A RATIONAL DESIGN FOR THE REHABILITATION OF ASPHALT PAVEMENTS

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ABSTRACT

The current approach to recycling frequently requires softening the hard asphalt to its original consistency. This type of approach is flawed because it duplicates the asphalt that resulted in the severe cracking and other forms of distress that caused the failure of the original pavement. The objective of pavement recycling should be a pavement in which no low temperature transverse pavement cracking or other evidence of pavement distress appears during its service lifetime.

This paper describes a design procedure which predicts the penetration and temperature susceptibility (as measured by the penetration viscosity number (PVN)) of an asphalt which will provide protection from the failure mechanisms that occur at the temperature extremes and heavy traffic conditions faced by pavement in the field. As part of this work, new soft grades of asphalts with unique viscosities and elastic properties were developed from polymer modified asphalts and softening agents. The design of several recycled mixes using soft grades of asphalts is described. Full depth hot-mix recycling field trials using the design method and soft grades of polymer modified asphalt are also described.

RÉSUMÉ

Le procédé actuel de recyclage nécessite souvent un ramollissement de l'asphalte solidifié, pour lui rendre sa consistance d'origine. Cette démarche n'est pas sans défaut, car elle revient à une duplication de l'asphalte qui est à l'origine du craquage ou de tout autre épuisement grave ayant causé la défaillance de l'ancien revêtement. Le résultat que l'on devrait pouvoir excompter du recyclage d'un revêtement est une chaussée exempte de craquage transversal de la chaussée, ou de toute autre forme de dégât, et cela pendant toute sa durée de vie en service.

Cet exposé décrit une méthode de conception permettant de prévoir la pénétration et la sensibilité à la température (définie par le taux de viscosité de pénétration (TVP)) d'un asphalte. Ceci doit permettre de le préserver des mécanismes d'altération que subit la chaussée à des températures extrêmes ou dans des conditions de circulation intense. Dans le cadre de cette recherche, de nouveaux types d'asphalte, dotés de propriétés élastiques et de viscosité exceptionnelles, ont été conçus à base d'asphaltes dopés aux polymères et d'agents amollissants. Nous rendons compte ici de la conception de plusieurs mélanges recyclés en laboratoire à partir d'asphaltes souples. Un compte-rendu des essais de mélange à chaud sur le terrain, à base d'asphaltes dopés aux polymères, sera également fourni.

1. INTRODUCTION

On many thousands of miles of existing highways in Canada, the asphalt pavements have seriously deteriorated because of cracking, rutting and patching. These pavements must be either rehabilitated or reconstructed.

In the past, these old pavements were broken up, removed from the job site and discarded on trash heaps. The OPEC oil arrangement of 1973 increased the price of asphalt substantially. Since nearby deposits of the good natural gravels employed as aggregates for pavements were becoming exhausted, suitable aggregate had to be hauled in from greater distances. In some cases, much more costly crushed quarried rock provided a replacement for diminishing supplies of choice gravels. Consequently, the cost of both asphalt and aggregates for new pavements increased significantly.

This large increase in cost for both asphalt and aggregate has led engineers to recycle the aggregates and asphalt binder in the old pavements. Using specialized equipment, the old pavements were broken up. New asphalt and aggregate were added to the old materials and mixed thoroughly. The material was used as a recycled paving mixture in either the base course or occasionally the surface course. The process was referred to as either hot mix recycling, or cold mix recycling.

Hot mix recycling is an active area of investigation as evidenced by the numerous reports which have appeared in the literature (1-7). All reports cited indicate that close adherence to good mix design practice is essential for successful pavement recycling. It is also recognized that the consistency of the recycled binder plays an important role in pavement behavior.

Robertson and Allen suggest bringing the aged binder to a desired penetration or viscosity with an appropriate recycling agent (1). They recommend the use of soft asphalts as recycling agents. Earl and Emery also recommend that soft grades of asphalt cement be used to bring the recycled binder to a specified penetration (3).

User agencies vary in the means of specifying binder consistency in recycled asphalt pavements. Fleming reports that the New Brunswick Department of Transportation uses either 200/300 or 300/400 penetration grade asphalt to provide a satisfactory mix (4). The initial combined penetrations of the aged and new asphalt cements used in recycled mixes average 20 mm lower than mixes using all new asphalt cement. However, recovered penetration values of both types of mixes have been about the same.

Stamatinos, at Saskatchewan Highways and Transportation, has developed a novel procedure for the design of the bitumen in hot recycled asphalt concrete pavement using a high float emulsion as the recycling agent (2). The concept of an apparent penetration is introduced which allows for the design of the recycled mix to suit the needs of the project in terms of final penetration of the asphalt.

McLuckie and co-workers from the Ministry of Transportation of Ontario recommend that recycled hot mix be engineered for a target penetration which should be sufficiently high to provide optimum performance (5). They have also developed an empirical formula to predict the final penetration of the binder in recycled hot mix (6).

McMillan and Palsat of Alberta Transportation describe the recycling procedure used in Alberta (7). The temperature susceptibility of the recycled asphalt is considered in conjunction with geographical location and anticipated traffic volumes. The temperature susceptibility of the asphalt is monitored by design charts using penetration at 25 C and absolute viscosity at 60 C.

Recently a design procedure has been developed by McLeod which utilizes the concept of the Penetration Viscosity Number (PVN) of an asphalt (8-13). PVN characterizes the quality of the asphalt to be used for pavements subjected to different traffic and temperature conditions. PVN is determined using the asphalt's penetration at 25 C and its kinematic viscosity at 135 C (14).

McLeod's early work (10-13) focused on new pavements. In his later publications (8,9), McLeod employed paving asphalt temperature susceptibility in the structural design of recycled asphalt pavements. This paper describes both laboratory work and field trials using the design theory developed by McLeod.

2. DESIGN PROCEDURE

To demonstrate the design procedure, two scenarios are considered; one in which the region has a freezing index of 500 and the other experiencing a freezing index of 2000. A brief step-wise description of the design procedure specifying the appropriate binder consistency in recycled pavement follows. A complete description of the design method can be found in references 12 and 13. It is assumed that the recycled pavement will be a 5.08 cm thick surface course on a heavily trafficked road. The PVN of the recycled asphalt in this example is 0.0. The following successive steps are involved:

1. Since the pavement is to be constructed as a single layer 5.08 cm thick, the average minimum temperature of the surface layer will be approximately the minimum pavement temperature at a pavement depth of 2.54 cm. The minimum pavement temperature for a freezing index of 500 is -17.2 C and -29.7 C for a freezing index of 2000 (Table 1).

2. Using Figure 1, a penetration of 25 C for a PVN of 0.0 that will just avoid low temperature pavement cracking is 105 for a minimum temperature of

-17.2 C (Freezing Index of 500) and 175 for a minimum pavement temperature of -29.7 C (Freezing Index of 2000).

3. Using Table 2, the predicted maximum temperature at a pavement depth of 2.54 cm is 51.1 C for a Freezing Index of 500 and 45.3 C for a Freezing Index of 2000.

4. The modulus of stiffness of the asphalt can be estimated by using Figures 2 and 3. A loading time of 0.012 seconds (loading time of a heavy truck travelling over a point in the pavement surface at 100 km/hr) is assumed. For a pavement service temperature of 51.1 C (Freezing Index of 500), a penetration at 25 C of 105 and a PVN of 0.0, the corresponding base temperature provided by Figure 2 is 47.8 C. The base temperature is determined by adding the temperature difference, as read in Figure 2, to the temperature employed for the penetration test (25 C). The base temperature can be looked upon as an adjusted softening point (ring and ball) of the asphalt cement. The maximum pavement temperature is 3.3 C above the base temperature. Using Figure 3, the stiffness modulus of the asphalt is 1.7 kg/cm (24.1 psi). Similarly for a pavement service temperature of 45.3 C (Freezing Index of 2000), a penetration at 25 C of 175 and a PVN of 0.0, the corresponding base temperature is 41.5 C. The maximum pavement temperature is 3.8 C above the base temperature. Using Figure 3, the stiffness modulus of the asphalt is estimated to be 1.7 kg/cm (24.1 psi).

5. As shown in Step 4, the moduli of stiffness of the asphalts chosen for Freezing Indexes of 500 and 2000 are both 24.1 psi. To determine the modulus of stiffness of the pavements containing these asphalts Figure 4 is used. It is assumed that the C has a value of 0.88 which represents compacted dense graded asphalt concrete with 14.5 percent VMA, three percent air voids and a maximum aggregate particle size of 5/8 inch. Both the modulus of stiffness of the pavement containing asphalt designed for a Freezing Index of 500 and the modulus of stiffness of the pavement containing asphalt designed for a Freezing index of 2000 were determined to be 30,000 psi. McLeod concluded that, based on paving asphalts in current use, it appears that a pavement layer has adequate stability if it develops a modulus of stiffness of from 20,000 to 25,000 psi under fast heavy truck traffic at its maximum pavement summer temperature (12).

6. Therefore, a well designed and constructed asphalt surface course, 5.08 cm thick, containing a paving asphalt of 105 penetration at 25 C and with a PVN of 0.0 would avoid low temperature transverse pavement cracking at a minimum winter temperature

of -17.2 C at a pavement depth of 2.54 cm, and would, at the same time, provide adequate stability for fast heavy truck traffic at a maximum summer pavement temperature of 51.1 C, also at a pavement depth of 2.54 cm. These conditions correspond to a region with a Freezing Index of 500. Similarly, for a Freezing Index of 2000, a well designed and constructed asphalt pavement surface course 5.08 cm thick containing a paving asphalt of 175 penetration at 25 C and with a PVN of 0.0 would provide a durable pavement for all seasons.

3. ASPHALT BLENDING STUDY

A laboratory study was initiated to produce asphalt blends containing bitumen recovered from asphalt pavements which would meet McLeod's design criteria for regions with Freezing Indices of 1000 and 2000 respectively. It was assumed that the pavement would consist of a 5.08 cm thick surface course on a heavily trafficked road.

For purposes of the research project, representative samples of RAP were obtained from a stockpile of a local paving contractor. In order to obtain enough reclaimed binder for evaluation with the various virgin binders a large quantity of recovered binder had to be obtained from the RAP material taken from the stockpile. An extraction procedure similar to that used by Robertson and Allen (1) was employed. The procedure is composed of the following steps:

1. A sufficient amount of RAP (20 kg) was placed in a suitable container, covered with trichloroethylene and stirred to ensure complete mixing. The material was left covered for a number of days, with occasional stirring.

2. The extract solution was decanted and collected. The solution was centrifuged to remove fines; the standard Abson recovery test (ASTM D1856) was run; and the recovered RAP binder was collected in fractions.

3. The penetration at 25 C, the kinematic viscosity at 135 C and the PVN value of each fraction was obtained and compared to other fractions.

Once a large enough quantity of the recovered RAP binder was obtained, the blending studies were initiated.

In the laboratory study the percentage RAP asphalt in the blends were from 20% to 50%. Soft grades of asphalts were required to soften the recycled asphalt to the appropriate consistency. Grade A asphalts (PVN > -0.5) were chosen for the study and their properties are shown in Table 3 and Table 4. The 200/300 and 300/400 asphalts are commercially available. The other asphalts, although custom formulated, can be made available commercially.

To aid in the design of the asphalt blends, Figures 5 and 6 were constructed. Similar charts can be found in references 12 and 13. The basic chart was developed by McLeod to illustrate an asphalt specification based on penetrations at 25 C, viscosities at 135 C and temperature susceptibilities of paving asphalts. The Freezing Index line is derived from Figure 1 and the modulus of stiffness line is calculated using Figures 2-4. The modulus of stiffness value is determined at a PVN of -0.5 and a penetration obtained from the Freezing Index line.

Assuming the asphalt blend has a PVN of -0.3 (the temperature susceptibility of the recycled asphalt), a penetration of approximately 140 is required for a Freezing Index of 1000 to meet McLeod's criteria for a durable pavement (see Figure 5). Similarly, at a PVN of -0.3, a penetration of approximately 210 is required for a Freezing Index of 2000 (see Figure 6).

As a rough guide, blending charts were constructed to predict the penetrations of the soft asphalts required to soften the RAP asphalt to the appropriate penetration at a given RAP percentage (Figures 7 and 8). The blending charts assumed a linear relationship between the log of the penetration of the asphalt blend at 25 C and the weight percentage of the recycled asphalt.

A penetration of 140 was targeted for a Freezing Index of 1000. Although the blending chart (Figure 7) predicted low penetrations for the blends made from 40% and 50% RAP asphalt, the actual data (Table 5) indicated satisfactory penetrations.

For a Freezing Index of 2000, a penetration of 210 was needed for the asphalt blends. Figure 8 predicted that the soft asphalts chosen would provide the proper blends at up to 40 weight percent recycled asphalt. At 50% recycled asphalt the predicted penetration was low.

The penetrations of the blends were softer than predicted for weight percentage of RAP asphalt up to and including the 40% level (Table 6). At 50% RAP, the penetration of the blend was slightly lower than required. This result may be significant and indicate that, in regions with Freezing Indices of 2000 or more, it will be difficult to produce a conventional low temperature susceptible asphalt ($-0.5 < PVN < 0.0$) which can soften RAP, at the 50% recycle level, to the penetration which meets McLeod's design criteria. One approach to overcome the problem is to raise the PVN of the soft asphalt by incorporating a small amount of an appropriate polymer into the asphalt. This approach will be discussed in the section dealing with field trials in a region with a Freezing Index of 3000.

4. MIX DESIGN

A modified Marshall method of design was used to obtain the laboratory data on the recovered blends of virgin binder and RAP asphalt from the laboratory mixes.

An HL4 mix type conforming to MTO Form 1150 specifications was chosen and the following design criteria was used:

Traffic Volume	>	5000 VPD
Marshall Stability		8900 N min
Air Voids, %		3-5
VMA, %		14.5 min
Mixing Temperature		150 C
Compaction Temperature		140 C
Percentage RAP		20,30,40,50

The coarse and fine virgin aggregate used in this study came from a source that McAsphalt Engineering Services has used for research purposes for many years because of its consistent physical properties. In order to meet physical requirements when using 50% RAP, the fine aggregate was screened on a 1.18 mm sieve and this finely graded aggregate was used as the blending sand. The data on the RAP aggregate and the virgin aggregate, used in this study, are shown in Table 7.

Mix designs were done on each of the 8 mixes prepared for this study. The mix design work is part of ongoing research initiated at McAsphalt Engineering Services to investigate factors affecting the mix design of recycled mixes. The results of the research project will be published at a later date.

To simplify the procedure and reduce variables, all the mixes were mixed and compacted at the same temperature, regardless of the percentage RAP or grade of virgin binder used. As a result, a variability in the physical properties of the mixes was observed. The analysis of the mixes designed for Freezing Indices of 1000 and 2000 are shown in Tables 8 and 9. Generally, the mix design criteria were met. Further study is required to refine the mix design for Blends 2 and 3 in Table 8 and Blend 3 in Table 9 in order to meet the VMA requirement.

The penetration at 25 C, the kinematic viscosity at 135 C and the PVN were measured for the asphalt recovered from mixes prepared in this study. It is interesting to compare the recovered penetrations to those obtained from the thin film oven test of the blends of RAP asphalt and virgin binder shown in Tables 5 and 6. In all cases, the recovered penetrations were higher than the thin film oven test results. Further field and laboratory work is required to duplicate the field conditions for producing recycled hot mix in the laboratory.

5. FIELD TRIALS

An opportunity arose in August, 1988 to design a recycled pavement using McLeod's design method as a criteria for determining the grade of virgin asphalt to be used in a recycled paving project.

A pavement recycling contract (MTO #88-205) was awarded to reconstruct a section of Highway 11 near Cochrane. Conventional 500+ asphalt was specified for the job. Part of the contract was set aside as a test section. McAsphalt Engineering Services was asked to design asphalt cements which would alleviate low temperature transverse pavement cracking and high temperature rutting in pavements.

In designing the asphalt the following considerations were taken into account:

1. The pavement was to be laid as a 5.08 cm surface course.

2. The RAP material would comprise 45% of the pavement.

3. The paving location had a Freezing Index of 3000.

Using Tables 1 and 2, the expected minimum winter temperature was determined to be -33.2 C and the maximum summer temperature to be 43.7 C for a pavement at a depth of 2.54 cm. Using this data, Figure 9 was constructed as a guide to determine the penetration and PVN of a blend of recycled asphalt and virgin asphalt which would satisfy McLeod's criteria for the job site.

A sample of the RAP was extracted by the Abson method. The recovered asphalt had a penetration at 25 C of 31 and a kinematic viscosity at 135 C of 637 (PVN = -0.77). Polymer modified asphalts were used to adjust both the penetration and PVN of the recycled asphalt. The polymer modified asphalts chosen for the study had the polymer chemically cross-linked to the asphalt. By chemically bonding the polymer to the asphalt, potential problems associated with the compatibility of the polymer modified asphalt and the recycled asphalt should be minimized.

Two polymer modified asphalts were formulated for the test sections. They were designated as 500+P and 800+P. Large scale batch runs of both grades of polymer modified asphalts were produced at the Polymac Engineered Asphalts plant in Oshawa, Ontario. The batch sizes for both the 500+P and 800+P were in the order of 90 to 100 metric tonnes. The physical properties of the polymer modified asphalts and those of conventional 500+ are shown in Table 10.

The mix design for the surface course called for 45% RAP content. Due to time constraints, laboratory blending studies with the soft asphalts and the recycled asphalts were not done. Using Figure 10, it was estimated that a blend of 800+P with 45% RAP asphalt would give an asphalt with a penetration of 255 at 25 C. Similarly, for 500+P and 500+ blends with 45% RAP asphalts, penetrations at 25 C of 150 and 165 were predicted.

Construction

The modified asphalt cements did not create any problems in handling for the contractor with regards to pumping into storage or in mixing. The drum plant operated at its normal mixing temperature of 145-150 C; and was rated at 300 tons per hour. For the test section, the plant was operated at 220 ton per hour and experienced no difficulties.

The mix produced appeared to be very uniform and was problem-free during laydown. The surface lift was 50 mm thick. The highway was paved with two pavers paving in echelon about 150 meters apart. Each paver was supported with a 10-12 ton breakdown roller and a seven rubber tired roller. The temperatures of the mat was in the range of 135 to 140 C.

Mix Data

Samples of the surface mixes made with 500+, 500+P and 800+P were obtained at the job site. The laboratory test results obtained on the field samples are shown in Table 11.

The surface mixes conform very closely in gradation with the job-mix formula except for slightly higher values in pass #200. The higher dust content accounts for the lower than expected VMA value. The asphalt cement content shows some fluctuation which can be attributed to the variation in asphalt cement content in the RAP material. The Marshall stability values are borderline for heavy traffic but suitable for medium traffic. All other physical requirements were met.

Data on Recovered Asphalt Cements

The asphalts were recovered from the job mixes by the Abson method. The data on the recovered asphalts is presented in Table 12. It is interesting to compare the penetrations at 25 C of the recovered asphalts using 500+ and 500+P. Although the 500+P virgin material had a lower penetration than the 500+ (639 to 540), the recovered penetration was higher for 500+P. As shown by Table 11, the physical properties of the mixes are essentially the same, except for the properties of the added virgin asphalts. It, therefore, can be concluded that the modified asphalt (500+P) did not age harden as much through the hot-mix process as the regular 500+ did.

As mentioned previously, time constraints prevented a laboratory blending study of the soft asphalts with the recycled asphalt. As a result, PVN values could not be obtained for the virgin blends. However, the PVN values were determined for the asphalts recovered from the hot-mix process (Table 12). Dr. McLeod has shown that the PVN of an asphalt recovered after the pavement was laid is the same, or very nearly the same (experimental error) as the PVN of the original asphalt that was selected for the pavement design (8). Therefore, the PVN values of the virgin asphalt blends are expected to be the same as those determined from the recovered asphalts in Table 12. As mentioned previously, the penetrations of the virgin blends are estimated from the blending charts. The predicted penetration and PVN values are shown in Table 13.

The data in Table 13 is plotted on Figure 9. From inspection of this chart, it is predicted that the recycled pavements made with 500+P and 800+P should provide protection against low temperature transverse cracking and high temperature pavement rutting at this location. The pavement made from 500+ is expected to develop low temperature transverse cracks. A research project has been initiated at McAsphalt Engineering Services to monitor the Cochrane Test Section annually, for signs of pavement distress.

Summary

1. Temperature susceptibility of an asphalt, as measured by PVN, and the Freezing Index at a paving site are used to rationally design a pavement containing recycled asphalt.

2. McLeod's design procedure is described in detail using two scenarios; one in which the paving site has a Freezing Index of 500 and the other paving site experiencing a Freezing Index of 2000.

3. A laboratory study is described in which blends of soft asphalts with varying amounts of recycled asphalt were made. The asphalt blends were designed to meet the penetration and PVN requirements for either a Freezing Index of 1000 or a Freezing Index of 2000.

4. The laboratory blending study indicates that a potential problem exists if conventional soft asphalts are used with 50% RAP in regions with Freezing Indices greater than 2000.

5. The data from the laboratory blending study were used to produce laboratory mixes containing varying amounts of recycled asphalt pavement. The asphalts recovered from these mixes had penetrations which were higher than the thin film oven residue penetrations of the virgin blends. Further field work and laboratory work is required to duplicate the field conditions for producing recycled hot mix in the laboratory.

6. A field trial using McLeod's design procedure is described. Polymer modified asphalts were used to modify the penetration and temperature susceptibility of the recycled asphalt to meet McLeod's criteria for a paving site with a Freezing Index of 3000.

7. Two new grades of polymer modified asphalts were produced for the field trials. These asphalts appear to age harden at a slower rate than the conventional asphalt used in the field trial.

8. The recycled pavements using the polymer modified asphalts satisfy McLeod's criteria and are predicted to resist low temperature transverse pavement cracking and high temperature pavement rutting. The recycled pavement using the conventional asphalt is predicted to have problems associated with low temperature pavement cracking. The test section will be monitored annually for signs of pavement distress.

References

1. Robertson, W.D. and Adams, B.B., "Mix Design - The Key to Successful Pavement Recycling", Proceedings, Canadian Technical Asphalt Association, Vol. 33, p. 330, 1988.

2. Stamatinos, G., "A Procedure for the Design of the Bitumen in Hot Recycled Asphalt Concrete", Proceedings, Canadian Technical Asphalt Association, Vol. 33, p. 178, 1988.

3. Earl, J.F. and Emery, J.J., "Practical Experience with High Ratio Hot Mix Recycling", Proceedings, Canadian Technical Asphalt Association, Vol. 32, p. 326, 1987.

4. Fleming, H.B., "Hot Mix Recycling of Asphaltic Concrete Pavements in the Province of New Brunswick", Proceedings, Canadian Technical Asphalt Association, Vol. 32, p. 204, 1987.

5. McLuckie, R.F., Korgemagi, P. and Villneff, H.C., "Performance of High Ratio Recycled Pavements in Northern Ontario", Proceedings, Canadian Technical Asphalt Association, Vol. 32, p. 42, 1987.

6. McLuckie, R.F., Bruneau, R., Korgemagi, P. and Lynch, D.F., "Computer Modelling in the Design Stage of Recycled Hot Mix Projects", Proceedings, Canadian Technical Asphalt Association, Vol. 30, p. 180, 1985.

7. McMillan, C. and Palsat, D., "Alberta's Experience in Asphalt Recycling", Proceedings, Canadian Technical Asphalt Association, Vol. 30, p. 148, 1985.

8. McLeod, N.W., "Relationship of Paving Asphalt Temperature Susceptibility as Measured by PVN to Paving Asphalt Specifications, Asphalt Paving Mixture Design and Asphalt Pavement Performance", Preprint, Proceedings, The Association of Asphalt Paving Technologists, Nashville, 1989.

9. McLeod, N.W., "Design of Dense Graded Asphalt Concrete Pavements", Proceedings, Canadian Technical Asphalt Association, Vol. 32, p. 352, 1987.

10. McLeod, N.W., "Pen-Vis Number (PVN) as a Measure of Paving Asphalt Temperature Susceptibility and its Application to Pavement Design", Proceedings, Paving in Cold Areas, Canada/Japan Mini-Workshop 3, Vol. 1, p. 147, 1987.

11. McLeod, N.W., "Employing Paving Asphalt Temperature Susceptibility in the Structural Design of Asphalt Pavement", Proceedings, Sixth International Conference on the Structural Design of Asphalt Pavements, Vol. 1, p. 248, 1987.

12. McLeod, N.W., "Using the Freezing Index for the Optimum Selection of Paving Asphalts with Different Temperature Susceptibilities for Any Pavement Site", Proceedings, Canadian Technical Asphalt Association, Vol. 30, p. 282, 1985.

13. McLeod, N.W., "Engineers Can Make Paving Asphalt Temperature Susceptibility Work For Them or Against Them", Proceedings, Canadian Technical Asphalt Association, Vol. 28, p. 2, 1983.

14. McLeod, N.W., "Asphalt Cements: Pen-Vis Number and Its Application to Moduli of Stiffness", Journal of Testing and Evaluation (ASTM), Vol. 4, p. 275, 1976.

15. Pfeiffer, J.Ph. and Van Doormaal, P.M., "The Rheological Properties of Asphaltic Bitumen", Journal of the Institute of Petroleum Technologists, Vol. 22, p. 414, 1936.

16. Van der Poel, C., "A General System Describing the Visco-Elastic Properties of Bitumens and Its Relation to Routine Test Data", Journal of Applied Chemistry, Vol. 4, p. 221, 1954.

17. Van der Poel, C., "Time and Temperature Effects on the Determination of Asphaltic Bitumens and Bitumen-Mineral Mixtures", Society of Plastics Engineers Journal, Vol. 11, p. 47, 1955.

18. Heukelom, W., "A Bitumen Test Data Chart for Showing the Effect of Temperature on the Mechanical Behaviour of Asphaltic Bitumens", Journal of the Institute of Petroleum, Vol. 55, p. 404, 1969.

TABLE 1

EFFECT OF FREEZING INDEX ON MINIMUM PAVEMENT TEMPERATURE, C, AT PAVEMENT DEPTH IN CENTIMETERS (#1)

FREEZING INDEX	MIN. PAVEMENT TEMPERATURE,C,AT PAVEMENT DEPTH,CM				
	0.0	1.27	2.54	5.08	10.16
4000	-36.1	-35.8	-35.7	-35.6	-29.4
3000	-33.8	-33.2	-33.2	-33.1	-27.3
2000	-30.5	-29.9	-29.7	-29.4	-24.1
1000	-24.7	-23.9	-23.5	-23.1	-18.7
500	-18.8	-17.7	-17.2	-16.7	-13.2

TABLE 2

EFFECT OF FREEZING INDEX ON MAXIMUM PAVEMENT TEMPERATURE, C, AT PAVEMENT DEPTH IN CENTIMETERS (#2)

FREEZING INDEX	MAX. PAVEMENT TEMPERATURE,C,AT PAVEMENT DEPTH,CM				
	0.0	1.27	2.54	5.08	10.16
4000	44.9	43.2	42.5	41.8	34.6
3000	46.2	44.4	43.7	42.9	35.8
2000	48.0	46.1	45.3	44.6	37.4
1000	51.1	49.1	48.2	47.3	40.3
500	54.3	52.0	51.1	50.1	43.1

#1. DATA TAKEN FROM TABLE 1 , p. 309 , REFERENCE 12 .

#2. DATA TAKEN FROM TABLE 2 , p. 310 , REFERENCE 12 .

TABLE 3

PROPERTIES OF ASPHALTS

TESTS	GRADE OF ASPHALT			
	RAP	190/210	200/300	300/400
KINEMATIC VISCOSITY @ 135 C , mm2/sec	1098	235	207	165
PENETRATION @ 25 C	25	204	275	355
@ 10 C	6	43	67	95
@ 4 C	2	18	33	43
PVN	-0.29	-0.19	0.01	-0.04
ABSOLUTE VISCOSITY @ 60 C,poises	32,559	626	478	265
R&B SOFTENING POINT, C	63.1	36.7	34.4	32.4
DUCTILITY @ 4 C ,cm	22 @ 25C	100+	100+	100+
THIN FILM OVEN TEST 50g 5 Hr 163 C				
% LOSS in Mass	0.6809	0.2890	0.3420	0.5076
KINEMATIC VISCOSITY @ 135 C , mm2/sec	1539	327	304	240
PENETRATION @ 25 C	17	117	158	200
@ 10 C	2	35	50	50
@ 4 C	0	18	32	24
PVN	-0.24	-0.35	-0.09	-0.18
% RETAINED PENETRATION @ 25 C	68.0	57.4	57.5	56.3
ABSOLUTE VISCOSITY @ 60 C,poises	87,613	1325	1052	805
R&B SOFTENING POINT, C	68.6	42.5	40.3	39.2
DUCTILITY @ 25 C ,cm	8	100+	100+	100+

TABLE 4

PROPERTIES OF ASPHALTS

TESTS	GRADE OF ASPHALT		
	500+	900+	1100+
KINEMATIC VISCOSITY @ 135 C , mm2/sec	113	95	83
PENETRATION @ 25 C	516	900 *	1150 *
@ 10 C	100	149	186
@ 4 C	53	70	95
PVN	-0.22	0.45 **	0.66 **
ABSOLUTE VISCOSITY @ 60 C,poises	164	118	80
R&B SOFTENING POINT, C	27.2	25.1	23.6
DUCTILITY @ 4 C ,cm	100+	100+	100+
THIN FILM OVEN TEST 50g 5 Hr 163 C			
% LOSS in Mass	0.4600	0.8592	0.7516
KINEMATIC VISCOSITY @ 135 C , mm2/sec	175	162	105
PENETRATION @ 25 C	274	392	574
@ 10 C	61	77	112
@ 4 C	35	40	57
PVN	-0.32	0.08	-0.21
% RETAINED PENETRATION @ 25 C	53.1	---	---
ABSOLUTE VISCOSITY @ 60 C,poises	397	262	150
R&B SOFTENING POINT, C	35.8	31.1	28.3
DUCTILITY @ 25 C ,cm	70.5	70	60

* ESTIMATED FROM SHELL BITUMEN TEST DATA CHART USING PENETRATION AT 10 C AND 4 C

** PVN VALUE IS BASED ON ESTIMATED PENETRATION AT 25 C FROM ABOVE

TABLE 5

PROPERTIES OF ASPHALT CEMENT BLENDS
FOR A FREEZING INDEX OF 1000

TESTS	ASPHALT BLENDS			
	20% RAP 80% 190/210	30% RAP 70% 200/300	40% RAP 60% 300/400	50% RAP 50% 500+
KINEMATIC VISCOSITY @ 135 C , mm2/sec	290	287	288	275
PENETRATION @ 25 C	142	138	138	135
@ 10 C	33	34	32	33
@ 4 C	21	16	18	20
PVN	-0.31	-0.36	-0.35	-0.46
ABSOLUTE VISCOSITY @ 60 C,poises	1058	1078	1040	972
R&B SOFTENING POINT, C	41.1	40.6	41.1	43.3
THIN FILM OVEN TEST 50g 5 Hr 163 C				
% LOSS in Mass	0.3488	0.3479	0.5036	0.4297
KINEMATIC VISCOSITY @ 135 C , mm2/sec	378	365	374	363
PENETRATION @ 25 C	94	94	90	91
@ 10 C	18	20	19	19
@ 4 C	12	11	9	10
PVN	-0.38	-0.43	-0.44	-0.48
% RETAINED PENETRATION @ 25 C	66.2	68.1	65.2	67.4
ABSOLUTE VISCOSITY @ 60 C,poises	1963	1964	1995	1897
R&B SOFTENING POINT, C	45.6	45.0	44.7	46.4

TABLE 6

PROPERTIES OF ASPHALT CEMENT BLENDS
FOR A FREEZING INDEX OF 2000

TESTS	ASPHALT BLENDS			
	20% RAP 80% 300/400	30% RAP 70% 500+	40% RAP 60% 800+	50% RAP 50% 1100+
KINEMATIC VISCOSITY @ 135 C , mm2/sec	205	196	191	196
PENETRATION @ 25 C	221	235	235	203
@ 10 C	49	47	44	36
@ 4 C	30	31	29	20
PVN	-0.33	-0.32	-0.37	-0.52
ABSOLUTE VISCOSITY @ 60 C,poises	357	383	424	528
R&B SOFTENING POINT, C	37.5	35.3	38.1	37.9
THIN FILM OVEN TEST 50g 5 Hr 163 C				
% LOSS in Mass	0.5285	0.5138	0.6440	0.7137
KINEMATIC VISCOSITY @ 135 C , mm2/sec	287	254	252	259
PENETRATION @ 25 C	146	158	160	134
@ 10 C	37	35	34	33
@ 4 C	21	19	19	20
PVN	-0.29	-0.39	-0.39	-0.56
% RETAINED PENETRATION @ 25 C	66.1	67.2	68.1	66.0
ABSOLUTE VISCOSITY @ 60 C,poises	1045	596	515	990
R&B SOFTENING POINT, C	41.1	40.6	39.7	44.4

TABLE 7

DATA ON AGGREGATE SAMPLES
WASHED SIEVE ANALYSIS

AGGREGATE TYPE	STONE	SAND	BLEND SAND	RAP
SIEVE SIZE	% PASS	% PASS	% PASS	% PASS
1 INCH 26.5mm				100
3/4 INCH 19.0mm	100			99.0
5/8 INCH 16.0mm	99.5			96.6
1/2 INCH 13.2mm	97.0			94.0
3/8 INCH 9.5mm	77.4	100		86.8
NO. 4 4.75mm	10.7	98.8		66.9
8 2.36mm	1.4	89.7	100	55.7
16 1.18mm	1.1	72.3	97.0	47.3
30 600um	0.9	40.5	54.5	37.7
50 300um	0.8	20.5	29.0	23.7
100 150um	0.7	8.1	9.5	12.3
200 75um	0.6	1.0	2.0	7.6
BULK SPEC GRAV	2.682	2.632	2.666	2.666
APP SPEC GRAV	2.784	2.750	2.753	2.740
% WATER ABS.	1.37	1.63	1.19	1.00
RAP ANALYSIS				
% AC				4.63
PENETRATION @ 25 C 100g 5 sec				25
KINEMATIC VISCOSITY @ 135 C mm2/sec				1098
PVN				-0.29

TABLE 8

ASPHALT MIX ANALYSIS

FREEZING INDEX = 1000

LABORATORY BLENDING

BLEND	HL4* SPEC	1	2	3	4
% RAP		20.0	30.0	40.0	50.0
% COARSE AGGREGATE		35.0	27.5	21.5	17.5
% FINE AGGREGATE		45.0	42.5	38.5	0.0
% BLEND AGGREGATE		0.0	0.0	0.0	32.5
% VIRGIN ASPHALT		4.65	3.92	3.56	2.90
%TOTAL ASPHALT		5.50	5.30	5.40	5.20
ASPHALT TYPE USED		190/200	200/300	300/400	500+
SIEVE SIZE	% PASS	% PASS	% PASS	% PASS	% PASS
1 INCH 26.5mm					
3/4 INCH 19.0mm	100		100	100	100
5/8 INCH 16.0mm	98-100	100	99.2	98.9	99.1
1/2 INCH 13.2mm	83-95	98.9	97.8	96.8	97.9
3/8 INCH 9.5mm	62-82	88.0	89.4	90.0	89.1
NO. 4 4.75mm	40-67	63.4	65.0	69.2	70.1
8 2.36mm	27-66	54.1	57.0	60.0	62.6
16 1.18mm	16-60	42.9	45.9	48.6	57.7
30 600um	8-47	27.5	30.1	32.8	40.0
50 300um	4-27	15.9	17.8	19.5	23.9
100 150um	1-10	7.8	9.0	9.8	11.6
200 75um	0-6	3.3	4.2	4.6	5.5
ASPHALT CONTENT %	4.5-6.5	5.25	5.25	5.38	5.20
MARSHALL STABILITY	8900MIN	10955	12081	10995	10204
FLOW INDEX	8 MIN	9.4	9.2	9.5	8.8
BULK S.G. RECOMPACTED		2.396	2.406	2.412	2.386
THEORETICAL MAX S.G.		2.508	2.497	2.502	2.519
% AIR VOIDS	3-5	4.47	3.64	3.60	5.28
% VMA		14.5	14.2	14.1	15.3
AVE. AGG. BULK S.G.		2.656	2.656	2.656	2.669
RECOVERED PENETRATION		119	114	109	103
KINEMATIC VISCOSITY		333	338	358	323
PVN		-0.30	-0.33	-0.29	-0.52

* NOTE: CURRENT MTO SPECIFICATION FOR HL4 SURFACE MIX

TABLE 9

ASPHALT MIX ANALYSIS

FREEZING INDEX = 2000

LABORATORY BLENDING

BLEND	HL4 * SPEC	1	2	3	4
% RAP		20.0	30.0	40.0	50.0
% COARSE AGGREGATE		35.0	27.5	21.5	17.5
% FINE AGGREGATE		45.0	42.5	38.5	0.0
% BLEND AGGREGATE		0.0	0.0	0.0	32.5
% VIRGIN ASPHALT		4.65	3.92	3.56	2.90
%TOTAL ASPHALT		5.50	5.30	5.40	5.20
ASPHALT TYPE USED		300/400	500+	600+	1100+
SIEVE SIZE		% PASS	% PASS	% PASS	% PASS
1 INCH 26.5mm					100
3/4 INCH 19.0mm	100		100	100	99.5
5/8 INCH 16.0mm	98-100	100	99.5	98.5	98.1
1/2 INCH 13.2mm	83-95	99.4	98.5	96.5	95.6
3/8 INCH 9.5mm	62-82	91.8	92.6	90.6	86.9
NO. 4 4.75mm	40-67	66.0	69.0	67.7	67.7
8 2.36mm	27-66	54.2	56.5	57.2	60.1
16 1.18mm	16-60	43.6	45.0	46.6	55.9
30 600um	8-47	27.7	29.6	30.9	39.1
50 300um	4-27	16.3	17.5	18.5	23.0
100 150um	1-10	8.0	8.8	9.5	11.7
200 75um	0-6	3.6	4.4	5.0	5.8
ASPHALT CONTENT %	4.5-6.5	5.34	5.35	5.10	5.15
MARSHALL STABILITY	8900MIN	9083	9096	9821	9714
FLOW INDEX	8 MIN	8.4	8.8	8.9	9.0
BULK S.G. RECOMPACTED		2.393	2.396	2.411	2.387
THEORETICAL MAX S.G.		2.513	2.508	2.512	2.517
% AIR VOIDS	3-5	4.76	4.47	4.02	5.16
% VMA		14.7	14.6	13.9	15.2
AVE. AGG. BULK S.G.		2.656	2.656	2.656	2.669
RECOVERED PENETRATION		169	197	205	159
KINEMATIC VISCOSITY		259	217	221	224
PVN		-0.27	-0.38	-0.29	-0.60

* NOTE: CURRENT MTO SPECIFICATION FOR HL4 SURFACE MIX

TABLE 10

TEST DATA ON ASPHALT CEMENTS

TESTS PERFORMED	RESULTS 500+	500+P	800+P
PENETRATION @ 25 C	639	540	1400 *
@ 10 C	78	187	515
@ 4 C	154	97	332
KINEMATIC VISCOSITY cs @ 135 C	163	550	267
PVN	1.04	3.44	4.81 **
ABSOLUTE VISCOSITY P @ 60 C	175	2350	114
FLASH POINT COC C	260+	260+	260+
DUCTILITY @ 4 C cm 1 cm/min	90	85	25
ELASTIC RECOVERY % @ 10 C	10.0	90.0	60.0
THIN FILM OVEN TEST 50g 5 hr 163 C			
% LOSS in Mass	0.269	0.317	0.251
PENETRATION @ 25 C	356	389	1000 *
@ 10 C	79	136	371
@ 4 C	46	62	183
% RETAINED PENETRATION	55.7	72.0	71.4
KINEMATIC VISCOSITY cs @ 135 C	211	789	392
PVN	0.46	3.36	4.58 **
ABSOLUTE VISCOSITY P @ 60 C	301	2989	340
DUCTILITY @ 25 C cm 5 cm/min	50	39	14.5
ELASTIC RECOVERY % @ 10 C	15.0	75.0	50.0

* ESTIMATED FROM SHELL BITUMEN TEST DATA CHART USING PENETRATION AT 10 C AND 4 C

** PVN VALUE IS BASED ON ESTIMATED PENETRATION AT 25 C FROM ABOVE

TABLE 11

ASPHALT MIX ANALYSIS

TYPE OF MIX HL4 SURFACE
PAVEMENT OWNER MINISTRY OF TRANSPORTATION ONTARIO

SAMPLE NO.	HL4 * SPEC	1	2	3
DATE SAMPLED		AUG/88	AUG/88	AUG/88
ASPHALT CEMENT TYPE		500+P	800+P	500+
SIEVE SIZE		% PASSING	% PASSING	% PASSING
1 INCH 26.5mm				
3/4 INCH 19.0mm	100	100	100	100
5/8 INCH 16.0mm	98-100	98.2	97.8	98.2
1/2 INCH 13.2mm	83-95	88.9	88.7	92.0
3/8 INCH 9.5mm	62-82	74.4	69.1	77.9
NO. 4 4.75mm	40-67	56.6	51.5	56.4
8 2.36mm	27-66	49.8	47.8	48.8
16 1.18mm	16-60	42.2	39.0	39.1
30 600um	8-47	24.9	25.1	24.4
50 300um	4-27	11.5	11.5	11.2
100 150um	1-10	6.7	5.9	6.1
200 75um	0-6	4.3	3.9	3.9
ASPHALT CONTENT %	4.5-6.5	4.82	4.53	5.04
MARSHALL STABILITY	8900 MIN	8513	8905	8785
FLOW INDEX	8 MIN	8.9	9.3	9.2
BULK S.G. RECOMPACTED		2.394	2.419	2.420
THEORETICAL MAX S.G.		2.506	2.518	2.513
% AIR VOIDS	3-5	4.46	3.93	3.69
% VMA	14.5 MIN	15.3	13.4	13.6
AVE. AGG. BULK S.G.		2.661	2.668	2.661
TESTS ON RECOVERED ASPHALT				
PENETRATION @ 25 C		128	158	109
KINEMATIC VISCOSITY @ 135 C		549	470	310
PVN		+0.60	+0.64	-0.52

* NOTE: CURRENT MTO SPECIFICATION FOR HL4 SURFACE MIX

TABLE 12

PROPERTIES OF RECOVERED ASPHALT

TESTS	ASPHALT MIXES		
LOCATION TYPE LIFT	1 500+P SURFACE	2 800+P SURFACE	3 500+ SURFACE
PENETRATION @ 25 C	128	158	109
@ 10 C	36	49	31
@ 4 C	22	34	22
KINEMATIC VISCOSITY cs @ 135 C	549	470	310
PVN	+0.60	+0.64	-0.52
ABSOLUTE VISCOSITY P @ 60 C	1996	1545	1340
DUCTILITY @ 25 C cm 5 cm/min	68	50	100
SOFTENING POINT R&B C	48.3	48.9	46.9

TABLE 13

ESTIMATED PENETRATIONS AND PVN VALUES OF ASPHALT BLENDS

ASPHALT BLEND	ESTIMATED PENETRATION (TAKEN FROM FIG. 10)	ESTIMATED PVN (TAKEN FROM FIG. 10)
500+ & 45% RAP	165	-0.52
500+P & 45% RAP	150	+0.60
800+P & 45% RAP	255	+0.64

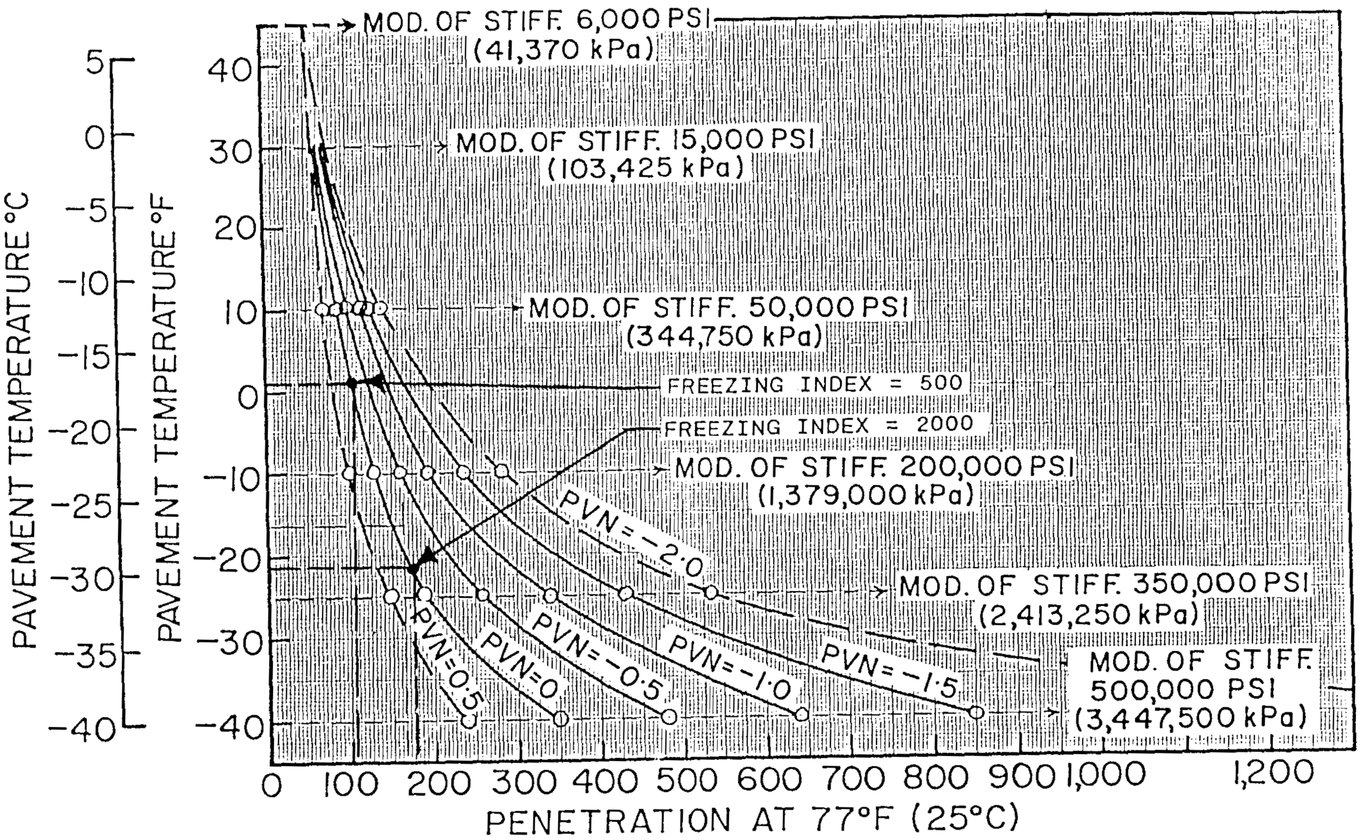

FIG. 1 CONTINUOUS SCALE FOR LOW PAVEMENT TEMPERATURES VERSUS CORRESPONDING MINIMUM PAVING ASPHALT PENETRATIONS AT 25 C TO AVOID LOW TEMPERATURE TRANSVERSE PAVEMENT CRACKING

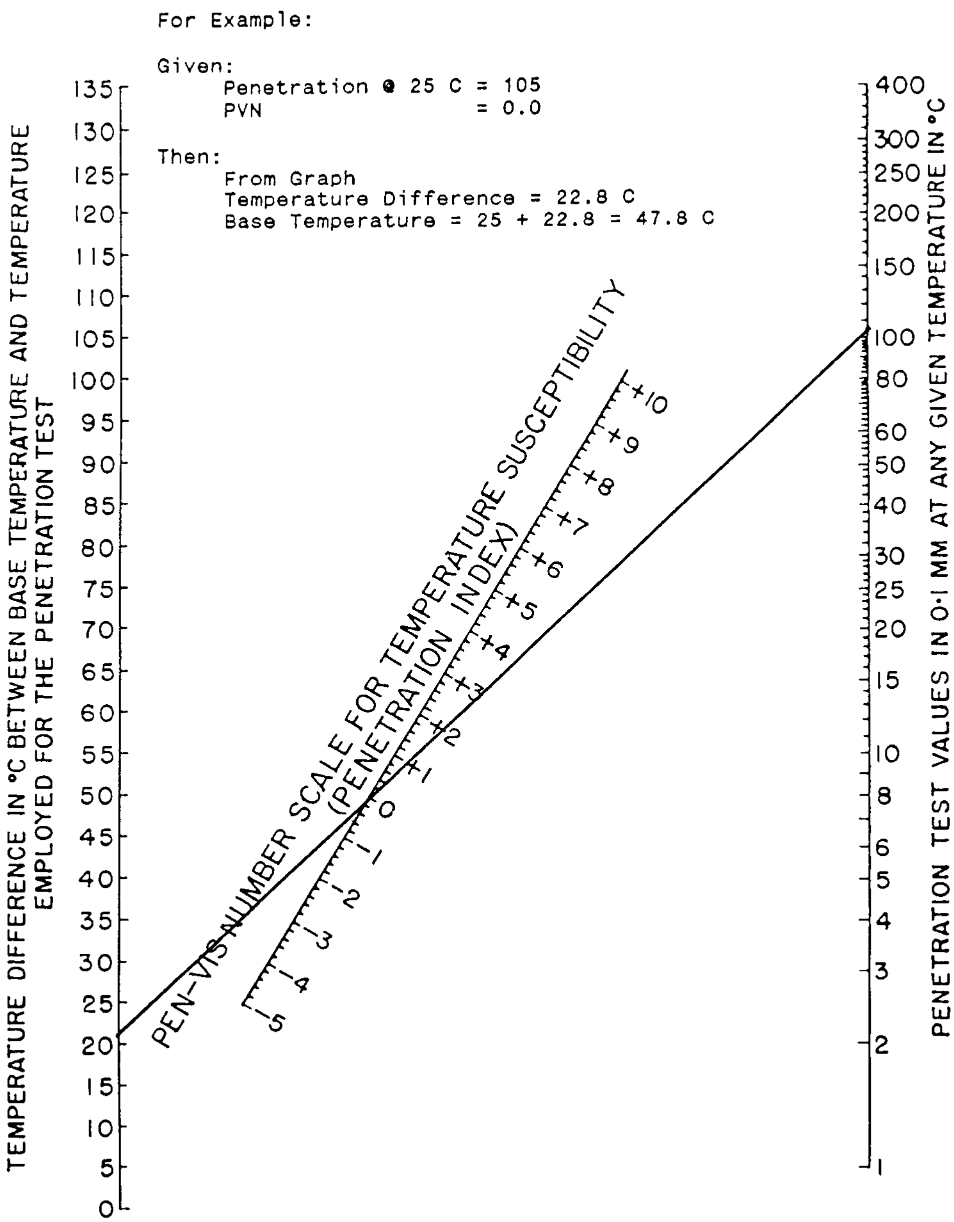

FIG. 2 RELATIONSHIP BETWEEN PENETRATION AT 25 C,PVN AND BASE TEMPERATURE FOR PAVING ASPHALTS (WITH CREDIT TO PFEIFFER,VAN DORMAAL AND VAN DER POEL, REF. 15, 16 & 17)

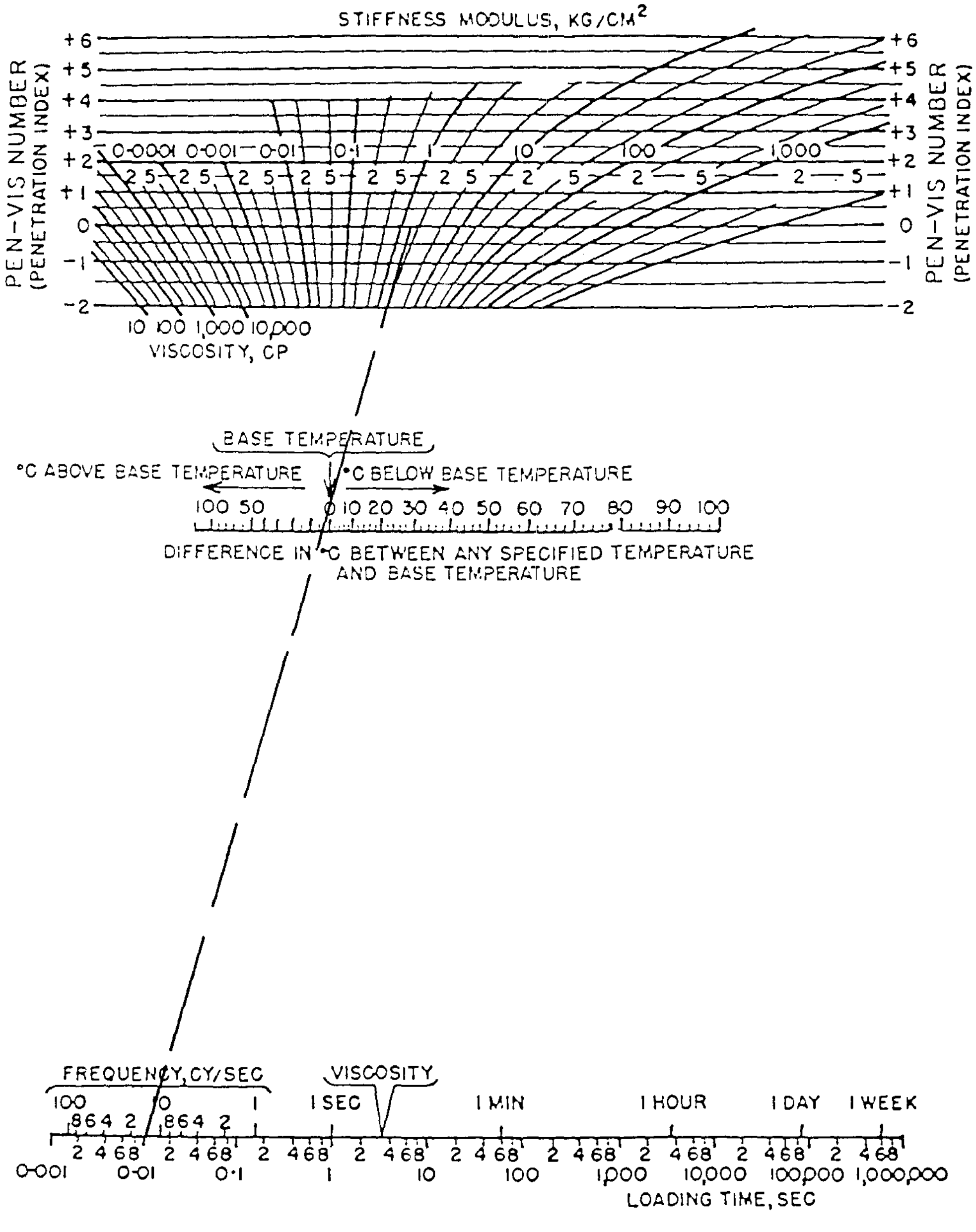

FIG. 3 SUGGESTED MODIFICATION OF HEUKELOM'S VERSION OF VAN DER POEL'S NOMOGRAPH FOR DETERMINING MODULUS OF STIFFNESS OF ASPHALT CEMENTS (REF.12 & 18)

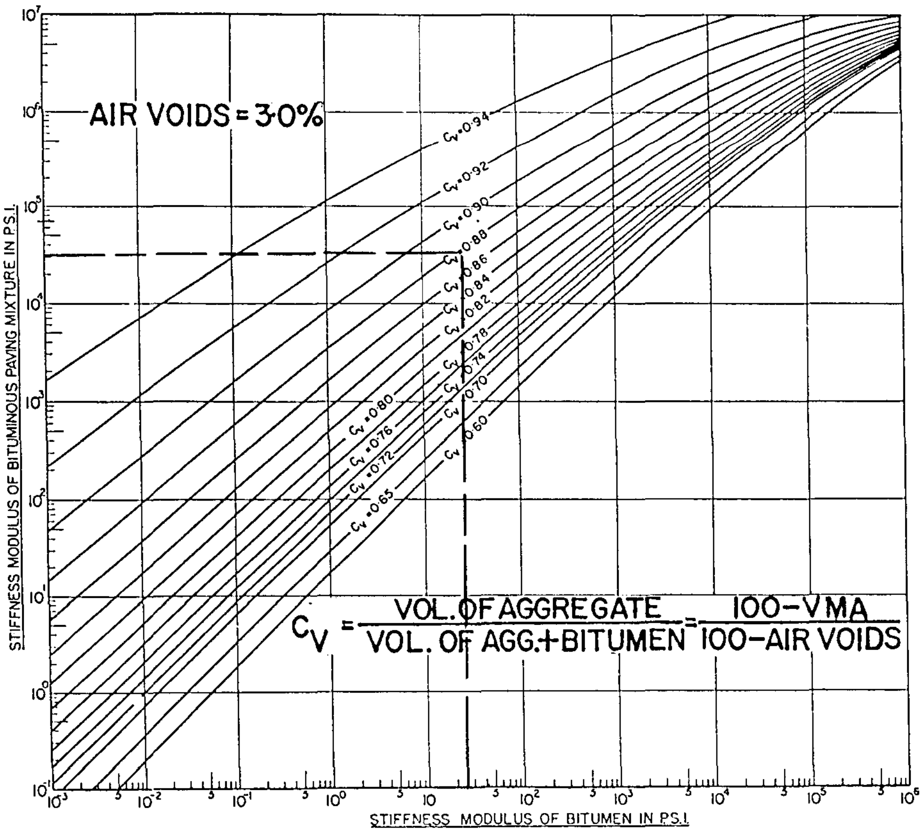

FIG. 4 NOMOGRAPH FOR DETERMINING MODULI OF STIFFNESS OF ASPHALT PAVING MIXTURES (WITH CREDIT TO VAN DER POEL,REF.16 & 17)

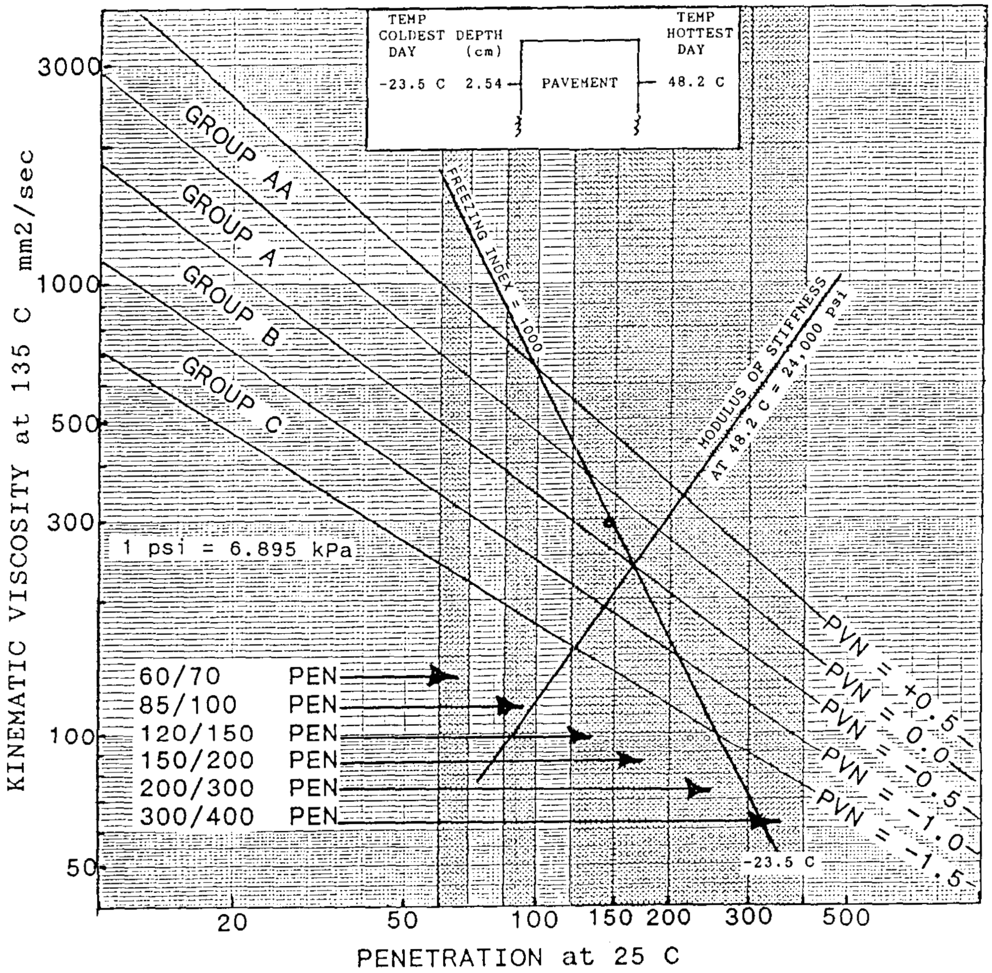

FIG.5 SELECTION OF COMBINATIONS OF TEMPERATURE SUSCEPTIBILITY (PVN) AND PENETRATION AT 25 C FOR PAVING ASPHALTS FOR HEAVY TRAFFIC AT A FREEZING INDEX OF 1000 (-23.5 C)

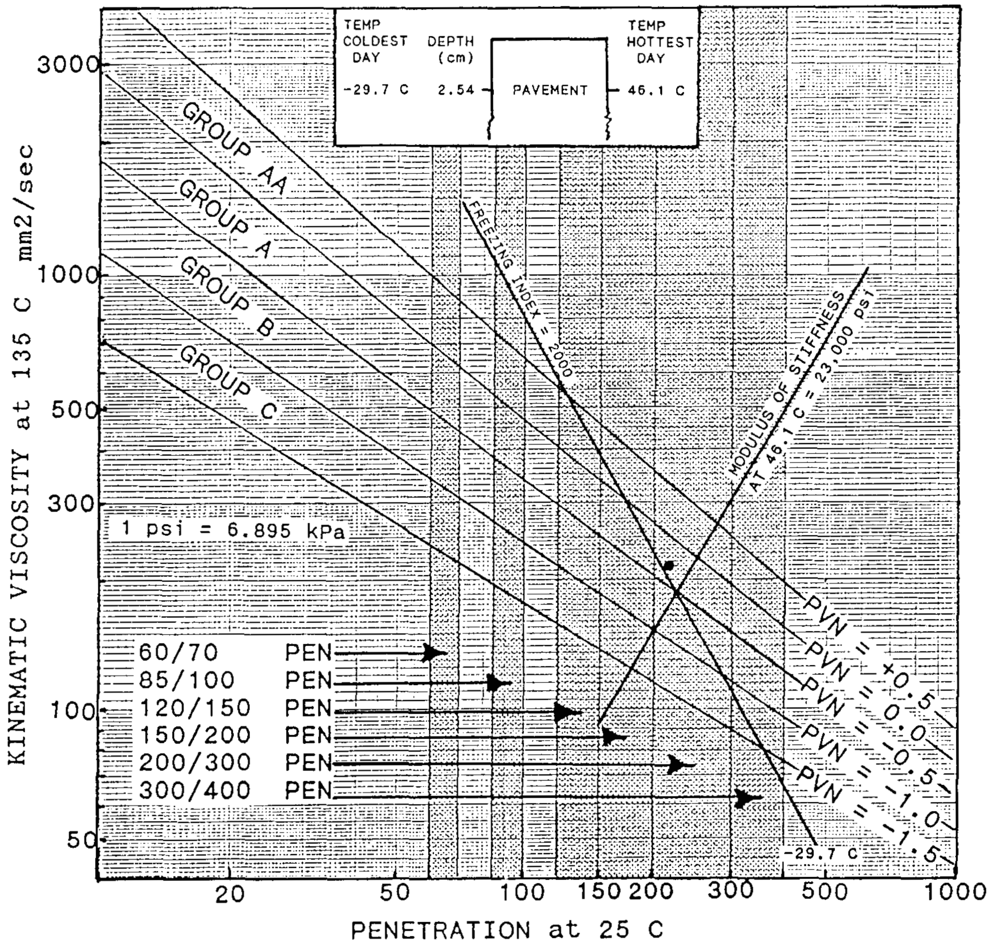

FIG. 6 SELECTION OF COMBINATIONS OF TEMPERATURE SUSCEPTIBILITY (PVN) AND PENETRATION AT 25 C FOR PAVING ASPHALTS FOR HEAVY TRAFFIC AT A FREEZING INDEX OF 2000 (-29.7 C)

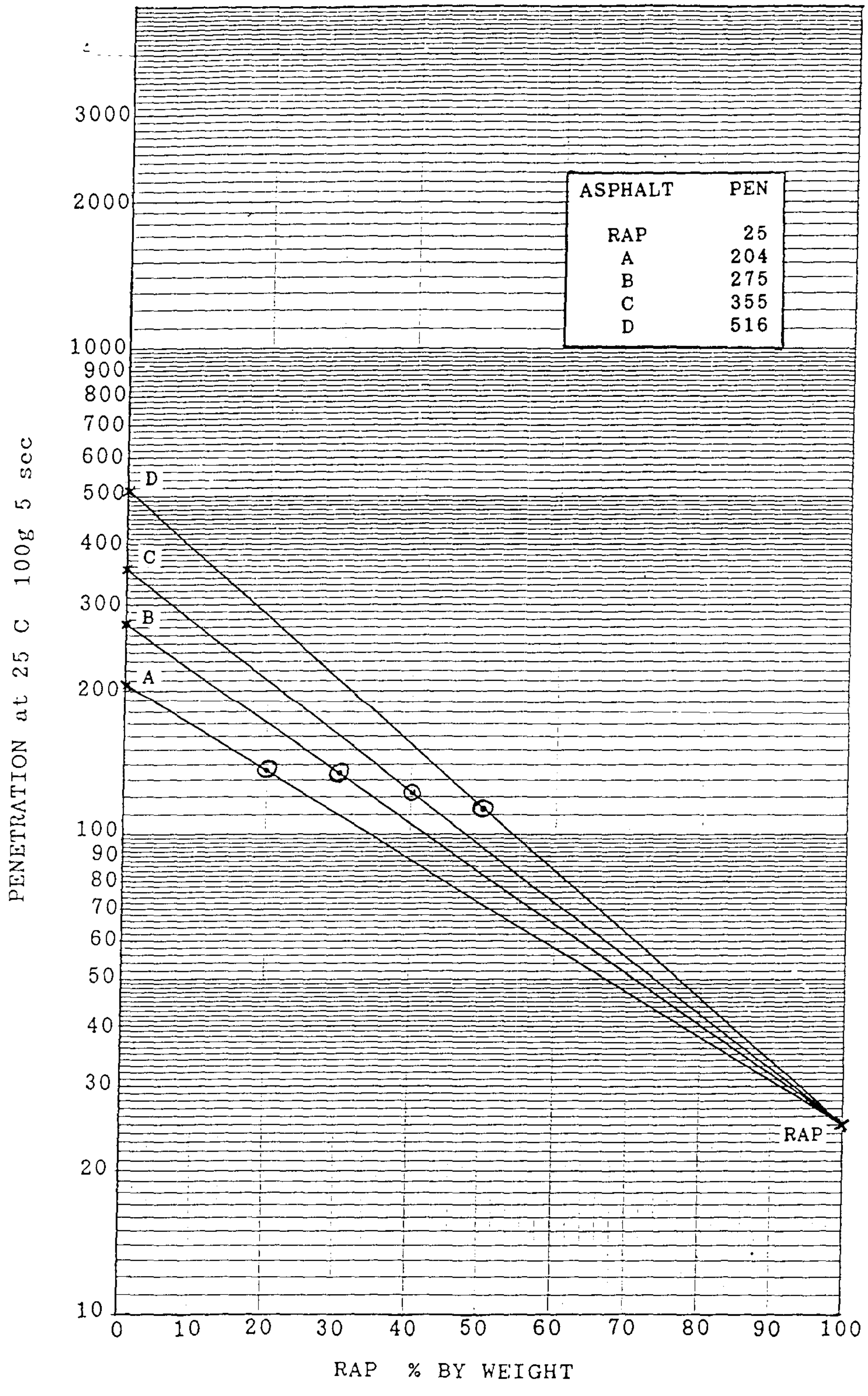

FIG.7 ASPHALT BLENDING CHART FOR FREEZING INDEX OF 1000

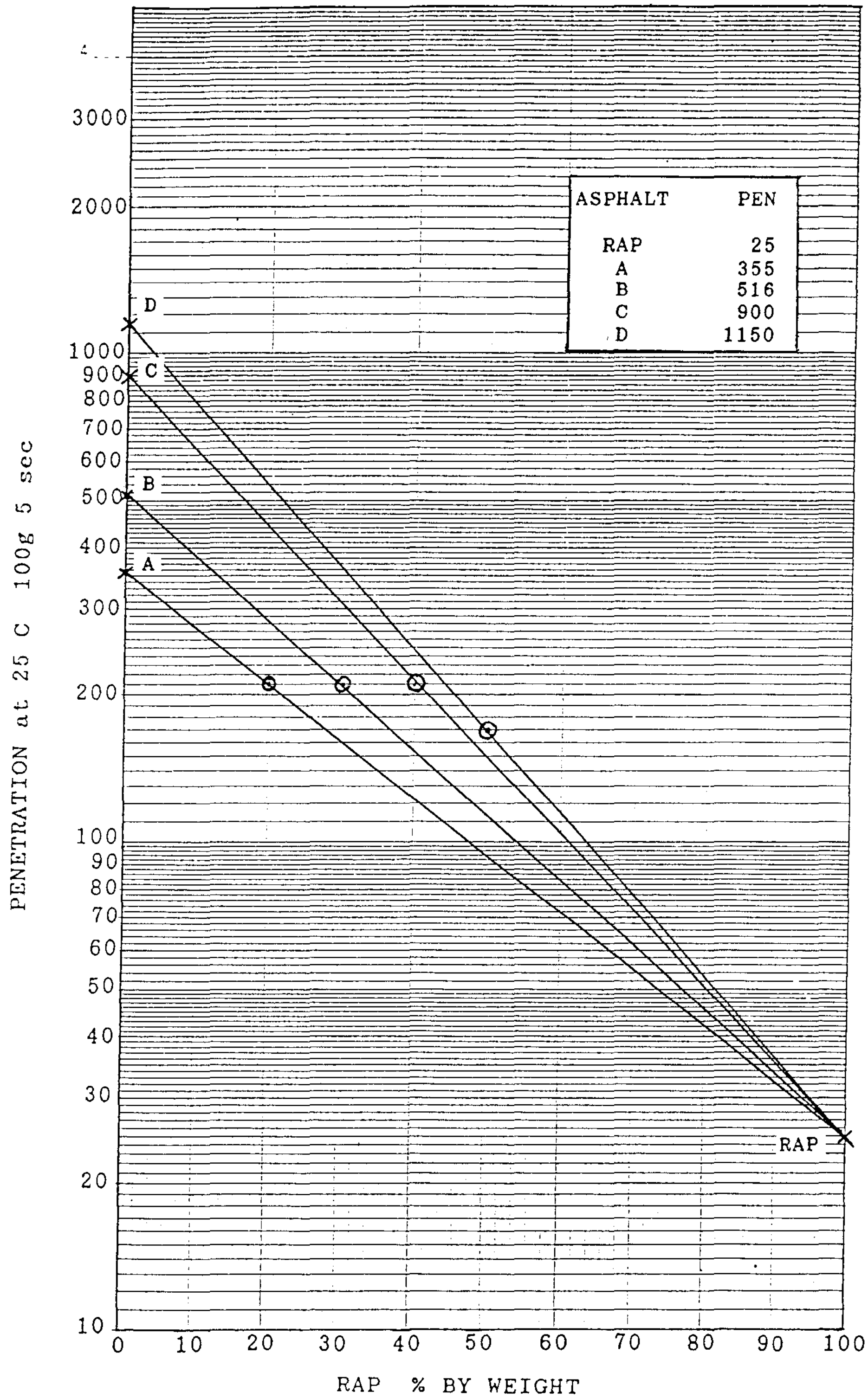

FIG.8 ASPHALT BLENDING CHART FOR FREEZING INDEX OF 2000

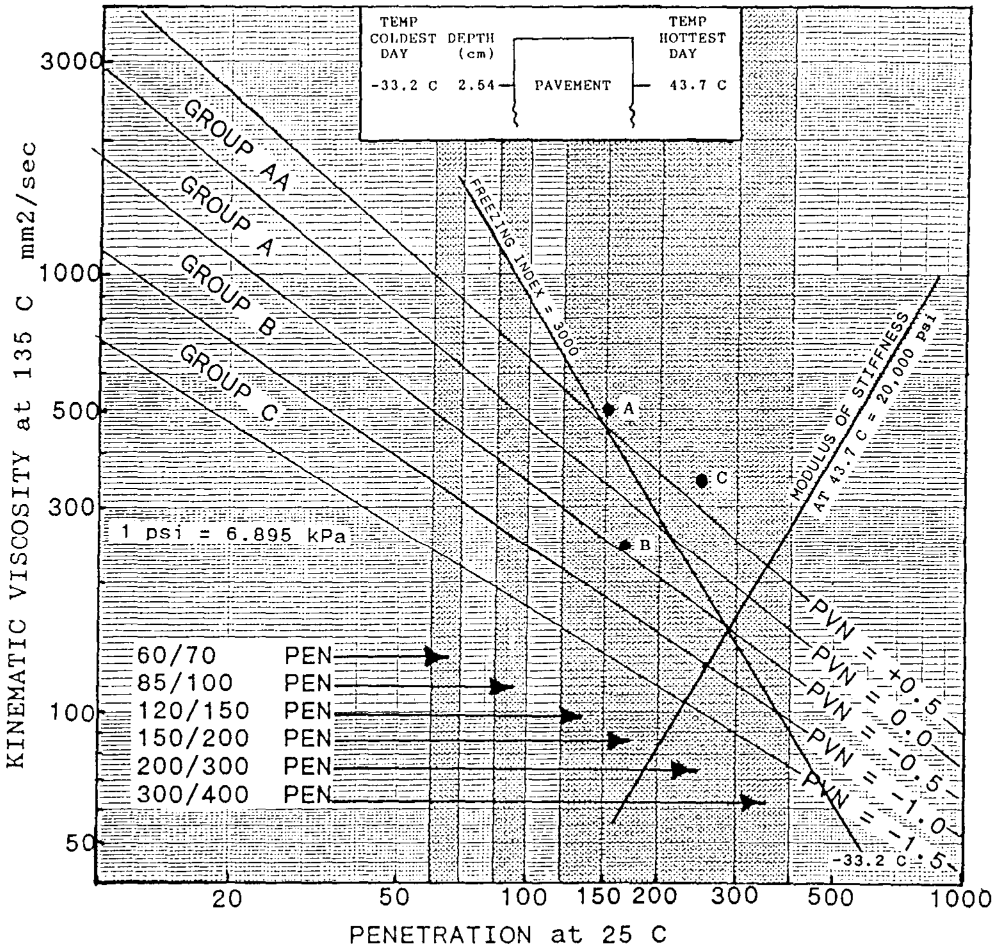

FIG.9 SELECTION OF COMBINATIONS OF TEMPERATURE SUSCEPTIBILITY (PVN) AND PENETRATION AT 25 C FOR PAVING ASPHALTS FOR HEAVY TRAFFIC AT A FREEZING INDEX OF 3000 (-33.2 C)

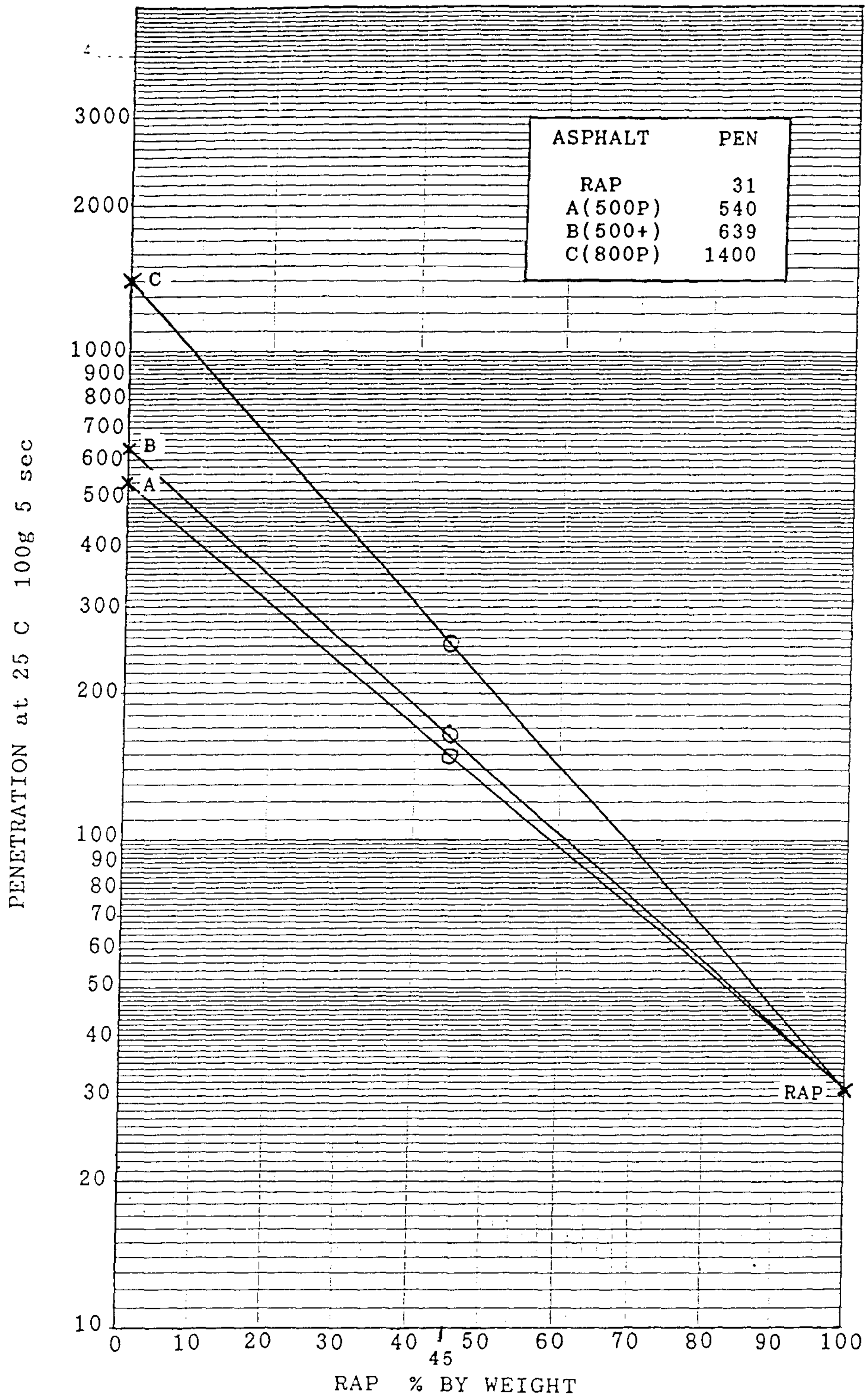

FIG.10 ASPHALT BLENDING CHART FOR FREEZING INDEX OF 3000