Outline of Paper*

Reduction in Transverse Pavement Cracking By Use of Softer Asphalt Cements

NORMAN W. McLEOD, Imperial Oil Limited, Toronto, Ontario

Low-temperature transverse pavement cracking is currently the most serious asphalt pavement performance problem in Canada. Analysis of samples from pavements in service and observation of their field behavior indicate that low-temperature transverse pavement cracking can be dramatically reduced by the use of softer asphalt cements. The results of theoretical studies are reported that support this conclusion. Evidence is presented, based on consideration of transverse pavement cracking in cold weather, that opposes grading asphalt cements by viscosity at 140 F, and firmly supports their continued grading by penetration at 77 F.

1. Most of the subject matter of this paper was presented at the 1968 Annual Meeting of the Highway Research Board, but was not published. Additional information, particularly on pavement samples, has been obtained since that time, and has been included in the present paper.

2. Transverse cracking is the most serious asphalt pavement performance problem in Canada between the Rocky Mountains and the mouth of the St. Lawrence River. Practically every conventional asphalt pavement made with 85/100 penetration asphalt in northern Ontario and Quebec, and those containing 150/200 penetration asphalt in the Prairie Provinces, that are more than two years old, have transverse cracks at intervals of from 5 to about 30 ft. This is true regardless of variations in the gravel aggregates being used for the paving mixtures, in the roadbed on which these pavements rest, and in the provincial highway departments' design and construction procedures. This problem of transverse pavement cracking is so serious that an answer must be found.

3. Observations of pavement performance in the field indicate that transverse pavement cracking in Canada is due to low temperature stresses and strains, since severity of pavement cracking appears to parallel severity of cold weather.

4. Looking back over the history of asphalt usage in Canada since 1930, it is recognized that with the softer SC 2, 3, 4, and 5 grades, or equivalent, employed for paving rural highways in earlier years, transverse pavement cracking was not a problem. It did not become a serious problem until after passage of the Trans-Canada Highway Act in 1949, when due to the higher standards that were adopted for the Trans-Canada Highway, the Prairie Provinces changed to 150/200 penetration, while considerable 85/100 penetration was used in northern Ontario and Quebec. Therefore, the history of asphalt usage in Canada indicates the need to return to softer grades of asphalt cement if transverse pavement cracking is to be avoided.

5. Observation of the performance of pavements in Norway that contain 300 penetration asphalt, and the Alberta Highway Department's experience with MC 2 and MC 3 mixed prime employed as a temporary pavement for from two to four years, are cited as examples of using soft asphalt cements that do not result in transverse cracking.

---

*This is an outline of the original manuscript; a copy of the complete paper can be obtained from the author.

6. In some milder parts of Canada, transverse cracks do not develop in pavements containing 85/100 penetration asphalt until after a number of years of service. This is believed to be due to the gradual hardening of the asphalt cement with age, and to the eventual corresponding loss of sufficient pavement flexibility to avoid transverse cracking. This provides further evidence that low-temperature transverse pavement cracking is associated with hard asphalt cements.

7. Like most generalizations, some exceptions to the conclusion that softer grades of asphalt cement would result in less transverse pavement cracking occurred on the Trans-Canada Highway north of the Great Lakes, where several pavements containing 150/200 penetration asphalt were badly cracked as well as those made with 85/100 penetration. Through the courtesy of the Ontario Department of Highways, samples were obtained from pavements in this area containing 85/100 and 150/200 penetration asphalt cements. At the same time a transverse crack survey was made of the pavement for a distance of 1000 ft at each sample location. The asphalt cements recovered from these pavement samples by our research department showed that for this particular region, very little transverse cracking occurred when the recovered asphalt had a penetration of 60 or higher at 77 F, and a penetration of 20 or more at 32 F. Consequently, for the milder low temperature conditions that occur immediately north of the Great Lakes, evidence from pavement samples and from transverse crack surveys in the field indicates that transverse pavement cracking could be reduced and largely eliminated by using softer asphalt cements, and by employing pavement design and construction procedures that would prevent hardening of the asphalt cement in service to 60 penetration at 77 F and to 20 penetration at 32 F. These penetration criteria would have to be increasingly higher for still colder areas.

8. In Manitoba, all asphalt pavements containing 150/200 penetration asphalt cements that are more than two years old have numerous transverse cracks, while those made with SC 6 (300/400 penetration) and SC 3000 (SC 5) are practically free from transverse cracks. Asphalts recovered from samples of these pavements obtained through the courtesy of the Manitoba Department of Highways showed penetrations at 77 F of 60 to 81 for the 150/200 penetration pavements, penetrations of 133 to 160 at 77 F for SC 6 (300/400 penetration) pavements that were up to 16 years old, and penetrations of 320 to 374 at 77 F for SC 3000 (SC 5) pavements that were three years old. These data provide further confirmation that the use of soft asphalt cements can dramatically reduce low temperature transverse pavement cracking.

9. The present investigation of transverse pavement cracking in Canada is related to a review of the pavement cracking problem in the central Midwest and central Atlantic Coast regions of the United States in the 1930's by The Asphalt Institute, which indicated a close relationship between pavement cracking and hardness of the asphalt binder. The results of the present study extend the conclusions of the earlier Asphalt Institute inquiry into a colder area.

10. It is recognized that the subgrade and granular base may be responsible for some transverse pavement cracking. Nevertheless, little or no transverse pavement cracking was observed when the softest grades of asphalt cement were employed. This leads to the tentative conclusion that in Canada at least, low temperature transverse pavement cracking is ordinarily due more to the characteristics of the paving mixture than to the foundation.

11. Experience has shown that little reduction in transverse pavement cracking occurs by changing to the immediately adjacent softer grade of asphalt cement, for example from 150/200 to 200/300 penetration. It is necessary to jump over one or two grades to a substantially softer grade, for example, from 85/100 to 150/200 penetration, or from 150/200 to 300/400 penetration, to achieve a very marked reduction in low temperature transverse cracking. At the same time, every good design and construction technique should be employed that will retard the rate of hardening of the asphalt cement in service. In addition to starting with a softer grade of asphalt cement, this includes designing for thicker asphalt films, low air voids, and requiring compaction by rolling during construction to much higher density, and preferably to 100 percent of laboratory compacted density.

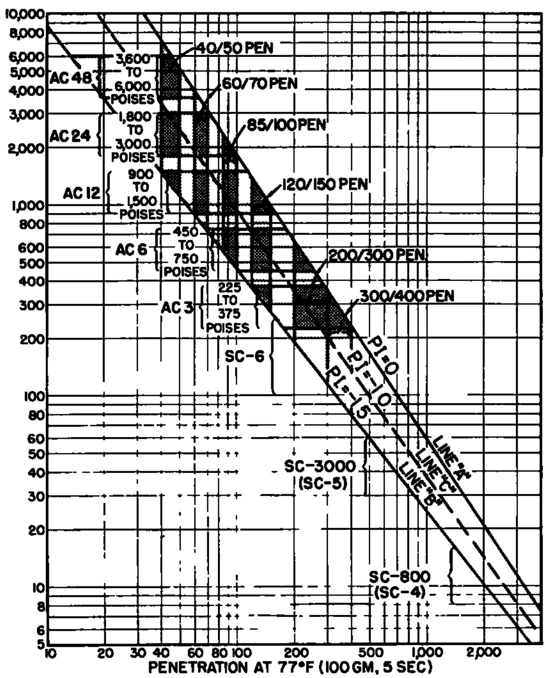

Figure 1. Correlation between viscosity at 140 F and penetration at 77 F for asphalt cements.

12. SC 6 should be discarded from all specifications in which it currently appears, because depending on crude oil source it includes all grades of asphalt cement from 150/200 to 600 penetration (Fig. 1) which in Canada, brackets lower penetration (150/200) or harder asphalt cements that result in serious transverse cracking, with higher penetration (600) or softer asphalt cements that do not. Consequently, any current SC 6 specification should be replaced with a specification for 300/400 penetration asphalt cement.

13. The adoption of softer grades of asphalt cements to reduce transverse pavement cracking could lead to two practical problems: (a) delayed rolling behind the spreader because of softness of the paving mixtures at high temperatures, and (b) rapid densification of a new pavement by traffic to 100 percent of laboratory compacted density which could lead to flushing or bleeding a few months after construction unless the paving mixture is properly designed. It is shown that the use of variable tire pressure pneumatic rollers, equipped for rapid adjustment of tire inflation pressure, would provide a solution to the first problem, and designing paving mixtures to have a minimum air voids value of 3 percent provides a simple and practical solution to the second.

14. Unlike the costly solutions proposed for most roadway problems, because soft asphalt cements are normally the same price as harder asphalt cements, the use of softer asphalt cements to solve the problem of low temperature transverse pavement cracking will not increase the initial cost of a pavement. Furthermore, there should be a substantial annual savings in the maintenance cost of filling from 100 to 300 or more cracks per mile per year.

15. Good engineering judgment is required when selecting a soft grade of asphalt cement to minimize transverse pavement cracking in cold weather, that is consistent with the need for adequate pavement stability for traffic in warm weather.

16. Since the performance of pavements in the field appeared to indicate the need for softer asphalt cements to minimize low temperature transverse pavement cracking, the next step was to look for theoretical confirmation of this conclusion.

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

18. It is shown in the paper that the tensile stress induced in a pavement due to pavement contraction caused by chilling over a given low temperature range in a specified time, varies directly with the modulus of elasticity of the pavement. When the tensile stress exceeds the tensile strength of a pavement, a crack occurs.

19. Heukelom, in the 1966 AAPT Proceedings showed that the strain at which an asphalt cement cracks when chilled, decreases very rapidly with an increase in the modulus of stiffness or hardness of an asphalt cement. (Rader's modulus of elasticity

is synonymous with Heukelom's modulus of stiffness.) This means that when chilled over a given low temperature range in a stipulated period of time, a pavement containing a hard asphalt cement is more likely to crack than when it contains a soft asphalt cement.

20. Hills and Brien, for a prepared discussion in the 1966 AAPT Proceedings, employed Heukelom's method to calculate the fracture temperatures (the temperature at which a pavement cracks because the tensile stress exceeds its tensile strength) of paving mixtures when they are cooled at a specified rate to low temperature. They also checked these calculated fracture temperatures by laboratory tests on actual paving mixtures and obtained quite good agreement. Hills and Brien concluded, as illustrated by Figure 2, that the temperature at which pavement cracking is to be expected can be lowered very substantially by the use of softer asphalt cements, and that for any penetration grade of asphalt cement, a lower pavement cracking temperature is associated with a higher PI (higher viscosity) than for a lower PI (lower viscosity) paving asphalt.

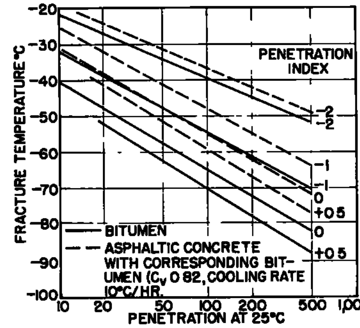

Figure 2. Influence of penetration and temperature susceptibility of bitumen on the fracture temperature of bitumen and asphaltic concrete. (Courtesy Hills and Brien.)

21. Rader's conclusions, relating modulus of elasticity (modulus of stiffness) of asphalt pavements to low temperature pavement cracking, were based on samples from particular pavements that he selected. Even if a simple laboratory test for measuring the modulus of stiffness of any proposed paving mixture can be devised, there is need for some general theoretical method that will enable an engineer to foresee or to forecast the influence that any proposed change in paving mixture design is likely to have on a paving mixture's modulus of stiffness (modulus of elasticity). Nomographs developed originally by Van der Poel and by Pfeiffer and Van Doormaal, that were modified by Heukelom and Klomp, and modified further by the author, make a general theoretical method for this purpose possible (Fig. 3). The procedure for preparing such charts is described in the paper.

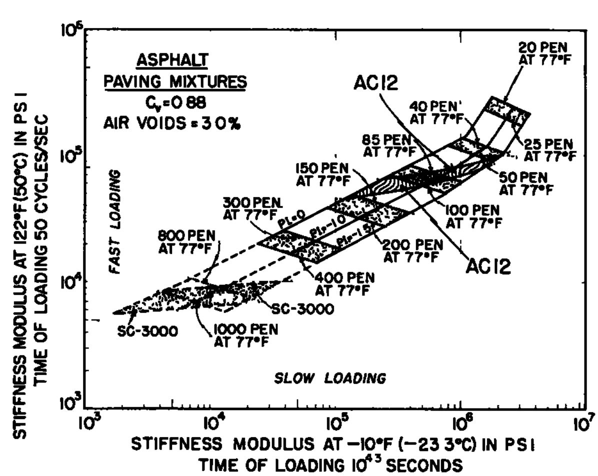

Figure 3. Relationship between stiffness moduli for asphalt paving mixtures for high rate of loading (high-speed traffic) at high temperature (122 F) vs slow speed of loading (temperature stresses) at low temperature (-10 F).

22. Figure 3 pertains to compacted paving mixtures containing 3 percent air voids, in which the volume of the aggregate is 87 percent of the volume of aggregate plus asphalt cement. These paving mixture would satisfy The Asphalt Institute design criteria for dense graded asphalt concrete made with aggregate of either 3/4- or 5/8-in. maximum particle size. The abscissa makes it possible to compare the moduli of stiffness of a specified paving mixture that have been developed by slow chilling to -10 F, when it contains 20/25, 40/50, 85/100, 150/200, 300/400 penetration asphalt cements, and SC 3000 (SC 5). Figure 3 shows that the modulus of stiffness of the paving mixture for this low temperature condition increases from about 2000 psi for the paving mixture containing SC 3000 (SC 5) with

a PI of 0.0 (high viscosity), to 2,000,000 psi when the paving mixture contains 40 penetration asphalt with a penetration index of -1.5 (low viscosity). This range of 1000-fold in modulus of stiffness is due solely to the differences in the hardness of the asphalt binder the paving mixture contains. Rader reported that the use of a softer asphalt cement was an effective method for reducing the modulus of stiffness of a paving mixture. This is verified by Figure 3.

23. Three full-scale test roads, each six miles long and each containing three 2-mi paved test sections, were constructed in southwestern Ontario in 1960 by the Ontario Department of Highways, to test the performance of asphalt pavements containing three different 85/100 penetration asphalt cements, one of high viscosity or high PI, one of intermediate viscosity or intermediate PI, and one of low viscosity or low PI. A different asphalt cement was incorporated into the pavement for each 2-mi test section, and all three asphalt cements were used in each 6-mi test road. In 1968 when these pavements were eight years old, a transverse crack survey was made, and the asphalt cement was recovered by our research department from pavement samples obtained through the courtesy of the Ontario Department of Highways from the nine test sections in the three test roads. Data on the recovered asphalt cements showed that in eight years they had in general hardened from 85/100 penetration to 30/40 penetration. Figure 4 shows a plot of the number of Type I transverse cracks per mile (transverse cracks that extend across the full lane width) vs the penetration index (PI) of the original 85/100 penetration asphalt cements. Figure 4 implies that a pavement made with a low viscosity 85/100 penetration asphalt cement with a PI of -1.5 could, after 8 years of service in southwestern Ontario, be expected to develop from 20 to 50 times as many Type I transverse cracks per mile as a pavement made with a high viscosity 85/100 penetration asphalt cement with a PI of 0.0. This confirms Hills and Brien's conclusion that for the same penetration grade of asphalt cement, more low temperature pavement cracking can be expected when the pavement contains a low PI (low viscosity) than when it contains a high PI (high viscosity) asphalt cement (Fig. 2).

24. In 1961, the Ontario Department of Highways constructed a test road 9 miles long in southwestern Ontario, to compare the pavement performance of two low viscosity (low PI) asphalt cements, one of 85/100 penetration, the other of 150/200 penetration. Both asphalt cements were from the same crude oil source, and both had a penetration index of approximately -1.64. The 85/100 penetration asphalt employed was the same as that provided by Supplier 3 (Fig. 4) for the three Ontario test roads constructed in 1960. This 9-mi test pavement was 2 in. thick and was laid as a single course, whereas the three 1960 test roads were 3 in. thick and were placed in two courses. A crack survey was made in 1967 (six years old) on representative sections of this 1961 test road just before a second course of asphalt concrete (which has been planned initially as part of stage construction) was laid. Point A (Fig. 4) indicates more Type I transverse cracks per mile in the 85/100 penetration pavement of this 1961 test road than in the worst of the three 1960 test roads. In part this may be due to the 2-in. pavement thickness of the 1961 test road as compared with the 3-in. pavement thickness of the three 1960 test roads, since when all other factors are equal, thinner pavements appear to develop more low temperature transverse cracks than thicker pavements. However, the portion of the

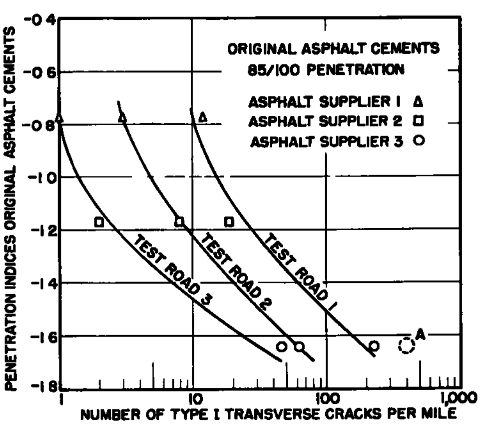

Figure 4. Relationship between penetration indices of original 85/100 penetration asphalt cements vs number of Type I transverse pavement cracks per mile after eight years of service.

1961 test road pavement containing the low PI (low viscosity) 150/200 penetration asphalt, which was also only 2 in. thick, showed no transverse cracking of any kind. That is, there was less transverse pavement cracking (actually no transverse cracking) in the pavement containing the low PI 150/200 penetration asphalt, than occurred in any test section made with 85/100 penetration asphalt with the highest PI (Fig. 4).

25. Consequently, observation of pavement performance in the field, analysis of samples from pavements in service, and the results of the theoretical studies that have been made, indicate that when all other factors are equal, low temperature transverse pavement cracking can be dramatically reduced and even eliminated by the use of softer asphalt cements. The use of softer asphalt cements for this purpose can be made still more effective, if it is combined with improved pavement design and construction procedures that will substantially retard the rate of hardening of the asphalt cement in service.

26. This study of low temperature transverse pavement cracking has a contribution to make to the current controversy over the proposed grading of asphalt cements by viscosity at 140 F with complete elimination of the penetration test, vs the current method of grading paving asphalts by penetration at 77 F. Figure 1 compares the grades AC 3, AC 6, AC 12, AC 24, and AC 48, that would result from the proposed grading by viscosity at 140 F vs the current grades in terms of penetration at 77 F. Figure 1 shows that one of the proposed grades by viscosity at 140 F, AC 12, would include all penetration grades at 77 F from 40/50 to 150/200 penetration. Consequently, grading asphalt cements by viscosity at 140 F implies with respect to AC 12, that pavement performance will be the same regardless of whether a paving mixture is made with 40/50 or with 150/200 penetration asphalt cement. It will be demonstrated that this assumption could lead to disaster as far as low temperature transverse pavement cracking is concerned.

27. The abscissa of Figure 3 indicates that the range of modulus of stiffness for slow loading at -10 F is about 4-fold for paving mixtures containing any current penetration grade, 85/100, 150/200 penetration, etc. For example, for the paving mixture containing 100 penetration asphalt with a PI of 0.0, the modulus of stiffness is 275,000 psi, but it is 1,000,000 psi when the paving mixture contains 85 penetration with a PI of -1.5. Figure 4 shows that for the 85/100 penetration grade, this 4-fold range in modulus of stiffness is associated with a range of from about 20-fold to about 50-fold in the number of low temperature transverse pavement cracks that occurred after 8 years of service in southwestern Ontario. Figure 1 indicates that for the proposed AC 12 grade for example, the corresponding range of penetration at 77 F is from 40/50 penetration to 150/200 penetration. The abscissa of Figure 3 shows that for a paving mixture containing approximately 180 penetration with a PI of 0.0, the modulus of stiffness at -10 F is about 110,000 psi, but it is 2,250,000 psi when the same paving mixture contains a 40 penetration asphalt cement with a PI of -1.5, a range of 20-fold in modulus of stiffness. Consequently, grading by penetration at 77 F provides paving mixtures with a 4-fold range in modulus of stiffness with an associated range of from 20-fold to 50-fold in the number of low temperature transverse pavement cracks per mile. Grading by viscosity at 140 F provides paving mixtures with a 20-fold range in modulus of stiffness ness, and this implies a corresponding range in degree of transverse cracking that is several times wider than from 20- to 50-fold. Paving mixtures containing AC 12 asphalt with the lowest penetration at 77 F (40/50 penetration) would show excessive low temperature transverse cracking, while those containing AC 12 with the highest penetration at 77 F (150/200 penetration) would show very much less, and possibly even no transverse cracks.

28. While grading asphalt cements by penetration at 32 F has not been proposed, Figure 5 indicates that this method for grading paving asphalts would have the great merit of eliminating the effect of differences in asphalt temperature susceptibility (PI) on modulus of stiffness values for paving mixtures subjected to slow loading by slowly chilling to -10 F. For four of the ranges of penetration at 77 F (Fig. 3), 40/50, 85/100, 150/200, and 300/400 penetration, Figure 5 demonstrates that for paving mixtures containing asphalt cements with the four corresponding ranges of penetration at 32 F, the boundaries for each grade by penetration at 32 F are vertical lines from PI = 0.0 to PI = 1.5, and the range in pavement modulus of

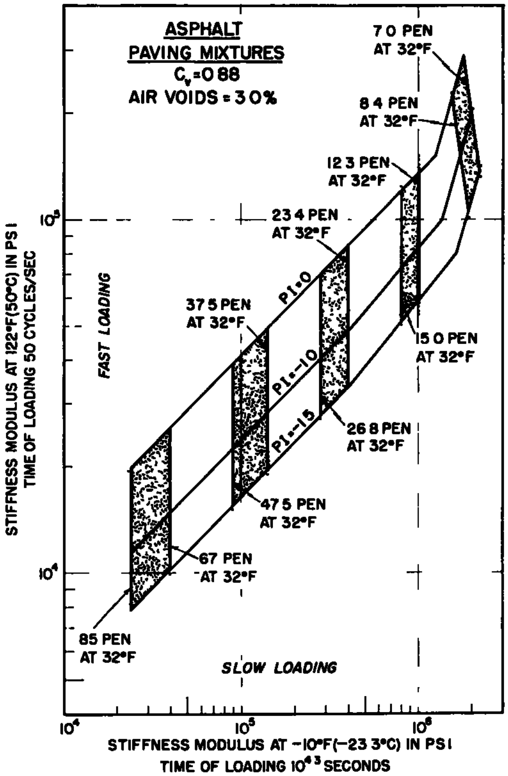

Figure 5. Relationship between stiffness moduli for asphalt paving mixtures for high rate of loading (high-speed traffic) at high temperature (122 F) vs slow speed of loading (temperature stresses) at low temperature (-10 F).

stiffness values for each grade of asphalt cement in terms of penetration at 32 F is only 1.5-fold. In comparison, when asphalts are graded by penetration at 77 F, Figure 3 shows that the range in modulus of stiffness is about 4-fold for paving mixtures containing each grade, and when asphalt cements are graded by viscosity at 140 F with elimination of the penetration test, for example AC 12, the permissible range in modulus of stiffness for paving mixtures incorporating each viscosity grade is 20-fold for the same low temperature conditions.

29. Insofar as the influence of the method for grading asphalt cements on low temperature transverse pavement cracking is concerned, since an increase in the low temperature modulus of stiffness of a pavement appears to result in a marked increase in low temperature transverse pavement cracking, Figures 3 and 6 indicate that grading asphalt cements by viscosity at 140 F would be far the worst method, since the range of modulus of stiffness would be 20-fold for each grade, for example AC 12 in Figure 3, while Figure 5 demonstrates that grading asphalt cements by penetration at 32 F would be the best method because the range of modulus of stiffness would be only 1.5-fold for each grade. On the other hand, with respect to high temperature construction operations, Figure 6 demonstrates that grading asphalt cements by viscosity at 140 F would be the best method since it would provide the narrowest range of viscosity at 140 F for each viscosity grade, while grading by penetration at 32 F would be the worst method because it would provide the widest range of viscosity at 140 F for each penetration at 32 F grade. Consequently, when both low temperature pavement performance and high temperature construction operations are considered, Figures 3 and 6 indicate that grading asphalt cements by penetration at 77 F provides the most desirable compromise. Figure 6 demonstrates that grading by penetration at 77 F provides a range of viscosity at 140 F intermediate between those of grading by viscosity at 140 F and by penetration at 32 F; and of much greater importance (Figs. 3 and 5), it provides a 4-fold range in pavement low temperature modulus of stiffness vs a 1.5-fold range for grading by penetration at 32 F and a 20-fold range for grading by viscosity at 140 F.

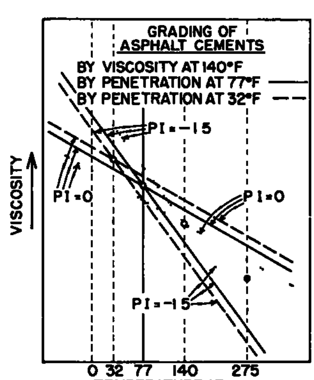

Figure 6. Consequences of grading asphalt cements by viscosity at 140 F, by penetration at 77 F, and by penetration at 32 F.

30. If restrictive specifications for asphalt cements are to be considered.

particularly when consideration is given to reducing or eliminating transverse pavement cracking at low temperatures, it is preferable that the restrictive specification should be based on grading asphalt cements by penetration at 77 F with a viscosity restriction, rather than grading them by viscosity at 140 F with a penetration at 77 F restriction. For example, 85/100 penetration asphalt with Line C in Figure 1 as a minimum viscosity requirement (PI = -1.0) is seen from Figure 3 to result in a permissible range in modulus of stiffness of about only 2.5-fold for slow loading (low temperature stress) at -10 F, 280,000 psi to 700,000 psi. On the other hand, it can be seen from Figures 1 and 3 that grading paving asphalts by viscosity at 140 F, for example 2000 ± 400 poises, with a specified range of penetration at 77 F of 60 to 120, results in a permissible range of pavement modulus of stiffness of about 6-fold (PI = 0.0 to PI = -1.2) for the same low temperature conditions, 200,000 psi to 1,200,000 psi. Since the wider the range of modulus of stiffness the more variable is the degree of low temperature transverse pavement cracking, these data imply that a restrictive specification based on grading by penetration and a minimum viscosity restriction, with its 2.5-fold range of modulus of stiffness, is greatly superior to a restrictive specification based on viscosity at 140 F and a wider permissible range of penetration at 77 F, with its 6-fold range of modulus of stiffness.

31. Figure 3 suggests that when it is guided by a need to greatly reduce or eliminate low temperature transverse pavement cracking, the selection of the penetration at 77 F grade of asphalt cement should be based on the maximum modulus of stiffness for the pavement that will just avoid low temperature pavement cracking throughout its service life. This will provide higher pavement stability for warm weather traffic. For example, when as illustrated by Figure 3, the lowest pavement temperature to be anticipated in some region is -10 F, if 85/100 penetration asphalt cement having a penetration index of 0.0 just avoids transverse cracking, then if an asphalt cement with a penetration index of -1.5 is being considered, its penetration grade should be 150/200. Figure 3 indicates that when all other factors are equal, paving mixtures containing either 85/100 penetration asphalt with a PI of 0.0, or 150/200 penetration asphalt with a PI of -1.5 will have the same modulus of stiffness at -10 F, and therefore, their low temperature service performance should be similar.

32. There appears to be a tendency in many areas to assume when selecting an asphalt cement, that only penetration grades with a high viscosity (high PI) should be specified. This fails to recognize the thoroughly demonstrated excellent service performance of many pavements that have been made with properly selected grades of low viscosity (low PI) asphalt cements. It also seems to be overlooked that low viscosity asphalt cements provide paving mixtures with less resistance to compaction by rolling; they provide a longer period of time during which compaction by rolling is effective, which is a very important advantage in colder climates; pavements compact faster to their ultimate density under traffic, which retards the rate of hardening of the asphalt binder in service, and lengthens pavement service life; and they provide pavements with substantially greater load carrying capacity per inch of thickness during the spring break-up period.

33. Finally, provided the old pavement is first covered with a substantial layer of stable granular material, there is some evidence that the use of softer asphalt cements in asphalt concrete overlays, will effectively reduce the amount of reflective cracking in the overlay that is presently occurring.