GENERAL DISCUSSION SECTION

DISCUSSION OF PAPER

on

Employing Paving Asphalt Temperature Susceptibility in the Structural Design of Asphalt Pavements

by N. W. McLeod, Vol. I, 1987

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I. IMPROVING BITUMINOUS PAVEMENT DESIGN AND PERFORMANCE

Since my paper for Session 1 was written more than a year ago, new information on paving asphalt temperature susceptibility has been developed. This new information provides further support for the main theme of my paper for Session 1, that the introduction of meaningful paving asphalt temperature susceptibility requirements into our specifications for paving asphalts would open a whole new world of understanding about the performance, or service behavior, of bituminous paved surfaces and how they should be designed. I would like to enter this new information into the record.

My paper points out that Anderson and Associates at Penn State University (1) indicated in Figure E of my paper, that the PVN value as a measure of a bitumen's temperature susceptibility was the same for the thin-film oven test residue as for each of a large number of original paving bitumens. Similarly, Kandhal and Koehler of PenDOT (2) showed in Table 4 of my paper, that even after seven years of service in six different test pavements, the PVN of each bitumen recovered from samples from the six pavements was very nearly the same as the PVN of the corresponding original bitumen. These six bitumens represented the complete range of bitumen temperature susceptibility, Groups A, B and C, Figure 2. In 1986, I had one of our sales engineers pick up at nine different locations throughout Ontario, samples of the bitumen being fed into the pug mill of the hot-mix plant, and samples of the paving mixture being discharged. By running the penetration test at 25C and the viscosity test at 135C on the original bitumen, on its thin-film oven test residue and on the bitumen recovered from the paving mixture sample, the corresponding PVN values could be obtained for each of the nine locations at which this sampling was done. The results are shown in Table 1. It is obvious that the three PVN values are approximately the same at each of the nine hot-mix plant sites for all three test conditions. Furthermore, each of the original bitumens satisfied Ontario's paving asphalt specifications, which in effect require a minimum PVN value of -0.8.

A paper by Professor Haas of the University of Waterloo and Associates (3), was presented at the annual meeting of The Association of Asphalt Paving Technologists in February 1987, on the results of a pavement investigation at 26 Canadian airports spread across Canada, with some of these pavements being more than 30 years old, Figure 1. Professor Haas found that the PVN values for the bitumens recovered from these pavement samples, had remained essentially unchanged in service. Consequently, these four completely independent investigations show that PVN as a measure of a paving bitumen's temperature susceptibility is a finger print that remains substantially unchanged throughout a pavement's service life. It should be noted that this information has been largely provided by the pavements themselves, and could not have been derived from laboratory studies alone.

This happens because the hardening of a bitumen in pavement service is an entirely different phenomenon than occurs from blowing air for several hours through a soft bitumen that has been heated to about 500F (260C), to produce roofing asphalt with its higher softening point or higher viscosity at 135C for any given penetration at 25C. The PVN is substantially constant throughout a pavement's service life, because the gradual hardening of the bituminous binder does not result in a Group C bitumen oxidizing to a Group B bitumen, or a Group B bitumen oxidizing to a Groups A bitumen, etc., Figure 2, as would be expected if the hardening of a bitumen in a pavement in service were due to the oxidation phenomenon that produces roofing asphalts.

Anyone who doubts this can very easily investigate it for himself by going to several hot-mix plants in his vicinity, and obtaining samples of the bitumen going into the hot-mix plant, and of the paving mixture being discharged. PVN values can be obtained by running the penetration at 25C and the viscosity in centistokes at 135C on the original bitumen, on its thin-film oven test residue, and on the bitumen recovered from the paving mixture sample that was taken from each hot-mix plant. My experience indicates that the three PVN values in each case will be very nearly the same.

Figure 2, which should be part of every paving asphalt specification, provides a clear visual chart on which penetration at 25C, and the corresponding viscosity at 135C for any paving asphalt in the world can be plotted as any coordinates of a point. One can see at a glance how any particular asphalt compares with all other paving asphalts. It will fall into one of three groups of temperature susceptibility, Group A, low temperature susceptibility, Group B, medium temperature susceptibility, or Group C, high temperatures susceptibility. Furthermore, Figure 2 also shows immediately whether the paving asphalt being assessed should be used for heavy traffic, low temperature susceptibility (Group A), for medium traffic, medium temperature susceptibility (Group B), or for light traffic, high temperature susceptibility (Group C).

Claims are sometimes made that a temperature susceptibility requirement in a paving bitumen specification, would exclude bitumens of known good pavement performance. It should be crystal clear that no paving bitumen would be excluded by Figure 2.

As a result of the finger print effect, the arrows in Figure 2 indicate that even after many years of pavement service, an original Group A bitumen will remain essentially as Group A, an original Group B bitumen will remain essentially as Group B, and an original Group C bitumen will remain essentially as Group C. The double heads on the arrows in Figure 2 indicate for a bitumen recovered from a old pavement, the direction in which it has hardened in service, and what its original penetration at 25C may have been.

Figure H of my paper for Session 1 shows that out of some 200 samples of paving bitumen from the U.S.A. and Canada (very few), for which inspection data were obtained by Halstead, Welborn and Boone of the U.S. Bureau of Public Roads, and published in Public Roads magazine in 1959 and 1960, about 50 percent of the samples were in Group A, about 25 percent in Group B, with the other 25 percent being divided between Group C and Group AA. Judging by Canadian experience, if this investigation were repeated at the present time, there would probably be a noticeable shift downward in the data, with less in Group A and more in Groups B and C.

Figures 5 and 7 of my paper for Session 1 guide the selection of the original bitumen for any cold weather paving site. Figure 5 indicates the combinations of original penetrations at 25C and viscosities at 135C that should be selected to avoid low temperature transverse pavement cracking throughout the service lives of pavements at sites with a variety of low winter pavement temperatures. Figure 7 furnishes an example of the selection of these original combinations of penetrations at 25C and viscosities at 135C to provide bitumens for one of these low winter temperatures, -23.3C (-10F). Figure 7 also indicates how these combinations of penetration and viscosity should be selected for heavy, medium and light traffic categories.

The data illustrated in Figure 9 of my paper for Session 1 demonstrates how engineers can take advantage of the increase in temperature with depth below the surface of a pavement on the coldest day of the year, and the decrease in temperature with depth below the surface of the pavement on the hottest day of the year, to employ bitumens of medium and high temperature susceptibilities for bituminous binder and base courses in regions where bitumens of low temperature susceptibility that should be reserved for the surface course, are scarce.

II. PENETRATION OF PAVEMENT RUTTING

The incorporation of meaningful temperature susceptibility requirements into paving asphalt specifications would improve our understanding of pavement rutting and its prevention.

Asphalt pavement rutting under traffic in warm weather has become a serious problem world wide. Pavement rutting depends partly on the aggregate in a paving mixture, but the properties of the bituminous binder that has been used are also important.

Bitumens exhibit two quite different properties, elastic and viscous, depending upon pavement temperature and time of loading by traffic. Under very fast loading, a point on a pavement is exposed to a time of loading of about 0.01 second by a wheel of a heavy truck traveling at 100 km/hour (60 miles/hour). Under this fast loading, even at summer temperatures, the bituminous binder approaches purely elastic behavior (obeying Hooke's Law). That is, the pavement structure deflect momentarily under the load applied, but rebounds to, or approximately to, its original level when the wheel has passed.

Under much slower or stationary traffic, as in a parking area, the viscous property of the bitumen becomes important, and because of viscous flow under load, the pavement tends to deform or rut under load.

Consequently, to eliminate or greatly reduce pavement rutting, when it is occurring, the viscosity of the bitumen should be increased. This means the substitution of a bitumen of higher viscosity at 135C. When this is not available, as shown by the small circles in Figure 10 of may paper in Session 1, or in Figure 3 of this discussion, the addition of a small percentage of a suitable polymer can increase the viscosity of the bitumen several times, and thereby greatly increases the resistance of a pavement to rutting.

In Figures 10 and 3, the lowest circles indicate the viscosity of a normal bitumen, while the higher circles illustrate the increase in bitumen viscosity that can be provided by the incorporation of small percentages of an appropriate polymer.

III. PAVEMENT STABILITY IN HOT CLIMATES WITHOUT FROST

Figure 3 of my paper for Session 1 and Figure 4 of this discussion pertain to the selection of bitumens for pavements in hot climates without frost. To maintain the same pavement stability regardless of the temperature susceptibility of the bitumen employed, both Figures 3 and 4 demonstrate that as the temperature susceptibility of the bitumen increases, the penetration of the bitumen at 25C must be decreased in order to maintain a constant pavement stability (modulus of stiffness).

In this regard, this section of my paper for Session 1 should have continued with the following example of this:

(a) 80/100 penetration at 25C, if its PVN = 0.0

(b) 70/86 penetration at 25C, if its PVN = 0.5

(c) 60/76 penetration at 25C, if its PVN = - 1.0

(d) 50/65 penetration at 25C, if its PVN = - 1.5

While the solution just described would take care of the problem of providing constant pavement stability, it does not eliminate or greatly reduce any pavement rutting that may be occurring, and the bitumens with lower penetrations at 25C might even increase rutting.

It was pointed out earlier that bitumen has two properties, elastic and viscous. It is the viscous property that is responsible for rutting. Therefore, insofar as the bituminous binder is responsible for rutting, the viscosity of the bitumen should be increased. As shown by the small circles in Figure 10 of my paper for Session 1 and by Figure 4 of this discussion, the addition of small percentages of a suitable polymer can increase the viscosity of a bitumen several times and thereby eliminate or greatly reduce pavement rutting.

At the same time, incidentally, as indicated by Figure 4, the pavement stability (modulus of stiffness) can also be substantially increased by incorporating a small amount of an appropriate polymer.

IV. PAVEMENT RECYCLING

Avoidance of low temperature transverse pavement cracking in cold climates is as important after pavement recycling as it should have been for the original pavement. Suitable guidelines to achieve this do not appear to be available at the present time. However, recognition of the importance of the temperature susceptibility of bitumens offers a promising approach to this problem, as illustrated by Figure 5.

The background for Figure 5 of this discussion is Figure 5 of may paper in Session 1, which illustrates the selection of original bitumens for paving mixtures to avoid low temperature transverse pavement cracking throughout a pavement's service life. For Figure 5 of this discussion, it is assumed that the minimum winter pavement temperature at Location 1 in some given area is -28.9C (-20F). Location 1 is the site of the proposed recycling project because the existing pavement shows serious low temperature transverse pavement cracking and other evidence of severe pavement distress.

Ordinarily, everyone will have forgotten what the characteristics of the original bituminous binder were when the badly cracked pavement at Location 1 was constructed many years ago, which upon extraction is found to have a penetration of 20 to 25C and a viscosity at 135C of 820 centistokes (PVN = -0.9). This indicates that the bituminous binder in this pavement is of medium temperature susceptibility, or in the Group B category, Figure 2.

It is assumed that the recycled pavement will carry much more traffic and that it is to be designed for the heavy traffic category in Figures 2 and 5. For the middle of the heavy traffic band (PVN = -0.25), and for a minimum winter temperature of -28.9C (-20F), Figure 5 indicates that this would require a bitumen of 180 penetration at 25C and a viscosity at 135C of 250 centistokes (PVN = -0.25), and would be in the Group A heavy traffic category (Point 2). This would be provided by Treatment A (Line 2), consisting of a single or a combination of softening agents that would change the bitumen penetration from 20 at 25C, and a viscosity of 820 centistokes at 135C (PVN = -0.9) in the old pavement, to a penetration of 180 at 25C and a viscosity of 250 centistokes at 135C (PVN = -0.25), in the recycled paving mixture. A large assortment of softening agents, including soft asphalts and commercial modifiers is available to the designer for this purpose.

After this treatment, according to the finger print effect, the bituminous binder in the recycled pavement would slowly harden in service as indicated by Line 3 in the heavy traffic category of Figure 5.

However, the engineer responsible for the recycled pavement project might decide that Treatment A resulting in an asphalt binder of 180 penetration at 25C and a viscosity of 250 centistokes at 135C (PVN = -0.25), might not have the required minimum stability at summer temperatures for the anticipated heavier traffic. He might therefore, favor Treatment B, for example, for the recycled pavement, to provide a bitumen with a penetration at 25C of 120 and a viscosity at 135C of 575 centistokes (PVN = + 0.5), Point 4. This would also avoid low temperature transverse pavement cracking at 28.9C (-20F) throughout the recycled pavement's service life, it if were properly designed and constructed.

It could be difficult to locate a normal combination softening agents that could change the penetration of 20 at 25C for the bitumen in the old pavement to 120 penetration at 25C in the new, and at the same time increase the bitumen's PVN from -0.9 to +0.5, because a PVN of +0.5 is outside of the range of PVN for nearly all bitumens used for paving. However, a PVN of +0.5 could be easily obtained by the addition of a small percentage of a suitable polymer (4).

Following Treatment B, and in accordance with the finger print effect, the bitumen in the recycled paving mixture could be expected to gradually harden in service along Line 5 within the heavy traffic category of Figure 5.

A similar method would be required for pavement recycling for other minimum winter pavement temperatures illustrated in Figure 5.

Figure 6 indicates a similar approach to the design of recycled paving mixtures for a given region that is free from frost (4). For the bitumen recovered from an old pavement, by determining its penetration at 25C and its viscosity at 135C, and plotting these data as a point on Figure 6, the temperature susceptibility (Group A, B or C) to which the bitumen in the old pavement belongs, can be quickly established. The background for Figure 6 is that of Figure 2 of this discussion.

Support for example, the recovered bitumen has a penetration of 20 at 25C, and that its viscosity at 135° C puts it into the Group B (PVN = -0.5 to -1.0) category, which is suitable for medium traffic, Point 1. Because of the anticipated increased traffic on this old pavement, the engineer has decided to design the recycled pavement for the heavy traffic category for which a Group A bitumen is required, for example, 120 penetration at 25C and a viscosity of 360 centistokes at 135C (PVN = -0.2). By adding an appropriate softening agent, or group of softening agents, (Treatment A) the old bitumen of 20 penetration and Group B can be softened to a Group A bitumen of 120 penetration and a viscosity of 360 centistokes at 135C (PVN = 0.2) as shown by Point 2 on Figure 6. After reconstruction, the bitumen in the recycled pavement will remain in Group A and will harden in service along Line 3, if it conforms to the finger print principle.

However, after further consideration, the engineer may decide he requires a harder bitumen of 85 penetration with a still lower temperature susceptibility, for example, a viscosity of 660 centistokes at 135C (PVN = +0.3), for the recycled paving mixture to carry the anticipated heavier traffic loading. In this case, starting with the recovered bitumen of 20 penetration at 25C from the old pavement, and incorporating the softening material or materials indicated by Treatment B, he may soften the 20 penetration bitumen in the old pavement to a penetration of 85 at 25C and a viscosity of 660 centistokes at 135C (PVN = +0.3), Point 4 in Figure 6. However, because a PVN of +0.3 is higher than normal paving bitumens or other usual softening agents can provide, he may have to incorporate a small percentage of an appropriate polymer to achieve a PVN of +0.3. This may also be necessary for Treatment A. After Treatment B, the bitumen in the recycled paving mixture can be expected to harden in service along Line 5 due to the finger print effect (4).

Because of the addition of the required softening materials, the bitumen content of a 100 percent recycled paving mixture would ordinarily be too high for adequate stability and resistance to rutting, and the incorportions of new aggregate would usually be necessary. In this case, the proportion of old pavement in the recycled mixture would have to be reduced. This, however, could have the advantage that the new aggregate incorporated could correct any deficiency in the gradation of the old pavement to be recycled.

For cold mix recycling, Treatment A or B, etc., could be applied in the form of an emulsion.

Figure 7 indicates that about six months time is ordinarily required for a bituminous emulsion to thoroughly cure and to develop the pavement stability that its base bitumen would provide if it were used in a hot paving mixture (5, 6). Figure 8 provides data on cured Types I, II and III emulsified asphalt paving mixtures made with increasingly inferior aggregates. The stabilities of these fully cured bituminous emulsion mixes are shown to compare favorably with corresponding hot mixes (5, 6).

Because of the time required to complete the fluxing action between the old bitumen in the pavement to be recycled and the softening agent that has been applied, the time to cure in cold recycling will probably be longer than is indicated by Figures 7 and 8. This will also probably be true for hot-mix recycling.

V. GENERAL COMMENTS

1. During the Conference, a comment was made with respect to Figure D in my paper for Session 1, that requires a reply.

Figure D shows the gradual increase over a period of more than 20 years, in the number of Type 1 low temperature transverse pavement cracks per lane mile that developed in three pavement test sections, each two miles in length. This is one of three Test Roads that Ontario constructed for triplicate test pavements in 1960. All three Test Roads provided the same results. The bitumens used in the three pavement test sections in each Test Road was 85/100 penetration but of a different temperature susceptibility in each test section, a PVN of -0.23 in one test section, a PVN of -0.41 in another test section, and a PVN of -1.35 in the third test section. The average minimum winter pavement temperature during this period was very nearly -20C.

Figure D shows that while there was a big difference in the number of Type 1 low temperature transverse pavement cracks per lane mile in the early life of the test sections, after 20 years the number of these cracks in the three test sections was approximately the same. The same pattern of low temperature transverse pavement cracking was replicated in all three Test Roads.

The comment that was made on Figure D during the Conference, was that after a long period of service (20 years), there was practically no difference in the number of Type 1 low temperature transverse pavement cracks per lane mile that had developed in the three pavement test sections made with 85/100 penetration bitumen with different temperature susceptibilities. Therefore, it was concluded, there would be no advantage in adding temperature susceptibility requirements to paving asphalt specifications.

This observation is probably a natural conclusion to draw from a first glance at Figure D. However, it is also open to another interpretation when it is realized that the real objective is no low temperature transverse pavement cracks after 20 years of pavement service, which is given as a best estimate by Figures 5 and 6 of my paper.

Consequently, my own interpretation of Figure D is that regardless of temperature susceptibility, 85/100 penetration bitumen was too hard a grade to have been selected, because even 85/100 penetration of the lowest temperature susceptibility began to develop Type 1 low temperature transverse pavement cracks after about only 7 or 8 years.

According to Figures 5 and 6 of my paper in Session 1, the grades of bitumen that could have been selected for the test pavements, that would have served without cracks for 20 years at a minimum winter pavement temperature of -20C, depends on the temperature susceptibility of the bitumen - the higher the temperature susceptibility, the higher the penetration at 25C that should have been selected as follows:

Low temperature susceptibility, Group A, PVN from 0.0 to -0.5

Corresponding penetration at 25C = 165 to 220
Corresponding viscosity cs at 135C = 310 to 187

Medium temperatures susceptibility, Group B, PVN from -0.5 to -1.0

Corresponding penetration at 25C = 220 to 280
Corresponding viscosity cs at 135C = 187 to 121

High temperature susceptibility, Group C, PVN from -1.0 to -1.5

Corresponding penetration at 25C = 280 to 345
Corresponding viscosity cs at 135C = 121 - 82

When observed from this view point, it is clear that temperature susceptibility requirements are urgently needed in paving bitumen specifications.

2. Figures 5 and 7 in may paper in Session 1 illustrate the need for significant temperature susceptibility requirements in paving asphalt specifications. With this continued absence from ASTM, AASHTO and most other national specifications, bitumens for heavy, medium and light traffic are considered equal, although pavement performance in the field demonstrates that they are quite unequal. Also differences in temperature susceptibility are completely over looked and disregarded, so that bitumens that develop numerous low temperature transverse pavement cracks are used indiscriminately in the same paving projects or in nearby projects with bitumens that are free from thermal cracking.

In the absence of these meaningful temperature susceptibility requirements in paving asphalt specifications, many millions of dollars are being spent each year filling cracks that should never have developed, in addition to the annual loss of other millions of dollars because of shortened pavement service lives.

VI. WARNING! DANGER!!

Paving mixtures that have been designed to avoid low temperature transverse pavement cracking should never be constructed on a badly cracked asphalt or portland cement pavement. The cracks will inevitably reflect through.

To obtain the most useful service from pavements that have been designed to avoid low temperature transverse pavement cracking, they should be placed on a well designed and properly constructed granular base course.

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Table 1

Comparis of PI (Pen/Pen) and PVN Values for Original Paving Asphalts, Their Thin-Film Oven Test Residues, and Recovery After Discharge from a Hot-Mix Plant.

ORIGINAL ASPHALT		PI PEN/PEN (HEUKELOM)			PVN		
NO	PEN	ORIGINAL	THIN FILM RESIDUE	PUGMILL DISCHARGE	ORIGINAL	THIN FILM RESIDUE	PUGMILL DISCHARGE
1	85/100	-2.86	-2.33	-1.81	-0.61	-0.67	-0.56
2	85/100	-1.63	-2.06	-2.00	-0.67	-0.69	-0.69
3	85/100	-2.73	-1.64	-2.18	-0.70	-0.68	-0.67
4	150/200	-1.73	-1.16	-0.65	-0.59	-0.67	-0.64
5	85/100	-1.98	-2.38	-0.81	-0.67	-0.69	-0.56
6	85/100	-1.23	-1.06	-0.84	-0.77	-0.64	-0.49
7	85/100	-0.94	-0.21	-0.80	-0.47	-0.41	-0.36
8	85/100	-1.11	-2.88	-1.93	-0.55	-0.56	-0.47
9	85/100	-1.24	-1.49	-1.92	-0.53	-0.52	-0.34

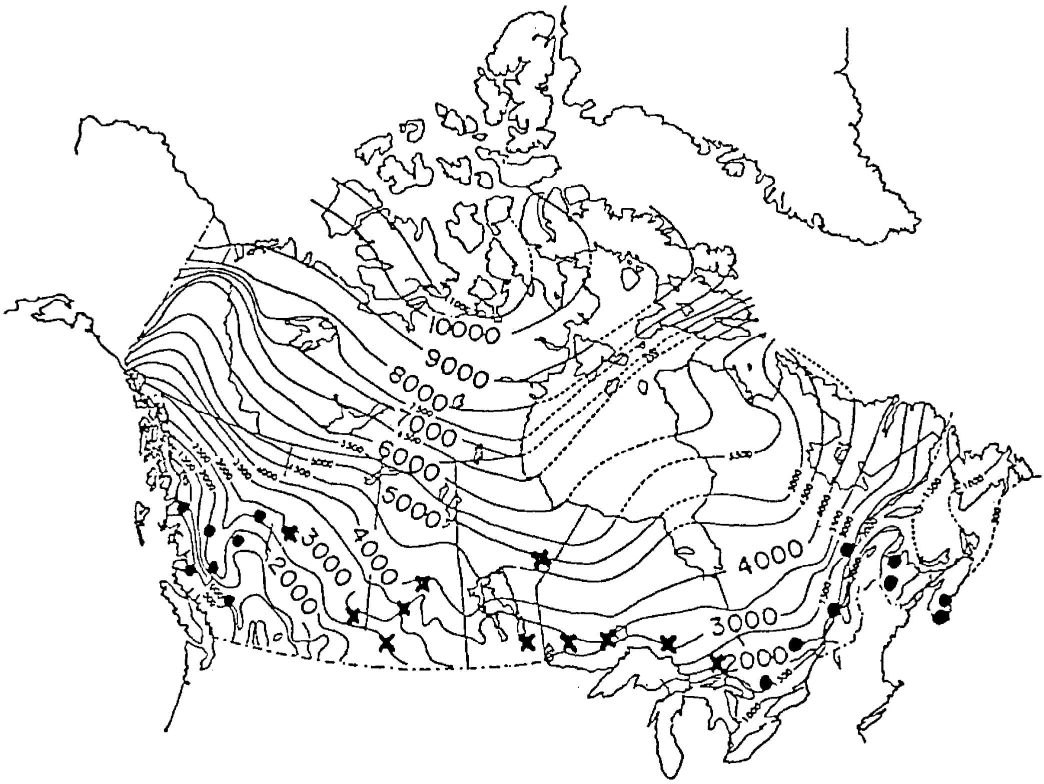

Figure 1 Approximate locations of the 26 airports (where x's indicate interior airports and o's indicate coastally associated airports). Freezing index countours are in $^{\circ}F$ days. (with credit to Ralph Haas)

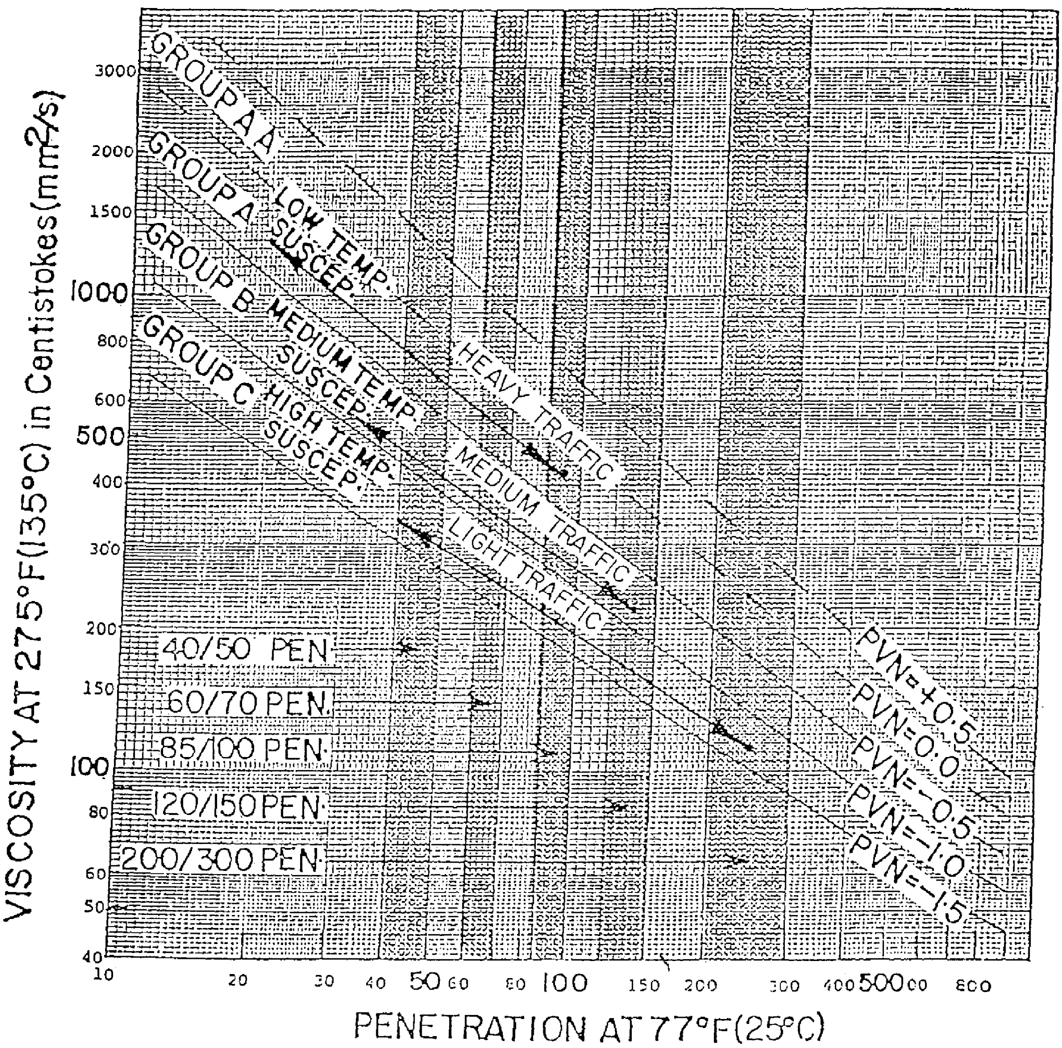

Figure 2 ILLUSTRATING A SPECIFICATION BASED ON PENETRATIONS AT 77°F (25°C), VISCOSITIES AT 275°F (135°C), AND TEMPERATURE SUSCEPTIBILITIES OF PAVING ASPHALTS.

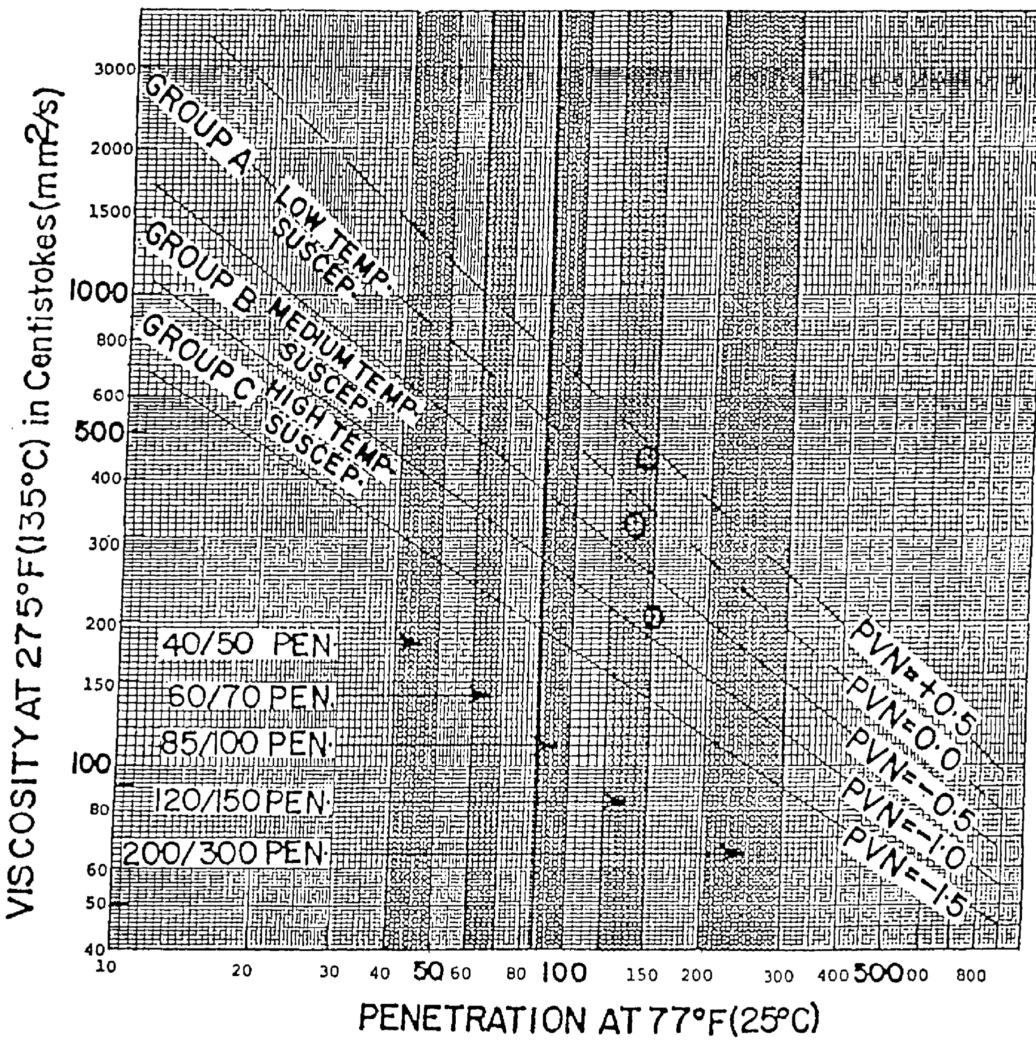

Figure 3 INFLUENCE OF A POLYMER ON THE TEMPERATURE SUSCEPTIBILITY OF A PAVING ASPHALT.

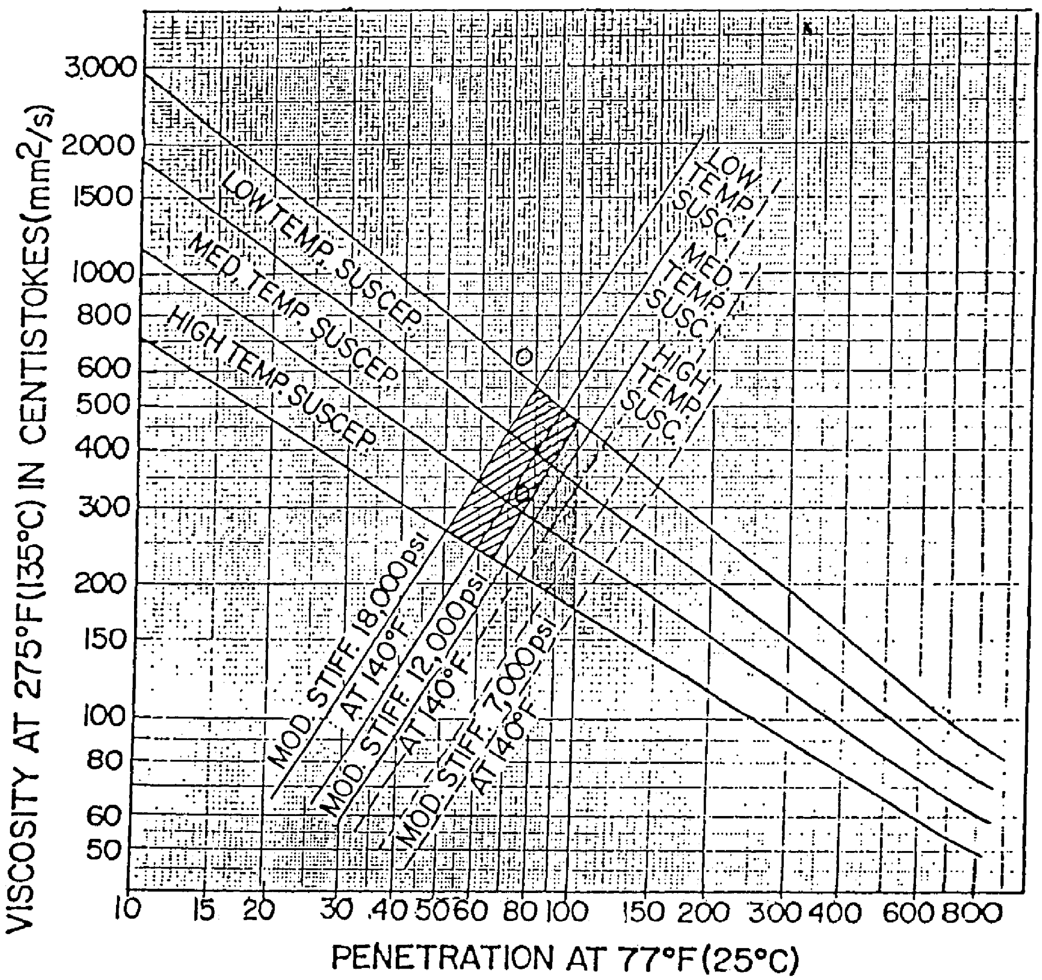

FIGURE 4 ILLUSTRATING HOW PAVING ASPHALT TEMPERATURE SUSCEPTIBILITY CAN BE MADE TO WORK FOR OR AGAINST ENGINEERS IN WARM CLIMATES.

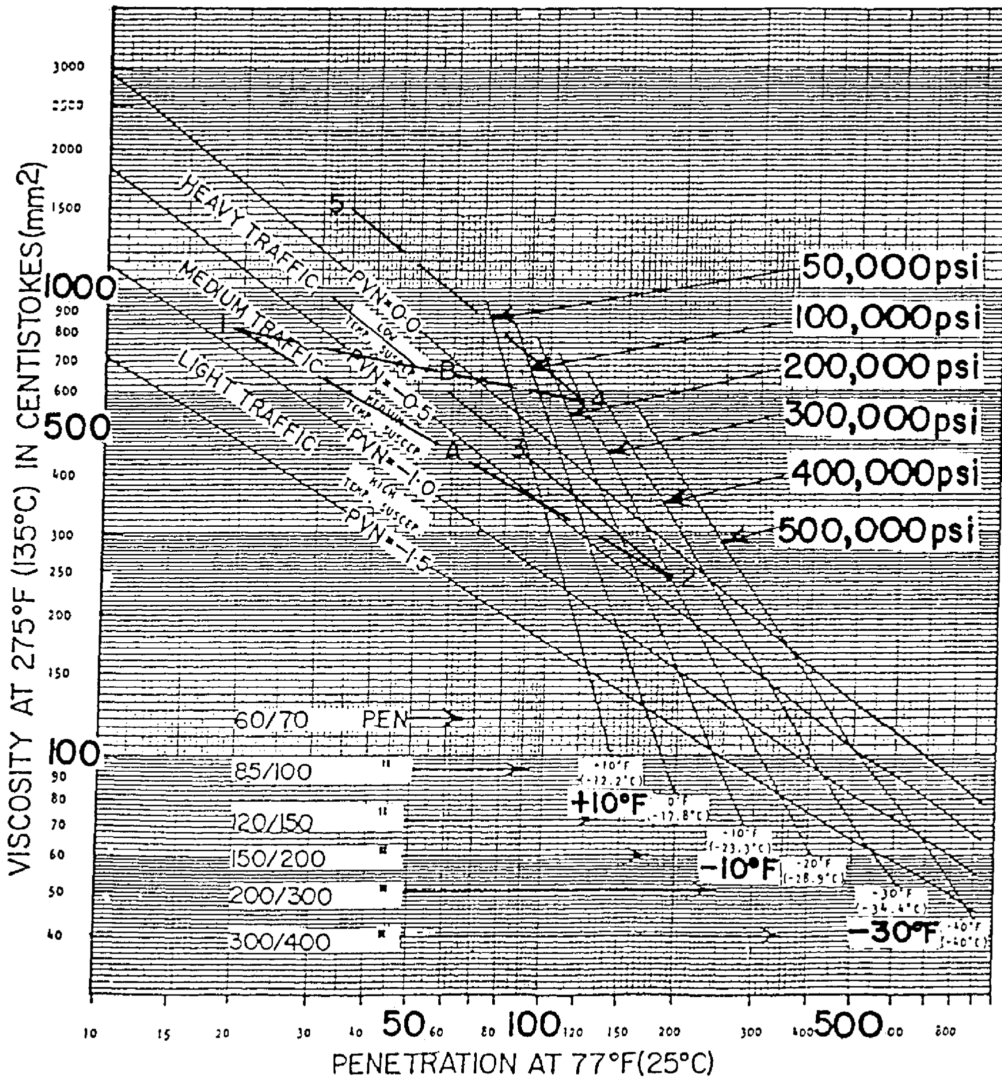

Fig.5 Chart to Guide the Design of Recycled Asphalt Pavements in Cold Areas with Frost

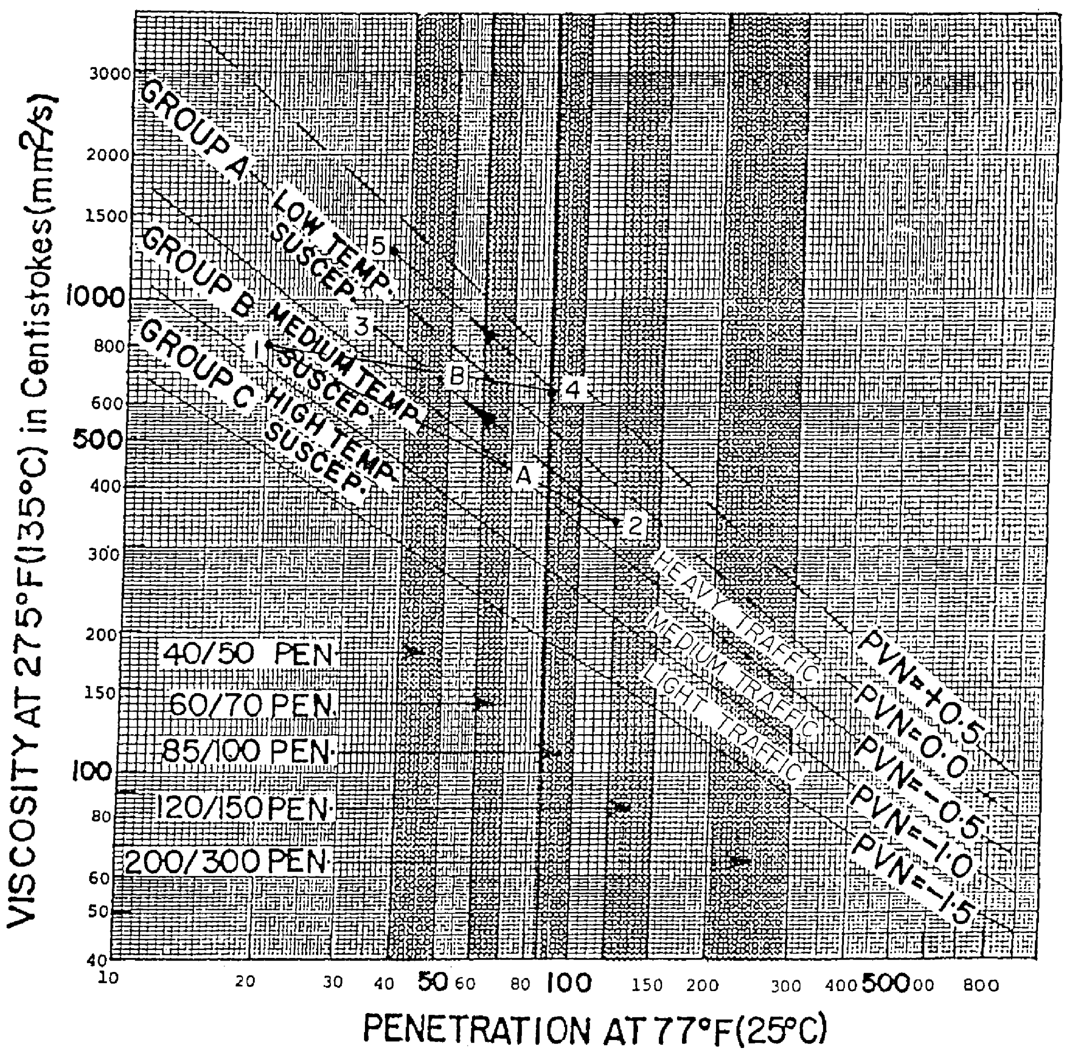

Figure 6 Chart to Guide the Design of Recycled Asphalt Pavements in Regions Without Frost

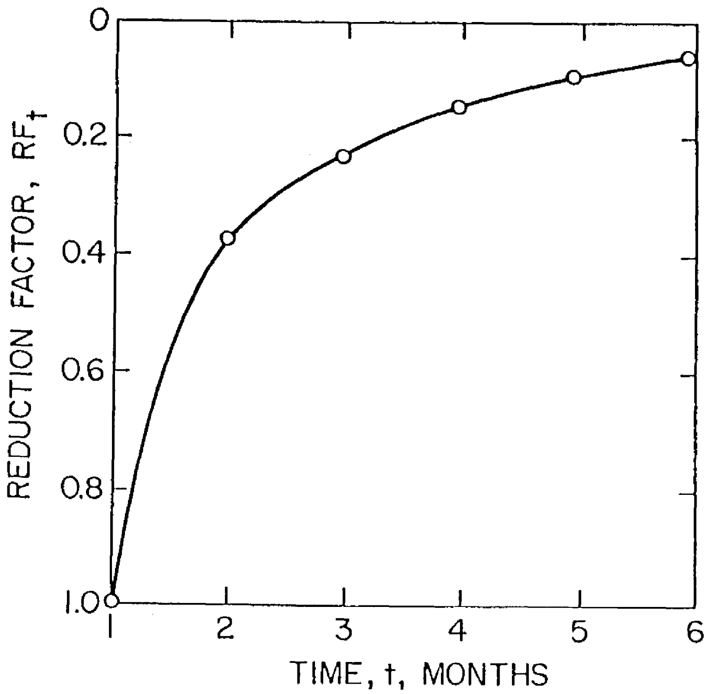

FIGURE 7. DEMONSTRATING THAT A CURING PERILD OF ABOUT SIX MONTHS IS REQUIRED FOR AN ASPHALT EMULSION MIX TO DEVELOP ITS FULL STRENGTH.

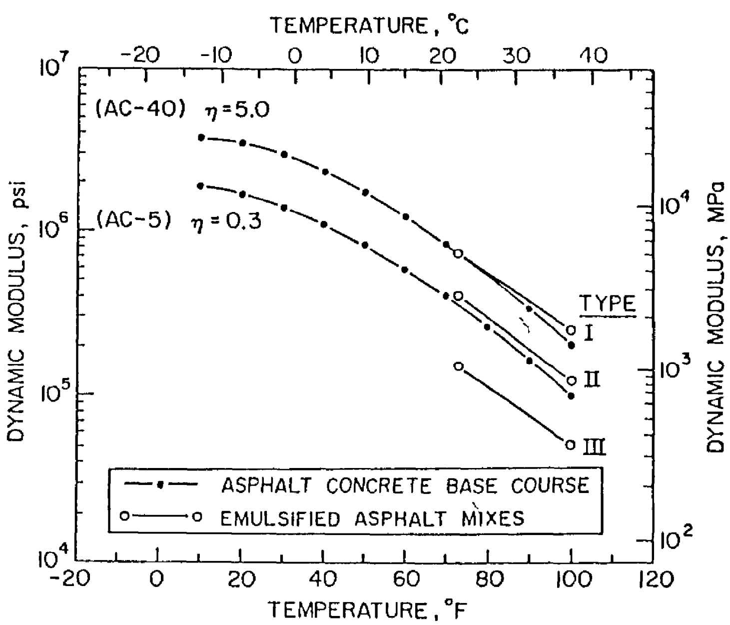

FIGURE 8 DEMONSTRATING THAT DEPENDING ON ITS TYPE (I, II, OR III) AN ASPHALT EMULSION MIX EVENTUALLY DEVELOPS STRENGTH EQUIVALENT TO THAT OF A CORRESPONDING HOT-MIX.

File: 06110 – CORRECTIONS

Errata:

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