The Case for Grading Asphalt Cements by Penetration at 77°F (25°C)

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ABSTRACT

The significance of the temperature susceptibility of asphalt cements, and the need to include this item in asphalt cement specifications is reviewed. The satisfactory service performance of pavements containing asphalt cements of higher temperature susceptibility is affirmed. The influence of pavement service temperature, and grade and temperature susceptibility of asphalt cements, on pavement moduli of stiffness developed by fast traffic in warm climates, by parked vehicles, and by slow chilling to low temperature in cold climates is examined. Contrary to what is indicated by Marshall tests, pavements containing asphalt cements of any given penetration at 77°F (25°C), or of any given viscosity at 140°F (60°C), develop higher moduli of stiffness (higher stability) under fast traffic at pavement temperatures *below* 100°F (37.8°C), when the asphalt cement is of high rather than of low temperature susceptibility. Guidance is provided for the selection of asphalt cements for pavements that will avoid low temperature transverse pavement cracking in cold climates, for pavements that will develop high moduli of stiffness (high stability) under fast traffic in tropical climates, and for pavements that will provide good service performance in both cold and warm weather in cool or moderate climates. A limited critical evaluation of grading asphalt cements by penetration at 77°F (25°C) versus grading by viscosity in poises at 140°F (60°C) is made.

Key Words: Asphalt cements, penetration at 77°F (25°C), temperature susceptibility, modulus of stiffness, hot weather, cold weather, short loading time, long loading time, viscosity at 140°F (60°C).

INTRODUCTION

The writer would like to begin by stating that he would have had no objection if the title of this paper could have referred to the viscosity of asphalt cements at 77°F (25°C) instead of to their penetration at 77°F (25°C). This would have been in agreement with the trend in North America during the past 15 years or so to express the consistency of asphalt cements in fundamental units of viscosity such as poises, centistokes, etc. However, in spite of more than a decade of laboratory effort, a simple, rapid, and acceptable viscosity tests that would measure the consistency of asphalt cements in fundamental units of viscosity at 77°F (25°C) has yet to be devised. Consequently, it appears that penetration at 77°F (25°C) will continue to be used as a consistency test for asphalt cements into the foreseeable future.

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This paper will review the case for continuing to grade asphalt cements by penetration at 77°F (25°C) under the following headings:

a) temperature susceptibility of asphalt cements.
b) substitution of minimum PVN values for minimum limits of viscosity at 275°F (135°C).
c) substitution of minimum PVN values for minimum limits of penetration at 77°F (25°C).
d) utility of asphalt cements of higher temperature susceptiblilty.
e) influence of fast traffic at higher service temperatures on pavement modulus of stiffness.
f) influence of parked vehicles on paving mixture design requirements for parking and similar areas.
g) influence of slow load application due to chilling to low temperatures on pavement modulus of stiffness.
h) selecting asphalt cements to avoid low temperature transverse pavement cracking.
i) selecting asphalt cements for good pavement performance in tropical climates.
j) selecting asphalt cements for good pavement performance in both cold weather and warm sunny weather.
k) grading asphalt cements by penetration at 77°F (25°C) versus grading by viscosity at 140°F (60°C).

1. Figure 1 indicates that temperature susceptibility is one of the most important characteristics of asphalt cements.

2. Temperature susceptibility refers to the change in consistency of an asphalt cement that occurs during any given change in its temperature.

3. The term "temperature susceptibility" has not quantitative meaning until units of measurement for temperature susceptibility have been provided. In Figure 1, the range of measurement of temperature susceptibility varies from a pen-vis number (PVN) or penetration index (PI) value of 0.0 to a PVN or PI value of −1.5, because this covers the range of temperature susceptibility of paving asphalts available in Canada, and also generally speaking, in the U.S.A.

4. Penetration index (PI) is a method that was devised by Pfeiffer and Van Doormal[1] to provide a measurement of temperature susceptibility from an asphalt cement's softening point (ring and ball) and penetration at 77°F (25°C). Because of the false softening points of asphalt cements from many Canadian crude oils, the penetration index method provides unrealistic values for the temperature susceptibilities of these asphalt cements. Consequently, an alternative approach for measuring temperature susceptibility termed pen-vis number (PVN), based on an asphalt cement's penetration at 77°F (25°C) and its viscosity in centistokes at 275°F (135°C), has been developed[2]. For normal asphalt cements the PI and PVN values are numerically equal, or very nearly so. This makes it possible to use PVN values with Van der Poel's nomographs[3,4], to determine modulus of stiffness values for asphalt cements and for asphalt paving mixtures. When applied to a large number of *normal* asphalt cements,

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Student's t test indicates that any differences between the PI and PVN values are not statistically significant.

5. As illustrated by Figure 1, two asphalt cements may have the same penetration or viscosity at 77°F (25°C), point o, but because of differences in temperature susceptibility their viscosities may differ widely at temperatures higher or lower than 77°F (25°C). This means that if an engineer wants the same pavement performance at say−25°F (−31.7°C), if a highly temperature susceptible paving asphalt, PVN = PI = −1.5, is to be used, a much softer grade of this asphalt at 77°F (25°C) must be selected, point X, than if an asphalt cement of low temperature susceptibility, PVN = PI = 0.0, is to be employed, point o. On the other hand, if the same paving mixture performance is required at 275°F (135°C) for the high temperature construction operations of mixing, spreading and breakdown rolling, a much harder grade at 77°F (25°C), point Y, must be selected for a highly temperature susceptible asphalt PVN = PI = −1.5, than when an asphalt cement of low temperature susceptibility PVN = PI = 0.0, is to be used, point o.

6. Figure 1 emphasizes the need to consider *both* its penetration at 77°F (25°C) *and* its temperature susceptibility when selecting the grade of asphalt cement for any pavement project. For example point o in Figure 1 could represent 100 penetration for two asphalt cements, one of low temperature susceptibility, PVN = PI = 0.0, the other of high temperature susceptibility, PVN = PI = −1.5. However, if the same pavement performance is to be provided at −25°F (−31.7°C) by these two asphalt cements of different temperature susceptibility, Figure 1 indicates that the required consistency of the highly temperature susceptible asphalt, PVN = PI = −1.5, as represented by point X, must be much softer than 100 penetration at 77°F (25°C), and could be 150 penetration at 77°F (25°C). On the other hand, if the same paving mixture performance for mixing, spreading, and breakdown rolling at 275°F (135°C) were the primary consideration, Figure 1 demonstrates that the required consistency of a highly temperature susceptible asphalt cement, PVN = PI = −1.5, as represented by point Y, must be harder than 100 penetration at 77°F (25°C), and could be 40 penetration at 77°F (25°C). By way of comparison, for both of these examples, the consistency of the asphalt cement of low temperature susceptibility, PVN = PI = 0.0, would remain at 100 penetration at 77°F (25°C) point o.

7. Figure 2 illustrates what can happen to pavement performance when asphalt cements of the same penetration at 77°F (25°C) but with widely different temperature susceptibilities are used in a given paving project for which all other conditions are equal. No one was even dreaming of low temperature transverse pavement cracking when this 6-mile Test Road was constructed by the Ontario Ministry of Transportation and Communications near London, Ontario, in 1960. Nevertheless, the differences in low temperature transverse pavement cracking provide one of the highly useful items of information that has resulted from the performance of this Test Road over the past 15 years. Three asphalt cements were used in this Test Road, one per each 2 mile test section. All three asphalt cements were 85/100 penetration, but their different temperature susceptibilities were represented by PVN values of −0.19, −0.36, and −1.34. It is clear from Figure 2, that the number of Type 1 low temperature transverse pavement cracks per lane mile increases with increasing temperature susceptibility of the three 85/100 penetration asphalt

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cements, and that by far the greatest number of cracks has occurred in the pavement containing the asphalt cement of the highest susceptibility PVN = −1.34. The answer to the low temperature transverse pavement cracking problem indicated in this case is not to reject the asphalt cement with a PVN value of −1.34 as is so often done, but to use a softer grade of asphalt cement as illustrated by point X in Figure 1, for example to select 150/200 penetration asphalt cement instead of the 85/100 penetration grade that was actually employed.

SUBSTITUTION OF MINIMUM PVN VALUES FOR MINIMUM VISCOSITY REQUIREMENTS AT 275°F (135°C)

1. Some current specifications in which asphalt cements are graded by penetration at 77°F (25°C), attempt to control the maximum temperature susceptibility that will be permitted by stipulating a minimum viscosity requirement at 275°F (135°C). It will be shown that this is not a precise method for this purpose.

2. Figure 3 illustrates a hypothetical specification of this kind for 85/100 and 150/200 penetration grades of asphalt cement. The minimum viscosity requirements at 275°F (135°C) are 175 centistokes for 150/200 penetration grade and 350 centistokes for the 85/100 penetration grade.

3. Figure 3 demonstrates that for this type of specification, the temperature susceptibility in terms of PVN values ranges from −0.43 to −0.61 for the 85/100 penetration grade, and from −0.74 to −1.08 for the 150/200 penetration grade. This means that an asphalt cement of higher temperature susceptibility, PVN =−0.61 is permitted for the 85 penetration limit than for the 100 penetration limit, PVN = −0.43 for the 85/100 penetration grade, and a higher temperature susceptibility, PVN = −1.08, is permitted for the 150 penetration limit than for the 200 penetration limit, PVN = −0.74, of the 150/200 penetration grade. Consequently, since asphalt cements of higher temperature susceptibility are much more abundant than those of low temperature susceptibility, asphalt manufactureres in general can be expected to crowd the higher temperature susceptible (PVN = −0.61) 85 penetration limit of the 85/100 penetration grade, and the higher temperature susceptible (PVN = −1.08) 150 penetration limit of the 150/200 penetration grade. Because of the harder asphalt cement associated with a lower PVN value in each of these two cases, Figure 2 indicates that this can be expected to increase the incidence of low temperature transverse pavement cracking. Furthermore, the asphalt cement in a new pavement begins its service as a harder material, which could shorten its useful service life.

4. As illustrated by Figure 3, these criticisms of inadequate control of temperature susceptibility by means of a minimum viscosity requirement at 275°F (135°C) can be eliminated by substituting one or more minimum PVN values. Through the substitution of a minimum PVN requirement of −0.5 for example, for the 85/100 penetration grade, the same temperature susceptibility would be required for the 85 penetration lower limit as for the 100 penetration upper limit of this grade. Also by substituting a minimum PVN requirement of −0.9 for example, the 150/200 penetration grade, the same temperature susceptibility is being specified for the 150 penetration lower limit as for the 200 penetration upper limit. This change would remove the present incentive of a lower PVN value as an inducement for an asphalt manufacturer to crowd the lower limit of the penetration range for any paving asphalt grade.

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5. Figure 4 illustrates the addition of a series of lines representing different PVN values, into the usual chart in which viscosity in centistokes at 275°F (135°C) is the ordinate axis and penetration at 77°F (25°C) is the abscissa. Each PVN line in Figure 4 represnets a different measure of temperature susceptibility. If a grade of asphalt cement made from a given crude oil by a steam or vacuum refining process has a certain temperature susceptibility, represented for example by a PVN value of say −0.4, all other grades of asphalt cement, harder and softer, made from the same crude oil by the same method of manufacture, will tend to have the same temperature susceptibility, that is a PVN value of −0.4. Figure 4 indicates that if an engineer believes there is some merit in stipulating the maximum temperature susceptibility (minimum PVN value) he will accept for asphalt cements, he can achieve this most easily by specifying a minimum PVN value for all asphalt grades, for example, a minimum PVN value of −1.0, or −0.8, etc. This would automatically indicate the corresponding values for penetration at 77°F (25°C) and viscosity in centistokes at 275°F (135°C) that would have to be provided for each penetration grade.

SUBSTITUTION OF MINIMUM PVN VALUES FOR MINIMUM LIMITS OF PENETRATION AT 77°F (25°C)

1. When asphalt cements are graded by viscosity in poises at 140°F (60°C), Figure 21, minimum limits of penetration at 77°F (25°C) are imposed on each viscosity grade to reduce the wide range of penetration at 77°F (25°C) that each viscosity grade at 140°F (60°C) would otherwise permit.

2. Nevertheless, Figure 5 demonstrates for two of these viscosity grade, AC10 and AC20 as examples, that these minimum penetration limits at 77°F (25°C) permit the use of asphalt cements with a wide range of temperature susceptibility as measured by PVN values. For the minimum penetration of 60 at 77°F (25°C) for the premium AC20 grade for instance, the minimum temperature susceptibility permitted for the 2400 viscosity limit is indicated by PVN = −0.66, point B, but the 1600 viscosity limit is PVN = −1.05, point A. Similarly, for the minimum penetration of 80 stipulated for the premium AC10 grade, temperature susceptibilities as measured by PVN values of −0.92 and −1.34 are indicated for the 1200 and 800 viscosity limits, point D and point C, respectively.

3. This means that for the minimum penetration of 60 at 77°F (25°C) for the premium AC20 viscosity grade, a substantially lower temperature susceptibility, PVN = −0.66, is being demanded for the 2400 viscosity upper limit, point B, than for the 1600 viscosity lower limit, PVN = −1.05, point A. Also for the minimum penetration of 80 at 77°F (25°C) established for the premium AC10 viscosity grade, a much lower temperature susceptibility, PVN = −0.92, is being stipulated for the 1200 viscosity upper limit, point D, than for the 800 viscosity lower limit, PVN = −1.34, point C.

4. It has already been pointed out that asphalt cements of higher temperature susceptibility are much more plentiful than those of lower temperature susceptibility. Furthermore, it needs to be clearly recognized that because of the urgent need for cat-cracker feed stock for conversion to gasoline and other light distillates, any knowledgeable refinery manager is going to remove as much of the liquid component from each crude oil as the asphalt

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specifications permit. This does not ordinarily harm the quality of the asphalt that remains, but the asphalt cement being produced will be harder. The asphalt refiner should not be blamed for this, since he has the right to assume that we who write the specifications for asphalt cements know what we are doing.

5. With the above two points clearly in mind, it should be apparent from Figure 5 that for the premium AC20 and AC10 grades, a well informed refinery manager is going to provide asphalt cement as near to point A and point C, respectively, as practically possible. Consequently, although Figure 5 demonstrates that the permissible range of penetration at 77°F (25°C) for the *premium* AC10 grade is from 120 to 60, and for the *premium* AC10 grade is from 180 to 80 penetration, the AC20 and AC10 asphalt cements shipped to paving projects will tend to approximate penetrations of 60 and 80 with PVN values of −1.05 and −1.34 respectively. A similar situation exists concerning the *regular* viscosity grades, AC10 and AC20, illustrated in Figure 5.

6. As demonstrated by Figure 5, this situation could be improved by substituting minimum PVN values for minimum penetration at 77°F (25°C) requirements for each viscosity grade, AC2.5 to AC40. Figure 5 indicates that the use of PVN = −0.85 minimum for AC20, and of PVN = −1.15 minimum for AC10 would:

a) ensure the same temperature susceptibility over the entire range of viscosity forming the left hand boundary of each viscosity grade, just as a PVN = −0.0 forms the right hand boundary for each of these grades.

b) decrease the present maximum permissible temperature susceptibility of the premium AC20 grade from PVN = −1.05 to PVN = −0.85, and for the premium AC10 grade from PVN = −1.34 to PVN = −1.15.

c) eliminate the current incentive to supply asphalt cements of low penetration and high temperature susceptibility represented in Figure 5 by point A for AC20, and by point C for AC10.

7. However, in order to maximize production of cat-cracker feed stock, asphalt manufacturers will still tend to avoid the higher penetration at 77°F (25°C) asphalt cements along the soft right hand boundary, PVN = 0.0 of Figure 5, and to crowd the lower penetration at 77°F (25°C) harder left hand boundary for each viscosity grade, PVN = −0.85 for the AC20 grade, and PVN = −1.15 for the AC10 grade. This is inherent in this method of grading asphalt cements by viscosity in poises at 140°F (60°C).

When asphalt cements are graded by penetration at 77°F (25°C), the penetration grade specified, whether it is the soft 300/400 penetration grade, or the much harder 60/70 penetration grade, establishes a very firm limit beyond which oily cat-cracker feed stock cannot be extracted. If cat-cracker feed stock is removed beyond the particular limit that applies to each penetration grade, the penetration at 77°F (25°C) of the asphalt cement will be lower than specified.

8. Figure 5 suggests the use of an average PVN value for each viscosity grade, for example, PVN = −0.85 for the AC20 grade, or PVN = −1.15 for the AC10 grade. However, for engineers who believe that the same temperature susceptibility should be stipulated regardless of the grade of asphalt cement being specified, it would be a simple matter to modify Figure 21 to make it similar to Figure 4, by inserting lines representing various PVN values, from which an approximate minimum PVN value could be selected.

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UTILITY OF ASPHALT CEMENTS OF HIGHER TEMPERATURE SUSCEPTIBILITY

1. In the past there has been a reluctance on the part of many engineers to use asphalt cements of higher temperature susceptibility. This attitude appears to have resulted primarily from two principle criticisms of these asphalt cements that they offer:

a) delayed breakdown rolling,

b) flushed or bleeding pavements.

Flushed or bleeding pavements result from either poor paving mixture design or from no paving mixture design, or from inadequate inspection and control of the paving mixture as it is being laid. Within the writer's experience, if a paving mixture has been designed to contain a minimum of 3 percent air voids for 75-blow Marshall compaction, and provided that through adequate field inspection this also applies to the paving mixture being placed, the pavement will never flush or bleed in service under even the heaviest traffic. If the writer's experience should be proven too optimistic in this regard, the remedy is a minimum of 4 percent air voids for 75-blow Marshall compaction instead of a minimum 3 percent air voids.

With regard to delayed breakdown rolling, this is due primarily to our present dependence on the steel wheel roller, and to our attitude that steel wheel rollers are like the weather and that nothing can be done about them. With the proper use of other compaction equipment, such as pneumatic-tire rollers with rapidly adjustable tire inflation pressures, delayed rolling need not occur. Other satisfactory equipment for this purpose could also be devised.

Delayed rolling can also be caused by poor paving mixture design.

2. Up to the present time, asphalt cements of lower temperature susceptibility have usually been available. Therefore, engineers in general have not had to face up to the special problems alreadyu referred to, that can be presented by the use of asphalt cements of higher temperature susceptibility.

3. However, this may be changing. With the crude oil pipeline being extended from Sarnia to Montreal, which will back out Venezuelan crude oil that has been the principal source for asphalt cements of low temperature susceptibility in Eastern Canada, the use of highly temperature susceptible asphalt cements from Western Canadian light crudes may become inevitable. The nationalization of the assets of the large multinational oil companies in Venezuela may also influence paving asphalt sources in the United States.

4. In view of a probable need for a substitute for asphalt cements, the U.S. Federal Highway Administration has recently undertaken a research study to develop alternative road binder materials. Consequently, in the not-too-distant future, engineers may be glad to obtain asphalt cement of any kind regardless of whether it is of high or low temperature susceptibility.

5. There is a great deal of evidence that little or no difference in pavement performance results from the use of asphalt cements of either high or low temperature susceptibility, *provided the proper grade of asphalt cement is selected,* and the asphalt paving mixture is well designed and constructed. For more than 40 years, pavements in Vancouver and in much of British Columbia have been made very largely with asphalt cements of high temperature

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susceptibility, and no part of Canada has better asphalt pavements. On three Ontario Test Roads, each six miles in length, that are now 15 years old, apart from transverse cracks which could be avoided by using a softer asphalt cement, there is no difference in the performances of high, medium, or low temperature susceptibility. In 1961, twenty miles of Ontario's 4-lane divided Highway 401 were paved using Western Canadian asphalt cement of high temperature susceptibility. After 14 years of service, this 20-mile section was overlaid this past summer, but primarily because of foundation distress, and not because of asphalt pavement deterioration.

Consequently, this and much similar evidence indicates that provided the proper grade of asphalt cement is selected, if carefully designed and controlled paving mixtures containing asphalt cements of high temperature susceptibility can be placed and compacted, they can ordinarily be expected to provide highly satisfactory service performance.

6. Even for engineers who would argue that asphalt cements of low temperature susceptibility provide superior pavement performance, not every highway is subjected to the high traffic volume of Ontario's Highway 401, or the New Jersey Turnpike, etc. If these asphalt cements of low temperature susceptibility should be in short supply, they should be reserved for the most heavily travelled roads and streets, and asphalt cements of higher temperature susceptibility should be employed for roads and streets carrying lesser traffic volumes. Specifications for asphalt cements that recognize these differences in usage should be prepared.

INFLUENCE OF FAST TRAFFIC AT HIGHER SERVICE TEMPERATURES ON PAVEMENT MODULUS OF STIFFNESS

1. The term "modulus of stiffness", which is equal to:

$$\frac{\text{Stress in p.s.i.}}{\text{Strain in inches per inch}}$$

provides a fundamental measure of pavement stability in pounds per square inch, that can be applied to any paving mixture, weak or strong.

2. The pavement modulus of stiffness values shown in Figure 6 and in other Figures in this paper, are based upon nomographs developed by Van der Poel[3, 4].

3. The asphalt pavement referred to throughout this paper contains dense graded aggregate of 5/8 inch nominal maximum particle size. It has a VMA value of 14.5 percent (based on the aggregate's ASTM bulk specific gravity), an air voids value of 3.0 percent (determined from its bulk compacted versus theoretical maximum specific gravities), and is represented by a C_v value of 0.88 on Van der Poel's nomograph[4].

4. The abcissa for Figure 6 indicates modulus of stiffness values that are developed in this pavement by the very slow rate of loading (time of loading, 20,000 seconds or 5.55 hours) resulting from slow chilling of the pavement during cold weather to −10°F (−23.3°C).

5. Resulting from a discussion with Claessen and Visser of the Royal Dutch Shell Laboratories, Amsterdam, The Netherlands, a loading time of 0.008 second, in one of Van der Poel's charts[3] has been taken equal to the time of loading for any point on an asphalt pavement by a heavy truck travelling at 100

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km per hour (62.2 miles per hour). The contact area between the truck tire and the pavement is assumed to be 20 cm (8 inches) in length.

Consequently the ordinate axis in Figure 6 indicates modulus of stiffness values developed in this asphalt pavement for a fast laoding time of 0.008 second, corresponding to the passage over any point on the pavement of a wheel of a heavy truck travelling at 100 km per hour (62.2 miles per hour).

The ordinate axis in Figure 6 shows modulus of stiffness values for this fast rate of loading that are developed by this pavement when it contains asphalt cements ranging from 800/1000 penetration at 77°F (25°C) to 20/25 penetration at 77°F (25°C),and for pavement service temperatures of 140°F (60°C), 122°F (50°C), 100°F (37.8°C), 77°F (25°C), 62°F (16.7°C), and 50°F (10°C).

6. The following very useful information is given by the ordinate axis of Figure 6:

a)An examination of Figure 6 indicates that for bands representing service temperatures of 140°F (60°C), 122°F (50°C), 100°F (37.8°C), and 77°F (25°C), the upper boundaries of these bands indicate modulus of stiffness values for pavements containing asphalt cements of low temperature susceptibility with a PVN value of 0.0, while the lower boundaries indicate moduli of stiffness for pavements containing asphalt cements of high temperature susceptibility with a PVN value of −1.5. It will be observed that the width of each band becomes narrower and narrower with decreasing service temperatures of 140°F (60°C), 122°F (50°C), 100°F (37.8°C), and 77°F (25°C), and that the band becomes only a line at 62°F (16.7°C). For the band representing a service temperature of 50°F (10°C), relative positions of the band boundaries are reversed, with the upper boundary indicating moduli of stiffness for pavements containing asphalt cements of high temperature susceptibility with a PVN = −1.5, and the lower boundary providing modulus of stiffness values for asphalt pavements containing asphalt cements of low temperature susceptibility with a PVN = 0.0.

b)For any given pavement service temperature, the modulus of stiffness (stability) of the paving mixture increases very markedly under fast loading as the penetration at 77°F (25°C) of the asphalt cement it contains becomes lower and lower (harder and harder). For example, at a pavement temperature of 122°F (50°C), the pavement modulus of stiffness increases from about 5,500 psi when the asphalt cement is 800/1000 penetration (SC3000) to about 80,000 psi when the asphalt cement is 40/50 penetration, both with a PVN of 0.0. this is an increase in pavement stability of nearly 15 times due entirely to the grade of asphalt cement in the paving mixture.

c)When the paving mixture contains asphalt cement of any given penetration at 77°F (25°C), the modulus of stiffness (stability) of the paving mixture increases very rapidly with a decrease in pavement temperature. For example, when the pavement contains asphalt cement of 85/100 penetration with a PVN of 0.0, the modulus of stiffness increases from about 20,000 psi at 140°F (60°C) to about 40,000 psi, 120,000 psi, 450,000 psi, and 1,400,000 psi, as the temperature is lowered to 122°F (50°C), 100° F (37.8°C), 77°F (25°C), and 50°F (10°C), respectively. This indicates an

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increase in pavement modulus of stiffness of 70 times when the temperature of the paving mixture is decreased from 140°F (60°C) to 50°F (10°C).

d)For any given grade of asphalt cement, for instance 85 / 100 penetration, for pavement temperatures above 100°F (37.8°C), for example 122°F (50°C) and 140°F (60°C), a somewhat higher pavement modulus of stiffness results if the asphalt cement is of low temperature susceptibility, PVN = 0.0, than if it has a high temperature susceptibility, PVN = −1.5. For example, at 140°F (60°C) the modulus of stiffness of the pavement containing 100 penetration asphalt cement with a PVN = 0.0 is 18,000 psi, but the pavement modulus of stiffness is 10,500 psi if the pavement contains 100 penetration asphalt cement with a PVN = −1.5.

e)However, for all service temperatures below 100°F (37.8°C), when the paving mixture contains asphalt cement of a given penetration at 77°F (25° C), it exhibits a higher pavement modulus of stiffness if the asphalt cement has a high temperature susceptibility, PVN = −1.5, than if it has a low temperature susceptibility, PVN = 0.0. At a service temperature of 77°F (25°C) for example if the pavement contains 85 penetration asphalt cement, it has a mixulus of stiffness of 360,000 psi if the asphalt cement has a PVN = 0.0, but has a moduldus of stiffness of 600,000 psi if the asphalt cement has a PVN = −1.5.

7. For paving projects in the past, and even at the present time, it has been and still is not uncommon practice to specify asphalt cement of some selected penetration at 77°F (25°C), e.g. 85/100, *regardless of the temperature susceptibility of the asphalt cement,* a practice that Figures 1, 2 and 6 demonstrate to be in serious error. Furthermore, engineers assume that because Marshall tests at 140°F (60°C) indicate that for any given paving mixture containing asphalt cement of a specified penetration at 77°F (25°C), e.g. 85 / 100 penetration, a higher Marshall stability is obtained if the asphalt cement has a low temperature susceptibility, PVN = 0.0, than if its temperature susceptibility is high PVN = −1.5, that pavements containing 85 / 100 penetration asphalt of low temperature susceptibiliyy, PVN = 0.0, will also be more stable at all lower pavement service temperatures than if they contain 85 / 100 penetration asphalt of high temperature susceptibility, PVN = −1.5.

8. One of the most important conclusions illustrated by Figure 6, is that under fast traffic, *only* for pavement service temperatures above 100°F (37.8° C), is the Marshall test able to predict correctly that when allother conditions are equal, a paving mixture containing an asphalt cement of a given penetration at 77°F (25°C), e.g. 85/100 penetration, has a higher stability (modulus of stiffness) if the asphalt cement has a low temperature susceptibility, PVN = 0.0, than if it has a high temperature susceptibility, (PVN = −1.5). Unlike Figure 6, the Marshall test fails to indicate that for pavement service temperatures below 100°F (37.8°C), pavements otherwise identical containing asphalt cement of any given penetration at 77°F (25°C) will develop a higher stability (higher modulus of stiffness) under fast traffic, if the asphalt cement has a high temperature susceptibility PVN = −1.5, than if it has a low temperature susceptibility, PVN = 0.0. For example,Figure 6 shows that under fast traffic at a pavement service temperature of 77°F (25°C), a pavement containing asphalt cement of 150 penetration at 77°F (25°C) with a PVN = 0.0, will develop a modulus of stiffness of 260,000 psi, while if it contains asphalt cement of 100 penetration at 77°F (25°C) with a PVN = −1.5, it will develop a modulus of stiffness of 350,000 psi.

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9. The Marshall test is fundamentally incapable of predicting this result because of its relatively long loading time of 3 seconds for a flow index of 10, compared with a loading time of 0.008 second applied by a heavy truck travelling at 100 km per hour (62.2 miles per hour).

10. For the large portion of every day, and the very high percentage of every year, when pavement service temperatures are less than 100°F (37.8°C), Figure 6 demonstrates that pavements containing 85/100 penetration asphalt for example, with a high temperature susceptibility, PVN = −1.5, develop under fast traffic a very much higher modulus of stiffness (higher stability) than when they contain 85/100 penetration asphalt cement of low temperature susceptibility, PVN = 0.0.

11. Figure 6 implies that even for pavement service temperatures of 105°F (40.6°C), for pavements containing asphalt cements of any specified penetration grade, pavement moduli of stiffness would be nearly the same regardless of the temperature susceptibilities of the asphalt cements. Only for pavement service temperatures of about 10°F (37.8°C) and upward would pavement modulus of stiffness values become noticeably higher if they contained asphalt cements of low, PVN = 0.0, than of high, PVN = −1.5, temperature susceptibility. For asphalt cement sof intermediate temperature susceptibilities, for example PVN = −0.5 and PVN = −1.0, differences in pavement modulus of stiffness due to these differences in temperature susceptibility for the same penetration grade of asphalt cement, would become substantial only at still higher pavement service temperatures. For example, under fast laoding, for pavements containing 100 penetration asphalt cements, Figure 6 indicates that the pavement modulus of stiffness at 122°F (50°C) would be 32,000 psi if the asphalt cement had a PVN = −0.5, and would be 29,000 psi if the asphalt cement had a PVN = −1.0, a decrease of about nine percent. However, for pavements containing 100 penetration asphalt cement, the pavement modulus of stiffness at 140°F (60°C) would be 15,000 psi if the asphalt cement had a PVN = −0.5, and would be 12,500 psi if the asphalt cement had a PVN = −1.0, a decrease of 20 percent.

INFLUENCE OF PARKED VEHICLES ON PAVEMENT DESIGN FOR PARKING AND SIMILAR AREAS

1. To provide satisfactory performance, asphalt pavements on parking areas must be able to support the wheel loads of parked vehicles for long periods, that may be several hours or even days, without the occurrence of any pavement distortion.

2. With respect to pavement design for parking areas, the important information is provided by the abscissa of Figure 7.

3. The ordinate axis of Figure 7 indicates pavement modulus of stiffness values at 122°F (50°C) for the fast loading time of 0.001 second, approximating the time of loading applied by some military air craft with their very high landing and take-off speeds.

4. The abscissa of Figure 7, indicates the influence of pavement service temperature, penetration grade of the asphalt cement at 77°F (25°C), and asphalt cement temperature susceptibility in terms of PVN values ranging from 0.0 to −1.5, on the modulus of stiffness values developed by a given pavement under the slow loading applied by the wheels of vehicles parked for 20,000 seconds (5.55 hours).

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5. It should be pointed out that the modulus of stiffness values indicated by the abscissa of Figure 7 are based upon a portion of one of Van der Poel's charts[3] where accurate readings are very difficult to make.

6. Examination of Figure 7, which pertains to pavement design for parking areas, indicates that the four bands representing pavement service temperatures of 122°F (50°C), 100°F (37.8°C), and 77°F (25°C), the upper boundary of each band indicates modulus of stiffness values for pavements containing asphalt cements of high temperature susceptibility with a PVN value of −1.5, while the lower boundary indicates moduli of stiffness for pavements containing asphalt cements of low temperature susceptibility with a PVN value of 0.0. However, the width of each band becomes smaller and smaller with decreasing service temperatures of 122°F (50°C), 100°F (37.8°C), and 77°F (25°C), and finally the band becomes only a line at a service temperature of 50°F (10°C).

7. The following information is indicated by the abscissa of Figure 7:

a) For any given grade of asphalt cement, the pavement modulus of stiffness decreases rapidly with an increase in pavement service temperature. When the pavement contains 85/100 penetration asphalt with a PVN = 0.0 for example, the pavement modulus of stiffness decreases from about 45 psi at 77°F (25°C) to about 1.0 psi at 122°F (50°C).

b) For any given pavement service temperature, the pavement modulus of stiffness increases as the asphalt cement contained in the pavement becomes harder. For example, at a pavement service temperature of 122°F (50°C), if the pavement contains 300/400 penetration asphalt cement with a PVN = 0.0, the pavement modulus of stiffness is about 0.2 psi, whereas it is 3.0 psi if the pavement contains 40/50 penetration asphalt cement with a PVN = 0.0.

c) When the pavement service temperature is held constant, a higher modulus of stiffness is developed by the pavement containing a given grade of asphalt cement if the asphalt cement has a PVN of 0.0, than if its PVN value is −1.5. For example, for a pavement containing 85/100 penetration asphalt with a pavement service temperature of 122°F (50°C), the pavement modulus of stiffness is about 1.0 psi if the asphalt cement has a PVN value of 0.0, but decreases to about 0.3 psi for a PVN value of −1.5 for the asphalt cement. Since the loading times for both parked vehicles and the Marshall tests are relatively long, it should be of general interest that the Marshall test also shows higher stability for paving mixtures containing asphalt cements of low temperature susceptibility.

8. The following conclusions appear to be indicated by the abscissa of Figure 7 with regard to paving mixture design for parking areas:

a) Because of very low modulus of stiffness values developed by pavements subjected to long loading periods at high pavement service temperatures, it would appear that the asphalt cement contributes very little to pavement stability under these particular conditions.

b) For the long periods of loading to which pavements are exposed in parking areas, it would seem that pavement stability depends very largely on the stability of the aggregate in the paving mixture. Lefebvre and Robertson[5] reached a similar conclusion from Marshall stability tests conducted on paving mixtures at the very slow rate of loading of 0.002 inch per minute.

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c)Pavement stability for parking area construction is increased by employing a harder than normal asphalt cement, for example 60/70 penetration instead of 85/100 penetration.

INFLUENCE OF SLOW RATE OF LOADING DUE TO CHILLING TO LOW TEMPERATURES ON PAVEMENT MODULUS OF STIFFNESS

1. Pavements that are slowly chilled to a low temperature on a cold winter night are subjected to a slow rate of loading (increasing tensile stress due to pavement contraction) over a period of several hours. For this paper, the time of loading is assumed to be 20,000 seconds, or 5.55 hours.

2. Due to overlap of the individual diagrams, it was not possible to illustrate the subject matter to be presented in a single chart. Therefore, Figures 8 and 9 should be considered together.

3. The ordinate axis for Figures 8 and 9 provides modulus of stiffness values at a pavement service temperature of 122°F (50°C), that are developed in a pavement for a loading time of 0.001 seconds, approximating the passage over a point in the pavement of a wheel of some military aircraft with their very high landing and take-off speeds. However, the pertinent information in Figures 7 and 8 is associated with the abscissa.

4. The abscissa in Figures 8 and 9 indicates the influence of low pavement temperatures, penetration grade of asphalt cement at 77°F (25°C), and asphalt temperature susceptibilities represented by PVN values from 0.0 to −1.5, on the pavement moduli of stiffness developed under slow chilling to the pavement service temperatures shown.

5. It should be noted that the ordinate axis and the abscissa are the same for Figure 7, which is concerned with pavement performance on parking lots, and for Figures 8 and 9 which pertain to pavement performance under the stresses created by chilling to low temperatures during winter. It was pointed out in the previous section that the top and bottom boundaries of each band in Figure 7 indicated modulus of stiffness values for paving mixtures containing asphalt cements of high temperature susceptibility, PVN = −1.5, and low temperature susceptibility, PVN = 0.0, respectively, that the width of each band becomes smaller and smaller as the pavement service temperature decreases from 122°F (50°C) to 100°F (37.8°C) to 77°F (25°C), and that these bands narrow to a single line at a service temperature of 50°F (10°C).

Figures 8 and 9 continue this trend below a service temperature of 50°F (10-°C), but with the positions of the top and bottom boundaries being reversed from their positions in Figure 7. Therefore, in Figures 8 and 9 the top and bottom boundaries of each band indicate modulus of stiffness values for paving mixtures containing asphalt cements of low temperature susceptibility, PVN = 0.0 , and high temperature susceptibility, PVN = −1.5, respectively. Furthermore, as the pavement service temperatures decrease below 50°F (10° C), to 30°F (−1.1°C), 10°F (−12.2°C), −10°F (−23.3°C), −25°F (−31.7°C), and −40°F (−40°C), the bands in turn gradually increase in width, that is for pavements containing asphalt cement of any given penetration at 77°F (25°C), the differences in pavement modulus of stiffness values for asphalt cements of high and low temperature susceptibilities become larger and larger.

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6. The following information is provided by the abscissa of Figures 8 and 9:

a) If the pavement service temperature remains constant, the pavement modulus of stiffness increases greatly as the penetration at 77°F (25°C) of the asphalt cement in the pavement is reduced (becomes harder and harder). For example, if a pavement is slowly cooled to a service temperature of -10°F (-23.3°C), the pavement modulus of stiffness increases from about 5000 psi if the pavement contains 800/1000 penetration asphalt cement (SC3000), to about 1,000,000 psi if it contains 40/50 penetration asphalt, both asphalts having a PVN value of 0.0. This is an increase of 200 times in pavement modulus of stiffness due solely to the grade of asphalt cement.

b) When the pavement contains asphalt cement of any given penetration grade at 77°F (25°C), there is a very large increase in pavement modulus of stiffness with a lowering of pavement service temperature. If the asphalt cement has a penetration of 150/200 with a PVN of0.0 for example, the pavement modulus of stiffness increases from about 2,500 psi at 30°F (-1.1°C), to 20,000 psi, 150,000 psi, 500,000 psi, and 1,000,000 psi, as the temperature is lowered to + 10°F (-12.2°C), -10°F (-23.3°C), -25° F (-31.7°C), and to -40°F (-40°C), respectively. This represents a 400-fold increase in pavement modulus of stiffness between + 30°F (-1.1°C) and -40°F (-40°C) due to the influence of temperature alone.

c) It is quite clear from Figures 8 and 9, that for any given pavement service temperature and grade of asphalt cement, a substantially higher pavement modulus of stiffness is associated with a PVN of -1.5 than with a PVN of 0.0. For example, for a pavement service temperature of -10°F (-23.3°C), and for the 85/100 penetration grade, the pavement modulus of stiffness is about 400,000 psi, if the asphalt cement has a PVN of 0.0, but is about 900,000 psi if its' PVN = -1.5.

SELECTING ASPHALT CEMENTS TO AVOID LOW TEMPERATURE TRANSVERSE PAVEMENT CRACKING

1. Low temperature transverse pavement cracking can be one of the worst pavement faults in cold countries. No engineer can take much pride in a pavement that contains numerous transverse cracks.

2. The writer[6] has studied this problem in depth for a number of years, and has concluded that low temperature transverse pavement cracking is likely to become serious if the pavement develops a modulus of stiffness of 1,000,000 psi at the lowest winter temperature to which it is exposed, for a loading time of 20,000 seconds (5.55 hours), corresponding to slow chilling on a cold night.

3. On this basis, avoiding low temperature transverse pavement cracking becomes a problem of selecting grades of asphalt cement for well designed and constructed asphalt pavements that will not exceed a pavement modulus of stiffness of 1,000,000 psi at the lowest pavement temperature experienced during the pavement's service lives.

Fabb[9] has shown that regardless of their temperature susceptibilities, all asphalt cements fracture during cooling when they reach the same low temperature modulus of stiffness. Also, Figure 24 demonstrates that an asphalt pavement of a given modulus of stiffness results when it contains an asphalt cement with the required corresponding modulus of stiffness which is constant regardless of the temperature susceptibility of the asphalt cement.

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4. While subject to revision as more information becomes available, the broken lines AA, BB, CC, DD, and EE in Figures 8 and 9 represent an attempt to select grades of asphalt cement that will avoid low temperature transverse pavement cracking at each of a wide range of minimum service temperatures during the life of the pavement. This selection has been made on the basis of an examination of thousands of miles of pavements in service, and on pavement performance at the Ste. Anne Test Road[7], and at three Ontario Test Roads[2]. It also recognizes that the higher the pavement service temperature, the more rapidly the asphalt cement will harden within a pavement, and the asphalt cement initially chosen must therefore be softer.

Therefore, the following table summarizes the selection of the original asphalt cements that are currently recommended to avoid low temperature transverse pavement cracking throughout the pavement's service life:

Minimum Service Temperature	Line	Initial Pavement Modulus of Stiffness	Asphalt Cements Recommended Penetration at 77°F (25°C) PVN = 0.0	PVN = -1.5
-40°F (-40°C)	AA	500,000 psi	320 pen	1000 pen
-25°F (-31.7°C)	BB	350,000 psi	195 pen	500 pen
-10°F (-23.3°C)	CC	200,000 psi	135 pen	240 pen
+ 10°F (-12.2°C)	DD	50,000 psi	92.5 pen	123 pen
+ 30°F (-1.1°C)	EE	15,000 psi	65 pen	75 pen

5. The Asphalt cements selected by lines AA, BB, CC, DD, and EE from Figures 8 and 9, and illustrated by the above table, have been transferred to Figure 10, which simplifies the selection of penetration grades of asphalt cement that should avoid low temperature transverse pavement cracking at each of the minimum service temperatures indicated.

6. The farther to the right of each oblique temperature labelled line in Figure 10 the asphalt cement is located, thehigher is the margin of safety against the development of low temperature transverse pavement cracking. For example, as indicated by the oblique line labelled -25°F (-31.7°C) in Figure 10, either an asphalt cement of 195 penetration at 77°F (25°C) with a PVN = 0.0, or an asphalt cement of 500 penetration at 77°F (25°C) with a PVN = -1.5, should provide a pavement that would avoid low temperature transverse pavement cracking if a minimum pavement service temperature of -25°F (-31.7°C) should occur during its service life. However, asphalt cements softer than these, and lying to the right of the -25°F (-31.7°C) temperature labelled oblique line, will provide a larger safety factor against the development of low temperature transverse pavement cracking at -25°F (-31.7°C).

SELECTING ASPHALT CEMENTS FOR GOOD PAVEMENT PERFORMANCE IN TROPICAL CLIMATES

1. Any method proposed for grading asphalt cements should be satisfactory for selecting asphalt cements for use in tropical climates, as well as in cold climates. When selecting asphalt cements for pavements in tropical climates, all requirements for good cold weather performance can be neglected. Consequently, pavements should ordinarily be designed to serve fast traffic at high or relatively high pavement service temperatures.

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2. Asphalt cements of 80/100 penetration are widely used for high volume traffic on asphalt paved highways in Thailand, the Philippines, and in other tropical areas. Pavement temperature studies by Kallas[8] at Washington, D. C. indicated that the pavement temperature at a pavement depth of 2 inches exceeded 120°F (48.9°C) for only one percent of the year. Service temperature at a pavement depth of 2 inches is considered most critical, because if the temperature is higher and higher at successive lesser depths below the surface, the pavement will be stable because of the thiness of the pavement layers at these higher pavement temperatures. Examination of Figure 6 shows that under fast traffic, a pavement containing 100 penetration asphalt cement with a PVN value of 0.00 or about 80 penetration with a PVN value of -0.8, has a modulus of stiffness of 37,000 psi at a pavement service temperature of 122°F (48.9°C). Consequently, for Figure 11, which is based on Figure 6, 80/100 penetration and harder asphalt cements are indicated to be satisfactory for heavy traffic in tropical climates, while asphalt cements softer than 80/100 may be used for pavement carrying medium to light traffic.

3. Figure 12, which is based on data taken from Figure 6, provides the following information:

a) Figure 12 indicates combinations of penetrations at 77°F (25°C) and temperature susceptibilities for asphalt cements that provide a pavement modulus of stiffness of 37,000 psi for a fast loading time of 0.008 second at pavement service temperatures of 140°F (60°C), 122°F (50°C), 100°F (37.8°C), and 77°F (25°C). For example, pavements containing asphalt cements of either 100 penetration with a PVN = 0.0, or 70 penetration with a PVN = -1.5, will develop a pavement modulus of stiffness of 37,000 psi at 122°F (50°C) for a fast loading time of 0.008 second.

b) Figure 12 demonstrates that a pavement modulus of stiffness of 37,000 psi under a fast loading time of 0.008 second, is provided by very much softer asphalt cements at lower pavement service temperatures of 77°F (25°C) and 100°F (37.8°C), than at higher pavement service temperatures of 122-°F (50°C) or 140°F (60°C). For example, a pavement modulus of stiffness of 37,000 psi is provided by asphalt cement of 315 penetration at 77°F (25°C) at a pavement service temperature of 100°F (37.8°C), whereas asphalt cements with penetrations ranging from 23 to 42 at 77°F (25°C) are required to provide a pavement modulus of stiffness of 37,000 psi at 140°F (60°C).

c) Figure 12 also shows that to develop a pavement modulus of stiffness of 37,000 psi under fast truck at pavement service temperatures above 100°F (37.8°C), the pavement must contain an asphalt of a lower penetration at 77°F (25°C), that is the asphalt cement must be harder, if it has a high temperature susceptibility, PVN = -1.5, than if it has a low temperature susceptibility, PVN = 0.0. For example, at a service temperature of 140°F (60°C), the asphalt cement must have a penetration of 23 at 77°F (25°C) if its PVN is -1.5, but must have a penetration at 77°F (25°C) of 42, if its PVN = 0.0. However to develop a pavement modulus of stiffness of 37,000 psi at pavement service temperatures below 100°F (37.8°C), this is reversed, for if the pavement contains an asphalt cement of high temperature susceptibility, PVN = -1.5, the asphalt cement must have a higher penetration at 77°F (25°C), that is, the asphalt cement must be softer, than if it has a low temperature susceptibility, PVN = 0.0.For

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example, to develop a pavement modulus of stiffness of 37,000 psi under fast traffic at a pavement service temperature of 77°F (25°C), the pavement must contain asphalt cement of about 1500 penetration at 77°F (25°C), if it has a PVN = –1.5, but the asphalt cement must be of about 1000 penetration at 77°F (25°C) if its PVN = 0.0.

d) For any given pavement service temperature indicated by Figure 12, a pavement modulus of stiffness higher than 37,000 psi is provided if the pavement contains an asphalt cement that *lies to the left* of the oblique line representing the pavement service temperature in question, that is, a harder asphalt cement. For example, the oblique line representing a pavement service temperature of 122°F (50°C) provides a modulus of stiffness of 37,000 psi when the pavement contains asphalt cement of 100 penetration at 77°F (25°C) with a PVN = 0.0. However, a similar pavement containing an asphalt cement of 70 penetration at 77°F (25°C) with a PVN = 0.0, which *lies to the left* of the oblique line representing a pavement service temperature of 122°F (50°C), would have a modulus of stiffness of about 52,000 psi at 122°F (50°C).

4. Figure 13, which is derived from Figure 6, indicates combinations of penetration at 77°F (25°C) and PVN values that provide the pavement modulus of stiffness associated with each of the oblique lines representing the different pavement service temperatures referred to. For each pavement service temperature shown, the penetration at 77°F (25°C) associated with asphalt cements with a PVN value of –1.5 vary very widely, depending upon pavement service temperature. As has been pointed out in earlier sections of this paper, Figure 13 demonstrates very clearly that for any given pavement service temperatures above 100°F (37.8°C), for the same pavement modulus of stiffness, the asphalt cement of 100 penetration at 77°F (25°C) with a PVN of 0.0, is a softer grade than the corresponding penetration at 77°F (25°C) of the asphalt cement with a PVN of –1.5. For any given pavement service temperature below 100° F (37.8°C), this is reversed, and for the same modulus of stiffness, the 100 penetration asphalt with a PVN of 0.0 is a harder grade than the corresponding penetration of the asphalt cement with a PVN of –1.5. For example, for a pavement service temperature of 122°F (50°C), pavements containing either asphalt cement of 100 penetration at 77°F (25°C) with a PVN PVN of 0.0, or asphalt cement of 70 penetration at 77°F (25°C) with a PVN value of –1.5, develop a pavement modulus of stiffness of 37,000 pounds. Here the 70 penetration asphalt cement with a PVN of –1.5 is harder than the 100 penetration asphalt with a PVN of 0.0. On the other hand, for a pavement service temperature of 77°F (25°C), pavements containing either asphalt cement of 100 penetration at 77°F (25°C) with PVN of 0.0 or asphalt cement of 145 penetration at 77°F (25°C) with a PVN of –1.5, each develop a pavement modulus of stiffness of 360,000 psi. In this case, the 145 penetration asphalt with a PVN of –1.5 is softer than the 100 penetration asphalt with a PVN of 0.0.

5. Figures 12 and 13 indicate that for asphalt pavements for tunnels, shaded areas, and other locations carrying rapidly moving traffic where pavement temperatures will always be less than 100°F (37.8°C), if engineers merely specify the grade of asphalt cement to be used, for example 85/100 penetration at 77°F (25°C), without regard for its temperature susceptibility, the pavement containing this grade of asphalt cement will develop a much

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higher modulus of stiffness (higher stability) under a fast rate of loading at all pavement service temperatures, if the asphalt cement has a high temperature susceptibility, PVN = −1.5, than if it has a low temperature susceptibility, PVN = 0.0. For example, at a pavement service temperature of 77°F (25°C) and for a loading time of 0.008 second, if the pavement contains 100 penetration asphalt cement with a PVN = 0.0, it will develop a modulus of stiffness of 360,000 psi, whereas if it contains asphalt cement of 100 penetration at 77°F (25°C) with a PVN = −1.5, it will develop a modulus of stiffness of 500,000 psi.

SELECTING ASPHALT CEMENTS FOR SATISFACTORY PAVEMENT PERFORMANCE IN BOTH COLD AND WARM WEATHER

1. When selecting an asphalt cement for a paving project in a cool climate, an engineer should be concerned about avoiding low temperature transverse pavement cracking in winter, together with providing adequate pavement stability for summer traffic. How can asphalt cements be selected in an attempt to satisfy simultaneously the requirements for both of these conditions?

2. The principles to be employed to answer this question are illustrated by Figures 14 to 18. These Figures may require modification as more information becomes available. The crosshatched areas in each of these Figures include the combinations of penetrations at 77°F (25°C) and PVN values that would provide pavements that would avoid serious low temperature transverse pavement cracking in winter at each of the minimum service temperatures indicated, and hopefully, may at the same time provide adequate stability under fast traffic in summer.

3. For each cross hatched area in Figure 14 for example, the oblique left hand boundary indicates combinations of penetrations at 77°F (25°C) and PVN values for asphalt cements which will provide a constant pavement modulus of stiffness and will avoid low temperature transverse pavement cracking under slow loading at the low pavement service temperature listed. The oblique right hand boundary of each cross hatched area shows combinations of penetrations at 77°F (25°C) and PVN values for asphalt cements that will provide the constant pavement modulus of stiffness indicated, for rapidly moving traffic at a warm pavement service temperature of 122°F (50°C).

The pavement modulus of stiffness value indicated for the left hand boundary of each cross hatched area in Figures 14 to 18 for slow loading at low temperatures, comes from Figure 10, while the pavement modulus of stiffness for the right hand boundary of each cross hatched area in these Figures is obtained from Figure 6.

4. The oblique lines representing pavement modulus of stiffness under fast traffic at higher service temperatures that form the *right hand* boundary of each cross hatched area in Figures 14 to 18, were selected to intersect the corresponding left hand boundary of each of these areas at either the upper or lower PVN boundary (PVN = 0.0 or PVN = −1.5) in each Figure as required. For example, this intersection of the left hand and right hand boundaries of each cross hatched area occurs on the PVN = −1.5 boundary in Figure 14, but can occur on the PVN = 0.0 boundary in Figure 16. This arrangement for the left hand and right hand boundaries of each cross hatched area, recognizes that the farther to the right of the left hand boundary of each cross hatched area the softer the asphalt cement becomes, and the larger is the

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factor of safety against the occurrence of low temperature transverse pavement cracking. It also recognizes that by selecting asphalt cements farther and farther to the left of the right hand boundary of each cross hatched area, the harder the asphalt cement becomes, and a higher and higher pavement modulus of stiffness is being provided for fast traffic in warm weather. Consequently, the asphalt cements within each cross hatched area represent an attempt to satisfy the requirements for satisfactory pavement performance in both cold and warm weather. Nevertheless, if an engineer decides that to achieve greater pavement stability for warm weather traffic he should select a harder asphalt cement to the left of the left hand boundary representing the minimum anticipated service temperature for the pavement to be constructed, he should realize that he is probably trading a greater incidence of low temperature transverse pavement cracking for the higher warm weather pavement modulus of stiffness he believes is required. For example, suppose the minimum expected pavement temperature in some locality is −10°F (−23.3°C) and the maximum service temperature anticipated is 122°F (50°C), which applies to the middle cross hatched area of Figure 14. Suppose too, that the asphalt cements available have a PVN value of −0.8. The intersection of the line representing a PVN = −0.8 with the left hand boundary of this cross hatched area occurs at a penetration at 77°F (25°C) of 180 for the asphalt cement. Figure 6 shows that the modulus of stiffness developed by a pavement containing 180 penetration asphalt cement with a PVN of −0.8 under fast loading at 122°F (50°C) is 19,000 psi. The engineer might feel that this pavement modulus of stiffness would not provide adequate pavement stability for warm weather traffic, and may decide to use 85/100 penetration asphalt with a PVN = −0.8. If this asphalt cement has an actual penetration of 90 at 77°F (25°C), Figure 6 indicates that a pavement containing it will develop a modulus of stiffness of 34,000 psi under fast traffic at 122°F (50°C). However, Figure 14 shows that 85/100 penetration asphalt is well to the left of the oblique line labelled −10°F (−23.3°C), representing the hardest grades of asphalt cement that should be used if low temperature transverse pavement cracking at −10°F (−23.3°C) is to be avoided. Consequently, if 85/100 penetration asphalt cement with a PVN of −0.8 is selected in this case, a substantial amount of low temperature transverse pavement cracking is to be expected.

5. Because the several cross hatched areas in each of Figures 14, 15, 16 and 18 could be confusing, two of these cross hatched areas have been isolated in Figure 17. Sketch (a) in Figure 17 provides an enlargement of the cross hatched area associated with the low temperature boundary labelled −10°F (−23.3°C) in Figure 14. Sketch (b) in Figure 17 provides an enlargement of the cross hatched area associated with the oblique low temperature boundary labelled + 30°F (−1.1°C) in Figure 16.

6. The left hand boundary, AB, in Sketch (a) of Figure 17 indicates combinations of penetrations at 77°F (25°C) and PVN values for asphalt cements that will provide the maximum pavement modulus of stiffness of 200,000 psi required to avoid low temperature transverse pavement cracking resulting from slow chilling to −10°F (−23.3°C). These range from a penetration of 240 for a PVN = −1.5, point A, to a penetration of 135 for a PVN = 0.0, point B. The right hand boundary, AC, shows combinations of penetrations at 77°F (25°C) and PVN values for asphalt cements that provide a constant pavement modulus of stiffness of 12,500 psi under fast truck traffic at

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122°F (50°C). These range from a penetration of 240 for a PVN of −1.5 to a penetration of 350 for a PVN of 0.0.

Normally, in order to provide higher pavement stability for fast traffic in warm weather, the highest pavement modulus of stiffness available within the constraints that apply is preferred. The highest pavement modulus of stiffness under fast truck traffic (loading time 0.008 second) at 122°F (50°C), that is still within the cross hatched area of sketch (a) of Figure 16, is developed at a point B, 30,000 psi. If it is available, this would be provided by an asphalt cement with a penetration at 77°F (25°C) of 135 and a PVN value of 0.0. Progressively lower values for pavement modulus of stiffness under fast traffic at 122°F (50° C) would be provided by pavements containing asphalt cements with a PVN value of 0.0 and corresponding penetrations at 77°F (25°C) that would place them on the upper boundary of sketch (a) between point B (30,000 psi), and point C (12,500 psi). However, the same corresponding values for pavement moduli of stiffness are developed by paving mixtures containing asphalt cements having combinations of penetrations at 77°F (25°C) and PVN values that range from −1.5 to 0.0. This is demonstrated by the broken lines DE and FG in sketch (a), which indicate combinations of penetrations at 77°F (25°C) and PVN values for asphalt cements that will provide pavements with moduli of stiffness of 14,500 psi and 20,000 psi, respectively, under fast loading at 122°F (50°C). Consequently, the same pavement modulus of stiffness values can be obtained for conditions of fast loading at 122°F (50°C), when pavements contain asphalt cements with a combination of penetrations at 77°F (25°C) and PVN values that lie along BA as well as with those that lie along BC, and those that are in between these two boundaries.

7. In sketch (b) of Figure 17, the left hand boundary LM, indicates combinations of penetrations at 77°F (25°C) and PVN values for asphalt cements that provide a constant pavement modulus of stiffness of 15,000 psi for a slow loading time of 20,000 seconds at + 30°F (−1.1°C), while the right hand boundary MN provides combinations of penetrations at 77°F (25°C) and PVN values for asphalt cements that result in a constant pavement modulus of stiffness of 580,000 psi for fast traffic at 77°F (25°C).

A high pavement modulus of stiffness for fast traffic in warm weather is normally highly desirable. With respect to sketch (b) in Figure 17, because pavement modulus of stiffness under fast traffic at 77°F (25°C) increases with increasing distance to the left of MN, the highest pavement modulus of stiffness for fast traffic at 77°F (25°C) within the cross hatched area, occurs at point L, 710,000 psi. Point L indicates an asphalt cement with a penetration of 75 at 77° F (25°C) and with PVN = −1.5. In the case of sketch (b) therefore, the highest pavement modulus of stiffness for fast traffic at 77°F (25°C), which occurs at point L, is on the PVN = −1.5 boundary.

8. Figures 14 to 16 indicate that for a large portion of each cross hatched area, no specification grade of asphalt cement exists. Consequently, if this method for selecting asphalt cements for cool climates were followed, specifications for asphalt cements should be revised to fill in these gaps.

Figure 18 demonstrates that similar gaps exist in portions of each cross hatched area when asphalt cements are graded by viscosity at 140°F (60°C), and should be filled by specifying new viscosity grades if this method of specifying asphalt cements for use in cool climates were to be followed.

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GRADING ASPHALT CEMENTS BY PENETRATION AT 77°F (25°C) VERSUS GRADING BY VISCOSITY AT 140°F (60°C)

1. AASHTO has recently adopted a specification for grading asphalt cements by viscosity at 140°F (60°C) but still retains its specification for grading asphalt cement by penetration at 77°F (25°C).

2. The five grades of asphalt cement specified by AASHTO based on grading by viscosity at 140°F (60°C), AC2.5, AC5, AC10, AC20, and AC40 are indicated by the ordinate axis of Figure 19, while the abscissa illustrates how these viscosity grades compare with corresponding grades of asphalt cement based on grading by penetration at 77°F (25°C).

3. Figure 19 demonstrates that asphalt cements of lowest temperature susceptibility, PVN = 0.0, provide the upper right hand boundary of this chart, while asphalt cements of highest temperature susceptibility PVN + −1.5, provide the lower left hand boundary.

4. It is also immediately apparent, that each viscosity grade at 140°F (60°C) includes a substantial number of penetration at 77°F (25°C) grades of asphalt cement. For example, the AC10 grade includes all penetration at 77°F (25°C) grades from 50/60 to 150/200 penetration. Furthermore, the harder low penetration grades with the highest temperature susceptibility for example 50/60 penetration occupy the left side of the chart in the vicinity of PVN = −1.5, while the softer high penetration grades with the lowest temperature susceptibility, for example 150/200 penetration, are located on the right side of the chart in the vicinity of the PVN = 0.0 boundary.

5. It was originally assumed that because each viscosity grade of asphalt, for example AC10 had the same viscosity at 140°F (60°C), the service performance of pavements containing all AC10 asphalts would be the same, whether they came from the low penetration at 77°F (25°C), highly temperature susceptible hard left side of the AC10 grade, for example 50/60 penetration, or from the high penetration at 77°F (25°C) low temperature susceptible soft right side of the AC10 grade, 150/200 penetration for example.

6. The serious low temperature transverse pavement cracking that was associated with the use of an AC10 grade of 50/60 penetration at 77°F (25°C) and a PVN value near −1.5 for example, very quickly indicated that all portions of the AC10 grade, or of any other viscosity grade at 140°F (60°C), do not provide the same pavement performance, Consequently to avoid this serious criticism, as illustrated by Figure 19, AASHTO excluded the more temperature susceptible low penetation at 77°F (25°C) asphalt cements on the hard left side of each viscosity grade by specifying a minimum penetration at 77°F (25°C) for each viscosity grade. This was done by establishing two specification tables, Table 2 of which specified a higher minimum penetration at 77°F (25°C) for each viscosity grade than Table 1, as shown in Figure 19.

7. Consequently, as illustrated by Figure 19, the current AASHTO specification based on viscosity grading at 140°F (60°C) restricts acceptable asphalt cements to those of higher penetration at 77°F (25°C) and of lower temperature susceptibility toward the soft right side of each viscosity grade.

8. Figure 20 has been prepared by plotting AASHTO viscosity grades at 140°F (60°C), AC2.5, AC5, AC10, AC20, and AC40, on Figure 10 which is intended to guide the selection of grades of asphalt cement that will eliminate

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low temperature transverse pavement cracking. It will be remembered that under conditions of very long loading time due to slow chilling to low temperature, if low temperature transverse pavement cracking is to be avoided at the low temperature indicated by any one of low temperature labelled oblique lines in Figure 20, the asphalt cement selected should lie either on this line or to the right of it. *The farther to the right* of this line the selected asphalt cement is located, the softer the asphalt cement becomes, and the higher is the factor of safety against the occurrence of low temperature transverse pavement cracking.

In general, Figure 20 indicates that only the high penetration at 77°F (25° C) asphalt cements of low temperature susceptibility from the soft right hand side of each viscosity grade satisfy this requirement. For example, only the soft right hand tip of the AC2.5 viscosity grade would provide asphalt cements that could avoid serious low temperature transverse pavement cracking at −40°F (−40°C), only the soft right hand tip of the AC5 viscosity grade would perform the same function for a low pavement service temperature of −25°F (−31.7°C), etc. In general, therefore, *with respect to the avoidance of transverse pavement cracking at low pavement service temperatures,* when asphalt cements are graded by viscosity at 140°F (60°C), Figure 20 justifies the exclusion of the low penetration at 77°F (25°C) asphalt cements of high temperature susceptibility from the hard left side of each viscosity grade which is illustrated by Figure 19.

9. Figure 20 demonstrates that there is no practical way in which grading asphalt cements by viscosity at 140°F (60°C) could utilize asphalt cements of high temperature susceptibility approaching PVN = −1.5, to eliminate low temperature transverse pavement cracking at−40°F (−40°C), −25°F (−31.7°C), or even at −10°F (−23.3°C). Consequently, if an asphalt shortage should develop, grading asphalt cements by viscosity at 140°F (60°C) imposes a very serious limitation on the range of asphalt cements that would be acceptable.

On the other hand, both Figure 10 and Figure 20 indicate that when asphalt cements are graded by penetration at 77°F (25°C), asphalt cements over the entire range of temperature susceptibility from PVN = 0.0 to PVN = −1.5, and even outside of these PVN values, can be selected to avoid low temperature transverse pavement cracking at −10°F (−23.3°C), −25°F (−31.7°C), −40°F (−40°C), or any other low pavement service temperature. For example, to avoid low temperature transverse pavement cracking at −10°F (−23.3°C), Figures 10 or 20 demonstrate that either 240 penetration asphalt cement with a PVN = −1.5, or asphalt cement of 135 penetration with a PVN = 0.0, or softer, could be selected.

10. Figure 21 refers to the selection of asphalt cements that will provide stable pavements under fast truck traffic in tropical climates. The data for preparing Figure 21 came from Figure 6. The oblique temperature labelled lines in Figure 21 indicate combinations of penetration at 77°F (25°C) and temperature susceptibility (PVN values for asphalt cements that would enable the pavements containing them to develop a modulus of stiffness of 37,000 psi under fast truck traffic at each of the high pavement service temperatures indicated. With respect to Figure 21, it will be recalled that a pavement containing an asphalt cement that *lies to the left* of the asphalt cements represented by one of the temperature labelled lines, the asphalt cement will be harder, and the pavement will develop a higher modulus of stiffness than the pavement modulus of stiffness associated with that particular temperature

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labelled line. For example, the oblique line in Figure 21 labelled 122° F (50°C) shows that a pavement containing asphalt cement of 100 penetration with a PVN = 0.0 will develop a modulus of stiffness of 37,000 pis under fast traffic at pavement service temperature of 122°F (50°C). However, if the same pavement contained an asphalt cement of 50 penetration at 77°F (25°C) with a PVN = 0.0, which lies to the left of the oblique line labelled 122°F (50°C) in Figure 21, it would develop a modulus of stiffness of 69,000 psi under fast traffic at 122°F (50°C).

11. In tropical countries, pavements with a higher modulus of stiffness would be expected to provide superior service performance because of their higher stability and their greater resistance to failure by fatigue.

12. With respect to the asphalt cements graded by viscosity at 140°F (60°C) that are represented in Figure 21, AC2.1, AC5, AC10, AC20, and AC40, it will be observed that the low penetration at 77°F (25°C) asphalt cements of highest temperature susceptibility on the hard left side of each viscosity grade lie farthest to the left of each pavement service temperature labelled line in Figure 21, and would therefore provide very much higher pavement moduli of stiffness under fast traffic at each of these higher pavement service temperatures, than corresponding high penetration at 77°F (25°C) asphalt cements of low temperature susceptibility from the soft right side of each of these viscosity grades. However, these low penetration at 77°F (25°C) highly temperature susceptible asphalt cements from the hard left end of each viscosity grade, that provide pavements with these very desireable higher moduli of stiffness under fast traffic at high pavement service temperatures, are precisely the asphalt cements that are excluded by the present AASHTO specification based on grading by viscosity at 140°F (60°C), as illustrated by Figure 19.

13. On the other hand, when asphalt cements are graded by penetration at 77°F (25°C), as clearly demonstrated by Figures 12 or 21, for any given penetration grade, it is the pavement containing asphalt cement of lowest temperature susceptibility that lies furthest to the left of any temperature labelled line in Figure 12 or Figure 21 and that will develop the highest pavement modulus of stiffness under fast traffic at pavement service temperatures of 122°F (50°C) or 140°F (60°C) in tropical climates. For example, a pavement containing asphalt cement of 70 penetration at 77°F (25° C) *with a PVN = -1.5,* would develop a modulus of stiffness of 37,000 psi at 122°F (50°C) under fast traffic, as indicated by Figures 12 or 21, whereas, if the pavement contained asphalt cement of 70 penetration at 77°F (25°C) *with a PVN = 0.0,* it would develop a modulus of stiffness of about 52,000 psi under fast traffic at a pavement service temperature of 122°F (50°C).

14. Consequently, if asphalt cements are graded by viscosity at 140°F (60° C), as indicated by Figure 20 only asphalt cements with high penetrations at 77° F (25°C) and of low temperature susceptibility from the soft right side of each viscosity grade at 140°F (60°C) can be selected for good low temperature pavement performance in cold climates. On the other hand, for surface courses under fast traffic at high pavement temperatures in tropical climates, Figure 21 demonstrates that pavements containing asphalt cements of any given viscosity grading at 140°F (60°C) will develop a very much higher modulus of stiffness (higher stability) when the asphalt cement comes from the hard left side (low penetration at 77°F (25°C) and high temperature susceptibility) of the viscosity grade 140°F (60°C) is selected. These two sets of requirements are completely opposite to each other.

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By comparison when paving asphalts are graded by penetration at 77°F (25° C), asphalt cement over the entire range of temperature susceptibility can be employed for good pavement performance at low temperatures in cold climates, Figure 10, while asphalt cements of low temperature susceptibility provide highest moduli of stiffness under fast hot weather traffic in either tropical or cold climates.

For pavements carrying fast traffic at any pavement service temperature below 100°F (37.8°C), for any given viscosity grade at 140°F (60°C), or for any given penetration grade at 77°F (25°C), higher pavement moduli of stiffness are provided when pavements contain asphalt cements of high temperature susceptibility.

15. Asphalt cements are components of asphalt pavements for which one of the most important properties is pavement modulus of stiffness. As Van der Poel[4] has shown, when the modulus of stiffness of an asphalt cement is known, the corresponding modulus of stiffness of a pavement containing this asphalt cement can be read from a nomograph. The steps required to achieve this are as follows:

a) Step 1: As illustrated by Figure 22, assume for example, that the penetration of an asphalt at 77°F (25°C) is 90, and that its PVN value[9] as a measure of its temperature susceptibility is −1.0. A straight line through a penetration of 90 on the left hand ordinate and PVN = −1.0 on the oblique middle line is projected to intersect the left hand ordinate. The point of intersection occurs at a temperature of 20°C (68°F). The temperature for the penetration test is 25°C (77°F). Therefore, the "base" temperature for the asphalt cement is 20 + 25 = 45°C (113°F). The "base" temperature can be looked upon as an adjusted softening point (ring and ball) of the asphalt cement.

b) Step 2: As an example, a time of loading of 0.008 second, and a service temperature of 122°F (50°C), are assumed. Relative to the base temperature of 45°C, the service temperature is 50−45 = 5°C above the base temperature.

c) Step 3: A straight line from a loading time of 0.008 second on the bottom horizontal line of Figure 23, through a temperature 5°C above the base temperature on the intermediate horizontal line, is projected upward to intersect the horizontal line representing a PVN = −1.0. This point of intersection occurs at 1.6 km/cm^2 or 22.7 psi, which is the modulus of stiffness of the asphalt cement.

d) Step 4: Enter the abscissa of Figure 24 at 22.7 psi, the modulus of stiffness of the asphalt cement, proceed vertically upward to the curve representing a C_v value of 0.88 (VMA = 14.5 percent, air voids = 3 percent), then horizontally to the left hand ordinate which provides corresponding moduli of stiffness for paving mixtures containing asphalt cements with the moduli of stiffness shown by the abscissa. The point of intersection with the left hand ordinate indicates that the modulus of stiffness for the paving mixture is 33,000 psi (2324 kg/cm^2).

16. A major argument that has been advanced to support grading asphalt cements by viscosity in poises at 140°F (60°C), has been that poises are fundamental units of viscosity, whereas units of penetration at 77°F (25°C) provide only an empirical measurement.

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The validity of this reasoning can be questioned, since as indicated by Figures 22 and 23, from the penetration at 77°F (25°C) of an asphalt cement and its temperature susceptibility as measured by its pen-vis number (PVN) the modulus of stiffness of the asphalt cement can be read from a nomograph, Figure 23, for any given service temperature and time of loading. Consequently the penetration at 77°F (25°C) of an asphalt cement is linked directly to its modulus of stiffness. In turn, modulus of stiffness is a fundamental property of an asphalt cement.

17. Engineers are or should be primarily concerned with the modulus of stiffness of the pavement containing any asphalt cement. Consequently, they need to be aware that relatively speaking neither the penetration at 77°F (25°C) nor the viscosity in poises at 140°F (60°C) of an asphalt cement exert more than a minor influence on pavement modulus of stiffness. This is because the modulus of stiffness of a pavement is much more greatly influenced by its environment in terms of service temperature and time of loading than by the penetration at 77°F (25°C) or viscosity at 140°F (60°C) and the temperature susceptibility of the asphalt cement it contains. Comparison of Figure 7 with Figure 6 indicates the enormous influence of loading time at any given service temperature on pavement modulus of stiffness, and therefore, as indicated by Figure 24, on the modulus of stiffness of the asphalt cement contained in the pavement. Under a parked vehicle, Figure 7 shows that a pavement containing 85/100 penetration cement with a PVN = 0.0 developed a modulus of stiffness of only 1.0 psi for a loading time of 20,000 seconds at 122°F (50°C), but as demonstrated by Figure 6, developed a modulus of stiffness of about 40,000 psi at 122°F (50°C) for a loading time of 0.008 second corresponding to fast truck traffic. This is a difference of 40,000 times due solely to a difference in loading times.

Similarly, Figure 6 demonstrates that for a loading time of 0.008 second, a pavement containing 85/100 penetration asphalt cement with a PVN = 0.0, develops a modulus of stiffness of about 19,000 psi at a temperature of 140°F (60°C), but develops a modulus of stiffness of 1,400,000 psi at a temperature of 50°F (10°C), and the pavement modulus of stiffness would be much higher at still lower service temperatures. This difference is about 74-fold due only to the difference in pavement service temperatures between 140°F (60°C) and 50°F (10°C).

By contrast, for a loading time of 0.008 second, and at a pavement service temperature of 122°F (50°C), for example, a pavement containing 300/400 penetration asphalt cement with a PVN of 0.0 develops a modulus of stiffness of about 12,500 psi, while if it contains 40/50 penetration paving asphalt with a PVN = 0.0, it develops a modulus of stiffness of about 75,000 psi. This represents a difference of only 6-fold for a normal practical range of asphalt cement grades. The influence of a difference in temperature susceptibility of asphalt cements is also relatively small. Figure 6 shows that for a fast loading time of 0.008 second and a pavement service temperature of 140°F (60°C), a pavement containing 85/100 penetration asphalt cement with a PVN = 0.0 will develop a modulus of stiffness of 19,000 psi, whereas if it has a PVN = −1.5 it will develop a modulus of stiffness of 11,000 psi, a difference that is less than 2-fold.

Consequently, the two environmental factors, difference in pavement service temperatures, and difference in times of loading, have an emormously

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greater influence on the moduli of stiffness developed by an asphalt pavement or by an asphalt cement, than practical differences in either penetration at 77°F (25°C), or viscosity in poises at 140°F (60°C), or in temperature susceptibility of an asphalt cement.

18. Figures 22 and 23 demonstrate that penetration at 77°F (25°C) is directly associated with *the modulus of stiffness of an asphalt cement, which is a fundamental property of asphalt cements.* At the present time, simple comprehensive easy-to-use nomographs like Figures 22, 23, and 24, that are based on the penetration at 77°F (25°C) and the associated temperature susceptibility (PVN) of an asphalt cement, which can be used to determine the modulus of stiffness of either the asphalt cement, or of a paving mixture containing the asphalt cement, as soon as the pavement service temperature and time of loading have been specified, do not exist in terms of asphalt cement viscosity grading at 140°F (60°C).

SUMMARY

1. The practical significance of the temperature susceptibility of asphalt cements, and of the need to refer to temperature susceptibility in asphalt cement specifications, is reviewed.

2. A proposal is made, and its advantages are illustrated in Figures 3 and 5, to more effectively control temperature susceptibility in specifications for asphalt cements, by substituting one or more minimum PVN values for minimum requirements of viscosity at 275°F (135°C) when asphalt cements are graded by penetration at 77°F (25°C), and for minimum requirements for penetration at 77°F (25°C) when asphalt cements are graded by viscosity at 140°F (60°C).

3. Reference is made to the very satisfactory service performance of pavements containing asphalt cements of high temperature susceptibility.

4. Figure 6 indicates the great influence on pavement modulus of stiffness (pavement stability) under fast truck traffic in warm weather, that can result from changes in pavement service temperature, and from changes in penetration at 77°F (25°C) and in temperature susceptibility of asphalt cements contained in these pavements.

5. Figure 6 also demonstrates that under fast truck traffic at pavement service temperatures 100°F (37.8°C), if a pavement contains asphalt cement of any given penetration at 77°F (25°C), it will develop a higher modulus of stiffness (higher stability) if the asphalt cement is of high rather than of low temperature susceptibility, this is contrary to Marshall test results probably because of the long loading time of the Marshall test (3 seconds for a flow index of 10) relative to the very short loading time (0.008 second) for a heavy truck travelling at 100km/hour (62.2 miles per hour). This also explains the high stability that has been exhibited by the many asphalt pavements in Canada that have been constructed with asphalt cements of high temperature susceptibility.

6. Figure 7 demonstrates that the asphalt cement appears to contribute very little to the stability of pavements supporting stationary vehicles for long periods, and that the stability of pavements in parking areas therefore, appears to depend primarily on the stability of the aggregate in the pavement.

7. Figure 10 has been prepared to guide the selection of asphalt cements for pavements that are being designed to avoid low temperature transverse pavement cracking.

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8. Figure 11, provides guidance for the selection of asphalt cements for pavements with adequate stability (modulus of stiffness) under fast traffic at high pavement service temperatures in tropical climates.

9. Figures 14 to 18 have been prepared to guide the selection of asphalt cements for good pavement performance in both cold and warm weather in cool to moderate climates.

10. The following limited comparison is made between grading asphalt cements by penetration at 77°F (25°C) and grading them by viscosity at 140°F (60°C):

a) With respect to grading asphalt cements by viscosity in poises at 140°F (60°C):

1. As demonstrated by Figure 20, only the soft right hand tip of any viscosity grade, representing asphalt cements of high penetration at 77°F (25°C) and low temperature susceptibility can be selected to provide pavements that will avoid low temperature transverse pavement cracking in cold climates.
2. As illustrated by Figure 21, pavements containing asphalt cements of any given viscosity grading at 140°F (60°C) will develop very much higher pavement modulus of the stiffness under fast traffic in tropical climates when the asphalt cement comes from the hard left side (low penetration at 77°F (25°C) and high temperature susceptibility) of the viscosity grade at 140°F (60°C) selected. These asphalt cements are excluded by the present AASHTO specification.
3. Consequently, when asphalt cements are graded by viscosity at 140°F (60°C), the asphalt cement requirements for good low temperature pavement performance in cold climates (high penetration at 77°F (25° C) and low temperature susceptibility), are completely opposite to the asphalt cement requirements for higher pavement modulus of stiffness in hot climates (low penetration at 77°F (25°C) and high temperature susceptibility.

b) With regard to grading asphalt cements by penetration at 77°F (25°C):

1. As shown by Figures 10 and 20, asphalt cements from the whole range of temperature susceptibility can be selected to provide pavements that will avoid low temperature transverse pavement cracking during cold winters.
2. As demonstrated by Figures 12 or 21, for fast traffic in tropical climates pavements containing asphalt cements of any given penetration at 77°F (25°C) will develop higher pavement modulus of stiffness when the asphalt cements are of low temperature susceptibility.
3. Consequently, when asphalt cements are graded by penetration at 77° F (25°C), asphalt cements from the entire spectrum of temperature susceptibility can be selected to avoid low temperature transverse pavement cracking in cold climates, but for pavements containing asphalt cement of any given penetration at 77°F (25°C), highest pavement modulus of stiffness will develop under fast traffic in tropical climates if the asphalt cement is of low temperature susceptibility.

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c) A major argument in favour of grading asphalt cements by viscosity in poises at 140°F (60°C) is that poises are fundamental units of viscosity whereas units of penetration at 77°F (25°C) are not. The validity of this argument can be questioned, since as illustrated by Figures 22 and 23, grading asphalt cements by penetration at 77°F (25°C) provides an essential linkage when determining the modulus of stiffness of an asphalt cement. *Modulus of stiffness is a fundamental property of an asphalt cement.*

d) At the present time, simple, comprehensive and easy-to-use nomographs like Figures 22, 23, and 24, that are based on the penetration at 77°F (25° C) and the temperature susceptibility of an asphalt cement, which can be used to determine the modulus of stiffness of the asphalt cement, or of a paving mixture containing the asphalt cement as soon as the pavement service temperature and time of loading have been specified, do not exist in terms of asphalt cement viscosity grading at 140°F (60°C).

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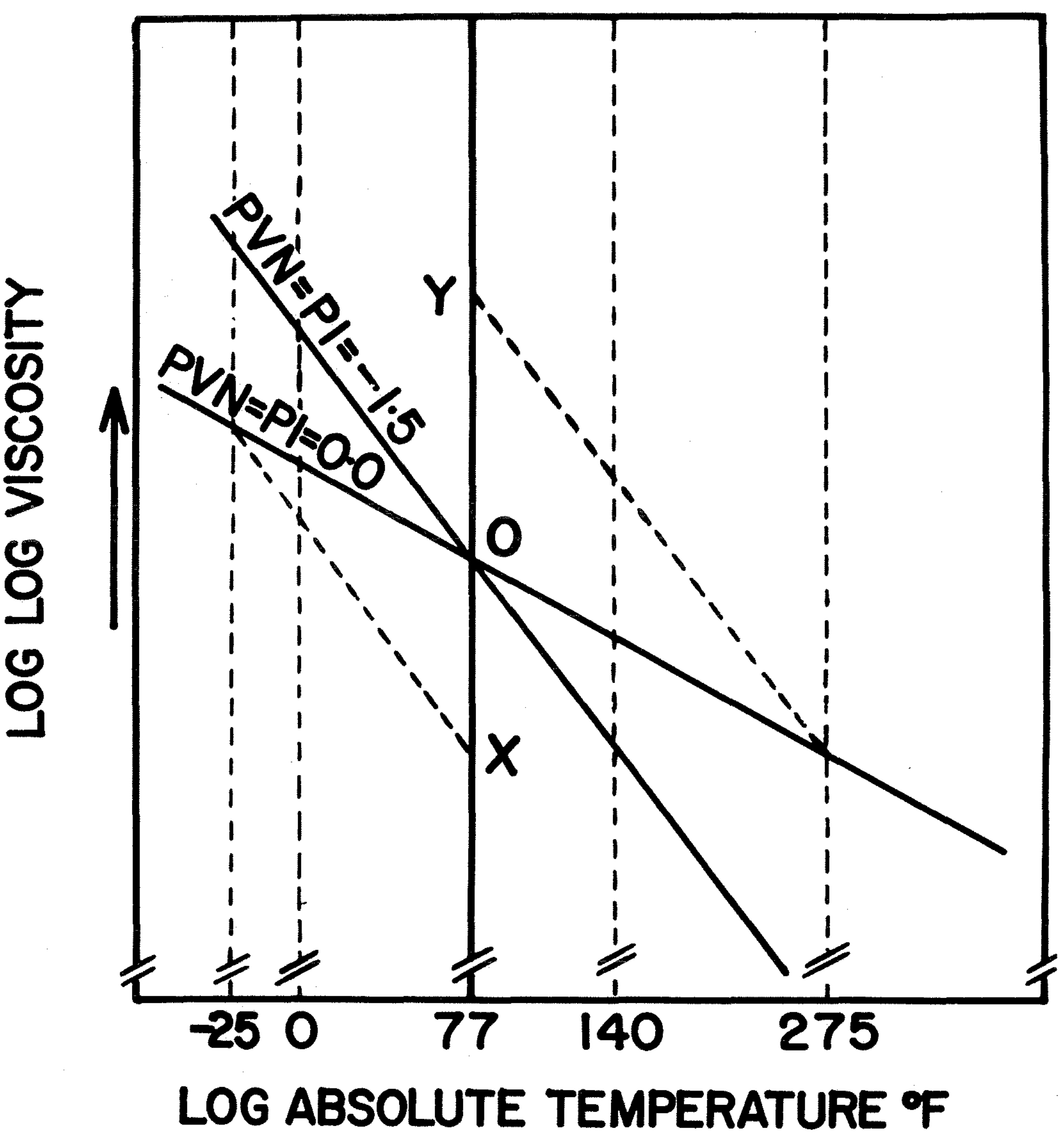

FIGURE 1 SKETCH ILLUSTRATING INFLUENCE OF PEN-VIS NUMBERS (PI VALUES) ON RELATIONSHIPS BETWEEN VISCOSITY AND TEMPERATURE OF ASPHALT CEMENTS.

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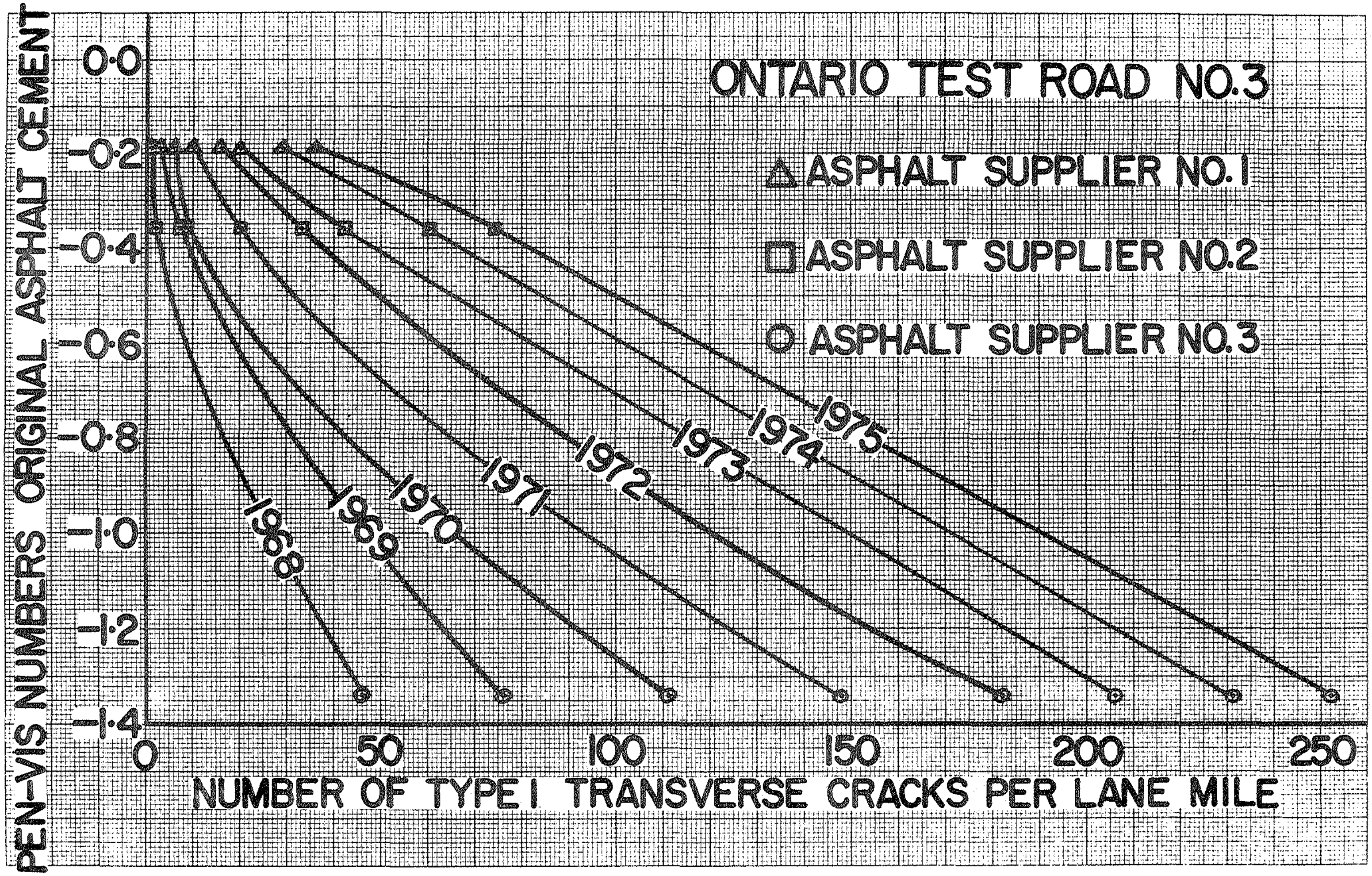

Figure 2 Illustrating annual increase in Type 1 low temperature transverse pavement cracks per lane mile in Ontario Test Road No. 3.

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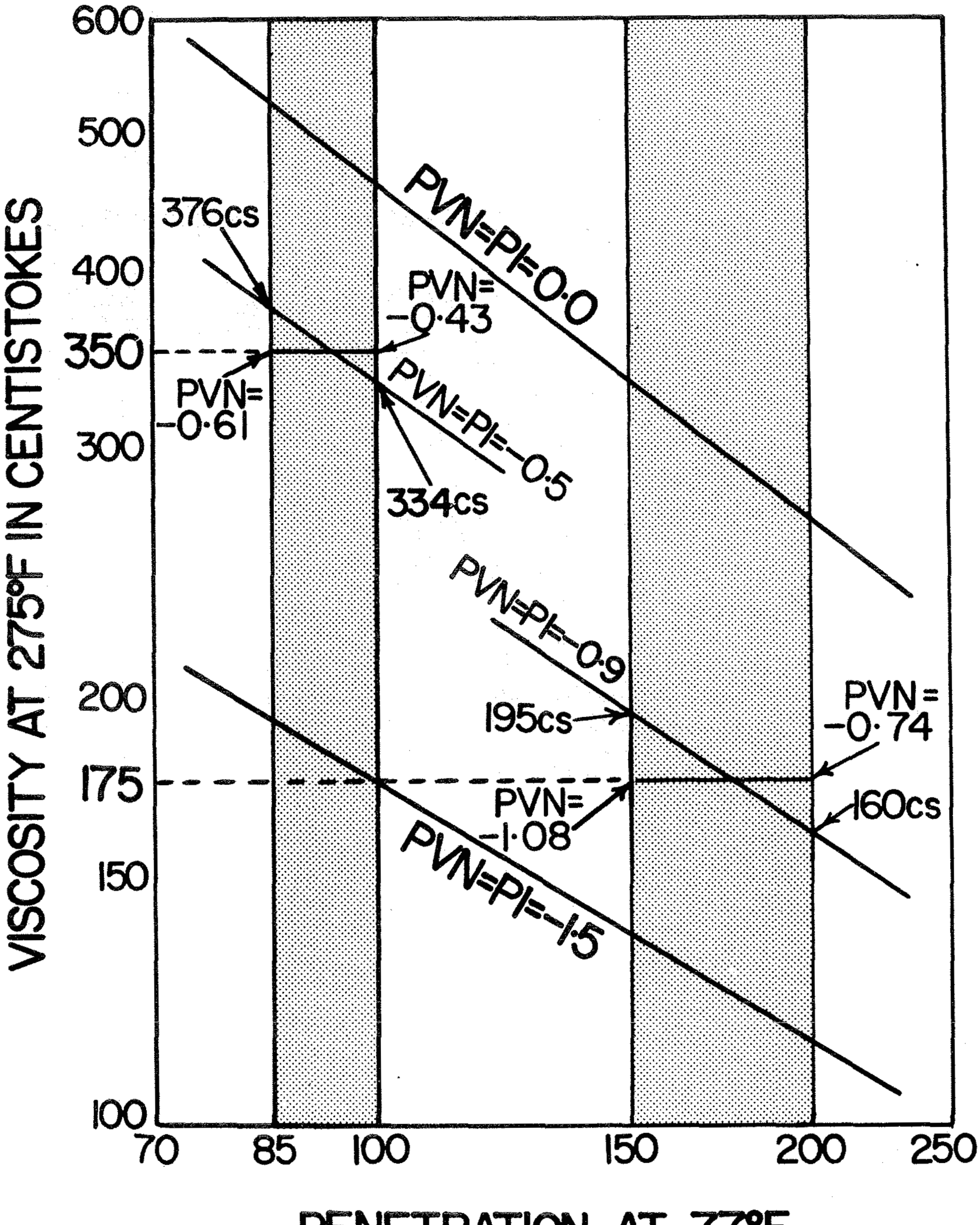

FIGURE 3 ILLUSTRATING BENEFITS FROM CONTROLLING THE TEMPERATURE SUSCEPTIBILITY OF ASPHALT CEMENTS BY MEANS OF MINIMUM PVN VALUES RATHER THAN BY MINIMUM VISCOSITY REQUIREMENTS AT 275°F.

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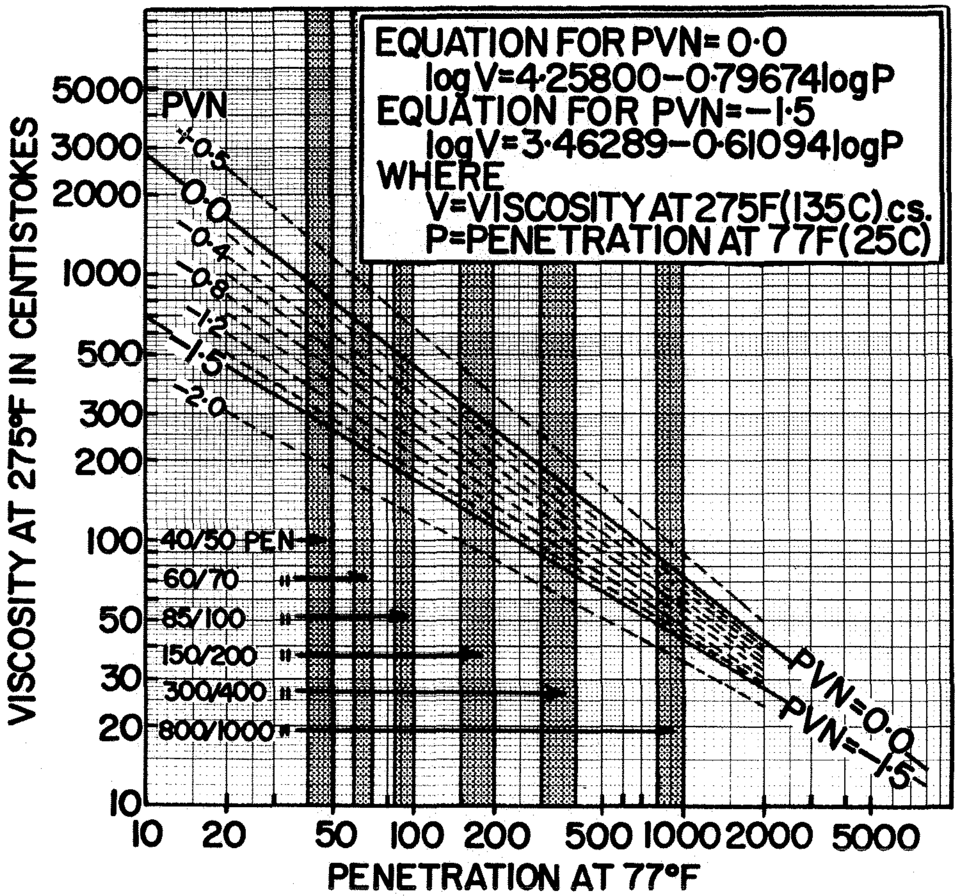

FIGURE 4 A CHART FOR THE DETERMINATION OF APPROXIMATE VALUES FOR PEN-VIS NUMBERS FOR ASPHALT CEMENTS.

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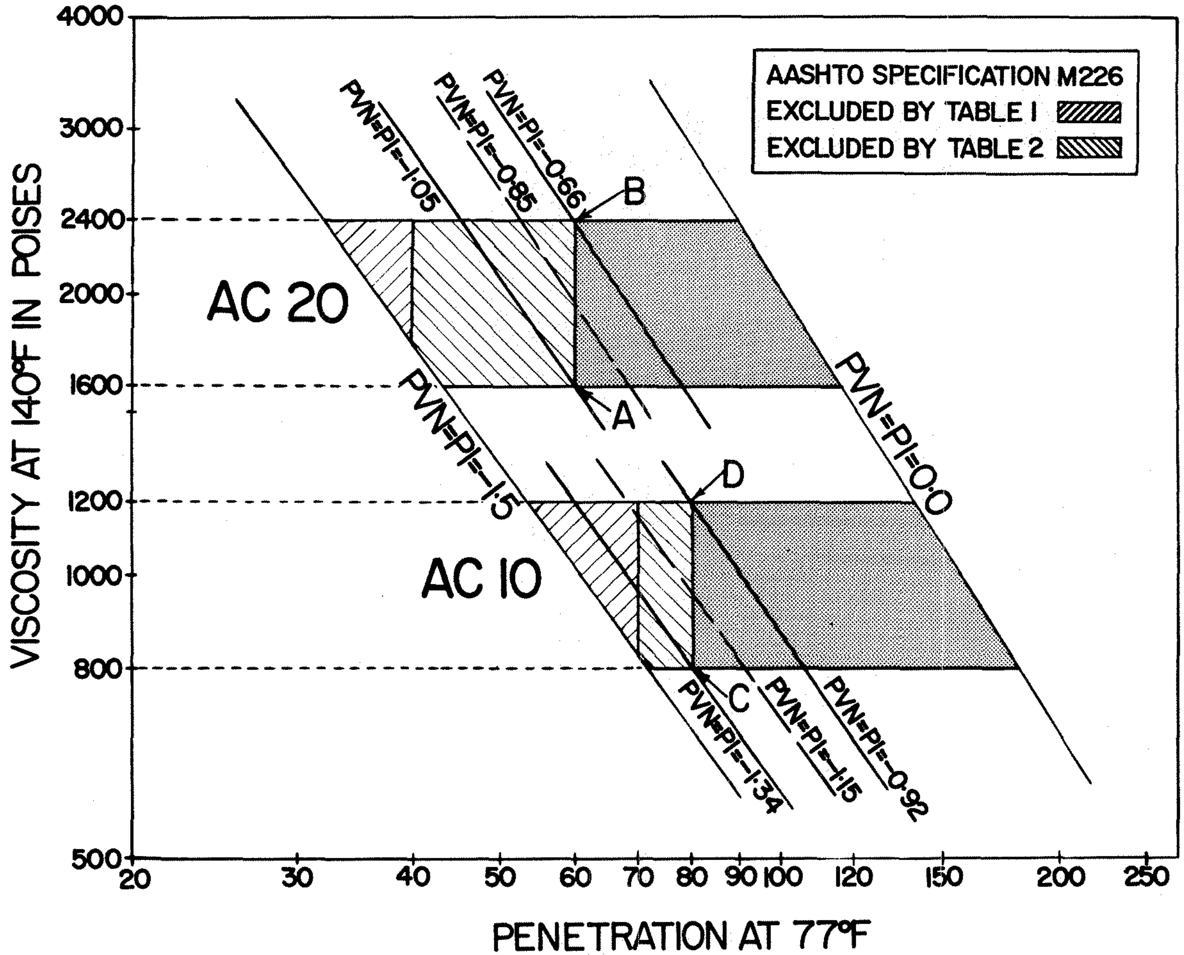

FIGURE 5 ILLUSTRATING BENEFITS FROM CONTROLLING THE TEMPERATURE SUSCEPTIBILITY OF ASPHALT CEMENTS BY MEANS OF MINIMUM PVN VALUES RATHER THAN BY MINIMUM PENETRATION REQUIREMENTS AT 77°F(25°C).

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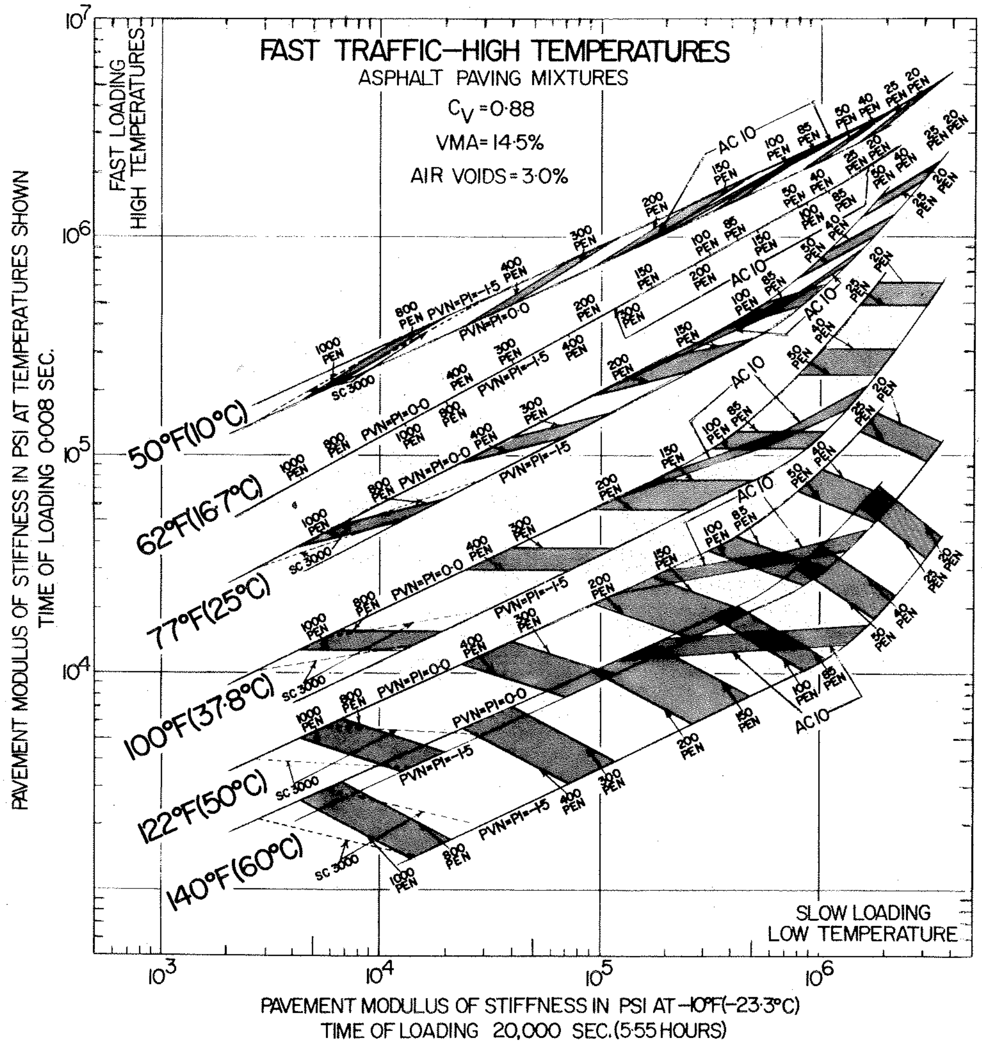

FIGURE 6 ILLUSTRATING INFLUENCE OF PAVEMENT TEMPERATURES, ASPHALT GRADE AND TEMPERATURE SUSCEPTIBILITY, ON PAVEMENT MODULI OF STIFFNESS (STABILITY) UNDER FAST TRUCK TRAFFIC AT HIGHER PAVEMENT TEMPERATURES.

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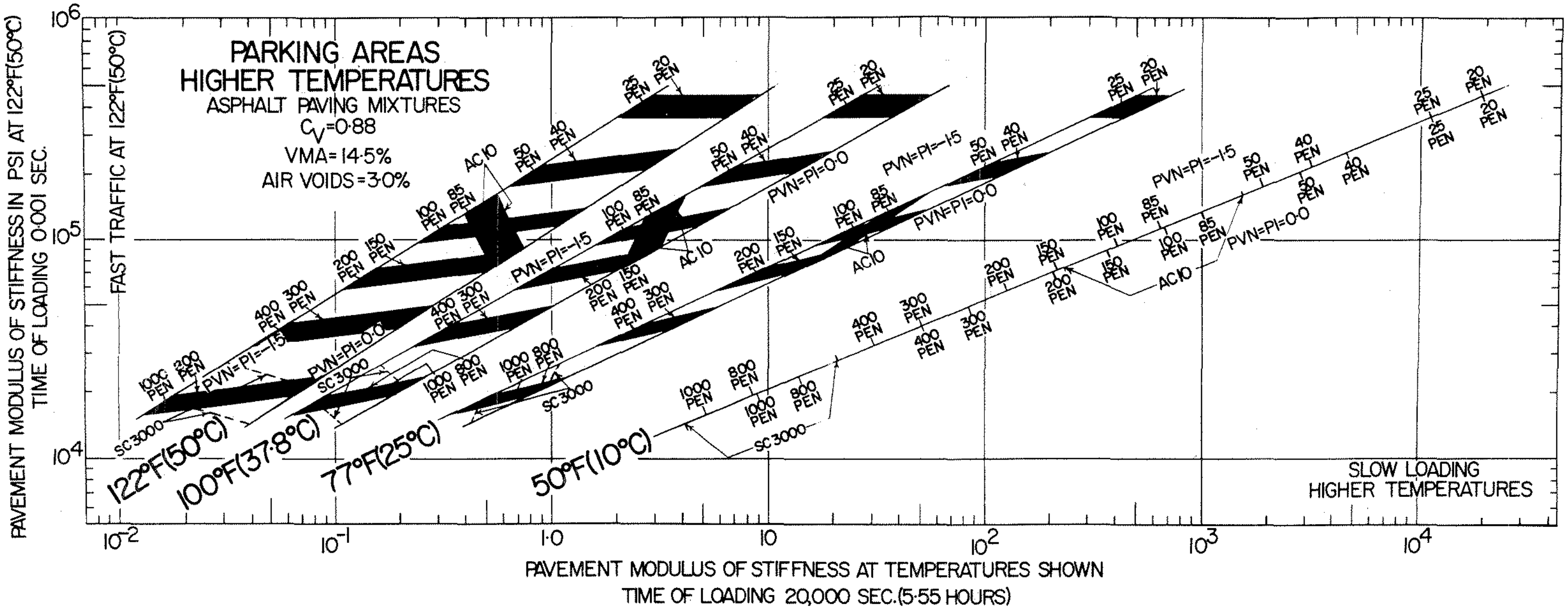

FIGURE 7 ILLUSTRATING INFLUENCE OF ASPHALT GRADE AND TEMPERATURE SUSCEPTIBILITY AND PAVEMENT SERVICE TEMPERATURE ON PAVEMENT MODULI OF STIFFNESS DEVELOPED BY PARKED VEHICLES.

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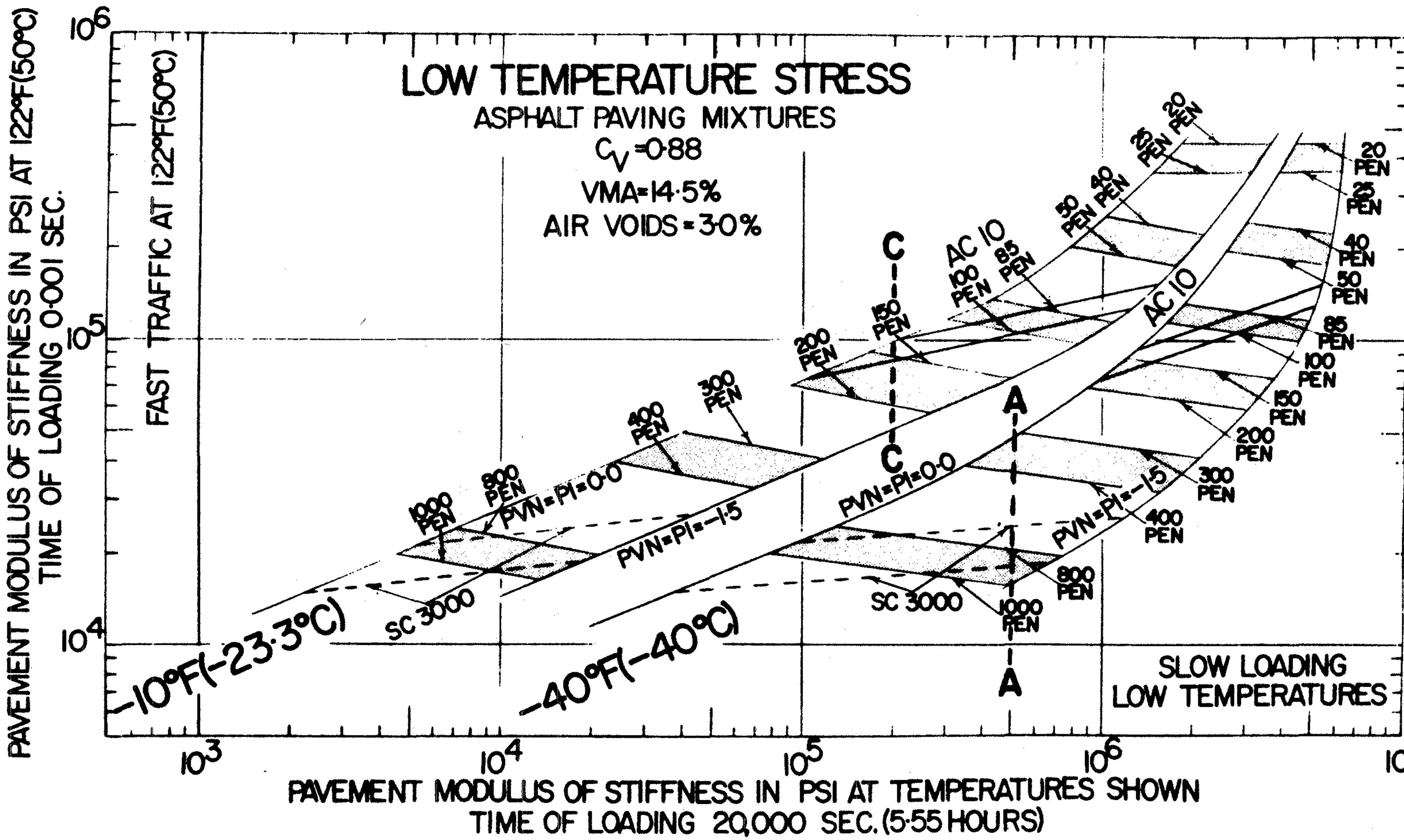

FIGURE 8 ILLUSTRATING FACTORS THAT CONTRIBUTE TO PAVEMENT MODULI OF STIFFNESS UNDER SLOW LOADING AT -10°F and -40°F.

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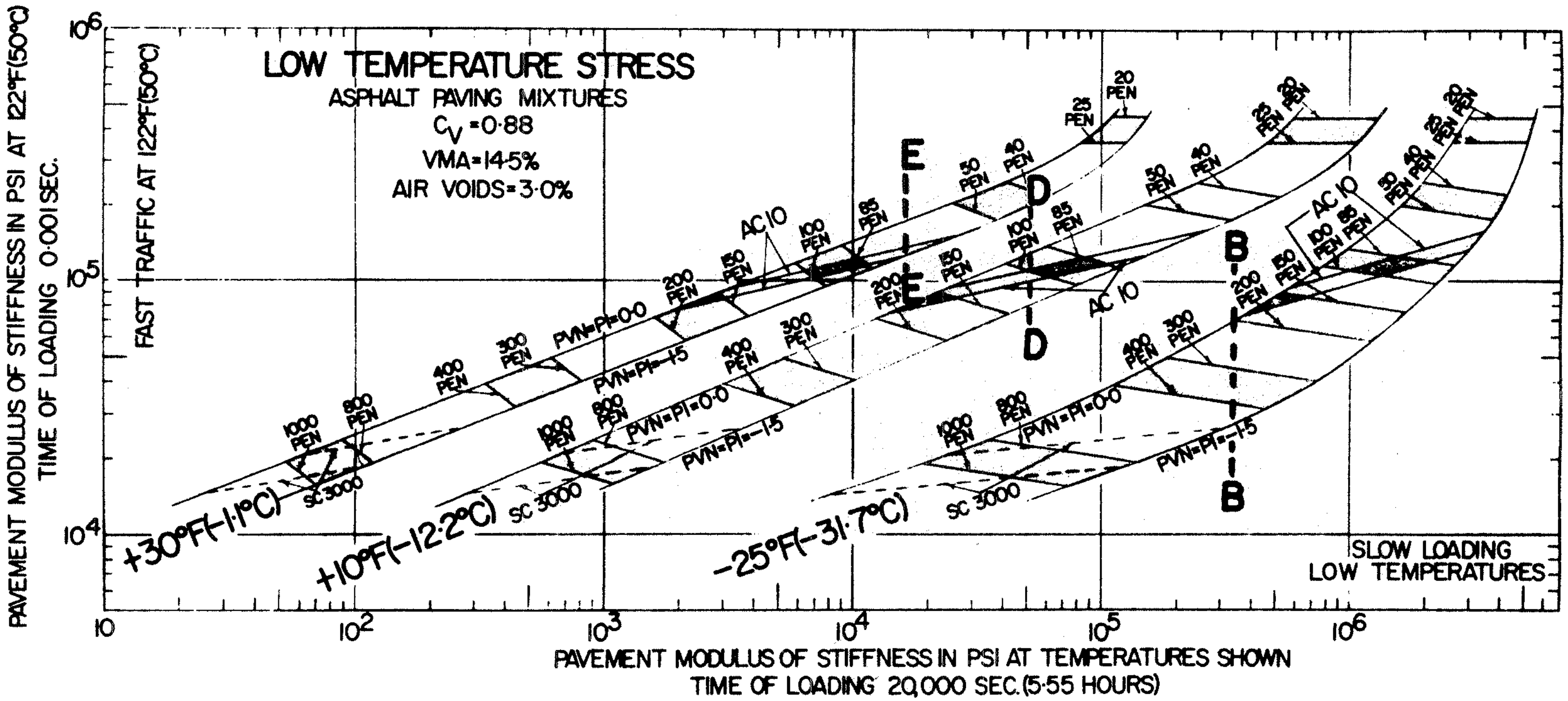

FIGURE 9 ILLUSTRATING FACTORS THAT CONTRIBUTE TO PAVEMENT MODULI OF STIFFNESS UNDER SLOW LOADING AT 30°F, 10°F, and -25°F.

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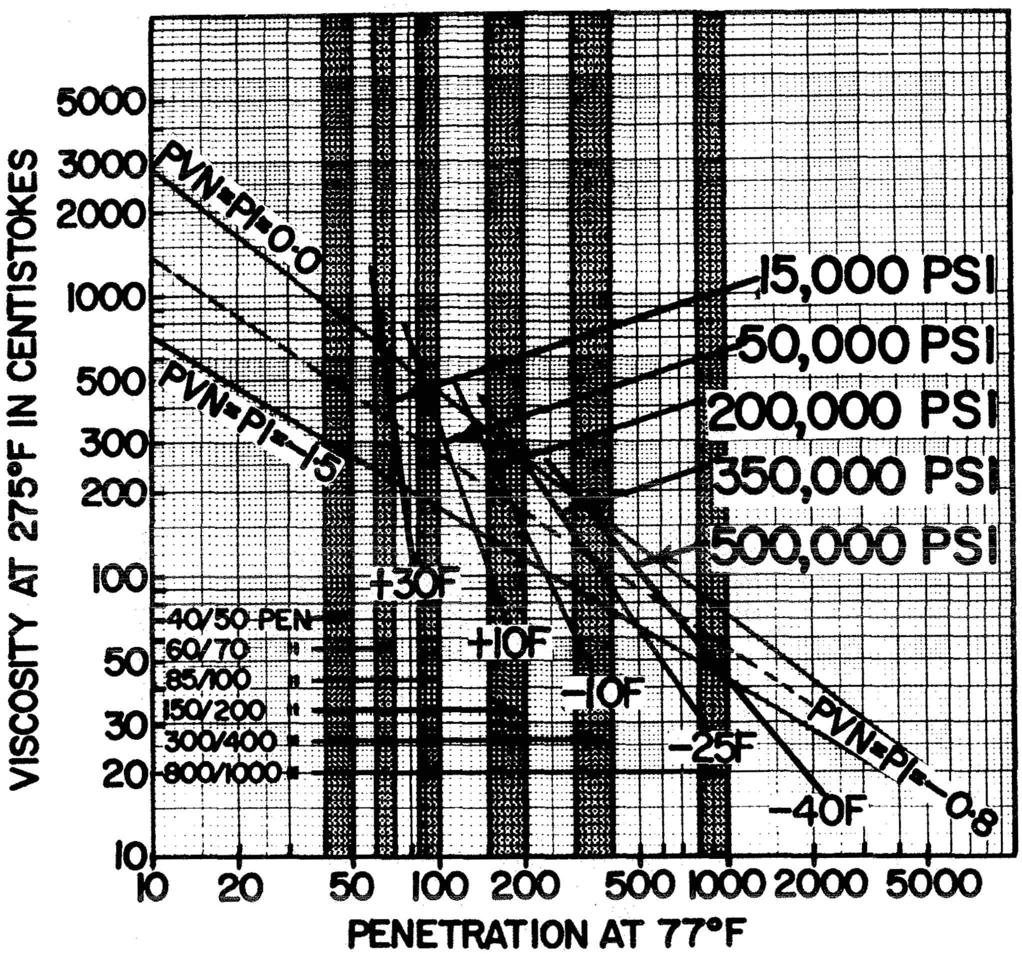

Figure 10 A chart for selecting grades of asphalt cement to avoid low temperature transverse pavement cracking.

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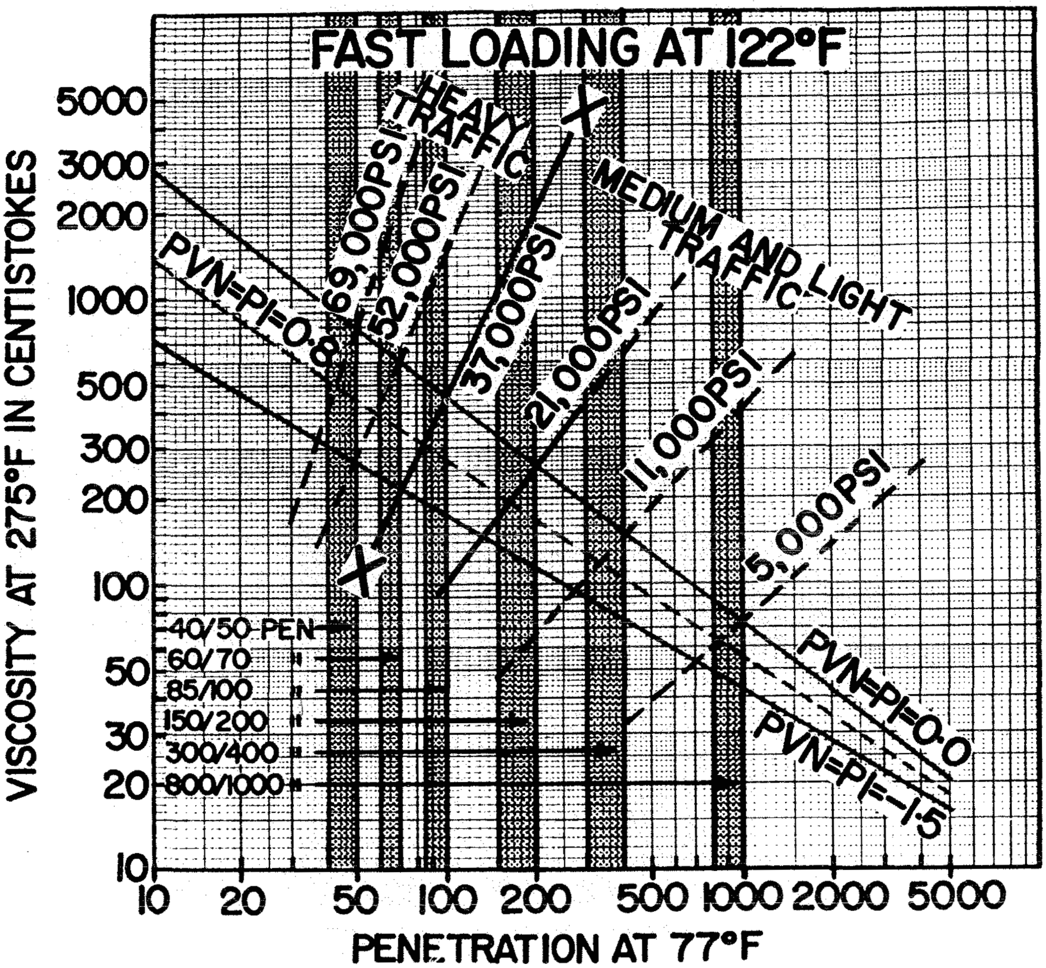

Figure 11 A chart for selecting asphalt cements for asphalt surface courses in hot climates, based on fast truck traffic and a temperature of 122°F at a pavement depth of 2 inches.

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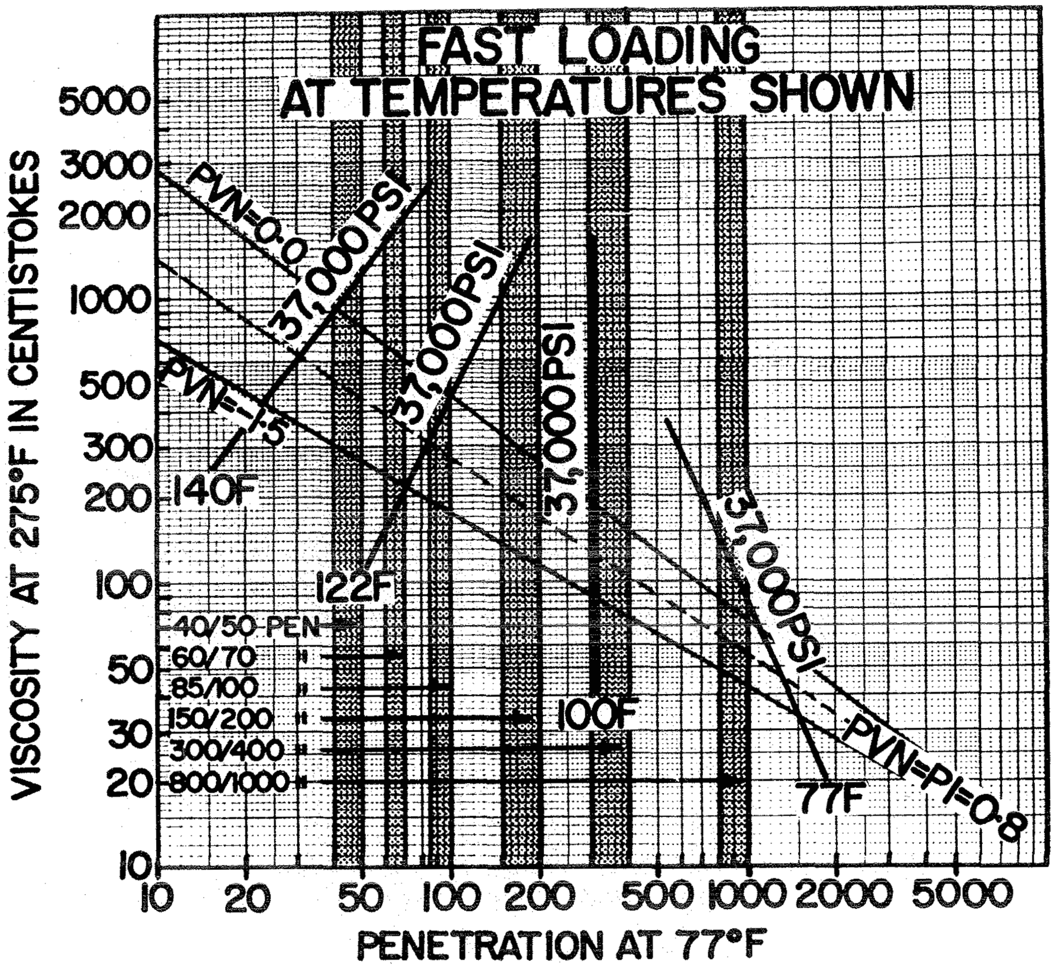

Figure 12 Illustrating combinations of penetrations at 77° F (25°C) and pen-vis numbers (PVN) for asphalt cements all of which provide a pavement modulus of stiffness of 37,000 psi under fast truck traffic at each of the pavement temperatures indicated.

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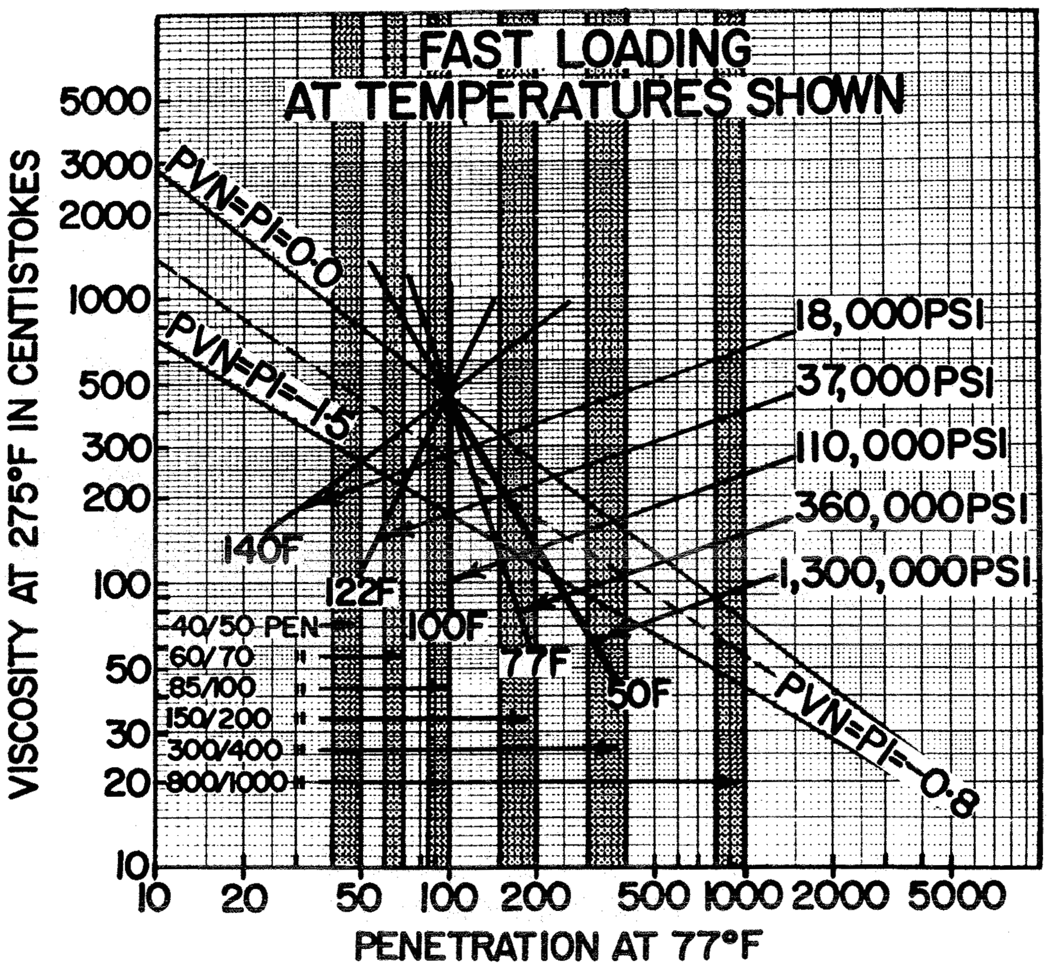

Figure 13 Illustrating combinations of penetrations at 77°F (25°C) and pen-vis numbers (PVN) for asphalt cements that provide identical pavement modulus of stiffness values under fast truck traffic at each of several service temperatures.

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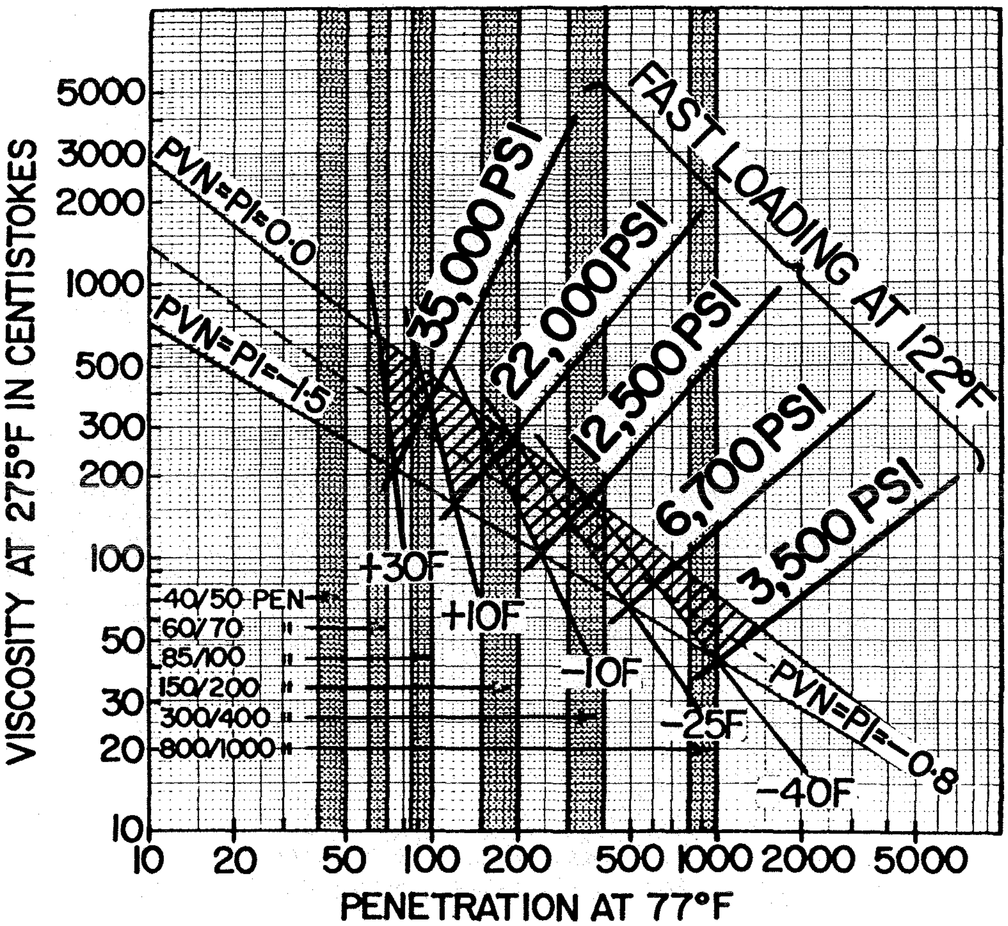

FIGURE 14 WHEN ASPHALT CEMENTS ARE GRADED BY PENETRATION AT 77°F(25°C), CROSS HATCHED AREAS GUIDE THE SELECTION OF ASPHALT CEMENTS THAT WILL PROVIDE THE PAVEMENT MODULI OF STIFFNESS UNDER FAST TRUCK TRAFFIC AT 122°F(50°C) ILLUSTRATED, WHEN TRANSVERSE CRACKING IS TO BE AVOIDED AT EACH OF THE LOW PAVEMENT TEMPERATURES INDICATED.

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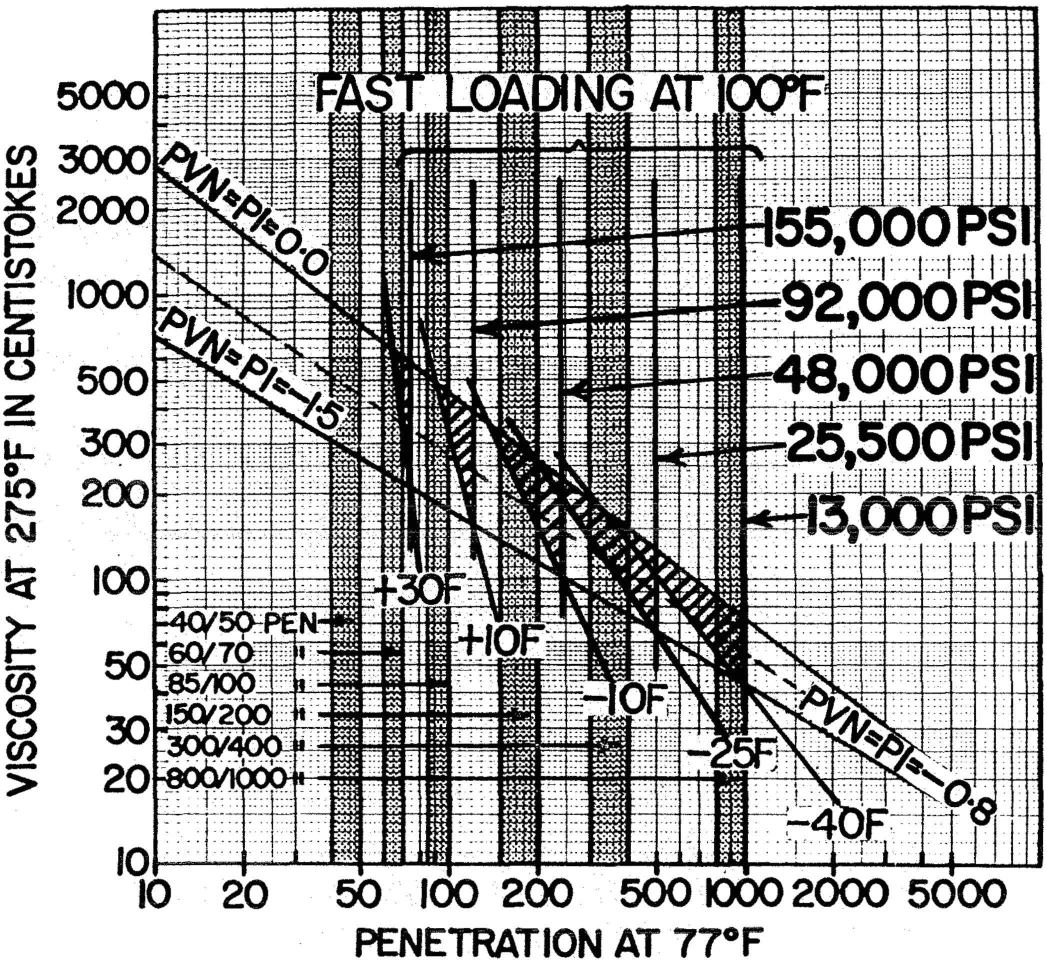

Figure 15 When asphalt cements are graded by penetration at 77°F (25°C) cross hatched areas guide the selection of asphalt cements that will provide the pavement moduli of stiffness under fast truck traffic at 100°F (37.8°C) illustrated, when transverse pavement cracking is avoided at each of the low pavement temperatures indicated.

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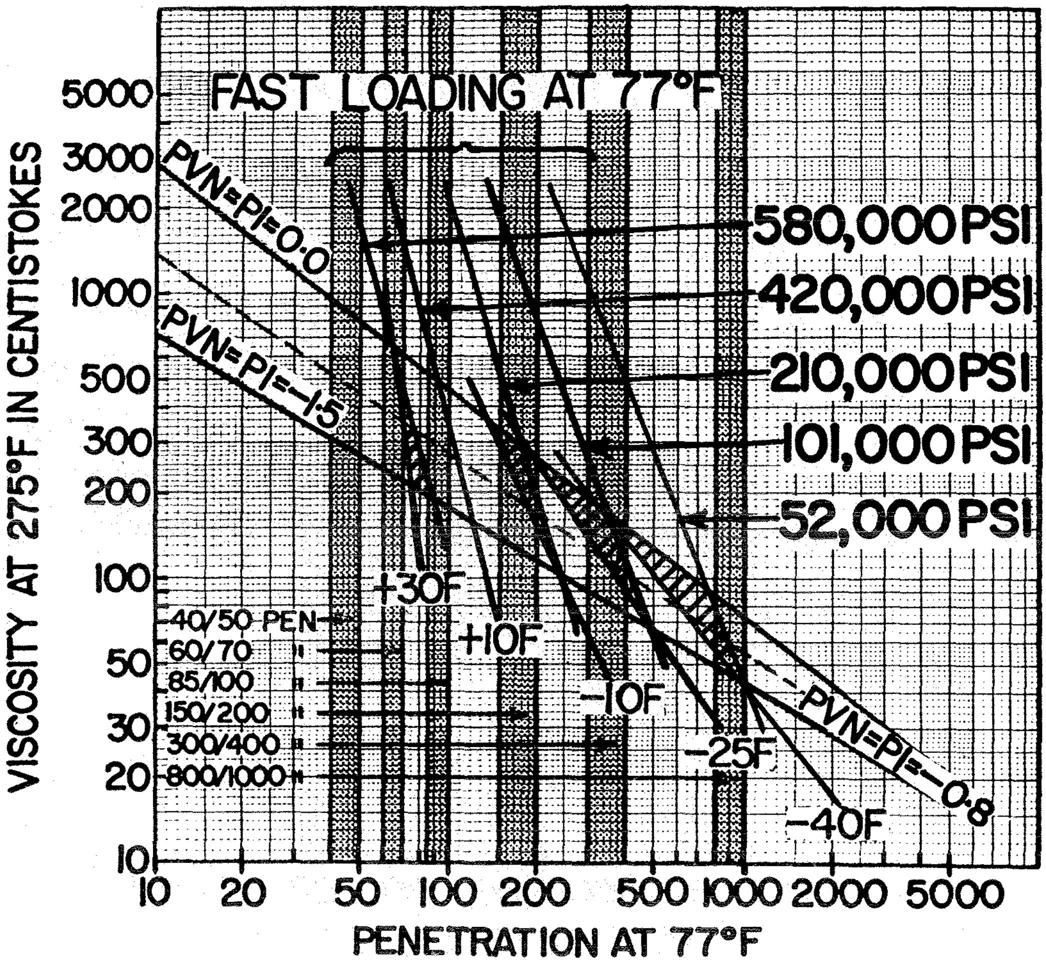

Figure 16 When asphalt cements are graded by penetration at 77°F (25°C) cross hatched areas guide the selection of asphalt cements that will provide the pavement moduli of stiffness under fast truck traffic at 77°F (25°C) illustrated, when transverse pavement cracking is avoided at each of the low pavement temperatures indicated.

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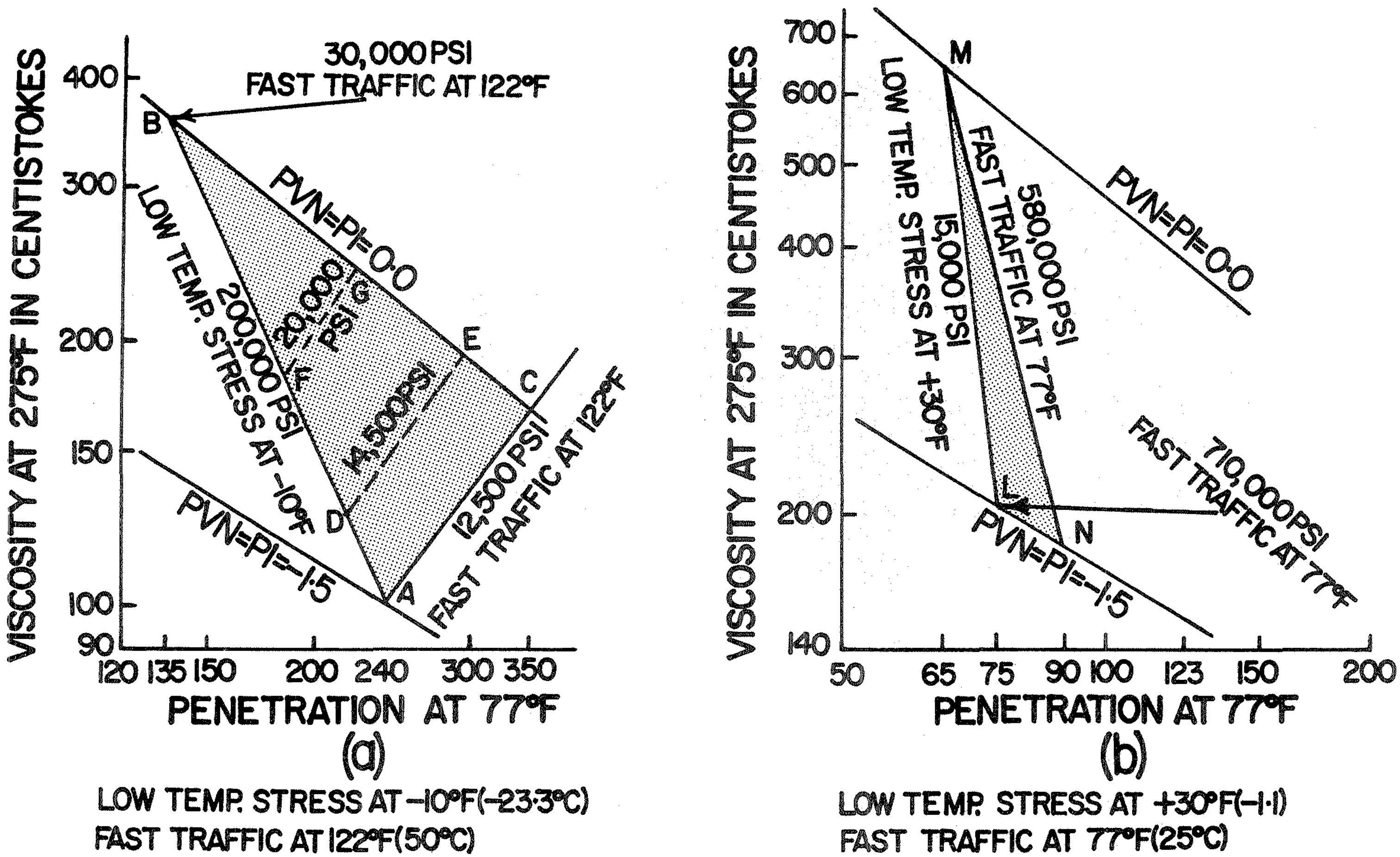

FIGURE 17 ENLARGED SKETCHES TO EXPLAIN THE SELECTION OF ASPHALT CEMENTS FOR GOOD PAVEMENT PERFORMANCE IN BOTH WINTER AND SUMMER IN COOL TO MODERATE CLIMATES.

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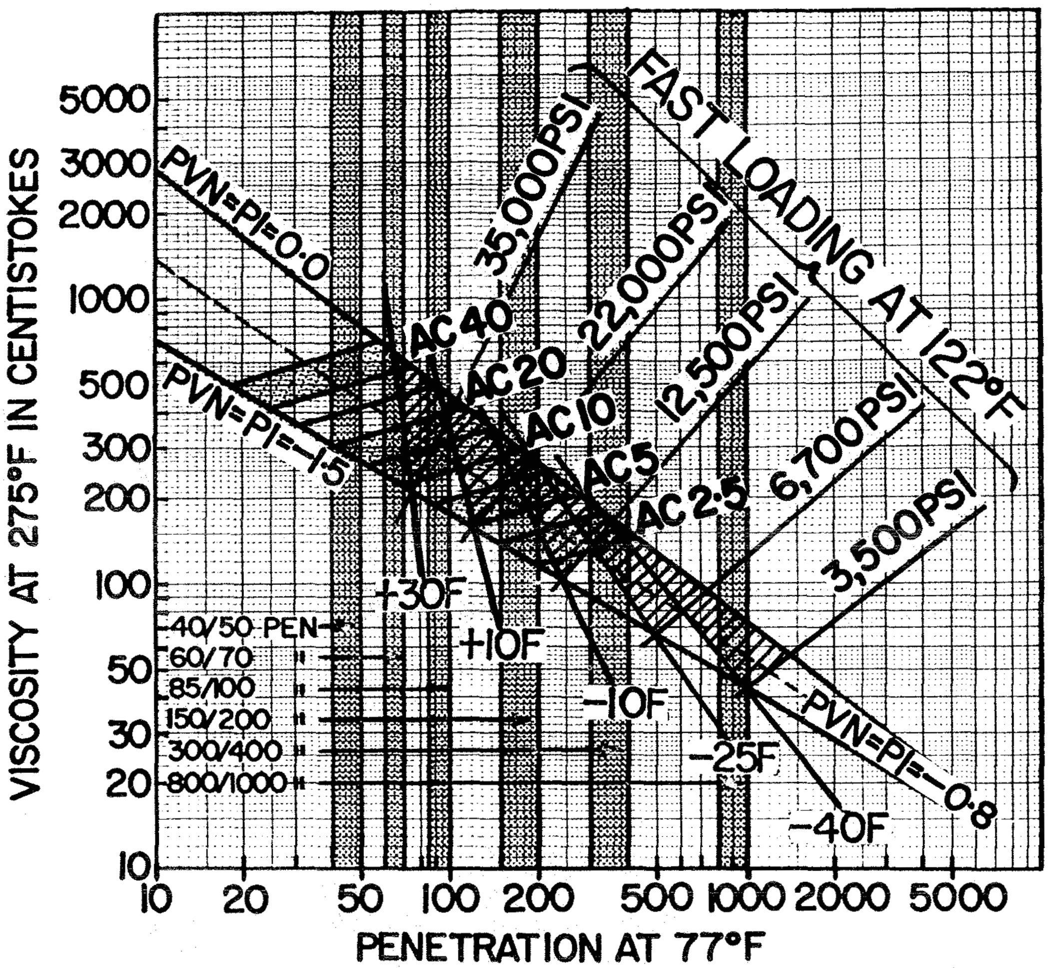

Figure 18 When asphalt cements are graded by viscosity at 140°F (60°C) cross hatched areas guide the selection of asphalt cements that will provide the pavement moduli of stiffness under fast truck traffic at 122°F (50°C) illustrated, when transverse pavement cracking is avoided at each of the low pavement temperatures indicated.

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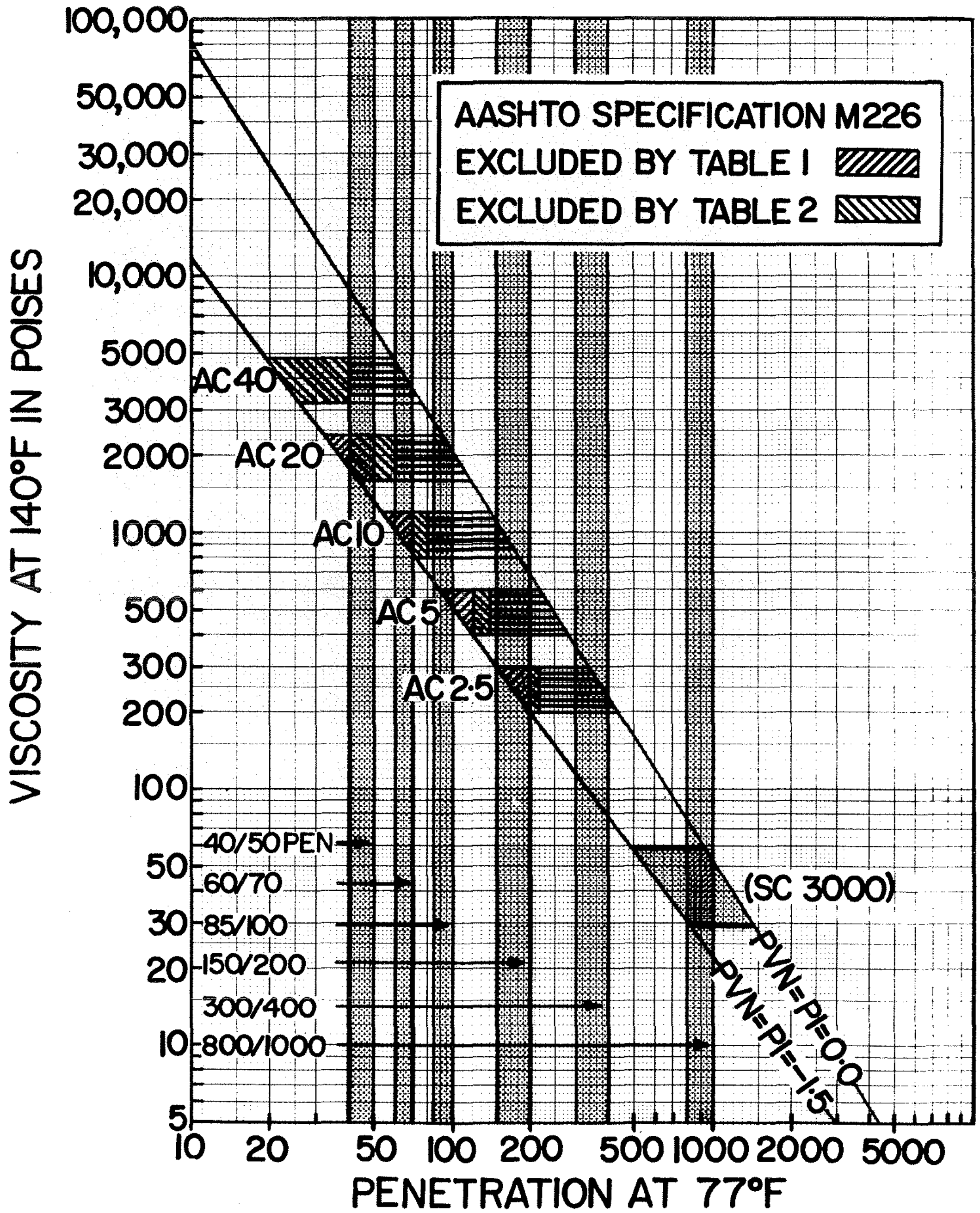

FIGURE 19 RELATIONSHIPS BETWEEN VISCOSITY AT 140°F IN POISES, PENETRATION AT 77°F, AND TEMPERATURE SUSCEPTIBILITY.

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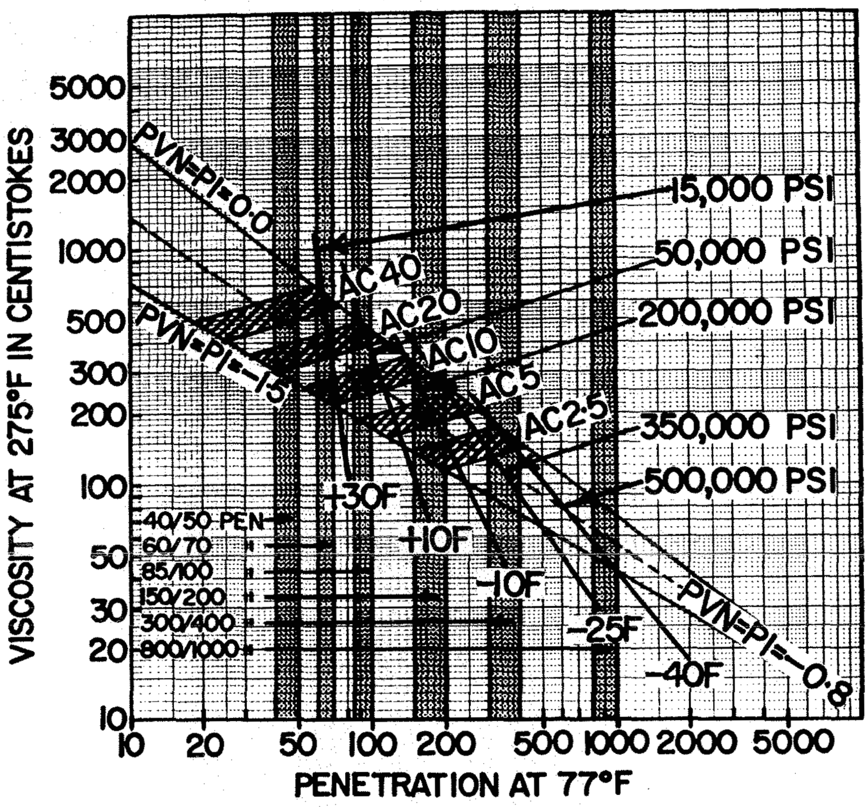

FIGURE 20 DEMONSTRATING THAT GRADING ASPHALT CEMENTS BY VISCOSITY AT 140°F(60°C) FAVOURS THE HIGH PENETRATION AT 77°F(25°C) AND LOW TEMPERATURE SUSCEPTIBILITY SOFT END OF EACH VISCOSITY GRADE WHEN AVOIDING LOW TEMPERATURE TRANSVERSE PAVEMENT CRACKING.

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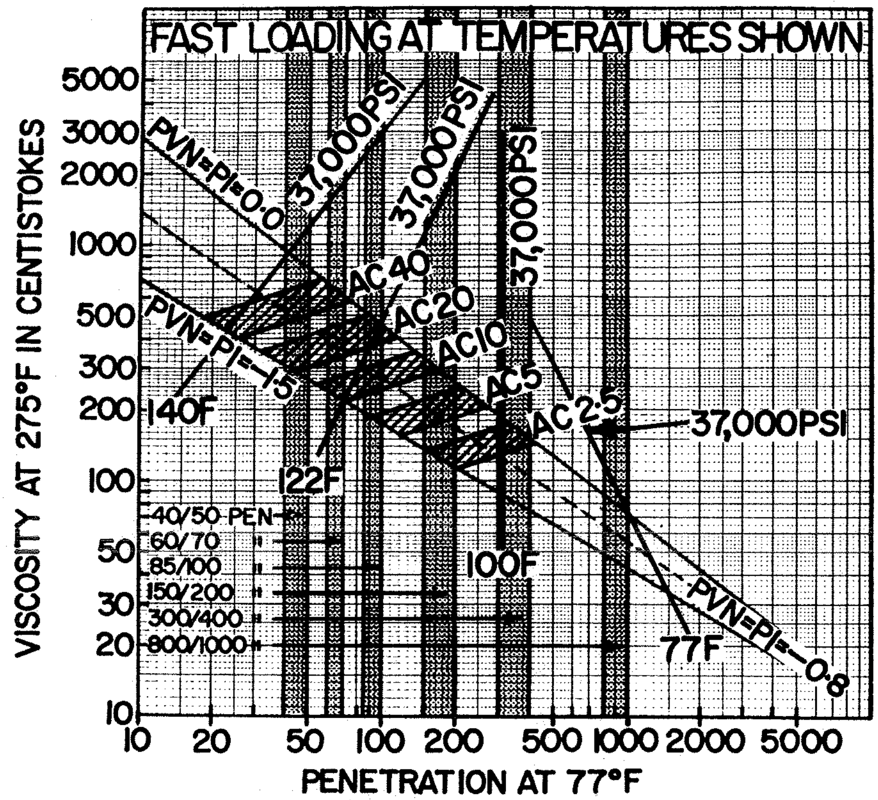

FIGURE 21 ILLUSTRATING THAT PAVEMENTS CONTAINING ASPHALT CEMENTS OF EACH VISCOSITY GRADE AT 140°F(60°C) WILL DEVELOP VERY MUCH HIGHER PAVEMENT MODULI OF STIFFNESS UNDER FAST TRAFFIC IN TROPICAL CLIMATES WHEN THE ASPHALT CEMENT COMES FROM THE HARD LEFT SIDE (LOW PENETRATION AT 77°F(25°C) AND HIGH TEMPERATURE SUSCEPTIBILITY) OF ANY VISCOSITY GRADE AT 140°F(60°C) SELECTED.

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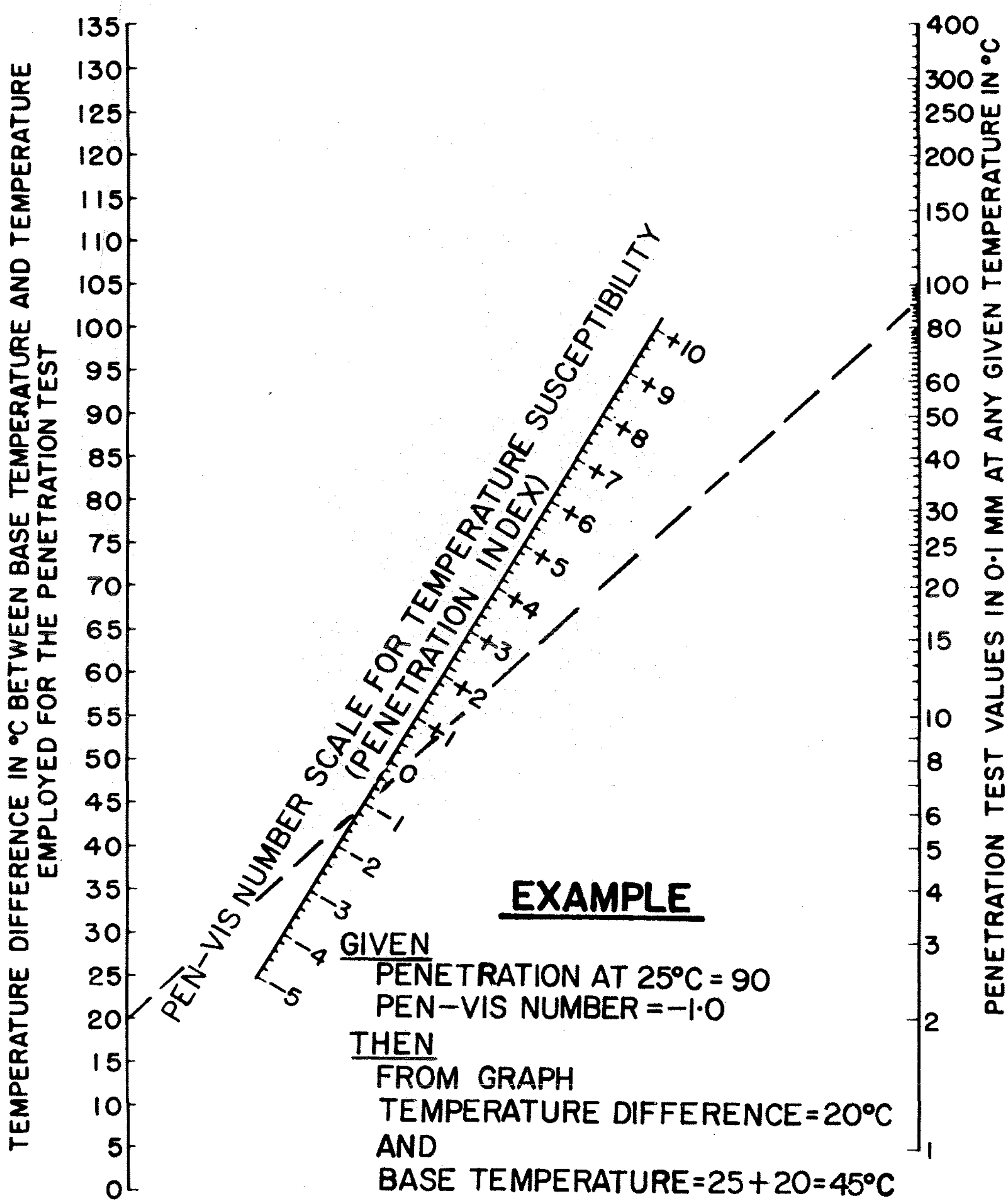

FIGURE 22 SUGGESTED MODIFICATION OF VAN DER POEL'S VERSION OF PFEIFFER AND VAN DOORMAAL'S NOMOGRAPH TO DEMONSTRATE RELATIONSHIP BETWEEN VALUES FOR PENETRATION AT 77°F(25°C), PEN-VIS NUMBER, AND BASE TEMPERATURE FOR ASPHALT CEMENTS.

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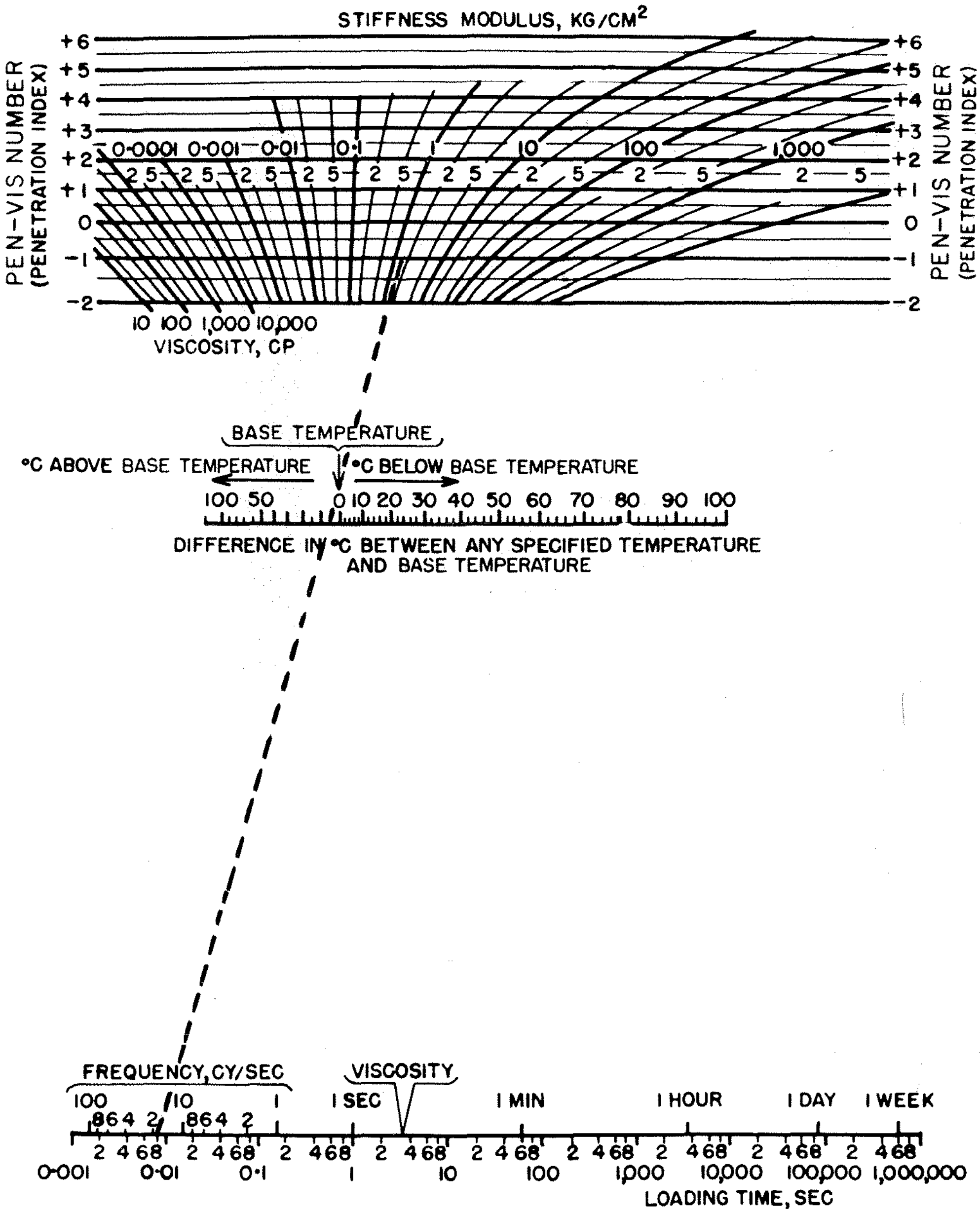

FIGURE 23 SUGGESTED MODIFICATION OF HEUKELOM'S VERSION OF VAN DER POEL'S NOMOGRAPH FOR DETERMINING MODULUS OF STIFFNESS OF ASPHALT CEMENTS.

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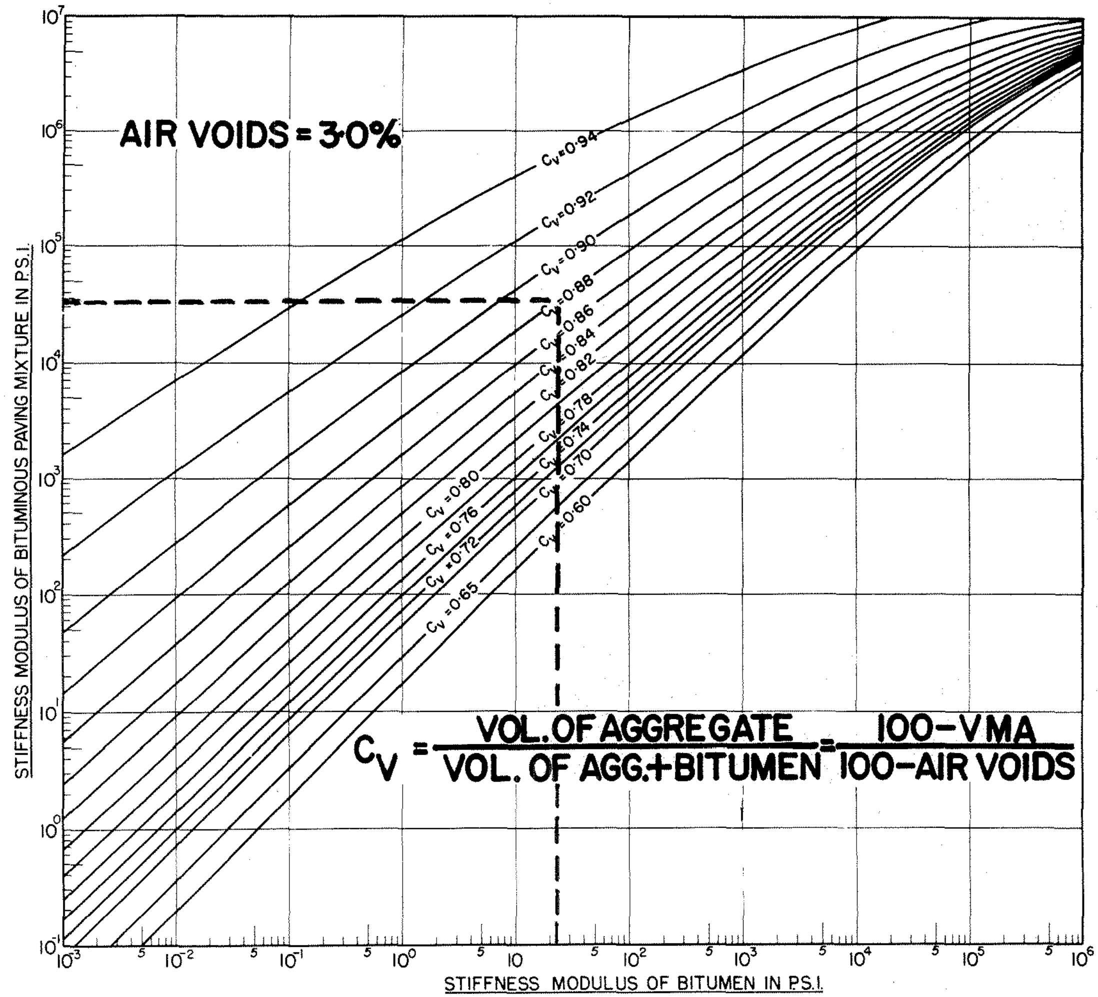

FIG.24 RELATIONSHIPS BETWEEN MODULI OF STIFFNESS OF ASPHALT CEMENTS AND OF PAVING MIXTURES CONTAINING THE SAME ASPHALT CEMENTS *(BASED ON HEUKELOM AND KLOMP).*

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