RELATIONSHIP BETWEEN PAVEMENT STRUCTURAL INTEGRITY

AND HARDNESS OF THE ASPHALT CEMENT

Norman W. McLeod*

Abstract

In colder climates, it is of questionable value to concentrate a great expenditure of effort on the design of a conventional, deep strength, or full depth asphalt pavement structure, if the integrity of the structure is to be impaired or destroyed by low temperature transverse pavement cracking. Several years of research on the problem of low temperature transverse pavement cracking in Canada, where this is currently the most serious pavement performance problem, have indicated that it can be most easily and inexpensively remedied by using softer grades of asphalt cement. Field and theoretical evidence are presented to support this conclusion. Finally, to bridge the gap between research and practice, a chart is provided to enable an engineer to select a grade of asphalt cement that will preserve the integrity of an asphalt pavement structure by avoiding low temperature transverse pavement cracking throughout the pavement's service life, provided the asphalt pavement has been properly designed and constructed.

INTRODUCTION

Figures 1, 2, and 3 illustrate how low temperature transverse pavement cracking influences the structural integrity of an asphalt pavement.

Transverse pavement cracks may originate in the subgrade and extend through the superimposed pavement structure. These cracks result from freezing or from shrinkage due to loss of moisture from the subgrade, and occur at intervals normally ranging from about 50 feet to several hundred feet. However, transverse cracks also originate in the pavement itself as a result of contraction stresses in the pavement caused by low cold weather temperatures. These latter transverse cracks are usually confined to the asphalt pavement layer, and they may occur at spacings as frequently as five feet apart. Because they are normally much more numerous, it is the second of these two types of transverse pavement cracks with which this paper is concerned.

Figure 1 provides a typical example of low temperature transverse pavement cracking that is confined to the asphalt pavement itself. The transverse cracks in this case occur at intervals of from 10 to 15 feet.

Low temperature transverse pavement cracks are of four basic types. Type 1 cracks extend completely across a traffic lane. Type 2 cracks begin at the shoulder and cross the traffic lane only part way. Type 3 cracks begin at the inside boundary (longitudinal joint) of a traffic lane but also cross the traffic lane only part way. Type 4 cracks occur in the central portion of a lane but do not extend to either lane boundary.

All four types of cracks ordinally occur in any pavement in which low temperature transverse cracking has become serious. However, best correlation has been found between the number of Type 1 transverse cracks per mile or other unit of length and characteristics of the asphalt cement or of the paving mixture.

As illustrated in the lower right corner of Figure 1, the initial transverse crack is frequently succeeded by the development of an additional parallel crack on each side of the original crack, and spaced several inches from it. The pavement between these parallel cracks may then gradually break into smaller pieces.

Sometimes these transverse cracks have little or no influence on a pavement's smoothness of ride. Even in this case however, no engineer can be very proud of a badly cracked pavement, or of the poor paving mixture design practice that is responsible for it.

On the other hand, as illustrated in Figure 3, dangerous bumps can follow the development of transverse cracks in asphalt pavements over subgrades that contain montmorillonite clay, which is subject to substantial volume changes with increase or decrease of moisture content. After the formation of a transverse crack, water enters, makes its way into the subgrade below, and causes it to swell. This results in a bump in the surface up to an inch or more in height, and extending out to from 9 to 12 inches from each side of the crack. These bumps in turn cause the pavement to be very rough riding, and they are very hazardous to high speed traffic.

It should be apparent therefore, that low temperature transverse pavement cracks impair the integrity of the asphalt pavement structure, which in turn results in excessive maintenance for crack filling, and a much shorter pavement service life.

In recent years, the occurrence of low temperature transverse pavement cracking has been such a serious asphalt pavement performance problem in Canada, that it has been receiving a great deal of attention from several investigators (1, 2, 3, 4, 5, 6, 7, 8). This problem has been investigated intensively by the writer during the past seven

*Vice President and Asphalt Consultant, McAsphalt Engineering Services, Toronto, Ontario, Canada

years (9, 10, 11, 12, 13, 14, and 15). He has concluded that the most practical and least costly solution to this problem is the use of softer grades of asphalt cement, and he has developed a chart, Figure 12, to guide the selection of asphalt cements that should avoid, or at least drammatically reduce, low temperature transverse pavement cracking.

Consequently, with respect to the theme for this Conference, Figure 12 represents the bridge between the research that has gone into this problem of preserving asphalt pavement structural integrity in cold climates, and a practical solution to this problem.

The field and theoretical evidence supporting this simple and inexpensive solution to this very serious problem, will be briefly reviewed.

1. <u>Supporting Evidence from the Field</u>

Evidence from the field supporting the conclusion that low temperature transverse pavement cracking can be reduced or eliminated, and the structural integrity of an asphalt pavement thereby preserved, through the use of softer asphalt cements, can be briefly summarized as follows:

1. The history of asphalt useage in Canada since 1930 indicates the need for softer asphalt cements to avoid low temperature transverse pavement cracking. In the early 1930's, thousands of miles of roads were paved with asphalt road mixes in which the asphalt binder was SC 250 (SC 2) or equivalent. As these pavements were gradually reconstructed with stronger and stronger bases, liquid asphalt grades of higher and higher viscosity, SC 800 (SC 3 and SC 4) and SC 3000 (SC 5), were used, and immediately after World War II the SC 6 grade (300/400 penetration) was widely employed. During this period, transverse pavement cracking was not a problem.

   In 1949, the Canadian Government offered to pay one-half the cost of a Trans-Canada Highway, and the Trans-Canada Highway Act was passed for this purpose. In Canada, providing highways is the responsibility of the provinces. Since the standards agreed to for the Trans-Canada Highway were higher than most of the provinces had been using, it was agreed that a harder grade of asphalt cement should be employed for the asphalt pavement. Consequently, 150/200 penetration asphalt was adopted in Western Canada, and the Maritime Provinces along the Atlantic seaboard, while both 85/100 and 150/200 penetration were used in Ontario and Quebec. Shortly after these harder grades of asphalt cement were adopted, transverse pavement cracking became a very serious pavement performance problem.

2. During a trip to Denmark and Norway in 1966, the writer was driven over about 600 miles of highway in the vicinity and west of Oslo, which is at latitude 61°N. The absence of transverse pavement cracking was so noticeable that enquiries were made about the grade of asphalt cement being used. It was 300 penetration, which is a soft grade of asphalt cement.

3. For the past 35 years, the Province of Alberta has used a mixed prime for the surface of the granular base before a hot mix pavement is laid. For the mixed prime, MC 250 (MC 2) or MC 800 (MC 3) is mixed into the top 2 or 3 inches of the gravel base. Because the asphalt binder is MC 2 or MC 3, the primed surface often serves as a wearing course for from 2 to 4 years before a hot mix pavement is laid over it. Transverse pavement cracking does not develop in this primed base with its soft liquid asphalt binder, but it becomes a serious problem soon after a hot mix pavement containing 150/200 penetration asphalt is placed over it.

4. At first when 85/100 penetration asphalt pavements are laid in southern Ontario, there is little or no transverse pavement cracking. However, this can become a serious problem after several years. Asphalt cements in pavement service becomes harder year by year. Consequently, after a number of years the asphalt cement in these pavements has hardened to such a degree that the pavement is no longer able to adjust to the low temperature contraction stresses to which it is subjected in cold weather, and it cracks transversely.

5. Observation of several thousand miles of asphalt pavement in Canada, the United States, and elsewhere in the world, has indicated that low temperature transverse pavement cracking tends to be more severe when harder grades of asphalt cement are used, and this is particularly true when the various grades of asphalt cement are made from any given crude oil. For example, a Test Road 9-miles long was paved in southern Ontario in 1961. All conditions for this pavement were identical except that for several miles 85/100 penetration asphalt cement was used as asphalt binder, while 150/200 penetration asphalt cement from the same crude oil was used for the balance of the pavement. Figure 1 shows the large number of transverse cracks that had developed in the 85/100 penetration pavement after just four years--more than 400 Type 1 transverse cracks per mile. Figure 4 is a picture of a typical section of the pavement made with 150/200 penetration asphalt cement taken at the same time. There are no Type 1, 2, 3, or 4 transverse cracks. Figure 5 is a picture of a 1700-foot section where 85/100 penetration pavement is laid in the right lane and 150/200 penetration pavement in the left lane. There are no transverse cracks in the 150/200 penetration pavement, but more than 400 Type 1 cracks per mile in the 85/100 penetration pavement.

6. Results from the Ste. Anne Test Road, a cooperative research project between the Manitoba Department of Highways and Shell Canada Limited, have clearly indicated the advantages from using softer asphalt cements to reduce and even to eliminate low temperature transverse pavement cracking (6,8).

Each of these six items of evidence from the field indicate that low temperature transverse pavement cracking, and the corresponding loss of structural integrity of asphalt pavements, is associated with the use of harder grades of asphalt cement, and that it is most practically and inexpensively avoided by using softer grades of asphalt cement.

2. Supporting Theoretical Evidence

The previous section of this paper provides evidence from the field that the use of softer asphalt cements can drastically reduce or eliminate low temperature transverse pavement cracking, and preserve the structural integrity of an asphalt pavement. We turn now to theoretical evidence that supports this conclusion.

1. In three papers published in AAPT Proceedings in the 1930's, Rader (16, 17, 18) concluded from his investigation of actual pavement samples in the laboratory, that if pavement cracking at low temperatures is to be avoided, pavements should have a low modulus of stiffness. He stated that this could be easily achieved by using softer asphalt cements.

2. In a prepared discussion in the 1966 AAPT Proceedings, Hills and Brien (19) concluded from theoretical and laboratory studies that the temperature at which pavement cracking is to be expected due to low temperature stresses, can be lowered very greatly by the use of softer asphalt cements, and that for any given penetration grade of asphalt cement, a lower pavement cracking temperature can be expected for a high PI (penetration index) than for a low PI asphalt cement, Figure 6.

The significance of the penetration index (PI) of asphalt cements is illustrated by Figure 7. It demonstrates that largely depending on the crude oils from which they are made, asphalt cements can differ greatly in the rate at which their viscosities change over a given range of temperature (temperature susceptibility), which is measured quantitatively in terms of their penetration index (PI) values(24). For two asphalt cements with the same viscosities (penetrations) at 77°F, Figure 7, at any given temperature above 77°F, a high PI asphalt cement (PI = 0.0) has a higher viscosity than a low PI asphalt (PI = -1.5). Below 77°F, these positions are reversed. Consequently, at any temperature below 77°F, of these two asphalt cements the one with the lower PI (PI= -1.5) will have the higher viscosity, and paving mixtures containing it will be stiffer.

3. The basic reasons that support the conclusion reached experimentally by Rader (16, 17, 18), and by Hills and Brien (19), that low temperature transverse pavement cracking is related to a high modulus of stiffness for an asphalt pavement at low temperature, will now be briefly examined.

If a bar of compacted asphalt paving mixture, say 12 inches long and 2 X 2 inches in cross section is slowly cooled, the bar will gradually become shorter and shorter due to the paving mixture's coefficient of contraction. If the bar is allowed to contract freely as it chills, nothing unusual will happen. It merely becomes shorter. However, if after it has been chilled to some low temperature, we stretch the bar back to its original length, we are subjecting the bar to a tensile stress. It will be able to sustain this tensile stress without cracking, only if the tensile strength of the bar is not exceeded.

If one mile or ten miles of asphalt pavement on a road are gradually chilled to a lower and lower temperature, since each foot length of pavement is attached securely to adjacent pavement, the pavement cannot contract (become shorter), unless it cracks transversely at one or more locations. Consequently, as the temperature of a pavement in service is lowered during the onset of a cold spell, because of its tendency to become shorter, a tensile stress is developed within the pavement since it is not free to contract. The lower the temperature to which the pavement is chilled, the higher is the tensile stress that is created.

The relationship between a pavement's modulus of stiffness at low temperature, and the tendency of a pavement to crack at low temperature, is illustrated by Equations (1), (2), and (3). Equation (1) illustrates the conventional relationship between stress, strain, and modulus of stiffness of an asphalt pavement:

$$S = \frac{\text{stress}}{\text{strain}} \qquad (1)$$

where

S = modulus of stiffness in psi
stress --- measured in pounds per square inch psi
strain --- measured in inches per inch

It will be noted from Equation (1) that the modulus of stiffness S of an asphalt pavement is similar to the modulus of elasticity E of other materials such as steel.

Equation (1) can be rearranged algebraically as:

$$\text{stress} = S\ (\text{strain}) \qquad (2)$$

As a first approximation, for all otherwise identical dense graded asphalt pavements, regardless of the softness or hardness of the asphalt cement they contain, it can be assumed that their coefficients of contraction are the same (20) when they are chilled over a given range of low temperature in a given time. Consequently, it follows that the strain tendency (tendency toward contraction or shortening) created in a given length of an asphalt pavement satisfying stipulated design and construction criteria, when its temperature is chilled over a given range in a specified time, is constant (approximatly) regardless of the hardness or softness of the asphalt cement employed. For these conditions therefore, Equation (2) can be written as:

stress = S (constant) (3)

Equation (3) indicates that the tensile stress induced in any pavement, when a given length of the pavement is cooled over a given temperature range in a given time period, varies directly with the modulus of stiffness of the pavement. Therefore, if the modulus of stiffness of a pavement is high, the tensile stress induced as a result of chilling under the conditions specified will be high, and vice versa, if it has a low modulus of stiffness, the induced tensile stress for the same conditions will be low, Equation (3).

It is axiomatic that when the induced tensile stress exceeds the tensile strength of a pavement, the pavement will crack. Rader's investigation (16, 17, 18) of low temperature pavement cracking indicated that this is most likely to occur when the modulus of stiffness of a pavement is high, that is, when a hard asphalt cement is used. Rader's conclusions have been verified by Hills and Brien (19), Figure 6. They are further confirmed by Figure 8, which illustrates data obtained from three 8-year old Ontario Test Roads each 6-miles in length, each of which was paved using three 85/100 penetration asphalts with different penetration index (PI) values, high, intermediate and low. In each of the nine pavement test sections each 2-miles in length, the asphalt cement had in general hardened to 30/40 penetration during the 8-year service period. Figure 8 indicates very clearly that the higher the modulus of stiffness of these pavements at 0°F, the greater is the number of transverse pavement cracks that occurred after 8 years.

Figure 9, developed by Heukelom (21), indicates why pavements with a higher modulus of stiffness develop more low temperature transverse pavement cracking. It will be remembered that a simple way to obtain a pavement with a high modulus of stiffness is to employ a hard asphalt cement, Figure 10. It will also be recalled that the amount of strain that tends to be developed in a given length of a given pavement when chilled over any specified temperature range, is approximately constant regardless of the grade of asphalt cement it contains (approximately constant coefficient of contraction), Equation 3. Figure 9 indicates that the harder the asphalt cement, the less strain it can tolerate without fracture. Therefore Figure 9 implies that low temperature transverse pavement cracking is more likely to occur when the asphalt cement has a high rather than a low modulus of stiffness, that is, when the pavement contains a hard rather than a soft asphalt cement.

5. Rader's conclusions, relating low temperature modulus of stiffness to asphalt pavement cracking, were based on samples from particular pavements that he selected. Even if an easily conducted laboratory test for measuring the modulus of stiffness of any proposed paving mixture at any given temperature can be devised, there is need for some simple theoretical method that will enable an engineer to foresee quickly or to forecast rapidly the influence that any proposed change in paving mixture design is likely to have on a paving mixture's modulus of stiffness for various temperatures and rates of load application.

Nomographs developed originally by Van der Poel (22, 23) and by Pfeiffer and Van Doormaal (24), that were modified by Heukelom and Klomp (25), and modified further by the writer (11), make a general theoretical method for this purpose available. The step by step procedure developed by the writer for this purpose is described in detail elsewhere (12), but is too lengthy to repeat here. However, the results of applying this method are illustrated by charts such as Figure 10 of stiffness values for slow chilling by various low temperatures of well designed dense graded paving mixtures made with aggregates of 3/4 inch nominal maximum particle size, compacted to 3 per cent air voids, and that satisfy the associated Asphalt Institute VMA requirement for compacted paving mixtures. The ordinate axis in these charts such as Figure 10, provides corresponding modulus stiffness values for the same paving mixtures for fast loading conditions (fast traffic) at summer pavement temperatures.

6. The abscissa of Figure 10, for example, makes it possible to compare for a given paving mixture, the moduli of stiffness values that have been developed as a result of slow chilling to -10°F, when the paving mixture contains 20/25, 40/50, 85/100, 150/200, 300/400 penetration asphalts or SC 3000 (SC 5). The abscissa of Figure 10 shows that the modulus of stiffness of the paving mixture at a low temperature of -10°F increases from about 2000 psi when the paving mixture contains SC 3000 (SC 5) with a penetration index (PI) of 0.0, to 2,000,000 psi when the same paving mixture

contains 40 penetration asphalt with a PI of of -1.5. This range of 1000-fold in modulus of stiffness values is due solely to the differences in the hardness of the asphalt binder that the paving mixture contains.

Rader (16, 17, 18) reported that the use of a softer asphalt cement was an effective method for reducing the modulus of stiffness of a paving mixture. This is verified by Figure 10. Furthermore, Hills and Brien (19) indicated, Figure 6, that the modulus of stiffness of an asphalt paving mixture is influenced by the penetration index of the asphalt cement. This is also verified by Figure 10. For example, for otherwise identical pavements that contain 85/100 penetration asphalt cement, Figure 10 demonstrates that at -10°F, if the pavement contains 100 penetration asphalt cement with a penetration index of 0.0, it has a modulus of stiffness of 275,000 psi, while it it contains asphalt cement of 100 penetration with a penetration index of -1.5, the pavement modulus of stiffness is 800,000 psi, which is approximately three times greater.

3. <u>Application to Pavement Structural Integrity</u>

The two previous sections of this paper demonstrate very clearly that both the evidence from the field, and theoretical considerations, show that the simplest and most practical solution to the low temperature transverse pavement cracking problem with its corresponding loss of pavement structural integrity, is the use of softer grades of asphalt cement. However, there is still the problem of selecting grades of asphalt cement that will enable pavements to avoid low temperature transverse pavement cracking and thereby maintain their structural integrity throughout their service lives. In this section an attempt is made to bridge the gap between research and practice by endeavouring to provide a solution to this problem.

From laboratory studies on pavement samples, the performance of four Ontario Test Roads, the results from the Ste. Anne Test Road (6, 8), and observations of the service behaviour of thousands of miles of asphalt pavements in Canada, the writer has tentatively concluded that the critical low temperature pavement modulus of stiffness at which low temperature transverse pavement cracking is likely to occur is 1,000,000 psi, when measured for a loading time of 20,000 seconds (5.55 hours), for a dense graded pavement with 3/4 inch nominal maximum particle size, and for 3 per cent air voids. Equivalent critical low temperature modulus of stiffness values would apply to pavements with other characteristics.

The factors that contribute to the development of a critical low temperature pavement modulus of stiffness value of 1,000,000 psi are:

1. The penetration of the asphalt cement at 77°F. When all other factors are equal, the higher the penetration at 77°F of the asphalt cement the less is the low temperature transverse pavement cracking that occurs, Figure 5.

2. The penetration index of the asphalt cement. When all other factors are equal, the higher the penetration index of the asphalt cement the less is the transverse cracking that occurs, Figures 6 and 11.

3. The rate of hardening of the asphalt cement in a pavement in service. When all other factors are equal, the harder the asphalt cement in a pavement, the greater is the amount of transverse cracking that develops. The asphalt cement in a pavement becomes harder year by year, and the higher the average pavement service temperature, the faster is this rate of hardening.

4. The lowest critical temperature that occurs at a pavement depth of 2 inches during the lifetime of the pavement. When all other factors are equal, the lower the critical minimum pavement temperature at a pavement depth of 2 inches, the greater is the amount of transverse cracking that occurs. The critical low pavement temperature is the temperature that results in the highest modulus of stiffness of the asphalt cement (greatest hardness of the asphalt cement) during the service life of a pavement. A pavement depth of 2 inches is specified to ensure that a substantial thickness of the asphalt pavement structure is being subjected to the contraction stresses and strains developed at the critical low temperature, that are responsible for transverse pavement cracking. With the new information becoming available (25), the minimum pavement temperature to be expected at a pavement depth of 2 inches can be calculated with reasonable accuracy from weather records that provide data on low air temperatures, time of exposure, and other pertinent factors.

5. The quality and adequacy of the pavement design and construction procedures. When all other factors are equal, pavements that have been properly designed and constructed will develop less low temperature transverse cracking. The asphalt binder in a pavement hardens rapidly if through poor design and construction practice the air voids are high and the asphalt content is low.

The grade of asphalt cement to be selected to maintain pavement structural integrity by avoiding low temperature transverse pavement cracking, must therefore provide an asphalt pavement that will not exceed a low temperature modulus of stiffness of 1,000,000 psi or equivalent for the rate of loading and other conditions specified, at any time during its service life, and particularly as it nears the end of its service life when the asphalt cement has hardened to its lowest penetration at 77°F. With this objective in mind, to guide the selection of the grade of original asphalt cement to be employed, the writer has prepared Table 1 and Figure 12 on the basis of presently available information. Table 1 and Figure 12 can be modified as required, if and when more authoritive data are developed.

For each minimum temperature at a pavement depth of 2 inches listed on the left side of Table 1, the asphalt cement can be selected on the basis of the corresponding pavement modulus of stiffness given in the right hand column of Table 1, which in turn is applied to an a appropriate chart, for example Figure 10. For instance, when the minimum temperature at a pavement depth of 2 inches is -10°F (abscissa of Figure 10), the right hand column of Table 1 indicates that the original asphalt cement selected should be not harder than would result in a pavement modulus of stiffness of 200,000 psi at -10°F, which Figure 10 in turn demonstrates should be not harder than 120/150 penetration for asphalt cements with a penetration index of 0.0, nor harder than 200/300 penetration for asphalt cements with a penetration index of -1.5. This is illustrated in Figure 12 by the diagonal line labelled -10°F.

The middle column in Table 1 indicates that if the original asphalt cement results in an initial pavement modulus of stiffness of 400,000 psi at a minimum pavement temperature of -10°F at a pavement depth of 2 inches, transverse pavement cracking could be anticipated, since the pavement could be expected to attain a low temperature pavement modulus of stiffness of 1,000,000 psi during its early service life. The abscissa of Figure 10 indicates that for a pavement modulus of stiffness of 400,000 psi at -10°F, the pavement would contain 85 penetration asphalt cement with a penetration index of 0.0, or 150 penetration asphalt cement with a penetration index of -1.5. Field experience has indicated that for a pavement temperature of -10°F, these grades of asphalt cement will result in substantial low temperature transverse pavement cracking, particularly in their later service lives, or that they are at least borderline in this respect.

Charts similar to Figure 10 have been prepared for the other low temperatures listed in the left hand column of Table 1 (12, 14). The modulus of stiffness values listed in the right hand column of Table 1 have been used in the manner just described with regard to Figure 10, to select asphalt cements from these charts that will avoid transverse pavement cracking at these low temperatures.

When using Figure 12 to select a grade of asphalt cement that will essentially avoid low temperature transverse pavement cracking during a pavement's service life, the grade of asphalt cement chosen <u>should lie to the right</u> of the diagonal line that represents the lowest temperature that is expected during a pavement's service life at a pavement depth of 2 inches. For example, when selecting an asphalt cement for paving the Alaska Highway (which is presently only at the discussion stage), where the lowest pavement temperature at a depth of 2 inches would be at least -40°F, an asphalt cement of 300 penetration or softer should be selected if its penetration index is 0.0, while 800 penetration or softer should be specified if its penetration index were -1.5. The other oblique lines with temperature lables in Figure 12 have similar significance.

If an engineer selects a grade of asphalt cement that lies to the left of the oblique line in Figure 12 that represents the minimum pavement temperature at a depth of 2 inches anticipated during a pavement's service life, he is gambling with the probability that low temperature transverse cracking will occur sometime during the service life of the pavement. Likewise, he is gambling with the structural integrity of the asphalt pavement.

Figure 12 emphasizes that selecting the grade of asphalt cement for a paving job <u>merely on the basis of its penetration at 77°F</u>, as has been common engineering practice for at least the past half century, <u>is no longer acceptable</u>. Figure 11 demonstrates very clearly that to continue this practice is simply an invitation to trouble since the penetration index of the asphalt cement must also be considered. Figure 11 is based on the performance of the three 6-mile Ontario Test Roads referred to earlier, in each of which three 2-mile sections were paved with three 85/100 penetration paving asphalts of high, intermediate, and low penetration index. In Figure 11, penetration index of the three asphalt cements in each Test Road is plotted versus the number of Type 1 low temperature transverse cracks that were counted after 8 years of service. Figure 11 demonstrates very forcefully that in a climate with moderate winter temperatures, the use of 85/100 penetration asphalt with a high penetration index, 0.0, may largely avoid low temperature transverse pavement cracking, whereas severe transverse cracking could be expected if 85/100 penetration asphalt with a low penetration index, -1.5, were employed. Consequently, if low temperature transverse pavement cracking is to be avoided, engineers, in colder climates particularly, should select the grade of asphalt cement on the basis of <u>both its penetration at 77°F and its penetration index</u>, as illustrated by the oblique temperature-labelled lines in Figure 12. Furthermore, this practice would help to preserve the asphalt pavement's structural integrity.

IV <u>Additional Brief Comments</u>

1. No mention has been so far made of the effect of softer asphalt cements on pavement performance under warm weather traffic. The successful experience of the cities of Edmonton, Alberta (population 4000,000+), and of Winnipeg, Manitoba (population 5000,000+), with 150/200 penetration paving asphalt for all city paving for several years, and of the Manitoba Department of Highways with the use of SC 3000 (SC 5 or

800/1000 penetration) for paving rural highways should be reassuring in this respect. Manitoba summer temperatures occasionally exceed 100°F. The Manitoba Department of Highways formerly used 150/200 penetration asphalt, but this resulted in such serious low temperature transverse pavement cracking that several years ago they changed over to SC 3000 (SC 5), which has cured this problem, and has shown no signs of pavement instability under Manitoba climatic and traffic conditions.

2. It has been Canadian experience with asphalt pavements over sand subgrades, that some transverse cracking can be expected regardless of the grade of asphalt cement employed.

3. It has been observed that for pavements made with any given harder grade of asphalt cement, more transverse cracks develop in thin than in thick pavements exposed to similar conditions. This is believed to be due to the greater temperature difference between the bottom and top of a thick than a thin asphalt pavement slab as a pavement is being chilled in cold weather (14). However, while the transverse cracks take longer to develop, and are less numerous in thick than in thin pavements, evidence from the field indicates that the simplest method for eliminating low temperature transverse pavement cracking from either thin or thick pavements, and thereby ensuring their structural integrity, is to employ softer grades of asphalt cement.

4. Pavements containing soft asphalt cements tend to densify much more rapidly under traffic (26). Therefore, when soft grades of asphalt cement are specified, 75-blow Marshall compaction effort or equivalent should be employed for paving mixture design in the laboratory, and paving mixtures should be designed for from 3 to 5 per cent air voids for surface courses, and from 2 to 4 per cent air voids for base courses, in addition to the minimum VMA values currently specified by The Asphalt Institute.

5. Regardless of the softness of the asphalt cement used for the overlay, reflection cracking can be expected in asphalt concrete overlays that are placed directly over badly cracked pavements, although the amount of reflection cracking that develops in the overlay should be less than when a harder grade of asphalt cement is employed. Only when the overlay is separated from the old pavement by a layer of essentially granular material about six inches thick, can it be assumed that asphalt concrete overlays containing soft asphalt cements will drastically reduce or even eliminate reflection cracking when placed over seriously cracked pavements.

6. When grading asphalt cements by viscosity at 140°F, the AC 10 grade for example, includes all asphalt cements from 50/60 to 150/200 penetration at 77°F. Consequently, as demonstrated by Figures 1, 4, and 5, grading asphalt cements by viscosity at 140°F ensures that low temperature transverse pavement cracking in colder climates will be very severe when an AC 10 asphalt of 50/60 penetration is used, but could be completely absent when an AC 10 asphalt of 150/200 penetration is employed. Therefore, grading asphalt cements by viscosity at 140°F is an invitation to highly variable low temperature transverse pavement cracking performance, with its correspondingly variable influence on asphalt pavement structural integrity in colder climates.

Summary

1. In colder climates, the structural integrity of asphalt pavements can be impaired or destroyed by low temperature transverse pavement cracking.

2. Research on the problem of low temperature transverse pavement cracking has indicated that the simplest and least expensive solution is the use of softer grades of asphalt cements.

3. Field and theoretical evidence is presented to support this conclusion.

4. A chart is provided to guide the selection of asphalt cements that should avoid low temperature transverse pavement cracking, and thereby preserve asphalt pavement structural integrity in colder climates.

References

1. L. Domachuk, P.S. Skarsgard, and R.H. Christianson, "Cracking of Asphalt Pavements Due to Thermal Contraction," Proceedings, Canadian Good Roads Association, 1964.

2. B.P. Shields and K.O. Anderson, "Some Aspects of Transverse Cracking in Asphalt Pavements," Proceedings, Canadian Technical Asphalt Association, Volume 9, 1964.

3. K.O. Anderson, B.P. Shields, and J.M. Dacyszyn, "Cracking of Asphalt Pavements Due to Thermal Effects," Proceedings, Association of Asphalt Paving Technologists, Volume 35, 1966.

4. R.C.G. Haas and K.O. Anderson, "Design Subsystem for the Response of Flexible Pavements at Low Temperatures," Proceedings, Association of Asphalt Paving Technologists, Volume 38, 1969.

5. R.W. Culley, "Relationships Between Hardening of Asphalt Cements and Transverse Cracking of Pavements in Saskatchewan," Proceedings, Association of Asphalt Paving Technologists, Volume 38, 1969.

6. F.D. Young and I. Deme, R.A. Burgess and O. Kopvillem, "Ste Anne Test Road," Proceedings, Canadian Technical Asphalt Association, Volume 14, 1969.

7. Canadian Good Roads Association Ad Hoc Committee, "Low Temperature Pavement Cracking in Canada," Proceedings, Canadian Good Roads Association, 1970.

8. R.A. Burgess, O. Kopvillem, and F.D. Young, "Ste. Anne Test Road -- Relationships Between Predicted Fracture Temperatures and Low Temperature Field Performance," Proceedings, Association of Asphalt Paving Technologists, Volume 40, 1971.

9. N.W. McLeod, "Softer Asphalt Cements Reduce Transverse Pavement Cracking" Presented Annual Meeting Highway Research Board, Washington D.C., January 15-19, 1968.

10. N.W. McLeod, "Reduction in Transverse Pavement Cracking by Use of Softer Asphalt Cements", Highway Research Board, Special Report 101, 1969.

11. N.W. McLeod, "Transverse Pavement Cracking Related to Hardness of Asphalt Cement", Proceedings, Canadian Technical Asphalt Association, Volume 13, 1968.

12. N.W. McLeod, "Prepared Discussion on Paper, Ste. Anne Test Road," Proceedings, Canadian Technical Asphalt Assoication, Volume 14, 1969.

13. N.W. McLeod, "Relationship Between Transverse Pavement Cracking and Hardness of Asphalt Cement", Presented, Montana Roads and Streets Conference, Montana State University, Bozeman, Montana, March 17, 18, and 19, 1970.

14. N.W. McLeod, "Influence of Hardness of Asphalt Cement on Low Temperature Transverse Pavement Cracking", Presented 6th World Highway Conference, Montreal, Canada, October 4 - 10, 1970.

15. N.W. McLeod, "Prepared Discussion on Paper, Ste. Anne Test Road--Relationships Between Predicted Fracture Temperatures and Low Temperature Field Performance," Proceedings, Association of Asphalt Paving Technologists, Volume 40, 1971

16. Lloyd F. Rader, "Investigations of the Physical Properties of Asphalt Mixtures at Low Temperatures", Proceedings, Association of Asphalt Paving Technologists, Volume 6, 1935.

17. Lloyd F. Rader, "Correlation of Low Temperature Tests with Resistance to Cracking of Sheet Asphalt Pavements", Proceedings, Association of Asphalt Paving Technologists, Volume 7, 1936.

18. Lloyd F. Rader, "Report on Further Research Work on Correlation of Low Temperature Tests with Resistance to Cracking of Sheet Asphalt Pavements", Proceedings, Association of Asphalt Paving Technologists, Volume 8, 1937.

19. J.F. Hills and D. Brien, "The Fracture of Bitumens and Asphalt Mixes by Temperature Induced Stresses", Proceedings, Association of Asphalt Paving Technologists, Volume 35, 1966.

20. G. Littlefield, "Thermal Expansion and Contraction Characteristics --Utah Asphalt Concretes," Proceedings, Association of Asphalt Paving Technologists, Volume 36, 1967.

21. W. Heukelom, "Observations on the Rheology and Fracture of Bitumens and Asphalt Mixes", Proceedings, Association of Asphalt Paving Technologists, Volume 35, 1966.

22. C.Van der Poel, " A General System Describing the Visco-Elastic Properties of Bitumens and Its Relation to Routine Test Data", Journal of Applied Chemistry, Volume 4, 1954.

23. C. Van der Poel, "Time and Temperature Effects on the Deformation of Asphaltic Bitumens and Bitumen-Mineral Mixtures", Society of Plastics Engineers Journal, Volume 11, 1955.

24. J. Ph. Pfeiffer and P.M. Van Doormaal, "The Rheological Properties of Asphaltic Bitumen", Journal of the Institute of Petroleum Technology, Volume 22, 1936.

25. J.S. Corlew and P.F.Dickson, "Methods for Calculating Temperature Profiles of Hot-Mix Asphalt Concrete as Related to the Construction of Asphalt Pavements", Proceedings, Association of Asphalt Paving Technologists, Volume 37, 1968.

26. N.W. McLeod, "Developments in Asphalt Pavement Compaction by Variable Tire Pressure Rollers", Proceedings, Canadian Good Roads Association, 1967.

FIGURE 1 PAVEMENT MADE WITH 85/100 PENETRATION ASPHALT. LOCATED WEST OF ORANGEVILLE, ONTARIO. 4-YEARS OLD.

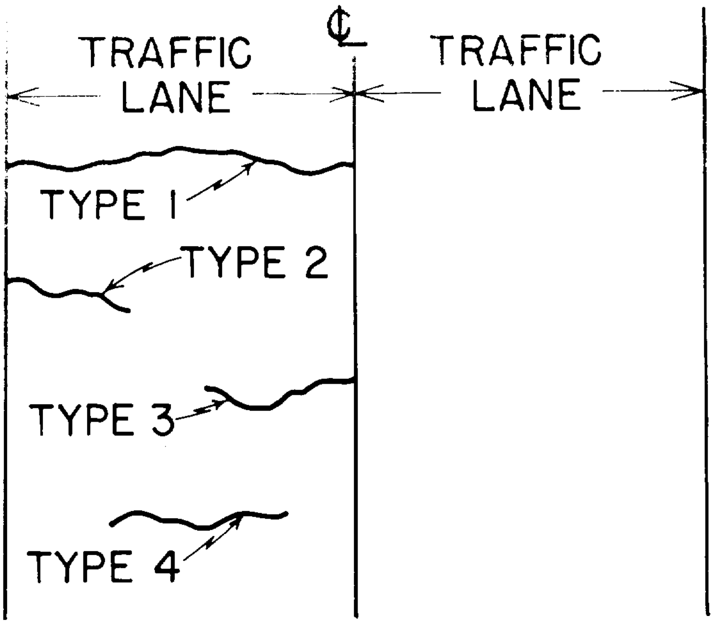


FIG. 2 TYPES OF TRANSVERSE PAVEMENT CRACKS.

FIGURE 3 BUMP HAS DEVELOPED AT EACH TRANSVERSE CRACK IN HOT-MIX PAVEMENT NEAR REGINA, SASKATCHEWAN.

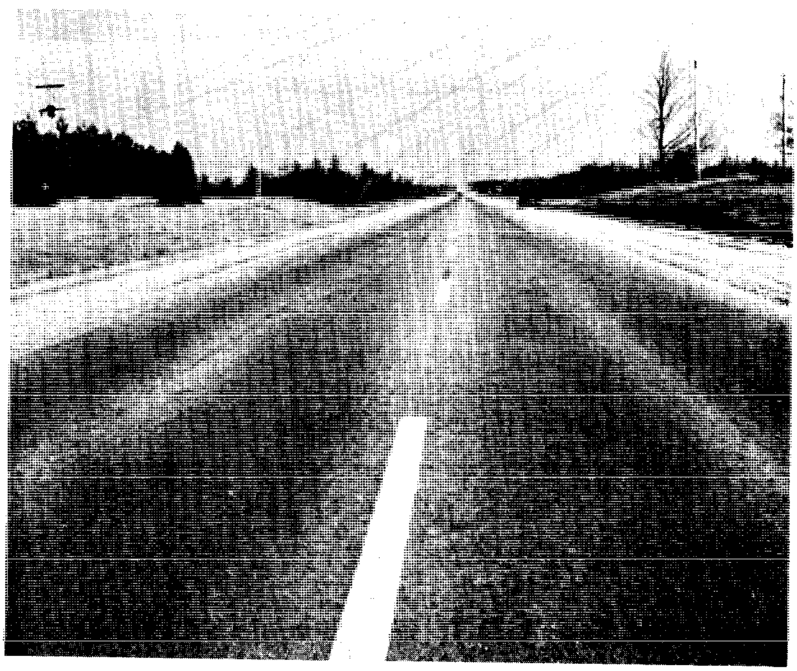


FIGURE 4 PAVEMENT MADE WITH 150/200 PENETRATION ASPHALT. LOCATED WEST OF ORANGEVILLE, ONTARIO. 4-YEARS OLD.

FIGURE 5 85/100 PENETRATION PAVEMENT IN RIGHT LANE, 150/200 PENETRATION PAVEMENT IN LEFT LANE. LOCATED WEST OF ORANGEVILLE, ONTARIO. 4-YEARS OLD.

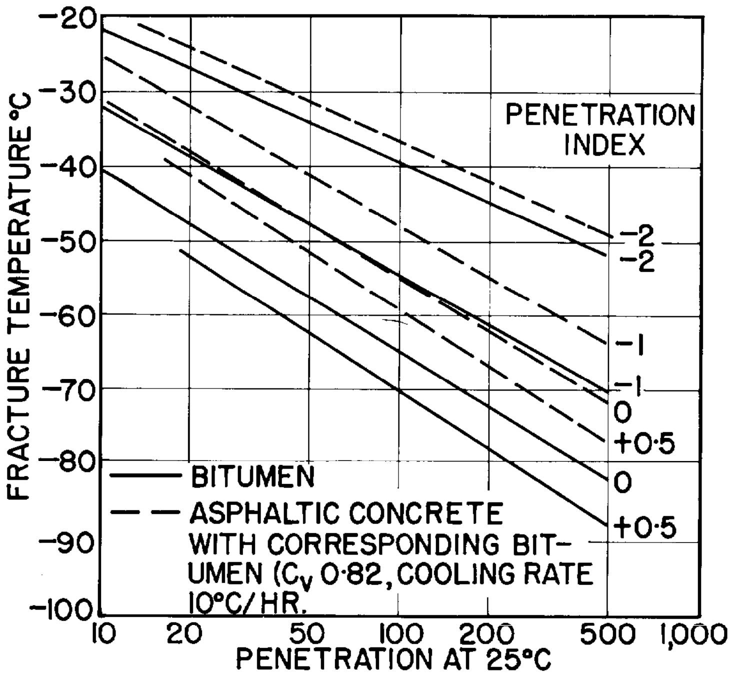


FIG.6 INFLUENCE OF THE PENETRATION AND TEMPERATURE SUSCEPTIBILITY OF BITUMEN ON THE FRACTURE TEMPERATURE OF BITUMEN AND AN ASPHALTIC CONCRETE

(COURTESY HILLS AND BRIEN)

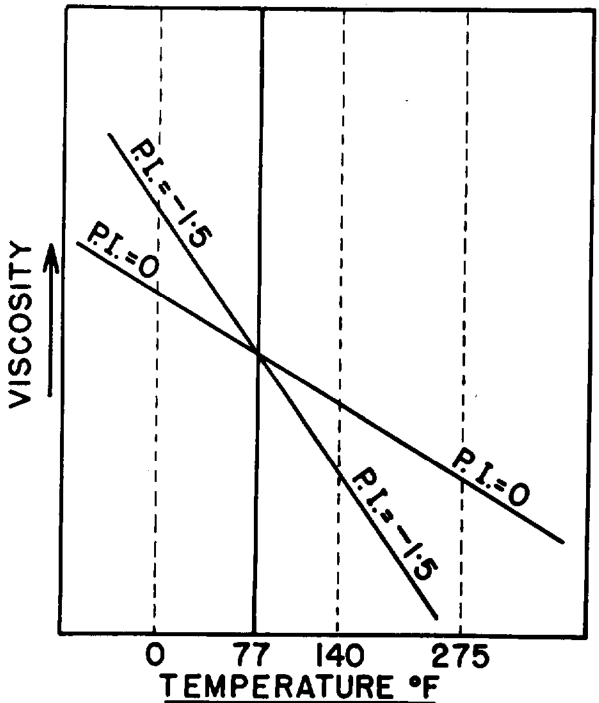


FIG. 7 SKETCH OF GENERAL RELATIONSHIPS BETWEEN VISCOSITY, TEMPERATURE AND PENETRATION INDICES FOR ASPHALT CEMENTS.

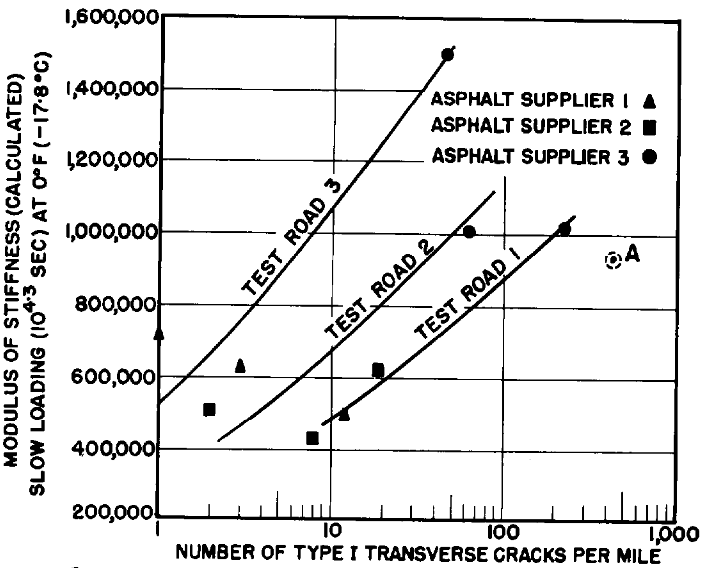


FIG. 8 INFLUENCE OF MODULI OF STIFFNESS (CALCULATED) OF 8-YEAR OLD TEST PAVEMENTS ON NUMBER OF TYPE I TRANSVERSE CRACKS PER MILE.

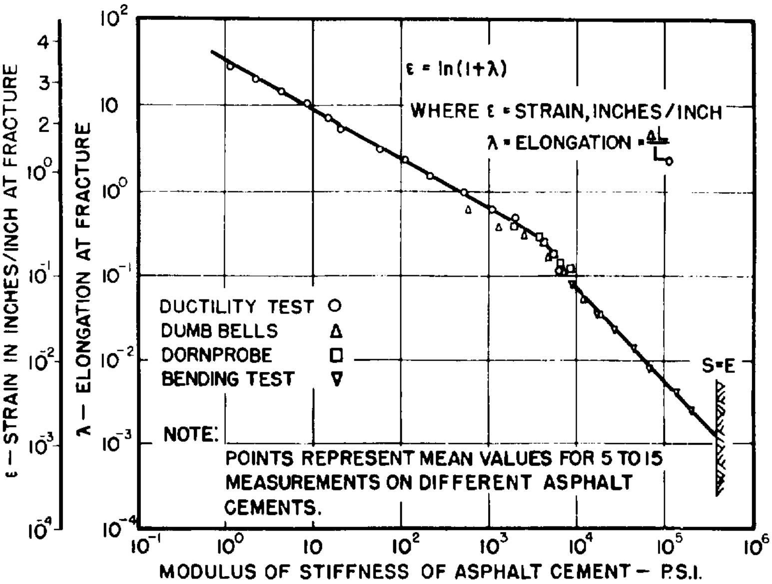


FIG. 9 INFLUENCE OF MODULUS OF STIFFNESS OF ASPHALT CEMENTS ON STRAIN AT FRACTURE.
(BASED ON HEUKELOM)

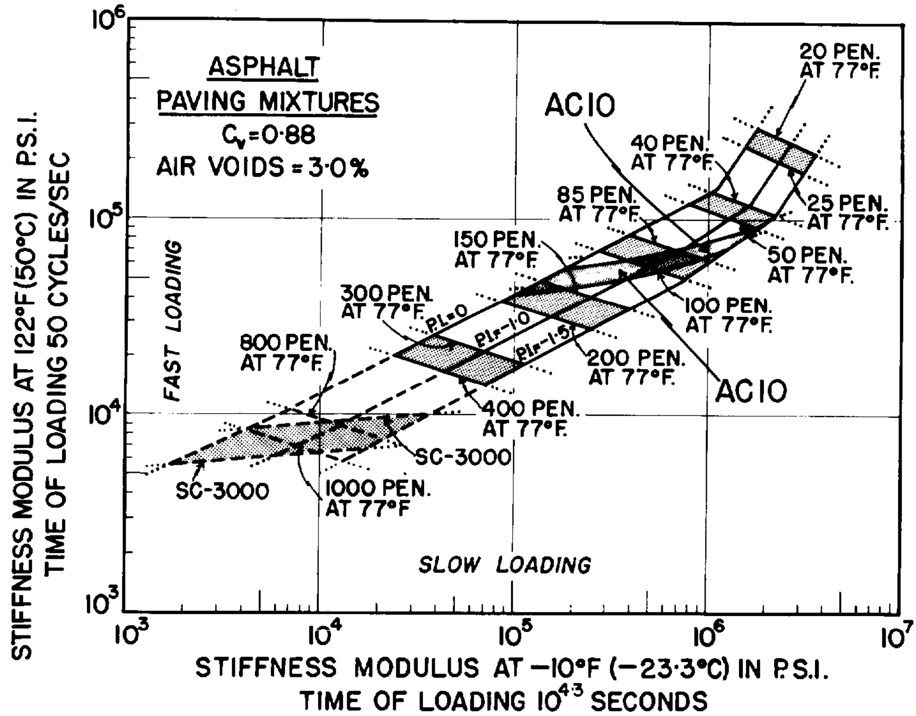


FIG. 10 RELATIONSHIP BETWEEN STIFFNESS MODULI FOR ASPHALT PAVING MIXTURES FOR HIGH RATE OF LOADING (HIGH SPEED TRAFFIC) AT HIGH TEMPERATURE (122°F) VERSUS SLOW SPEED OF LOADING (TEMPERATURE STRESSES) AT LOW TEMPERATURE (−10°F).

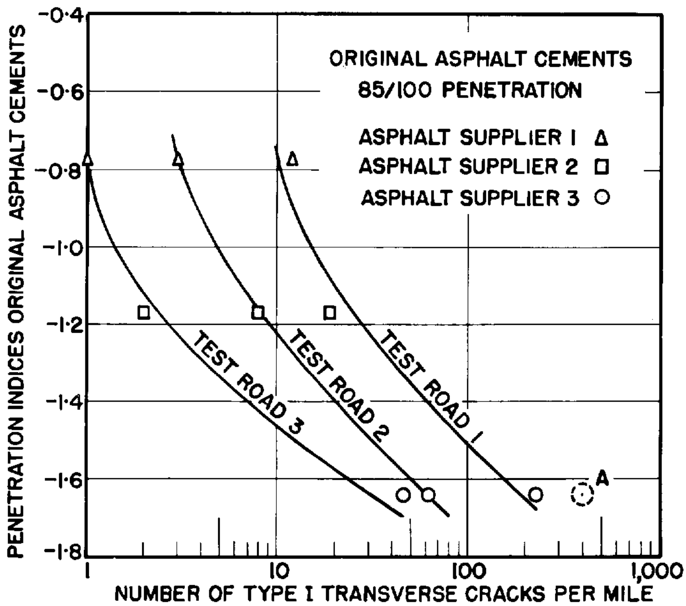
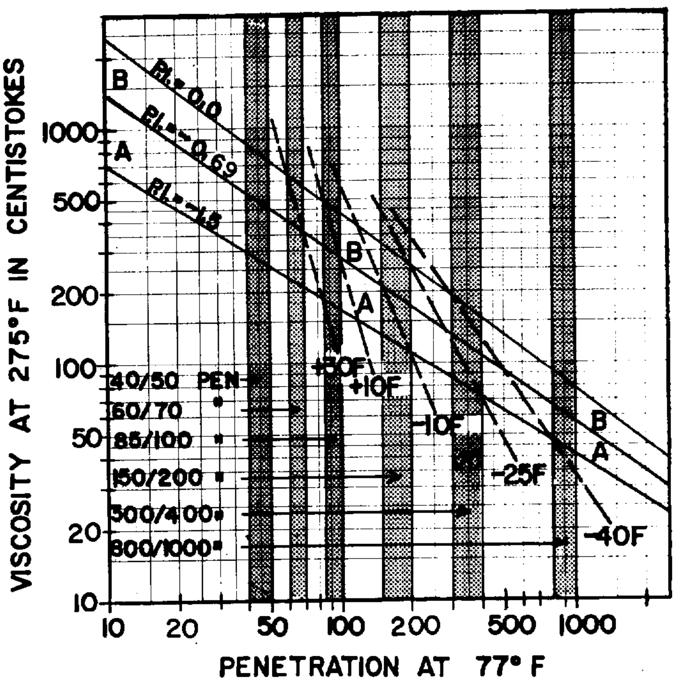


FIG. 11 RELATIONSHIP BETWEEN PENETRATION INDICES OF ORIGINAL 85/100 PENETRATION ASPHALT CEMENTS VERSUS NUMBER OF TYPE I TRANSVERSE PAVEMENT CRACKS PER MILE AFTER 8 YEARS OF SERVICE.



FIG·12 A CHART FOR SELECTING GRADES OF ASPHALT CEMENT TO AVOID LOW TEMPERATURE TRANSVERSE PAVEMENT CRACKING

TABLE 1

Influence of minimum pavement temperature on the pavement modulus of stiffness* to be employed for selecting the grade of asphalt cement to be used.

Minimum temperature at a depth of two (2) inches below the surface of the pavement	Pavement modulus of stiffness values to be employed when selecting the grade of asphalt cement to be used*	
	Initial modulus of stiffness for pavement containing the asphalt cement selected, at which low temperature transverse pavement cracking can be expected during the pavement's service life.	Initial modulus of stiffness for pavement containing the asphalt cement selected, at which low temperature transverse pavement cracking should be eliminated during the pavement's service life
°F	PSI	PSI
-40	1,000,000	500,000
-25	700,000	350,000
-10	400,000	200,000
+10	100,000	50,000

*Note: These critical low temperature modulus of pavement stiffness values are determined on the basis of the writer's revision (11, 12) of Pfeiffer's and Van Doormaal's chart, on the writer's modification (11, 12) of Heukelom's and Klomp's revision of Van der Poel's original monograph, and upon a loading time of 20,000 seconds, roughly six hours, as the rate at which a pavement is being stressed due to chilling to low temperature. They are also restricted to well designed paving mixtures with 14 per cent VMA (3/4 inch nominal maximum particle size), that have been thoroughly compacted to 3 per cent air voids. Equivalent critical modulus of stiffness values would apply to pavements with other characteristics.