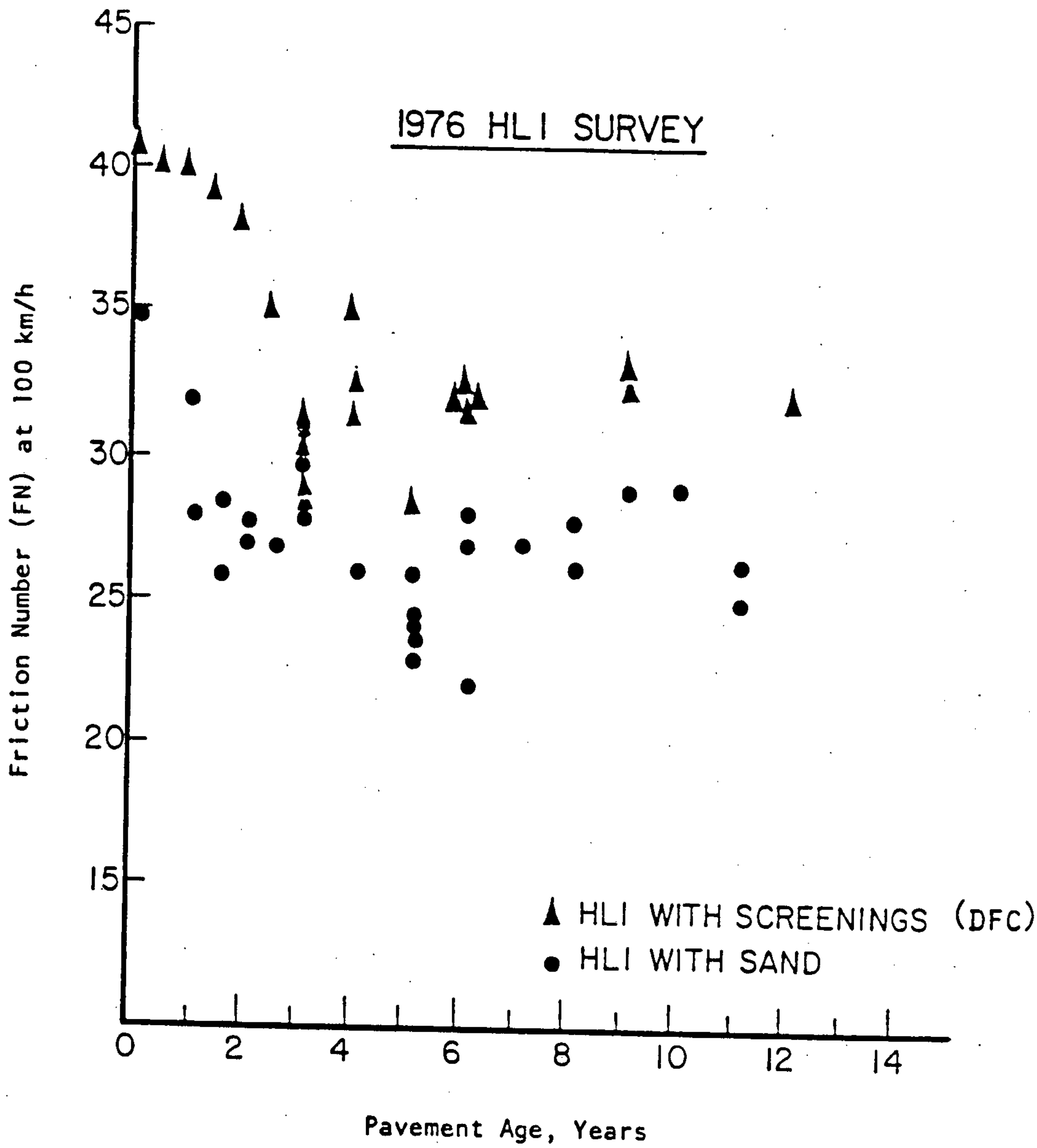


FIG. 9: FRICTION SURVEY OF HL-1 MIXES
LAID IN SOUTHERN ONTARIO

APPENDIX

OPEN FRICTION COURSE MIX - Item No.

Description

This special provision covers the requirements for open friction course (O.F.C.) mix.

General Requirements

Open friction course mix shall meet the requirements for HL 1 as specified in OPSS 310 except as otherwise stated in this special provision.

Materials

Aggregates

The fine aggregate shall be washed screenings. The raw material or coarse and fine aggregates shall be obtained from sources listed on the Supplementary Aggregate Sources List for Open Friction Course Mix. The coarse and fine aggregates shall be obtained from the same source and they shall meet the following gradation requirements:

Coarse Aggregate

M.T.C. Sieve Designation	Percentage Passing
13.2 mm	100
11.2 mm	95 - 100
9.5 mm	85 - 100
6.7 mm	20 - 50
4.75 mm	0 - 15
75 µm	0 - 2 (0 - 1 for gravel)

Fine Aggregate

M.T.C. Sieve Designation	Percentage Passing
9.5 mm	100
4.75 mm	85 - 100
2.36 mm	50 - 70
1.18 mm	25 - 45
600 µm	10 - 30
300 µm	10 - 20
150 µm	0 - 10
75 µm	0 - 3

Physical Requirements for Coarse Aggregate

Steel slag shall not be required to met the Absorption by Weight and Petrographic Number requirements of Table 3, OPSS 1003.

The total amount of non-slag constituents, such as furnace brick, incompletely fused fragments, lime, wood, rock, etc., in steel slag shall not be more than 3 percent by mass and the wood content alone shall not be more than 0.5 percent by mass.

Mix Proportions

The approximate coarse and fine aggregate proportions by mass for the open friction course mix are:

65% - 70% retained on 4.75 mm sieve
30% - 35% passing 4.75 mm sieve

The actual proportions shall be determined by mix design. The quantity of asphalt cement required is determined by multiplying the A.C. content specified in the contract by the actual mass of the open friction course mix placed.

The approximate asphalt cement contents and field densities for various aggregates experienced by the M.T.C. are as follows:

Origin of Raw Material For Aggregates	% A.C. (By Mass)	Approx. Density Kg/m²/10mm Thickness or 90% of Laboratory Marshall Density
Gravel	5.3	21.2
Quarried Trap Rock	5.0	23.0
Steel Slag	5.2	25.5

Mix Distribution

The tonnage shown in the tender is based on a combination of traprock coarse and fine aggregates. If steel slag or gravel aggregates are used, the tonnage of actual mix placed shall be adjusted for density difference so that the specified course thickness is maintained.

Mix Production

The mix shall be produced in a batch plant.

Hot Mix Storage Bins

The use of hot mix storage bins for storing this mix shall not be permitted.

Pavers

All pavers shall be equipped with either tamper bars or vibratory screeds.

Construction

Preparation and Placement of the Mixture

If the mixing plant is equipped with a dust collector system which discharges directly into the boot of the hot elevator, such a system shall be purged of any fines accumulated from other previous production, before any open friction course mix (OFC) is manufactured. This procedure will take approximately two (2) hours to complete.

The temperature of the OFC mix, at discharge from the asphalt plant, shall not exceed 140° C.

The OFC mix shall be placed within one hour of discharge from the asphalt plant.

The air temperature for placement of OFC shall be 12° C minimum.

The Contractor shall provide an on-site dump area where, at the direction of the Authority Inspector, vehicle boxes shall be cleaned of all deleterious material immediately after the discharge of OFC.

Sampling and Testing

The Contractor shall demonstrate his ability to produce the desired mix before the initial placement of surface course on the contract. This shall be done at the plant by sampling and testing from a minimum of two batches of the size which will be used. Testing will take approximately two hours. After the testing period, the Contractor may start placing the mix on the road providing the test mix is satisfactory. If the test mix is unsatisfactory, corrections shall be made and the testing procedure repeated.

Trial Area

A surface course trial area will not be required for the open friction course.

Compaction of Mixture

Compaction of the mix shall be with steel-tired rollers only. Two 9-11 t steel-tired rollers shall be provided for each paver in use. Compaction shall be carried out immediately after the mixture is placed due to rapid cooling of the mixture.

Requirements for Completed Pavement Courses

Temporary Ramps

At the end of each completed portion, prior to opening of the lanes to traffic, the completed sections of the bituminous surfacing shall be ramped down to the existing pavement at a slope of 25 mm in 3 m.

The material to be used for construction of the ramps shall be as determined on the site by the Engineer.

In all cases, the transition shall not form part of the permanent pavement but shall be removed before the paving of the adjacent section.

Measurement for Payment

The payment quantities indicated on the tender are based on mixes consisting of traprock aggregates only. The quantity for payment for steel slag and gravel O.F.C. mix incorporated into the work shall be determined by multiplying the total measured mass of O.F.C. mix with the appropriate factor given in the table below:

Origin of Raw Material for Aggregates	Multiplying Factor
Gravel	1.09
Quarried Trap Rock	1.00
Steel Slag	0.90

DENSE FRICTION COURSE MIX - Item No

Dense friction course mix shall meet the requirements of HL 1 as specified in OPSS 310 except as follows:

Aggregates

The coarse and fine aggregates shall be obtained from the trap - rock or slag sources on the List of Designated Sources for HL-1 coarse aggregate. The coarse aggregate shall meet the requirements for HL-1 and the fine aggregate shall be unwashed. The coarse and fine aggregates do not have to be obtained from the same source.

Asphalt Cement

a) Supply: - When the Authority supplies asphalt cement, the Authority will supply up to 4.5% asphalt cement (by mass) for the equivalent tonneage of trap - rock mix; the Contractor shall supply any additional asphalt cement required, depending on the aggregate selected by the Contractor, up to the percentage shown below for the aggregate combination utilized. The Authority will provide any asphalt cement required beyond the percentage shown for the combination utilized.

b) Content: - Regardless of the type of aggregates used, the quantity of asphalt cement required is determined by multiplying the A.C. content specified in the mix design by the actual mass of the dense friction course mix placed.

Mix Proportions and Characteristics

The approximate coarse and fine aggregate proportions (by volume) for the dense friction course mix are:

Retained 4.75 mm sieve 55%
Passing 4.75 mm sieve 45%

The approximate asphalt cement content and density for the various combinations of aggregates experienced by the Authority are as follows:

Coarse Aggregate	Fine Aggregate	% A.C. (By Mass)	Approx. Density kg/m^2/10mm Thickness @ 96% of Laboratory Marshall Density
Trap Rock	Trap Rock	4.5	27.0
Trap Rock	Steel Slag	5.4	28.0
Trap Rock	Blast Furnace Slag	6.0	24.3
Steel Slag	Steel Slag	5.7	28.5
Steel Slag	Trap Rock	5.1	28.0
Steel Slag	Blast Furnace Slag	6.1	26.0
Blast Furnace Slag	Blast Furnace Slag	8.6	21.3
Blast Furnace Slag	Steel Slag	7.0	24.4
Blast Furnace Slag	Trap Rock	5.3	23.2

The actual mix proportions, asphalt cement content and density, shall be determined by mix design. The Marshall void content of the mix shall be set at 2.5%.

Mix Distribution

The tonneage shown in the tender is based on a combination of 55% trap-rock coarse and 45% trap-rock fine aggregate (by volume). If other aggregate types and combinations are used, the tonneage of actual mix placed shall be adjusted for the density difference so that the specified course thickness is maintained.

Sampling and Testing

The contractor shall demonstrate his ability to produce the desired mix before the initial placement of surface course on the contract. This shall be done at the plant by sampling and testing from a minimum of 2 batches of the size which will be used. Testing will take approximately two hours. After the testing period, the Contractor may start placing the mix on the road providing the test mix is satisfactory. If the test mix is unsatisfactory, corrections shall be made and the testing procedure repeated.

Trial Area

A surface course trial area will not be required for the dense friction course.

Measurement for Payment

The payment quantities indicated on the tender are based on the mixes consisting of trap rock aggregates only. The quantity for payment shall be determined by multiplying the total measured mass of the dense friction course mix incorporated into the work by the appropriate factor given in Table 1 below, depending on the aggregate combination supplied.

Coarse Aggregate	Fine Aggregate	Multiplying Factor
Trap Rock	Trap Rock	1
Trap Rock	Steel Slag	0.97
Trap Rock	Blast Furnace Slag	1.11
Steel Slag	Steel Slag	0.95
Steel Slag	Trap Rock	0.98
Steel Slag	Blast Furnace Slag	1.04
Blast Furnace Slag	Blast Furnace Slag	1.27
Blast Furnace Slag	Steel Slag	1.11
Blast Furnace Slag	Trap Rock	1.16

Warrant: Always with this tender item.

C

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C-1

Friction Course

By Gerald S. Triplett and Thomas D. White*

FRICTION COURSE

Although porous friction course (PFC), as they are termed by the U.S. Federal Aviation Administration (FAA), have had relatively few years of application in the United States to airport pavements, open-graded asphalt friction course (OGAFC), as they are termed by the U.S. Federal Highway Administration (FHWA), have been used for a number of years in the United States on highway pavements. In application to highway pavements, they evolved from surface treatment seal coats into plant-mix seal coats.

In the late 60's, the FHWA began publicizing the success of friction courses to the various states, and in 1971, the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, began a study under contract to the FAA to develop construction specifications and a laboratory mix design procedure for friction courses for use on airport pavements. WES conducted an extended performance evaluation of friction courses on several airport pavements constructed in 1971 and 1972. This evaluation continued through March 1975. These friction courses were located in different climatic areas of the United States. They were constructed using a range of asphaltic materials, aggregate types, and gradations. In addition, they were subjected to a wide range of aircraft traffic types and levels. Laboratory testing, along with field evaluation, provided the basic data for recommending a mix design procedure and finalized specifications for airport friction courses. The FHWA has published a manual entitled "Design of Open-Graded Asphalt Friction Courses," Report No. FHWA-RD-74-2, for use in design of highway friction course. This manual is based on a number of years of experience and evaluation by highway engineers.

FRICTION COURSE APPLICATION

The primary reasons for using friction courses include pavement sealing and improved skid resistance. Other beneficial aspects of friction courses are:

a) A minimum of material is used to provide skid resistance.
b) The riding quality of structurally sound pavements is extended.
c) Minor surface irregularities are corrected.
d) Quieter riding surfaces are provided.
e) Tire splash and spray are reduced.
f) Visibility of paint stripes and other pavement markings is improved in wet weather.

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Thomas D. White, Chief, Pavement Materials Research Facility of U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, USA.

g) Night visibility (less glare from pavement surfaces) is improved during wet weather.

h) Traffic delays caused by construction are minimized.

In respect to improved skid resistance, it was only recently that full recognition was given to improvement of wet skid resistance afforded by the use of OGAFC or PFC and, in particular, to alleviation of the phenomena known as "hydroplaning". Hydroplaning is the condition of a fast-moving vehicle's tires skiing on a pressure film of surface water. Figure 1 depicts this phenomenon. The potential seriousness of hydroplaning incidents on highways and airport pavements encouraged various agencies responsible for setting criteria to evaluate the use of friction courses to alleviate this problem. This evaluation was made easier by successful applications of the friction course to airfields in Western Europe and Great Britain and highways in the western part of the United States.

REDUCTION OF HYDROPLANING POTENTIAL

Currently, friction courses are promoted in the United States for their ability to drain water internally and thereby eliminate the water film that can cause hydroplaning. Although this function contributes to drainage of surface water and subsequent reduction in hydroplaning potential, this is only one function of friction courses. The primary benefit of friction courses in reducing hydroplaning potential is pressure relief in the water film between a vehicle's tires and the pavement surface. High internal voids and the coarse surface macro-texture of friction courses contribute significantly to pressure relief. The functions performed by friction course can be grouped by these two characteristics.

a. High internal voids.

1) Provides internal pressure relief channels.
2) Provides flow channels for internal drainage of surface water.
3) Provides temporary storage of a small amount of surface water.

b. Coarse surface macro-texture.

1) Provides pressure relief channels on the surface.
2) Provides flow channels for surface water.
3) Provides, in general, tire-pavement contact above surface water film.

EXPERIENCE WITH FRICTION COURSE COMPONENTS

Generally, the maximum size aggregate for both highway and airport use has been ½ in., and the constructed pavement thickness has varied from approximately ¾ to 1 in. Aggregate quality in highway friction course has ranged from hard to soft friable aggregate with an L.A. abrasion loss upper limit of 45; whereas, aggregates for airport friction courses have generally had a higher quality requirement with an upper L.A. abrasion limit of 25. The FAA adopted a proposed specification by the United States Air Force based on the British specification entitled "Open-Graded Macadam Friction Course" as a general guideline in construction of initial friction courses. However, the as-constructed friction course gradations on airport pavements have exhibited a wide range in gradation and surface texture. Figure 2 shows cores taken from a number of these pavements. A wide range of gradations has also been used by highway departments including adopted gradations specifically for friction courses as well as AASHTO standard gradations. A similar variation is reflected in asphalt hardness that has been utilized, ranging from 40–50 penetration to 120–150 penetration and ranges in viscosity grades of from AC-10 to AC-40. In addition, neoprene-rubberized asphalt, anti-stripping agents, and silicone have been used.

When a one-sized aggregate is used in the friction courses, raveling has been a problem. Raveling has also been a problem where a relatively low asphalt content is used. There are advantages and disadvantages of asphalts with extremes of consistency. This would tend to suggest specifying an average of consistency for the asphalt.

LABORATORY TESTING PROGRAMS

The WES research effort was concerned with a number of tests in the mix design and evaluation of friction courses. Although this paper is not intended as a presentation of a detailed laboratory program, there were a number of items studied in this effort involving test methods that proved to be valuable in evaluating constructed friction courses and making final recommendations for a mix design method and specification requirements. As a result, several of these items will be discussed.

COMPACTION AND DENSITY

In the laboratory study, it was necessary to arrive at a satisfactory method of compacting friction course samples that would compare with in site friction course pavement. However, in addition to there not being an existing recommended compaction effort, there also did not exist an acceptable method of determining friction course density. As a result, although field friction course core samples had been collected, they were not evaluated until a satisfactory means of measuring density could be adopted.

Initially, friction course samples prepared for laboratory evaluation of mixture properties were prepared by adopting a compaction effort that gave an ultimate density with the Marshall handhammer. Samples were compacted with increasing numbers of blows, and a compactive effort was adopted at a density beyond which little additional compaction would be expected. The height of the sample and mold diameter was used to determine volume for density calculations. Comparison of permeability characteristics between laboratory and field course samples indicated the ultimate density compactive effort was too severe. As a result, a re-evaluation of compactive effort was made to obtain comparable permeability between laboratory field samples. A compactive effort of 10 blows on one side of the sample with a Marshall hammer was adopted.

The primary problem with determining friction course density was in arriving at the volume of the sample. Methods of evaluating volume included.

a) Weighing in air and water.
b) Parafin coating.
c) Immersion in mercury.

d) Plastic vacuum packaging.
e) Measurement of sample geometry.

Of the methods evaluated for determining volume. measurement of sample geometry gave the most reproducible results. and this procedure was incorporated into field sample evaluations. The procedure consisted of measuring the height and diameter of the sample at four equally spaced points on the perimeter.

Sample density is calculated with the above volume and sample weight in air. Voids total mix and voids filled with asphalt can be calculated after the asphalt content is determined by extraction.

PERMEABILITY TESTS

The permeability test evolved through various states. The first proof of the use of a permeability test and its reproducibility was in a simple ¼-in. falling head test shown in Figure 3. The second evolution of the test involved construction of a plastic standpipe with a 2-in. inside diameter and a 4-in. baseplate with a foam rubber gasket on the bottom of the baseplate that contacted the pavement surface. This device is shown in Figure 4. The test was developed in the laboratory and was evaluated on specimens that had a ¾-in. friction course cap compacted on top of a dense base sample. Both constant head and falling head tests were run on these samples with seemingly good agreement as far as the relative display of permeability. However. field testing on an in situ friction course pavement indicated that the type of flow was different from what was obtained on 4-in.-diam samples in the laboratory. In the laboratory. flow was taking place down and horizontally out the sides of the friction course core. In the field, water flow was taking place not only horizontally but also upward and out the surface beyond the perimeter of the 4-in. -diam baseplate. As a result, the diameter of laboratory samples was changed from 4 to 6 in. This sample geometry resulted in a similar flow as observed in the field. Figure 5 shows the sample geometry. Subsequent field and laboratory comparisons of permeability indicated laboratory permeabilities comparing favorably with field measured permeabilities. Both constant head and falling head field permeability tests were conducted. The constant head permeability tests were run with 4-, 6-, 8-, and 10-in. heads. The falling head permeability tests were run from 10 to 5 in. It was determined that permeability characteristics were the same for either constant head or falling head tests. Therefore, the simpler falling head test was adopted for continuing evaluations. Figure 6 shows the field setup of the WES permeability device. The test apparatus can be made portable with a water supply. It was determined that the permeability test results were sensitive to the surcharge applied to the standpipe. A standard surcharge of 100 lb was adopted. The permeability of the friction course mix proved to be extremely valuable in subsequent evaluations of constructed friction courses. These evaluations will be described later.

ASPHALT DRAINAGE

Literature review indicated an asphalt drainage test had been used by several highway departments for determining the asphalt content of friction course type mixes. This test involved making up samples of friction course mix with increasing asphalt content and placing the samples on an appropriate surface, i.e., Kraft paper, glass, or metal. These samples were then placed in an oven at 140^{O}F for time periods ranging from overnight to 24 hours. Afterwards, the samples were removed from the oven, allowed to cool, and the amount of drainage to the interface observed. According to the literature, the amount of drainage that was recommended varied anywhere from 0 to 100 percent coverage of the interface.

It was felt that this test was not representative of the conditions under which asphalt drainage might occur. As a result, the test was modified by placing the samples in an oven for 2 hours at 250^{O}F. The samples are then removed, allowed to cool, and the amount of drainage observed. Figures 7 and 8 show a series of samples and the amount and type of drainage that occurred. An average value of 50 percent coverage was used to evaluate mixes made with different asphalts and types of aggregates. A laboratory study of three asphalts and three aggregate types indicated that the asphalt drainage test was sensitive to only one of these aggregates in the sense that a 50 percent coverage level fell within a reasonable asphalt content based on practical experience in construction. It is recognized that the adopted 50 percent coverage level is not absolute, but some of the series of tests indicated the 50 percent coverage level was not observed at asphalt contents of 9 and 10 percent. Because of this and the subjective nature of the evaluation, the asphalt drainage test has been recommended only as a secondary validation test or for obtaining additional information about undesirable drainage characteristics of the asphalt and the aggregate to be used in a particular job.

SURFACE AREA CHARACTERISTICS

An evaluation of aggregate surface area characteristics involved determining the aggregate surface area constants using the California Kerosene Equivalency Test Method 303-F. In using these aggregate surface area constants along with the relationship 2K + 4.0, it was found that the coarse aggregate fraction surface constant K_c could be used to obtain an estimate of asphalt content. Some data reflecting estimates of asphalt content for laboratory aggregates using this relation are shown in Figure 9. The reasonableness of the estimate of asphalt content was evaluated by results of the asphalt drainage test, water permeability, and field observations during construction that indicated this relationship could be used with confidence. Figure 10 shows laboratory permeability data used in the above evaluation.

FIELD EVALUATION OF FRICTION COURSES

During construction, there are three variables that affect performance and appearance of this type mix. They are gradation, asphalt content, and mixing temperature or viscosity. When the gradation varies or excess asphalt is placed in the mix, or the mix is manufactured at too high a temperature or viscosity, problems occur such as drainage of asphalt to the lower portion of the mix being hauled or drainage in the laydown machine hopper creating "rich" spots in the pavement.

The philosophy of arriving at a reasonable asphalt content after the asphalt-aggregate system has been characterized considers the fact that a

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constant gradation would allow use of a reasonable asphalt content and result in a given asphalt film thickness at a given temperature. Figure 11 shows the function of the asphalt in the friction course. The film thickness and amount and rate of the asphalt drainage can be controlled by the mixing temperature or viscosity. However, the film thickness and asphalt drainage can also be affected by the amount of asphalt selected at a given constant temperature. Asphalt drainage will occur when asphalt is available in excess of that needed for the film at the constant temperature. The amount and rate of drainage can be increased by increasing the asphalt content. However, an upper limit on binder content occurs when the film thickness that is necessary to hold aggregate particles in place is exceeded. When this condition exists, mix consistency is lost and aggregate particles can be removed easily from the mix while the mix is still at a mixing and compaction temperature.

The friction course should not be placed on pavements that are structurally unsound. Experience has shown that they will not restrict or reduce reflective cracking. In fact, a friction course applied to an inadequate pavement structure will result in debris and continuing maintenance problems.

The WES evaluation program of airport friction courses consisted of conducting in-place permeability tests, friction measurements using the British Portable Tester, laboratory permeability tests, extractions, determination of asphalt content, gradations, recovery tests, viscosity at 140°F, 225°F, and 275°F, and penetration at 77°F. Where possible, testing was done both in and out of traffic. These evaluation tests were conducted over a 3-year period including 1973, 1974, and 1975. A summary is shown in Tables 1, 2, and 3.

After evaluation of the permeability data, a reasonable minimum desirable permeability of 1000 ml/min was adopted. These criteria were correlated with voids total mix and percent passing the No. 8 sieve. The data are shown in Figures 12 and 13. The correlation of this data indicated that the 1000 ml/min flow could be attained at an 82 percent confidence level with a maximum 20 percent passing the No. 8 sieve and a 30 percent voids total mix.

A recommended friction course gradation for airports reflecting the above correlation and the current friction course gradation for highways recommended by the FHWA are shown here:

Sieve Size	FAA	Highway
½ in.	100	100
3/8 in.	80–100	100
No. 4	25–40	30–50
No. 8	12–20	5–15
No. 200	3– 5	2– 5

For airport friction course, job mixing temperatures and original asphalt viscosity data were used to arrive at a recommended mixing viscosity of 275 ± 25 centistokes. The FHWA recommends a mixing viscosity range of from 700 to 900 centistokes. There is significant difference in these two

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mixing ranges. The philosophy of the mixing viscosity range for airports is predicated on obtaining some drainage to the interface with the underlying pavement and still maintaining an adequate asphalt film thickness at the asphalt content selected from the 2K + 4.0 relation. The procedure for selecting the asphalt content recommended by the FHWA also includes the above relation, and at the higher mixing viscosity range, the chance for drainage of excess asphalt would be better.

CONSTRUCTION

Care must be taken to maintain a continuous flow of aggregate to the asphalt plant to prevent temperature fluctuations. The state of North Carolina originally used a specification that allowed 0 to 5 percent passing the No. 200 sieve. This has been changed to require a minimum of 2 percent passing the No. 200 sieve. This increases in fines has aided in maintaining a constant temperature as well as providing a matrix with which the aggregate is coated. Obviously, smoothness of the finished pavement is also related to continuity of operations. The small amount of fine aggregate in this mix means lower moisture content which aids in the mix production rate. Wide-width paving is also recommended so that the asphalt plant can operate at a normal production rate. The ¾- to 1-in. thickness of friction course at 10- to 12-ft lane widths results in a low production rate and start and stop operations of the asphalt plant with a poor control of mix proportions and temperature.

Most agencies use a tack coat that consists of about 0.5 gal per square yard of a type SS-1 emulsion. If the emulsion is diluted with equal parts of water, 1.0 gal per square yard is applied.

A significant proportion of compaction is obtained by the laydown machine screed. Since this is a characteristics of this mix, temptation to speed the paver should be resisted. If minimum drainage is desired, the roller should stay close to the paver; as when the mix is compacted, asphalt drainage is stopped. Where some drainage is desired, the roller should be held back a few minutes. One to two passes of a steel-wheel roller is satisfactory. Minimum distortion of the friction course under the roller can be expected. Handwork can be accomplished with ease.

The greatest number of complaints about this mix are those of the mix adhering to truck bodies during transit, and this condition becomes more severe as the length of haul is increased. This can be minimized if the mix is transported in trucks with smooth dump beds that have been sprayed with a nonpetroleum release agent. There have been instances where silicone has been added to the release agent, improving the discharge of the material from the truck. When temperatures are cool or the haul time is more than a few minutes, the mix should be covered during transportation to prevent cooling and the formation of lumps that could distort the roadway surface.

There are ambient temperature limitations on construction of friction courses. The pavement is thin with high voids. This contributes to cooling. Cold base and air temperature greatly reduce the workability of the friction course. Friction course specifications by various agencies included seasonal limitations, i.e. ambient temperatures of 60°F, or base temperatures of 60°F.

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SUMMARY

The performance of the friction course mix has been outstanding. Region 9 of the FHWA conducted an evaluation of the coefficient of friction of all types of pavement surfaces. Overall, 738 tests were conducted of which 211 were on friction course. The friction couse had the highest coefficient of friction of any pavement with an average value of 0.52. The results of extensive research on stopping distances on various types of aggregate conducted by the Louisiana Highway Department are shown in Figure 15. The traffic carried by this project was approximately 80,000 vehicles per day. In North Carolina, smoothness as measured with the BPR Roughometer has had values in the 30 in. per mile range on some friction courses, and the vast majority of all projects in North Carolina are in either the high 40 or low 50 in. per mile values.

The limitations of the mix are related to its void content. It is susceptible to oil and gasoline drippings, making it unsuitable for parking areas and streets with slow-moving traffic. When it is placed in the cool weather or the fall in areas where the use of tire chains are prevalent, it has been damaged during the first winter's use. This condition can be minimized by placing the mix early in the summer to allow hardening of the surface when it is to be constructed in these areas. In a paper presented at the 1976 Association of Asphalt Pavement Technologists meeting, MAJ Robert Boyer of the United States Air Force stated that icy conditions had not been detrimental to the use of this mix for airfield paving where the transverse slope exceeded 1 percent.

Even with recognition of the limitations, this mix provides a surface for both airfields and highways that must be considered for the traveling public.

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Table 1

1973 PFC Evaluation

Site No.	Location	Traffic Area	Asphalt: Viscosity, 10^2 cSt, at Cited Mixing Temperature 140°F	225°F	275°F	Penetration 1/10 mm	Content* Percent	Percent Aggregate Passing Cited Sieve Size: 3/4 in.	1/2 in.	3/8 in.	No. 4	No. 8	No. 16	No. 50	No. 200	Flow Rate for Falling Head Permeability ml/min: Field	Laboratory	Average Skid Resistance BPN**: Dry	Wet
4	NAS, Dallas	In	24,508	67.73	9.06	16	5.4	100	100.0	100.0	41.1	16.6	7.5	3.5	1.7	2662		94	56
		Out	--†	--†	--†	--†	--†	100	100.0	100.0	47.2	18.7	8.0	4.0	2.4	4288		92	68
5	Kirtland AFB††																		
	Test section 1	Out	2,507	18.64	3.56	49	4.8	100	81.6	57.0	30.8	25.4	18.7	11.2	7.1	861	Replicate tests indicated water impermeable surface	96	83
	Test section 2	Out	11,437	41.69	6.21	24	5.4	100	92.1	76.1	48.5	27.7	19.0	11.6	8.3	1429		87	72
	Test section 3	Out	2,493	18.53	3.38	44	5.3	100	100.0	95.9	55.0	35.1	26.6	17.7	12.0	406		85	67
	Test section 4	Out	2,174	17.96	3.52	47	5.1	100	98.4	83.4	46.2	30.6	21.6	13.3	8.9	121		88	72
	Test section 5	Out	12,293	43.16	6.96	30	5.2	100	90.6	66.9	33.0	21.9	16.7	11.7	8.3	708		94	72
	Test section 6	Out	8,617	37.29	6.07	32	5.5	100	95.9	85.8	51.6	34.8	26.0	16.4	11.0	78		90	71
	Test section 7	Out	4,836	26.99	4.83	34	5.7	100	96.3	87.7	70.4	58.5	43.2	25.2	16.6	0		80	66
	Test section 8	Out	16,052	49.84	7.24	24	4.3	100	53.5	29.6	24.4	21.0	17.4	10.2	5.8	--‡		82	61
6	Great Falls	In	9,744	35.06	5.60	34	6.2	100	98.3	93.7	40.1	20.0	13.8	8.5	4.2	3710		99	80
		Out	--†	--†	--†	--†	--†	100	100.0	97.8	43.2	19.1	11.4	7.0	4.3	3574		100	76
7	Stapleton	In	6,185	40.07	7.00	42	6.3	100	100.0	99.4	46.4	22.1	16.0	9.8	5.8	602		93‡‡	74‡‡
		Out	5,618	38.28	6.61	45	--†	100	100.0	98.2	40.4	20.7	15.7	9.1	5.1	2334			
8	Bartlesville	In	56,443	111.56	13.97	29	5.9	100	100.0	99.3	46.0	25.8	16.4	9.2	6.1	1202		99	75
		Out	47,318	101.38	13.10	28	--†	100	100.0	98.6	44.3	21.6	13.5	7.2	4.4	2122		94	79
9	Salt Lake City	In	10,880	58.52	8.90	31	--†	100	84.6	63.1	25.1	12.1	7.5	3.1	1.5	3101		94	64
		Out	5,072	37.04	8.58	29	4.6	100	79.9	58.0	23.6	12.6	8.3	3.2	1.5	4039		100	73

Note: Pease AFB, Hot Springs Airport, and Nashville Metropolitan Airport were not included in the 1973 evaluation.

* Based on amount extracted from field core.

** The BPN (British Portable (Tester) Number) represents the frictional property of the PFC as determined using ASTM E 303-69.

† Not enough material was available to conduct this test both in and out of traffic area.

†† Due to the limited amount of traffic applied to the test sections, it was assumed that the results were indicative of an out of traffic area.

‡ Permeability was too high to measure.

‡‡ Value is average BPN for the test section at Stapleton; access to the runway itself was restricted.

Table 2

1974 PFC Evaluation

Site No.	Location	Traffic Area	Asphalt: Viscosity, 10^2 cSt, at Cited Mixing Temperature 140°F	225°F	275°F	Penetration 1/10 mm	Content* percent	Percent Aggregate Passing Cited Sieve Size 3/4 in.	1/2 in.	3/8 in.	No. 4	No. 8	No. 16	No. 50	No. 200	Flow Rate for Falling Head Permeability ml/min Field	Laboratory	Average Skid Resistance BPN** Dry	Wet
1	Pease AFB	In	4,149	28.91	4.98	52	5.0	100	100.0	91.3	38.0	19.6	13.4	7.7	4.8	476		94	60
		Out	5,535	34.02	5.83	45		100	100.0	95.5	42.6	23.9	16.5	8.5	5.0	2031		94	72
2	Hot Springs	In	8.158	40.40	6.46	33	5.2	100	100.0	98.8	31.7	13.9	9.1	5.8	3.8	3000	Replicate tests indicated water impermeable surface	94	72
		Out	10,828	56.99	6.90	--†	--†	100	100.0	98.7	40.5	15.5	9.9	5.8	3.9	4800		95	74
3	Nashville	In	6,151	31.25	5.37	38	6.6	100	100.0	99.7	51.5	29.3	17.2	6.3	2.2	108		94	52
		Out	11,139	45.64	6.93	26	--†	100	100.0	100.0	47.8	29.8	20.2	12.6	10.0	1403		88	73
4	NAS, Dallas	In	36,892	79.96	10.18	12	5.7	100	100.0	100.0	38.3	14.1	6.8	3.4	2.4	3216			68
		Out	55,593	98.00	11.88	11	--†	100	100.0	100.0	48.9	20.2	8.3	3.5	2.2	3675		95	66
5	Kirtland AFB††																		
	Test section 1	Out	6,323	27.52	5.00	27	4.6	100	89.7	65.0	35.6	30.1	23.0	13.6	8.2	363		87	63
	Test section 2	Out	13,022	40.85	6.20	22	5.5	100	90.6	79.6	54.0	34.5	26.6	14.9	8.4	1265		83	67
	Test section 3	Out	20,264	48.39	7.21	20	5.3	100	100.0	88.4	49.7	31.0	22.7	14.2	9.0	67		84	63
	Test section 4	Out	4,292	22.53	3.93	32	4.7	100	98.8	92.8	51.2	32.9	25.1	16.8	10.4	33		81	67
	Test section 5	Out	5,850	25.93	4.80	32	3.8	100	86.1	59.3	29.4	20.6	15.8	11.1	7.4	373		82	66
	Test section 6	Out	4,892	23.63	4.31	31	4.3	100	97.6	85.9	48.3	32.3	22.6	14.5	10.1	0		83	62
	Test section 7	Out	--	--	--	--	--	--	--	--	--	--	--	--	--	--		82	68
	Test section 8	Out	13,201	45.20	6.31	23	4.0	100	56.1	25.9	17.7	15.7	12.4	8.9	6.2	--‡		80	63
6	Great Falls	In	10,809	39.24	6.09	27	6.4	100	95.8	85.5	41.5	25.9	20.0	11.8	4.1	1354		95	76
		Out	24,320	61.20	7.99	23	--†	100	100.0	97.0	40.9	18.4	11.2	7.1	4.2	2058		98	83
7	Stapleton	In	11,035	38.58	6.81	38	6.6	100	100.0	99.6	43.9	22.2	16.2	9.2	4.6	67		98	62
		Out	5,500	53.67	8.62	33	--†	100	100.0	97.8	47.8	24.5	18.1	9.8	4.7	719		94	74
8	Bartlesville	In	172,924	218.64	21.92	22	5.6	100	100.0	98.6	44.7	23.7	15.2	8.6	5.8	1539		95	67
		Out	146,148	195.36	23.36	22	--†	100	100.0	99.3	47.4	22.3	13.6	7.1	4.4	1452		96	67
9	Salt Lake City	In	16,667	66.33	10.21	23	5.6	100	89.4	68.1	28.7	14.4	9.4	4.6	2.5	641		--‡‡	61
		Out	16,636	64.24	10.06	23	--†	100	78.1	58.5	24.3	14.9	10.9	6.0	3.4	3027		--‡‡	65
10	Greensboro§	In	--	--	--	--	6.5§§	--	--	--	--	--	--	--	--	--		--	--
		Out	--	--	--	--	--	100	100.0	97.0	38.0	15.7	--	--	2.0	4824		90	63

* Based on amount extracted from field core.
** The BPN (British Portable (Tester) Number) represents the frictional property of the PFC as determined using ASTM E 303-69.
† Not enough material was available to conduct this test both in and out of traffic area.
†† Due to the limited amount of traffic applied to the test sections, it was assumed that the results were indicative of an out of traffic area.
‡ Permeability was too high to measure.
‡‡ Surface was too wet to measure dry BPN.
§ Newly constructed pavement.
§§ Design asphalt content.

Table 3

1975 PFC Evaluation

Site No.	Location	Traffic Area	Asphalt: Viscosity, 10^2 cSt, at Cited Mixing Temperature 140°F	225°F	275°F	Penetration 1/10 mm	Content* percent	Properties of Mix: Percent Voids Total Mix	Density pcf	Percent Aggregate Passing Cited Sieve Size: 3/4 in.	1/2 in.	3/8 in.	No. 4	No. 8	No. 16	No. 50	No. 200	Flow Rate for Falling Head Permeability ml/min: Field	Laboratory
1	Pease AFB	In	3,344	28.45	5.27	46	4.9	27.2	119.2	100**	100**	94.8**	40.2**	22.2**	14.4**	7.6**	4.5**	No flow	542
		Out	4,243	26.80	5.05	49	5.2	28.2	114.2										1591
2	Hot Springs	In	12,852	48.31	7.48	30	5.2	32.3	109.3	--	--	--	--	--	--	--	--		2490
		Out	20,765	66.85	9.48	25	5.0	39.3	96.7	--	--	--	--	--	--	--	--		3859
3	Nashville	In	7,775	35.97	6.02	31	6.3	17.1	128.0	--	--	--	--	--	--	--	--		--
		Out	18,213	59.75	8.04	24	5.4	31.0	108.0	--	--	--	--	--	--	--	--		12861
4	NAS, Dallas	In	59.706	99.00	12.36	8	5.3	41.0	104.1	100	100	100	37.1	13.3	6.1	3.0	2.1		2412
		Out	71,979	110.02	13.02	9	5.0	42.9	101.2	100	100	100	47.7	19.6	7.9	3.5	1.9		3508
5	Kirtland AFB††																		
	Test section 1	Out*	8,330	32.08	5.37	31	5.0	24.3	121.5	100	91.3	68.9	40.6	35.0	26.9	15.0	8.4		1591
	Test section 2	Out*	8,237	37.50	6.09	21	4.6	26.0	119.2	100	90.6	75.8	46.8	25.8	18.1	11.8	8.2		853
	Test section 3	Out*	19,549	49.39	7.42	20	5.0	21.8	126.6	100	98.0	89.7	48.8	30.5	21.4	12.9	7.9		300
	Test section 4	Out*	5,742	21.06	3.90	36	4.6	27.5	118.3	100	98.6	90.2	51.9	33.5	25.1	16.6	10.1		19
	Test section 5	Out*	6,693	25.55	4.95	28	4.7	30.3	112.7	100	89.6	73.8	41.2	29.2	22.5	13.9	8.1		780
	Test section 6	Out*	5,616	24.77	4.58	28	5.0	24.6	123.6	100	99.3	88.9	50.9	34.2	23.8	14.6	10.0		111
6	Great Falls	In	2,944	30.22	5.13	34	6.7	17.7	123.4	100	100	95.1	39.4	18.9	12.6	8.0	4.2		776
		Out	16,872	48.81	7.03	25	5.8	28.6	108.6	100	100	95.9	45.2	20.5	12.5	7.5	4.4		3508
7	Stapleton	In	7,781	46.27	7.97	33	6.3	16.0	127.3	100	98.7	96.7	46.4	26.1	19.7	10.3	4.9		917
		Out	11,730	56.04	9.19	30	6.0	20.8	120.4	100	99.0	95.6	53.1	29.3	22.0	11.5	5.5		977
8	Bartlesville	In	217,062	235.37	24.44	21	5.6	24.3	113.6	100	100	99.2	44.8	24.1	14.9	8.4	5.6		1029
		Out	183,404	211.79	22.58	20	5.6	27.2	109.2	100	100	97.4	45.0	22.2	13.6	7.2	4.5		1575
9	Salt Lake City	In	34,674	121.14	16.12	15	4.6	24.1	145.4	100	87.7	69.7	32.9	16.5	10.5	5.5	3.1		1429
		Out	29,641	84.52	13.23	19	4.7	30.3	133.3	100	92.3	72.1	32.0	16.8	11.7	5.9	3.0		1354
10	Greensboro	In	5,549	39.08	7.30	49	6.0	28.9	112.9	100**	100**	98.1**	49.5**	19.0**	10.5**	4.8**	2.7**		2573
		Out	5,179	39.41	7.26	44	6.2	28.4	113.7										3508

* Based on amount extracted from field core.
** Due to limited amount of material available, combined gradation was run.
† Permeability decreased markedly on samples taken progressively toward runway center line.
†† Due to the limited amount of traffic applied to the test sections, it was assumed that the results were indicative of an out of traffic area.

C-12

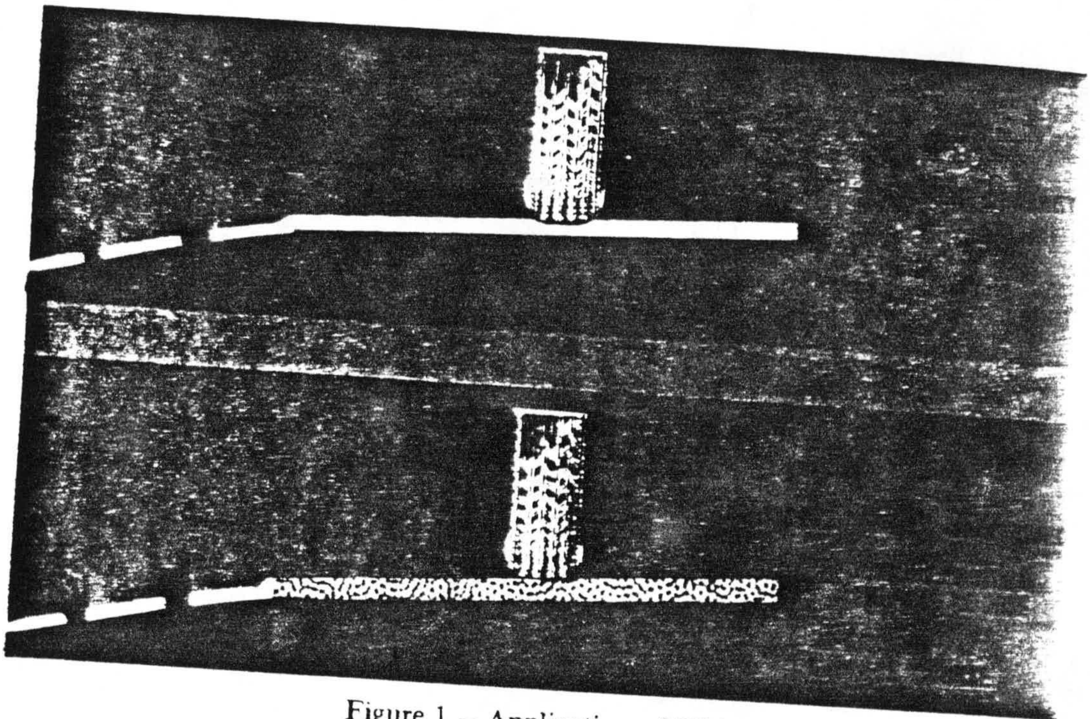

Figure 1 – Application of PFC

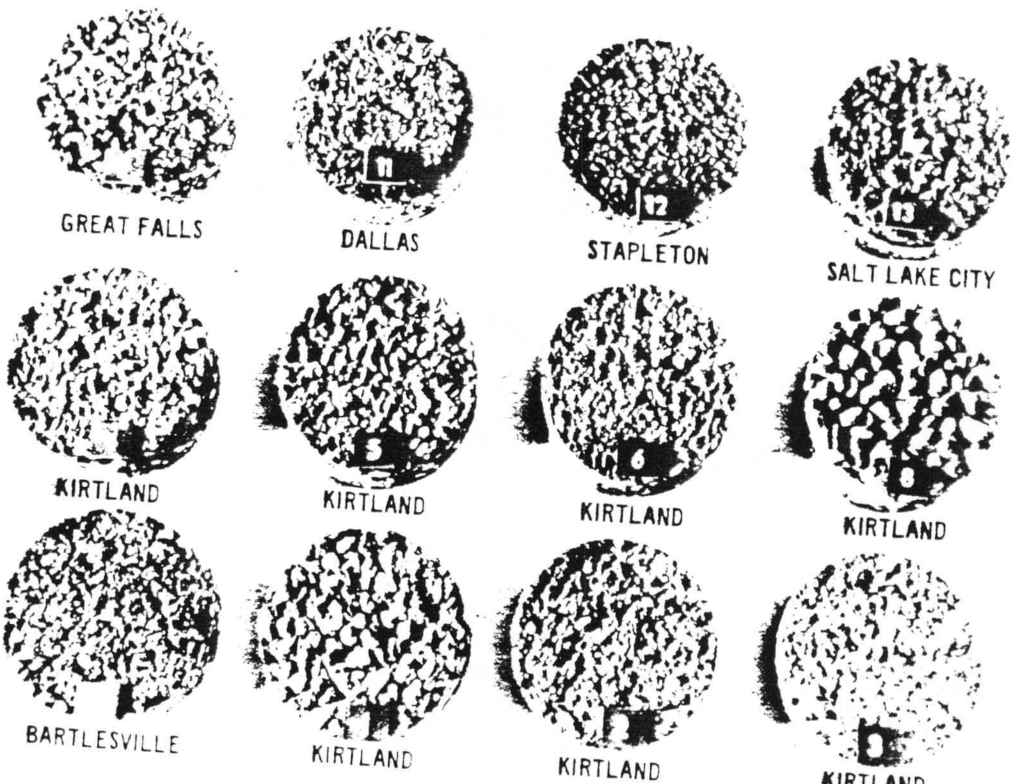

Figure 2 – Surface textures of PFC field cores

C-15

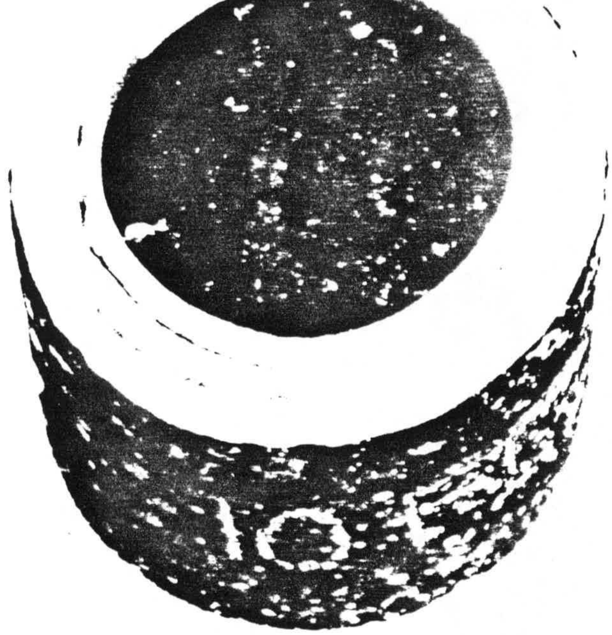

Figure 3 – ¼ in. falling head permeability test sample

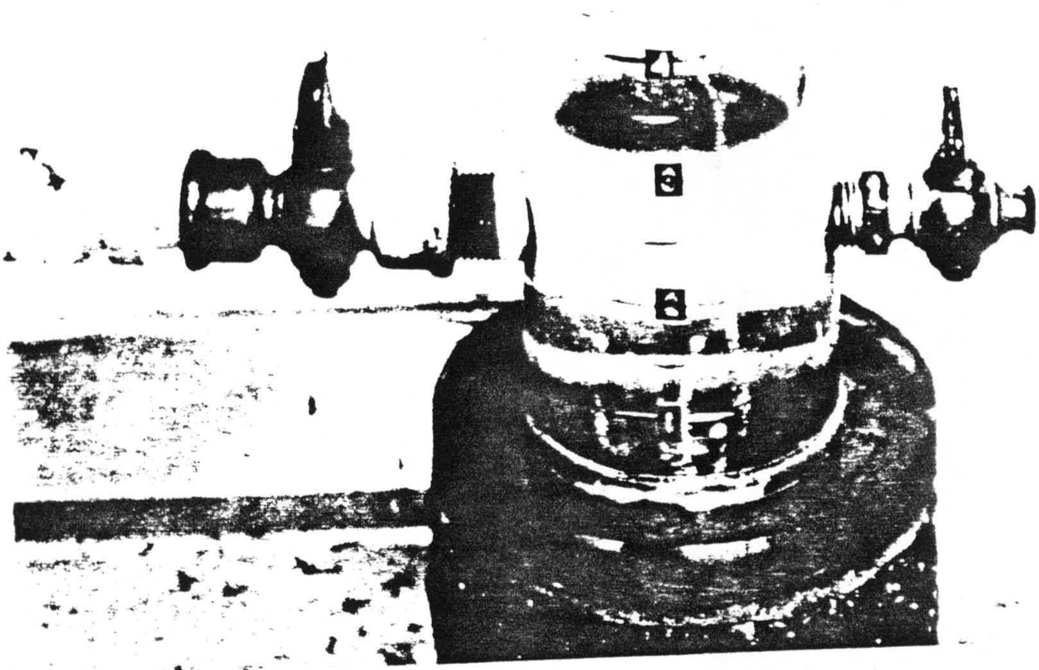

Figure 4 – Permeability apparatus on 4-in. -diam sample

C-14

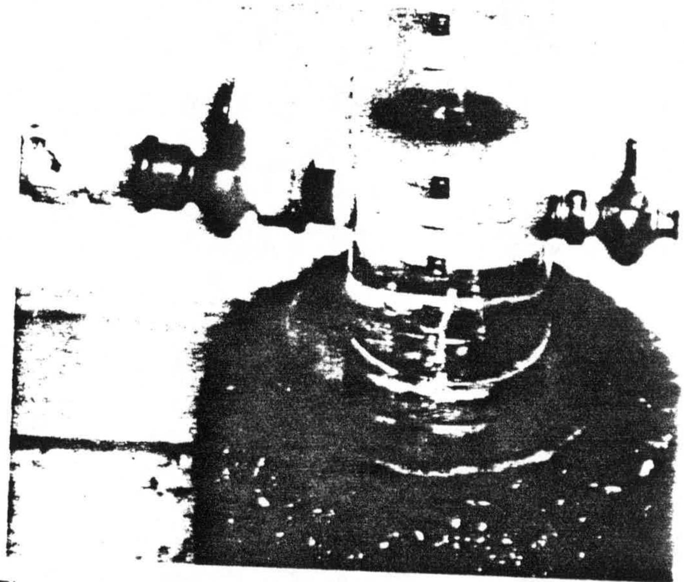

Figure 5 – Permeability apparatus on 6-in. -diam sample

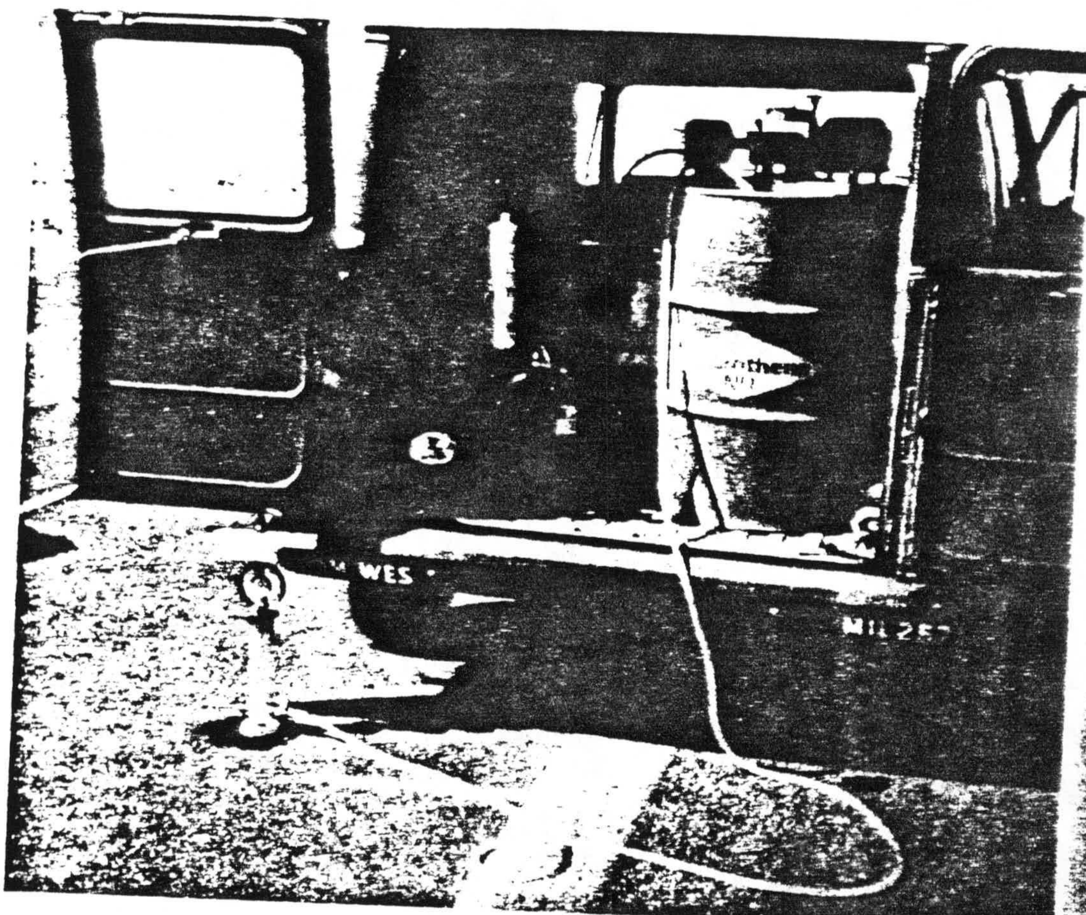

Figure 6 – Permeability apparatus

C-15

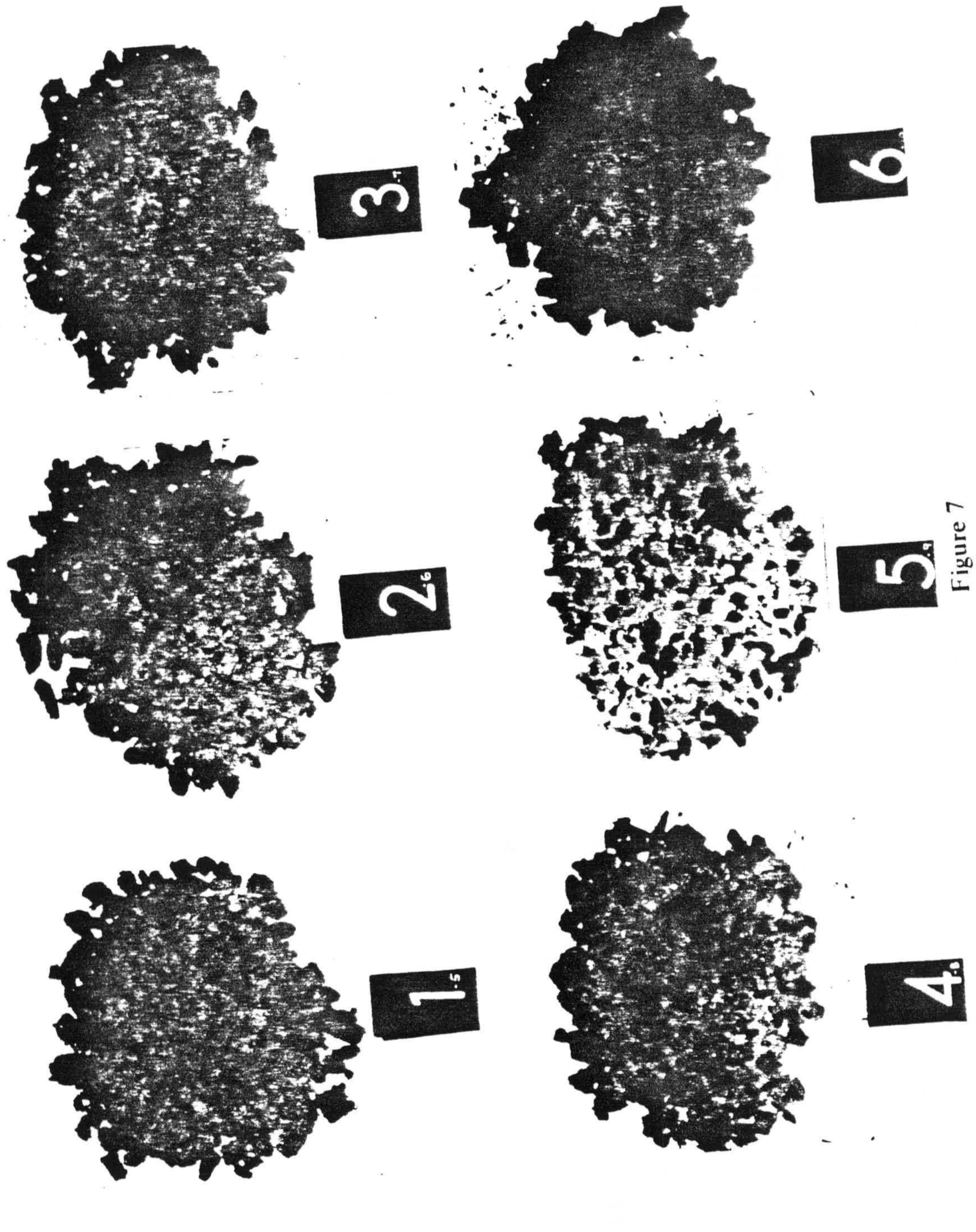

Figure 7

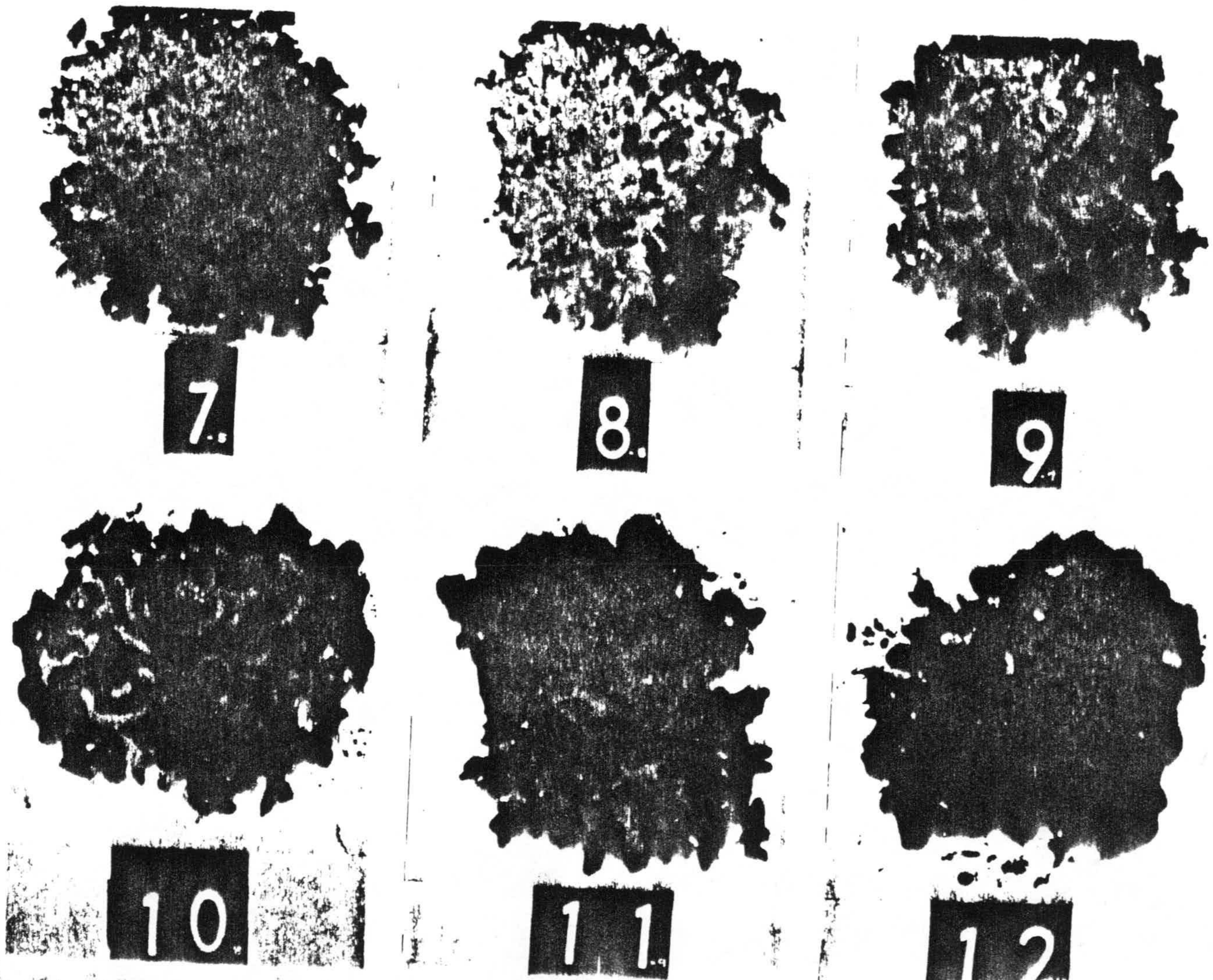

Figure 8

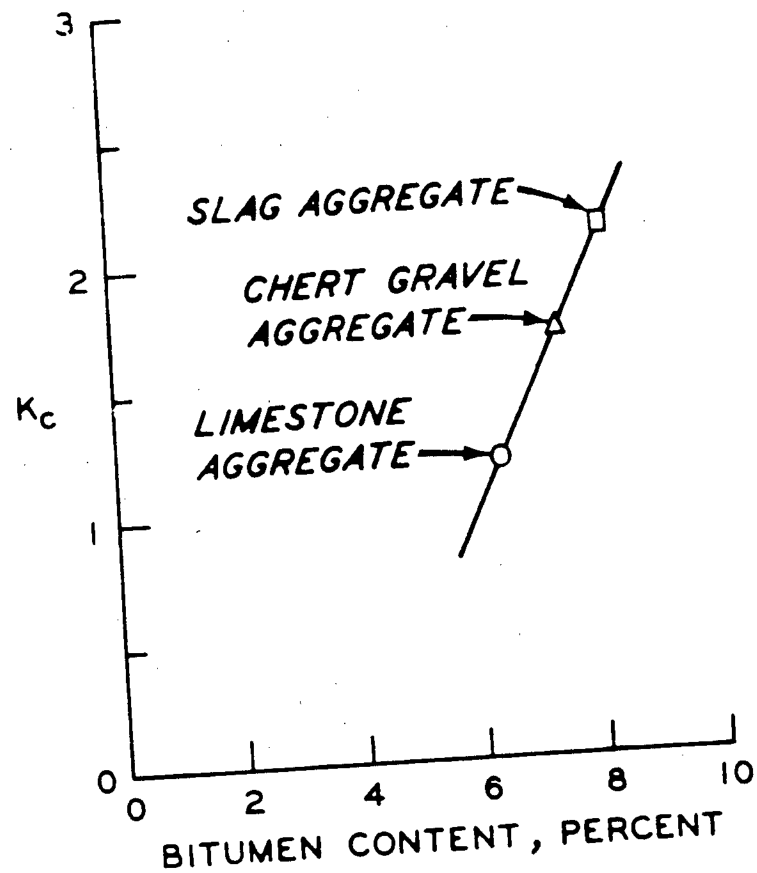

Figure 9 – K_c vs estimate of bitumen content

C-18

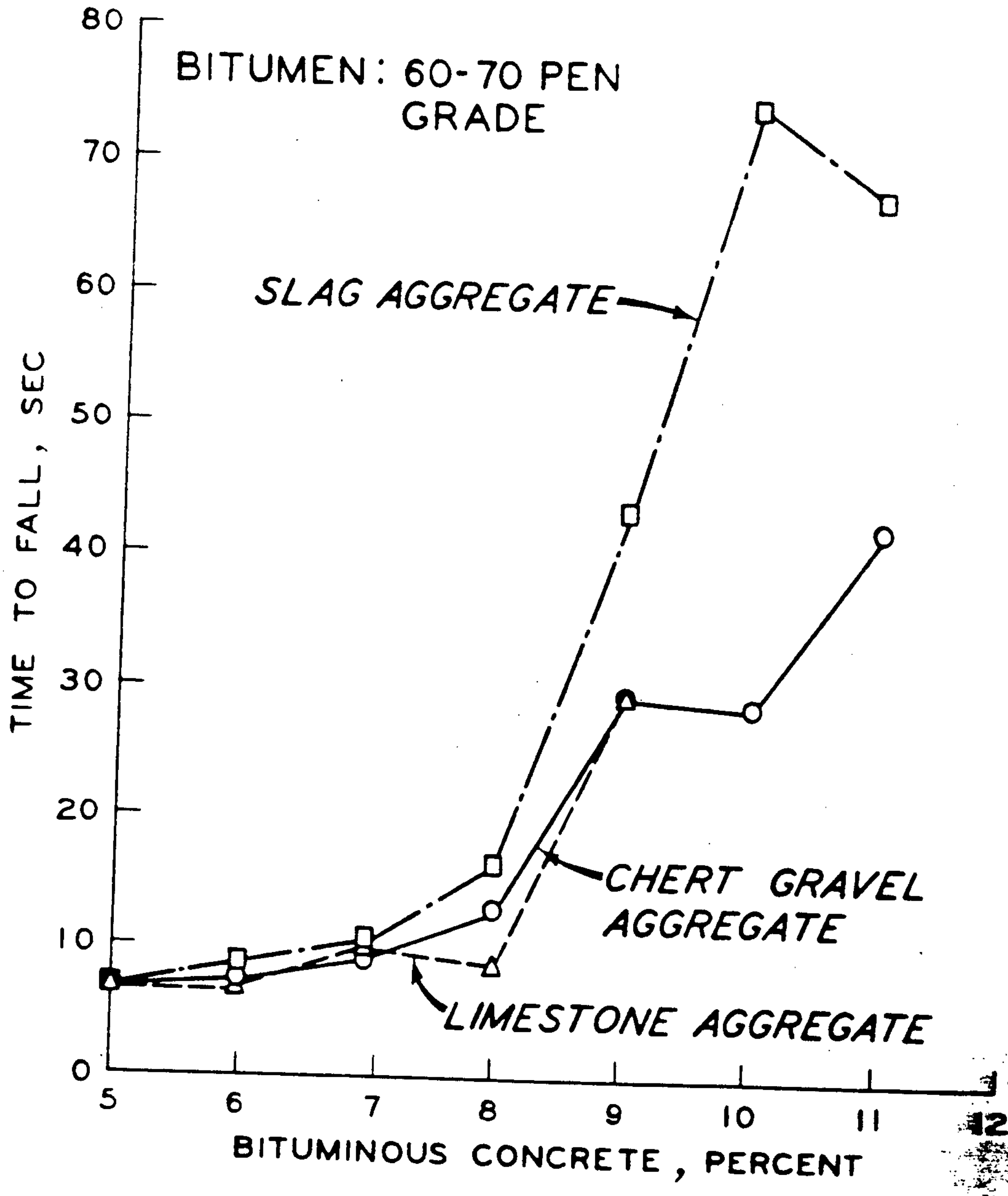

Figure 10 – Falling head permeability

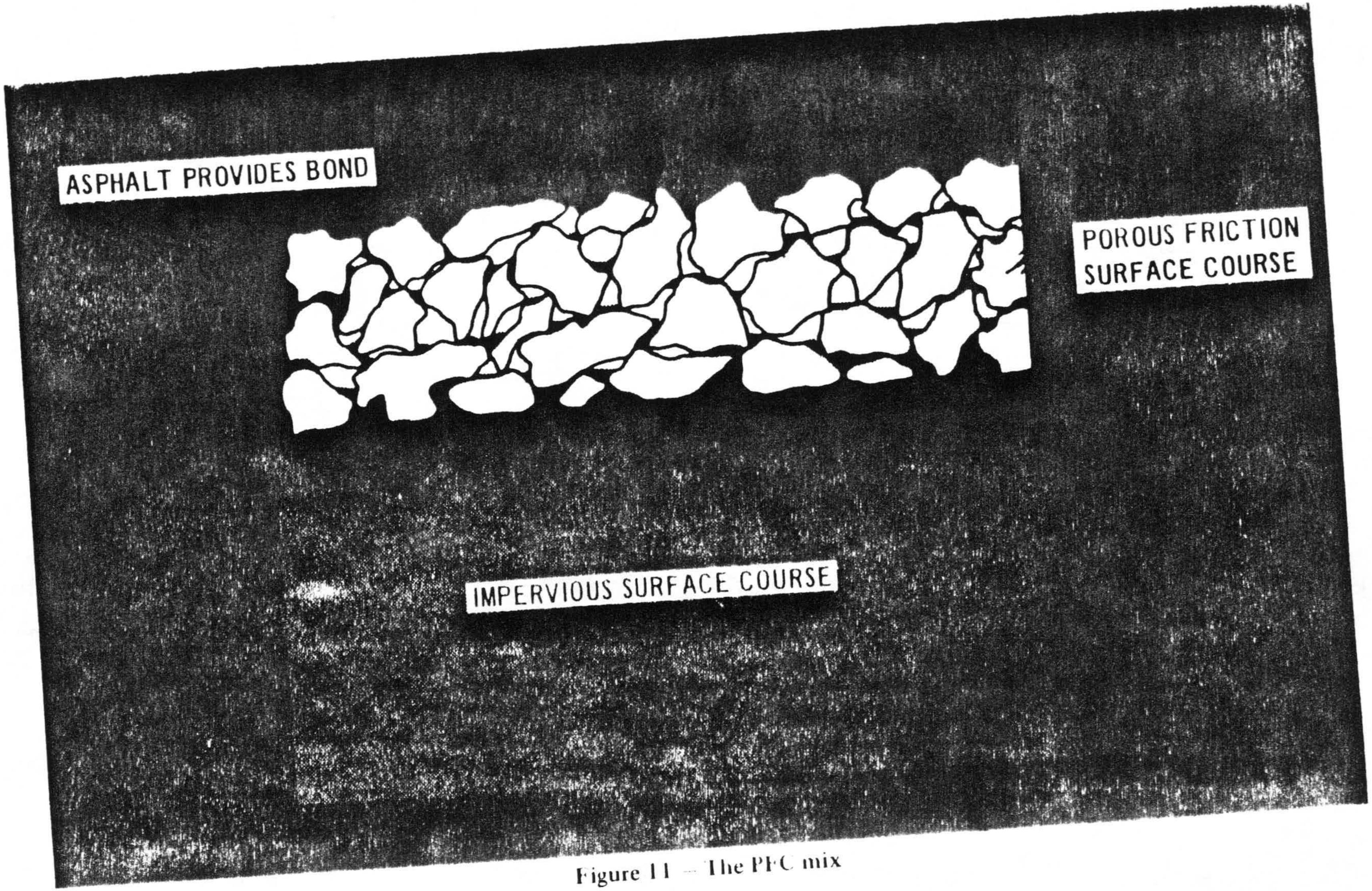

Figure 11 — The PFC mix

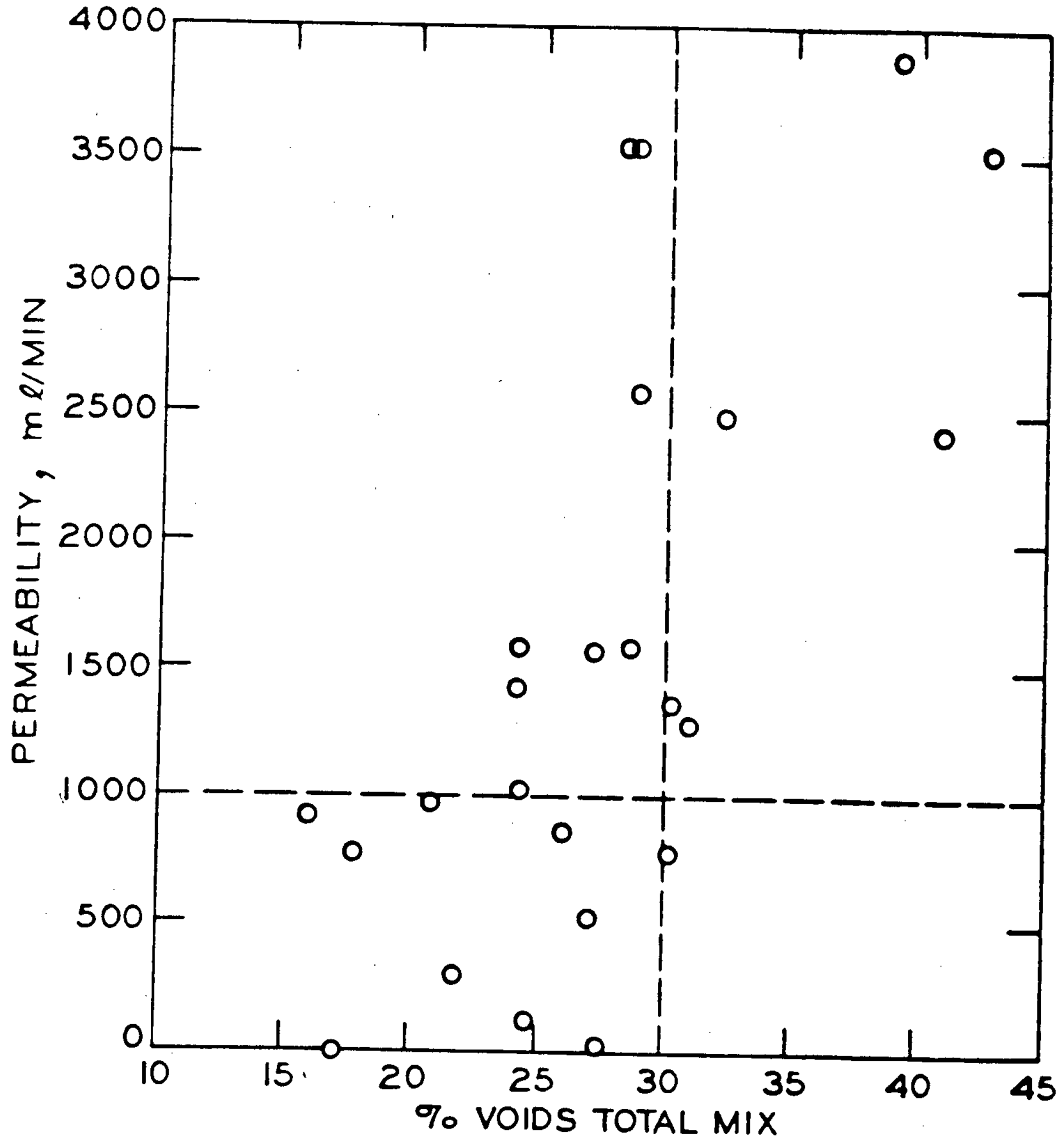

Figure 12 – PFC field permeability

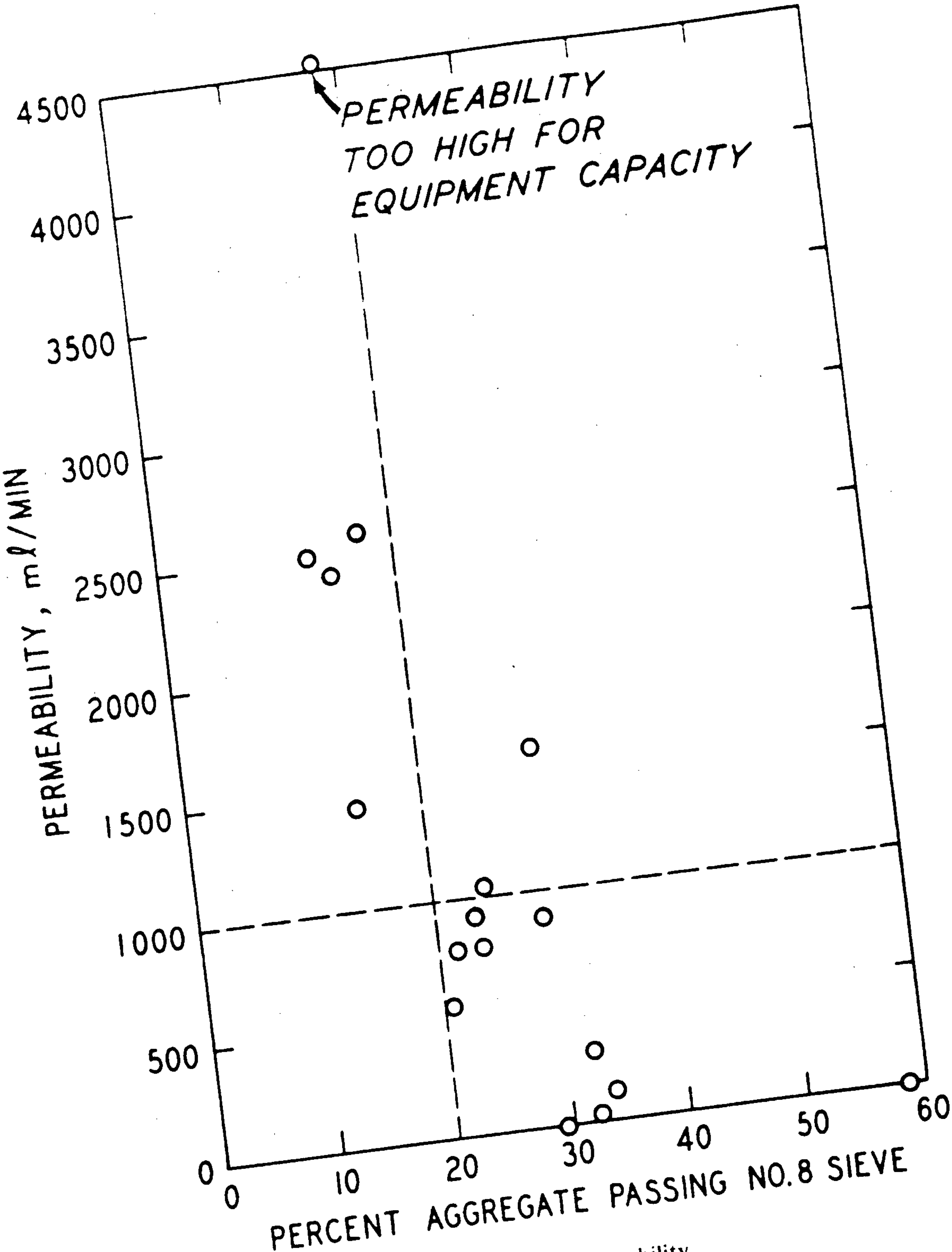

Figure 13 – PFC field permeability

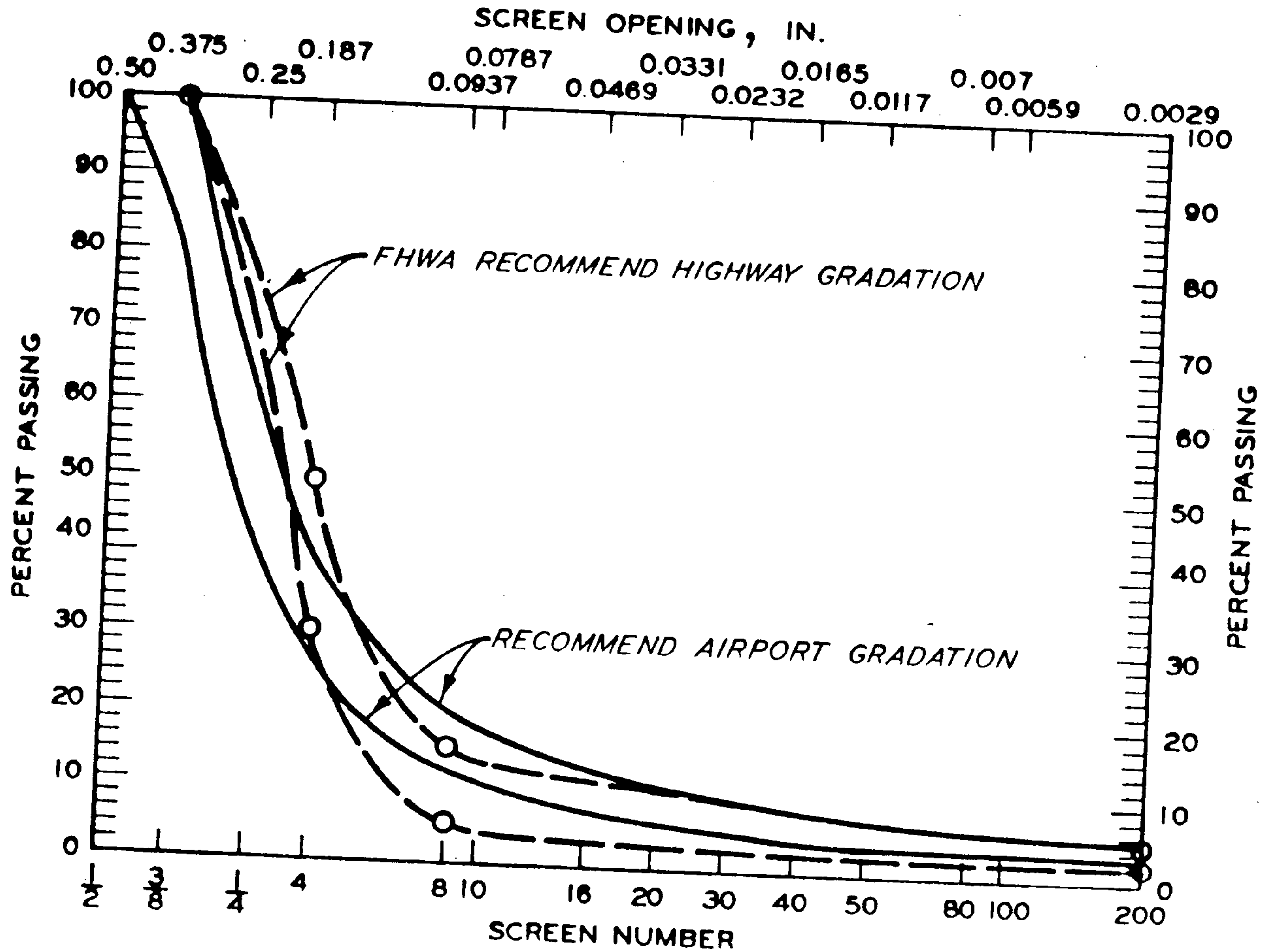

Figure 14 – Aggregate grading chart

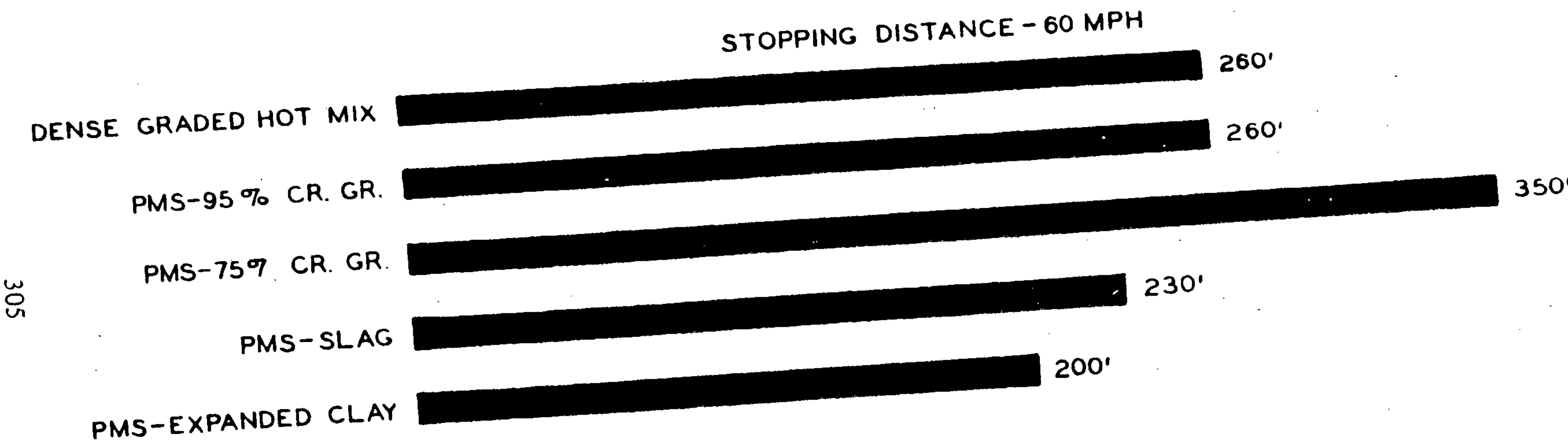

Figure 15 – Heavy traffic pavement 32 months

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NOVEMBER 1974

CL-10

CONSTRUCTION LEAFLET NO. 10
THE ASPHALT INSTITUTE
ASPHALT INSTITUTE BUILDING
COLLEGE PARK, MARYLAND 20740

GENERAL

An open-graded friction course* consists of a high-void, hot asphalt plant mix that permits rapid drainage of rainwater through the course and out to the shoulder. The mixture is characterized by a large percentage of one-sized coarse aggregate to ensure a minimum of 15 percent air voids. It prevents tire hydroplaning and provides a skid-resistant pavement surface.

Hydroplaning is a combination of circumstances resulting in tires being separated from the pavement by a thin film of water. This can occur with high speed and an accumulation of water on a smooth, impervious pavement surface.

In addition to preventing hydroplaning and providing a skid-resistant surface, open-graded friction courses offer other benefits:

- A minimum of material is used to provide skid resistance
- The riding quality of structurally sound pavements is extended
- Minor surface irregularities are corrected
- Quieter riding surfaces are provided
- Tire splash and spray are reduced
- Visibility of paint stripes and other pavement markings is improved in wet weather
- Night visibility (less glare from pavement surface) is improved during wet weather
- Traffic delays caused by construction are minimized.

There are some limitations. Open-graded friction courses must be placed in warm weather, as ambient temperatures for placing are critical. Surfaces on which they are placed must be impervious and reasonably smooth. They are susceptible to oil and gasoline drippings, making them unsuitable for parking areas and streets with slow-moving traffic.

*Several names are used for open-graded friction courses: plant-mix seal, porous friction course, popcorn mix, and others.

MIX COMPOSITION

Aggregate Grading

Aggregate grading requirements vary in different areas but generally it is agreed that difficulties are not experienced when the amount passing the No. 8 sieve does not exceed 15 percent and the amount retained between the No. 4 and the 3/8 in. (9.5 mm) sieves is at least 40 percent. The addition of mineral filler may aid in obtaining a thicker asphalt film, lessening the runoff of asphalt during hauling and placing of the mix and rendering mixing temperatures less critical.

Many different aggregate gradings are being used for open-graded mixes, and studies are underway to determine the most practical ones. Meanwhile, the following aggregate gradation and asphalt content range are suggested:

Sieve	Percent Passing	Sieve	Percent Passing
1/2 in.	100	3/8 in.	100
3/8 in.	90-100	1/4 in.	85-100
No. 4	30-50	No. 8	15-32
No. 8	5-15	No. 16	0-15
No. 200	2-5	No. 200	0-3
Asphalt Cement, % by wt. of dry aggregate	6.0 to 7.0*	Asphalt Cement, % by wt. of dry aggregate	5.0 to 6.5*

*Typical range. The proper asphalt content for aggregates with high or low specific gravities and aggregates that absorb asphalt may be above or below the typical range.

Aggregate Quality

The mineral aggregate must be highly resistant to polishing and apart from this requirement can be any sound, crushed aggregate having an abrasion loss [ASTM Test Method C 131 (AASHTO Test Method T 96)] of less than 45 percent. Mineral filler, if used, should be limestone, hydrated lime, or dolomite meeting the requirements of ASTM Specification D 242 (AASHTO Specification M 17).

Asphalt Grades

The recommended grades of asphalt cement for the paving mixture are AC-10 and AC-20; or AR-40 and AR-80, AASHTO Specification M 226. In areas where penetration grades are used, 60-70 and 85-100 penetration asphalt cements, AASHTO Specification M 20, are recommended. AC-40 or AR-80 is recommended for mixes used in extremely warm climates and areas of high traffic volume.

Asphalt Content Selection

The proper amount of asphalt is important to ensure bonding to the pavement and to prevent raveling. Also, if too much asphalt is used it may drain off in the truck during transport, be carried through the paver, and cause fat spots in the pavement.

Asphalt contents of open-graded mixes will normally range between 6.0 and 7.0 percent by weight of dry aggregate. The best asphalt content may fall outside this range, however, if absorptive aggregates or aggregates with apparent specific gravities outside the range of 2.55 - 2.75 are used. One method of determining the proper asphalt content is to mix trial batches in the laboratory and store them overnight at 140°F (60°C). The proper asphalt content is then selected by eye. A mix is selected from which a small amount of asphalt drains to the bottom of the pan and the mix still appears glossy. A heat-resistant, clear glass dish may be used for better visibility of the drained asphalt.

Another method is to determine a surface constant for the aggregate portion retained on the No. 4 sieve and, with this surface constant, compute the estimated asphalt content. Surface capacity is determined as follows:

(a) Place into a funnel, approximately 3-1/2 inches (90 mm) in diameter, exactly 100 g of dry aggregate passing the 3/8-inch (9.52 mm) sieve and retained on the No. 4 sieve (this fraction is considered to be representative of the coarse aggregate in the mix).

(b) Immerse sample and funnel in a beaker containing SAE No. 10 lubricating oil at room temperature for 5 minutes.

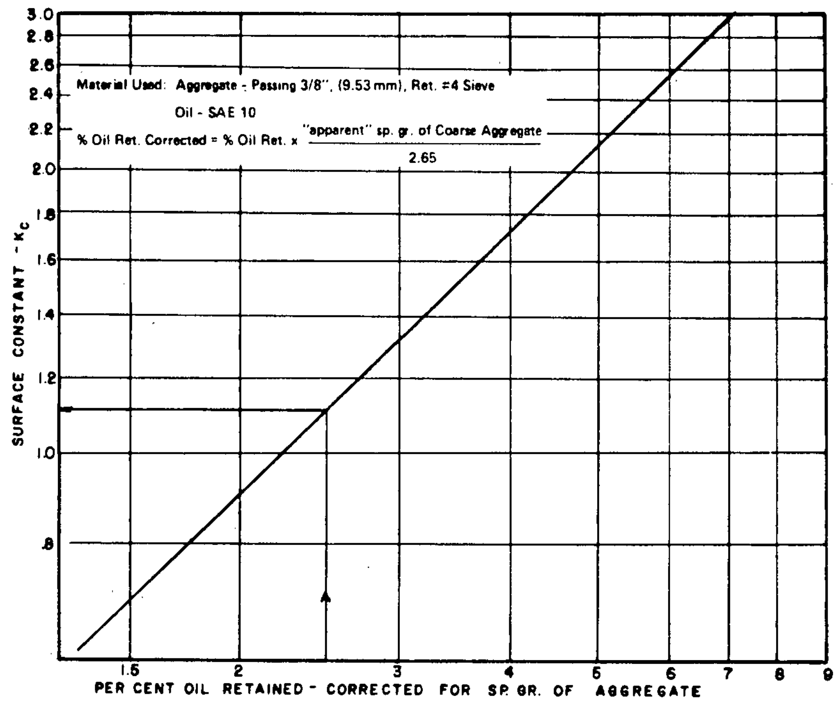
(c) Remove funnel and sample from oil and drain for 15 minutes at a temperature of 140°F (60°C).

(d) Weigh the sample after draining and determine the amount of oil retained as a percent of the dry aggregate weight. (Note: Duplicate samples are prepared to check results. Average value is used unless there is a large discrepancy, in which case the test is rerun.)

(e) Use chart in Figure below to determine the surface constant, K_c.

The estimated optimum asphalt content then is determined:

Asphalt Content, percent by weight of aggregate = $2.0 (K_c) + 4.0$.



Additives

In some cases, a heat-stable, anti-stripping additive may be required. Laboratory tests should be conducted to determine the need for an additive. Typically used is an amount of additive measuring 0.5 percent of the amount of asphalt cement.

Silicone, added to asphalt cement in the amount of 1 oz (30 mℓ) to 5,000 gal. (19 m^3), has been reported to improve the laydown and handling. Also, added to the truck body lubricant, it has been found to aid in preventing adherence of the asphalt to the truck bed.

PREPARATION OF EXISTING SURFACE

Repairs

Holes and depressions should be repaired by removing all loose and defective material to sound pavement and replacing with a proper hot-mix asphalt patching material. The patching mixture must be compacted to produce a tight surface conforming to the adjacent pavement area.

Excess asphalt in patches and joints should be removed by a pavement planing machine, a joint cleaning machine, or other approved method.

Cracks in a structurally-sound pavement, if wider than 1/8 in. (3 mm), should be filled with emulsified asphalt slurry or with a sand-asphalt mixture.

Leveling

When the old surface is extremely rough or uneven a leveling course of asphalt concrete should be placed prior to placing the open-graded mix.

Tack Coat

A tack coat may not be necessary if the open-graded mixture is to be placed on a clean, newly-laid asphalt course. But if a tack coat is needed SS-1, SS-1h, CSS-1, or CSS-1h emulsified asphalt, diluted with an equal amount of water, should be applied at the rate of 0.05 to 0.15 gal./yd^2 (0.23

to 0.68 ℓ/m^2) and allowed to cure before placing the wearing course. The tack coat should be applied on only as much pavement as can be covered with the open-graded friction course in the same day.

Immediately prior to application of the asphalt tack coat all loose and foreign material should be removed by sweeping or by blowing, or both.

CONSTRUCTION

Mixing Temperature

If its viscosity is too low, asphalt cement will drain off the aggregate, so it is necessary to maintain as low a mixing temperature as practicable while still obtaining coating of the aggregate. This is normally between 225°F (107°C) and 250°F (121°C).

Transporting the Mix

The mix should be transported to the job site in clean vehicles with smooth dump beds that have been sprayed with a non-petroleum release agent. It also is desirable to limit the time of haul to avoid drainage of the asphalt to the bottom of the truck bed. The mix should be covered during transportation to prevent cooling and the formation of lumps that could distort the roadway surface.

Placing the Mix

Placing the mix in an appropriate ambient temperature and on a surface sufficiently warm to minimize the risk of excessive cooling before completion of rolling is of paramount importance. Holding the aggregate particles in place is solely the function of the film of asphalt. The asphalt cannot perform this function properly if the mix is too cool when rolled.

The mix should be placed with an asphalt paver except in odd-shaped and other areas that are inaccessible to the machine. The minimum thickness should be 2 times the maximum size of aggregate in the mix. If any irregularities occur, they should be removed and replaced before rolling. Hand placing should be avoided except where it is absolutely necessary. Open-graded mixes not only are difficult to place and work by hand, but cool so rapidly that excess time used for placing by hand may result in a lack of bond between the particles of aggregate by the time the mix is ready to roll.

Compaction

A thin course compresses very little under the roller and, as it cools quickly, it must be rolled as soon as possible. A high degree of densification is not the goal with this type of mix - the aim is firm seating and contact of the aggregate particles. One or two coverages with a steel-wheeled roller weighing not more than 10 tons (9 metric tons) is sufficient. Additional rolling may be excessive, causing a break in the bond of asphalt between aggregate particles, particularly after the mix has cooled.

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E

11721 Glen Mill Road
Rockville, Maryland 20854
November 15, 1983

Messrs:

Bernard Kallas
Richard Langlois
Richard Meininger
David Tunnicliff

Gentlemen:

Enclosed are tabulations of Job-Mix Formulas for Open Graded Plant Mixtures (Friction Course), that I agreed, at the June ASTM Meeting, to send to you.

The specifications were selected more or less to cover states in different geographical areas.

I hope they will be of some value to you.

Sincerely yours,

York

J. York Welborn

E-2

Table 16: Job-Mix Formula - Open Graded Plant Mixtures (Friction Courses)

Table 16 shows the master range for gradation, asphalt content, mixing temperature, and allowable tolerances for the job-mix for open-graded plant mix friction courses (OGFC) used in 10 States, FHWA and AASHTO specifications.

For all agencies the maximum nominal size aggregate is either 1/2-inch or 3/8-inch. In most cases the smaller sizes are controlled by the No. 4, No. 8 and No. 200 sieves. Two States specify No. 16 and two specify No. 50 sieve sizes. The amount passing the No. 200 sieve varies from 0 to 5 percent. The asphalt contents range from 5 to 7 up to 6 to 12 per cent.

The aggregate gradings vary as illustrated below:

passing 1/2 inch sieve, % 85-100 to 100
passing 3/8 inch sieve, % 22-43 to 85-100
passing No.4 sieve, % 5-25 to 30-50
passing No.8 sieve, % 0-7 to 10-30
passing No.16 sieve, % 5-15 to 18-24
passing No.50 sieve, % 3-6 to 10-25
passing No.200 sieve, % 0-0.5 to 3-5
asphalt content, % 5-7 to 6-12

TABLE 16 JOB-MIX FORMULA - OPEN GRADED PLANT MIXTURES (FRICTION COURSES)

Aggregate Total Passing	ALASKA Range	ALASKA Tolerance	CALIFORNIA Range	CALIFORNIA Tolerance	GEORGIA Range		GEORGIA Tolerance		KENTUCKY Range		KENTUCKY Tolerance	LOUISIANA Range	LOUISIANA Tolerance		NEW YORK Range	NEW YORK Tolerance	UTAH (TYPE A) Range	UTAH (TYPE A) Tolerance
	Type II				D-I	D-II	D-I	D-II	Type I	Type II			1 Test	2 Test				
3/4 inch			100			100	±7										Ideal Mix	
1/2 "			88-100		100	90-100			100			100			95-100		100	0
3/8 "	100	±7	22-43	±7	85-100	40-75	±6.1	±6.1	90-100	100		90-100	±10	±7			97	±2
1/4 "															48-64	±5		
No. 4	30-50	±7			10-40	5-25	±5.7	±5.7	25-50	50-100	±6	20-50	±10	±7	8-18		40	±4
No. 8			2-3	±5	0-10	0-10	±4.6	±4.6	5-15	10-30	±4 (Type 2 only)	0-15					30	±3
No. 10													± 9	±6				
No. 16	5-15	±6															21	±3
No. 40																		
No. 50																	13	±2
No. 80																		
No. 100																		
No. 200					0-4	0-4	±2	±2				0-6	±3	±2	2-5		4	±1
Asphalt Cement					6.0-7.25	5.5-7.0							±.6	±.4	5-7.0		By Engineer	
Mixing Temp.													±25	±25°F	225-250			
Aggregate Temp.			Max. 275°F		Mix Temp. Delivered ±20°F from Job-Mix													

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TABLE 16 (Cont'd) JOB-MIX FORMULA - OPEN GRADED PLANT MIXTURES (FRICTION COURSES)

Aggregate	VIRGINIA (TYPE S-8)			WASHINGTON (CLASS D)		WEST VIRGINIA		FHWA		AASHTO	
	Range	Tolerance		Range	Tolerance	Range	Tolerance	Range	Tolerance	Range	Tolerance
Total Passing		1 Test	1/ 3 Tests	% Mix						3/	
3/4 inch											
1/2 "	100	±10	±5.6			100	±7.0	100	±7		
3/8 "	85-100	±10	±5.6	100		85-100	±5.0	85-100	±7		
1/4 "	15-32	±10	±5.6	30-50	±10						
No. 4		±9.0	±5.0	5-15	1/4" Sieve	30-50	±3.0	30-50	±7		±8
No. 8	0-7			-	±8	5-15		5-15	±6		±5
No. 10											
No. 16											
No. 40											
No. 50				3-7							
No. 80											
No. 100											
No. 200	0.0-0.5	±3.0	±1.7			2-5	±3.0	2-5	±2.5		±2
Asphalt Cement	6.0-12.0	±0.8	±0.41			As directed by Engineer		2/ 4-8	±0.5		±0.5
Mixing Temp.	210-250					250-325°F	Job Mix ±20°F				

1/ Tolerances for 2, 4 and 5 tests also given.
2/ Range in bituminous material for porous aggregate 4-12%.
3/ May aggregate temperature for viscosity of 800c$_s$t

REV 6/10/83-79

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(21)

THE DEVELOPMENT OF SPRAY-REDUCING MACADAM ROAD

SURFACINGS IN THE UK 1967-1987

by

D M COLWILL & M E DAINES, TRANSPORT & ROAD RESEARCH LABORATORY (UK)

ABSTRACT

With the development of the motorway system in the UK from the late 1950's, increases in traffic speeds and intensities have accentuated the problem of vehicle-generated spray. Although some reduction in spray dispersion can be achieved by improved mudguard design, a more effective solution is to use a permeable wearing course that acts both as a sponge and as a draining layer.

For roads, pervious macadam, using a 20mm size aggregate, was developed from the 10mm nominal size 'friction course' that originated in the 1950's to minimise aquaplaning on airfield runways. The evolution of pervious macadam has been primarily through a number of road trials that led to specification trials by the Department of Transport. The resulting specification for pervious macadam is included in the latest revision of British Standard 4987.

The material can be expected to have effective spray reducing properties for 3 years for a traffic flow of 7000 cvd (commercial vehicles per lane per day) or for 6 years for 2500 cvd.

In order to improve the long-term durability of the material and its economic viability, a road trial was started in 1984 to study the performance of pervious macadams with polymer-modified binders.

1. INTRODUCTION

The introduction of higher speed aircraft in the 1950's gave rise to the need for runway surfacings that were free from standing water capable of inducing aquaplaning and subsequent loss of control of aircraft during braking. The solution to this problem was found in a material, known as 'airfield friction course', which provided a free-draining surfacing. The maximum size aggregate used in this application was 10mm so that damage to jet engines by any loose chippings was minimised. This concept was subsequently adapted to roads because increasing traffic flows and speeds gave rise to the hazard of reduced visibility from spray.

In the UK roads are wet for between quarter and half of the year, depending on location. Estimates of accidents in which spray is a contributory factor vary from 1.3 to 10 per cent of all wet-road accidents (1) (2). Szatkowski and Brown (3) have estimated the cost of accidents caused by spray to be about one-third of that of accidents caused by skidding on wet roads. There are other detrimental aspects of spray that are less easily quantifiable; these include the stress on drivers on high-speed roads, particularly in the overtaking situation, and the nuisance to cyclists and pedestrians in urban areas.

Limited benefit of spray reduction can be achieved by improved design of mudguards on commercial vehicles but a more effective solution is to use a water-permeable 'pervious' wearing course that acts as a sponge and draining layer. To be effective a pervious wearing course must retain a free-draining structure. In general, this is more difficult to achieve on roads than on aircraft runways because of the heavy canalised nature of most road traffic and accumulations of dust and detritus. General factors which will contribute to a material with these properties are a stable, mostly single-sized aggregate matrix and a stiff but flexible durable binder. In the application of pervious materials as road surfacings it is possible to use larger aggregate particles than the 10mm used in the airfield application with the consequent potential of larger sizes of voids that are less likely to become blocked. The viscosity of the binder has to be increased in order to make the mixture more resistant to rutting but, because the surfacing is permeable, the binder is subjected to weathering throughout its depth; this renders it liable to hardening and subsequent embrittlement. When the binder has hardened to a viscosity of about 20 pen , surface fretting then occurs, followed by disintegration. In order to reduce these effects of weathering, present research is aimed at modifying the binder so that the film thickness can be increased without the risk of binder drainage and the onset of embrittlement delayed by improving the low temperature rheology.

The evolution of this type of surfacing has been primarily through a number of road trials because it has not been possible to simulate accurately in the laboratory the long-term effects of traffic on the effective spray reduction of the materials and the natural weathering

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process of the binder on the durability of the surfacing.

The greatest benefits from a spray reducing surfacing will occur on the most heavily trafficked sites but of course, these provide the most difficult circumstances in which to obtain acceptable performance from this type of material. Spray measurements determined from a vehicle-mounted optical back scatter measuring device suggest that when the road is very wet, pervious macadam generates only about 10 per cent of the spray level from the hot rolled asphalt surfacing used in the UK. An additional benefit of pervious macadam is that it generates about 6-8 dBA less noise under wet conditions, compared with rolled asphalt (4) (5). In noise-sensitive areas the quieter surfacing may be a more acceptable solution than the suppression of noise in the dwellings or compensation payments. Structurally, 40mm of pervious macadam is equivalent to about 16mm of rolled asphalt or 20mm of dense bitumen macadam (6).

2. EARLY ROAD TRIALS

The first pervious macadam wearing course was laid on Motorway M40 in 1967 (7). The material used was a 19mm nominal size wearing course, with a grading complying with the then current British Standard 1621 for an 'open-textured' bitumen macadam and with 100 pen bitumen containing 4 per cent natural rubber as binder. The performance of this material was carefully monitored for more than 10 years during which time the traffic increased from 600 cvd to 1900 cvd. Jacobs (8) reported that the initial surface texture was well over 2mm which subsequently dropped to remain reasonably constant at about 2mm. The draining properties were markedly reduced after two years but in all other respects the material

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remained very effective as a road surfacing and produced less tyre noise than other surfacings with a similar surface macrotexture.

Warwickshire County Council experimented with the 10mm friction course at about the same time on a similarly trafficked site and came to the same conclusions about the performance of this material as those reported by Jacobs from the 20mm material.

Brown (9) carried out an experiment with 10mm friction course and with 20mm pervious macadam using two bitumens of 100 pen and 200 pen from different crude oil sources, as well as a 100 pen bitumen modified by the addition of natural rubber. On this much more heavily trafficked site, carrying 4500 cvd for the first 16 months and 2300 cvd subsequently, it was found that the coarser 20mm material with the harder bitumen (100 pen) retained the spray reducing properties for more than six years. A surprising finding was the difference in the reduction of permeability measured in similar materials containing bitumen from different crude sources. The 20mm macadam made with a 100 pen bitumen from a Venezuelan crude source showed a reduction of 80 per cent in 2 years whereas that made using a similar grade bitumen from a Middle East source showed a reduction of only 33 per cent.

In 1973 the opportunity was taken to lay pervious macadam (20mm nominal size aggregates and 100 pen bitumen) on the southbound carriageway of Motorway M1 which carried about 7000 cvd in the nearside lane (10). Effective spray reduction was achieved for 3 years under the heaviest motorway traffic. It was also observed at this site that after 2½ years the permanent deformation in the nearside wheeltrack was about 1mm for the pervious macadam when the conventional surfacing for this site, rolled asphalt, had deformed by 3mm (3).

As a result of these experiments the most suitable composition of pervious macadam was found to be 20mm nominal size aggregate with a grading similar to Grading 1 in Table 2 using 100 pen bitumen binder; subsequently the Department of Transport carried out a number of specification trials to prove the material and this specification is included in the latest revision of British Standard 4987. The surfacing would be expected to have effective spray-reducing properties for 3 years under a traffic flow of 7000 cvd and for 6 years with a traffic flow of 2500 cvd. It was considered that there should be benefits from the use of elastomeric additives although the trials using natural rubber had not produced conclusive results.

In 1975 an experiment was started at Buckden, Cambridgeshire, on Trunk Road A1 carrying 2300 cvd, to provide information on the performance of a range of wearing-course materials including open-textured and pervious macadams. The results after seven years traffic have been summarised in Table 1 (5) in terms of the relative performance of the materials with respect to a number of properties.

TABLE 1

Relative performance of surfacings at Buckden after 6 years

Aspect of performance	Open textured macadam	Pervious macadam	'Delugrip' RSM †	Dense bitumen macadam	Rolled asphalt	Surface dressing
Resistance to deformation	***	***	****	****	****	N/A
Durability	***	**	***	**	****	***
Skid resistance (Low speed)	*****	*****	*****	*****	****	*****
Skid resistance (High speed)	****	*****	***	****	****	*****
Riding quality	****	***	*****	*****	***	*
Spray suppression	***	*****	**	*	**	***
Noise reduction	****	****	****	***	**	*
Ease of application	***	***	***	***	**	****
Area/Unit cost	**	**	*	**	*	*****

In applying a merit rating a mark of ***** has been given for 'Very good' ranging to * for 'Poor'.

† 'Delugrip' is a proprietary dense bitumen macadam made using two aggregates of different abrasion rates.

The pervious macadam showed advantages in retention of skid resistance at high speed, spray suppression and noise reduction, and disadvantages in durability and cost.

3. 1984 ROAD TRIAL

This trial was laid on Trunk Road A38, Burton By-Pass, in Staffordshire with the objective of comparing the performance of pervious macadams made with a range of conventional and polymer-modified bitumens. The performance of the materials may be improved in the following ways:

(1) Reducing binder drainage in the interval between mixing and laying to enable a higher binder content to be used; the resulting thicker binder film should delay the onset of embrittlement.

(2) Rendering the macadam more resistant to deformation and closing-up by adjusting the aggregate grading and by improving the rheological properties of the binder.

Fifteen trial surfacings were laid in August and September 1984; the traffic flow is about 3500 cvd in the nearside lane and about 400 cvd in the offside lane.

3.1. Aggregate

The coarse aggregate was specified to have a minimum polished stone value of 60, a maximum aggregate crushing value of 16, a maximum aggregate abrasion value of 12 and a flakiness index not exceeding 20. The main aggregate grading used was Grading 1 in Table 2, which is similar to that used in the earlier trials (3). One section of the slightly coarser Grading 2 in Table 2 was laid; this grading was the result of co-operative work involving the British Aggregate Construction Materials Industries, the Refined Bitumen Association and TRRL.

TABLE 2

A38 Burton By-pass: specified aggregate gradings

BS Sieve (mm)	Per cent by mass passing	
	Grading 1	Grading 2
20	100-5	100-5
14	65±15	60±10
6.3	25±5	20±5
3.35	10±5	10±5
75 um	4.5±1.5	4.5±1.5

In all except three of materials used in the trial, (Sections 2, 3 and 4) the filler was specified to contain 2 per cent (by mass of the aggregate) of hydrated lime to act as an anti-stripping agent and as a binder stiffener.

3.2. Binders and binder contents

100 pen bitumen was used as the control binder and the full list of the materials used in the experiment is given in Table 3. Hitherto the binder contents for pervious macadams in the UK have been based on experience, unlike the United States, where some qualitative and semi-quantitative types of binder drainage test have been used to assist in the specification of binder contents (12) (13) (14).

However the design binder contents in this work were determined by a recently developed quantitative binder drainage test on the total mix. In this test (11) a sample of pervious macadam is placed in a perforated basket and then put in an oven over a pre-weighed tray. The weight of material draining onto the tray is determined at the

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TABLE 3

A38 Burton By-pass : designation of sections

Section no.	Aggregate grading	Binder type	Target Binder content per cent ±0.3
1	1	70 pen bitumen	3.7
2	1	100 pen bitumen*	3.7
3	1	Shell bitumen+epoxy resin*	3.7
4	1	100 pen bitumen+Inorphil**	5.0
5	1	100 pen bitumen+5.0% 18-150 EVA***	4.2
6	1	100 pen bitumen+5.0% 18-150 EVA***	3.7
7	1	Mobil Mobilplast grade C1	4.2
8	1	200 pen bitumen+5.0% 18-150 EVA***	3.7
9	1	100 pen Esso bitumen +5.0% modified EVA	4.2
10	1	200 pen Shell bitumen + SBS†	4.2
11	1	200 pen Shell bitumen + SBS†	4.2
12	1	100 pen BP bitumen + SR††	5.0
13	2	100 pen bitumen	3.7
14	1	100 pen bitumen+Pulvatex NR†††	5.0
15	1	100 pen bitumen (control)	3.7

*4.5% limestone filler (no hydrated lime)
** Inorphil fibres (alumino magnesium silicate) added at 9 per cent of binder percentage (no hydrated lime)
*** Ethylene Vinyl Acetate 18 per cent Vinyl Acetate content 150 Melt Flow Index (ICI)
†Styrene-butadiene-styrene block copolymer
††Synthetic rubber
†††Pulvatex NR (Natural Rubber) added at 8.3 per cent of binder percentage. Equivalent to 5.0 per cent of natural rubber in binder.

end of the test period. This drained material is essentially a mixture of binder and filler and it is assumed that the ratio of filler to binder in the drained material is the same as that in the original mixture. The amount of binder draining and hence the binder content remaining in the mixture can then be calculated. By carrying out the test over a range of binder contents, a curve relating binder content retained to initial binder content can be drawn, as shown in Fig 1. Surprisingly, a peak is reached beyond which the binder content retained in the mix actually reduces rapidly with increasing initial binder content. From Fig 1, the highest practical binder content consistent with a minimum of drainage can be deduced. The binder drainage test mostly perform -ed at 160°C over 3 hours, was carried out for all the binders used in this trial and the values for the critical binder content (the lowest level at which binder drainage appears), the maximum retained binder content and the maximum binder content of the 'as mixed' material are recorded in Table 4.

The relationship between the laboratory test and practice was investigated in a practical trial that was carried out before the test sections were laid. In this trial, lorry loads of pervious macadam travelled 80 km and stood for a further 2±½ hours. Samples were taken from the tops of the lorry loads for analysis both at the mixing plant and after the journey and standing time. Although there was no visible drainage, analysis results showed reductions of binder content of up to 0.9 per cent that confirmed the trend of the binder drainage test result, although the trial results showed greater drainage than the test predicted (11).

Nevertheless this test formed a rational basis for the specification of the binder contents used in the test sections. In specifying a binder content, it would be inappropriate to set a level greater than the maximum as-mixed value that would indicate appreciable drainage, or below the critical binder content that would reduce durability. Bearing in mind such factors as specification tolerance on target binder content, the precision of the drainage test, and the desirability to reduce the number of variables in a full-scale trial, small differences in the binder drainage test results were ignored. These factors, together with, in some cases, the proprietor's option supported the selection of three groups with target binder contents of 3.7, 4.2 and 5.0 per cent.

TABLE 4

Results of binder drainage tests*

Section No.	Binder type	Binder content per cent			
		Critical (approx)	Max. retained	Max. as-mixed	Trial target ±0.3
1	70 pen bitumen	3.5	3.5	3.5	3.7
2	100 pen bitumen (no hydrated lime)	2.8	4.0	4.5	3.7
3	Shell bitumen+epoxy resin ††	4.0	>5.0	>5.0	3.7
4	100 pen bitumen+Inorphil	>7.0	>7.0	>7.0	5.0
5	100 pen bitumen+5.0% 18-150 EVA	4.0†	4.2†	4.5†	4.2
6	100 pen bitumen+5.0% 18-150 EVA	4.0†	4.2†	4.5†	3.7
7	Mobil Mobilplast C1	3.5	3.8	4.0	4.2
8	200 pen bitumen+5.0% 18-150 EVA	3.5	3.9	4.0	3.7
9	100 pen bitumen**+5.0% Esso modified EVA	3.5	3.8	4.2	4.2
10	200 pen Philmac bitumen+SBS	4.0	4.3	4.5	4.2
11	200 pen Shell bitumen+SBS	4.5	>5.0	>5.0	4.2
12	100 pen BP bitumen+SR	>5.0	>5.0	>5.0	5.0
13	100 pen bitumen (grading 2)	3.4	3.4	3.5	3.7
14	100 pen bitumen+Pulvatex	>5.5	>6.0	>7.0	5.0
15	100 pen bitumen	3.0	3.6	4.0	3.7

*3 hours at 160°C
**BP bitumen used in drainage test. Esso bitumen used in trial.
†2 hours at 160°C.
†† 2 hours at 120°C

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3.3 Observations on laying the trial sections.

The materials were laid by two pavers operating in echelon (except for the epoxy resin material): this enabled a well compacted permeable and invisible longitudinal joint to be made. In general, there was a delay between mixing and laying of 3 to 5 hours; however, this did not result in load temperatures being appreciably lower than the target mixing temperatures. With the epoxy resin material, laying took place as soon as the lorries arrived on site and in this case a satisfactory but visible longitudinal joint resulted.

Because the target binder contents were set at values only slightly higher than the critical binder contents given in Table 4, a small reduction in measured binder contents for site samples would be expected. Only 3 of the 15 sections showed some evidence of binder drainage; in those 3 cases average binder contents for site samples were more than 0.3 per cent below the target values.

Prior to opening the road to traffic, measurements of texture depth and relative hydraulic conductivity were made in the nearside wheelpath of the nearside lane. Measurements of skid resistance (sideway force coefficient (sfc) were made after 6 weeks of trafficking. Results are given in Table 5. Cores were removed from both lanes of each section and various measurements were made including voids open to water and resistance to permanent deformation. These results are given in Table 6; details of the methods of measurement used have been given by Daines (11).

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The compositions of the polymer modified binder could not be checked against the specifications because standard procedures are not available for the analyses. Techniques, such as infra-red spectroscopy, can be used with some polymers but this method cannot be used with all the polymers used in this trial. The contributors assured the compositions of their proprietary binders and the Laboratory's staff supervised the blending of the other polymers. Work is continuing to develop methods of measuring the polymer content of binders.

3.4. Future measurements

Regular measurements are being made of surface texture, hydraulic conductivity, profile, skidding resistance and visual condition. Spray suppression and noise levels are also included in the programme. Surface texture and profile are measured by systems using infra-red lasers as sensors (15), skid resistance by the long established sideway-force method and spray suppressions by the more recently developed optical back-scatter device (16).

After two years trafficking there are some signs of differences in the performance of the various materials but it is too early to draw any conclusions about the relative merits of the additives used.

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TABLE 5

Initial surface measurements

Section No.	Texture depth (mm)*	Relative hydraulic conductivity† s^{-1}		Skid resistance s.f.c.**
		n.s. lane	o.s. lane	
1	2.5	0.38	0.38	0.66
2A	3.1	0.21	0.18	) 0.62
2B	5.5	0.72	0.62	)
3	3.1	0.50	0.41	0.66
4	3.6	0.24	0.16	0.63
5	3.3	0.33	0.23	0.63
6	3.1	0.32	0.28	0.64
7	3.0	0.23	0.31	0.57
8	2.6	0.24	0.44	0.62
9	2.5	0.25	0.41	0.62
10	3.2	0.40	0.47	0.62
11	3.7	0.41	0.44	0.62
12	3.4	0.19	0.19	0.58
13	3.1	0.41	0.58	0.62
14	2.7	0.17	0.26	0.63
15	2.9	0.42	0.37	0.62

* Nearside lane September 1984.
** November 1984 nearside lane.
† Reciprocal for outflow time of 0.00125 m^3, corrected for apparatus constants.

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TABLE 6

Results of tests on cores of wearing course†

Section No.	Binder	Core No.	Thick-ness (mm)	Specific gravity	Bulk density (Mg/m^3)	Voids open to water (%)	Rate of tracking (mm/h)
1	70 pen bitumen	1 2	36 47	2.404 2.378	1.817 1.936	24.4 18.6	* 0.6
2	100 pen bitumen (no hydrated lime)	3 4	60 48	2.414 2.370	1.825 1.890	24.4 20.3	0.9 1.1
3	Shell bitumen+epoxy resin	5 6	32 42	2.400 2.400	1.770 1.813	26.3 24.5	0.3 0.2
4	100 pen bitumen+ Inorphil	7 8	35 36	2.335 2.344	1.907 1.828	18.3 22.0	* *
5	100 pen bitumen+5.0% 18-150 EVA	9 10	- 47	- 2.362	- 1.867	- 21.0	- 2.4
6	100 pen bitumen+5.0% 18-150 EVA	11 12	47 47	2.371 2.333	1.916 1.884	19.2 19.2	0.8 0.3
7	Mobil Mobilplast C1	13 14 15 16	33 32 36 40	2.325 2.265 2.356 2.327	1.882 1.859 1.890 1.940	19.1 17.9 19.8 16.6	0.5 0.2 0.7 0.6
8	200 pen bitumen+5.0% 18-150 EVA	17 18 19 20	29 33 36 41	2.320 2.347 2.366 2.356	1.785 1.912 1.796 1.907	23.1 18.5 24.1 19.1	* 1.9 1.0 0.2
9	100 pen Esso bitumen +5.0% Esso modifed EVA	21 22	51 40	2.342 2.382	1.941 1.930	17.1 19.0	0.9 0.3
10	200 pen Philmac bitumen+SBS	23 24	48 40	2.412 2.307	1.970 1.855	18.3 19.6	1.4 0.8
11	200 pen Shell bitumen+SBS	25 26	48 53	2.351 2.352	1.865 1.949	20.7 17.1	0.3 0.3
12	100 pen bitumen+SR	27 28	46 41	2.282 2.317	1.898 1.916	16.8 17.3	0.3 1.4
13	100 pen bitumen (grading 2)	29 30	39 40	2.336 2.404	1.871 *	19.9 *	5.2 *
14	100 pen bitumen+ Pulvatex	31 32	39 47	2.268 2.280	1.839 1.945	18.9 14.7	2.2 0.4
15	100 pen bitumen	33 34	59 47	2.370 2.388	1.939 1.805	18.2 24.4	0.4 1.0

†Cores taken from nearside wheel track of nearside lane.
*Core disintegrated.

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4. GENERAL CONCLUSIONS

Pervious macadam surfacings have been shown to have advantages over other types of surfacing, in particular the suppression of spray, the lower noise levels and the maintenance of high speed skid resistance. The major disadvantage is the relatively short life of the material on heavily trafficked sites where the advantages outlined above are most apparent to the road user.

Efforts have been made to improve the durability of the material by using polymers and mineral fibres enabling higher binder contents to be used. If the life of the surfacing can be increased without significant loss in other properties then this type of material will become more economically attractive and may be used more widely.

5. ACKNOWLEDGEMENTS

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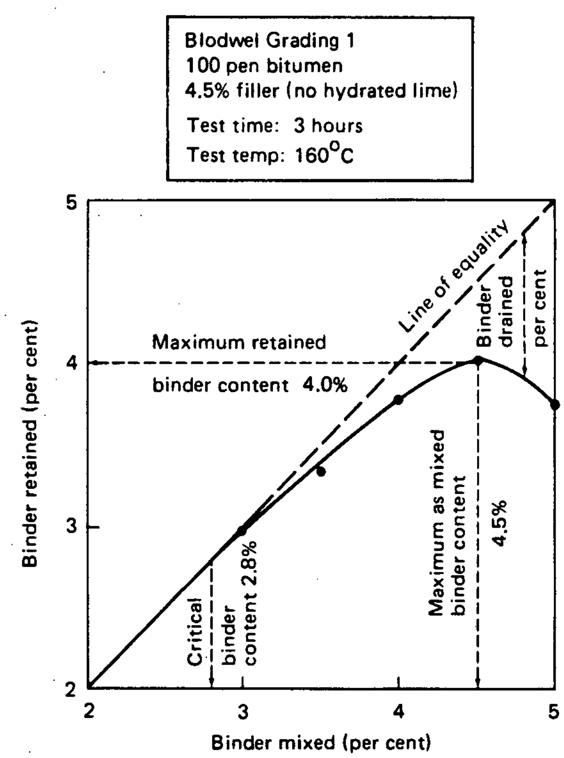

Fig.1 Typical binder drainage test result

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Virginia's Experience With Open-Graded Surface Mix

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The Virginia Department of Highways and Transportation has used the bituminous open-graded, porous friction course (PFC) since 1972 to resurface hazardous locations and roadways needing routine resurfacing. A before and after accident study of one location revealed a significant decrease in wet pavement accidents after it was paved with the PFC. Skid tests have revealed good to excellent skid resistance on all sections of the PFC. Some problems have been encountered with flushed spots in the pavement, minor raveling, deformation under severe traffic, damage from spilled fuel, and dirt in air voids. Most of these problems have been resolved, and future use will be determined by the long-term durability of the mix.

In Virginia, constant attention is directed toward the development, construction, and maintenance of pavement surfaces that provide good skid resistance. Most of the bituminous pavement surfaces on the state's highly traveled highways are dense-graded, although the surface texture may vary because of differences in aggregate gradations among the mix types used. When properly constructed, pavements having a dense-graded mix in the surface course usually give good skid resistance; however, to prevent wet weather skidding accidents requires a mix that will provide excellent drainage of surface water. For example, good surface drainage is a paramount consideration where thick surface water films are prevalent because of geometrics and where speed and traffic maneuvers create uncontrollable hydroplaning skids.

Because of the apparent need for an antihydroplaning mix, an open-graded, porous friction course (PFC) that had been used by several states was investigated. The PFC is designed as an open mix with interconnecting voids that provide drainage for heavy rainfall. The rainwater drains vertically through the PFC to an impermeable underlying layer and then laterally to the edge of the pavement.

In addition to providing high skid resistance during rainfall, the PFC, as compared to other mix types, reportedly (1)

1. Reduces spray and splash,
2. Enhances the visibility of pavement markings,
3. Reduces nighttime surface glare in wet weather,
4. Reduces tire-pavement noise, and
5. Allows use of thin layers and a minimum of material.

Virginia's experience has verified these advantages; however, noise measurements have not proved that porous friction course reduces tire-pavement noise. There was no appreciable difference in measured noise levels for a dense-graded mix and the PFC in a series of tests performed on a limited number of Virginia pavements.

FIELD INSTALLATIONS

In 1972, PFC was used to resurface two short test sections. A 0.72-km (0.45-mile), two-lane section was placed on US-60 in central Virginia by using a lightweight aggregate in one lane and a crushed marble aggregate in the other. Some problems were encountered in controlling the aggregate gradation for the test section, which is often the case with small quantities of materials, particularly when a new gradation is used. The variability in the gradation caused some areas to be overly dense and to lack the desired permeability.

A second section, 0.6 km (0.4 mile) long on a four-lane roadway, was placed on US-23 north of the Virginia-Tennessee state line. Several wet pavement accidents had occurred at this location, and a before and after accident study was made to determine the safety benefits of the mix.

These two sections represented the initial experience with the PFC for both state and contractor personnel, although at least one Virginia contractor had worked with an open-graded mix in North Carolina. Initially, contractor personnel were rather dubious about the PFC and the required construction techniques; however, experience has tended to dispel their doubts.

In 1973 the PFC was placed on at least one section in each of the state's eight highway districts. As experience with PFC increased, problems were eliminated and workmanship was improved. Approximately 8.2 Gg (9000 tons) were placed in 1973, some of it on a section

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of Interstate highway.

In 1974, approximately 22.7 Gg (25 000 tons) were placed, including 16.3 Gg (18 000 tons) on Interstate highways. Most of the Interstate sections on which the PFC was placed carry traffic volumes of about 13 000 vehicles per day on four lanes; however, a section on the Richmond-Petersburg Turnpike carries approximately 46 000 vehicles per day on six lanes.

MIX DESIGN

The first of the two sections placed on US-60 in 1972 had the following design gradation.

Sieve	Percentage Passing	Sieve	Percentage Passing
12.5 mm	100	No. 8	10 to 30
9.5 mm	90 to 100	No. 16	0 to 20
No. 4	30 to 50	No. 200	0 to 4

The asphalt contents were 7 and 11 percent for the crushed marble aggregate and lightweight aggregate mixes respectively. The optimum asphalt content was selected by visual observation of trial mixes in the laboratory. The mixing temperature was specified to be between 104 and 132°C (220 and 270°F).

An 85 to 100 penetration asphalt cement was used for both the mix and the tack coat. A heavy tack coat [0.32 dm³/m² (0.07 gal/yd²)] was used to ensure an impermeable underlying layer. When applying the tack coat, the contractor had to raise the temperature of the asphalt very high before it would flow uniformly, which the contractor considered objectionable. A cationic emulsion tack coat was used on the US-23 job. Approximately 0.5 dm³/m² (0.1 gal/yd²) of residual CAE-2 (CRS-2) asphalt was applied on US-23, and, because of the ease with which it was applied and the apparent success achieved, a decision was made to allow either 85 to 100 penetration asphalt cement or cationic emulsion to be used on future jobs. Although the US-23 job was successful, during the long haul from the plant to the job the asphalt drained to the bottom of the truck, and the result was several fat spots in the pavement.

The mix gradation specified in 1973 was very similar to size No. 8 stone (ASTM D692), which is usually available at all quarries. As before, the optimum asphalt content was selected through visual inspection of laboratory samples, including some observations of asphalt drainage from mixes placed on glass plates. The 1973 and current specifications are given elsewhere (4). The mixing temperature was specified to be 93 to 124°C (200 to 255°F); a temperature of approximately 107°C (225°F) was found preferable.

Very few changes were made in the specifications for 1974; however, the Federal Highway Administration (FHWA) design procedure (2) was examined with the idea of possibly improving the mix and refining Virginia's design procedure. The FHWA procedure consists basically of a gradation design and an asphalt content design. This procedure was used to develop designs for six mixes that had previously been used in pavement resurfacing, and the designs were compared to those actually used (3). Pavement performance was used to evaluate whether the correct design had been used. The design asphalt contents from the FHWA procedure were consistently lower than those used in the field, and only one aggregate type was found to require an asphalt content significantly different from that selected by the sample observation method. However, the design procedure was useful for certain aggregates. The method was adopted and is now being used to estimate optimum asphalt content; however, because Virginia's PFC gradation is rather fixed, i.e., No. 8 stone, the gradation design was not considered useful.

PROBLEMS

Construction

The CAE-2 (CRS-2) tack coat, on occasion, tended to stick to truck tires, then drop off, and puddle, causing flushed spots. However, when the emulsion has been allowed to cure properly, it has proved to be satisfactory.

Problems have been experienced when the mixing temperature has not been properly controlled. An unsatisfactory pavement was obtained when the temperature of the mix was too high. Excess asphalt migrated to the bottom of the trucks and, when deposited in one area, formed flushed spots in the pavement.

Long hauls tended to magnify the problems of asphalt drainage in truck bodies and excessive cooling and lumping of the mix on the exterior surface. It is advisable to limit the plant-to-paver time lapse.

Maintenance

No major maintenance problems have been experienced, although some minor ones have arisen. A section of I-81 consisting of crushed gravel appeared to be raveling approximately 6 to 12 months after construction. To determine future maintenance possibilities, a diluted cationic emulsion was applied to a short length of the section to arrest the raveling. The emulsion penetrated the PFC and will, it is hoped, provide an asphalt coating to prevent further raveling. The treated and untreated sections will be observed and compared.

At a toll booth on the Richmond-Petersburg Turnpike, on the lanes carrying heavy truck traffic, some deformation and densification are beginning to show approximately 1 year after construction, which indicates that possibly this mix should not be used under very severe traffic conditions.

The PFC is more susceptible to damage from spilled fuels than is a dense-graded mix, because spillage penetrates the mix and the underlying surface. Fuel spilled from an overturned truck on the Richmond-Petersburg Turnpike severely damaged a short section of pavement. This situation requires removal of the damaged mix, usually with a heater planer, and replacement with fresh mix.

Voids of cores from nine projects ranged from 21 to 32 percent, and these projects have maintained good drainage characteristics. However, examination of cores from the Richmond-Petersburg Turnpike revealed reduced voids in wheel paths and between wheel paths, apparently from the accumulation of dirt. The effectiveness of the PFC may be reduced if the environment is very dirty and dirt penetrates the voids.

RESULTS

Durability

One of the initial primary concerns with the PFC was the service life and general durability because the open-grading would expose the asphalt cement and thus make it subject to early oxidation and weathering. To prevent early deterioration due to oxidation and weathering, the mix is designed with thick asphalt films and should contain as much asphalt as possible.

Inasmuch as the oldest PFC in Virginia has been in service for only 3 years, it is not possible to reach any conclusions on its long-term durability at the present time.

Stability

Rut depths were measured on 11 sections of open-graded surface mix and two sections of regular dense-graded surface mix. The open-graded mix had a rut depth range of 1 to 3 mm (0.04 to 0.12 in) and averaged 2 mm (0.07 in).

The dense-graded surface mix, which showed no visible rutting, had a rut depth of 3 mm (0.10 in), and the dense-graded section with some visible rutting had a measured rut depth of 7 mm (0.26 in). Therefore the rut depth and stability of the open-graded mix are equivalent to those of a good dense-graded mix.

Skid Resistance

Table 1 gives the average skid numbers for some of the PFC pavements. Although not shown in Table 1, some of the sections have been tested at regular intervals and have not shown any appreciable change in skid resistance.

All of the sections have good skid resistance, and the first section, the one with lightweight aggregate on US-60, has a skid number of 72. This section has low traffic volume, but it is expected that similar results would be obtained under high traffic volumes.

Most of the sections have been placed for routine maintenance purposes; however, some were designed to reduce wet pavement accidents by enhancing the road's skid resistance. The section on US-23 had a high incidence of wet pavement accidents, which are believed to be caused by excessive surface water films. The excessive films were believed to be a result of the pavement geometry and surface type, so it was thought that a porous surface would alleviate the problem.

A survey of accidents 1 year before and 1 year after installation of the PFC revealed a significant reduction in wet pavement accidents. In the year before installation, 39 percent (7 of 18) of the accidents occurred during wet weather, but during the year after installation only 17 percent (2 of 12) of the accidents occurred during wet weather, which is considered normal. In this instance the benefits of the PFC are evident.

Other sections have been placed in locations that had experienced skidding accidents, but it is too early to evaluate their effectiveness.

FUTURE PLANS

Evaluation of the PFC sections will be continued. Such courses probably will be used for some routine maintenance overlays and at locations where wet pavement accidents are a problem. The durability of the mix will probably determine the long-range use.

ACKNOWLEDGMENTS

When Virginia began using the PFC in 1972, North Carolina highway engineers who had considerable experience with the mix were consulted and provided invaluable assistance. The original specifications and construction procedures were patterned after those of North Carolina.

REFERENCES

1. Open-Graded Asphalt Friction Courses. Asphalt Institute, College Park, Md., Construction Leaflet 10, Nov. 1974.
2. R. W. Smith, J. M. Rice, and S. R. Spelman. Design of Open-Graded Asphalt Friction Courses. Office of Research and Development, Federal Highway Administration, Interim Rept., Jan. 1974.
3. G. W. Maupin, Jr. Investigation of Asphalt Content Design for Open-Graded Bituminous Mixes. Virginia Highway and Transportation Research Council, March 1974.
4. Special Provisions for Bituminous Porous Friction Course. Virginia Department of Highways and Transportation.

Table 1. Average skid numbers of typical PFC pavements, spring 1975.

Route	Year Constructed	Vehicles per Day per Lane	Skid Number[a]
US-23	1972	90[illegible]	6[illegible]
US-23	197[illegible]	90[illegible]	6[illegible]
US-460	197[illegible]	26[illegible]	64
US-460	197[illegible]	220[illegible]	6[illegible]
US-60	197[illegible]	45[illegible]	5[illegible]
US-60[c]	197[illegible]	45[illegible]	72
US-60	197[illegible]	200[illegible]	5[illegible]
US-301	197[illegible]	370[illegible]	54
US-17	197[illegible]	295[illegible]	5[illegible]
US-301	197[illegible]	105[illegible]	6[illegible]
US-29	197[illegible]	430[illegible]	6[illegible]
I-8[illegible]	197[illegible]	340[illegible]	6[illegible]
I-8[illegible]	1974	325[illegible]	6[illegible]
Va-4[illegible]	197[illegible]	180[illegible]	6[illegible]
US-50	197[illegible]	130[illegible]	5[illegible]

[a]Predicted car values from ASTM skid test trailer.
[b]Marble aggregate.
[c]Lightweight aggregate.

Discussion

Prithvi S. Kandhal, Pennsylvania Department of Transportation

The author has pointed out asphalt drainage problems during transit from the mixing plant to the job site. This can possibly be avoided if the mix temperature is established on asphalt viscosity considerations. FHWA has recommended that the target mixing temperature be in the range that will correspond to asphalt viscosities of 7 to 9 cm^2/s (700 to 900 centistokes) (5). The Pennsylvania Department of Transportation has designed and placed seven experimental sections of open-graded asphalt friction course from 1974 to 1975. According to our experience, the viscosity range should be 11 to 15 cm^2/s (1100 to 1500 centistokes). We did not encounter any drainage or crusting problem within this range, even though the mix was hauled more than 32 km (20 miles) in some cases.

The mix gradation specified by Virginia in 1973 consists essentially of coarse aggregate only. However, FHWA has recommended that at least some fine aggregate be used to provide a choking action for the stabilization of the coarse aggregate fraction. Use of coarse aggregate alone is not only economical, but also should result in improved permeability. It is hoped that the continual evaluation of these experimental sections will indicate whether the fine aggregate is needed from the standpoint of stability and durability.

REFERENCE

5. R. W. Smith, J. M. Rice, and S. R. Spellman. Design of Open-Graded Asphalt Friction Courses. Federal Highway Administration, FHWA-RD-74-2, Jan. 1974.

Author's Closure

The temperature-viscosity curves of AC-20 asphalt cements obtained in the past under viscosity specifications were examined. They showed little variation, so the required mixing temperature was rather constant. We felt that it was preferable to specify the mixing temperature, which has been established by experience. Some of the drainage problems may be attributed to the fact that the mix is designed to have thick asphalt films and that sufficient fines to soak up excess asphalt were absent.

We do not use the fine aggregate for the choking action, and there have been no apparent problems with stability under normal use. As I indicated, rut depths for the open-graded mix are comparable to those for a well-designed dense-graded mix.

H

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H-1

Design, Construction, and Performance of Asphalt Friction Courses

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During 1969 to 1971, eight test pavements of open-graded asphalt friction courses were constructed in Pennsylvania. Details of design, construction, and performance of these pavements are discussed. Four test pavements incorporating two aggregate types and control sections of dense-graded bituminous surface were constructed in 1974 near Philadelphia. The asphalt friction courses were designed according to the Federal Highway Administration procedure modified in terms of asphalt mixing viscosities. The performance of the 1974 test pavements is evaluated every 6 months by obtaining skid test data at three speeds, by measuring air permeability, and by determining the average surface texture depths. Interim data obtained so far suggest that a minimum air void content of 25 percent is necessary to maintain the desired permeability that is lost in most pavements from traffic action and clogging by debris. A highly skid-resistant gravel aggregate was used for this project in the asphalt friction course and the dense-graded surface course. After 1½ years' service, the skid-speed gradient of both pavements is almost equal and approaches 0.45. In the case of dolomite aggregate (medium skid resistance), the asphalt friction course has a substantially lower speed gradient compared to the dense-graded surface course. These tests are being continued to study long-range performance and durability.

High-speed rubber-tired vehicles operating on wet pavements can experience a hazardous phenomenon known as hydroplaning. A layer of water on the pavement causes the tire to lose contact with the pavement surface. The result is the vehicle's loss of maneuverability and braking capability.

Obviously, we must devise some method to remove the water from the pavement surface. Open-graded asphalt friction courses (also called open-graded plant-mix seal coat and porous friction course, among others), which are high-void bituminous mixtures placed on existing pavement surfaces in thin layers [nominally 19 mm (¾ in)], have been used to drain surface water through their porous structures. In addition to reducing the risk of hydroplaning, asphalt friction courses are believed to have several other advantages (1), such as improved skid resistance at higher speeds during wet weather, minimized wheel path rutting, minimized splash and spray during wet weather, lowered highway noise levels, improved visibility of painted traffic markings, and retarded ice formation on the surface.

A survey of the literature (2,3,4,5,6,7,8,9) reveals that several agencies have used this type of asphalt surfacing, but with different mix compositions and mix design methods (Table 1). Evidently, this resulted in both success and failure in the construction and performance of the open-graded mixes, but the experience gained has helped develop suitable interim specifications and design methods for such applications. It is with this intent that the experience of the Pennsylvania Department of Transportation (PennDOT) with the design, construction, and performance of asphalt friction courses is being reported in this paper.

TEST PAVEMENTS, 1969 TO 1971

Eight separate projects (Table 2) were constructed in Pennsylvania between September 1969 and September 1971. In September 1969, 22.4 km (14 miles) of two-lane pavement were constructed and an additional 6.2 km (3.9 miles) in June 1970 in the north central region, and, in September 1971, 7.2 km (4.5 miles) were constructed in the same region and 2.4 km (1.5 miles) in south central Pennsylvania. This provided a total of 38.2 km (23.9 miles) for evaluation.

Design and Materials

The open-graded mixes first used in the four western states of Colorado, Wyoming, Utah, and New Mexico were also used in Pennsylvania (Table 1). Both limestone and gravel aggregates were used for comparison on projects 3 and 5; AC-20 asphalt cement was used on all projects. Initially, the asphalt content was established by calculating the percentage of asphalt as 1.5 Kc (surface capacity) plus 3.5.

The value of Kc was obtained by the CKE test using the coarse aggregate fraction and SAE 10 lubricating oil (1). Trial mixes with different percentages of asphalt were made and stored overnight at 140°F (60°C) in pans. We selected the mixes that met the following criteria.

Table 1. Comparison of mix gradations.

State	Gradation (% passing)					Asphalt Content (%)
	12.5 mm	9.5 mm	4.75 mm	2.36 mm	75 µm	
North Carolina	100	90 to 100	25 to 45	4 to 17*	0 to 2	6 to 10
Colorado, Wyoming, Utah, New Mexico	100	95 to 100	30 to 50	10 to 25	0 to 5	6 to 7
California, Arizona, Nevada Hawaii	100	90 to 100	30 to 50	15 to 32	0 to 3	5 to 7
Louisiana	100	95 to 100	30 to 55	5 to 20*	0 to 6	4 to 10
Texas	100	90 to 100	40 to 60	9 to 20*	0 to 5	5 to 7.5
Virginia (1973)	100	84 to 100	10 to 40	0 to 10	0 to 2	6 to 12
FHWA recommendation (1974)	–	100	30 to 50	5 to 15	2 to 5	–

Note: 1 mm = 0.039 in and 1 µm = 0.0039 in.

*Sieve size converted from 2 mm (no. 10) to 2.36 mm (no. 8) for comparison.

Table 2. Test pavements, 1969 to 1971

Project	County	Date Placed	ADT	Depth (mm)	Substrate Condition	Present Status
1	Centre	9/69	2 600	12.5	Fair: minimum cracking and rutting, slippery	Poor: 40% surface material lost from traffic wear; failure due to thin application, scheduled for resurfacing
2	Centre	9/69	9 400	12.5	Fair: slight wheel track rutting, slippery	Poor: 50% surface material lost from traffic wear; failure due to thin application, scheduled for resurfacing
3	Clearfield	9/69	6 000	12.5	Poor: heaved and sunken areas, wide transverse cracks	Resurfaced in 1973; failure due to poor pavement structure and thin application
4	McKean	9/69	2 650	12.5	Extremely poor: extensive cracking and rutting	Resurfaced in 1972; failure due to poor pavement structure and thin application
5	Centre	6/70	26 000	16.0	Good: slippery[a]	Good: in-service, original open surface texture kneaded and tightened by traffic
6	McKean	8/71	3 500	12.5	Fair: transverse and longitudinal cracks, raveling	Good: in-service, some reflective cracks present, slightly kneaded surface texture, 5% surface lost from raveling
7	Franklin	9/71	3 200	16.0	Good: slippery	Good: in-service, slightly kneaded surface texture
8	Mifflin	10/71	14 600	16.0	Good: slippery, some scattered cracks and rutting	Good: in-service, surface worn through to original surface in scattered areas, very tightly kneaded mat

Note: 1 mm = 0.039 in.
[a]Skid number 25.

1. A small but not excessive amount should drain to the bottom of the pan;
2. The mix should appear glossy rather than dull; and
3. If a freshly prepared mix is molded into [102 by 102 by 16-mm (4 by 4 by ⅝-in)] pats on the glass plate, the mix should exhibit a complete seal on the glass plate and open texture on the surface.

The composition of the mixes based on laboratory extractions is given elsewhere (10). The average percentage passing the 6.35-mm (no. 3) sieve was 18.

Construction Data and Procedure

The condition of the roadways prior to the application of the friction course was documented (10). A brief description is given in Table 2. In most cases RS-1 emulsified asphalt was applied at 0.23 L/m^2 (0.05 gal/yd^2) as a tack coat, which was often damaged by construction traffic. Mix temperatures ranged from 127 to 135°C (260 to 275°F). Although the mix design method allows some extra binder for flow-down during and immediately after placement to form a complete seal, such flow was not observed.

No serious problems were encountered during transport, placement, or compaction of these mixes. Compaction was accomplished with two to three passes of a 9-Mg (10-ton) steel-wheeled roller. Traffic permitted on the friction courses immediately after completion of rolling caused no damage.

Performance and Skid Data

The present status of the projects is described briefly in Table 2. The first four projects are of dubious experimental value, because the friction course was placed at a thickness of 13 mm (½ in) or less. This caused premature loss of aggregate and, consequently, early failure of the test sections. Failure resulted from the structurally unsound pavements underneath these applications. The raveling of the open-graded mix usually began near structural or reflective cracks.

It has been observed that debris and traffic action have closed up the voids in open-graded friction courses and that for all practical purposes these surfaces are impermeable. Although the friction courses in areas of low average daily traffic (ADT) volume have maintained good surface texture, those in areas of high traffic volume (12 000 to 24 000 ADT) have developed a tight, coarse texture similar to that of a dense-graded mix. The average percentage passing the 2.36-mm (no. 8) sieve in these mixes was 18, which should obviously be lowered if permeability is to be maintained as traffic becomes heavier.

The skid test data from these projects (Figure 1), with the exception of one carbonate aggregate source (project 8), show generally good to excellent results. Those projects using coarse gravel aggregate are consistently higher in skid resistance. The averages (total of eight projects) show gravel surfaces to be about 20 skid numbers higher than carbonate surfaces. For individual projects, where both aggregate types were used on the same site, the gravel surfaces are about 10 to 15 skid numbers higher.

It is evident from Figure 1 that initially these test pavement skid resistances were lower because of the presence of a thick asphalt film surrounding the aggregates at the surface. Skid resistance increased when aggregate microtexture was exposed by traffic wear.

All skid test data were obtained at 64 km/h (40 mph) on a one-wheel towed trailer as per ASTM test designation E-274.

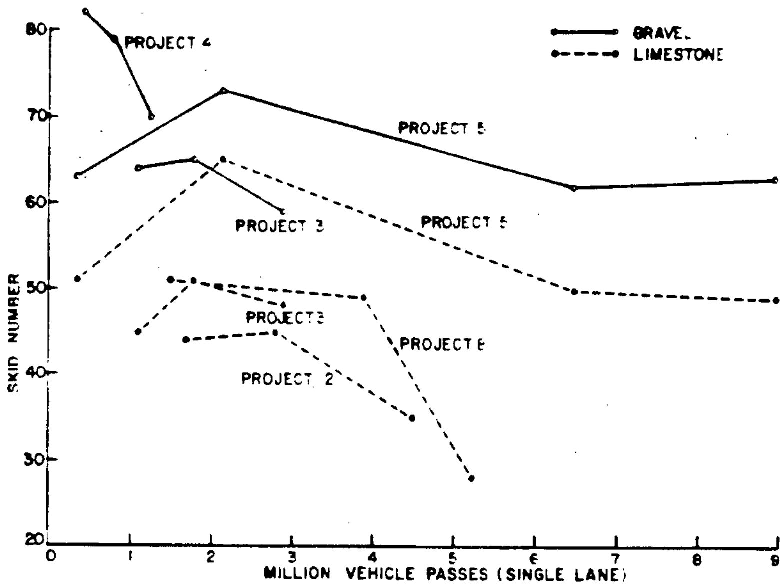
TEST PAVEMENTS, 1974

Judging from experience gained from the 1969 to 1971 test pavements, we felt it was necessary to consider the following factors.

1. Gradation. We observed, as mentioned earlier, that the gradation should be made coarser to maintain permeability of the open-graded mixes. The amount of material passing the 2.36-mm (no. 8) sieve should be decreased.
2. Asphalt content. The percentage of asphalt had previously been selected by conducting a series of asphalt "drainage" tests on several trial mixtures made with various asphalt percentages. It was still possible that the mix could contain either too little asphalt, which could cause raveling, or too much, which could result in flushing. A more reliable method was needed.
3. Mix temperature. Mix temperatures were chosen arbitrarily. Logically, viscosity should be used in establishing mix temperatures.

The design procedure described by Smith, Rice, and Spelman (1) seemed to be reliable and logical. This method had been used successfully on several Federal Highway Aministration (FHWA) R&D demonstration projects. In the design procedure, the optimum content of fine aggregate is established by finding the void

Figure 1. Pavement skid data, 1969 to 1973



capacity of coarse aggregate and providing a minimum air void content of 15 percent. The asphalt content is determined from the surface capacity of the predominant aggregate size fraction. Optimum mixing temperature is based on asphalt viscosity.

Therefore 1974 test pavements of open-graded asphalt friction course were designed and placed according to the FHWA procedure. The project is located near Philadelphia on Route 252 (LR 144) in Delaware County (Figure 2). The roadway is 7.3 to 9.1 m (24 to 30 ft) wide and carries an ADT of 18 000. High traffic volume and heavy use of studded tires (35 percent during winter months) had badly worn the existing bituminous pavement, which was otherwise structurally sound with a minimum of cracking. Before paving, maintenance forces placed a thin leveling course in some areas of excessive rutting.

Design and Materials

The project included these four test sections (1 mm = 0.039 in) constructed in October 1974:

Section	Material	Aggregate	Thickness (mm)
Control	ID-2A wearing course	Gravel	38
Experimental	Asphalt friction course	Gravel	19
Control	ID-2A wearing course	Dolomite	38
Experimental	Asphalt friction course	Dolomite	19

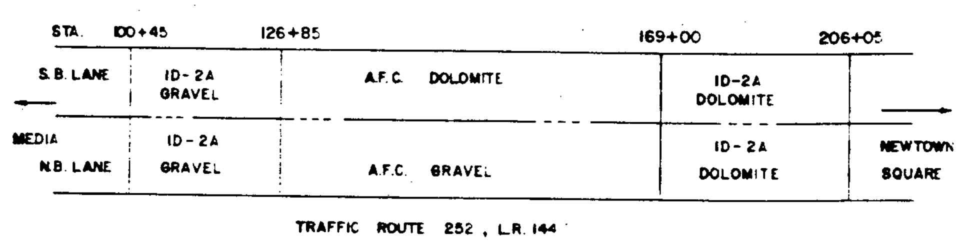
Pennsylvania ID-2A is a dense-graded surface course mix that is widely used in the state and served here as a control for comparison purposes. Crushed gravel was used to provide a highly skid-resistant surface, and the dolomite aggregate was specified for medium skid resistance.

The mix designs for asphalt friction courses were prepared at PennDOT's Bureau of Materials, Testing, and Research (BMTR). The design data are given in the table below [1 mm = 0.039 in and 1°C = (1°F - 32)/1.8]. The mixes were designed to provide 15 percent air voids. The voids in mineral aggregate (VMA) ranged from 37.2 to 39.2 percent.

Test	Asphalt Friction Course Mix: Gravel	Asphalt Friction Course Mix: Dolomite
Coarse aggregate in blend, %	85	95
Fine aggregate in blend, %	15	5
Specific gravity of coarse aggregate	2.545	2.819
Specific gravity of fine aggregate	2.747	2.700
Specific gravity of 9.50 to 4.75 mm fraction	2.622	2.847
Unit weight (vibrated), PCF	96.5	110.3
Voids mineral aggregate, %	39.2	37.2
Optimum fine aggregate, %	16.4	13.4
Kc	1.60	1.40
AC = 2 Kc + 4.0	7.2	6.8
AC (corrected), aggregate basis, %	7.3	6.3
AC, mix basis, %	6.8	5.9
Optimum mix temperature, °C	110	112.8
Asphalt viscosity at the optimum mix temperature, CST	1700	1400

According to the FHWA procedure, the target mixing temperature lies in the range corresponding to asphalt cement viscosities of 7 to 9 m^2/S (700 to 900 centistokes). However, while designing these mixes we observed that the 7- to 9-m^2/S range resulted in too much drainage. The optimum mix temperatures yielding satisfactory drainage corresponded to asphalt cement viscosities of 14 and 17 m^2/S (1400 and 1700 centistokes) for dolomite and gravel, respectively. Several other designs by BMTR have confirmed that a higher range of asphalt viscosity is required.

Figure 2. Pavement location map, 1974.



Construction Data and Procedure

Placement of the open-graded friction course mix went smoothly, and the mix that showed no signs of asphalt drainage or aggregate segregation had a somewhat rich appearance, as expected.

One or two passes of a steel-wheeled roller easily compacted the mix. Repeated rolling was of no value and even caused some degradation of the aggregate. The thickness of the compacted mat averaged 22 mm ([illegible] in.), slightly higher than the 19 mm ([illegible] in.) specified.

Because of the delays between trucks arriving at the job site, the paver remained stationary for periods of time. As a result, the screed heaters, by lowering viscosity, caused the asphalt in the mat to drain, leaving dry-looking strips about 0.3 m (1 ft) wide across the lane. The condition did not seem to be detrimental, but it will be observed for any future effects.

The open-graded gravel mix appeared to be somewhat more open textured than the dolomite, as shown in Figure 3, which also shows the dense-graded ID-2A surface courses.

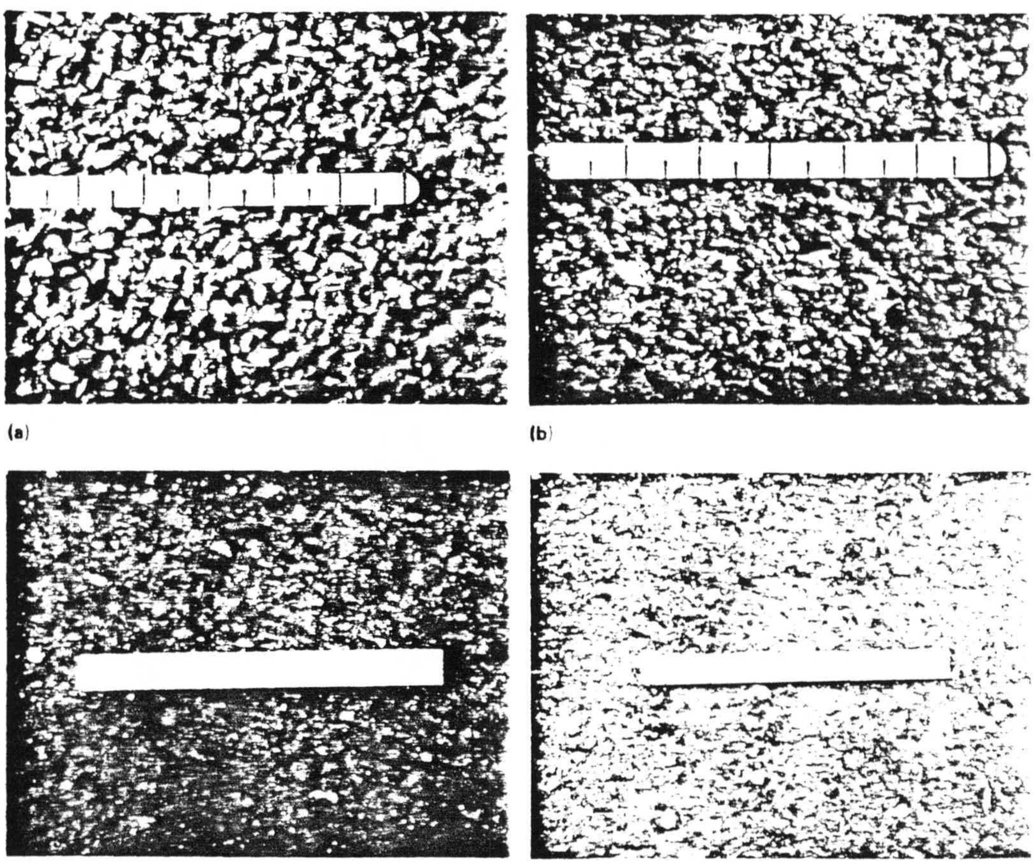
The mix designs and results of the plant and field test samples for the open-graded mixes are shown in Table 3. Samples of the open-graded gravel mix conformed well to the design. The plant sample of the open-graded dolomite mix was high on the 4.75-mm (no. 4) sieve, and the field sample was high on both that and the 2.36-mm (no. 8) sieve, as well as on asphalt content.

The mixes for the ID-2A wearing course also used the same gravel and dolomite aggregates. The material was designed to meet the requirements of PennDOT specifications.

Table 3. Mix design and test sample results for open-graded mixes

Item	Percentage Passing						
		Gravel			Dolomite		
	Specification Limits	Design	Plant Sample	Job Sample	Design	Plant Sample	Job Sample
Sieve size							
9.5 mm	100	100	100	100	100	100	100
4.75 mm	30-50	31.[illegible]	42.4	41.8	34.9	53.9	51.9
2.36 mm	5-15	14.7	14.7	15.[illegible]	12.7	11.[illegible]	17.0
75 µm	2-5	1.9	3.[illegible]	2.8	3.6	3.2	4.6
Percentage of asphalt by weight of mix	6.0-8.0	6.8	6.8	6.8	5.9	5.9	6.4
Mixing temperature, °C	126.7 (max)	107.2-112.8	–	–	110-115.6	–	–

Note: 1 mm = 0.039 in, 1 µm = 0.0039 in, and t°C = (t°F - 32)/1.8



(a) (b) (c) (d)

Figure 3. Comparison of mixes: (a) open-graded gravel, (b) open-graded dolomite, (c) ID-2A dense-graded gravel, and (d) ID-2A dense-graded dolomite

Figure 4 Skid data on gravel mixes.

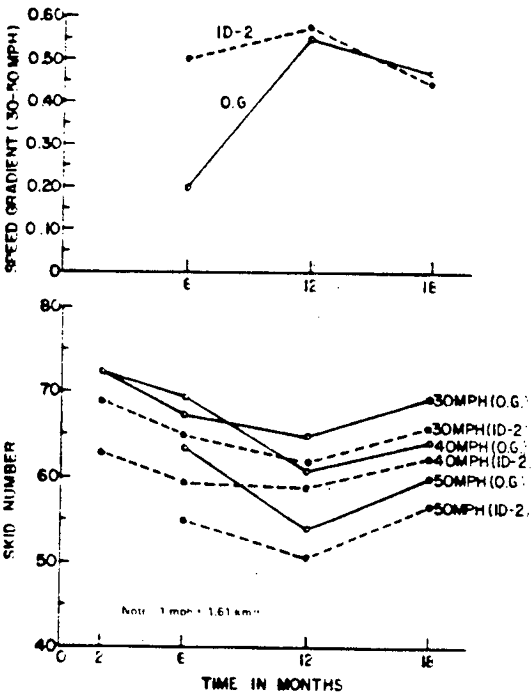
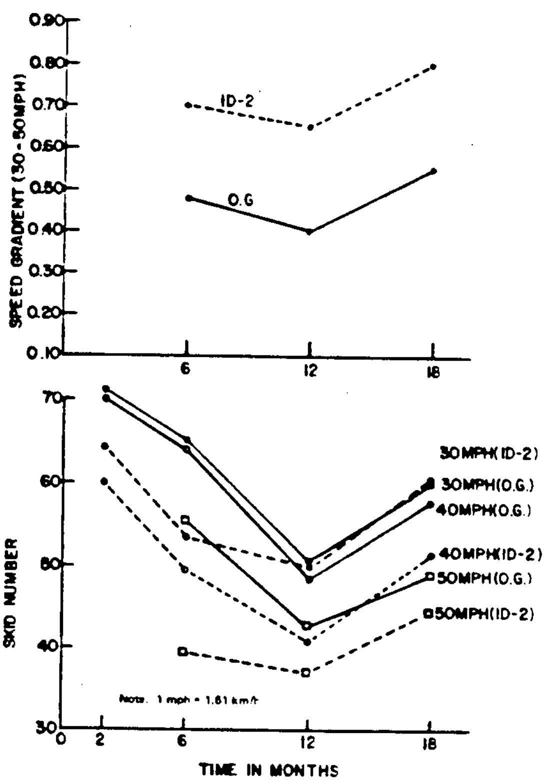


Figure 5. Skid data on dolomite mixes.



Performance Evaluation

The test pavements were constructed in October 1974 and have been evaluated at 6-month intervals since 2 months after placement. The evaluation includes judging visual appearance and measuring skid, permeability, and surface texture.

Table 4. Air permeability data.

Mix Type	Permeability (cm³/min) At 20 Days	At 6 Months	At 12 Months	At 18 Months
Open-graded gravel				
W*	20 000+	15[illegible]	46[illegible]	0
C	20 000+	19[illegible]	0	0
Open-graded dolomite				
W	8 60[illegible]	5[illegible]	56[illegible]	7[illegible]
C	6 10[illegible]	74[illegible]	115[illegible]	3[illegible]
ID-2A gravel				
W	[illegible]	44[illegible]	0	0
C	2[illegible]	23[illegible]	0	0
ID-2A dolomite				
W	114	1[illegible]	0	0
C	26[illegible]	4	0	0

Note: 1 cm³ = 3.38 fluid oz.

*W = in the wheel track area and C = in the center of the lane.

Skid Testing

Tests were conducted at speeds of 48, 64, and 80 km/h (30, 40, and 50 mph) so that we could determine speed gradients. The skid level for each test section was taken as the average of 10 tests taken at two test sites. Skid test data for ID-2A gravel mix and open-graded gravel mix are shown in Figure 4. After 1½ years in service, the open-graded gravel mix is only two or three skid numbers higher than the ID-2A gravel mix. The speed gradient of both mixes is almost equal and approaches 0.45.

The open-graded mixes are generally thought to have lower speed gradients when compared with conventional dense-graded surface mixes. However, it is evident from this study that, if the aggregate possesses high skid resistance, this may not be generally true. If the aggregate—such as dolomite in this study—is not shown to be highly skid resistant, the open-graded mix has a substantially lower speed gradient (Figure 5). It seems that the microtexture predominates over the macrotexture when the mix contains highly skid-resistant aggregate, whereas macrotexture becomes a predominant factor when the mix contains relatively less skid-resistant aggregate. Continual evaluation of this project is necessary to drawing any firm conclusions.

Permeability

Permeability of the pavement surfaces has been measured periodically with the air permeability meter developed by the Pennsylvania State University (11). This device measures the rate of air flow in cubic centiliters per minute through the pavement at selected pressure differentials. Air pressure is applied to the surface of the pavement via a circular chamber sealed to the pavement with grease. Permeability readings are shown in Table 4.

Initially, the open-graded mixes had considerably higher permeability than the ID-2A dense-graded mixes. However, after 1½ years' service, the test pavements, compacted under traffic and clogged with debris, lost their permeability. Only the open-graded dolomite mix has so far retained some permeability, although it is insignificant and is approaching zero.

A minimum air void content of 15 percent was provided in the mix, according to the FHWA procedure, to ensure adequate subsurface water drainage, but apparently this minimum content will have to be increased to 25 percent, by reducing the fine aggregate content in the mix. This can have other implications.

A maximum amount of fine aggregate is desirable because it imparts a "chocking" action to the coarse aggregate particles and because it prevents mixture raveling (1). A possible compromise is to limit the amount of aggregate passing the 4.75-mm (no. 8 sieve to a maximum of 10 percent.

Surface Texture

Measurements of the pavement surface texture are being made with the sand track device developed by the Pennsylvania State University and modified by PennDOT (11). This device works first by placing the tester or a level area of the pavement. Then the hopper is filled with a specific amount of sand and, driven along by a spring motor, deposits a strip of sand on the pavement surface. The length of the strip will vary according to the roughness of the surface. The readings are then converted to the average texture depths shown in the following table (1 mm = 0.039 in). After 18 months in service, there is no significant difference between the open-graded mix and the ID-2A surface mix.

	Surface Texture Depth (mm			
Mix Type	At 20 Days	At 6 Months	At 12 Months	At 18 Months
Open-graded gravel	0.0036	0.0046	0.0042	0.0029
Open-graded dolomite	0.0033	0.0030	0.0030	0.0028
ID-2A gravel	0.0025	0.0044	0.0043	0.0029
ID-2A dolomite	0.0017	0.0033	0.0018	0.0023

CONCLUSIONS AND RECOMMENDATIONS

Test Pavements, 1969 to 1971

We have been evaluating these pavements for 5 to 6 years and have made the following observations.

1. Open-graded mixes should not be placed less than 19 mm (¾ in) thick.
2. Structurally unsound pavements cannot be corrected by applying an open-graded mix, which only results in premature failure of the application.
3. Debris and traffic action have closed up the voids in the open-graded mixes. In areas having an ADT over 12 000, the mixes developed a tight, coarse texture somewhat similar to that of a dense-graded mix. The average percentage of aggregate passing the 4.75-mm (no. 8) sieve in these mixes was 18, which is evidently excessive.
4. The open-graded pavement surfaces became impermeable, for all practical purposes, within 1 to 2 years.
5. Raveling usually began either where the mix was placed thinly over high spots or where there were edges or perimeters of cracks and joints in the pavement.
6. If properly laid, the average service life of an open-graded surface seems to be 5 to 6 years.

Test Pavements, 1974

Because the pavements have been evaluated for just 1½ years, this is only a progress report. We have made the following observations.

1. Optimum mix temperatures yielding satisfactory drainage corresponded to asphalt viscosities of 14 and 17 m^2/S (1400 and 1700 centistokes) respectively for dolomite and gravel aggregates. The range 7 to 8 m^2/S 700 to 900 centistokes recommended in the FHWA design procedure seems too low.
2. Open-graded mixes were designed, according to the FHWA design procedure, with 15 percent air voids to provide adequate permeability. However, after 1½ years' service the pavements lost their permeability from compacting under traffic and clogging of voids with debris. We estimate that a minimum air void content of 25 percent is necessary to maintaining permeability. The possible disadvantages of very high air void content (raveling, for instance) are not very clear.
3. After 1½ years in service, the open-graded gravel mix is only two to three skid numbers higher than the dense-graded ID-2A gravel mix. The speed gradient of 48 to 80 km/h (30 to 50 mph) for both mixes is almost equal and is approaching 0.45. This runs contrary to the general belief that the macrotexture of open-graded mixes gives them lower speed gradients than dense-graded mixes. It seems that microtexture predominates over macrotexture if a mix contains a highly skid-resistant aggregate, such as the gravel used in this project.
4. If the aggregate, such as the dolomite aggregate used in this project, is not highly skid resistant, the open-graded mix has a substantially lower speed gradient compared with the ID-2A dolomite mix after 1½ years in service. Macrotexture becomes a predominant factor if the mix contains relatively lower skid-resistant aggregate.

The evaluation of these test pavements will continue so that long-range performance and durability of the open-graded mixes can be compared with those of the dense-graded mixes.

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I

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de dissipation des contraintes constituée de 4 mm de mastic bitumineux réalisé avec un bitume de distillation directe de pénétration 100 ; couche d'accrochage de 300 g/m² d'adhésif caoutchouc-résine.

4. Enrobés ouverts drainants

Nés au cours des années 60, développés initialement sur les pistes d'aérodromes, les enrobés ouverts drainants présentent de nombreux avantages maintenant bien connus : adhérence par temps de pluie, suppression des projections d'eau, réduction du bruit, coût relativement faible. Plusieurs communications ont apporté des données nouvelles d'un grand intérêt sur ces revêtements.

La formulation de ces revêtements est maintenant bien maîtrisée. Il est nécessaire d'obtenir une teneur en vides en place dépassant 20 %. Les films de bitume doivent être suffisamment épais pour assurer une bonne durabilité, mais la teneur en liant est limitée par le risque de séparation du liant ; l'emploi de bitumes polymères, ou bitumes poudrette de caoutchouc, plus visqueux aux températures d'enrobage, permet d'augmenter sensiblement la teneur en liant. Plusieurs auteurs font état de l'emploi de liants modifiés pour les sites difficiles où l'on souhaite une grande durabilité, ou bien pour des enrobés pour lesquels on a recherché une teneur en vides particulièrement élevée.

Le caractère drainant diminue dans le temps par le compactage dû au trafic et le colmatage par les salissures. Sur les revêtements étudiés par **Koester** (Suisse) la drainabilité reste plus forte dans le passage des roues qu'entre les roues, ce qui montre que l'effet de nettoyage par le trafic l'emporte sur le compactage (figure 13).

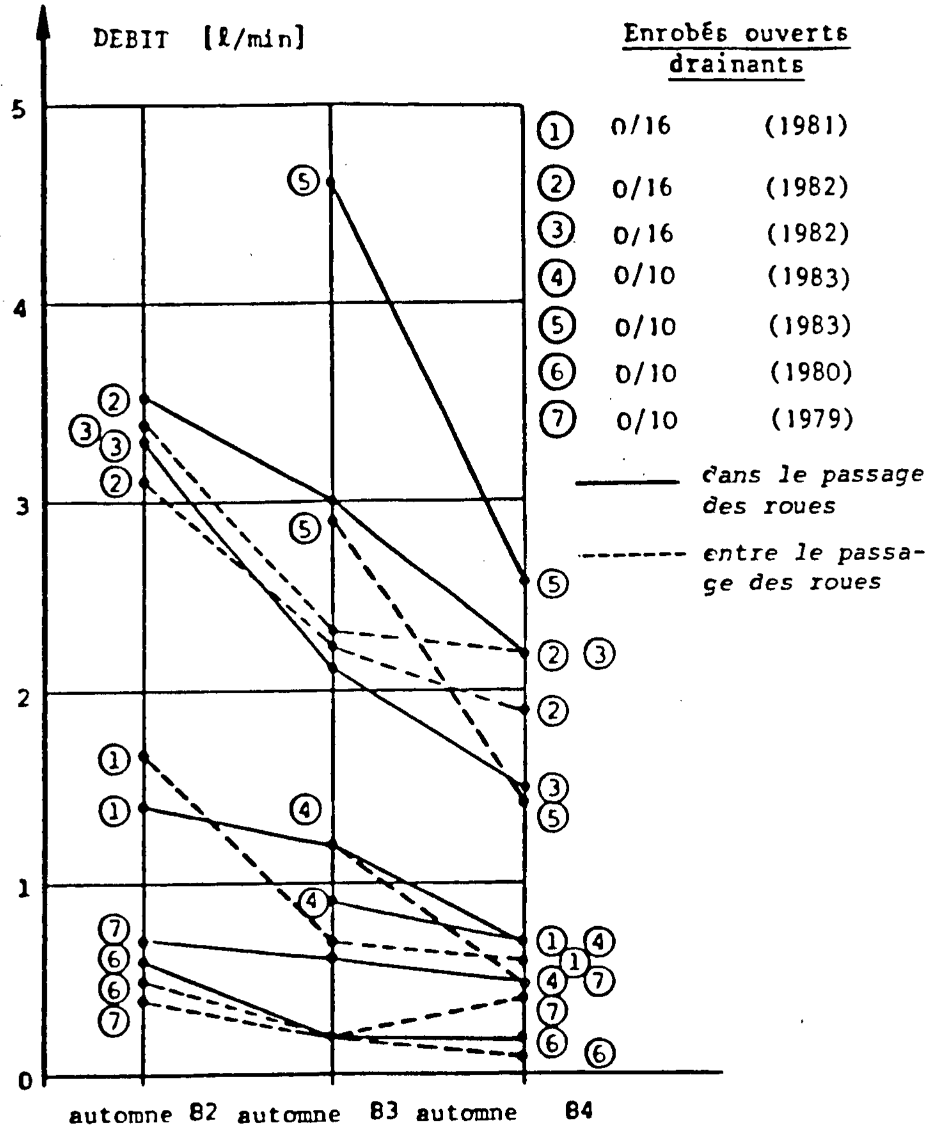


Figure 13. Evolution en fonction du temps du débit d'eau absorbée à travers des enrobés ouverts drainants (Koester)

Les enrobés drainants se caractérisent par une faible décroissance de l'adhérence (sur chaussée arrosée juste avant le passage de la roue de mesure) avec la vitesse. Cependant, pour obtenir un niveau moyen d'adhérence satisfaisant, il est nécessaire d'utiliser des granulats ayant une résitance au polissage élevée.

Le bruit du trafic est réduit sur les couches de roulement en enrobé drainant ; cette propriété, qui était sans doute accessoire lors de la création de la technique, devient maintenant dans bien des cas l'incitation principale à leur emploi, notamment pour les voies rapides urbaines. Il y a d'abord réduction du bruit de roulement à la source : le lien qu'il y a, pour les revêtements bitumineux classiques, entre faible chute de l'adhérence avec la vitesse et bruit de roulement élevé, n'existe pas pour les enrobés drainants. Mais ils ont aussi des capacités d'absorption acoustique : **Koester** (Suisse) et **Heerkens** (Pays-Bas) montrent que l'absorption peut atteindre 90 % dans certaines fréquences, fonction de l'épaisseur des couches. Il en résulte une réduction du bruit du trafic mesuré en bord de chaussée. **Hoban** (Grande-Bretagne) fait état d'une réduction de 3 à 4 dB(A) sur chaussée sèche, et de 7 à 8 dB(A) sur chaussée mouillée. **Heerkens** a procédé à une optimisation de la composition des enrobés drainants sur le plan de leurs propriétés acoustiques ; l'optimum qu'il a défini est un enrobé discontinu 0/2 - 8/11 à 20 - 24 % de vides en place, en épaisseur 40 mm, la durabilité et la stabilité d'une formule à teneur en vides aussi forte étant obtenue par l'emploi de bitume poudrette de caoutchouc dosé à 5,5 %. La réduction de niveau du bruit continu équivalent par rapport à un béton bitumineux dense, et par rapport à un enrobé drainant classique, est donnée dans le tableau 1.

Malgré leurs propriétés très intéressantes, les enrobés drainants sont peu utilisés. Il faut sans doute en rechercher la raison dans leur comportement particulier pour ce qui concerne la viabilité hivernale.

De par leur très forte teneur en vides, ils ont des propriétés d'isolation thermique différentes de celles des enrobés classiques, si bien que le verglas n'y apparaît pas au même moment, et que la neige ne s'y comporte pas de la même façon. De plus, les sels de déverglaçage sont drainés par la porosité du revêtement, de telle

Tableau 1. Bruit du trafic sur divers revêtements par comparaison avec le bruit sur un béton bitumineux dense

	Véhicules légers et poids lourds (20 % de PL)	Véhicules légers seuls
Dalles de béton	+ 4,3 dB(A)	+ 3,3 dB(A)
Béton bitumineux dense	0	0
4 cm d'enrobé drainant classique	− 2,6 dB(A)	− 3,0 dB(A)
4 cm d'enrobé drainant optimisé du point de vue acoustique	− 3,4 dB(A)	− 3,7 dB(A)

sorte que le salage préventif n'y a pas la même efficacité.

La communication de **Koester** (Suisse) a le grand intérêt de donner sur ce point des indications chiffrées (figure 14). Elle montre clairement que lorsque le niveau d'adhérence est faible sur les enrobés classiques, il peut être élevé sur les enrobés drainants, mais qu'il y a effectivement des cas où l'adhérence, excellente sur les enrobés classiques, peut être faible sur les enrobés drainants. La communication montre précisément dans quels cas ces situations se présentent. Cependant, les auteurs de communications qui ont abordé ce point s'accordent pour dire que le problème est soluble. Ainsi **Gérardu** estime que pour les Pays-Bas l'entretien hivernal des enrobés drainants ne pose pas de problème les hivers normaux ; il en pose cependant les hivers particuliers où il y a des périodes de gel-dégel nombreuses ; les problèmes de viabilité hivernale peuvent être résolus dans presque toutes les conditions mais ils nécessitent plus d'attention de la part des services d'entretien.

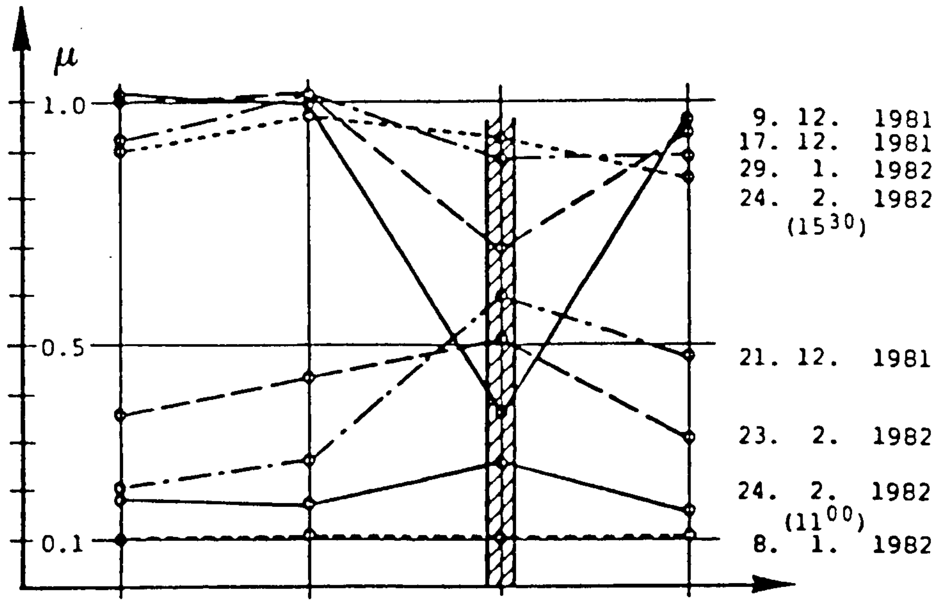


Figure 14 Adhérence comparée, à différentes dates, sur des sections contiguës de trois revêtements compacts et un revêtement ouvert drainant (Koester).

Discussion

La première partie de la discussion a permis à trois auteurs d'apporter des compléments à leur communication.

A la demande des rapporteurs, **M. Srivastava** (Pays-Bas) a d'abord apporté des précisions sur la méthode qu'il a utilisée pour caractériser les améliorations qu'apporte l'emploi des liants modifiés décrits dans sa communication, du point de vue de la résistance des enrobés à la propagation des fissures. Cette méthode repose sur l'application des théories de la mécanique de la rupture.

M. Chavet (Belgique) a complété sa communication sur l'expérience belge en matière d'enrobés drainants, en présentant d'abord une application comme couche de roulement sur un radier de tunnel dans un site où la nappe phréatique est très haute. Après avoir donné des chiffres sur la réduction du bruit du trafic obtenue sur le Ring de Bruxelles (7 dB(A)), il a précisé que le gain est particulièrement marqué sur chaussée mouillée ; l'augmentation de la teneur en vides et de l'épaisseur de la couche favorise la réduction du bruit de roulement. Un chantier expérimental visant à comparer divers liants, modifiés ou non, en enrobés ouverts drainants, a été réalisé. Il a signalé enfin que l'échec du revêtement réalisé sur le circuit automobile de Spa-Francorchamps ne remet pas en cause la technique des enrobés drainants.

M. Nielsen (Danemark) a apporté quelques informations complémentaires sur l'expérience de son pays en matière de liants modifiés, notamment sur le procédé Chemcrete, pour lequel il a précisé que sur un chantier le durcissement du liant ne s'était pas produit au niveau attendu.

Il a également montré les résultats d'une étude de l'effet de la modification du liant sur le comportement à la fatigue de bétons bitumineux, mettant en évidence une amélioration relativement faible.

Le premier thème de la discussion proprement dite a porté sur les liants modifiés

M. Brûlé (France) a demandé si le processus de modification du bitume par l'additif Chemcrete était vraiment différent d'un vieillissement, processus que l'on cherche justement à éviter ou à retarder ; il a également demandé des précisions sur l'élévation de la température de fragilité Fraass signalée par **M. Korskgaard** dans sa communication.

M. X..., répondant à la fois à M. Nielsen et à M. Brûlé a signalé qu'il ne faut pas généraliser l'observation faite sur une route particulière où le durcissement ne s'est pas produit : plusieurs observations sur d'autres routes ont montré que le résultat attendu était obtenu ; le durcissement résultant de l'emploi de l'additif conduit à un bitume différent d'un bitume vieilli, comme le montrent des essais sur enrobés ; de même l'élévation du point de Fraass n'empêche pas un bon comportement de l'enrobé à basse température. Bien sûr, dans un pays à climat froid il ne faudrait pas utiliser un bitume de base trop dur, à une teneur trop faible.

Sur une question de **M. Ishai** (Israël), craignant à propos du procédé Durflex que la température de ramollissement bille et anneau très élevée obtenue n'ait des inconvénients, **M. Croccolo** (Italie) a précisé que pour ce liant, il faut augmenter la température d'enrobage et la durée du malaxage et utiliser des granulats présentant une bonne granularité. Il s'agit d'un procédé encore très récent pour lequel on ne peut pas encore donner d'informations sur le comportement dans le temps.

En réponse à **Mme Cvoboda** (Bulgarie), **M. Bonnot** a précisé que la compatibilité entre un bitume et un polymère peut être vérifiée d'une part sur le plan macroscopique, en examinant si l'addition du polymère produit pendant le mélange une modification visible de l'équilibre colloïdal du bitume ; et d'autre part sur le plan microscopique, par observation de la structure du liant par microscopie optique de fluorescence. On ne peut pas parler de compatibilité indépendamment des moyens utilisés pour faire les mélanges. Sur la question du développement réel de l'emploi des liants modifiés en Europe, il précise que dans plusieurs pays on a dépassé le niveau des chantiers expérimentaux et que l'on est passé à une application sur chantiers réels, parfois de grande taille ; cependant les liants modifiés ne représentent pas des quantités plus importantes que quelques pour cent des liants utilisés.

M. Van Der Heide (Pays-Bas) s'est interrogé sur l'utilité réelle de l'emploi des liants modifiés dans les couches de surface, du fait que les fissures de fatigue partent des couches inférieures et que l'orniérage se produit surtout dans les couches de liaison ou inférieures ; quant aux couches de base, ne vaudrait-il pas mieux améliorer la composition des enrobés plutôt que d'avoir recours à des liants modifiés ? Pour **M. Bonnot,** l'emploi de liants modifiés dans les couches de surface peut être justifié pour réduire la tendance à l'orniérage, qui peut se produire dans ces couches si elles sont épaisses ; et pour améliorer leur résistance à la fissuration ou leur durabilité. De même, dans une couche de base, l'amélioration de la formulation et l'emploi de liants modifiés ne sont pas incompatibles, un liant modifié permettant par exemple d'augmenter la teneur en liant sans risque d'orniérage.

M. Harlin (France) a présenté des résultats obtenus après neuf ans sur un enrobé modifié par un bitume SBS : les caractéristiques du liant et le module et la résistance à la fatigue de l'enrobé ont très peu évolué dans le temps.

Le second thème de la discussion a été les essais sur enrobés

M. Leutner (RFA) a rappelé sur des exemples que le choix de la dimension et de la forme des éprouvettes d'enrobés doit tenir compte de la dimension des plus gros granulats.

M. Peffekoven (RFA) souligne l'intérêt des essais d'orniérage (passage répété d'une roue chargée) pour l'étude de la résistance aux déformations permanentes ; ces essais ont en effet pour avantage de comporter l'application d'une pression de contact analogue à celle qui existe dans la réalité, à une température analogue à celle rencontrée l'été dans les couches de surface, et de s'appliquer à des échantillons soumis à une étreinte latérale. Il met en garde contre des études visant à mettre en évidence l'amélioration de résistance aux déformations permanentes résultant de l'emploi de bitumes modifiés, qui utiliseraient des essais de chargement statique, et sans étreinte latérale.

Les enrobés ouverts drainants ont constitué le dernier thème de la discussion

M. **Palli** (Suisse) se demande si la réduction du bruit de roulement résultant de l'emploi d'enrobés ouverts drainants se traduira réellement par une diminution du bruit d'ensemble dû au trafic, pour les riverains. **M. Bonnot** répond que si l'on a effectivement constaté une réduction du bruit de roulement pour un véhicule isolé, moteur coupé, on dispose aussi de mesures de bruit dû au trafic qui confirment l'efficacité des enrobés ouverts drainants. Ceci résulte du fait qu'avec les véhicules actuels, au-delà d'une vitesse assez basse (50 à 60 km/h) le bruit de roulement est prépondérant ; de plus les enrobés ouverts drainants ont un pouvoir d'absorption du bruit.

M. Palli s'inquiétant des problèmes particuliers de viabilité hivernale posés par des enrobés ouverts drainants, au vu notamment des résultats de mesure figurant dans la communication de **M. Koester, M. Nievelt** (Autriche) signale qu'il n'y a pas eu de problème de formation de verglas sur les sections des autoroutes autrichiennes, revêtues d'enrobés ouverts drainants, même pendant l'hiver rigoureux 1984-1985 ; il estime que les films épais de liants, par leur souplesse, réduisent la possibilité de formation de verglas.

M. Van Gorchum indique qu'une enquête réalisée aux Pays-Bas a montré que depuis l'hiver 1978-1979, qui avait entraîné de grosses difficultés, il n'y a pas eu de problèmes de viabilité hivernale, mais qu'il faut répandre plus de sel.

Enseignements à tirer de la session IV, du point de vue français

Dans le domaine des liants modifiés, la France apparaît comme particulièrement bien placée par rapport aux autres pays européens, à la fois pour ce qui concerne la mise au point de liants à caractéristiques intéressantes et le développement de leur emploi en enduits superficiels et en enrobés. Il est significatif que la seule communication consacrée à l'étude du processus de modification du bitume par addition de polymères soit une communication française. Le niveau de modification des propriétés des liants, par rapport à celles du bitume, obtenu sur les bitumes polymères mis sur le marché en France, semble élevé par rapport à ce qu'il en est dans certains autres pays européens.

Ceci ne veut pas dire que des progrès ne restent pas à faire dans certains domaines. Il faut poursuivre les efforts faits pour élucider les mécanismes de la modification, lorsque le polymère est ajouté en faible proportion (3 à 5 %) c'est-à-dire lorsqu'il n'y a pas de matrice continue de polymère gonflé. Il est sans doute possible d'améliorer l'efficacité des procédés utilisés pour réaliser le mélange bitume polymère, pour obtenir une microstructure fine et stable. Il faut arriver à une parfaite maîtrise des processus de fabrication, notamment lorsque l'on vise à obtenir une réaction chimique entre bitume et polymère. Le vieillissement des bitumes polymères doit être étudié, ainsi que les facteurs permettant de le retarder ; il est rassurant que la discussion ait montré qu'il était possible d'obtenir des bitumes polymères ayant une bonne stabilité à long terme.

Le principal progrès qui reste à faire consiste à établir les relations qui existent entre les résultats des essais de laboratoire faits pour caractériser les liants modifiés et les propriétés d'usage de ces liants, qui se traduisent elles-mêmes dans le comportement ultérieur des enrobés bitumineux et des enduits superficiels. Pour les enrobés utilisés en couche épaisse, on sait prévoir le comportement des enrobés par des modèles théoriques de mécanique des chaussées, utilisant les résultats d'essais de laboratoire sur les enrobés, à cette réserve près que tous les processus de dégradation ne sont pas modélisables (par exemple le vieillissement). Pour les enrobés en couche mince et très mince et les enduits superficiels, on n'a pas cette ressource : le choix des essais de laboratoire les plus significatifs du comportement et la fixation des critères nécessitent un important travail d'observation du comportement sur chaussée, prolongé pendant une durée suffisamment longue.

La procédure d'avis technique sur les liants et enrobés spéciaux va permettre une meilleure information des utilisateurs en France, qui auront de plus l'assurance que sous un même nom il leur est fourni un même liant. Nous n'avons pas prévu de faire ce qui est fait en Suisse (communication de **Fetz**), où l'on est allé plus loin en fixant des spécifications minimales à satisfaire par un liant pour qu'il mérite le nom de bitume modifié par un polymère. Les liants modifiés étant très nombreux, avec des caractéristiques très diverses adaptées à leurs multiples usages, des spécifications, pour être vraiment utiles, devraient reposer sur une classification des liants modifiés en grandes catégories, avec indication de valeurs limites pour chacune d'elles ; il nous a semblé qu'établir de telles spécifications n'était pas conciliable avec le caractère de procédés spéciaux d'entreprise, encore en pleine évolution, des bitumes polymères.

Plusieurs communications de la Session IV montrent qu'il y a encore un certain scepticisme envers les avantages réels des liants modifiés sur le plan économique. Pour les enduits superficiels, par exemple, il faudrait mieux savoir dans quelles catégories de trafic et de sites il est avantageux d'utiliser les liants modifiés, et dans quels cas, au contraire, on peut se contenter d'utiliser des liants.

Pour les enrobés d'entretien en couche mince il faudrait chiffrer, en termes de durabilité supplémentaire, l'avantage apporté par l'emploi de liants modifiés. Il est urgent d'apporter des réponses à ces questions, dans l'intérêt même de cette technique.

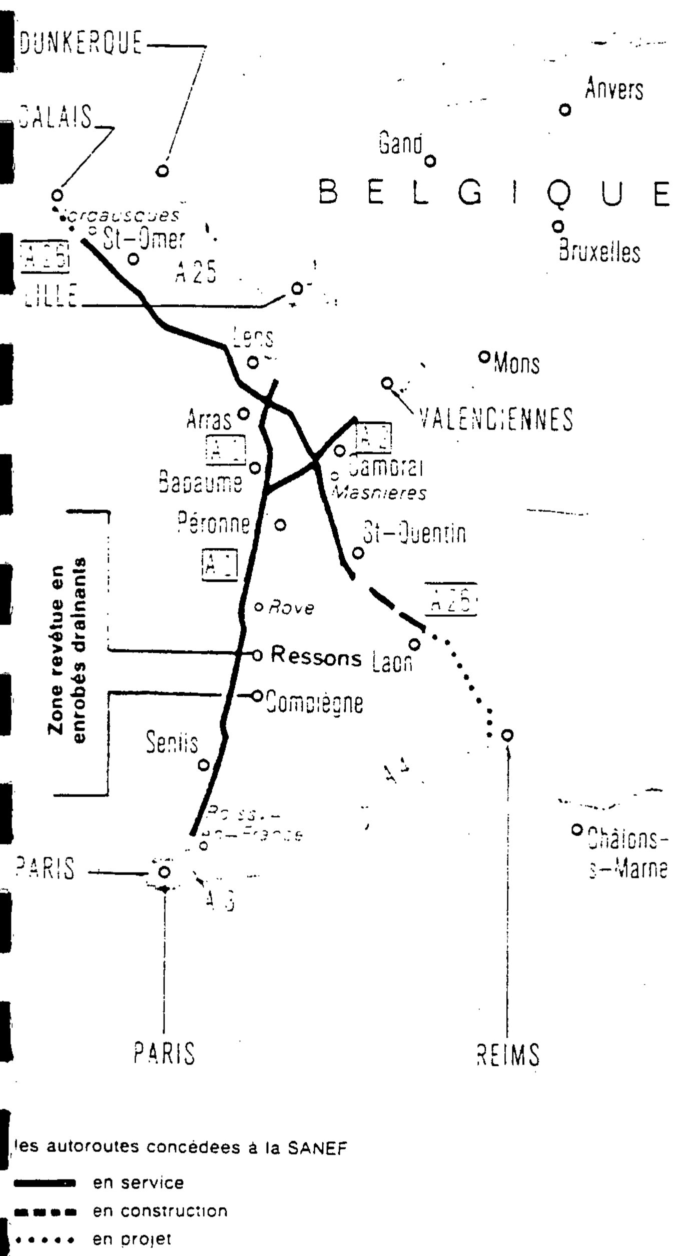
Pour ce qui concerne les enrobés drainants, il apparaît que plusieurs pays ont une expérience plus étendue que la nôtre. Les planches expérimentales et les quelques réalisations opérationnelles existant en France ont pourtant bien permis de mettre en évidence l'étendue des avantages des couches de roulement en enrobés drainants par temps de pluie : bonne adhérence, amélioration spectaculaire de la visibilité, notamment lors du dépassement des véhicules lourds, grâce à la suppression des projections d'eau, bonnes caractéristiques photométriques (limitation de la spécularité qui augmente d'éblouissement par les phares) ; de plus le niveau de bruit de roulement est le plus bas de tous les revêtements actuellement connus, la résistance au roulement est plus faible pour un même niveau d'adhérence à grande vitesse par temps de pluie, l'aspect du revêtement est esthétique, et à même nature de liant le coût au mètre carré est plus faible. C'est dans le comportement particulier de ces revêtements vis-à-vis de la formation du verglas, du maintien de la neige, et de l'efficacité des traitements chimiques de déneigement et de déverglaçage, que se trouve l'explication de la réserve de la plupart des maîtres d'œuvre français devant ces revêtements. Les observations et résultats de mesures figurant dans les communications confirment que le problème existe (voir notamment les très intéressantes mesures de **Koester** en Suisse). En France, le SETRA a souhaité entreprendre pendant l'hiver 1985-1986 des mesures analogues, avant de prendre une décision sur une extension de l'emploi de ce type de revêtements. Il est logique de penser que leurs possibilités d'emploi sont fonction de la région climatique ; par ailleurs on hésitera beaucoup moins à utiliser ces revêtements sur des sections longues d'autoroutes, où ils peuvent faire l'objet d'une surveillance attentive en hiver, avec adaptation de l'emploi des fondants chimiques, que sur des sections relativement courtes du réseau classique où il n'est pas possible de prendre les mêmes mesures.

Une expérience d'enrobés drainants sur l'autoroute A1

Gérard BORDONADO
Directeur de l'agence du Nord de Scetauroute

Le programme d'élargissement de l'autoroute A 1 Paris-Lille (les sections comprises entre la barrière de Chamant et l'embranchement de l'autoroute A 2 Paris-Bruxelles à Combles prévoyait la mise en place simultanée d'un tapis d'enrobés sur la plate-forme existante dans les zones où des opérations de renforcement léger ont été prévues par la Direction d'Exploitation de la SANEF.

Figure 1. Plan de situation



Parmi ces zones, le tronçon situé entre les échangeurs de Compiègne et de Ressons présentait la particularité d'avoir un taux d'accidents par temps de pluie, de 33 % supérieur à la moyenne de l'autoroute. Ce caractère particulier semble notamment dû au profil en long de l'autoroute à la traversée de la vallée de l'Aronde qui présente des pentes de 3,5 % génératrices d'accumulation d'eau dans la partie basse de l'autoroute. En outre, certaines zones de changement de dévers présentent les mêmes inconvénients d'évacuation lente des eaux de pluie.

Le trafic moyen journalier de l'autoroute A 1 dans cette section atteint 35 000 véhicules/jour avec un pourcentage élevé de 27 % de poids lourds. Ce trafic présente des pointes de 40 000 v/j, le taux de poids lourds pouvant atteindre 40 % certains jours de la semaine. En outre, le trafic de nuit reste élevé.

Une formule de revêtement spécial a donc été recherchée pour cette zone particulière. Une solution intéressante consiste à utiliser des enrobés drainants susceptibles de donner de bonnes caractéristiques antidérapantes tout en permettant de réduire voire de supprimer les projections de brouillard d'eau dans le sillage des véhicules et notamment des poids lourds.

Des réalisations d'enrobés drainants ont été faites depuis 1977 dans des conditions extrêmement variables de site et de climat. Elles ont montré les difficultés à résoudre le compromis entre la durabilité, la sécurité et le confort tout en tenant compte du coût. Cependant, l'analyse des réalisations françaises et étrangères faites dans ce domaine aboutit généralement aux constatations d'avantages et d'inconvénients suivantes :

• Avantages

- Diminution importante d'eau sur la chaussée
- Moins de projection d'eau et suppression de phénomènes d'aquaplanage
- Très bonne adhérence
- Bonne résistance à l'orniérage
- Surface peu éblouissante
- Plus faible résistance au roulement que sur les enduits d'où l'intérêt par rapport à la consommation de carburant
- Nette amélioration du niveau sonore au roulement.

• Inconvénients

Ils concernent principalement une adaptation éventuelle de l'entretien hivernal et l'appréhension de chute des propriétés drainantes dans le temps.

La Société des autoroutes du nord et de l'est de la France (SANEF) a demandé à son maître d'œuvre Scetauroute (agence du Nord) d'examiner l'opportunité d'utiliser un revêtement drainant sur la section Compiègne - Ressons de l'autoroute A1 afin de résoudre les problèmes de sécurité (aquaplanage) de cette zone particulièrement exposée.

Notre attention a été attirée par le procédé « Drainochape » proposé par la Société Beugnet et qui avait fait l'objet d'expérimentations dans la région.

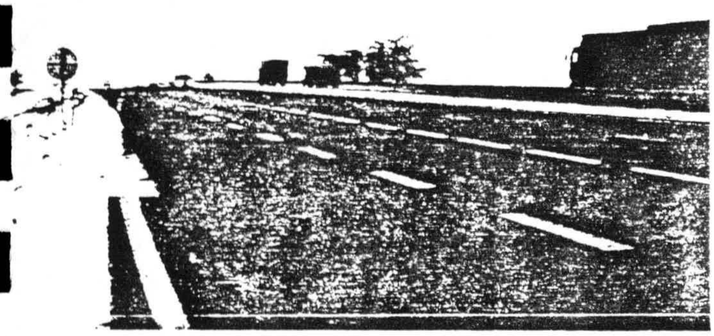


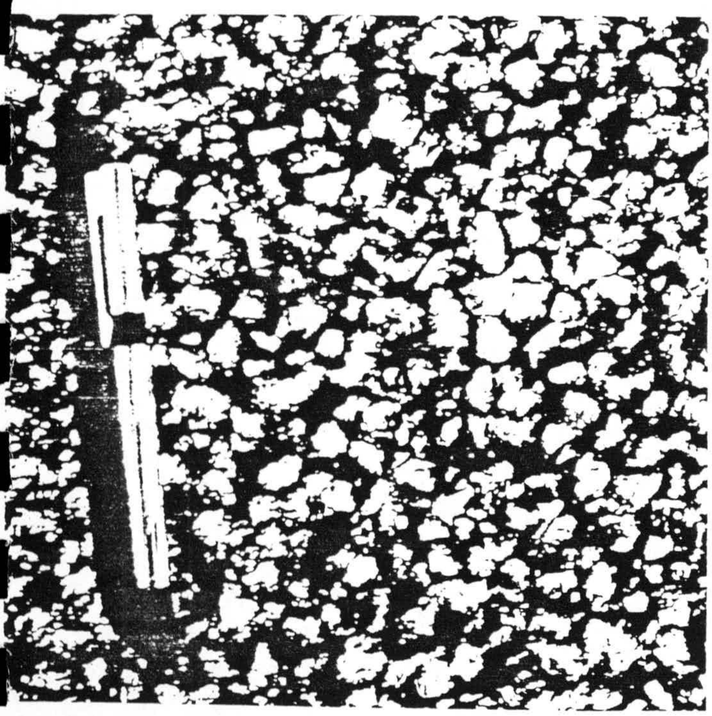
Figure 2 Chaussee revêtue avec des enrobes drainants

En effet, ce type de revêtement a été mis en œuvre au cours de l'année 1983 sur une voie urbaine à fort trafic à Lille (rue Solferino, cf. article de MM. Roussel et Deleurence, n° 618, avril 1985, *Revue générale des routes et des aérodromes*, pp. 71-76. Les resultats obtenus sont intéressants.

Une première planche expérimentale a été réalisée avec ce procédé sur l'autoroute A 26, à la fin 1983, sur une surface de 4 000 m² à l'occasion du renouvellement de la couche de roulement sur un support présentant quelques fissures. Les résultats constatés en 1984 ont été encourageants. Cependant, le trafic moyen de l'autoroute à cet emplacement était de 4 000 véhicules/jour avec 27 % de poids lourds.

L'analyse de ces premières expérimentations nous incitait à retenir pour l'autoroute A 1 un revêtement drainant avec une structure présentant des pores efficaces permettant d'absorber, dans un premier temps, les précipitations et d'évacuer ensuite latéralement les eaux de ruissellement. La capacité de stockage de l'enrobé étant liée à l'épaisseur du tapis et à sa porosité, c'est un revêtement de 4 cm d'épaisseur qui a été retenu afin de satisfaire au drainage vertical et horizontal. En effet, les couches minces d'enrobés drainants de 2 à 2,5 cm d'épaisseur favorisent surtout le drainage horizontal à la surface de la chaussée. En ce qui concerne la granulométrie, la formule discontinue semble plus favorable à la formation de canaux communicants. En tout état de cause, le pourcentage de vide d'un enrobé réellement drainant devrait être supérieur à 15 %.

Figure 3 Aspect de surface des enrobes drainants



Une telle formation structurelle pose le problème de la tenue à la fatigue. L'absence d'éléments fins et la présence de vides doivent être compensés par un film plus épais de liant avec des caractéristiques physico-chimiques élevées. La surface spécifique du liant au contact avec les agents atmosphériques est plus importante, d'où une plus grande susceptibilité aux phénomènes d'oxydation et de désenrobage. Ces considérations semblent militer en faveur d'une forte teneur en liant (6 à 7 %) et de l'emploi de liants spéciaux à forte viscosité. Il est intéressant d'utiliser un liant ayant une faible susceptibilité à la température, ce qui est favorable pour la tenue à la fatigue ainsi qu'à l'orniérage. Dans ce domaine, les enrobés drainants à granularité discontinue et confectionnés avec des liants au bitume élastomère ou au bitume caoutchouc présentent un intérêt certain.

Parmi ces formules élaborées d'enrobés drainants actuellement proposés sur le marché, le « Drainochape » est apparu intéressant avec la formulation suivante :

- granulats durs (micro Deval < 10)
- granulats concassés 6/10 .... 88 %
- sable 0/2 .... 11 %
- chaux grasse .... 1 %
- bitume caoutchouc .... 6.5 %

Le liant est composé de :

- 81 % de bitume 80/100,
- 16 % de poudrette de caoutchouc,
- 3 % d'huile de synthèse.

L'élaboration du liant s'effectue dans une unité mobile de fabrication. La montée en température est de 210 °C, la viscosité du mélange de 1 300 centipoises, la température de ramollissement « bille et anneau » de 60 °C.

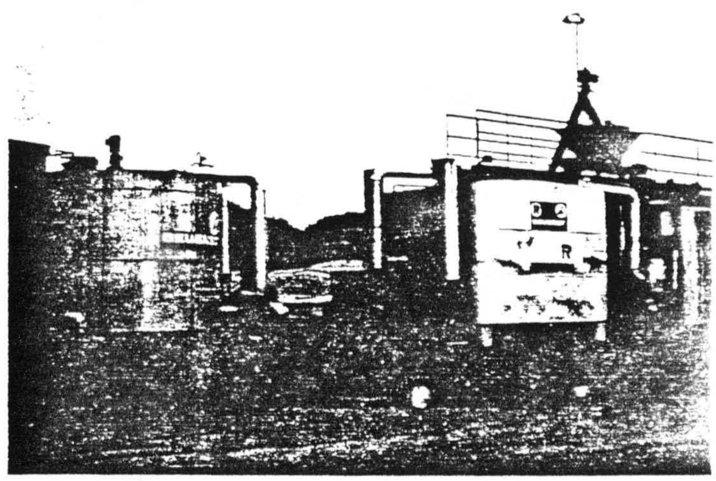


Figure 4 Unite mobile de fabrication du liant bitume-caoutchouc

L'enrobé drainant ainsi fabriqué présente un pourcentage de vide de 20 % et une densité égale à 2.

Cet enrobé répond aux préoccupations que nous avions eues initialement.

- Le pouvoir drainant est satisfaisant compte tenu du pourcentage de vide et de granularité discontinue formant des pores efficaces communicants.

- Du point de vue de la tenue à la fatigue, l'épaisseur du film de liant, les caractéristiques rhéologiques et d'élasticité élevées de celui-ci, sa capacité de déformation aux basses températures sont des éléments positifs.

- En ce qui concerne le ressuage, la température de ramollissement élevée permet d'éviter ce risque.

- Pour pallier les déformations d'orniérage, le granulat dur concassé et la faible susceptibilité thermique du liant sont favorables.

- Pour conserver les performances du liant lors du vieillissement, les qualités intrinsèques du liant sont prépondérantes. Celui-ci contient des éléments anti-oxydants et pas d'éléments volatils. En outre, l'épaisseur du film de liant est une bonne garantie de résistance à l'effet d'oxydation.

• Chantier expérimental de l'autoroute A 1

En septembre 1984, la chaussée à trois voies de circulation, dans le sens Lille - Paris, entre Ressons et Compiègne, a été revêtue d'enrobés drainants « Drainochape » de 4 cm d'épaisseur (81 kg/m²) sur une longueur de 10 km.

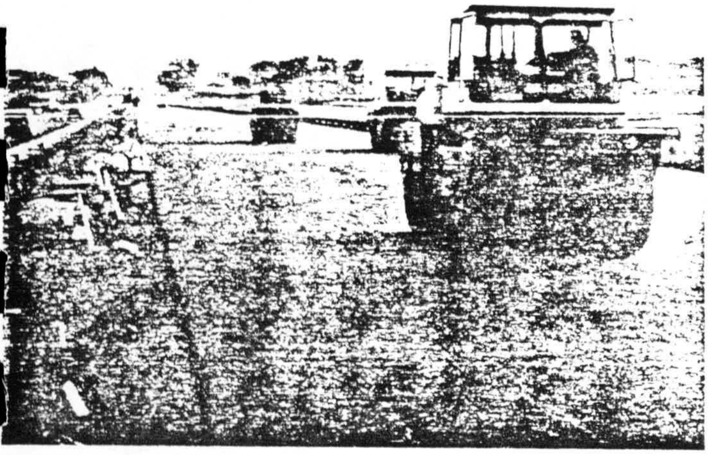


Figure 5. Compactage des enrobés

Compte tenu de l'état du support et afin d'obtenir une parfaite étanchéité, l'application préliminaire d'un enduit au bitume caoutchouc (Flexochape) a été réalisé. 140 000 m² d'enrobés drainants ont été mis en œuvre sans difficultés particulières par rapport à un chantier d'enrobés classiques.

Cependant, quelques précautions sont à prendre au niveau du compacteur qu'il convient d'effectuer à une température de l'enrobé de l'ordre de 140 °C. En effet, la fabrication s'effectue avec une température de 180 °C et un compactage à température élevée pourrait favoriser quelques déformations de surface. L'intensité du compactage doit également être dosée. Le compactage vibrant est souhaitable. Cependant une vibration trop importante pourrait entraîner l'attrition du granulat et provoquer localement une densification au détriment des effets drainants de l'enrobé.

Les études de formulation et le contrôle de fabrication ont été effectués par le laboratoire de l'entreprise Innoroute chargée de l'exécution du tapis.

Les contrôles de mise en œuvre ont été faits par Scetauroute et le laboratoire régional de Saint-Quentin.

Les résultats de contrôle ont corroboré les études préalables faites par le laboratoire de l'entreprise.

Parallèlement, certains essais sont effectués conformément à un programme de suivi des enrobés mis en œuvre.

Ces essais sont les suivants :
- mesures de densité,
- mesures de déformations transversales,
- mesures de macrorugosité (hauteur au sable),
- mesures de coefficients de frottement longitudinal et transversal,
- mesures de perméabilité.

Cependant les enrobés drainants présentant une forte macrorugosité, il semble que l'essai de profondeur au sable soit assez peu significatif pour déceler l'évolution du produit. Par ailleurs, l'essai de perméabilité, très ponctuel, semble mal adapté à une structure fortement drainante.

Après une année de circulation à forte densité, le revêtement mis en œuvre a subi, durant l'hiver rigoureux 1984-1985, des températures variant entre − 15 et − 20 °C pendant une longue période.

Le comportement des enrobés drainants « Drainochape » s'avère satisfaisant si on se réfère aux premiers résultats du suivi de comportement.

- La rugosité géométrique fait apparaître quelques pertes peu excessives en valeur relative, la texture demeurant grossière.

- La profondeur au sable mesurée dans les traces du trafic canalisé de la voie lente est située entre 1,85 et 2 mm après un an de circulation.

- Les mesures de perméabilité ne montrent pas d'évolution significative, le revêtement restant qualifié de perméable aux termes d'appréciation du mode opératoire du LCPC.

- Les relevés de profils en travers ne révèlent aucune déformation transversale significative.

- Les mesures de la masse volumique apparente donnent une appréciation de perte de vide de l'ordre de 1,5 % dans la zone la plus exposée au trafic.

- L'examen visuel de l'enrobé dans les zones suivies ne révèle aucune dégradation et notamment aucun phénomène d'arrachement ou de plumage.

En ce qui concerne les problèmes de viabilité hivernale qui pourraient être générés par les enrobés drainants, le Service d'Exploitation de la SANEF n'a relevé aucune sujétion particulière en la matière. Il convient de noter que le salage est effectué au moyen de chlorure de sodium et de chlorure de calcium.

Les remarques suivantes ont été faites :
- pas de salage ni d'intervention supplémentaire par rapport aux autres types de revêtements ;
- la réaction du sel est légèrement plus lente en raison vraisemblablement du manque d'eau superficielle mais cela ne semble pas être un inconvénient majeur ;
- une meilleure retenue du sel sur la chaussée lors du salage sous forte circulation d'où une rémanence plus longue ;
- pas d'écoulement d'eau sur la chaussée avec risque de gel lorsque la neige fond sur les bandes dérasées ou les voies non entièrement déneigées, ce qui constitue un avantage dû à la drainabilité de l'enrobé ;
- une tendance à retenir la neige poudreuse sous fort vent avec un seul cas constaté de légère formation de congères.

Certains points particuliers restent à signaler à la suite de cette expérimentation.

- Le premier consiste à attirer particulièrement l'attention sur le fait de ne pas appliquer le revêtement drainant sur le support présentant des défauts susceptibles de piéger l'eau qui doit pouvoir, sans entrave, s'évacuer latéralement.

- Le second concerne le passage de la zone de revêtement drainant au revêtement d'enrobés classiques. Le passage d'une chaussée sèche à une chaussée recouverte d'un film d'eau provoque des projections subites d'eau derrière les véhicules et sont susceptibles par l'effet de surprise de provoquer des accidents. La solution qui a été retenue sur la chaussée de l'autoroute A 1 consiste à aménager, à l'aval de la zone recouverte d'enrobés drainants, un tapis de 300 ml constitué d'enrobés à densité progressive (augmentation de la quantité de sable).

L'expérience d'application d'enrobés drainants faite sur l'autoroute A 1 s'est limitée à l'utilisation d'un seul produit parmi ceux qui sont actuellement sur le marché et ne peut donc conduire à une conclusion comparative. Cependant, un certain nombre de critères de formulation, de mise en œuvre et de fonctionnement des enrobés drainants ont pu être vérifiés à cette occasion.

D'ores et déjà le produit expérimenté donne grande satisfaction sur le plan de la tenue au trafic intense et lourd avec des conditions atmosphériques qui ont été particulièrement agressives depuis un an.

La poursuite du suivi de cette zone d'essais permettra d'apprécier le comportement de ce matériau dans le temps.

Les premiers essais de contrôle du niveau sonore faits sur la rue Solferino à Lille donnent de bons résultats. Une campagne de mesures doit être faite sur l'autoroute A 1. La chaussée dans le sens Paris-Lille de l'autoroute A 1 a également reçu, en octobre 1985, un revêtement drainant sur une zone de 9 km faisant face à celle traitée en 1984. Ce nouveau chantier a permis de bénéficier des expériences de mise en œuvre de l'année précédente.

Banque de données de la DIRR

118241 IRRD Publicat. 86P00552
ENROBES DRAINANTS AU BITUME CAOUCHOUC RUE SOLFERINO A LILLE
ROUSSEL,C; CUDL-LILLE; DELEURENCE,J-C; CETE LILLE
Publication name: REV GEN ROUTES AERODR
PARIS FRANCE , ISSN: 0035-3191
Document data: SERIE, Date: 1985-04, No: 618, 71-6, Pages: ,
3,
Figures: , 7, Tables: , 4, Photos: , Language in: FRANCAIS, Refs:
0
, Level: A , Abs. in: ENGLISH/DEUTSCH/ESPAGNOL
Availability of document: , Code for centre: LCPC ; 1st form
at
centre: ORIG SUR PLACE
Source of record: LCPC, F
Source number: 86-8601-LC015F

LES AUTEURS PRESENTENT LE CHANTIER UTILISANT LE BITUME
CAOUTCHOUC
FLEXOCHAPE EN ENROBE DRAINANT DRAINOCHAPE POUR LA REFECTION
DES
CARACTERISTIQUES DE SURFACE DE LA CHAUSSEE. IL
TRAITE
SUCCESSIVEMENT DE : 1 - LA PREPARATION DU BITUME CAOUTCHOUC - 2 -
DE
LA REALISATION DU CHANTIER : REALISATION D'UNE
MEMBRANE
D'IMPERMEABILISATION EN BITUME CAOUTCHOUC, FABRICATION ET MISE
EN
OEUVRE DE L'ENROBE DRAINANT, ET INDIQUE QUELQUES RESULTATS A
COURT
TERME DU POINT DE VUE ASPECT VISUEL, BRUIT DE ROULEMENT, GLISSANCE.

Subject Classification: LIANTS ET MATERIAUX HYDROCARBONES , 31
/
CONSTRUCTION DES CHAUSSES ET DES REVETEMENTS , 52
Controlled Terms: ENROBE , 4967 / BITUME , 4963 / CAOUTCHOUC
,
7494 / DECHET , 4563 / ETANCHEITE , 5921 / TEXTURE SUPERFICIELLE
,
3053 / ZONE URBAINE , 0313 / FRANCE , 8036 / CHANTIER , 3628
/
FABRICATION , 3647 / MISE EN OEUVRE (APPL) , 3623
Uncontrolled Terms: DRAINOCHAPE / FLEXOCHAPE / LILLE

118240 IRRD Publicat. 86P00551
LES ASPECTS TECHNIQUES DES ENROBES DRAINANTS AU BITUME
CAOUTCHOUC
FLEXOCHAPE. PROCEDE DRAINOCHAPE
SAINTON,A; BEUGNET
Publication name: REV GEN ROUTES AERODR
PARIS FRANCE , ISSN: 0035-3191

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5,
Figures: , 0, Tables: , 6, Photos: , Language in: FRANCAIS, Refs:
4
, Level: A
Availability of document: , Code for centre: LCPC ; 1st form
at
centre: ORIG SUR PLACE
Source of record: LCPC, F
Source number: 86-8601-LC014F

APRES UN HISTORIQUE SUR L'APPARITION DU LIANT FLEXOCHAPE
L'AUTEUR
PRESENTE LE PROCEDE DRAINOCHAPE. IL PRESENTE D'ABORD LES
AVANTAGES
DES ENROBES DRAINANTS PUIS LES RAISONS DU RECOURS
AU
BITUME-CAOUTCHOUC COMME LIANT : RESISTANCE REMARQUABLE AUX TESTS
DE
VIEILLISSEMENT, GRANDE VISCOSITE PAR RAPPORT AU BITUME
CLASSIQUE,
VOIRE AU BITUME ELASTOMERE CE QUI NECESSITE UNE TENEUR EN LIANT
PLUS
ELEVEE ET SE TRADUIT PAR UN FILM PLUS EPAIS AUTOUR DES
GRANULATS,
POINT DE RAMOLLISSEMENT BILLE ET ANNEAU 20 A 25 % SUPERIEUR A
CELUI
DU BITUME 60/70. IL TRAITE ENSUITE DE L'OPTIMISATION DE
LA
FORMULATION DES ENROBES DRAINANTS AU BITUME CAOUTCHOUC ET DECRIT
LES
PREMIERS CHANTIERS EXPERIMENTAUX.

Subject Classification: LIANTS ET MATERIAUX HYDROCARBONES , 31
/
CONSTRUCTION DES CHAUSSES ET DES REVETEMENTS , 52
Controlled Terms: ENROBE , 4967 / BITUME , 4963 / CAOUTCHOUC
,
7494 / DECHET , 4563 / ETANCHEITE , 5921 / TEXTURE SUPERFICIELLE
,
3053 / COMPOSITION DU MELANGE , 4714 / SECTION EXPERIMENTALE ,
2778
/ CHANTIER , 3628 / AUTOROUTE , 2752 / FRANCE , 8036
Uncontrolled Terms: FLEXOCHAPE / DRAINOCHAPE / A 26

115935 IRRD Publicat. 85P12494
COMITE TECHNIQUE DES CARACTERISTIQUES DE SURFACE - RAPPORT
-
CHAPITRE VI - CARACTERISTIQUES DE SURFACE DES ENROBES DRAINANTS
CARROLL,TJ; AIPCR,UK; CASTAGNETTA,V; AIPCR,ITALIE;
GRATIA,G;

AIPCR,FRANCE; MAJCHERCZYK,J; AIPCR,FRANCE; MORA
TORRES,C;
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Publication name: XVII CONGRES MONDIAL DE LA ROUTE,
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Publisher: ASSOCIATION INTERNATIONALE PERMANENTE DES CONGRES DE
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ROUTE
BOULEVARD DE LA TOUR MAUBOURG,2 F-75007 PARIS FRANCE
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Figures:
, 3, Tables: , 0, Photos: , Language in: FRANCAIS, Refs: 31
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Level: A
Availability of document: , Code for centre: LCPC ,
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assigned: 1 ; 1st form at centre: ORIG SUR PLACE
Source of record: LCPC, F
Source number: 85-8510-LC037F

LA PRESENCE D'EAU DE PLUIE SUR LA SURFACE DES ROUTES CONSTITUE
A
DIVERS TITRES UN DANGER POUR LES CONDUCTEURS DE VEHICULES.
UN
MATERIAU ENROBE DRAINANT QUI PEUT ABSORBER L'EAU DE
RUISSELLEMENT
ET, GRACE A SA STRUCTURE INTERNE AVEC VIDES, PERMET LE DRAINAGE
DE
L'EAU JUSQU'AUX BORDURES DES CHAUSSEES, PRESENTE EVIDEMMENT UN
GRAND
INTERET POUR L'INGENIEUR DE LA VOIRIE. CE MATERIAU EST UTILISE
AVEC
SUCCES, DEPUIS DE NOMBREUSES ANNEES, SUR LES PISTES D'AERODROMES,
EN
QUALITE DE REVETEMENT DRAINANT, MAIS JUSQU'A PRESENT, IL N'A PAS
ETE
ADOPTE A GRANDE ECHELLE SUR LES CHAUSSEES CAR SA DURABILITE A
LONG
TERME N'EST PAS TOUJOURS ASSUREE. C'EST POURQUOI, LES TRAVAUX
SE
POURSUIVENT EN VUE D'AMELIORER LES PROPRIETES DE DRAINAGE ET
DE
DURABILITE DES ENROBES DRAINANTS. LE PRESENT CHAPITRE (VOIR
DIRR
115930 POUR LE RAPPORT DANS LEQUEL IL FIGURE) VISE A ELARGIR ET
A
METTRE A JOUR LES DONNEES ACQUISES EN MATIERE D'UTILISATION ET
DE
PERFORMANCES SUR CES MATERIAUX. IL TENTE AUSSI DE FORMULER
DES
OBSERVATIONS SUR LEURS APPLICATIONS ET LEURS DEVELOPPEMENTS
FUTURS

DANS DIFFERENTS PAYS (AUSTRALIE, BELGIQUE, DANEMARK, FRANCE, GRANDE
BRETAGNE, REPUBLIQUE FEDERALE D'ALLEMAGNE, ITALIE, JAPON, PAYS-BAS,
NORVEGE, AFRIQUE DU SUD, ESPAGNE, SUEDE, SUISSE, USA). UNE GRANDE
PARTIE DE L'INFORMATION CONTENUE DANS LES TABLEAUX PROVIENT DES
DEBATS DU SYMPOSIUM INTERNATIONAL ET DU SEMINAIRE INTERNATIONAL
ORGANISES RESPECTIVEMENT EN 1976 ET 1981 PAR LE CENTRE D'ETUDES POUR
LA CONSTRUCTION DES ROUTES AUX PAYS-BAS. CES DONNEES ONT ETE
COMPLETEES PAR DE NOUVELLES INFORMATIONS CHAQUE FOIS QU'ON A PU EN
OBTENIR.

Subject Classification: PROPRIETES DES SURFACES DES CHAUSSEES , 23
/ CONSTRUCTION DES CHAUSSES ET DES REVETEMENTS , 52 / LIANTS ET
MATERIAUX HYDROCARBONES , 31
Controlled Terms: CONFERENCE , 8525 / PLUIE , 2507 / REVETEMENT
(CHAUSSEE) , 2972 / DANGER , 1673 / CONDUCTEUR , 1772 / ENROBE ,
4967 / ETANCHEITE , 5921 / TEXTURE SUPERFICIELLE , 3053 /
RUISSELLEMENT , 4329 / PISTE D'ENVOL , 2787 / AEROPORT , 2776 /
DRAINAGE , 2937 / DURABILITE , 5910 / UTILISATION , 9084 /
CARACTERISTIQUES , 5925 / EUROPE , 8034 / AUSTRALIE , 8006 / AFRIQUE
DU SUD , 8103 / TRAITEMENT ANTIDERAPANT , 3040 / JAPON , 8053 / USA
, 8122

500725 IRRD Research 85E05148
ENROBES DRAINANTS
MOUTIER,F; LE ANGERS
Research organisation: LABORATOIRES DES PONTS ET CHAUSSEES
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Sponsor: MINISTERE DE L'URBANISME, DU LOGEMENT ET DES TRANSPORTS
(DEPARTMENT OF CITY PLANNING, HOUSING AND TRANSPORTATION) BOULEVARD

SAINT GERMAIN,244 F-75775 PARIS CEDEX 16 FRANCE
- , Reported: 4 , Start: 1977 , Annual budjet: - ,
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Source of record: LCPC, F
Source number: 85-LCPC-15159F
IRF No. : 1E(820)

LE STOCKAGE DE L'EAU EN SITE URBAIN, LORS DES PRECIPITATIONS ABONDANTES, POURRAIT CONDUIRE A MIEUX REGULER LES EAUX PLUVIALES DANS LE RESEAU COLLECTEUR DES VILLES ET AINSI LIMITER SON DIMENSIONNEMENT. CE STOCKAGE POURRAIT SE REALISER DANS DES STRUCTURES DE CHAUSSEES POREUSES ET DRAINANTES. POUR REPONDRE A CE BESOIN, IL EST NECESSAIRE, EN L'ETAT ACTUEL DE NOS CONNAISSANCES : - DE FAIRE DES ETUDES DE FORMULATIONS DE COUCHES DE BASE / - DE CARACTERISER MECANIQUEMENT LES ENROBES (BASE ET SURFACE) / - D'EVALUER LA POROSITE ET LA PERMEABILITE (INTERFACE COMPRISE). LE PROGRAMME ESSAIERA DE REPONDRE A LA MISE AU POINT DE FORMULATIONS CONCILIANT DE BONNES CARACTERISTIQUES MECANIQUES, DE PERMEABILITE ET DE POROSITE.

Subject Classification: LIANTS ET MATERIAUX HYDROCARBONES , 31
Controlled Terms: PROJET DE RECHERCHE , 8557 / COUCHE DE BASE , 2961 / POROSITE , 5938 / CARACTERISTIQUES , 5925 / MECANIQUE , 5455 / INTERFACE , 5429 / ENROBE , 4967 / PLANCHE EXPERIMENTALE , 2776 / ENROBE OUVERT , 4921 / COMPOSITION DU MELANGE , 4714 / TEXTURE SUPERFICIELLE , 3053 / ETANCHEITE , 5921 / REVETEMENT SOUPLE , 2944

314844 IRRD Publicat. 83P11836
DRAINIERENDE BELAEGE
REVETEMENT DRAINANTS
PONTEVILLE,H; DREYER,P; CHRISTEN,Y
Publication name: ST U VERKEHR, Code: CH
ZUERICH SUISSE , ISSN: 0039-2189
Document data: PERIODIKUM, Date: 1982, Vol: 68, No: 5, 137-9,

Pages: , 0, Figures: , 0, Tables: , 3, Photos: , Language in:
FRANCAIS, Refs: 0 , Level: A
Availability of document: , Code for centre: FG , Code assigned:
DOK 29957 ; 1st form at centre: ORIG Z EINSICHT
Source of record: FG, D
Source number: 83-8309-FG030D

BERICHTET WIRD UEBER AUSFUEHRUNG (1979) UND ERFAHRUNGEN MIT EINEM ENTWAESSERNDEN BELAG IM ZUGE DER 1965 VIERSTREIFIG AUSGEBAUTEN KANTONALSTRASSE 780 ZWISCHEN TREYTORRENS UND RIVAZ (DEZALEY), MIT DEM DER GEFAHR DES AQUAPLANING INSBESONDERE IN VERWINDUNGSSTRECKEN OHNE LAENGS- UND QUERGEFAELLE ENTGEGENGEWIRKT WERDEN SOLLTE. UM VERTIKALE UND HORIZONTALE ENTWAESSERUNG ZU ERREICHEN, WURDE DER 25-30 MM DICKE BELAG AUS AUSFALLKOERNUNG 0/10 MM (DAVON 65 % GEBROCHENER SPLITT) AUFGEBAUT, UNTER VERWENDUNG EINES SPEZIALBINDEMITTELS AUS 80 % HARTBITUMEN UND 20 % STEINKOHLENTEERPECH. DAS RHEOLOGISCHE VERHALTEN ENTSPRICHT EINEM BITUMEN 60/70 BEI NORMALEN UMWELTTEMPERATUREN UND EINEM B 80/100 BEIM EINBAU (D.H. 100 BIS 120 GRAD C). BEI AUSGEZEICHNETEN HAFTEIGENSCHAFTEN, EINEM HOHLRAUMGEHALT VON 12 % UND GUTEN GRIFFIGKEITSEIGENSCHAFTEN ERFUELLT DER BELAG DIE IN FRANKREICH GELTENDEN BESTIMMUNGEN FUER ENTWAESSERNDE BELAEGE. WEITERE VERSUCHE WURDEN 1981 MIT NEUEN BELAEGEN 0/14 MM UND 0/16 MM WEGEN DER RD. 1,5 %IGEN NACHVERDICHTUNG DER 0/10 MM BELAEGE UNTERNOMMEN. HIERZU LIEGEN ABER NOCH KEINE MESSERGEBNISSE VOR. DIE INSGESAMT POSITIVEN ERGEBNISSE WERDEN DIE KOMMISSION VSS 5 VERANLASSEN, BEI DER UEBERARBEITUNG DER NORM SN 640 431 "BITUMINOESE VERSCHLEISS- UND TRAGSCHICHTEN" ENTWAESSERNDE BELAEGE MIT AUFZUNEHMEN.

Subject Classification: DECKENBAU , 52 / BITUMINOESE BAUSTOFFE ,

31
Controlled Terms: DECKE (STRASSE) , 2972 / BITUMINOESES MISCHGUT
,
4967 / DURCHLAESSIGKEIT , 5921 / OBERFLAECHENTEXTUR , 3053
/
KORNVERTEILUNG , 6200 / AUSFALLKOERNUNG , 4597 / BINDEMITTEL ,
4948
/ BITUMEN , 4963 / PECH , 4950 / HOHLRAUMGEHALT , 5938 /
GRIFFIGKEIT
, 3031

114736 IRRD Publicat. 83P05244
DRAINOROUTE - MESURE DU POUVOIR DRAINANT DE LA TEXTURE
D'UNE
SURFACE ROUTIERE
BRENGARTH,M; LR BORDEAUX; LAGANIER,R; LCPC
Publication name: BULL LIAISON LAB PONTS CHAUSS
PARIS FRANCE , ISSN: 0458-5860
Document data: SERIE, Date: 1983-01/02, No: 123, 17-28, Pages: ,
7
, Figures: , 4, Tables: , 7, Photos: , Language in: FRANCAIS,
Refs:
7 , Level: A , Abs. in: ENGLISH/DEUTSCH/ESPAGNOL/RUSSE
Availability of document: , Code for centre: LCPC ; 1st form
at
centre: ORIG SUR PLACE
Source of record: LCPC, F
Source number: 83-8305-LC041F

LES SURFACES ROUTIERES SONT DIRECTEMENT CONCERNEES PAR LE
CONTACT
DES PNEUMATIQUES. LA PRESENCE D'EAU PENALISE CE CONTACT VITAL
POUR
LA CONDUITE DES VEHICULES. L'EVACUATION DE CETTE EAU SOUS
LES
PNEUMATIQUES EST FONCTION ENTRE AUTRES DE LA TEXTURE DE LA
SURFACE
DE LA CHAUSSEE. L'EVALUATION DE LA QUALITE D'EVACUATION DE L'EAU
A
FAIT L'OBJET DE RECHERCHES QUI ONT CONDUIT A LA MISE AU POINT
D'UN
APPAREIL OPERATIONNEL, LE DRAINOROUTE. L'ARTICLE SITUE CES
MESURES
PAR RAPPORT AUX PROCEDES EXISTANTS (HAUTEUR AU SABLE...), DECRIT
LA
GENESE ET LE PRINCIPE DE LA METHODE DE MESURE. UNE
PREMIERE
CAMPAGNE D'AUSCULTATION DES REVETEMENTS FRANCAIS PRECISE
LES

QUALIFICATIONS DES SURFACES ROUTIERES OBTENUES. (A).

Subject Classification: EVACUATION DES EAUX - GEL-DEGEL , 26
Controlled Terms: APPAREIL DE MESURE , 6155 / CONTINU , 9006 / EAU
, 4355 / SURFACE , 6438 / TEXTURE SUPERFICIELLE , 3053 / REVETEMENT
(CHAUSSEE) , 2972 / EVACUATION DES EAUX , 2937 / DEBIT (ECOULEMENT)
, 4323 / CONTACT (PNEU ROUTE) , 5440 / FRANCE , 8036 / QUALITE
,
9063
Uncontrolled Terms: DRAINOROUTE

114276 IRRD Publicat. 83P00475
LES ENROBES DRAINANTS EN HOLLANDE. UNE EVALUATION
GERARDU,JJA; VAN GORKUM,F; VAN DER PLAS,JJ
Publication name: REV GEN ROUTES AERODR
PARIS FRANCE , ISSN: 0035-3191
Document data: SERIE, Date: 1982-06, No: 587, 77-83, Pages: , 10,
Figures: , 5, Tables: , 1, Photos: , Language in: FRANCAIS, Refs:
11 , Level: A , Abs. in: ENGLISH/DEUTSCH/ESPAGNOL
Availability of document: , Code for centre: LCPC ; 1st form at
centre: ORIG SUR PLACE
Source of record: LCPC, F
Source number: 83-8301-LC011F

COMMUNICATION PRESENTEE A LA SESSION 3 DU SYMPOSIUM EUROBITUME 1981. (VOIR FICHE SESSION 3 : 112955). AU DEBUT DES ANNEES 70 LE STUDIE CENTRUM WEGENBOUW A DECIDE LA MISE EN PLACE D'UN GROUPE DE TRAVAIL DONT L'OBJECTIF SERAIT L'AMELIORATION DES PROPRIETES DE SURFACE DES CHAUSSEES BITUMINEUSES EN HOLLANDE, ET PLUS PARTICULIEREMENT, LEURS CARACTERISTIQUES ANTI-GLISSANCE. LES ACTIVITES DE CE GROUPE ONT CONDUIT A LA MISE AU POINT DES COUCHES DE ROULEMENT EN ENROBES DRAINANTS. DE NOMBREUX ESSAIS, EN LABORATOIRE ET SUR LE TERRAIN, ONT ETE MENES SUR DES COUCHES DE 40 MM D'EPAISSEUR DENOMMEES COUCHES DE ROULEMENT EN ENROBES DRAINANTS (C.R.D.) ET PAR LA SUITE SUR DES COUCHES DE FRICTION EN ENROBES

DRAINANTS (C.F.D.) D'UNE EPAISSEUR DE 20 MM. CETTE COMMUNICATION PRESENTE LES RESULTATS D'ESSAIS AINSI QUE LES CONCLUSIONS ET RECOMMANDATIONS AFFERENTES A L'UTILISATION DE CES DEUX TYPES DE COUCHES DE SURFACE. LES PRINCIPAUX POINTS TRAITES SONT : - LES CRITERES DE CHOIX D'UNE C.R.D., - UNE ESTIMATION COMPARATIVE DU COUT DE C.R.D. ET DE COUCHE DE ROULEMENT BITUMINEUSE CLASSIQUE, - LES SPECIFICATIONS CONCERNANT LES MATERIAUX, L'ETUDE DE FORMULATION / L'APPORT STRUCTUREL D'UNE C.R.D. DANS LE CADRE DU DIMENSIONNEMENT DE CHAUSSEE, LES SPECIFICATIONS DE FABRICATION, REPANDAGE ET COMPACTAGE DES ENROBES DE C.R.D., - LES CARACTERISTIQUES DE C.R.D. TELLES QUE REDUCTION DES ECLABOUSSURES ET PROJECTIONS D'EAU, LE NIVEAU SONORE DU TRAFIC ET LA REFLEXION DE LA LUMIERE, - L'ENTRETIEN NORMAL DES C.R.D., - L'ENTRETIEN HIVERNAL. LES CONCLUSIONS HOLLANDAISES SONT COMPAREES A L'ETAT DES CONNAISSANCES AMERICAINES DANS CE DOMAINE. (A).

Subject Classification: LIANTS ET MATERIAUX HYDROCARBONES , 31 / MATERIELS ET METHODES D'ENTRETIEN , 61
Controlled Terms: CONGRES , 8525 / ENROBE , 4967 / TEXTURE SUPERFICIELLE , 3053 / ETANCHEITE , 5921 / CHAUSSEE SOUPLE , 2944 / COUCHE DE ROULEMENT , 2980 / COUT , 0176 / SPECIFICATION (CAHIER DES CHARGES) , 0147 / COMPOSITION DU MELANGE , 4714 / FABRICATION , 3647 / MISE EN OEUVRE (APPL) , 3623 / CARACTERISTIQUES , 5925 / ENTRETIEN , 3847 / GLISSANCE , 3031 / NIVEAU DE BRUIT , 6747 / PROJECTION (PAR VEH) , 1312 / LUMINANCE , 0525 / SERVICE HIVERNAL , 2593

114210 IRRD Publicat. 82P20039
CORRECTION DES TRONCONS GLISSANTS PAR L'EMPLOI D'ENROBES OUVERTS

CORRECCION DE TRAMOS DESLIZANTES MEDIANTE EL EMPLEO DE MEZCLAS
ABIERTAS DRENANTES
-
Publication name: BOL INF (PROBISA)
MADRID ESPAGNE , ISSN: 0376-7086
Document data: SERIE, Date: 1979, No: 30, 3-16, Pages: , 8,
Figures: , 3, Tables: , 0, Photos: , Language in: ESPAGNOL, Refs: 0
, Level: A
Availability of document: , Code for centre: LCGE ; 1st format
centre: ORIG SUR PLACE
Source of record: LCGE, F, LCPC
Source number: 82-8212-LG017F

AU COURS DES DERNIERES ANNEES ON A PRECONISE L'UTILISATION DES
ENROBES OUVERTS EN COUCHES FINES DRAINANTES ET ANTI-DERAPANTES DANS
LES ROUTES IMPORTANTES, LES AUTOROUTES ET LES AEROPORTS. ON A
PROCEDE A DES ESSAIS DE LABORATOIRE POUR ETUDIER LE DOSAGE ET LES
CARACTERISTIQUES MECANIQUES DE CES ENROBES COMPOSES DE GRANULATS DE
HAUTE QUALITE ET DE BITUMES DE PENETRATION MODIFIES PAR DES RESINES
PLASTIQUES, DES POLYMERES ET AUTRES ADJUVANTS. A PARTIR D'ENROBES
A FROID ET A CHAUD ON A EFFECTUE DES ESSAIS SUR PISTES DE
LABORATOIRE EN VARIANT LES CONDITIONS DE TEMPERATURE ET DE PRESSION.
ON A EGALEMENT ETUDIE LES TYPES DE CURE ET LES CONDITIONS DE
CELLE-CI LORSQUE LES BITUMES DE BASE ONT ETE FLUIDIFIES PAR DES
SOLVANTS LEGERS, EN VUE D'UN EMPLOI DANS DES LIEUX ELOIGNES DES
USINES D'ASPHALTE. SI LE CHOIX DES LIANTS MODIFIES EST CORRECT, LES
CARACTERISTIQUES MECANIQUES SONT BONNES, MEME AVEC UNE TRES FAIBLE
TENEUR EN FINES.

Subject Classification: LIANTS ET MATERIAUX HYDROCARBONES , 31
Controlled Terms: ENROBE CHAUD , 4997 / ENROBE , 4967 / ENROBE
FROID , 4988 / ROUTE , 2755 / TEXTURE SUPERFICIELLE , 3053 /

POLYMERISATION , 7481 / RESINE SYNTHETIQUE , 7460 / ENROBE OUVERT
,
4921 / GLISSANCE , 3031 / ESSAI , 6255 / BITUME , 4963 / CUT BACK
,
4963 / ETANCHEITE , 5921 / COMPOSITION DU MELANGE , 4714 /
VISCOSITE
, 5936

112792 IRRD Publicat. 82P06406
RECHERCHES RECENTES EFFECTUEES PAR LES ORGANISMES DE
L'UNION
TECHNIQUE INTERPROFESIONNELLE DES FEDERATIONS NATIONALES DU
BATIMENT
ET DES TRAVAUX PUBLICS. TITRE II : CONNAISSANCE DES SOLS -
ETUDE
SUR DES ENROBES POREUX, PERMEABLES ET DRAINANTS (P.P.D.)
MAJCHERCZYK,R; CEBTP
Publication name: ANN ITBTP
PARIS FRANCE , ISSN: 0020-2568
Document data: SERIE, Date: 1981-06, No: 395 (ESSAIS
MES-185),
24-8, Pages: , 7, Figures: , 2, Tables: , 0, Photos: , Language
in:
FRANCAIS, Refs: 0 , Level: A
Availability of document: , Code for centre: LCPC ; 1st form
at
centre: ORIG SUR PLACE
Source of record: LCPC, F
Source number: 82-8201-LC027F

L'ETUDE A POUR BUT DE SUIVRE LE COMPORTEMENT D'UN
REVETEMENT
POREUX, PERMEABLE ET DRAINANT (PPD) SOUS L'ACTION DU TRAFIC
A
DIFFERENTS NIVEAUX : A - CARACTERISTIQUES DE SURFACE / B
-
MECANIQUE / C - HYDRAULIQUE. LES ESSAIS CONDUISENT
AUX
CONSTATATIONS SUIVANTES : 1 - LE REVETEMENT EST ANTIDERAPANT / 2
-
LA TENUE MECANIQUE EST EXCELLENTE / 3 - IL N'Y A PAS
APPARITION
D'ORNIERAGE / 4 - LE REVETEMENT A TENDANCE A SE FERMER
LEGEREMENT
EN SURFACE PAR COLMATAGE (FINES, FEUILLES, ETC) / CEPENDANT,
SUR
LES TRACES DE CIRCULATION, LE REVETEMENT EST PLUS PERMEABLE, CE
QUI
CONFIRMERAIT LE PROCESSUS DE DECOLMATAGE DU A L'ACTION
DES
PNEUMATIQUES.

Subject Classification: LIANTS ET MATERIAUX HYDROCARBONES , 31
Controlled Terms: TEXTURE SUPERFICIELLE , 3053 / PERMEABILITE
,
5921 / ENROBE , 4967 / POROSITE , 5936 / DRAINAGE , 2937 / ESSAI
,
6255 / EN PLACE , 6226 / LABORATOIRE , 6237 / CIRCULATION , 0655
/
COMPORTEMENT , 9001 / GLISSANCE , 3031 / ORNIERE , 3081 /
DEFLEXION
, 5586

108287 IRRD Publicat. 79P32078

REVETEMENTS EN BETON AVEC SURFACE A HAUT POUVOIR DRAINANT, TEXTURE PRONONCEE ET COEFFICIENT DE FROTTEMENT ELEVE

WILK,W; ROUTES EN BETON SA, WILDEGG
Publication name: LA ROUTE EN BETON, Code: 5103
WILDEGG SUISSE
Document data: SERIE, Date: 1978-07, No: 116, 1-8, Pages: , 7,
Figures: , 2, Tables: , 11, Photos: , Language in: FRANCAIS, Refs:
2 , Level: A
Availability of document: , Code for centre: LCPC ; 1st format
centre: ORIG SUR PLACE
Source of record: LCPC, F
Source number: 79-7903-LC090F

L'AUTEUR PRESENTE LES TROIS TYPES DE REVETEMENTS EN BETON AYANT DES PROPRIETES PARTICULIEREMENT FAVORABLES EN CE QUI CONCERNE LE POUVOIR DRAINANT ET LA PROFONDEUR DE STRUCTURE DE LEUR SURFACE AINSI QUE L'EVOLUTION DANS LE TEMPS DE LEUR COEFFICIENT DE FROTTEMENT EN FONCTION DE LA VITESSE : 1) BETON A SURFACE DENUDEE (BETON LAVE) / 2) BETON CLOUTE / 3) BETON SANS SABLE ("NO FINES CONCRETE"). IL ESSAIE DE MONTRER QU'IL EST POSSIBLE DE CONSTRUIRE DE TELS REVETEMENTS RATIONNELLEMENT ET ECONOMIQUEMENT DE FACON A REPONDRE AUX PLUS HAUTES EXIGENCES.

Subject Classification: CONSTRUCTION DES CHAUSSEES ET DES REVETEMENTS , 52

Controlled Terms: CHAUSSEE RIGIDE , 2964 / TEXTURE SUPERFICIELLE
,
3053 / COEFFICIENT DE FROTTEMENT , 5460 / DRAINAGE , 2937 /
SURFACE
, 6438 / CLOUTAGE , 3050
Uncontrolled Terms: BROSSAGE

108045 IRRD Publicat. 79P30694
EXPERIMENTATION SUR UN ENROBE POREUX, PERMEABLE, DRAINANT
MAJCHERCZYK,R; CEBTP; MARCHI,P; SALVIAM-BRUN
Publication name: REV GEN ROUTES AERODR
PARIS FRANCE ., ISSN: 0035-3191
Document data: SERIE, Date: 1978-04, No: 541, 23-30, Pages: ,
9,
Figures: , 5, Tables: , 5, Photos: , Language in: FRANCAIS, Refs:
5
, Level: A , Abs. in: ENGLISH/DEUTSCH/ESPAGNOL
Availability of document: , Code for centre: LCPC ; 1st form
at
centre: ORIG SUR PLACE
Source of record: LCPC, F
Source number: 79-7902-LC034F

APRES UN EXAMEN DES FORMULATIONS UTILISEES EN ANGLETERRE ET
EN
BELGIQUE, LES AUTEURS DECRIVENT LES EXPERIMENTATIONS
FRANCAISES,
AVEC LES MESURES DE GLISSANCE AU STRADOGRAPHE ET DE PERMEABILITE
AU
DRAINOMETRE CEBTP, LA DETERMINATION DE LA RUGOSITE MOYENNE ET
LES
ESSAIS DE PERCOLATION IN SITU. ILS ANALYSENT LES RESULTATS
OBTENUS
(A).

Subject Classification: LIANTS ET MATERIAUX HYDROCARBONES , 31
Controlled Terms: ENROBE , 4967 / TEXTURE SUPERFICIELLE , 3053
/
PERMEABILITE , 5921 / BELGIQUE , 8008 / GRANDE BRETAGNE , 8119
/
FRANCE , 8036 / COMPOSITION DU MELANGE , 4714 / MESURE , 6136
/
PERCOLATION , 4315 / GLISSANCE , 3031 / IN SITU , 6226

500725 IRRD Research 79R27823
ENROBES DRAINANTS
MOUTIER,F; LR ANGERS
Research organisation: LABORATOIRES DES PONTS ET CHAUSSEES -
ROAD
AND BRIDGE LABORATORIES BOULEVARD LEFEBVRE 58 F-75732 PARIS CEDEX
15

FRANCE Projet code: 1-33-36-9
Sponsor: MINISTERE DE L'ENVIRONNEMENT ET DU CADRE DE VIE
-
MINISTRY OF ENVIRONMENT AND QUALITY OF LIFE BOULEVARD SAINT
GERMAIN
244 F-75775 PARIS CEDEX 16 FRANCE MINISTERE DES TRANSPORTS
-
MINISTRY OF TRANSPORT AV DU PRESIDENT KENNEDY 32 F-75775 PARIS
CEDEX
16 FRANCE
Total budjet ($): - - , Reported: 2 , Start: 1977 ,
Estd.
complete: 1979 , Annual budjet: - 77000F , Position: EN
COURS
1979-05
Source of record: LCPC, F
Source number: 79-LCPC-15159F
IRF No. : 1E(820)

L'OBJECTIF DE CETTE FICHE EST LA DEFINITION ET LA MISE AU
POINT
D'ENROBES DRAINANTS. LE PROGRAMME DE 1979 PREVOIT : -LE SUIVI
LEGER
DE PLANCHES EXPERIMENTALES EXISTANT EN AUVERGNE, EN HAUTE-SAVOIE
ET
EN REGION PARISIENNE / -LA REALISATION D'UNE PLANCHE
EXPERIMENTALE
SOUS TRAFIC LOURD, DANS DES CONDITIONS CLIMATIQUES
DIFFERENTES
(REGION OUEST) / -LA SYNTHESE DES RESULTATS ACQUIS
/
-L'ACHEVEMENT DE L'ETUDE BIBLIOGRAPHIQUE ENTREPRISE EN 1977.

Subject Classification: LIANTS ET MATERIAUX HYDROCARBONES , 31
Controlled Terms: TRAFIC , 0655 / LOURD , 9028 / ENROBE , 4967
/
DRAINAGE , 2937 / PLANCHE EXPERIMENTALE , 2778 / ENROBE OUVERT
,
4921 / COMPOSITION DU MELANGE , 4714 / ESSAI , 6255 / ORNIERE ,
3081
/ BITUME , 4963 / POLYMERE , 7481 / TEXTURE SUPERFICIELLE , 3053
/
REVETEMENT SOUPLE , 2944 / VOIE POUR VEHICULES LOURDS , 2808
/
BIBLIOGRAPHIE , 8518

104934 IRRD Publicat. 77P20543
LES ENROBES DRAINANTS A USAGE ROUTIER - INTERETS ET LIMITES DU
PROCEDE
SIMONCELLI,JP; SHELL FRANCAISE
Publication name: REV GEN ROUTES AERODR
PARIS FRANCE , ISSN: 0035-3191
Document data: SERIE, Date: 1976-07/08, No: 522, 35-41, Pages: , +
, Figures: , +, Tables: , +, Photos: , Language in: FRANCAIS, Refs:
6 , Level: A , Abs. in: ANGLAIS/ALLEMAND/ESPAGNOL
Availability of document: , Code for centre: LCPC ; 1st form at
centre: ORIGINAL SUR PLACE
Source of record: LCPC, F
Source number: 77-LCPC-16462F

LES ENROBES OUVERTS POUR COUCHE DE ROULEMENT APPELES
INDIFFEREMMENT : - PERVIOUS BITUMEN MACADAM / - OPEN FRICTION
COURSE / - DRAINAGE ASPHALT , SEMBLENT SE DEVELOPPER A L'ETRANGER,
PLUS PARTICULIEREMENT EN GRANDE BRETAGNE ET DANS LES PAYS
SCANDINAVES. L'INTERET DE CES TYPES DE REVETEMENT RESIDE DANS LE
SOUCI CROISSANT D'AMELIORER LES CONDITIONS DE SECURITE DE
L'AUTOMOBILISTE. EN EFFET, LES ENROBES DRAINANTS REDUISENT
SENSIBLEMENT LES BROUILLARDS D'EAU DANS LE SILLAGE DES VEHICULES
(AMELIORATION DE LA VISIBILITE PAR TEMPS DE PLUIE) ET LES RISQUES
D'AQUAPLANAGE (PAR REDUCTION DU FILM D'EAU). LE PROPOS EST ICI
D'EXPOSER LE RESULTAT DE CES EXPERIENCES ETRANGERES, ET D'ETUDIER
DANS QUELLE MESURE CES SOLUTIONS POURRAIENT CONTRIBUER A RESOUDRE
CERTAINS PROBLEMES RELATIFS A L'ENTRETIEN DES CHAUSSEES FRANCAISES
(A).

Subject Classification: LIANTS ET MATERIAUX HYDROCARBONES , 31
Controlled Terms: ENROBE OUVERT , 4921 / COUCHE DE ROULEMENT ,
2980 / DRAINAGE , 2937 / GRANULOMETRIE , 6200 / FABRICATION , 3647
/

MISE EN OEUVRE (APPL) , 3623 / ESSAI , 6255 / LABORATOIRE , 6237
/
ENTRETIEN , 3847 / ROYAUME UNI , 8119 / PERMEABILITE , 5921 /
TENEUR
EN VIDES , 5938 / RUGOSITE GEOMETRIQUE , 3053 / GLISSANCE , 3031
/
MARSHALL , 6290 / DUREE , 5414 / RIGIDITE , 5931

500725 IRRD Research 77R19975
ENROBES DRAINANTS
MOUTIER,F; LR ANGERS
Research organisation: LABORATOIRES DES PONTS ET CHAUSSEES -
ROAD
AND BRIDGE LABORATORIES BOULEVARD LEFEBVRE 58 F-75732 PARIS CEDEX
15
FRANCE Projet code: 1-33-36-7
Sponsor: MINISTERE DE L'EQUIPEMENT ET DE L'AMENAGEMENT
DU
TERRITOIRE BOULEVARD SAINT GERMAIN 244 F-75775 PARIS CEDEX 16
FRANCE
, Reported: 1 , Start: 1977 , Estd. complete: 1979 116000F
;
Position: EN COURS 1977-05-02
Source of record: LCPC, F
Source number: 77-LCPC-15159F
IRF No. : 1E(820)

L'OBJECTIF DE CETTE FICHE NOUVELLE EST LA DEFINITION ET LA MISE
AU
POINT D'ENROBES DRAINANTS. LE PROGRAMME DE 1977 PREVOIT : -
UNE
ETUDE BIBLIOGRAPHIQUE SUR LE DOMAINE D'EMPLOI DE CETTE
TECHNIQUE
D'ENTRETIEN DANS LES CONDITIONS PARTICULIERES FRANCAISES / -
DES
ETUDES DE LABORATOIRE POUR METTRE AU POINT LE CARACTERE DRAINANT
DES
FORMULATIONS D'ENROBES ENVISAGEES. PAR AILLEURS, UNE
PLANCHE
EXPERIMENTALE SUR CHAUSSEE A TRAFIC LOURD SERA REALISEE AFIN
DE
VERIFIER LA PERMANENCE DU CARACTERE DRAINANT.

Subject Classification: LIANTS ET MATERIAUX HYDROCARBONES , 31
Controlled Terms: ENROBE , 4967 / DRAINAGE , 2937 /
PLANCHE
EXPERIMENTALE , 2778 / ENROBE OUVERT , 4921 / COMPOSITION DU
MELANGE
, 4714 / ESSAI , 6255 / ORNIERE , 3081 / BITUME , 4963 / POLYMERE
,
7481 / TEXTURE SUPERFICIELLE , 3053 / REVETEMENT SOUPLE , 2944
/

J

ACKNOWLEDGMENT: EI

24 378480

EFFECT OF OIL FIELD TRUCKS ON LIGHT PAVEMENTS

Oil field traffic is identified and an estimate of increased annual cost associated with a reduced pavement serviceability is determined. The analytic procedure examines the effects of oil well traffic on a light-duty pavement. Evaluation is based on the concept of pavement serviceability developed at the AASHTO Road Test. A reduced pavement service life results in an increased annual cost of a low volume light-duty pavement section.

Mason, JM, Jr (Texas A&M University) **ASCE Journal of Transportation Engineering** Vol. 109 No. 3, May 1983, pp 425-439, 7 Ref.

ACKNOWLEDGMENT: EI
ORDER FROM: ESL

24 378482

ASSESS SUBGRADE RUTTING POTENTIAL BY STRESS FACTOR

This paper introduces the parameter stress factor in pavement design and research as an expedient and useful test to check the subgrade rutting potential in a flexible pavement.

Chou, YT (Waterways Experiment Station) **ASCE Journal of Transportation Engineering** Vol. 109 No. 3, May 1983, pp 462-470, 8 Ref.

ACKNOWLEDGMENT: EI
ORDER FROM: ESL

24 378487

ACHIEVING BETTER ROADS FOR LESS

Computerized pavement evaluation systems and pavement maintenance programs are described.

Davis, A (Allan Davis Associated, Connecticut) Christman, R **Public Works** Vol. 114 No. 5, May 1983, pp 70-71

ACKNOWLEDGMENT: EI
ORDER FROM: ESL

24 378489

OPEN FRICTION COURSE ON A PORTLAND CEMENT CONCRETE BASE: A FOUR-YEAR PROGRESS REPORT

This report documents the first 4 years of performance of a 1-in. thick open-friction-course and its adjacent conventional dense-graded top course (control), placed directly over a portland cement concrete pavement. The pavements were evaluated by analyzing changes in properties of the in-place mixes and by tracking changes in condition of the surfaces. The physical properties of the mixes were examined in extracted pavement cores, including aggregate gradation, binder penetrations and viscosities, and mix void content.

Dodge, KS (Federal Highway Administration)
New York State Department of Transportation Res Rpt. No Date, n.p., 11 Ref.

ACKNOWLEDGMENT: EI
ORDER FROM: ESL

24 378490

OPEN FRICTION COURSES ON AN ASPHALT CONCRETE BASE: A SEVEN-YEAR PROGRESS REPORT

This report documents the performance of two open-friction courses—having 1/2-in. and 1/4-in. maximum-sized aggregates—and their adjacent conventional New York State 1A top-course (control) over the final 4 years of their 7-year design lives. The physical properties examined by means of extracted pavement cores were aggregate gradation, binder penetration and viscosities, and void content. Testing of frictional performance, rut depths, microtexture and macrotexture, rideability, and cracking were used to evaluate the pavement's surface performance.

Dodge, KS (Federal Highway Administration)
New York State Department of Transportation Res Rpt. No Date, n.p., 10 Ref.

ACKNOWLEDGMENT: EI
ORDER FROM: ESL

24 378497

ARIZONA DOT ADOPTS PMS AND SAVES A BUNDLE

The Pavement Management System (PMS), devised by Woodward-Clyde Consultants for Arizona DOT, was first applied to the 1980-1981 highway preservation program after cost estimates for the fiscal year-had been determined by the previous process. The PMS process resulted in the substitution of a $32 million preservation program for the $46 million program developed by pre-PMS methods. The $14 million saved and subsequently spent on other highway-related projects occurred due to two factors. First, the tendency had been to allow the pavements to deteriorate to a rather poor condition before preservation action was taken. However, analysis shows that less substantial but slightly more frequent preventative measures keep the pavements in good condition most of the time at less overall cost than more substantial and costly corrective measures. Second, past corrective actions were often quite conservative, i.e., involving asphaltic concrete resurfacing of up to 5 in, based on the assumption that the thicker layer would ensure a longer period of time before the pavement deteriorated to unacceptable standards. The PMS prediction models indicate that there is no significant difference between the rate of deterioration of pavements resurfaced with 3 in and 5 in of asphaltic concrete.

TRNews No. 107, 1983, p 11

ORDER FROM: TRB Publications Off

24 378571

CALIBRATION SERVICES FOR PAVEMENT SURVEY EQUIPMENT. EXECUTIVE SUMMARY

Pavement survey equipment was investigated to determine what equipment is in use, what calibration services are required, and how these services can be provided. The major pavement survey equipment in use are the locked-wheel skid tester, response-type road meters, and dynamic-structural-capacity equipment. Other equipment in use or under development are profilometers, British Pendulum Testers, sand-patch gear, outflow meters, Mu Meters, falling-weight deflectometer, and keyboard-pavement-distress survey equipment. Calibration needs of these types of equipment are identified. Candidate Calibration Services are identified and evaluated through use of a rating scheme devised for this purpose. A mobile calibration scheme was selected which provides services to skid testers, roughness meters, structural-capacity devices, and microtexture and macrotexture equipment. A Pilot Plan and a Full Program Plan were developed for the national implementation of these services. Analysis and recommendation of a funding scheme are also included. Report FHWA/RD-82/135 is the Final Report, the companion volume. (FHWA)

Moreland, PB
Automated Management Systems, Incorporated, Federal Highway Administration Final Rpt. FHWA-RD-82-134, Aug. 1982, 17p Contract DOT-FH61-80-C-00122

ORDER FROM: NTIS PB83-250837

24 378572

CALIBRATION SERVICES FOR PAVEMENT SURVEY EQUIPMENT

Pavement survey equipment was investigated to determine what equipment is in use, what calibration services are required, and how these services can be provided. The major pavement survey equipment in use are the locked-wheel skid tester, response-type road meters, and dynamic-structural-capacity equipment. Other equipment in use or under development are profilometers, British Pendulum Testers, sand-patch gear, outflow meters, Mu Meters, falling-weight deflectometer, and keyboard-pavement-distress survey equipment. Calibration needs of these types of equipment are identified. Candidate Calibration Services are identified and evaluated through use of a rating scheme devised for this purpose. A mobile calibration scheme was selected which provides services to skid testers, roughness meters, structural-capacity devices, and microtexture and macrotexture equipment. A Pilot Plan and a Full Program Plan were developed for the national implementation of these services. Analysis and recommendation of a funding scheme are also included. Report No. FHWA/RD-82/134 is the Executive Summary report. (FHWA) and edge strains. Loading applied were 20 kip single-axle, and 34 kip tandem-axle, a 42 kip tandem-axle, and a 42 kip tridem-axle. Theoretical analysis was also conducted using a finite element program.

Also published as Minnesota Department of Transportation, St. Paul Investigation Number 209.

Tayabji, SD Ball, CG Okamoto

Construction Technology Labs FHWA/MN/RD-83/07, Oct. 1983, 54p

ORDER FROM: NTIS PB85-134989/WTS

24 393672

EVALUATION OF THE PAVEMENT CONDITION INDEX FOR USE ON POROUS FRICTION SURFACES

This report documents the results of a field study conducted to evaluate the use of the Pavement Condition Index (PCI) on porous friction surfaces (PFS). Pavements at seven landing field installations using PFS were studied. Results showed that the major problems on this type of surface were: (1) deterioration of underlying asphalt concrete material due to stripping of the asphalt binder; (2) delamination due to loss of bond between the PFS and underlying layer and (3) raveling/weathering due primarily to jet blast. Based on the findings of this study, several modifications were recommended for incorporation into current procedures for evaluating and managing PFS pavements: (1) Modify severity-level definitions for longitudinal/transverse cracks and for raveling/weathering; (2) Rate low severity dense-graded patches as medium-severity; (3) Use a surface treatment of asphaltic material if permeability loss is more than half the original; (4) Develop a nondestructive test to locate areas of delamination; (5) Modify the PCI of older PFS pavements carefully to document when failures occur; and (6) Collect all available PCI and construction date information for PFS pavement and use it to develop a PCT Time Chart.

Kohn, SD Shahin, MY

Army Construction Engineering Research Laboratory CERL-TR-M351, July 1984, 23p

ORDER FROM: NTIS AD-A144-521/2

24 393673

PERFORMANCE OF CIVIL AIRPORT PAVEMENT WITH LIME-CEMENT-FLYASH BASE COURSE

The background and application of lime, cement and flyash are reviewed in order to explain the performance of civil aviation airport pavements constructed with lime-cement-flyash as a stabilizing base course. The report states that performance of these pavements has been good and that the state of the art presently provides experimental techniques and laboratory tests to assure an economical and safe design. It is observed that many of the problems are associated with environmental forces and long-term behavior of the materials. A recommendation is that long-term performance together with the effectiveness of any remedial measures should be systematically monitored and catalogued so that any needed changes in the technology can be identified. Also, construction procedures and specifications limits can now be provided to the airport pavement engineering community on the basis of existing data and additional laboratory investigations.

McLaughlin, AL

Federal Aviation Administration DOT/FAA/PM-84/10, Apr. 1984, 23p

ORDER FROM: NTIS AD-A144 614/5

24 393761

PERU EXPERIMENTAL ROAD PROJECT. FINAL REPORT

In the early 1960's an experimental highway project was constructed using the newly developed AASHO Test Road—Structural Number Design Concept. The project was built on Route 108 in the Town of Peru. When completed in 1962-63 three sections of comparable structural strength were available for evaluation. The first section used soil cement as a base course. This section was immediately overlaid with 2 inches of bituminous concrete containing wire mesh reinforcing mats. The second section contained an asphalt stabilized base course which consisted of a hot sand mixture with a low asphalt content. The third section had a crushed gravel base. On several occasions performance evaluations and pavement deflection measurements were obtained for this experimental project. These data are included in this report. In October 1984 the final evaluation was completed on this project. The results indicated that Benkelman Beam deflections using a 22 kip axleload were quite similar on the asphalt stabilized base and the gravel base sections. The results also indicated that the asphalt stabilized base and the crushed gravel base sections had very similar serviceability rating. The performance of the soil cement section was similar to that of a rigid pavement. Immediately after completion, transverse cracks appeared approximately every 30 feet. When the overlay and steel mats were placed, transverse cracking increased to every 16 feet-the length of the mats. These numerous transverse cracks adversely affected the rideability of the section. Otherwise this section has retained its original shape and shows no load induced distress. Because this section is similar to a rigid pavement lower deflections were measured. All sections on this road are tentatively scheduled to receive a thin overlay sometime in 1986-88. (Author)

Rand, D

Maine Department of Transportation Tech Paper 85-1, Jan. 1985, 25p, 4 Fig., 2 Tab.

ORDER FROM: Maine Department of Transportation, Materials and Research Division, Box 1208, Hogan Road, Bangor, Maine, 04402

24 393762

PAVEMENT FRICTION MEASUREMENT ON CURVES

This publication is a final report on Federally sponsored contract DOT-FH-11-9212, Task Order No. 7. The report addresses the effectiveness of an E-274 frictional trailer to obtain representative values on non-tangent sections of roadway. Special equipment was installed in the trailer to provide dynamic wheel load and lateral acceleration. Comparisons were made of frictional values obtained on tangent and adjacent curve sections, some superelevated and some flat. Comparisons were made relative to the effect of direction of travel on friction numbers. All data was averaged and analyzed statistically. The results of this study indicated that an E-274 trailer with one wheel testing capability does not produce representative values on non-tangent sections if dynamic vertical and horizontal forces are not measured. However, if the trailer is modified to have two wheel testing capability the average values compare very favorably with adjacent tangent frictional levels. (Author)

Madden, DA

Maine Department of Transportation, Federal Highway Administration Final Rpt. Tech Paper 84-3, DOT-FH-11-9212, Dec. 1984, 32p, 3 Fig., 10 Tab., 5 Phot., 1 App.

ORDER FROM: Maine Department of Transportation, Materials and Research Division, Box 1208, Hogan Road, Bangor, Maine, 04402

24 393763

WHITE PAINT FOR HIGHWAY THAW SETTLEMENT CONTROL

Roads built on permafrost are often difficult to maintain because of permafrost melt induced settlement caused by black pavement absorbing more sunlight than a lighter-colored surface. One way to counteract this would be to point the pavement white to reflect more sunlight measurements of several short painting pavement sections between Fairbanks and Delta, Alaska, show that this does indeed reduce settlement. However, there are some grave drawbacks: the cost of applying paint, safety (i.e. increase slipperiness and snow sticking and frost forming sooner on the cooler surface), and settlement continuing near unpainted shoulders even though the center of the road is protected.

Reckard, MK **Research Notes** Vol. 4 No. 7, Jan. 1985, 2p

ORDER FROM: Alaska Department of Transp and Public Facilities, Division of Planning, Northern Region, 2301 Peger Road, Fairbanks, Alaska, 99701

24 393770

CORRELATION OF A ROUGHNESS METER

This publication addresses the problem of calibration of a May's Ride Meter. A limited amount of roughness data were obtained with a CHLOE Profilometer and level survey. This information was compared to values obtained with May's Ride Meter over the same sections. Regression analyses indicated that the Mays-CHLOE correlation was the most acceptable. (Author)

Madden, DA

31 380043

MAINTENANCE OF WEARING COURSES. LEVELLING MIXTURES [BELAEGGNINGSUNDERHAALL BASERAT PAA MASKINJUSTERINGAR]

Levelling mixtures are used as a thin wearing course or as a levelling course under a new wearing course. Generally, a mix containing a relatively high binder content is used in order to obtain high resistance to wear from studded tyres. Different compositions of dense graded bituminous mixtures with a maximum particle size of 12 mm and a bitumen penetration of 145-210 (MAB 12T) were tested on six experimental roads. The purpose of this investigation was to study how different mixes of MAB 12T influence wear and deformation. Results show that the wear from studded tyres was the most prominent cause of rutting. The best composition turned out to be the one with coarse aggregate 8-12 mm. Good correlation was obtained between the field tests and laboratory tests in the Troeger apparatus. (TRRL) [Swedish]

Hultqvist, B VTI **Topics** Monograph 1983, 29p, Figs., Tabs., 3 Phot., 3 Ref., Apps.

ACKNOWLEDGMENT: TRRL (IRRD 270964), National Swedish Road & Traffic Research Institute

31 381338

ENGINEERS CAN MAKE PAVING ASPHALT TEMPERATURE SUSCEPTIBILITY WORK FOR THEM OR AGAINST THEM

Paving asphalt temperature susceptibility is defined, and a method for its measurement in terms of pen-vis number (PVN) values is described. It is shown how engineers can make paving asphalt temperature susceptibility work for instead of against them when selecting paving asphalts for pavements in a warm climate, in a cold climate, and for heavy, medium and light traffic. A method is presented for selecting paving asphalts of different temperature susceptibilities for surface, binder and base course layers for heavy, medium and light traffic in colder climates.

This paper was presented at the Annual Conference, Canadian Technical Asphalt Association, Quebec City, Quebec, November 14, 15 & 16, 1983.

McLeod, NW
McAsphalt Engineering Services 1983, n.p., 21 Fig., 1 Tab., 18 Ref.

ORDER FROM: McAsphalt Engineering Services, 2220 Midland Avenue, Toronto, Ontario MIP 3E6, Canada

31 381345

SULPHUR EXTENDED ASPHALT FOR AIRPORT PAVEMENT

The conclusions of this study are: the anticipated excess of sulphur has not materialized and may not materialize in the near future. The price of sulphur is much too high, except in localized areas, to be an economical substitute for asphalt. Those installations of SEA in place perform as well as conventional asphalt paving and no particular advantage has been noted. However, these installations have not been in place long enough to give an indication of long or short life and continued monitoring is needed. It is recommended that two applications of SEA be investigated: The use of SEA for airport apron pavement where fuel spillage is a problem. This use has been investigated only briefly at the Corps of Engineers Waterway Experiment Station and no data is available. The use of SEA as a binding agent for porous friction courses (PFC). Because of the higher stability of AEA, its use in PFC could solve the problem of ravelling and loss of bond of this type surface treatment. (Author)

Horn, F
Federal Aviation Administration PM-83-2-LR, June 1983, 18p, 7 Ref.

ORDER FROM: Federal Aviation Administration, 800 Independence Avenue, SW, Washington, D.C., 20591

31 381800

RECYCLING/REJUVENATING AGED ASPHALT PAVEMENTS USING HOT-MIX PROCESS

The article deals with hot-mix recycling from the point of view of an emulsified asphalt producer-in this case the Asphalt Division of Chevron U.S.A., Inc. The process described is intended to restore worn-out asphalt pavements to high quality pavements. Also included are methods used to evaluate the reclaimed asphalt pavement, design a new mix, restore the aged asphalt, and prepare and construct a renewed pavement using the reclaimed material, together with design procedures, recycling agent specifications, and specifications and construction guides.

Better Roads Vol. 52 No. 1, Jan. 1982, p 10

ACKNOWLEDGMENT: EI
ORDER FROM: ESL

31 381801

PAVEMENT CONSULTANT'S VIEW TOWARD SUCCESSFUL ROAD SURFACE RECYCLING

Recycling is now a pavement maintenance rehabilitation alternative having progressed through considerable research and experimentation. The Federal Highway Adminstration Recycling Demonstration Project No. 39 has shown that both hot and cold pavement recycling can save rehabilitation costs and conservation of natural resources and energy consumption when selected, after evaluation, as a viable candidate. This article discusses three major considerations for insuring the success of such projects. The three factors are pavement evaluation, method of pavement removal, and recycled mixture design.

Better Roads Vol. 52 No. 2, Feb. 1982, pp 19-20

ACKNOWLEDGMENT: EI
ORDER FROM: ESL

thickness plus the laboratory-measured elastic and damping properties of the tire tread rubber. The method has evolved into a more mathematically complex procedure after validation tests on a number of roads. Each additional refinement has made the method more accurate but possibly not, at this stage, as practical as simpler, partly empirical methods that recently have been developed elsewhere. The paper, however, which is presented in simple terms, demonstrates that the moderate use of tread rubber temperature categories will enable the sideways force or locked-wheel friction to be predicted accurately for any speed, wetting condition, or tread rubber properties for bald and patterned tires. In the event of the technique being finally validated, it could be largely automated for simplicity.

Frictional Interaction of Tire and Pavement. A symposium sponsored by ASTM Committee E-17 on Traveled Surface Characteristics and F-9 on Tires, Akron-Fairlawn, Ohio, 11-13 November 1981.

Yandell, WO (New South Wales University, Australia) Taneeranon, P (Prince of Songkla University, Thailand) Zankin, V (New South Wales University, Australia) **ASTM Special Technical Publications** STP 793, HS-035 409, 1983, pp 304-322, 13 Fig., 7 Ref.

ACKNOWLEDGMENT: National Highway Traffic Safety Administration
ORDER FROM: American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania, 19103

24 381287
PAVEMENT SURFACE CHARACTERISTICS AND MATERIALS

The papers in this Special Technical Publication fall into two general categories: measuring and predicting pavement skid resistance characteristics; and strategies for reducing wet weather accidents on highways. The two topics are related since a wet weather safety program is dependent, among other things, on a good skid resistant pavement surface, which in turn requires methods to test, describe, and predict its characteristics. The papers include a comparison of macrotexture measurements, a method to describe texture characteristics beyond a one number descriptor, methods to predict friction performance and accident risk, and methods used in implementing a safety improvement program.

A symposium sponsored by ASTM Committees E-17 on Traveled Surface Characteristics and D-4 on Road and Paving Materials, Orlando, Florida, 11 December 1980. Includes HS-035 452—HS-035 458.

Hayden, CM, Editor **ASTM Special Technical Publications** STP 763, HS-035 451, 1982, 124p, Figs., Tabs., Refs.

ACKNOWLEDGMENT: National Highway Traffic Safety Administration
ORDER FROM: American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania, 19103

24 381288
MEASURING SURFACE TEXTURE BY THE SAND-PATCH METHOD

Components of variance were analyzed for 720 measures of concrete pavement texture depth obtained by the sand-patch method. The measurements were made in connection with a complete factorial field experiment involving four texturing methods used on two sections each of five different paving jobs. Each pavement section was tested at three different sites by three different operators performing two tests each. The analysis permitted estimates of the repeatability and reproducibility of the sand-patch test, as well as errors that can be expected in measuring the mean texture depths of a section of textured pavement.

A symposium sponsored by ASTM Committees E-17 on Traveled Surface Characteristics and D-4 on Road and Paving Materials, Orlando, Florida, 11 December 1980.

Chamberlin, WP Amsler, DE (New York State Department of Transportation) **ASTM Special Technical Publications** STP 763, HS-035 452, 1982, pp 3-15, 6 Fig., 6 Tab., 8 Ref.

ACKNOWLEDGMENT: National Highway Traffic Safety Administration
ORDER FROM: American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania, 19103

24 381289
MACROTEXTURE AND DRAINAGE MEASUREMENTS ON A VARIETY OF CONCRETE AND ASPHALT SURFACES

As part of a major study to develop methods for predicting tire friction performance on all types of pavements, macrotexture measurements were taken on a variety of concrete and asphalt surfaces using several different volumetric and drainage techniques. Expressions are developed which relate data obtained with each technique. Factors influencing these measurements, including operator technique and type of equipment, are identified. Comparisons also are given with skid resistance values obtained using a British portable pendulum tester. Outflowmeter measurements are presented to show the effect of surface finishes and treatments on drainage characteristics. The need to measure other surface texture parameters, such as microtexture, is suggested from comparative tire friction and surface macrotexture data obtained on two different wet surfaces. The paper concludes with comments relative to the necessity for additional studies to evaluate different surface microtexture measurement techniques in an effort to provide sufficient information to enable researchers to predict tire-pavement friction performance.

A symposium sponsored by ASTM Committees E-17 on Traveled Surface Characteristics and D-4 on Road and Paving Materials, Orlando, Florida, 11 December 1980.

Yager, TJ (Langley Research Center) Buehlmann, F (Institute of Technology, Zurich) **ASTM Special Technical Publications** STP 763, HS-035 453, 1982, pp 16-30, 11 Fig., 1 Tab., 14 Ref.

ACKNOWLEDGMENT: National Highway Traffic Safety Administration
ORDER FROM: American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania, 19103

24 381290
SURFACE TEXTURE CLASSIFICATION: A GUIDE TO PAVEMENT SKID RESISTANCE

The ability of a driver to stop on a wet pavement surface has been shown as a relationship between a tire and the pavement surface texture. For a number of years, the Ontario Ministry of Transportation and Communications has been classifying pavement surface textures and correlating these textures with the skid number of the surface, as measured by a brake-force trailer. The skid trailer number can be explained now in terms of the pavement surface texture. This paper contains a summary of the test procedure, a discussion of the texture classification system, and the relationship of the six texture parameters is discussed in terms of the equation used to generate a skid number at 100 km/h (62 mph). The advantages of using this system as a complement to present skid testing procedures are outlined, with particular attention to its use in those areas which cannot be tested by the brake-force trailer and in the area of mix design studies. The paper concludes with a discussion of some potential uses for the test method in future research work in Ontario, including the semiautomation of the interpretation procedure.

A symposium sponsored by ASTM Committees E-17 on Traveled Surface Characteristics and D-4 on Road and Paving Materials, Orlando, Florida, 11 December 1980.

Holt, FB Musgrove, GR (Ontario Ministry of Transportation & Communic, Can) **ASTM Special Technical Publications** STP 763, HS-035 454, 1982, pp 31-44, 8 Fig., 1 Tab., 5 Ref.

ACKNOWLEDGMENT: National Highway Traffic Safety Administration
ORDER FROM: American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania, 19103

24 381291
SURFACE MATERIALS AND PROPERTIES RELATED TO SEASONAL VARIATIONS IN SKID RESISTANCE

A three-year research program was initiated in 1978 at the Pennsylvania Transportation Institute by the U.S. Department of Transportation to investigate possible causes for seasonal and short-term skid resistance variations. The primary objective is to determine the parameters which can be used to predict the influence of seasonal and short-term effects. This paper is concerned with the material parameters influencing the long-term seasonal variations. Data are analyzed from 21 test surfaces in State College, Pennsylvania and 10 test surfaces in Tennessee and North Carolina. The data include skid resistance measurements according to the ASTM Test for Skid Resistance of Paved Surfaces Using a Full-Scale Tire (E 274-79), British Pendulum Number measurements, calculated percent normalized skid number gradient, and average daily traffic volumes. An exponential curve is fitted to the skid number data for the asphalt pavements, while a linear relationship best fits the data for portland cement concrete surfaces. The coefficients of the resulting seasonal variation curves are regressed against pavement and traffic parameters to provide predictors for the long-term effects. Significant predictors are found to be British Pendulum Number and average daily traffic. Further predictors are suggested by the results of a pavement polishing experiment carried out on the 21 Pennsylvania test surfaces. Good agreement is observed between the two sets of test data.

A symposium sponsored by ASTM Committees E-17 on Traveled Surface Characteristics and D-4 on Road and Paving Materials, Orlando, Florida, 11 December 1980.

Hill, BJ Henry, JJ (Pennsylvania State University, University Park) **ASTM Special Technical Publications** STP 763, HS-035 455, 1982, pp 45-60, 9 Fig., 7 Tab., 7 Ref.

ACKNOWLEDGMENT: National Highway Traffic Safety Administration
ORDER FROM: American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania, 19103

24 381292
SKID RESISTANCE PREDICTIVE MODELS FOR ASPHALTIC CONCRETE SURFACE COURSES

Skid resistance performance models for dense and open graded asphaltic concrete surface courses are presented. Previous studies for dense graded mixes and high traffic volumes resulted in a predictive linear model for the skid number (SN) at 100 km/h (60 mph) (SN 100) in terms of known aggregate and mix parameters and available traffic data. However, the SN 100 does approach a constant level requiring a rational function to describe traffic influences. Further work has confirmed the overall importance of mix designs in achieving desired skid resistance with accumulated traffic influences, particularly in preventing coarse aggregate immersion due to traffic compaction. High stability mixes (all steel slag, blast furnace slag, or traprock, for instance) have proven most suitable, and coarse aggregate factors such as polished stone value and aggregate abrasion value are of secondary importance once adequate levels are provided. Using a wider range of test sections, improved predictive models have been developed for various traffic volumes and surface types. Full details on model development are given.

A symposium sponsored by ASTM Committees E-17 on Traveled Surface Characteristics and D-4 on Road and Paving Materials, Orlando, Florida, 11 December 1980.

Emery, JJ (Trow Limited Consulting Engineers) Lee, MA (Hard (RM) Associates Limited) Kamel, N (Gulf Canada Limited) **ASTM Special Technical Publications** STP 763, HS-035 456, 1982, pp 61-72, 8 Fig., 7 Ref.

ACKNOWLEDGMENT: National Highway Traffic Safety Administration
ORDER FROM: American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania, 19103

24 381293
FRICTIONAL PERFORMANCE OF PAVEMENTS AND ESTIMATES OF ACCIDENT PROBABILITY

Objectives of this study were to evaluate standard and experimental surfaces throughout Kentucky in terms of skid resistance and effects of traffic, and to provide criteria for judging suitability of these surfaces to satisfy requirements for skid resistance and economics. The effects of traffic were quantified by regression analysis and scatter of data. Criteria included an estimate of accident risks, effects of speed on skid resistance, and seasonal variations in skid resistance. Pavements on low volume roads (less than 1000 vehicles per day) maintained adequate skid resistance. Open-graded friction courses, with the possible exception of sections using phosphate slag aggregate, maintained adequate skid resistance to meet design requirements. The adequacy of other pavements may be judged from the criteria provided herein. Estimates of accident reduction were made by combining the relationship between skid numbers for each pavement type. Those reductions were used to calculate benefits that, along with costs of overlay, were used to determine benefit-cost ratios. Benefits exceeded costs for roads having annual average daily traffic (AADT) greater than 750, 2500, and 5000 and skid numbers (SN) less than 24, 30, and 35, respectively.

A symposium sponsored by ASTM Committees E-17 on Traveled Surface Characteristics and D-4 on Road and Paving Materials, Orlando, Florida, 11 December 1980.

Burchett, JL Rizenbergs, RL (Kentucky Department of Transportation) **ASTM Special Technical Publications** STP 763, HS-035 457, 1982, pp 73-97, 8 Fig., 7 Tab., 13 Ref.

ACKNOWLEDGMENT: National Highway Traffic Safety Administration
ORDER FROM: American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania, 19103

24 381294
ONTARIO'S WET PAVEMENT ACCIDENT REDUCTION PROGRAM

Ontario's approach to the identification and treatment of black spot highway locations is presented. Highway locations with an excessive rate of wet pavement accidents are identified and ranked utilizing Ontario Ministry of Transportation and Communications computerized accident data files. Criteria for site selection, procedures for subsequent site investigation, and selection of appropriate remedial measures are outlined and discussed. Rehabilitation of pavements with low friction levels, and experiencing a high rate of wet pavement collisions, has resulted in substantial reductions in accidents. Collision data before and after treatment at various sites are presented. This paper provides design and performance information on modified bituminous surface course mixes currently used by the Ministry. Such mixes maintain better surface textures and provide longer lasting skid resistance characteristics. These mixes are used for black spot treatments, and in new surface construction on main highways.

A symposium sponsored by ASTM Committees E-17 on Traveled Surface Characteristics and D-4 on Road and Paving Materials, Orlando, Florida, 11 December 1980.

Kamel, N (Gulf Canada Limited) Gartshore, T (Ontario Ministry of Transportation & Communic, Can) **ASTM Special Technical Publications** STP 763, HS-035 458, 1982, pp 98-117, 5 Fig., 8 Tab., 13 Ref.

ACKNOWLEDGMENT: National Highway Traffic Safety Administration
ORDER FROM: American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania, 19103

24 381315
PETROMAT SYSTEM

A protective membrane system consisting of a nonwoven polypropylene fabric sealed with asphalt cement is described. This system protects the subgrade from water intrusion, retards reflection cracking, improves pavement fatigue life, and reduces secondary cracking. This brochure describes the material specifications, the equipment, and the construction procedure. Details are given of the fabric, the asphaltic sealant and the aggregate as well as the asphalt distributor equipment, fabric laydown equipment, and miscellaneous equipment. The construction procedure is described including the surface preparation, application of sealant, falonic placement, hot mix overlay, and seal coats. Special considerations such as ambient temperatures, emulsion cure time, asphalt quantity, tack coat, limitations, and recycling.

Manufactures Product Brochure.

Phillips Fibers Corporation 1978, 8p, Figs., Tabs., Phots.

ORDER FROM: Phillips Fibers Corporation, P.O. Box 66, Greenville, South Carolina, 29602

24 381321
IRF HOLDS PAVEMENT MANAGEMENT SEMINAR IN CARTAGENA, COLUMBIA

Delegates from 17 countries participated in an Inter-American Seminar on Pavement Management which was intended to provide information about the pavement management concept in general and to discuss potential benefits of its application. The objective of pavement management is to improve the overall ratio of benefit-to-cost during the life cycle of paved roads. Pavement management systems employ computer capabilities and consist of connected modules which can be upgraded or modified to meet the specific conditions of real conditions. They encompass a wide spectrum of activities and include the planning and programming of investments, design, construction, maintenance and the periodic evaluation of performance. The presentations at the seminar included a description of the Columbian government's policy for road maintenance, a paper on the U.S. experience in rehabilitation programming, and a paper on the French experience in this area. Practical experiences in Latin America with the Highway Design and Maintenance Model (H.D.M.) developed by the World Bank was also described. Papers were read on the goals of pavement management, the formation and implementation of a pavement management system in Washington State, the use of hand-held computers in the maintenance of low-volume roads, and the World Bank's view on the economic management of road networks.

World Highways Vol. 34 No. 9, Nov. 1983, pp 4-6, 3 Phot.

ORDER FROM: International Road Federation, 525 School Street, SW, Washington, D.C., 20024

24 381323

HISTORIC PAVEMENT, SITE OF CPR DEMO

A demonstration of modern methods of rehabilitating concrete pavements was conducted on the historic Mount Vernon Memorial Parkway which was constructed over 50 years ago. This newsletter describes the history of the construction of this roadway and techniques involved in the restoration such as diamond grinding, partial and full depth patching, undersealing, installation of load transfer devices, cleaning and resealing of cracks and joints, and various non-destructive testing methods. Short presentations on pavement management, slab replacement, pavement evaluation, and subsealing are also included.

ACPA Newsletter Vol. 19 No. 5, 1983, 12p, Phots.

ORDER FROM: American Concrete Pavement Association, 2625 Clearbrook Drive, Arlington Heights, Illinois, 60005

24 381325

INVESTIGATION OF THE FAA OVERLAY DESIGN PROCEDURES FOR RIGID PAVEMENTS

The existing FAA overlay design procedures and their history of development are first briefly presented in the report. This is followed by a detailed summary of consultant's reports, which include the identification of deficiencies in the existing procedures with suggested improvements. Immediate improvements to several items in the existing procedures are presented for use as new paragraphs and modification of existing paragraphs in the FAA Advisory Circular. Items to be addressed in a Phase II continuation study are presented.

Chou, YT

Waterways Experiment Station, Federal Highway Administration Final Rpt. DOTFAA-PM-83-22, Aug. 1983, 156p, 23 Fig., 13 Tab., Refs. Contract DOT-FAA-PM-83-22(I)

24 381333

EQUIPMENT AND STANDARD FOR ROADWAY CONSTRUCTION ACCEPTANCE BASED ON SMOOTHNESS

This study deals with a method for testing smoothness of pavement (both rigid and flexible) for construction acceptance. A multi-wheel profilometer is evaluated for its ability to accruately measure roadway smoothness. Measurement results were correlated with simulated response of other type of smoothness meters based on an absolute survey of road profile. The multiwheel profilograph is recommended for acceptance of pavement based on smoothness. (FHWA)

Griffin, RG, Jr

Colorado Department of Highways Final Rpt. CDH-DTP-R-83-4, Feb. 1982, n.p. Contract 1590

24 381779

CRITERIA FOR USE OF ASPHALT FRICTION SURFACES

The most common types of asphalt surfaces used to upgrade frictional characteristics of pavements are seal coats, open-graded mixes, and dense-graded mixes. This report of the Transportation Research Board provides information on current engineering practices, legal and regulatory considerations, and criteria for selection of appropriate types of asphalt friction courses. (Author)

Halstead, WJ **NCHRP Synthesis of Highway Practice** No. 104, Nov. 1983, 41p, 9 Fig., 6 Tab., 36 Ref., 1 App.

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24 381783

FATIGUE-BASED CRITERIA FOR SEASONAL LOAD LIMIT SELECTION

During spring thaw, restrictions on allowable axle weights (load limits) are often applied to flexible pavement sections in seasonal frost areas to prevent premature failure of thaw-weakened pavements. Currently, load limits are selected on the basis of experience. An approach to load limits that is based on controlling seasonal rates of fatigue consumption is described. Fatigue consumption can be determined from fatigue curves that relate critical tensile strains in the pavement section to the number of load repetitions causing fatigue failure. By using a layered-elastic computer program, strain is determined for the traffic loads applied to the pavement while it is in various seasonal states. Seasonal values for elastic-response parameters (resilient modulus and Poisson's ratio) are determined in laboratory tests on appropriately conditioned specimens. By relating the fatigue damage produced to the number and magnitude of loads applied during each of the seasonal pavement conditions, the effects of alternative load limit policies on remaining pavement life can be compared. In an application of the method to an existing pavement it was decided that the maximum axle load permitted during the spring-thaw period should be one that produced the same rate of fatigue consumption as the normal-summer-fall legal maximum of 18.9 kips. Using this criterion, the maximum spring-thaw load for the pavement would be 11.5 kips. Comparisons indicated that the remaining service life under the posted 14-kip load limit would be 80 percent of the life remaining if the 11.5-kip load limit were imposed. If no special spring-thaw period load limit is imposed, the remaining service life of the pavement will be reduced to 40 percent of the life remaining under the 11.5-kip limitation. (Author)

This paper appeared in Transportation Research Record 918, Frost Action on Transportation Facilities.

Hardcastle, JH Lottman, RP (Idaho University, Moscow) Buu, T (Idaho Department of Transportation) **Transportation Research Record** No. 919, 1983, pp 22-30, 8 Fig., 2 Tab., 12 Ref.

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24 381785

THE VAL GAGNE PAVEMENT INSULATION EXPERIMENT

Since the first successful treatment of a frost heave problem in 1966 using Sytrofoam HI brand (trademark of Dow Chemical, now called Dow Chemical Canada, Inc.) extruded polystyrene foam insulation, Ontario has used substantial quantities of insulation. However, knowledge of the performance of the insulation has been limited to sparsely documented observations of some sites where different types and amounts of insulation were used. In 1972 a joint experiment was launched by the Ministry and the Dow Chemical Inc. to construct, instrument, and observe the performance of pavement insulation at Val Gagne in Ontario. Three thicknesses of insulation and four different taper designs were used in the experiment. Winter temperature profiles, frost penetration depths, and frost heave measurements were observed during the winters of 1973-1977. The results of these observations were used to verify a two-dimensional finite element heat flow computer program intended for use in the design of insulation for controlling frost penetration. Although the program accurately predicts ground temperature for uninsulated situations and thinly insulated sections, changes in the program are needed to correct inaccuracies in predictions of ground temperatures when thick insulation is used. The results were also used to develop a set of frost penetration prediction curves for various thicknesses of insulation and for locations with different degree-days of freezing temperatures. These curves may be used to select the appropriate insulation thickness for any acceptable depth of frost penetration. Styrofoam insulation recovered from the test site after 5 years shows virtually no structural changes in thermal properties. (Author)

This paper appeared in Transportation Research Record 918, Frost Action on Transportation Facilities.

Louie, TM (Dow Chemical Canada, Incorporated) Phang, WA Chisholm, RA (Ontario Ministry of Transportation & Communic, Can) **Transportation Research Record** No. 918, 1983, pp 34-42, 14 Fig., 5 Tab., 14 Ref.

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34 369287
EVALUATION OF PLATINIZED NIOBIUM WIRE ANODES FOR CATHODIC PROTECTION OF BRIDGE SUPPORT STRUCTURES
An investigation was conducted to determine whether platinized niobium wire could be used as anode material to provide cathodic protection without necessitating the use of a conductive surface mix, as has been done previously. Experiments were carried out both in the field and in the laboratory. In the field, various anode spacings were used to determine optimum spacing for corrosion protection. These experiments indicated that the platinized niobium anodes could not spread the voltage evenly across the bridge deck to establish proper cathodic protection. Because of the higher voltages required to overcome concrete resistance, some acid formed at the anodes and attacked the concrete. (Author)

Fromm, HJ Pianca, F (Ontario Ministry of Transportation & Communic, Can) **Transportation Research Record** No. 860, 1982, pp 40-45, 15 Fig., 6 Ref.

This paper appeared in Transportation Research Record No. 860, Snow Control, Traffic Effects on New Concrete, and Corrosion.

ORDER FROM: TRB Publications Off

34 369332
USE OF GEOTEXTILES TO BRIDGE THERMOKARSTS THEORETICAL ANALYSIS AND REPORT
This report summarizes the results of a search of available literature and examination of various theoretical methods of analysis to develop a design scheme for using geotextiles as a reinforcement for roadway embankments. The purpose of this reinforcement is to create an embankment able to bridge voids or depressions in the foundation soils caused by melting permafrost. It was concluded that very stiff geotextile fabrics of high tensil strength must be used. The fabric should be placed as close to the bottom of the embankment as possible, and must be strong enough not to rupture under the imposed loadings. The design method proposed includes graphical solutions for the equations developed, and examples of their use. (Author)

Kinney, TC (Shannon and Wilson, Incorporated)
Alaska Department of Transp and Public Facilities AK-RD-82-21, Aug. 1981, 67p, 7 Fig., Tabs., 1 App.

34 369335
ENVIRONMENTAL AND SAFETY ASPECTS OF THE USE OF SULFUR IN HIGHWAY PAVEMENTS—VOLUME II FIELD EVALUATION PROCEDURES
The use of sulfur in highway paving mixtures has introduced questions regarding the pollutants generated, their environmental impact and the safety aspects associated with mix preparation and placement. This report presents the Field Evaluation Procedures based on the results of a more detailed investigation in which these factors were assessed. The evaluation procedures deal with the safety and environmental aspects of storage and handling, formulation, construction, operation and maintenance of highway pavements containing sulfur, including the possible generation of noxious and abnoxious fumes, dust and gases. This report discusses methods and equipment for monitoring potential emissions and pollutants and recommends safety practices for the handling of sulfur and sulfur-modified asphalt mixtures and pavements. The final report was prepared in three volumes of which the Field Evaluation Procedures is Volume II. The other two volumes are: Volume I—Evaluation of Environmental and Safety Hazards and Volume III—Annotated Bibliography. (FHWA)

Saylak, D Deuel, LE Izatt, JO Jacobs, C Zahr, R Ham, S
Texas Transportation Institute, Federal Highway Administration Final Rpt. FHWA-RD-80-192, July 1982, 58p Contract DOT-FH-11-9457

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34 369337
DESIGN OF OPEN GRADED FRICTION COURSES WITH SULFUR EXTENDED ASPHALT BINDERS
The combination of the anticipated shortage of asphalt cement and the projected abundance of sulfur has led to the investigation of the potential for substituting this element for the former in the paving industry. This research study was conducted to incorporate sulfur with asphalt to form Sulfur-Extended Asphalt (SEA) binders for use in Open Graded Friction Course (OGFC) mixtures. The experimental design variable included aggregate type, asphalt cement, level of sulfur contents in the binder and method of preparing SEA binders. The studies indicate that, with minor modifications, the existing FHWA (Federal Highway Administration) mix-design procedure may also be used for preparing SEA-OGFC mixtures. In an analysis of variance study, it was found that minimal differences existed between binders produced by direct-substitution method and emulsification. Test results also showed that SEA-OGFC system exhibited improved structural drainage and freeze-thaw properties over conventional OGFC systems. Based on the test results obtained in this study, a proposed SEA-OGFC mix-design procedure, patterned after the existing FHWA method, has been developed. (FHWA)

Saylak, D Ho, KK Gallaway, BM Little, DN
Texas Transportation Institute, Federal Highway Administration Final Rpt. FHWA-RD-82- 53, Sept. 1982, 211p Contract DOT-FH-11-9588

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34 369439
PROMISING PAVEMENT MARKING MATERIAL
The paper reports on an epoxy thermoplastic pavement marking material developed by the Federal Highway Administration's Office of Research and the Southwest Research Institute.

Public Works Vol. 113 No. 6, June 1982, pp 50-51

ACKNOWLEDGMENT: EI
ORDER FROM: ESL

34 369536
GEOGRIDS FOR SLOPE STABILIZATION
The application of high-strength tensar geogrids in overcoming slope instability is discussed. The open structure of such materials offers interlocking anchorage for soils without generating slip planes. Where geogrids are used on cohesive fills for the reinstatement of earth slips, an additional moment of resistance required for the reinforcing grids is calculated for each critical circle to achieve a design factor of safety. A restoring moment is then calculated from the allowable tensile capacity of the grids and the sum of the lever arms for each layer. The allowable tensile capacity of the grid is limited to 60 per cent of its ultimate strength measured at a strain of 50 mmm/min at 20 deg C. Examples are discussed of the use of geogrids in such applications as embankment stabilization in unstable rock or soils and also in other reinforcing applications. (Author/TRRL)

Dixon, J Langley, P (Netlon Limited) **Civil Engineering** July 1982, pp 42-44, 2 Fig., 4 Phot., 5 Ref.

ACKNOWLEDGMENT: TRRL (IRRD 264414)

34 369537
DESIGN PROCEDURES
The article presents a brief diagrammatic guide intended to act as an aid in the selection of filter fabrics and geotextiles. Three main aspects of selection are considered: 1) some suggestions are made concerning the main function roles in different typical filter fabric design layouts; 2) a phase-function triangle which shows the consequent generic groupings of designs in terms of fabric function requirements; and 3) a logic chart is presented which suggests some of the considerations and decisions involved in geotextile selection for reinforcement and filtration applications. (Author/TRRL)

Rankilor, PR (Manstock Geotechnical Consultancy Services) **Civil Engineering** July 1982, pp 38-39, 3 Fig., 1 Tab.

ACKNOWLEDGMENT: TRRL (IRRD 264415)

34 369538
HYDROTEC-A GEOTEXTILE WATER WELL
Problems of well screen efficiency in unconsolidated and types of consolidated strata are caused by conflicting requirements of allowing groundwater flow and also restricting soil ingress. Solutions which require the use of gravel packs, metallic or plastics screens fall short of theoretical performance due to practical difficulties. The article describes the hydrotec well screen which consists of three plastics sleeves surrounding a central base pipe. The function of the perforated base pipe is to provide support required by the well screen and is produced in a range of plastics materials.

Purdue University/Indiana State Highway Comm JHRP, United States Congress, Federal Highway Administration, (JHRP-82-5) Intrm Rpt FHWA/IN/JHRP-82/5, Aug. 1982, 290p HP&R 1-(19) Part II

ORDER FROM: NTIS PB83-142554

31 369503
BITUMINOUS MIXTURE WITH EPOXY RESIN PRESENTS PERSPECTIVE FOR BRIDGE SURFACINGS WITH LONG SERVICE LIFE [EPOXY-ASFALT BIEDT PERSPECTIEF VOOR LANGERE LEVENSDUUR VAN BRUGDEKKEN]

An experimental bridge surfacing of epoxy-asphalt on a state highway was constructed to study the workability and service life. Marshall and fatigue tests were carried out on the epoxy-asphalt. It is concluded that (1) the stability of epoxy asphalt is five times higher than of conventional asphalt; (2) resistance against cracking is 40 to 100 times higher; (3) production and application of epoxy-asphalt has to be tightly organized and (4) the actual service life of the expensive epoxy-asphalt has to be much higher than of conventional bridge surfacings. (TRRL) [Dutch]

Jongejan, M **Wegen** Vol. 56 No. 2, Feb. 1982, pp 59-61, 2 Fig., 2 Tab.

ACKNOWLEDGMENT: TRRL (IRRD 264164), Institute for Road Safety Research

31 369525
PROCEEDINGS OF A NATIONAL SYMPOSIUM ON BINDER ECONOMY AND ALTERNATE BINDERS IN ROAD AND BUILDING CONSTRUCTION, NEW DELHI, NOVEMBER 1981. PART II: DISCUSSIONS AND RECOMMENDATIONS

The report contains part 2 of the proceedings, which includes discussions of papers presented in part 1, within the following technical sessions: (1) binder economy techniques for hydraulic and other cementitious binders; (2) alternate hydraulic and other cementitious binders; (3) binder economy techniques for hydrocarbon binders; and (4) alternate hydrocarbon binders. (TRRL)

Central Road Research Institute, India Monograph 1981, 164p, 6 Fig., 2 Tab.

ACKNOWLEDGMENT: TRRL (IRRD 264382)

31 369775
ADDING DUST COLLECTOR FINES TO ASPHALT PAVING MIXTURES

The report contains a state of the art on the effects and use of mineral fillers in general and collected dust fines in particular. The report also documents the results of study on the characteristics and variability of baghouse dust collected from asphalt mix plants representative of different plant types (drum mix and batch), generic aggregate types, and dust collection systems. The report also contains recommended guidelines for the proper handling of dust and the actual test data on samples of dust. (Authors)

Anderson, DA Tarris, JP (Pennsylvania State University, University Park) **NCHRP Report** No. 252, Dec. 1982, 90p, Figs., Tabs., 61 Ref., Apps.

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31 369799
SEGREGATION OF ASPHALT MIXES CAUSED BY SURGE SILOS—FINAL REPORT

Segregation of asphalt mixes continues to be a problem in Virginia, particularly with base mixes and coarse surface mixes. Although the problem is encountered primarily on jobs using surge silos, it has been related to other factors such as mix design and handling or paving techniques. This report discusses changes in equipment and production procedures that reportedly have alleviated the problem, including specifications devised to eliminate segregation in the surge bin. Also discussed is a field project in which an attempt was made to prevent segregation by changes to the equipment and the production and paving processes. (FHWA) [illegible]

[illegible] Transportation Research Council, Virginia [illegible] and Transportation, Federal Highway [illegible]

Administration, (VHTRC 82-R47) Final Rpt. FHWA-VA-82/47, Mar. 1982, 12p HP&R 1754

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31 370097
OPEN GRADED ASPHALT CONCRETE AND RECYCLING OF PAVEMENT MATERIAL [DRAENERANDE ASFALTBETONG OCH AATERANVAENDNING AV BELAEGGNINGSMATERIAL-TVAA INTRESSANTA NYHETER INOM BELAEGGNINGSOMRAADET]

The advantages of pervious asphalt concrete are (1) appreciable reduction in risk of aquaplaning or loss of friction, (2) less glare on wet surfaces, (3) less spray, (4) better reflectivity. The finished pervious pavement has a voids content of 20-25%, due to more than 85% of aggregate being greater than 2 mm. Filler and binder contents are about 5% each. The relatively high binder content coats the aggregate thickly, which enhances bond and prevents displacement of binder. Mixing temperatures must not exceed 115-120 deg C. Pervious and normal mixes cannot be made at the same time, as the latter requires higher temperatures. Fibres are added to pervious mix to reduce mixing temperature. Air temperature during spreading must not be less than 10 deg C. Course thickness must be at least 2.5 times greater than the aggregate size. 10-12 t static roller should be used immediately behind paver. Durability and wear resistance are comparable to conventional surfacings. Accidents on wet pavements are reduced. Interest in recycling has greatly increased. Up to 50% recovered material can be added to the mix, but optimum proportion is about 20-30%. Cost of additional equipment is quite high, and a good supply of recovered material must be available to make recycling economically viable. (TRRL) [Swedish]

Liljedahl, B **Stadsbyggnad** Vol. 48 No. 1, Jan. 1982, pp 22-24, 3 Fig.

ACKNOWLEDGMENT: TRRL (IRRD 264092), National Swedish Road & Traffic Research Institute

31 370172
POSSIBILITIES FOR WHEEL TRACKING PREVENTION IN PAVEMENTS BY USING POLYMER IN ASPHALTIC MIXTURES [MOGUCNOSTI SPRECAVANJA KOLOTRAGA NA KOLOVOZNOM ZASTORU PRIMENOM POLIMERA U ASFALTNIM MESAVINAMA]

In the paper the influence of polymers on properties of bituminous mixtures has been observed. A survey of the experience and use of asphaltic mixtures with added bitumen in Yugoslavia and some other countries has been given. The results obtained relating to bit 60 bitumen and bitumen enriched with different types of polymer at the Institute for Roads in Belgrade have been presented. It has been found that the effect of polymer on the properties of asphaltic mixtures depends upon the type of a polymer and that the change of rheological characteristics with temperature also depends upon the type of a polymer. The best results have been achieved with the use of the sbs polymer (triblock-copolymer styrol-butadiene-styrol). Very good results have been achieved with the use of the ecb polymer (mixture of copolymer, ethylene and some other monomers with bitumen) while the pib (polyisobutylene) does not show satisfactory results. (TRRL) [Serbian]

Svetel, D **Savetovanje o Kolovoznim Konstrukcijama** 1982, pp 319-335, 2 Fig., 6 Tab.

ACKNOWLEDGMENT: TRRL (IRRD 264693)

31 370287
LATEX IMPROVEMENT OF RECYCLED ASPHALT PAVEMENT

The investigation compared the performance of a single unmodified milled recycled asphalt concrete to milled asphalt concrete modified by addition of three types of rubber latex. Latex was added at 2, 3, 5, and 8 percent latex by weight of asphalt in the asphalt concrete. Latices used were a styrene-butadiene (SBR) a natural rubber (NR), an acrylonitrile-butadiene (NBR), and four varieties of out-of-specification SBR latices. Marshall tests, while indecisive, showed a modest improvement in properties of SBR and NR-added material at 3 and 5 percent latex. Addition of NBR latex caused deterioration in Marshall stability and flow over that of control. Repeated load tests were run using the indirect tensile test, analyzed by the VESYS program, which computes "life" of pavements. Repeated load tests showed scarce resources. These include: use of full-depth asphalt pavements, use of high strength portland cement concrete so as to permit thinner pavements, and using sulfur as a replacement for part of the asphalt in sulfur-extended asphalt (SEA) mixes. Also, the importance of internal structure drainage is becoming clearer, and promising new developments in this area include the use of filter fabric-wrapped aggregate, the use of porous base layers, and the placement of pipe drains along pavement edges. Other developments include creation of crack-filler materials that will stretch significantly more at low temperatures than previously, hot mix recycling of asphalt pavements and sophisticated computer programs for use in cost-effective maintenance scheduling.

Phang, WA (Ontario Ministry of Transportation & Communic, Can) *Transportation Research News* No. 101, 1982, pp 2-8, 1 Fig., 2 Tab., 1 Phot., 13 Ref.

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24 367350
PERFORMANCE OBSERVATIONS ON OPEN-GRADED BITUMINOUS CONCRETE OVERLAYS IN CONNECTICUT

Performance data are presented for open-graded overlays of different ages. The overlays investigated were all placed on Interstate highways that had average daily traffic volumes in excess of 20,000 vehicles/day. Associated with one project was the application of open-graded overlays of varying thickness and support layers. All overlays have exhibited high skid resistance, which has stabilized at skid numbers 40-50, irrespective of lane or traffic volume. Attempts to apply thermoplastic striping were unsuccessful because snowplows tended to remove not only the stripes but also a portion of the underlying pavement to which they adhered. Compared with conventional overlays, there appears to be no advantage gained in terms of resistance to reflective cracking by using open-graded overlays. Air-permeability tests indicate a certain choking of the void structure in open-graded pavements with time. The removal of snow, and especially ice, from open-graded pavements is somewhat more difficult than it is from conventional pavements because of the greater surface area presented for adhesion and the loss of chemical deicers into the void structure. In this respect, greater amounts of deicers are normally required for open-graded pavements than anticipated. (Author)

Dougan, CE (Connecticut Department of Transportation) *Transportation Research Record* No. 843, 1982, pp 51-57, 16 Fig., 4 Tab., 7 Ref.

This paper appeared in Transportation Research Record No. 843, Asphalts, Asphalt Mixtures, and Additives.

ORDER FROM: TRB Publications Off

24 367430
POROUS PAVEMENT: RESEARCH; DEVELOPMENT; AND DEMONSTRATION

This paper discusses the U. S. Environmental Protection Agency's porous pavement research program along with the economics, advantages, potential applications, and status and future research needs of porous pavements. Porous pavements are shown to be an available stormwater management technique which can be used on parking lots and low volume roadways to reduce both stormwater runoff volume and pollution.

Field, R (Environmental Protection Agency) Masters, H Singer, M *ASCE Journal of Transportation Engineering* Vol. 108 No. TE3, May 1982, pp 244-258, 8 Ref.

ACKNOWLEDGMENT: EI
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24 367463
SYSTEM FOR INVENTORYING ROAD SURFACE TOPOGRAPHY (SIRST)

An experimental trailer-mounted instrumentation system which surveys and records data on the roadway topography while being towed at normal highway speeds has been developed and tested. The system uses non-contacting electro-optical sensors to measure the relative height of the roadway surface along 12 selected paths which are spaced at intervals across the 12-ft. width of a normal traffic lane. Data on the cross slope and longitudinal slope of the surface and the direction of travel are obtained from a gyro-type inertial reference unit mounted on the instrumentation trailer. Compensation for vehicular bounce is obtained through use of a double integrated vertical accelerometer. At intervals of one (or two) feet along the roadway a solid-state data acquisition system samples the output from each height sensor; the roll, pitch and azimuth signals from the inertial reference system; the output from the accelerometer and the double integrated accelerometer signal. This data is digitized and recorded on a digital cassette type magnetic tape recorder. The cassette tape is used to provide an input to a computer for analysis and plotting purposes. Programs to permit computer plotting of the data to show the topography of the roadway surfaces were developed. Preliminary tests of the system have indicated height sensing accuracy to better than 0.01-in. (0.25mm) and the slope measurement accuracy to better than 0.2 deg. The tests have also demonstrated the capability of the system to collect data at 1-ft. intervals while being towed at speeds up to 35 mph and at 2-ft. intervals at speeds up to 55 mph. Further evaluation is needed to establish the accuracy under dynamic conditions and the correlation of the data on roadway surface topography with that determined by other measurement techniques. (FHWA)

King, JD Cerwin, SA
Southwest Research Institute, Federal Highway Administration, (15-4017, Part II) Final Rpt. FHWA-RD-82- 62, Aug. 1982, 269p

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24 367469
ENERGY CONSUMED IN CONCRETE ROAD PAVEMENTS

The report examines the energy consumed in the construction of portland cement concrete road pavements in New South Wales. Included are the stages in constituent material manufacture and road construction which consume energy, the amounts and sources of energy consumed, and future trends in energy demands and energy conservation affecting concrete roads. For plain, jointed reinforced, and continuously reinforced concrete pavements there are only small variations in the amounts of energy consumed among rural highways, urban arterial roads and freeways. A concrete pavement is more energy efficient than a flexible pavement. (TRRL)

Hodgkinson, JR
Cement and Concrete Association of Australia Monograph No. 49, May 1980, 19p, 2 Tab., 9 Ref.

ACKNOWLEDGMENT: TRRL (IRRD 255334), Australian Road Research Board

24 367486
TECHNICAL REVIEW OF FIRST INTERNATIONAL CONFERENCE ON CONCRETE BLOCK PAVING UK, SEPTEMBER 1980

This report reviews the first international conference on concrete block paving, held at the University of Newcastle Upon Tyne in September 1980. Developments and use of concrete blocks in the Netherlands, West Germany, the UK and the US are summarised in detail, together with the extensive series of testing carried out at the National Institute for Transport and Road Research in South Africa. Where necessary, material not presented at the conference, but of relevance to discussion, is included. Apart from the South African work, little research is being carried out overseas into the design of concrete block pavements and Australian engineers should look to the work done in South Africa and currently being performed in Australia for their design information. It is clear that concrete block pavements are a viable alternative to conventional pavement types in certain applications and their use is very widespread throughout the world. Concrete block pavements have greatest potential in residential street applications and heavy duty applications such as container terminals. Work in Australia must be geared towards refining designs so that concrete blocks can become more competitive with more traditional pavement materials. Concrete blocks could also have a big future in developing countries (a). The ISBN of the microfiche version is 0 86910 067 X. (TRRL)

Sharp, KG *Australian Road Research* Monograph No. 118, Apr. 1982, 25p, 24 Fig., 15 Tab., 1 Phot., Refs.

ACKNOWLEDGMENT: TRRL (IRRD 255354), Australian Road Research Board

24 367599
DESCRIPTION AND EVALUATION OF THE ALASKA PAVEMENT RATING PROCEDURE

This report describes and examines pavement condition rating methods used on Alaska's roadways since 1978. The methods were intended to provide the specific performance data necessary to optimize construction/maintenance planning and the allocation of available funds. Rating elements include

Casola, E (Naples University, Italy) **Strade** Vol. 83 No. 1199, Nov. 1981, pp 539-552, 8 Fig., 4 Tab., Refs.

ACKNOWLEDGMENT: TRRL (IRRD 263852)

24 368919
LONG TERM OBSERVATIONS OF PERFORMANCE OF EXPERIMENTAL PAVEMENTS IN OHIO
This report presents long term evaluation data and analyses for eight (8) experimental pavement projects constructed in Ohio. The study projects include both rigid and flexible pavements and are scattered throughout the state. Pavement age is currently approaching 10 years for some projects. The pavements were extensively monitored and tested at the time of construction, and during 1979 and 1980 as part of this research study. Collected data included pavement condition rating (PCR) of visible distress, Dynaflect deflection, test properties of core and subgrade samples, estimated remaining structural life and overlay requirements. (FHWA)

Majidzadeh, K
Resource International, Incorporated, Ohio Department of Transportation, Federal Highway Administration Final Rpt. FHWA/OH-81/009, July 1982, n.p.

ORDER FROM: NTIS PB83-119982

24 369236
POST-TENSIONED CONCRETE OVERLAY OF AIRPORT RUNWAY
The paper describes the installation of a post-tensioned concrete overlay for a commercial airfield pavement at O'Hare International Airport in Chicago Illinois.

Lamberson, EA **Concrete Construction** Vol. 27 No. 3, Mar. 1982, p 261

ACKNOWLEDGMENT: EI
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24 369277
MINIMIZING REFLECTION CRACKING OF PAVEMENT OVERLAYS
Reflection cracks are fractures in a pavement overlay that are the result of, and reflect, the crack or joint pattern in the underlying layer. Reflection cracks can cause early deterioration of an overlay, thereby increasing maintenance costs and decreasing the useful life of the overlay. Methods that have been used to minimize reflection cracking of asphalt concrete overlays include (a) greater thickness of overlay, (b) changes in the viscosity of the asphalt, (c) additives incorporated into the asphalt concrete mixture, (d) treatments to the existing pavement before overlaying (seal coats, rejuvenators, heater-scarifying, crack filling, pavement breaking, stabilization, and recycling), and (e) stress-relieving interlayers (asphalt-rubber, membranes, fabrics, low-viscosity asphalt concrete, open-graded asphalt concrete, and aggregate). Results of various tests using these methods are presented in the synthesis. (Author)

Sherman, G **NCHRP Synthesis of Highway Practice** No. 92, Sept. 1982, 38p, Figs., Tabs., 94 Ref., 1 App.

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• 24 369405
OPEN FRICTION COURSES ON AN ASPHALTIC CONCRETE BASE: A SEVEN-YEAR PROGRESS REPORT
This report documents the performance of two open-friction courses (OFC)—having 1/2-in. and 1/4-in. maximum-sized aggregates—and their adjacent conventional New York State 1A top-course (control) over the final 4 years of their 7-year design lives. These mixes were placed in August 1973 on the northbound lanes of Rte 9 in Clifton Park, Saratoga County. An evaluation of the first 3 years of service was reported in Research Report 58, Performance of Open-Graded Friction Course Overlays. The pavements were evaluated by analysis of mix properties and surface performance. The physical properties examined by means of extracted pavement cores were aggregate gradation, binder penetration and viscosities, and void content. Testing of frictional performance, rut depths, microtexture and macrotexture, rideability, and cracking were used to evaluate the pavement's surface performance. Overall results indicate that the physical properties of the OFC mixes have deteriorated to a greater extent than in their controls, with no apparent detriment to surface performance. The OFCs have maintained equal or better surface performance than their controls. The extent to which the OFCs improve friction appears dependent on traffic volumes, with higher volumes providing greater improvement. The finer OFC gradation provides more frictional improvement than the coarser gradation. (FHWA)

Dodge, KS
New York State Department of Transportation, Federal Highway Administration, (Res Rpt. 98) FHWA/NY/RR-82/98, Res Rpt. 149-1, Oct. 1982, 29p HP&R

ORDER FROM: NTIS PB83-146894

• 24 369407
AN OPEN FRICTION COURSE ON A PORTLAND CEMENT CONCRETE BASE: A FOUR-YEAR PROGRESS REPORT
This report documents the first 4 years of performance of a 1-in. thick open-friction-course (OFC) and its adjacent conventional dense-graded top course (control), placed directly over a portland cement concrete pavement. The control section was placed on the eastbound lanes of Rte 17 in the Town of Kirkwood, Broome County, during the fall of 1975, and the OFC section in the adjacent westbound lanes during June of the following year. The pavements were evaluated by analyzing changes in properties of the in-place mixes and by tracking changes in condition of the surfaces. The physical properties of the mixes were examined in extracted pavement cores, including aggregate gradation, binder penetrations and viscosities, and mix void content. Pavement surfaces were monitored for frictional performance, micro-and macro-texture, rut depth, rideability, and cracking. Results indicate that the control mix provides better performance as a composite material, but the OFC exhibits better surface performance with the exception of joint cracking severity and rideability. (FHWA)

Dodge, KS
New York State Department of Transportation, Federal Highway Administration, (Res Rpt 97) Intrm Rpt. FHWA/NY/RR-82/97, Res Rpt 149-1, Oct. 1982, 31p HP&R

ORDER FROM: NTIS PB83-140442

24 369408
IMPROVEMENT OF PAVEMENT RIDEABILITY IN UTAH
The primary objective of this study was to determine ways to improve the rideability of Utah roads by (1) increasing the effectiveness of present methods and (2) applying new methods using available surface quality measuring equipment. Ride measuring devices utilized by Utah were tested and found to be inadequate by themselves as standard measurement tools for construction acceptance testing. The Mays Ride Meter is recommended, however, for use in conjunction with construction acceptance testing with the stringline on all new bituminous concrete pavements. Mays roughness data would identify and locate, by station, rough pavement areas that may be in violation of surface tolerance specifications. These areas would then be tested with the stringline according to Utah's existing surface tolerance specifications. This procedure should make the use of the stringline in identifying surface deviations more efficient and effective than random site selection. The Cox Profilograph is recommended for similar surveys on all new portland cement concrete pavements prior to construction acceptance testing with the stringline or the straightedge. It is recommended that the Mays Ride Meter be used as a pavement roughness survey tool to evaluate deteriorated pavements programmed for rehabilitation or major maintenance. This would identify rough pavement areas that should be considered for lane-leveling or planing prior to an overlay or other activity. Proper preparation of the surface prior to the activity at the identified locations should result in improvement of the rideability of the pavement following the surfacing activity. A limited correlation was found to exist between accident rates and pavement roughness for certain classes of roads in Utah. (FHWA)

Long, JA Belangie, MC Anderson, DI
Utah Department of Transportation, Federal Highway Administration, (UDOT-MR-82-1) Final Rpt. FHWA/UT-82/1, Aug. 1982, 65p HP&R PR-0010(4)

ORDER FROM: NTIS PB83-147314

problems of particular materials and considering the need for further drainage studies. Volume 2 is FHWA/RD-81/080, Users Manual. (FHWA)

Carpenter, SH Darter, MI Dempsey, BJ Herrin, S
Illinois University, Urbana, Federal Highway Administration Final Rpt. FHWA-RD-81-79, SSD-2-80, Sept. 1981, 144p
Contract

DOT-FH-11-9175

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24 348652
A PAVEMENT MOISTURE ACCELERATED DISTRESS (MAD) IDENTIFICATION SYSTEM, USERS MANUAL--VOLUME 2
This report is a users manual designed to provide the engineer with a rational method of examining a pavement and determining rehabilitation needs that are related to the causes of the existing distress, particularly moisture related distress. The key elements in this procedure are the MAD Index developed in Volume 1, the Pavement Condition Index (PCI) and the Moisture Distress Index (MDI). Step by step procedures are presented for calculating each parameter. Complete distress identification manuals are included for asphalt surfaced highways and jointed reinforced concrete highways with pictures and descriptions of all major distress types. Descriptions of the role moisture plays in the development of each distress type are included. A chapter is devoted to the interpretation of results with major emphasis on how the results indicate moisture distress, or the lack of it. The interpretation allows specific recommendations to be formulated by the engineer concerning the urgency of the needed rehabilitation as well as the type of rehabilitation and the need for the rehabilitation to address moisture problems in the pavement. Volume 1 is FHWA/RD-81/079. (FHWA)

Carpenter, SH Darter, MI Dempsey, BJ
Illinois University, Urbana, Federal Highway Administration Final Rpt. FHWA-RD-81-80, SSD-4-80, Sept. 1981, 238p
Contract

DOT-FH-11-9175

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24 348695
PERFORMANCE OF OPEN-GRADED ASPHALTIC CONCRETE FRICTION COURSES IN ARIZONA
There has been a growing emphasis, particularly in the past seven to eight years, on the placement of what have become known as open-graded asphaltic concrete friction courses (ACFCs). Such placement is as a final, or wearing, course for asphaltic concrete pavements and is used not only for highways but for airport runways as well. It was replaced in July 1976 that 47 states have now tried some type of open-graded mix and that 20 or 25 states are continuing this type of surfacing on a regular basis. The following performance aspects of proper ACFC design, construction, and maintenance, based on observations made over the past 25 years, are discussed: (a) Although the film coatings on particles in an open-graded ACFC are larger than those in dense-graded designs, a planned maintenance program that requires a fog seal of rejuvenators and/or combined asphalt rejuvenators every two of three years is essential (service life is affected by the lack of such a program); (b) an open-graded ACFC has the ability to hide surface reflective cracking, and it also provides space for subsequent fog seals of rejuvenating agents to retard cracking; (c) since an open-graded ACFC is sensitive to bitumen quantity, temperatures, and hauling distances, consideration should be given to control of the construction season; (d) adequate sealing of the existing pavement surface prior to placement of an open-graded ACFC is essential; and (e) under high traffic volumes and speeds, an open-graded ACFC facilitates the handling of traffic during construction and reduces the splashing effects of surface water. (Authors)

Allen, JG Peters, RI (Arizona Department of Transportation) *Transportation Research Record* No. 821, 1981, pp 1-4, 3 Fig., 7 Refs.
This paper appeared in TRB Record 821, Bituminous Mixes, Concrete Pavements and Structures, Testing, and Construction Prices.

ORDER FROM: TRB Publications Off

24 348696
PERFORMANCE COMPARISON BETWEEN A CONVENTIONAL OVERLAY AND A HEATER-SCARIFICATION OVERLAY
The heater-scarification technique has become one of the most commonly accepted forms of pavement surface recycling in use today. This has been due primarily to the record of successful performance exhibited by these projects over a relatively long period of time. The performance characteristics of a typical heater-scarification overlay project are analytically examined and compared with those of a conventional overlay. The comparison examines fatigue cracking caused by wheel loadings and thermal-fatigue cracking caused by daily temperature cycles. The results are presented for one combination of aged asphalt and recycling agent and one overlay type. The results show that for this combination the commonly held statement that a 19-to 25-mm (0.75-to 1.0-in) depth of heater scarification with 38-mm (1.5 in) of overlay will perform as well as 89 mm (3.5 in) of conventional overlay has some validity. The calculations illustrate the need for laboratory testing to select the best recycling agent for the particular asphalt being recycled and the need to tailor the characteristics of the recycled binder to produce the desired product. (Author)

Carpenter, SH (Illinois University, Urbana) *Transportation Research Record* No. 821, 1981, pp 4-12, 13 Fig., 19 Refs.
This paper appeared in TRB Record 821, Bituminous Mixes, Concrete Pavements and Structures, Testing, and Construction Prices.

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24 348697
ANALYSIS AND REPAIR OF WATER-DAMAGED BITUMINOUS PAVEMENT
An investigation of several bituminous concrete pavements on the Interstate system that experienced failures suspected to have been caused by stripping is reported. On two of the pavements, the degree of deterioration and potential serviceability was determined from the indirect tensile strength of cores and Dynaflect test results. Recommendations based on the investigation have resulted in repairs that are believed to be best suited to each situation. An emulsion mix design was developed for stripped bituminous concrete removed from a project with the expectation that it could be used as a surface mix on a highway with a low volume of traffic; however, because of risks involving performance, it was recommended for use as a base course. Resurfacing on a project that had experienced stripping failure is being monitored, and its performance is being evaluated. (Author)

Maupin, GW, Jr (Virginia Highway & Transportation Research Council) *Transportation Research Record* No. 821, 1981, pp 12-16, 3 Fig., 6 Tab., 3 Ref.
This paper appeared in TRB Record 821, Bituminous Mixes, Concrete Pavements and Structures, Testing, and Construction Prices.

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24 348705
MAGNITUDE OF HORIZONTAL MOVEMENT IN JOINTED CONCRETE PAVEMENTS
A section of US-23 near Chillicothe, Ohio, has been used as a test pavement for the past seven years. Variables included in the test section are slab length, type of subbase, saw-cut configuration, type and coating of dowel bars, and skewed joints. Both hand and electronic measurements of horizontal movement have been made. The hand measurements, made monthly, gave the long-term movements. The electronic measurements were continuous readings taken for one-week periods for each set of joints. Enough data have been collected to set up a computer program on a statistical basis to interpret the results. The results show that the short-term movements are greater than the long-term movements. The short-term movements are as great as 0.25 in (6.44 mm) regardless of whether the slab length is 40 or 21 ft (12.2 or 6.4 m). The long-term movements are much smaller and are almost directly proportional to slab length. It is recommended that the preformed seal be designed for the long-term movements but be able to accommodate the larger short-term movements as an upper limit. The bond between the seal and the joint face should be able to take some tension as a further guarantee of holding the seal in place in case of large joint openings. (Authors)

Minkarah, I Cook, JP McDonough, JF (Cincinnati University) *Transportation Research Record* No. 821, 1981, pp 61-67, 13 Fig., 2 Tab., 6 Ref.
This paper appeared in TRB Record 821, Bituminous Mixes, Concrete Pavements and Structures, Testing, and Construction Prices.

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24 348742
STRUCTURAL DESIGN OF INTERURBAN AND RURAL ROAD PAVEMENTS
Procedures for the structural design of pavements for interurban and rural roads are presented and a choice of four different road categories,

reinforced concrete pavement (CRCP) and (b) determination of a set of material properties that will provide satisfactory performance for 20 years without maintenance and satisfactory performance for the next 10-20 years with normal maintenance. To accomplish this goal, the most important distresses occurring in CRCPs and the material properties that affect those distresses were indentified. Mathematical models to predict those distress by using the identified material properties were selected. A range of values for each material property was selected and resulting distresses were predicted. The distresses studied included fatigue cracking, punchouts, crack spalling, steel rupture, and low-temperature and shrinkage cracking. The mathematical models selected for the analysis were ELSYM5 for modeling fatigue cracking and CRCP-2 for modeling low-temperature and shrinkage cracking. Punchouts, crack spalling, and steel rupture were incorporated into the analysis of low-temperature and shrinkage cracking. Input values were selected for each model, and ranges of the material properties affecting distress were identified and used in the analyses. The results for each study are discussed, and practical criteria are cited to evaluate the level of material properties required to provide zero- maintenance performance. A set of material properties is identified, and the trade-offs on material properties are discussed.

This paper appeared in Transportation Research Record 756, Concrete Pavements and Pavement Overlays.

Elkins, GE Roberts, FL (Austin Research Engineers, Incorporated) Kennedy, TW (Texas University, Austin) *Transportation Research Record* No. 756, 1980, pp 1-7, 7 Fig., 2 Tab., 11 Ref.

ORDER FROM: TRB Publications Off

24 326537

POROUS PAVEMENT. PHASE I. DESIGN AND OPERATIONAL CRITERIA

Design and operational criteria, utilization concepts, benefits and disadvantages, as well as other characteristics of porous pavements are presented in this report. Particular emphasis is placed on porous asphalt pavements, but the criteria and design approach are applicable to all other porous pavement types. The design considerations presented in this report include siting problems, load bearing design, and hydrologic design. A brief history of porous pavement development and previous experience with porous pavement by several designers, contractors, and operators are described. A computer model for hydrologic performance evaluation of existing or proposed porous pavement systems is also described in this report. Load bearing design criteria are based on previous work conducted for porous asphalt pavements. Appendices to this report include a sample set of specifications for porous asphalt construction and a list of soils and their permeability classes as prepared by the U.S. Soil Conservation Service.

Prepared by Espey, Huston and Associates, Inc., Albuquerque, NM.

Diniz, EV
Municipal Environmental Research Laboratory Final Rpt. Aug. 1980, 100p

Grant EPA-R-806338

ACKNOWLEDGMENT: NTIS
ORDER FROM: NTIS

PB81-104796

24 326607

FIBERGLASS-REINFORCED RIGID POLYURETHANE EXPEDIENT PAVEMENT SUBJECT TO SIMULATED F-4 AIRCRAFT TRAFFIC

A multipurpose expedient paving system is being developed to enable more rapid construction of expeditionary airfields by Marine Corps forces engaged in an amphibious landing. Previous research has resulted in a conceptual pavement, FIBERMAT, which consists of a facing of fiberglass-reinforced polyester resin (FRP) bonded to a core of fiberglass-reinforced rigid polyurethane foam. FIBERMAT has been subjected to a series of laboratory tests to define response to stress fatigue and environmental cycling. A similar structural sandwich of FRP and rigid polyurethane foam has been tested and found to meet F-4 aircraft static load, tailhook impact, and engine exhaust blast requirements. This report documents the results of a traffic test conducted on a section of FIBERMAT having a 5-inch-thick fiberglass-reinforced foam core and a 1/4-inch-thick FRP facing. Distributed traffic was applied to the test section with a load cart which simulated a main gear of an F-4 aircraft. The cart was equipped with a 30-7.7, 18-ply-rating tire inflated to 265 psi and loaded to 27,000 pounds. The first failure within the test section was recorded at 136 coverages (1,306 passes) of the load cart, and the entire test section was considered failed at 310 coverages (2,141 passes). (Author)

Springston, PS
Naval Construction Battalion Center, (F53536) CEL-TN-1578, May 1980, 64p

ACKNOWLEDGMENT: NTIS
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AD-A089266/1

24 327274

PERMANENT DEFORMATION OF FLEXIBLE PAVEMENTS

Seven pairs of pavement with granular bases were tested under controlled conditions. One pavement in each pair contained fabric inclusions. An improved testing facility was developed, including: (1) servo-hydraulic system for the loading carriage; (2) amplification and read-out system for pressure cells; (3) linearizing unit for strain coils; (4) transducers for measuring vertical and resilient deflection; (5) techniques for measuring in situ strain on fabric inclusions; (6) extensive use of nuclear density meter to monitor pavement and foundation materials. The following conclusions are drawn: (1) No improvement in performance resulted from fabric inclusions. (2) No consistent reduction in in-situ stresses, resilient strains, or permanent strains was observed as a result of fabric inclusion. (3) No consistent improvement in densities resulted from fabric inclusions. (4) Some slip apparently occurred between fabric and soil on those pavements which involved large deformations. The slip occurred between fabric and crushed limestone base rather than between fabric and silty-clay subgrade. (Author)

Brown, SF Broderick, BV Pappin, JW
Nottingham University, England, (1T161102BH57) June 1980, 165p

Grant DA-ERO-78-G-114

ACKNOWLEDGMENT: NTIS
ORDER FROM: NTIS

AD-A087859/5

24 329616

D-CRACKING AND AGGREGATE SIZE

An extensive study of the problem has recently been completed in the state of Ohio. The first phase of the Ohio study described involved a comprehensive survey of existing exposed concrete pavements. Its purpose was to determine the extent and severity of D-cracking in Ohio. The survey involved interstate roads, U. S. roads and state roads. Nearly half of the total mileage and nearly half of the total number of joints evaluated were on interstate roads. Several test methods were examined to evaluate their usefulness in identifying coarse aggregates which were likely to be involved in the formation of D-cracking.

Whitehurst, EA (Ohio State University) *Concrete Construction* Vol. 25 No. 8, Aug. 1980, p 593

ACKNOWLEDGMENT: EI
ORDER FROM: ESL

24 330276

TEMPERATURE CORRECTION OF SKID RESISTANCE VALUES OBTAINED WITH THE BRITISH PORTABLE SKID RESISTANCE TESTER

The skid resistance value (srv) obtained with the "British portable skid resistance" tester is partly dependent on the ambient temperature conditions at the time of test. Because of this, two equations were developed by the Transport and Road Research Laboratory to correct values to a common temperature of 20 degrees C, one based on the measurement of the "wet" surface temperature and the other based on the (shade) air temperature. These two equations have been found to be incompatible. An investigation of the effect of ambient temperature has been done to clarify this situation and develop correction equations suitable for general use in Australia; particularly for use with the data obtained for Australian Road Research Board Project 314-Assessment of Seasonal Variation in Skid Resistance. The correction equations obtained and estimates of their precision are reported. The equations are of the form: $srv(20) = srv(t)/(1-a(t-20))$ where $a = 0.00525$ for t = surface and 0.00816 for t = air temperature (A). (TRRL)

Oliver, JWH
Australian Road Research Board Monograph. Intl Rpt Air 314-2, Sept. 1980, 16p, 3 Fig., 5 Tab., 6 Ref.

24 302231

EVALUATION OF OREGON'S FIRST PROJECT IN HOT-MIX ASPHALT RECYCLING

Pavement recycling has been suggested as a workable alternative to more conventional methods of pavement rehabilitation and a means of off-setting some of the problems that result from spiraling energy costs and shortages of raw materials. The Woodburn asphalt recycling paving project, Oregon's first experience with using a hot-mix process in large-scale recycling of asphalt concrete, is discussed. The project is described, overlay and mix designs are indicated, the construction program and the specific equipment used are reviewed, the program of materials sampling and testing and data collection is described, and test results are summarized. Special emphasis is given to an investigation of possible changes in material properties through the construction process. A summary is presented of the factors that most affect the production of emissions. Costs and fuel consumption are examined, and possible savings over a similar, conventional paving project are highlighted. Specific recommendations are presented for the benefit of other agencies that are considering similar projects, and future research needs are outlined. /Author/

This paper appeared in TRB Record No. 712, Bituminous Materials and Skid Resistance.

Whitcomb, WG (Oregon State University) Beecroft, G Wilson, JE (Oregon Department of Transportation) *Transportation Research Record* No. 712, 1979, pp 15-23, 9 Fig., 5 Tab., 7 Ref.

ORDER FROM: TRB Publications Off

24 302233

FATIGUE PERFORMANCE OF A BITUMINOUS ROAD MIX UNDER REALISTIC TEST CONDITIONS

A study whose purpose was the verification of Miner's rule for estimating the cumulative damage resulting from the phenomenon of fatigue is reported. A repeated-bending apparatus driven by a minicomputer, which was devised to generate and control stress or strain waves of variable amplitudes, is described. The fatigue behavior of a bituminous mix subjected to nine different loading patterns (simple, random, and block) was determined. The influence of rest periods of different lengths was studied for these cases. It is concluded that (a) to the extent that the spectrum of load amplitudes is known, a prediction method derived from Miner's law is applicable with an acceptable accuracy for random sequences that include no rest periods and (b) rest periods markedly increased fatigue life for the three loading patterns considered. These initial conclusions were used to derive a generalized form of Miner's law for loading conditions in which both stress amplitudes and the duration of rest periods are variable. This generalized law was verified by simulating actual conditions of traffic loading in fatigue tests. /Author/

This paper appeared in TRB Record No. 712, Bituminous Materials and Skid Resistance.

Francken, L (Centre de Recherches Routiers, Brussels) *Transportation Research Record* No. 712, 1979, pp 30-37, 7 Fig., 2 Tab., 8 Ref.

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24 302235

EFFECTS OF TEXTURES AND THE AGGREGATES THAT PRODUCE THEM ON THE PERFORMANCE OF BITUMINOUS SURFACES

Results of a Pennsylvania State University study of the characteristics of pavement surface textures and the aggregates that produce them are reported. The primary requirements of bituminous surfaces are durability and safety. Surface microtexture induces high levels of friction at low vehicle speeds, and surface macrotexture facilitates the drainage of water from the tire-pavement interface and reduces glare and splash and spray. Aggregate gradation largely determines the design of pavement surfaces. It is concluded that, to retain microtexture, the aggregate must contain a high proportion of hard mineral content embedded in a softer matrix or be composed predominantly of sharp, hard crystals well cemented in a porous configuration. To provide and retain adequate macrotexture, aggregate particles must be hard and tough and 3 to 19 mm (0.12 to 0.75 in.) in size. Angular, bulky particles perform better than rounded, flaky particles. Textures that improve skid resistance on wet surfaces were found to reduce glare and splash and spray, thereby increasing the safety of the surface. /Author/

This paper appeared in TRB Record No. 712, Bituminous Materials and Skid Resistance.

Henry, JJ (Pennsylvania State University, University Park) Dahir, SH (Pennsylvania State University, Middletown) *Transportation Research Record* No. 712, 1979, pp 44-50, 8 Fig., 2 Tab., 18 Ref.

ORDER FROM: TRB Publications Off

24 302236

SKID RESISTANCE OF BITUMINOUS-PAVEMENT TEST SECTIONS: TORONTO BY-PASS PROJECT

As part of a program to determine the most suitable method of improving the driving qualities of Canada's Highway 401 Toronto By-Pass, 18 bituminous test sections were constructed in 1974 on the existing concrete pavement. The test sections include dense-graded and open-graded bituminous mixes that contain a variety of aggregate types including traprock, steel slag, and blast-furnace slag. A comprehensive test program in which the skid characteristics of various test sections were monitored by brake-force and side-force skid trailers and texture was analyzed by use of photo-interpretation techniques is described. Skid resistance was measured in weather conditions that varied from drizzle to slush from heavy snow by using a continuously recording side-force-friction trailer. Not all of the mixes have provided the required level of skid resistance, particularly in the driving lane and the center lane where large numbers of trucks travel. The most striking results of the project are (a) the excellent performance of bituminous mixes that contain crushed traprock or slag screenings as the fine aggregate and (b) the low skid resistance of many mixes in which the fine aggregate consists of natural sand blended with limestone screenings. All mixes were characterized by a general decline in skid resistance during the first four years as texture depths were reduced by compaction under traffic. The first phase of pavement improvement on the Toronto By-Pass, in which bitumnous overlays were used with an open-graded surface-course mix, is described. Data on mix composition, skid resistance, and noise characteristics are also presented. /Author/

This paper appeared in TRB Record No. 712, Bituminous Materials and Skid Resistance.

Ryell, J Corkill, JT Musgrove, GR (Ontario Ministry of Transportation & Communic, Can) *Transportation Research Record* No. 712, 1979, pp 51-61, 7 Fig., 4 Tab., 11 Ref.

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24 303084

POROUS FRICTION COURSES-CURRENT STATUS

This paper describes Country Roads Board experience with open graded friction course asphalt. Trial sections were placed in 1974 and 1975 and their performance monitored. Testing has been carried out on skid resistance and binder hardening. These show that a high level of skid resistance has been maintained and that the thickness of the binder film is important to the rate of hardening of the binder. (Author/TRRL)

Program and papers from Pavement Surface Drainage Symposium, Sydney, New South Wales, 2-3 May 1979.

Rebbechi, JJ (Victoria Country Roads Board, Australia) Australian Road Research Board 1979, 14 p., 8 Tab.

ACKNOWLEDGMENT: TRRL (IRRD 239253), Australian Road Research Board.

24 303415

EVALUATION AND CALIBRATION OF ROAD METER DEVICES FOR MEASURING PAVEMENT RIDEABILITY

This report is divided into three parts. Part one covers the state of the art of Road Meter technology and describes some recent significant advances. The second part describes the evaluation of a velocity sensor for measuring axle movement to determine roughness rather than the normal method of mechanically determining the movement between axle and car body. Part three describes methods of Road Meter calibration, and limited testing of a dynamometer type calibration device constructed at the laboratory. (FHWA)

This project was performed in cooperation with the Department of Transportation, Federal Highway Administration.

Neal, BF

California Department of Transportation, California Department of Transportation, (19303-653171) Final Rpt. FHWA-CA-TL-79-14, June 1979, 46 p.

HP&R F-7-34

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24 392358
EXPERIENCES WITH POROUS ASPHALT; EXPERIMENTAL SECTIONS ON A12 NEAR DRIEBERGEN [ERVARINGEN MET ZEER OPEN ASFALTBETON; PROEFVAKKEN OP A12 BIJ DRIEBERGEN]

In 1973 experimental sections of road of porous asphalt were constructed on state highway 12 in the Netherlands. The composition of the applied porous asphalt and the construction of the experimental sections of road are described. The Marshall properties as determined with different bitumen contents, the mean gradation, the percent air voids and the results of texture depth and skidding resistance measurements relating to the experimental sections are given. Resistance against permanent deformation, durability, structural strength, skidding resistance, winter performance, traffic noise aspects and carriageway marking of porous asphalt pavements are discussed. The necessity of research into service life on one hand and maintenance and winter maintenance on the other hand is outlined. Conclusions are drawn and recommendations are given. (TRRL) [Dutch]

Gerardu, JJA (Wegbouwkundige Dienst) Heide, JPJ van der (Vereniging Voor Bitumineuze Werken) **Wegen** Vol. 58 No. 6, June 1984, pp 207-216, 3 Fig., 6 Tab., 9 Phot., 20 Ref.

ACKNOWLEDGMENT: TRRL (IRRD 278613), Institute for Road Safety Research SWOV

24 392431
COMPUTER PROGRAMS FOR ANALYTICAL DESIGN OF ASPHALT PAVEMENTS

During the years 1980-84 a number of main frame and micro computer programs for the analytical design of ashphalt pavements have been developed at the University of Nottingham. This paper describes the basis of the computations together with procedures adopted. The main frame programs are versatile and can deal with a range of design problems. The micro computer programs involve some simplifications but are particularly useful for preliminary designs and the comparison of alternative solutions. Designs made with the use of a main frame program are compared with the current empirical recommendations of Road Note 29. Practical applications of the programs are also given, such as the development of design charts, and the use of the programs to demonstrate the effect of variations in binder content and void content on the design thickness. (TRRL)

Brown, SF Brunton, JM (Nottingham University, England) **Highways and Transportation** Vol. 31 No. 8/9, Aug. 1984, p18, 11 Fig., 4 Tab., 19 Ref.

ACKNOWLEDGMENT: TRRL (IRRD 279193)
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24 392520
SEASONAL VARIATION OF DEFLECTION ON GRAVEL AND SURFACE DRESSED (Y1G) ROADS. RESULTS FROM FWD MEASUREMENTS 1979-82 [DEFLEKTIONENS SAESONGSVARIATION PAA GRUS-OCH Y1G-VAEGAR. RESULTAT AV FALLVIKTSMAETNINGAR 1979-82]

To measure bearing capacity during the summer and the autumn instead of during the short period of spring thaw has obvious advantages. The equipment is more economically used and the problem to decide when to measure during the spring thaw is avoided. The variation in bearing capacity during summer-autumn on the roads studied was found to be small within the year as well as between years. To correct a deflection measured during the summer or the autumn to a design value (spring value) an adjustment factor is required. The factor is estimated on mean values from sections on gravel and y1g (single surface treatment with graded gravel aggregate) roads on different subgrades. The sections have a length from 70 m to 2400 m and most of them are situated in the County of Oestergoetland. A necessity for the use of seasonal factors is that the sections are relatively homogeneous concerning subgrade and pavement materials. (Author/TRRL) [Swedish]

Jansson, H
National Swedish Road & Traffic Research Institute, (0347-6049) Monograph No. 391, 1984, 14p, 8 Fig., 1 Tab., 4 Ref.

ACKNOWLEDGMENT: TRRL (IRRD 278915), National Swedish Road & Traffic Research Institute

24 392536
CONCRETE PAVEMENTS IN DENMARK [BETONGBELAEGGNINGER I DANMARK]

Concrete pavements have been constructed in Denmark since 1925. The concrete in these old pavements has presented a good durability during 40 years. The problems have, however, been numerous in concrete pavements constructed from 1965 to 1970. They cover about 42 km of motorways and 142000 sq m in military airfields. The Danish Technological institute has carried out extensive investigations of these recently constructed pavements. Individual investigations of old concrete pavements have also been performed. The article presents briefly the causes of damage to the pavements. A new code of practice which will result in more durable concrete pavements is mentioned. Particular stress is laid on the new quality control system. (TRRL) [Danish]

Damgaard Jensen, A (Teknologisk Institut, Byggeteknik) **Nordisk Betong** 1984:1, Jan. 1984, pp 29-30, 6 Phot., 6 Ref.

ACKNOWLEDGMENT: TRRL (IRRD 278934), National Swedish Road & Traffic Research Institute

24 392622
BRICK STREETS IN KANSAS: THEN AND NOW

The author has treated this subject from the viewpoint of what might be termed the practical, rather than the theoretical, aspect, giving views which have been derived from the actual construction of pavements, and the studied observation of the relative merits of the different materials; and some statistics.

Kicher, JR **Public Works** Vol. 115 No. 9, Sept. 1984, p105

ACKNOWLEDGMENT: EI
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24 392627
DESIGN AND MAINTENANCE OF UNPAVED ROADS

The design of an unpaved road is generally done in a non-technical manner. While many of the elements of design are the same as for a paved road, the decisions are more likely to be based upon what works best, rather than a value in a blue book. The designer may be a road superintendent, a township trustee, or even a motor grader operator. Natural resources development, especially coal and oil, will create the need for some additional unpaved roads. As fringe areas of cities develop, unpaved roads will serve until a paved surface can be justified.

Cashatt, JP **Public Works** Vol. 115 No. 9, Sept. 1984, p154

ACKNOWLEDGMENT: EI
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24 392629
DATA ANALYSIS TECHNOLOGY FOR SKID RESISTANCE IS ESTABLISHED

The safety of the public on the highways has long been a subject of major concern which is especially heightened when highway surfaces are wetted or inundated during periods of rainy weather. This concern and the important econmic necessity of providing the best aggregates for pavement surfaces at competitive costs have led to activation of research designed to develop pavements which are both skid resistant and also economically feasible. A major study on economic skid resistant asphalt surfaces is now active. Researchers are seeking to devise improved methods to select the most economical coarse aggregates possible that could provide pavements with enhanced skid resistant asphalt surfaces.

Texas Transportation Researcher Vol. 20 No. 2, Apr. 1984, pp 10-11

ACKNOWLEDGMENT: EI
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24 392682
TESTS WITH A SVN HEAVY VEHICLE SIMULATOR ON EXPERIMENTAL SECTIONS WITH BASES OF WATERBOUND MACADAM AT MARIANHILL, PINETOWN, NATAL [TOETSE MET 'N SWAARVOERTUIGNABOOTSER (SVN) OP EKSPERIMENTELE WATERGEBINDEMACADAMSEKSIES TE MARIANHILL, PINETOWN-OMGEWING, NATAL]

This report describes the execution of hvs tests on two experimental sections with bases of waterbound macadam with depths of 150 mm and pavement engineers. The PCI was found to be much more consistent than ratings by individual engineers since it is based on measured distress data, and not on subjective judgment.

Shahin, MY Kohn, SD
Army Construction Engineering Research Laboratory Final Rpt. CERL-TR-M-268-VOL-2, July 1979, 120 p.

ACKNOWLEDGMENT: NTIS
ORDER FROM: NTIS

AD-A074171/0

24 307930
PASCO-KENNEWICK INTERCITY BRIDGE
The author describes the planning, design considerations, quality control program, and construction techniques involved in building the 763 m long Intercity Bridge in Washington State. This structure is reported to be the largest precast prestressed cable-stayed bridge built in North America.

Grant, A (Grant (Arvid) & Associates, Incorporated) *Prestressed Concrete Institute, Journal of* Vol. 24 No. 3, No Date, pp 90-109

ACKNOWLEDGMENT: EI
ORDER FROM: ESL

24 307945
ROAD SURFACING OF OPEN ASPHALT EMULSION CONCRETE. FOLLOW-UP [Vaegbelaeggning av oeppen asfaltemulsionsbetong, Aeb oe. Uppfoeljning]
A surfacing of open asphalt emulsion concrete was compared with a conventional dense asphalt concrete. During a two year follow-up study the following factors were investigated: surface lightness, glare, evenness, noise, friction, strength, composition, permeability and wear. The open asphalt emulsion concrete showed advantages concerning external noise, reduction of aquaplaning, splash and glare from surface reflection. Wear was inferior compared with conventional surfacings. The draining ability of open asphalt emulsion concrete results in acceptance of deeper ruts than in conventional surfacings. This indicates that the durability of open asphalt emulsion concrete surfacings is equivalent to conventional. [Swedish]

Tyllgren, P
Svenska Byggnadsentreprenoerfoereningen Monograph 1979, 70 p., Figs., 13 Tab., 20 Phot.

ACKNOWLEDGMENT: TRRL (IRRD 242527), National Swedish Road & Traffic Research Institute

24 307996
A SYSTEM APPROACH TO FLEXIBLE PAVEMENT DESIGN IN AUSTRALIA
This paper was presented at Session 13 Pavement Management Systems 1. A decision made in planning, design, construction, maintenance and materials may result in a significant change in the performance of a road and hence in the resulting total cost. A system is established which, in a logical manner, sets down and assesses the effect of the factors influencing performance. At the same time it provides a basis on which to choose an appropriate design among a number of alternative designs, maintenance policies and economic analyses wherein the variability of materials, traffic, environment, cross-section, etc. are accounted for insofar as they control performance. Its principal purpose is to achieve the best use of available funds. Particular consideration is given to the input information required by the designer, the generation of alternative strategies satisfying the objectives and the economic evaluation for selecting the optimum strategy. The development of the system has shown a completed earth of information in a number of activities and hence provides a coherent and valuable guide to research needs. (TRRL)
Proceedings from the Ninth Australian Road Research Board Conference, Brisbane, August 21-25, 1978.

Scala, AJ. *Australian Road Research Board Conference Proc* Proceeding Vol. 9 No. 4, 1979, pp 24-37, 13 Fig., 7 Tab.

ACKNOWLEDGMENT: TRRL (IRRD 239365), Australian Road Research Board

24 308003
A TRAFFICKING TEST ON DOLERITE BASES
This paper was presented at Session 23-Pavement Performance. It describes a laboratory trafficking test on dolerite road base material. The aggregate was installed in the test machine at a range of moisture contents and densities and loaded by a rolling wheel. The relative performance of the bases is assessed from measurements of the permanent deformation. Results from the test show that the deformation behaviour is very dependent on the moisture content, whilst differences in density have much less effect. If the base can be kept at a low moisture content, about 3 per cent, the deformations should be small, but the material will readily take up water. (TRRL)
Proceedings from the Ninth Australian Road Research Board Conference, Brisbane, August 21-25, 1978.

Sparks, GH Davis, EH (Sydney University) *Australian Road Research Board Conference Proc* Proceeding Vol. 9 No. 4, 1979, pp 297-304, 16 Fig., 1 Tab., 3 Ref.

ACKNOWLEDGMENT: TRRL (IRRD 239369), Australian Road Research Board

24 308017
USE OF OPEN-GRADED PLANT MIX IN NEW SOUTH WALES
This paper was presented at session 24-surfacings and surface friction 2. Open-graded plant mix has been used as a wet weather friction course on freeways, high speed urban and rural roads and accident prone locations in New South Wales since 1967. This mix is designed to provide A permeable pavement surface layer which will maintain a satisfactory frictional level during wet weather by allowing the water to permeate into the surface and slowly drain to the sides of the pavement by lateral displacement, thereby reducing the incidence of surface ponding. In the high speed road situation, this mix has the further advantage of reducing vehicle noise. This paper is an extension of the work reported by Ross and Rufford (1972) and summarises the the former and subsequent investigational work carried out by The Department of Main Roads, New South Wales. This summary includes measurements of TRRL pendulum tester and ml mu-meter friction, permeability and textural properties of the surfacings under various traffic conditions and looks at the effects of aggregate type and binder on the performance of these surfacings. Recommendations are made on the assessment of effective life of alternative mixes in field service. (TRRL)
Proceedings from the Ninth Australian Road Research Board Conference, Brisbane, August 21-25, 1978.

Gaughan, RL Leung, JSY (New South Wales Department of Main Roads,Australia) *Australian Road Research Board Conference Proc* Proceeding Vol. 9 No. 3, 1979, pp 149-156, 6 Tab.

ACKNOWLEDGMENT: TRRL (IRRD 239349)

24 308022
WATER ENTRY THROUGH UNSEALED GRAVEL ROAD SHOULDERS
This paper was presented at Session 23-Pavement performance. It is concerned with the conditions under which unsealed gravel road shoulders are effectively impermeable to pavement edge infiltration. Simple hydrological analyses are used to show how the surface condition of the shoulder, the properties of the shoulder material and regional climate affect the probability of water penetration through the shoulder into the pavement. The results are applied to typical locations in tropical Australia. (TRRL)
Proceedings from the Ninth Australian Road Research Board Conference, Brisbane, August 21-25, 1978.

Wallace, KB Leonardi, F (James Cook University, Australia) *Australian Road Research Board Conference Proc* Proceeding Vol. 9 No. 4, 1979, pp 283-296, 12 Fig.

ACKNOWLEDGMENT: TRRL (IRRD 239372)

24 308038
SULPHUR-ASPHALT PAVEMENTS: THE MINNESOTA DOT PROJECTS
Recent projects involving the use of sulphur extended asphalt (SEA) indicates that SEA mixtures are at least equal to conventional mixtures in performance and durability. The first project was part of an experimental overlay to examine various ways of reducing reflection cracking. Details of the equipment and job are briefly outlined. The mix temperature was about 290 degrees F. The SEA mixture was placed through a Blaw-Know PF 180H paver in a normal manner. Hydrogen sulphide emissions were well within established limits. The second project involved control sections of recycled asphalt base and binder course mixture. Experimental sections contained 30/70 percent old and new material. The new material contained 40/60

ACKNOWLEDGMENT: Federal Highway Administration
ORDER FROM: NTIS

PB81-100448

24 322733

DESIGN PREDICTION OF PAVEMENT SKID RESISTANCE FROM LABORATORY TESTS

The objective of this research has been to develop and refine methods for pre-evaluating aggregates and paving mixtures so that predictions can be made covering skid resistance properties of proposed and in service pavement types. The equipment used during the testing included a K.J. Law Locked Wheel Pavement Friction Tester, a British Portable Tester, a North Carolina type small wheel circular tack wear and polish machine built by KsDOT personnel, a device for plotting a linear traverse profile of a pavement sample, and stereophotography equipment. A usable correlation was established between the field testing using the data from the British Portable Tester and the Locked Wheel Pavement Friction Trailer at speeds of 40 and 55 mph. To extend this correlation, core samples were extracted from the Locked Wheel Tester Skid Path and were subjected to wear on the small wheel circular tack with periodic surface friction testing using the British Portable Tester. The final step was to remix and remold the cored pavement samples or make samples with new materials to obtain an "as new" surface and again subject these samples to wear on the small wheel circular track with periodic testing using the British Portable Tester to find the British Pendulum Number (BPN). Other segments of the project included efforts to correlate Stereo-Photography Number (SPN) vs. Locked Wheel Pavement Friction Tester SN, Stereo-Photography Number (SPN) vs. BPN on the wear and polish machine and Linear Traverse Number (LTN) vs. BPN on the wear and polish machine. Some research was conducted with various chat (chert)/limestone mixtures in an attempt to establish a blend offering good resistance to skid and wear and polish. Results from the study indicate that predictions can be made of the surface friction and possibly the durability properties of pavement design by laboratory testing. (FHWA)

Parcells, WH, Jr Metheny, TM Maag, RC
Kansas Department of Transportation Final Rpt. FHWA-KS-80-1, Aug. 1980, 27p

HP&R 76-1

ACKNOWLEDGMENT: Federal Highway Administration
ORDER FROM: NTIS

PB81-104226

24 322735

NEW AND INNOVATIVE METHODS AND MATERIALS FOR PAVEMENT SKID RESISTANCE

This report describes an evaluation and classification of pavement surfaces with respect to skid resistance. The study was conducted by means of a questionnaire survey of agencies within and adjacent to California, and by testing and examination of 45 existing pavement surfaces. The test program included standard skid tests at two speeds and additional tests with a smooth tire at one speed. Surface textures were measured by stereophotographs to obtain a "texture profile." The approximate cost of the surface, the amount of traffic exposure, and vehicle accident data were included in the evaluation. The pavement surfaces were ranked on the basis of skid number, speed gradient, and texture. Systems which ranked well under heavy of medium traffic included open-graded asphalt concretes with and without epoxy modification, textured cement concretes, and expoxy chip seals. Conventional and rubberized chip seals were found suitable for medium or light traffic. Dense- graded epoxy-asphalt concretes generally ranked about the same as the control section of asphalt concrete. The corrective surface treatments considered new and in novative were all quite expensive compared to conventional treatments. Wet pavement accident data did not provide any criteria for establishing minimum levels of skid resistance. (FHWA)

Page, BG
California Department of Transportation, Federal Highway Administration, (FHWA-CA-TL-3143-7659) Final Rpt. FHWA-RD-78-145, July 1977, 109p

Contract DOT-FH-11-8480

ACKNOWLEDGMENT: Federal Highway Administration
ORDER FROM: NTIS

PB81-104234

24 322990

MATERIAL PROPERTIES OF ZERO-MAINTENANCE FLEXIBLE PAVEMENT

This study involved models selected as suitable for the prediction of important distresses that have occurred historically in flexible pavements and the determination of material properties that will provide 20 years of satisfactory performance without maintenance and an additional 10-20 years of satisfactory performance with normal maintenance. To accomplish the overall objective, results were used from a previous study that identified the most important distresses occurring in flexible pavements, identified the material properties that affect those distresses, and selected mathematical models to predict those distresses by using the identified material properties. This paper presents that range of values selected for each of the material properties and discusses the distressses predicted by using the selected mathematical models. The distresses selected for study included fatigue cracking, rutting, and low-temperature cracking. The mathematical models selected for the analysis were VESYS for modeling fatigue cracking and rutting and the Shahin- McCullough model for low-temperature cracking. Input values were selected for each of these models, and ranges of the material properties affecting distress were established. The results for each study have been included and discussed, and practical criteria have been cited to evaluate the level of material properties required to provide zero-maintenance performance. The effects of each set of material properties used are identified, and the trade-offs of the affects of material properties on the distresses are discussed. (Author)

This paper appeared in Transportation Research Record No. 755: Evaluation and Analysis of Flexible Pavement Components Properties.

Roberts, FL (Roberts, FL) Kennedy, TW (Texas University, Austin)
Transportation Research Record No. 755, 1980, pp 1-7, 3 Fig., 3 Tab., 30 Ref.

ORDER FROM: TRB Publications Off

24 322991

DISTRESS BEHAVIOR OF FLEXIBLE PAVEMENTS THAT CONTAIN STABILIZED BASE COURSES

The distress behavior of full-scale experimental pavements is analyzed and discussed. The pavements contained five different base-course materials, namely, bituminous concrete, aggregate cement, aggregate-lime-pozzolan, aggregate bituminous, and crushed stone. Three types of aggregate--limestone, slag, and gravel--were used in the aggregate-cement base. Distress behavior discussed includes rutting, surface roughness, and cracking. Distress behavior observed is related to pavement response, which was analyzed by using the BISAR computer program. The critical responses analyzed are maximum tensile strain at the bottom of the base course and maximum compressive strain at the top of the subgrade. Various equations relating distress and response are established that permit prediction of the amount of rutting, roughness, and cracking, and allowable subgrade compressive strains to limit different distress modes within specified levels are also established. Field distress data are also related to the present-serviceability-index (PSI) values of each test pavement. From these relationships, various levels of each mode of distress manifestation are established for each level of PSI drop. Results obtained from this study may be useful in selecting allowable distress levels and allowable subgrade compressive strain for pavement design and can also be helpful in developing the relationship between distress and performance. (Author)

This paper appeared in Transportation Research Record No. 755 Evaluation and Analysis of Flexible Pavement Components and Properties.

Wang, MC (Pennsylvania Transportation Institute) Gramling, WL (Pennsylvania Department of Transportation) *Transportation Research Record* No. 755, 1980, pp 7-14, 10 Fig., 3 Tab., 21 Ref.

ORDER FROM: TRB Publications Off

24 322992

NONLINEAR CHARACTERIZATION OF GRANULAR MATERIALS FOR ASPHALT PAVEMENT DESIGN

In view of the well-established nonlinear resilient properties of unbound granular materials, analytically based pavement-design procedures should take proper account of this characteristic. The importance of including a failure criterion in the nonlinear model is demonstrated; the potentially high modulus of granular materials is not being realized in situ because of the unfavorable stress conditions that develop. The nonlinear model that has been written into the pavement-design computer program ADEM is

Syndicat Prof des Exploitants D'Usines D'Enrobage Monograph July 1981, 55p, Figs., Tabs., Photos.

ACKNOWLEDGMENT: TRRL (IRRD 112513), Central Laboratory of Bridges & Highways, France

31 361581

RECYCLED PAVEMENT: I-95 HERSEYTOWN-BENEDICTA-SHERMAN

In the summer of 1980, a hot recycled project was constructed on Interstate 95 in the towns of Herseytown, Benedicta, and Sherman. The top 3 inches of deteriorated hot bituminous pavement was removed to a width of 25 feet by a PF-750 CMI rotomill. The project included 9.6 miles of the NB lane and 0.9 miles of the SB lane. The material was then recycled through a Boeing Drum Mixer, using 70 percent milled material, 30 percent virgin aggregate, and 1.8 percent total binder material consisting of 50 percent aniomic emulsion (HFMS-2) and 50 percent softening agent (Mobisol-30). The recycled mixture was placed in the milled area and the entire project, including the shoulders, was then covered with 1 inch of new wearing surface. (Author)

Pilsbury, AN
Maine Department of Transportation Tech Paper 82-5, Mar. 1982, 21p, Figs., 1 App.

31 361686

IMPROVEMENTS IN HEAVY DUTY ASPHALT SURFACING

The authors examine the defects of the present system of designing asphalt surfacings. They recommend specific requirements for the current need to withstand heavy traffic volumes and axle loadings and describe how these needs may be met. At present, only two types are commonly specified- hot rolled asphalt to BS594 amd dense macadam to BS4987. Both of these types have limited scope in meeting deformation and skid resistance requirements. A binder is required with low susceptibility to extremes of temperature and a selection and grading of the aggregate is needed to ensure that the mix will carry the highest possible proportion of the binder without appreciable loss of stability or excessive flow. Evidence suggests that this could be achieved by a continuously graded mix such as asphaltic concrete using a fortified binder. Tests on the stability of mixes show that there is apparently no accurate correlation between Marshall stability and deformation on the dry wheel tracking test at 60 degrees centigrade. Designs using polymer asphalt cement binders are suggested to meet the 1.5mm texture depth requirements. The extra cost of binders could be offset by a reduction in the thickness of layers. A flexible performance specification is required, enabling a choice to be made of particular materials suitable to each site. (TRRL)

Buckmaster, C Laitinen, J *Highways and Public Works* Vol. 49 No. 1858, Oct. 1981, p 23, 2 Tab., 3 Phot.

ACKNOWLEDGMENT: TRRL (IRRD 260479)

31 361712

MATERIALS TECHNOLOGY FOR RECYCLING ASPHALT

Recycling bituminous materials has aroused considerable interest in the past few years. Recycling processes have been discussed in detail in the literature and it is clear that coated material removed from an existing pavement can be processed to produce a product which appears to be suitable for paving operations. However, little attention has been directed towards the material itself. Thus the objective of this paper is to discuss the state of knowledge with regard to the material itself and suggest how recycling may be developed now and in the future. (Author/TRRL)

Stock, AF (Dundee University, Scotland) *Highway Engineer* Vol. 29 No. 3, Mar. 1982, pp 10-15, 4 Fig., 2 Tab., 25 Ref.

ACKNOWLEDGMENT: TRRL (IRRD 261166)

31 361902

ROAD SAFETY. RESEARCH AND PRACTICE

Brings together in a single volume up-to-date, international research relating to the most important aspects of road safety. The book's unique features consist of a series of short review chapters designed to provide a wealth of useful information to all those with research and professional interests in road safety. Contributors are from many different countries. Although the book is primarily psychological in nature, its contents spans a wide range of topics from ergonomic/engineering aspects of road safety through to the education of children in road safety to cross-national differences in road safety practice. The volume also embraces safety in relation to wide range of road users: vehicles, cycles and motorcycles, and pedestrians including children, the elderly, and the handicapped.

Foot, H, Editor Chapman, A, Editor Wade, F, Editor
Praeger Publishers 1981, 224p

ORDER FROM: Praeger Publishers, CBS Educational and Professional Bldg, 521 Fifth Avenue, New York, New York, 10175

31 362021

AN EVALUATION OFF THE ASPHALTENE SETTLING TEST

This report describes a study which was undertaken to evaluate the asphaltene settling test, to investigate the possible relationships between settling time and physical properties of asphalt, and to determine the effect of asphalt modifiers and additives. Two hundred and sixty-two virgin asphalt cements, 5 samples of extracted asphalts, 14 different anti-stripping agents, and 5 different asphalt softening agents were included in this study. Results of this study, along with previous findings at the Laramie Energy Technology Center, indicate that a great deal of additional work is required if the test is to have practical value and significance. Nevertheless the findings of this study indicate that the test has fair repeatability but is sensitive to test temperature. Settling times were very dependent on the producer; however, no relationships were found between test results and specification type asphalt characteristics. The addition of anti-stripping and softening agents tended to reduce settling times with respect to virgin asphalts. A modified test procedure is recommended in order to simplify the procedure, to reduce time and cost of performing the test, and to improve the repeatability of the test. (FHWA)

Kennedy, TW Lin, C-C
Texas University, Austin, Texas State Department of Highways & Public Transp, Federal Highway Administration, (Res Rpt 253-2) Intrm Rpt. FHWA/TX-81/39253-2, Dec. 1981, 71p
HP&R

3-9-79-253

ORDER FROM: NTIS

31 362028

OPTIMIZATION OF DESIGN OF ASPHALTIC PAVING MIXTURES

This study concerned the optimization of asphaltic paving mixtures, through evaluation of: Marshall mix design characteristics considering the effects of aggregate type and gradation and compaction method; mixture optimization with respect to rutting characteristics; and optimization with respect to fatigue criteria. Surface courses mixes were prepared with three aggregates (limestone-limestone sand, gravel-natural sand, and slag-slag sand) at three gradations (dense-graded, gap-graded and open-graded) and Marshall samples were prepared using kneading, gyratory and 50-blow drop hammer compaction. Effect of aggregate type and gradation on rutting and fatigue were also evaluated. Results indicate that compaction method significantly influences Marshall stability, density and air voids, with gyratory compaction at 60 gyrations and 1 degree angle closely approximating field compaction. It was also found that optimum asphalt content of open and gap graded mixes could not be determined using the Marshall procedure with its existing limits; air voids of both gradations exceeded the 5% limit and density curves showed no distinct peaks and a monotonically decreasing behavior with increased AC. Aggregate type and gradation also were significant in the rutting and fatigue performances, open-graded limestone mixes also achieved satisfactory moduli that may be less temperature-sensitive and rutting performance similar to the dense-graded mixes. Dense-graded surface mixes did not always show the best fatigue performance; open-graded mixes, particularly limestone, achieved fatigue lives as high and sometimes higher than dense-graded mixes, indicating that limestone open-graded mixes show some promise in optimizing mixes for Marshall parameters as well as rutting/fatigue. (FHWA)

Majidzadeh, K El-Mitiny, MR El-Mojarrush, MA Safwat, N
Ohio State University, Ohio Department of Transportation, Federal Highway Administration, (EES-560) Final Rpt. FHWA/OH-81/005, Feb. 1980, n.p.
HP&R

14304(0)

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predictions are in good agreement at least up to 2.5 million standard axles. Above this value the comparison was inconclusive. However, agreement even to this extent, together with the rational nature of the approach, suggests that pilot applications of the technique in a wider context are justified. Nevertheless, the method requires further testing for longer design lives and higher values of subgrade modulus (or CBR). A technique for overlay design, where the overlay also consists of unbound material, is proposed. (TRRL)

Golden, SJ *Road Construction* Monograph NRC218, Nov. 1980, 34p, 1 Fig., 8 Tab., 25 Ref.

ACKNOWLEDGMENT: TRRL (IRRD 259285), An Foras Forbartha

24 349516

TIRE/ROAD NOISE ON AN OPEN-GRADED FRICTION COURSE

A significant part of traffic noise is caused by the interaction of tires with the road. A relatively efficient way to abate tire/road noise is to use a road pavement with low-noise characteristics. A pavement group considered beneficial for noise suppression is the so-called open-graded pavements, where the finegraded portion of the material is very small resulting in a surface with many interconnected open channels able to efficiently drain water and air in the tire/road interface through the road surface. Measurements of tire/road noise from one tire type have been made for speeds of 70 and 90 km/h on two pavements, one of which is an open-graded friction course and the other a conventional, dense-graded asphalt concrete pavement. It was found that the open-graded pavement reduced tire/road noise by 3db(a) relative to the dense pavement. In relation to the latter pavement, the noise reduction was considerable at high frequencies, whereas there was some impairment at low frequencies. A reduction of 3 db corresponds to a halving of sound energy. Concerning noise, the tested open-graded pavement is certainly better than the presently common dense pavements, but the data also indicate that it is not quite as efficient for noise suppression as an earlier tested open-graded pavement type. Possible ways to optimize noise qualities of open-graded friction courses are discussed. (TRRL)

Sandberg, U *VTI Rapport* Monograph No. 221A, 1981, 16p, 6 Fig., 1 Tab., 3 Phot., 8 Ref.

ACKNOWLEDGMENT: TRRL (IRRD 259130), National Swedish Road & Traffic Research Institute

24 349517

INFLUENCE OF STUD SIZE ON PAVEMENT WEAR AND STUD EFFICIENCY. OBSERVATIONS MADE IN FRANCE AND THE USA [DUBBSTORLEKENS INVERKAN PAA VAEGSLITAGE OCH VAEGGREPP. VAERDERING AV ERFARENHETER I FRANRIKE OCH USA]

One of the most important parts of the French stud regulations concerns stud flange diameter (max 6.5 mm) and stud weight (max 2g). A working group at the National Swedish Road and Traffic Research Institute has studied the investigations which support the new regulations in France are discussed the results with French experts. An investigation at Washington State University, USA, has also been studied. The investigations cover pavement wear (France and USA) and stud efficiency (France only). The pavement wear tests have been carried out in special outdoor machines on circular test tracks with different types of studs on real pavements. The stud efficiency has been studied at comparative braking and concerning tests with different cars and studded tyre equipment on ice tracks. The general conclusion that small flange studs cause less pavement wear than conventional studs must be accepted. However, the rate of wear in relation to increasing flange diameter and stud weight seems to be overestimated. It is not shown in a significant way that the efficiency of light, small flange studs are comparable to the efficiency of conventional studs. (TRRL) [Swedish]

Lidstroem, M Ohlsson, E *VTI Meddelande* Monograph No. 249, 1981, 25p, 14 Ref.

ACKNOWLEDGMENT: TRRL (IRRD 259131), National Swedish Road & Traffic Research Institute

24 349539

FURTHER INVESTIGATIONS INTO THE LOAD-SPREADING OF CONCRETE BLOCK PAVING

Loading tests have been carried out in the laboratory on areas of block paving laid on flexible sub-bases. These tests followed a previous investigation in which the block paving had been laid over a rigid sub-base. In the earlier work, it was concluded that the load-spreading of block paving could result in the level of stress at the sub-base surface being 40 per cent less than the stress applied to the paving, and that the interlock which produced the load-spreading improved with loading. Further tests were considered desirable because it was not known whether the reduction in stress depends upon the type of sub-base and also because flexible rather than rigid sub-bases are often used in practice. Blocks of various shapes and thicknesses were used in the tests, laid on "sub-bases" of various types. The results indicate that the conclusions drawn from the earlier work slightly underestimated the load-spreading that could be achieved with a flexible sub-base. It is considered that the level of stress reduction provided by the pavement could reach 50 per cent. Ancillary tests showed that the horizontal force experienced by an edge restraint, as the result of a vertical force applied to the paving, is low. (Author/TRRL)

Clark, AJ *Cement and Concrete Association Technical Report* No. 545, Sept. 1981, 15p, 8 Fig., 3 Tab., 2 Phot., 5 Ref.

ACKNOWLEDGMENT: TRRL (IRRD 259407)

24 349616

INTERLOCKING CONCRETE BLOCK PAVING SEMINARS

The article summarizes information presented at an August 1981 series of lectures held in Christchurch, Wellington, Auckland and Hamilton. Australian tests carried out on the full scale road simulator of the University of New South Wales are described. More than 20 full sized pavements of block thicknesses between 60 and 160 mm were studied. Investigations were made to determine the effect of block dimensions and laying pattern, the features of bedding sands, sub-base materials and traffic characteristics on pavement performance. The best performance came from units laid in a herringbone pattern and block shape was an important factor in transmitting shear between units. The work led to the publication of an Australian design guide recommending particular types of paving units for various anticipated traffic loadings giving a 20 year life of up to 4.5 million standard axles. Pavement thicknesses relative to the subgrade modulus, minimum sub-base thicknesses and design criteria for block pavements on cement stabilized bases and sub-bases are discussed. (TRRL)

New Zealand Concrete Construction Vol. 25 Oct. 1981, pp 25-30, 5 Fig., 3 Tab., 3 Phot.

ACKNOWLEDGMENT: TRRL (IRRD 259752)

24 349635

MEASUREMENT OF THE "AGGRESSIVITY" OF FREIGHT TRAFFIC ON PAVEMENTS. NARDO EXPERIMENT--REPORT NO 2 [MISURE DELL' "AGGRESSIVITA" DEL TRAFFICO MERCI SULLE PAVIMENTAZIONI, ESPERIMENTO DI NARDO--RAPPORTO N.2]

This article deals with the design of flexible and rigid pavements and the measurement of their resistance to the effects of heavy freight vehicles. Six chapters ideal with: (1) politico-economic considerations regarding road transport and the reasons for the research; (2) premises; (3) the experimental track; (4) methods of developing the experimental data; (5) theoretical-experimental correlation; and (6) illustration of initial experimental results; "aggressivity" of certain configurations. (TRRL) [Italian]

Dellegrini, G *Autostrade* Vol. 23 No. 4, Apr. 1981, pp 3-33, 10 Fig., 7 Tab., 20 Phot.

ACKNOWLEDGMENT: TRRL (IRRD 259788)

24 349780

REFLECTION CRACKING TREATMENTS--ALAMEDA AVENUE

This report describes the construction, testing, and performance of a crumb rubber-asphalt mixture used as a stress absorbing membrane interlayer and also Petromat to control reflection cracking on an urban highway. Test sections included the SAMI, Petromat, and standard overlay. The center portion of this road consisted of previously overlaid concrete pavement while the outside lanes were originally constructed of asphalt pavement with aggregate base. Findings indicate only fair performance in controlling linear cracking on the overlaid concrete and acceptable perforamnce was not obtained from either treatment on the overlaid asphalt areas due to base problems. (FHWA)

Swanson, HN Donnelly, DE LaForce, RF
Colorado Department of Highways, Federal Highway Administration, (CDH-DTP-R-80-11) Final Rpt. FHWA-RD-80-S01206, Oct. 1980,