

THE EXPANDED MONTANA ASPHALT QUALITY STUDY
USING HIGH PRESSURE LIQUID CHROMATOGRAPHY

Prepared for the
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and
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ABSTRACT

This report describes a study of asphalts by High Performance Gel Permeation Chromatography (HP-GPC). The asphalts were obtained from pavements in 15 states. Performance of the pavements with respect to cracking (especially transverse cracking) was compared with the HP-GPC data. General trends were found in this study. Asphalts with lesser amounts of large molecular size (LMS) material tend to give better performance than do those with larger amounts. The level of LMS content above which cracking predominates is a function of climate in that more LMS material can be tolerated in warmer zones than in colder areas. Data is given for all climate zones and LMS limits are also recommended.

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Other studies involved a series of Florida samples which showed that the effects of mixing temperature and aging in pavement on the HP-GPC profile depend upon the asphalt and, presumably, the aggregate. Some asphalts are more sensitive than others and show larger increases in LMS content.

Samples from recycling projects in which various design and mix criteria were used, were analyzed. HP-GPC shows the effects of the addition of recycling agents and virgin asphalts.

Steps which may be taken to implement the results of this project are suggested. Knowledge is at a stage in which the technique may be used in monitoring asphalt supplies, aiding in design of both normal and recycled pavements and in shadow specifications. Instigation of a national specification involving HP-GPC would appear to be premature at this time.

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INTRODUCTION

Background

One would be hard-pressed to put a monetary value on the streets and highways in this nation. They represent more than the cost of construction and materials used, for some accounting must be made of the value of goods and services, the convenience to vacationers, farmers, businessmen, and others who daily use this vast network. Some accounting must also be made of the cost in inconvenience, in damage to property, and in time, danger and loss of life that accrue when these roads are cracked, rutted or otherwise damaged.

Obviously, many factors affect the performance of a paved roadway, including the materials from which it is constructed, the climate and soils which are its constant companions, construction techniques, traffic loads, and so on. The sheer number of variables makes an attack on the problem as a whole virtually impossible. However, such factors may be profitably studied individually. One of these factors is asphalt cement. The results of some of our studies on this material will be the subject of this report.

In 1976, in response to the need of the Montana Department of Highways, we began a series of studies by which we hoped to establish a relationship between some measureable characteristic of asphalt cement and the tendency of a pavement constructed with that asphalt to crack. Results of this work will be summarized in the next section. It will suffice to say at this point that a relationship between the molecular size distribution of an asphalt, as determined by High Performance Gel Permeation Chromatography (HP-GPC), and the cracking behavior of the roadway was found in the State of Montana. Because only a few refineries

have supplied asphalt cement to the state over the years, and for other reasons, it was felt that broader verification of these findings was required. Thus, in order to determine the generality of our results in Montana, a Pooled-Fund Study involving 17 additional states was initiated. This study has not only broadened the range of asphalt sources available for examination, but also has brought into play a wide variety of climatic factors, construction traditions, traffic loads, etc. Results of our work during this two-year Pooled-Fund Study will be the subject of this report.

Summary of Previous Projects

The first two projects performed in this laboratory under the auspices of the Montana Department of Highways involved the study of a series of established pavements in the state (1,2). These pavements were selected to represent a range of cracking performance from excellent, virtually crack-free appearance, to bad, severely cracked status. A wide span of ages and sources of asphalt were also sought. Asphalt cement extracted from samples of these roadways was subjected to analysis by High Performance Gel Permeation Chromatography, HP-GPC. By use of this analytical tool, molecules in a mixture are separated according to their size.

These studies showed not only that there are differences among asphalts which are evidenced by HP-GPC, but also that those differences can be related to the cracking performance of the asphaltic pavement from which those asphalts were taken. The molecular size distributions (MSD) of asphalts from Montana's best roads (i.e., 14-20 years old with little or no cracking) are virtually identical. Moreover, the differences observed between these asphalts and those taken from cracked pavements are a matter of degree rather than of kind. This information permitted the identification of an asphalt "model" which was representative of Montana's best roadways. It is now reasonable to assume that asphalts which closely match this model should perform well under conditions found in Montana. This model is for finished asphalt, that is, asphalt which has been extracted from an established pavement. It is valid only when major construction or design flaws do not occur.

During the third project, a number of factors which contribute to the molecular size distribution of the finished asphalt were explored

(3). Among these factors were heat, specific aggregates, hydrated lime, flyash and antistripping agents. It was found that heat alone affected the molecular size distribution of an asphalt cement very little, if at all. However, the other agents, especially in conjunction with heat, as in the mixing process, did affect the MSD in ways that were, again, a matter of degree rather than of kind.

A simple method by which the effects on the MSD of asphalt of processing and lay down in the field may be duplicated in the laboratory was developed during that study. This laboratory simulation procedure will permit the examination of a variety of parameters associated with asphalt quality. Moreover, it will facilitate the use of HP-GPC as a design tool because the proper combination of asphalt, aggregate and additive needed to match the model and to control other possible problems can be determined in the laboratory.

Other broad studies were also begun during these earlier projects (2,3). For example, a series of roadways are being monitored from construction through the aging process. This study will enable the testing of the predictive capabilities of the HP-GPC technique. It will also permit determination of the extent to which the MSD of an asphalt changes with time in service.

Another study undertaken was that of recycling (3). Several Montana projects were observed using the HP-GPC technique. The effect of recycling agents on the salvaged material was demonstrated. By use of the laboratory simulation procedure, a means by which the salvaged material could be made to closely approach the model was shown.

The work accomplished during the first three projects served to show that differences among asphalts could be discerned by HP-GPC and that

these differences could be related to cracking performance. It also demonstrated a variety of ways in which common construction practices, such as the inclusion of additives in the mix, could affect the MSD of an asphalt. It also produced a simple method by which the final MSD of an asphalt can be predicted in the laboratory. Most important, however, was the establishment of a model for a finished asphalt for the State of Montana.

Thus, the potential utility of the HP-GPC technique was well established. Unfortunately, one crucial fact was not, and could not have been, established by this work: that is, the general applicability of the analytical technique to a variety of asphalts and a broad range of conditions that could be found only in other areas of the country. It was to close this gap that the current study was undertaken.

Objectives

Work conducted in the Department of Chemistry at Montana State University and sponsored by the Montana Department of Highways has shown a relationship between the molecular size distribution (MSD) of an asphalt and the performance of that asphalt in a pavement. The basic criterion for performance has been the extent of cracking. This is tied to the conviction of many experienced highway professionals in the State of Montana that pavement cracking is one of the major modes by which asphalt pavements ultimately fail. The effects on MSD of mixing with aggregates and other additives and fillers have been studied. Significant differences in MSD among asphalts from various crude oil and/or refinery sources have been demonstrated.

Results indicate that the method, which uses High Performance Liquid Chromatography in the gel permeation mode (HP-GPC), will prove useful to asphalt consumers and producers. It may contribute to:

1. augmentation of the standard physical tests for asphalt;
2. the prediction of asphalt performance;
3. the design of normal and recycled pavements; and ultimately,
4. the writing of purchase specifications and,
5. quality control.

Until now, the study has been confined to Montana and to the four refineries which supply asphalt within the state. These refineries have historically produced asphalt from a limited number of crude oil sources. This, of course, limits the general applicability of the principle. It also restricts the confidence with which the writing of models and specifications based on the HP-GPC technique can be approached. Therefore, this study, by which these limitations might be removed, was undertaken.

The broad purpose of the Pooled-Fund Study has been to examine and analyze asphaltic pavements which represent different asphalt sources and various environmental conditions but which should come from areas united by a common concern with cracking of asphaltic pavements.

The objectives of this study have been:

1. To determine the validity with which an HP-GPC model of asphalt may be applied to asphalts in a broad geographical region in which pavement cracking is a concern.

2. To further refine the HP-GPC model of asphalt; specifically to determine the optimum percentages of components; and to determine the acceptable variability in these parameters.

3. To develop guidelines for the use and treatment of asphalts which fall near the boundaries of the model.

4. To determine the applicability of the HP-GPC technique and model to the analysis of salvaged and recycled pavements.

5. To develop an implementation plan in cooperation with the MDOH (and, possibly, other cooperating states) whereby the results of the research may be used to aid quality control or to design normal or recycled pavements or to write purchase specifications, as appropriate.

The work has been intended to expand upon studies completed during the first three projects carried out in this laboratory. Three general areas will be addressed in the report to follow: the correlation of performance of established roadways with HP-GPC profile; the evaluation of current virgin asphalts; the applicability of the HP-GPC technique to the recycling of asphaltic pavements.

Review of Data Interpretation

As stated earlier, HP-GPC is a technique whereby the molecules in a mixture are separated according to size. It permits the largest molecules to pass most quickly through the columns but successively retards the progress of smaller ones. It is roughly analogous to a sieve analysis. The resultant chromatogram, as in Figure 1, represents the relative amount (vertical axis) of material appearing at a given elution time (horizontal axis). Larger molecules and aggregations are seen first, on the left of the trace; successively smaller ones follow to the right. This is referred to as the molecular size distribution (MSD) or molecular size profile. The precise elution times and shapes of the profiles are functions of column packing, length of pathway, flow rate, etc., but are relatively constant for a given, carefully controlled system for a specific asphalt.

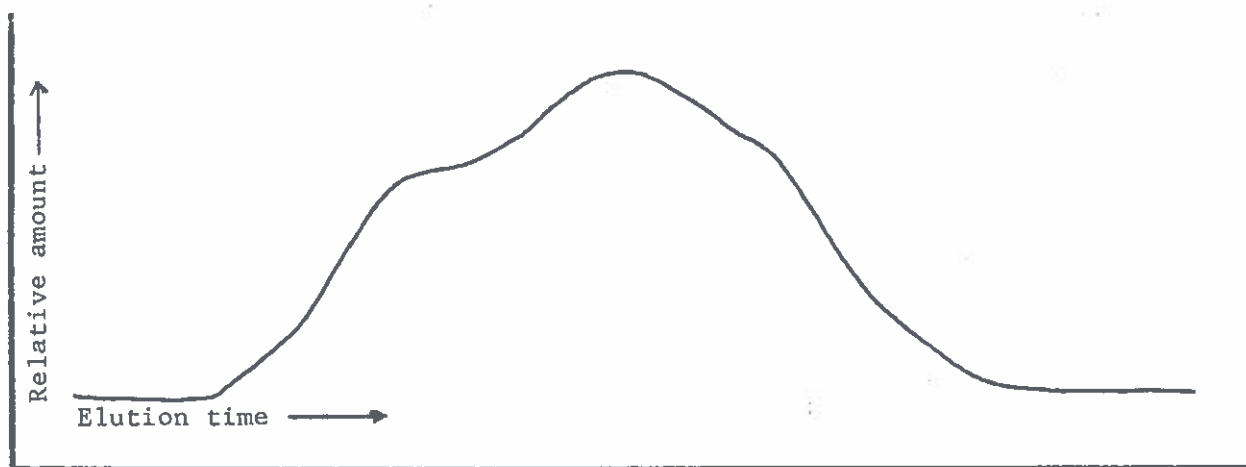


Figure 1. Sample Asphalt Chromatogram

Asphalts may be compared in two ways (Figure 2): by visual observation of the chromatograms and by mathematical determination of the areas under the curves. By simply looking at these traces, one can determine that asphalt A contains many more large materials than does asphalt B; those materials are larger in A than in B. Asphalt A also contains more of the medium and smaller materials than does B.

The area between the baseline and the curve may also be determined. We have divided the total area into three portions which we have called the large molecular size (LMS), medium molecular size (MMS) and small molecular size (SMS) regions. As a result, we can compare asphalts by comparing the percentage of LMS materials in each, for example.

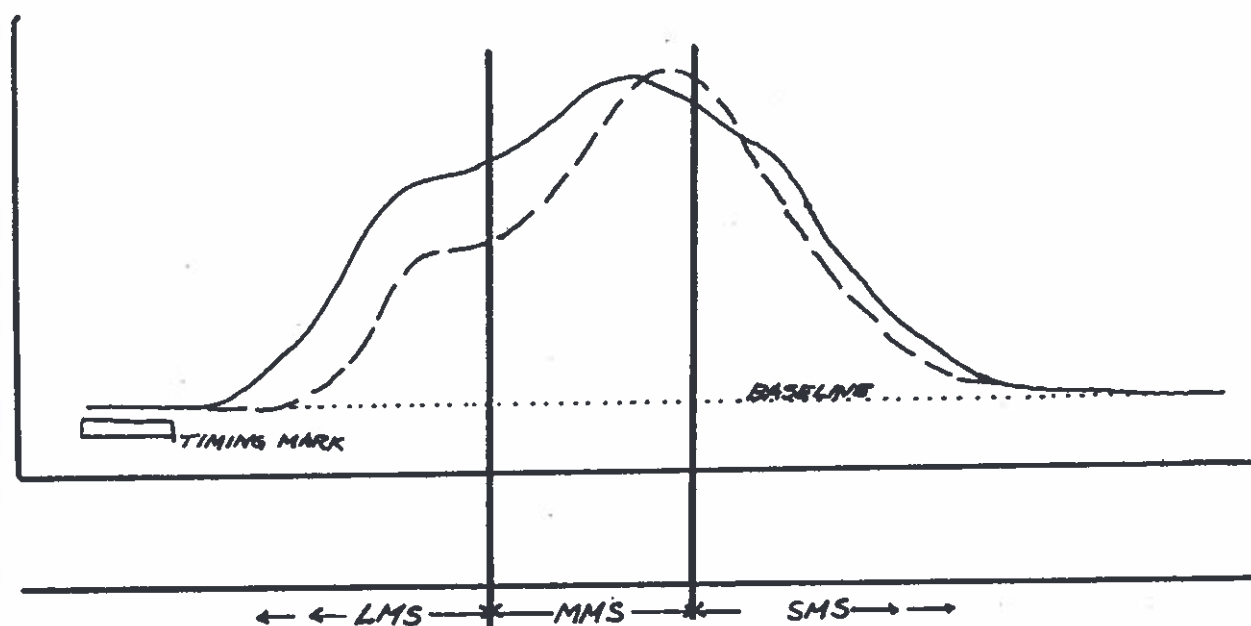


Figure 2. Means of Comparing Data
— Asphalt "A"
--- Asphalt "B"

The cut-point for the LMS area was selected to maximize the differences between Montana asphalts relative to the Montana model with respect to LMS. This was done because earlier work had determined that the tendency of an asphalt to crack could be measured by the amount of LMS material in that asphalt relative to the Montana model. If the asphalt had more LMS material than the model, it was more likely to crack.

The actual size or molecular weight of the material eluting at a given time has not been determined. There are no models for asphalt because it is so complex a material. Polystyrene standards and other molecules are used in the calibration of the columns, but the molecular weights of these standards have little if any relationship to the asphalt. Therefore, levels of LMS, MMS and SMS are strictly relative. They simply give a reproducible means by which to describe and discuss the differences among asphalts. In the ensuing report, the differences between asphalts will most often be described in terms of the LMS material. It should not be inferred that the remainder of the distribution is unimportant to the performance of the asphalt. Indeed, a proper balance among components is required. However, the differences among asphalts with regard to their cracking behavior are predominantly in the LMS region.

IV. Summary of the Project/Executive Summary

The Pooled-Fund study described in this report was undertaken in an effort to verify and extend the results of work done in the state of Montana. This research involved the analysis of asphalts extracted from roadways of known performance by a technique known as high performance gel permeation chromatography, HP-GPC. The results of these analyses were then correlated with performance, specifically, transverse cracking.

Seventeen states, in addition to Montana, cooperated in the Pooled-Fund effort. Three subjects were explored by HP-GPC: analysis of performance-related samples from the states; investigation of current production asphalt cement samples; study of recycling projects.

Samples were selected in 15 states from roadways, the cracking performance of which was visible. Some samples were selected from rutted pavements in two states. Efforts were made to eliminate from consideration those pavements in which cracking performance was likely to have been adversely affected by such factors as sub-grade failure, base construction, etc.

The asphalts extracted from the samples were analyzed by HP-GPC, chromatograms were compared and percentages of large, medium and small molecular size (LMS, MMS, SMS) materials in each asphalt were calculated. An unexpectedly rich variety of asphalt cements was found. For example, the percentages of LMS material ranged from as little as 6 to well over 40.

It was expected that the optimum molecular size distribution (MSD), specifically, the optimum concentration of LMS material, for a finished asphalt in a given region would be a function of climate. Therefore, a scheme for dividing the country into climate zones (4) based on freeze-thaw activity as well as on duration and intensity of cold has been used

for climate evaluation. These broad zones have been subdivided in some cases by geographical regions.

The data has been considered state-by-state and by climate zone within each state. A summary of the data is given in Table 1.

This data shows that nowhere in the country has an asphalt with more than 36% LMS given excellent cracking performance. Also, warmer climate areas can use asphalts with larger amounts of LMS material than colder areas. We believe that the trends exhibited in this data are strong enough to warrant steps being taken in implementation. Suggestions are made in the next section of this report.

Within broad climate zones, there are some differences in the performance/LMS% parameters. For example, in zone 3b, New Jersey appears to require somewhat lighter asphalt (in terms of amount of LMS) than does southwestern Ohio. The reasons for this may lie in actual differences in climate or in traffic loading or design and construction traditions. That is, the data for a given area reflects the sum of the conditions in that area.

The recommended maximum percentage of LMS in asphalts for a climate zone is based on the available data and is intended to allow a margin for local climate and other effects. There are a few cases in which asphalts containing more LMS material than the suggested model have performed well. The success rate with such materials has been low, however, and they have not influenced the recommended maxima. The recommended limits may require some modification as experience is gained. Nevertheless, we believe that adherence to such a model can help to reduce or even eliminate the incidence of long-term transverse cracking.

TABLE 1. Summary of HP-GPC and Performance Data by Climate Zone

Zone	Location	E ⁽¹⁾	C ⁽²⁾	Notes	R ⁽³⁾
3a	GA	36	37	rutting below 32%	35
3b	NJ	28	31		27
	PA-SE	33	—	young pavement	
	OH-SW	33	34		31
	IL-S	35	—	young pavement	
5a	NM-SW	25	26		24
5b	NM-WC	—	26		23
8	PA-SW	—	28		26
	OH-SC	31	32		29
9	NM-NE	—	26		21
14	PA-N	22	25	young pavement	24
	OH-NC	—	29		24
	OH-NE	—	31		24
	IL-C	37	39	exception, young	24
15	CO-Denver	24	26		23
	WY-E	20	22	exception at 23%	20
	SD	23	24		22
16	NM-NW	19	26		20
	CO-W	22	24	exception at 25%	22
	UT-Mtn	24	26		23
	UT-W	25	29		25
	ID-S	19	21	exception at 30%	19
	ID-SE	—	18		17
	ID-N	17,28	29	exception at 28%?	19

TABLE 1. (cont'd). Summary of HP-GPC and Performance Data by Climate Zone

Zone	Location	E ⁽¹⁾	C ⁽²⁾	Notes	R ⁽³⁾
19	IL-NO	—	26		25
	MN-SE	26,30	31		26
20	MN-SW	—	31		21
21a	CO-Mtn	27	—	exception?	20
	WY-Mtn	25	27		
23	MN-N	—	28		20

(1) highest %LMS at which consistent excellent performance was found.

(2) lowest %LMS at which consistent cracking was found.

(3) highest %LMS recommended for that zone, finished asphalt.

A few aphalts were found which, in spite of their very low LMS content, tend to crack severely, frequently during the first winter. Some early work on discriminating these anomalous asphalts and suggestions for necessary further work are presented.

It should be stressed at this point that the molecular size profiles and area percentages are functions of the HPLC system and conditions used and the cut points selected. They are not to be construed as absolutes. Nevertheless, the comparisons between asphalts will be similar in any properly configured and operated system.

Current production (1982) samples were obtained and analyzed. In general it appeared that many (although not all) of the asphalts presently in service were not duplicated in the new supplies.

The current production asphalts also made some points clearly. Asphalts of a given penetration or viscosity grade may vary widely in MSD (Section III. A.). Different grades from the same refinery may be identical in terms of MSD. Very frequently, the differences between the same grade from different refineries are vastly greater than the differences between grades from the same refiner. Other comments could be made, but the point is that penetration and/or viscosity do not correlate with data from HP-GPC. Neither do they correlate with long-term cracking performance.

Samples from recycling projects were interesting. They showed that, under most circumstances, there is no significant increase in LMS content in the salvaged asphalt caused by reprocessing. That does not preclude a decrease in penetration, however. They also showed that the amounts of salvaged and virgin material along with their respective area percentages can be used to calculate the area percentages of the recycled asphalt.

In conclusion, it was found that the performance of asphalt pavements with respect to cracking around the country has been generally poor. Asphalts with lesser amounts of LMS material have tended to give better performance than have those with larger amounts. The level of LMS content above which cracking predominates is a function of the climate. The trends in this data are such that the technique can be immediately useful to highway departments.

IMPLEMENTATION

In this section, ways in which the results of this research may be used will be discussed. This will include some things that can be done now as well as suggestions for further work to increase the future usefulness of the work.

The authors must stress at this point that HP-GPC analyses will not and can not provide a panacea that will cure all asphalt pavement problems. It can not replace penetration and/or viscosity grading, but should supplement them. The best asphalt as defined by HP-GPC can not cover for inadequate design or poor construction practices. However, it is a necessary adjunct to excellent design and careful construction. Sadly, the best asphalt appears not to be able to prevent reflection cracking from PCC bases, cement-treated bases, badly-cracked asphalt concrete, etc. It may be able to delay the inevitable, however. Data from HP-GPC analysis has no relationship to stripping. In some cases the molecular size distribution of an asphalt does contribute to rutting, but there are a number of important contributors to rutting that must not be overlooked. Nevertheless, properly designed and constructed pavements will crack if the asphalt contains too much LMS material. The right asphalt gives the roadway (and the taxpayers) a better chance. HP-GPC can help to find the right asphalt.

- Actions to be taken now -

- 1) A requisite first step in using the results of this research is to increase the familiarity of a variety of highway department personnel with the work. HP-GPC is a new tool in the arsenal and can seem very forbidding when it need not be. (We will be happy to help in this

process in any way we can including a visit to discuss the work and answer questions in person.)

2) HP-GPC can be used to monitor the virgin asphalt cements being received. Are they changing? Are certain types associated with tender pavements? Do certain types crack very rapidly? What are the similarities or differences among grades and sources? Actually, this is the beginning of a system of records that will enable the tracking of performance of asphalts in service. We feel that this is vital, has too long been neglected, and should be instituted even if HP-GPC is not adopted.

3) HP-GPC can be used to predict cracking. The analyses must be done on finished asphalts. The models suggested in this report can be used for the predictions and may then be adjusted, if necessary, as the predictions are or are not borne out.

4) A simple procedure for simulating the effect on MSD of heating with aggregate and other additives and of placement on the roadbed is available. This permits the prediction of performance before construction. It is just a short step to using the technique in design. Does a given asphalt react with a particular aggregate or additive in such a way as to make cracking inevitable? What changes in materials can be made to eliminate the problems? Can two asphalts be blended to overcome the deficiencies of both and thereby match a model? Such questions can more easily and inexpensively be answered in the laboratory than on the roadway. We believe that design is the area in which HP-GPC can be most helpful.

5) Using the laboratory simulation procedure mentioned above, HP-GPC can also be used in the design of recycling projects. What is the

nature of the salvaged asphalt? What needs to be done to bring it into compliance with the model? What materials can be used? What proportions are needed? Targeting a viscosity or penetration value can not answer these questions, but such a value must be considered in addition to the HP-GPC results.

An obvious question is "Must we buy an HPLC instrument?" In order to do very early, exploratory work, arrangements can probably be made to have the work done in another laboratory. But, as the intensity of the efforts grow, such an investment becomes necessary. Some highway departments have purchased HPLC systems and are actively pursuing HP-GPC studies. Others probably have instrumentation that is presently being used for other purposes and would require only the purchase of gel permeation columns. We stand ready to help in this process.

- Actions to be taken soon -

There are certain topics which require further research.

1) It is very important that methods be found for discriminating between low IMS asphalts that perform well and those that crack. This would require the collection of some additional samples (a small group are on hand in this laboratory) and the exploration of a variety of possible tests such as the Corbett analysis and temperature susceptibility measurements mentioned earlier, perhaps some low-temperature physical tests and infrared analyses.

2) States should consider the construction of a series of test sections in which the only variables are the sources of the asphalt cements and any additives regularly used in the state. This might be a cooperative effort among states which share asphalt sources and climate types. Such experiments have several goals. First, they permit testing

of the predictive capabilities of the HP-GPC model. Second, they provide hard evidence about the performance of various asphalts and the effects of additives. Montana and Pennsylvania have constructed such test sections.

3) States may choose to construct several projects using "shadow specifications" in an effort to get a feeling for how a specification based on HP-GPC would work. They may also institute "special provisions" on a project or two. These exploratory ventures help in the familiarization process, etc. Montana is already undertaking such projects.

4) States may also make contacts with the various refiners supplying their asphalts in order to explore the possibilities of enlisting cooperation in improving asphalt quality. Montana has just begun this process. We believe that refiners would prefer to supply asphalt cements that will perform well. States will have to be prepared to pay more for such asphalts, however.

5) In practical terms, we believe that institution of HP-GPC models as nationwide specifications would be premature at this time. We feel that a process of familiarization and exploration as outlined above is necessary. States may, as they feel confident, begin to set up more local specifications, but, to do that wholesale would be to invite failure, in our opinion.

I. Notes on Sampling, Report Organization and Climate

A. Sampling

Fifteen of the eighteen states participating in the Pooled-Fund Study submitted performance related samples. A number of criteria for selecting sampling sites on existing roadways were sent to each state in advance of a visit by project personnel. A copy of portions of a letter containing these criteria is included in Appendix D.

As a practical matter, some of these criteria had to be adjusted to permit obtaining the best possible set of samples in each state. For example, in some states it was very difficult, if not impossible, to find roadways in the 14-20 year age category in either excellent or good condition. This complicated the definition of models.

Another difficulty was posed by the lack of background information. The sample documentation requested for each core is also included in Appendix D. All too often, the only data available beyond that observed during site selection was the construction date for the most recent lift and the penetration or viscosity grade of the asphalt cement used in that lift. This made correlations with other factors virtually impossible to assess for most states.

Only one core was requested from each project because earlier work had shown a remarkable correspondence of the MSD's of asphalts from cores randomly selected from a project, provided, of course, that a change in refinery or crude source did not occur during construction. It was expected that records would alert us to that possibility.

Cores from the selected sites were shipped to this laboratory where they were logged in and checked against available data. Each core was halved vertically and one half was reserved. The upper 1/4 inch of the

other half was removed to avoid interference from various possible contaminants. The remainder was separated into individual lifts. The full procedure for sample preparation is included in Appendix E. The samples were subsequently analyzed by HP-GPC procedures delineated in Appendix A.

B. Report Organization

The data will be discussed in the next section in terms of HP-GPC chromatograms and/or area percentage data, taking into account climatic factors, traffic counts and other available information. In figures, area percentage data will often be given as two numbers in parentheses. These numbers will be %LMS - %SMS. All areas are based on comparison with the Montana Model asphalt with 19% LMS and 38% SMS.

Each lift in a core (separate layer in the construction) will be designated by a letter in the sample designation. For example GA-9a will represent the uppermost lift (a) from sampling site number 9 in Georgia.

In tables comparing %LMS with performance, the following conventions are observed. "Bad" indicates that the pavement was in poor or bad category, regardless of age. "Cracking" signifies a relatively young pavement (7 years or less) which showed significant cracking but may have been in the good category by the actual extent of cracking. "Good" represents pavements in the good category which were more than 7 years old. "Excellent" is reserved for those pavements which were more than six years old and which showed very little if any cracking. Not included in these tables in general are pavements constructed over cement treated bases or PCC, or which showed evidence of stripping. Any exceptions to the above conventions are noted in the table.

Another concept that will be discussed is asphalt "type." During the course of the study, the existence of distinctive types of asphalt, as defined by the shapes of the chromatograms, has become evident. These types probably arise from differences in crude source and/or refinery processing. In the report, these types will be designated by state abbreviation and letter (eg. AK-A; NJ-A). "A" types from different states may or may not be similar.

Refinery sources will be designated by the state abbreviation and a Roman numeral (eg. NJ-I). The state indicated may or may not be the location of the refinery; that is, the designated state is that from which the sample was submitted. Neither the sources of crude nor the processes used by these refineries will be discussed. These important topics require further study.

Current production samples, that is, asphalts from individual refinery sources before mixing with aggregate or other treatment, were also obtained. The documentation requested for these samples is included in Appendix D. The HP-GPC data will be discussed in Section II in terms of the relationships between the new asphalt cements and those asphalts already on the roads as well as with regard to their ability to match a model for a particular area. These new asphalts will also be discussed in more general terms in Section III. A.

Recycling samples were also obtained from most states. These will be discussed in Section III. C. A series of test sections in which the variables were confined to mixing temperature were sampled by Florida in lieu of a general, performance related study. These will be discussed in Section III. B.

C. Climate

There is little question that climate affects the performance of asphaltic pavements. It has been expected that the HP-GPC model for a crack-resistant asphalt cement would not be the same for warmer regions of the country as for colder areas. However, correlating climate with HP-GPC profile requires some method of assessing climate that has meaning with respect to the pavement.

Several different climate maps are available including two from USDA, one in which the country is divided into zones by the number of freeze-thaw cycles (air temperature) each year (Figure 3) and another by the average annual minimum temperature (Figure 4). Still another map is derived from "freezing index", which involves the number of degree-days below freezing in an area. A somewhat different approach has been promulgated by Williams (4). His method assumes that air temperature

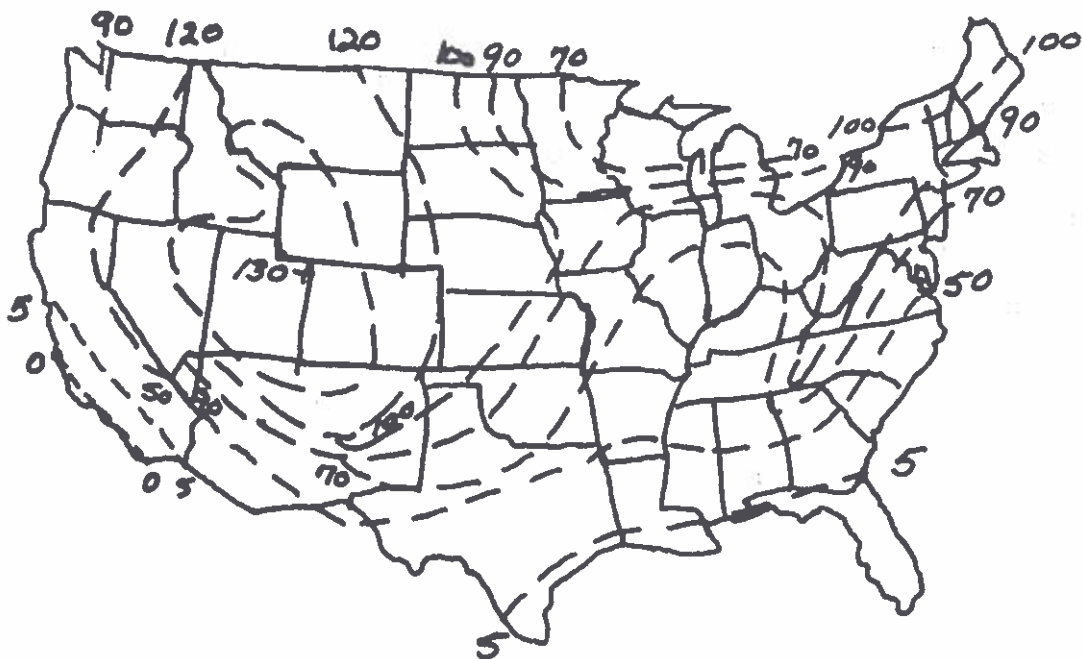


Figure 3. Average Annual Times of Freeze and Thaw.

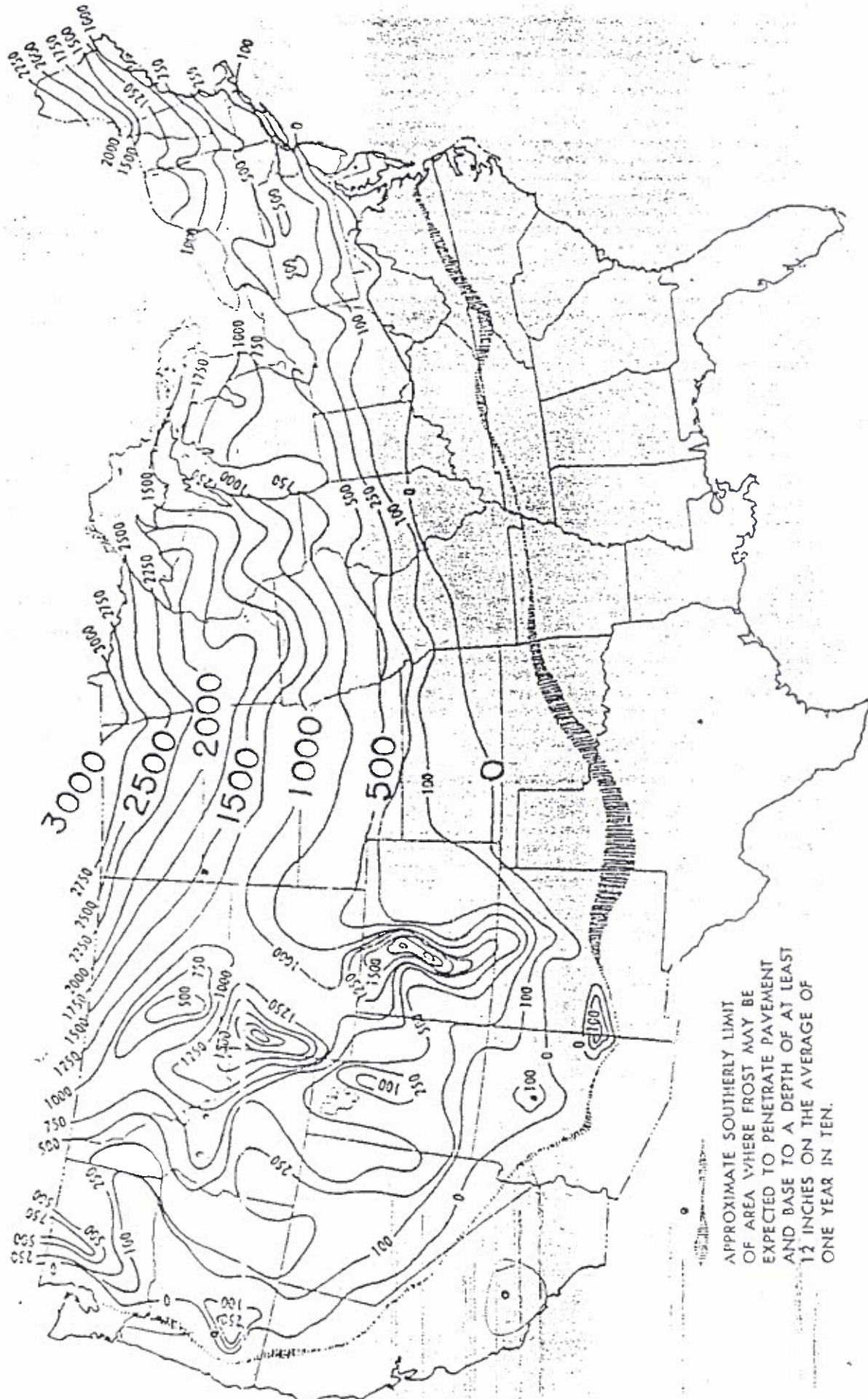


FIG. 11 FREEZING INDEX MAP OF THE UNITED STATES.

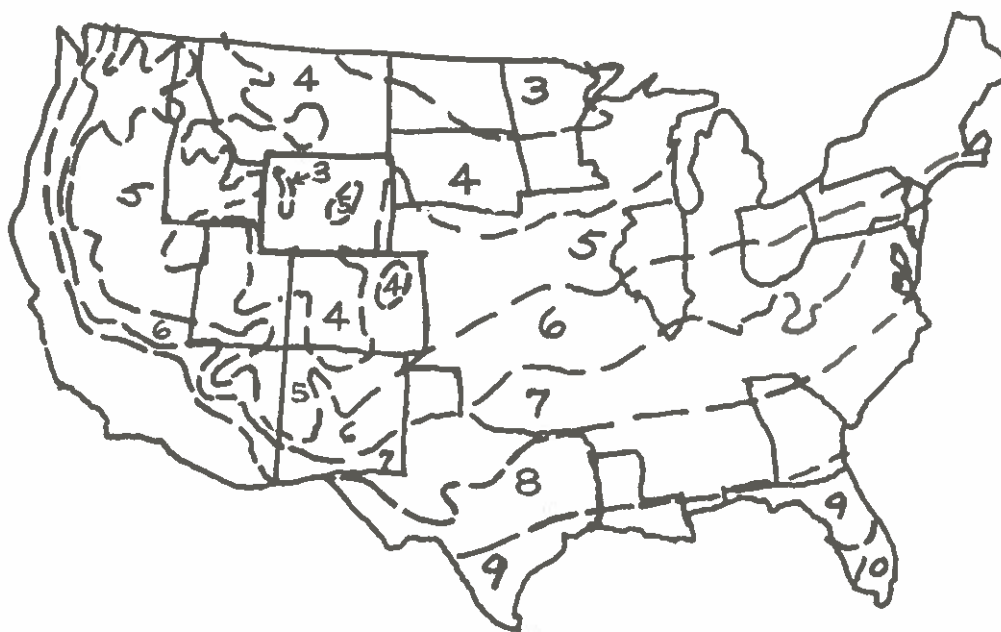


Figure 4. Climate Zones By Annual Average Minimum Temperature.

below 28°F are more closely related to soil freezing and that air temperatures above 34°F result in significant thawing. He has then divided the country into zones by the intensity and frequency of freeze-thaw cycles on a monthly basis. Although his approach can not be detailed here, a map showing the resulting climate zones is shown in Figure 5.

Each of these approaches results in somewhat different zone-boundaries. However, all give rather broad zones with no consideration of significant variations which occur within those zones, for example in mountainous regions of the west.

In this report, climate zones as defined by Williams will be used with some modifications based on the other climate zones as well as geographical considerations, particularly in the west.

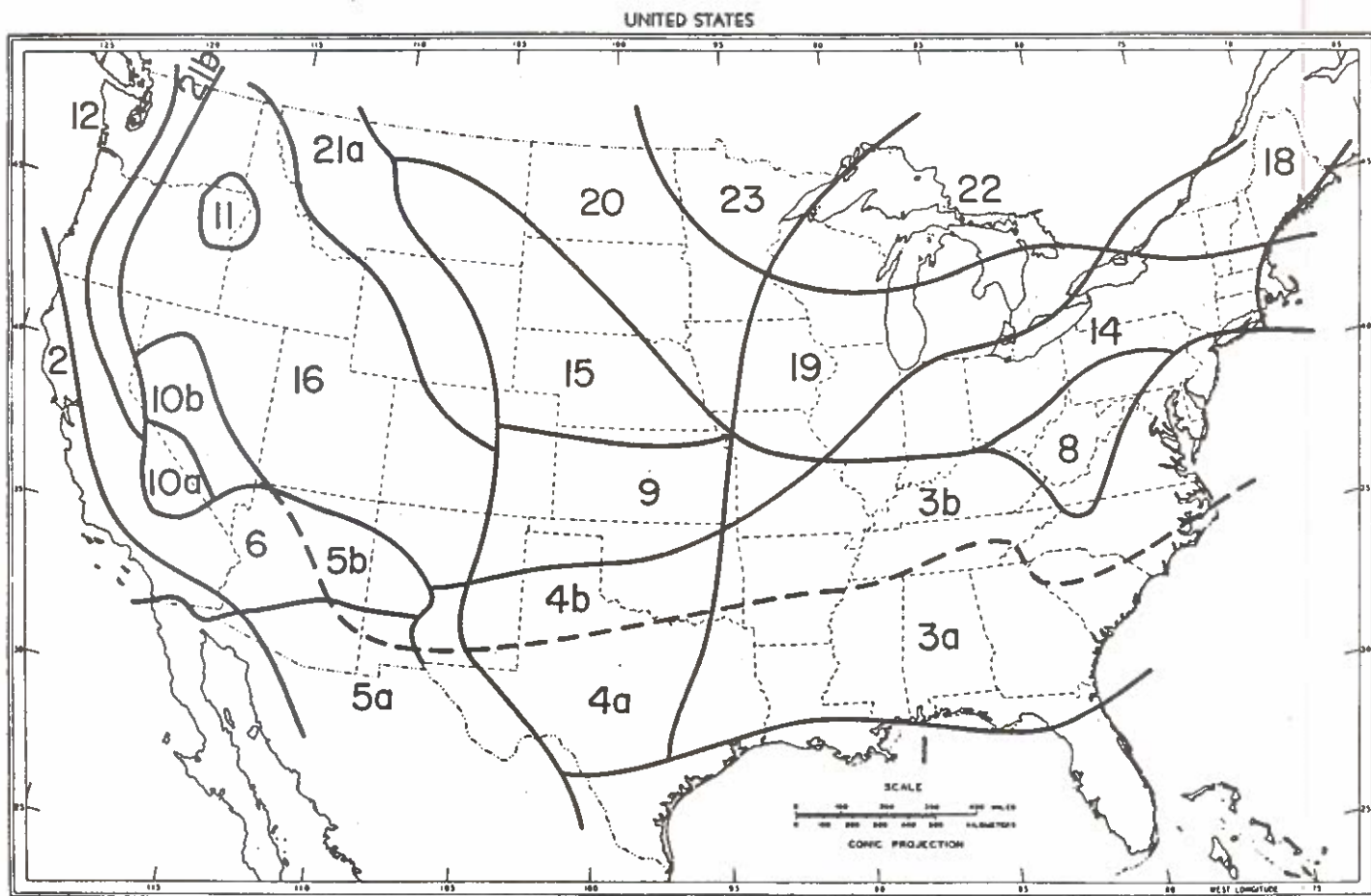


FIGURE 5. CLIMATE ZONES AS DEFINED BY WILLIAMS.

II. Established Pavements in the Cooperating States

A. The Southern Tier

Four states, Georgia, Louisiana, Texas and New Mexico, are included in this group. Data from each state will be presented and then a summary of the region will be given. Louisiana submitted only current production asphalt comments.

Although the climates of the Texas panhandle and Georgia differ considerably and New Mexico presents a series of climate zones, these states certainly have the mildest climates of the cooperating states. Therefore, it is convenient to treat them as a group.

1. Georgia

The state of Georgia has just one climatic region according to Williams; in general, this region undergoes a series of freezes, probably between 5 and 50 each year, which only rarely last for more than a day (Zone 3a).

Four types of asphalt were found in the samples (Figure 6). These were obtained from 11 sources.

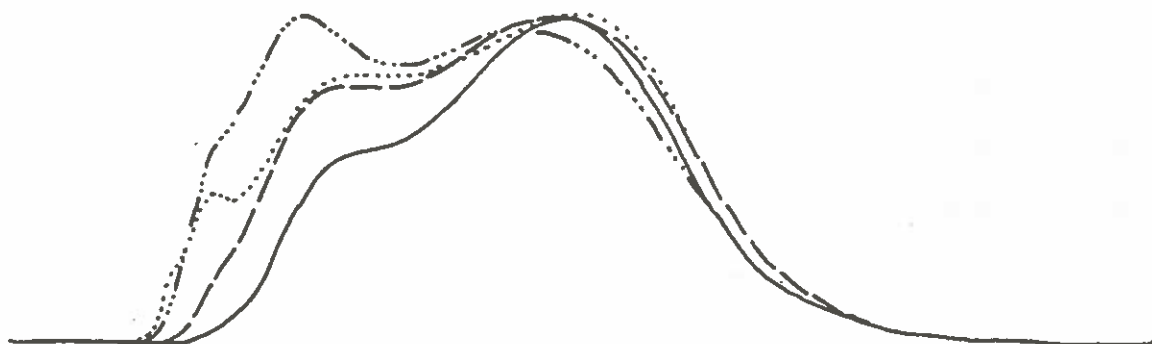


Figure 6. Georgia Asphalt Types

- Type GA-A
- Type GA-B
- .. Type GA-C
- .. Type GA-D

In the southern part of the state, the range of performances are exemplified by the chromatograms in Figure 7. GA-1 was one of several sections demonstrating similar performances (poor) with this type of asphalt. GA-8 represents a series of pavements which were in excellent condition, although only 7 to 11 years old. In fact, GA-8 was the only Georgia pavement constructed over a cement-treated base that had not cracked, regardless of the nature of the asphalt. It did consist of 10 inches of asphalt concrete, however.

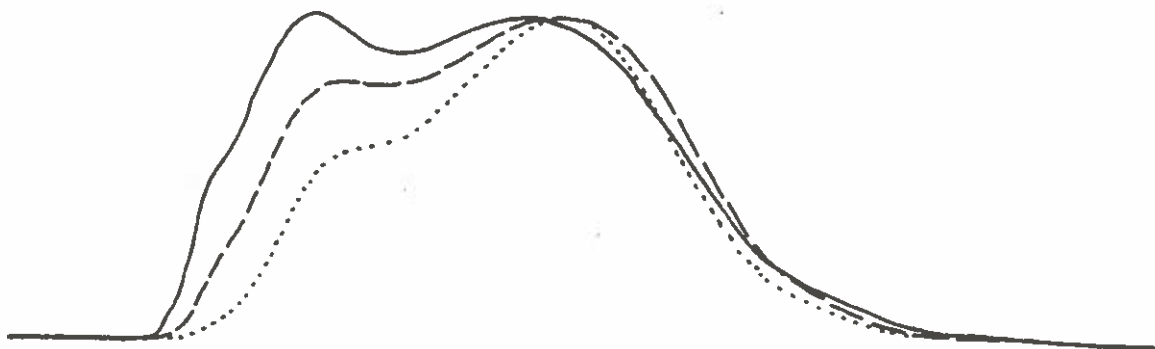


Figure 7. Southern Georgia
 — GA-1 13 years, poor (40.6 - 23.5)
 -- GA-8 7 years, excellent (32.0 - 29.3)
 .. GA-44 5 years, rutting (24.5 - 30.7)

GA-44 is one of a series of pavements in which it appears that the asphalt itself had contributed to rutting. The LMS content of these asphalts ranged between 27 and 32%. The pavements were not cracked unless they had been constructed on cement-treated bases. These cores were rich in appearance, but no more so than other non-rutted samples from Georgia. It appears that there are several contributors to rutting in the state, including stripping, poor compaction and asphalts with relatively small amounts of LMS material.

Table 2 charts the maximum amount of LMS material in a lift of a sample against the performance of the corresponding roadway. Samples from both northern and southern areas are included. Samples in which cracking was associated with cement-treated bases or in which rutting was associated with excessive voids or stripping are not included.

In the northern portion of the state, all appropriate samples were cracked. Again, cracking was sometimes associated with cement-treated bases and rutting was associated with stripping.

In our opinion then, asphalts for use in the southern portions of the state should contain 33-35% LMS after mixing and lay-down. With higher LMS contents, cracking is likely; with lower LMS concentrations, rutting may ensue. In the northern part of the state, no positive models were available and the negative models indicate that the amount of LMS should be kept below 31%.

Only two current production samples were submitted. These were from the same refinery (Figure 8). The AC-5 would not be used for paving but rather in recycling. The AC-30 contained too much LMS to contribute to rutting and should, unless unusually sensitive to heat and aggregate, perform well. Again, however, few asphalts can withstand the stresses that are apparently imposed by cement-treated bases.

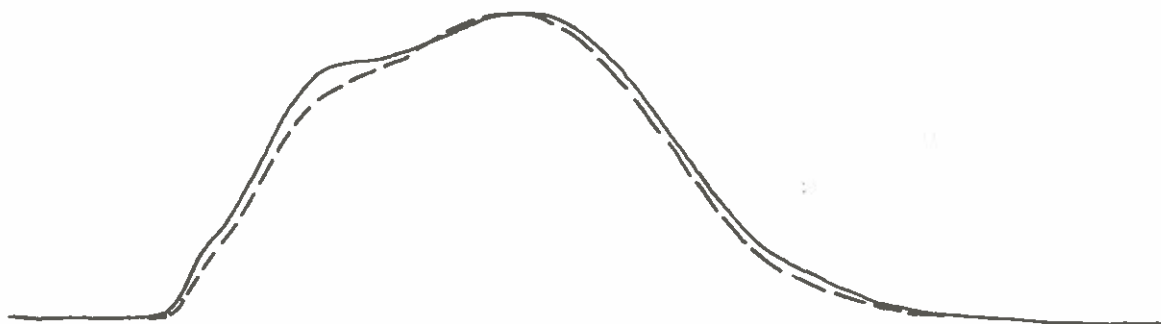


Figure 8. Current Production Asphalt Cements
— GA - 60 Refinery I/AC-5
-- GA - 61 Refinery I/AC-20

Table 2. Performance vs %LMS in Georgia

% LMS	Zone 3a	
	South	North
48		
46		
44	bad	
42	bad	
40		bad
		bad
	bad, cracking	cracking
38	good	
	excellent, good	bad
36	excellent	
34		
32	rutting	
		bad
30		
	rutting	
28		
	rutting	
26		
24		
22		
20		
18		
16		
14		
12		

IIA. 2. Texas

Sixteen cores from nine different roads were obtained from the Lubbock district in the Panhandle area of Texas. Six of these were from the recycling project to be discussed separately; three were from a single project testing pavement interlayer systems. Clearly, the sampling from Texas was smaller than would have been desired.

This district is in climate region 4b (Figure 5). Here, as in Georgia, the activity can be regarded as a series of freezes; however, there are more cycles (about 70), and more occasions when the temperature remains below freezing for two successive days.

The district has been constructing pavements with the products from two refineries. Three types of asphalt were found in the cores (Figure 9). Six of the pavements contained asphalt type TX-A. Two of these were very young (one and two years at time of sampling) and were performing well. However, older pavements of 8, 15 and 25 years

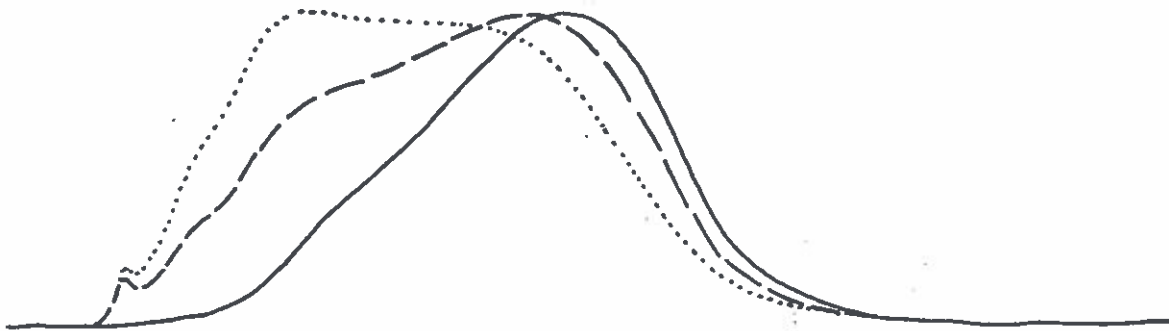


Figure 9. Texas - Asphalt Types

- Type TX-A
- Type TX-B
- ... Type TX-C

containing type TX-A were in poor to bad condition. In the one remaining case, an overlay of this material was performing well after seven years (TX-6). (The original pavement in TX-6 was constructed with a type B asphalt.) The type A asphalts contained between 19.4 and 22.8% LMS material and, in this sampling, no pattern of MSD vs. performance could be discerned.

Six of the pavement samples contained asphalt type B. One of these (TX-6) was mentioned above. Because it had been overlaid, its performance was unknown. Two more were in new overlays which will be discussed later. Of the three remaining, one was 14 years old and excellent, another of unknown age was severely alligator-cracked and has since been overlaid, a third showed little cracking in the passing lane but had severely alligatored in the driving lane. The driving lane has been recycled. In this small sampling, no pattern of molecular size distribution vs. performance could be discerned, but it is obvious that this asphalt type can be prone to alligator cracking under some circumstances. It should be noted that the alligator cracking was distributed throughout the lane and not confined to wheelpaths.

One set of three samples came from experimental sections designed to test stress-relieving membrane interlayers. The project was constructed over an alligator-cracked length of type B asphalt (the solid line in Figure 10) one year before sampling. Three different types of stress-relieving membranes (labelled I, II and III) were utilized. Asphalts of the same grade but from two refineries were then placed in wearing courses. In the section using membrane I (TX-4a), a type B overlay began

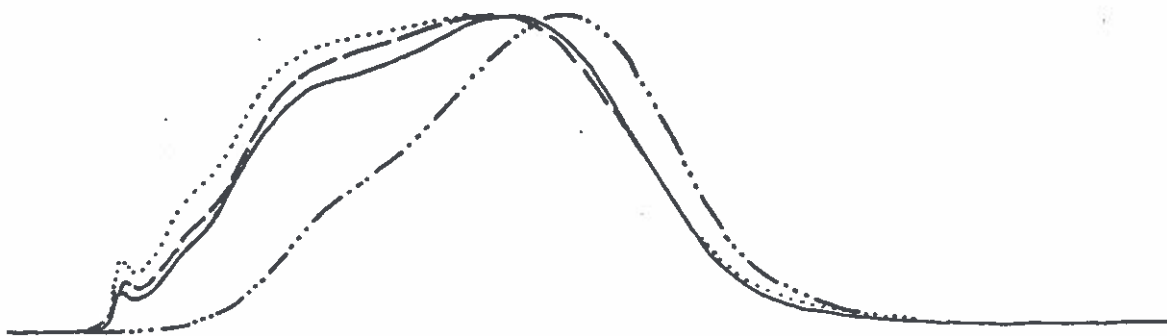


Figure 10. Tests of Stress Relieving Membranes

- Underlying pavement (40.7 - 18.7)
- Severely alligator-cracked
- TX-4a 1 year, excellent but inconsistent (43.6 - 16.2)
- ... TX-5a 1 year, poor (46.1 - 15.7)
- .. TX-6a 1 year, excellent (21.1 - 30.6)

to show some alligator cracking within a year. This cracking was confined to an area within the shadow of a grain elevator, although the section extended well to either side of that structure.

Enough alligator cracking occurred within the year to put the section using membrane II (TX-5a) into the "poor" category. Some of these cracks were pumping, indicating failure of the membrane.

The last section, with membrane III (TX-6a), showed no cracking after a year. The overlay in this section was constructed with a type A asphalt, however. These sections began as tests of interlayer systems but may be complicated by differences in asphalt. It cannot be shown whether the lack of cracking in the latter section results from the success of the membrane or of the asphalt. Chromatograms for these sections are shown in Figure 10.

Only one example of a type C asphalt was supplied by the Lubbock district. That was from a seven-year-old excellent pavement. This asphalt is from the same refinery as type B. However, no conclusions can be reached on just one sample, especially one still in its adolescence.

The chromatograms for the current production asphalts in Figure 11 show that the asphalts being supplied by Refinery I are essentially the same as those seen on the roads in Lubbock as type A, whereas the products from Refinery II are precursors of the type B asphalts. It seems unlikely that these Refinery II products could be precursors of type C asphalts unless this asphalt is unusually sensitive to heat and contact with aggregate.

The performance of neither of these asphalts follows the anticipated model. We were surprised to find that the asphalts from Refinery I were consistently cracked and that those from Refinery II were not always cracked. A few further tests conducted on these asphalts will be discussed in a section on "Exceptions".

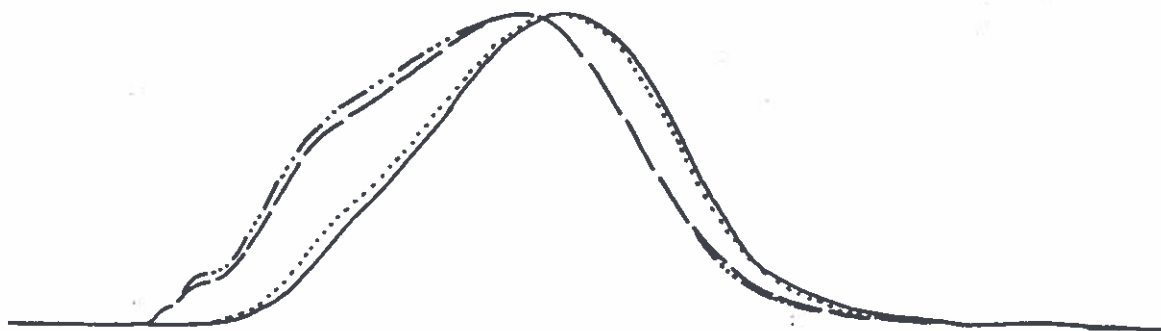


Figure 11. Texas-Current Production Asphalt Cements

- TX 17 Refinery I/AC-10, 1982
- TX 18 Refinery II/AC-10, 1982
- ... TX 20 Refinery I/AC-20, 1982
- TX 19 Refinery II/AC-20, 1982

IIA. 3. New Mexico

New Mexico is the most complex, climatologically, of the states involved in this study. Figure 5 shows nine climate zones; use of other climate rating systems does not result in much simplification.

Moreover, samples were selected based on a desire to cover the various sources, ages and performances, rather than strictly on climate zone, so some zones have been rather sparsely sampled.

Five asphalt types from at least seven sources were found among the samples. These are illustrated in Figure 12. The data in Table 3 shows that, in the harshest zone, 16, excellent performance has been obtained from asphalts with 19 and 24% LMS and bad performance with 22 and 26% LMS. No excellent pavements were found in either zone 9 or 5b. However, a 16 year old pavement with 26% LMS that was in good condition was found in zone 9.

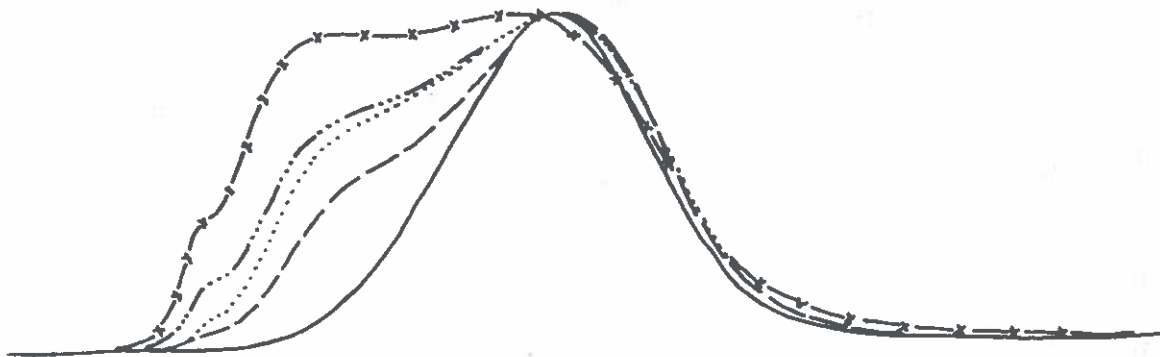


Figure 12. New Mexico--Asphalt Types

- Type NM-A
- - - Type NM-B
- Type NM-C
- ... Type NM-D
- x - Type NM-E

Table 3. Performance vs %LMS in New Mexico.

% LMS	Zone			
	5a	5b	9	16
48				
46				
44				
42			bad	
40				
38	bad			
36			bad	
34		bad		
32		bad		
30	good bad cracking	bad		
28	bad, cracking bad	bad		
26	bad, good excellent	bad	good	bad
24	excellent			excellent
22				bad
20				
18				excellent
16				
14				
12				

In zone 5a, the mildest climate area, asphalts were clustered between 24 and 31% LMS. The excellent performers contained the least amount of LMS material. Good and bad performers were scattered in the remainder of this group. It is interesting that the least satisfactory performers in this latter group at 27-28% were constructed on asphalt-treated bases whereas those which gave better performance (31 and 26% LMS) were constructed on plant mix bases. The asphalt treated base material usually was stable enough to survive coring, but it was very open and dry. That is, the depth of dense-graded material in these pavements was as much as 50% less than in those with plant mix bases. However, of the excellent roads, one was on plant mix base, the other on asphalt-treated base. The point to be made is that, in this area, asphalts with finished amounts of LMS material of 24-25% will perform nicely on either type of base construction. However, it appears that asphalts with slightly more LMS are more sensitive to base construction. Even the "good" roads do display some cracking.

The longevity of such roads as NM-67 (16 years, good, 26% LMS) in zone 9 and NM-65 (13 years, excellent, 24% LMS) in zone 16 has been puzzling. Not only does the asphalt contain more LMS material than it "should", but also, the pavements were constructed on cement treated bases. In other states in the study, the presence of CT bases has almost invariably been correlated with cracking. New Mexico has sometimes defied that pattern. However, the state had some unique construction practices which are no longer followed. They provided for a CT base to be covered by a six inch cushion of aggregate base before placement of the asphalt concrete. Although this was not always successful in preventing cracking, its association with these particular pavements is

striking. In the cases in which cracking did occur, the LMS content of the asphalt was much higher, however. (Figure 13.)

The better performers have been found among B and C type asphalts. The only type A was found in the lower lift of a 10 year old, poor, pavement. The upper lifts contained 29.5% LMS, and the roadway was in zone 5b, where such an asphalt would not be expected to perform well so it is difficult to assess the value of the type A.

Types D and E asphalts are similar to types B and C in Texas. The performances have not been exciting in either state, although they were mixed in Texas (see Section IIA. 2)

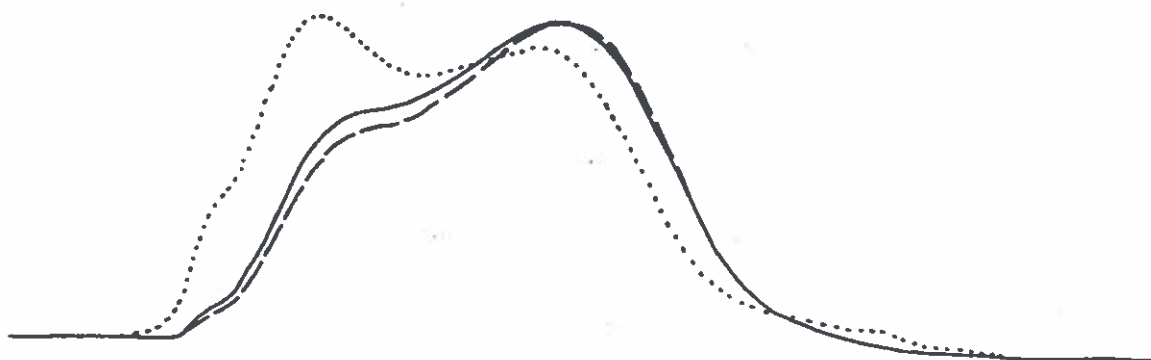


Figure 13. New Mexico - Cement Treated Bases

- NM-67 16 years, good (25.9-26.9)
- NM-65 13 years, excellent (24.2-28.0)
- ... NM-1 18 years, bad (42.2-18.4)

Taking all of this into consideration, the following suggested maximum LMS percentages for finished asphalts for the climate zones in New Mexico are:

Zone 16 - 20%

Zone 9 - 21%

Zone 5b - 23%

Zone 5a - 24%

The chromatograms of current production asphalts are shown in Figure 14. These asphalts vary considerably in both LMS as well as SMS regions. No precursor of type NM-E asphalts appears among these virgin asphalt cements. Sample NM-90 is a likely precursor of type D asphalts. Performance has not been gratifying for this material in the past.

NM-92 will probably, after heating with aggregate, result in type C asphalt which should perform particularly well in zones 5a and 5b. NM-93 and 94 will generate more LMS upon processing and are most likely to succeed in zones 9 and 16.

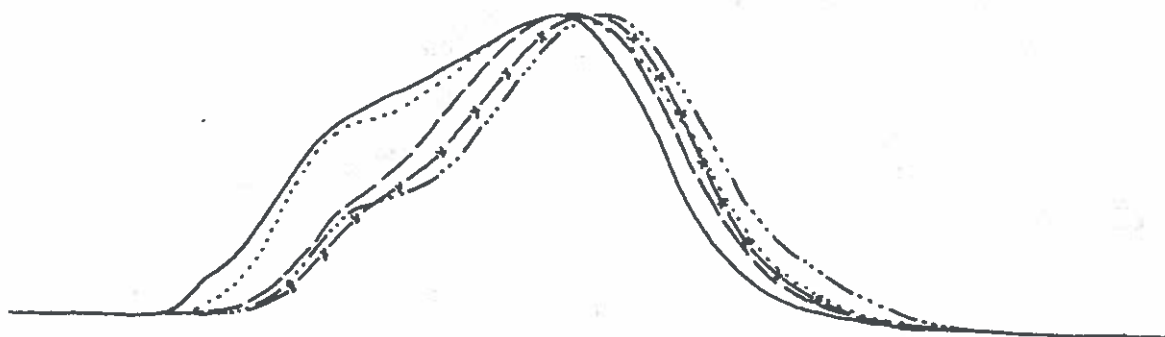


Figure 14. New Mexico - Current Production

- NM-90 Refinery I/AC-10, 1982 (27.1-24.9)
- NM-91 Refinery II/85-100, 1982 (15.0-34.1)
- ... NM-92 Refinery III/85-100, 1982 (22.1-31.6)
- NM-93 Refinery IV/AC-10 (Utah spec. 1982 (11.9-44.9)
- x- NM-94 Refinery V/85-100, 1982 (11.5-39.5)

IIA. 4. Louisiana

This state, which Williams divides into zone 3b and, even milder, zone 1, did not submit performance-related samples to this project. Five samples of virgin asphalt cements were obtained. The chromatograms for these are shown below. All were AC-30 grade, each from a different refinery. LA-1, -2 and -3 have very similar profiles in the region representing larger materials but differ in the SMS area. The other two asphalts show more variation in the LMS area.

Based on performance data from Georgia, asphalts LA-1, -2 and -3 have potential to contribute to rutting. Excellent performance should be anticipated from LA-4 and -5.

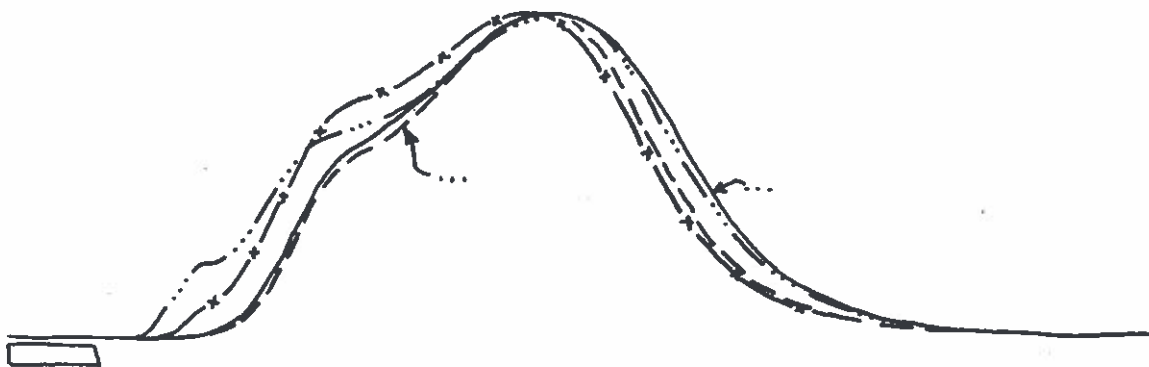


Figure 14a. Louisiana-Current Production

—	LA 1	- Ref. I	(24.6-30.7)
--	2	II	(26.3-25.1)
...	3	III	(24.3-30.8)
-..	4	IV	(32.7-26.2)
--x	5	V	(34.0-20.8)

IIA. 5. Summary of the Southern Tier

The three states along the southern border of the country which submitted performance related samples to the study are Georgia, Texas and New Mexico. Louisiana contributed current production asphalts.

The climate zones represented are listed in Table 4.

Table 4. Climate Zones in Southern Tier.

Georgia	Louisiana	Texas (Lubbock)	New Mexico
Zone 3a	Zone 3a	Zone 4b	Zone 5a 5b 9

The range of asphalt types found are represented by chromatograms in Figures 15, 16 and 17. The types with lower amounts of LMS are drawn in 15 and those with higher amounts in 16. All are combined in Figure 17. The latter drawing is admittedly complex but it does give a graphic idea of the variety of asphalts which have been used in just three states.

Of the 12 asphalts shown, three came from one refinery (TX-B, TX-C and NM-E). These asphalts were quite unusual, especially in terms of Corbett analyses (Section IIF.). There were no other overlaps.

In the mildest zone, southern Georgia, asphalts of type GA-A tend to rut. One would expect, therefore, that the other asphalt types in Figure 15 might also contribute to rutting in that zone and others like it. In this same area, type GA-B asphalts with 33-35% LMS should be expected to perform well. Presumably, TX-B and NM-D ought to do well, also. Others shown in Figure 16 would probably not give acceptable performance. (Recall that the TX-B and -C asphalts are unusual materials and may not fit the HP-GPC model, however).



Figure 15. Asphalt Types in Southern States.

- Type NM-A
- Type NM-B
- ... Type TX-A
- .. Type GA-A
- x Type NM-C



Figure 16. Asphalt Types in Southern States.

- Type TX-B
- Type NM-D
- ... Type GA-B
- .. Type GA-C
- x Type NM-E
- o Type TX-C
- ◊ Type GA-D

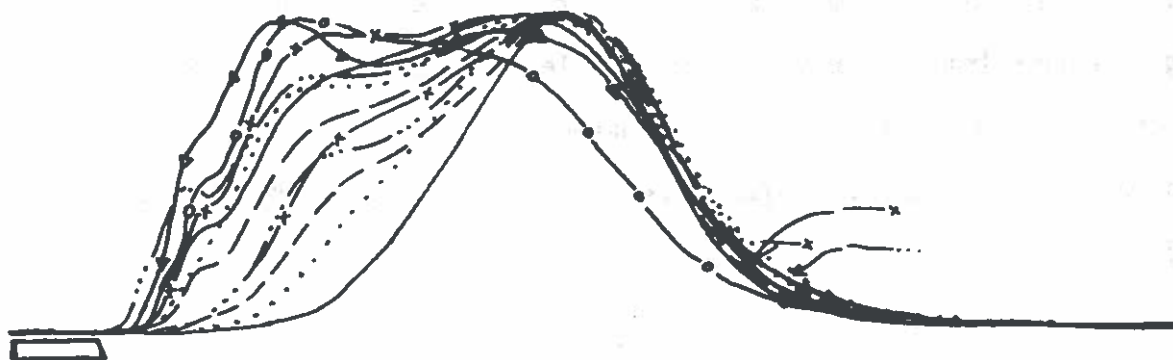


Figure 17. Combined Asphalt Types from Georgia, Louisiana, Texas and New Mexico

In the coldest zone in New Mexico, types NM-B and NM-C with 20-21% LMS are expected to perform well. Type GA-A might also be good. Type TX-A is known to crack in a much milder area and should undergo further testing before use in New Mexico. NM-A is an unknown with regard to performance and should be similarly treated. Similar statements might be made about the milder zones in New Mexico, except that the allowable LMS content should be somewhat higher (about 23-24%). This still excludes types NM-D and -E and, therefore, the other types shown in Figure 16.

Since the Lubbock district is slightly milder than these New Mexico zones, types such as NM-B, NM-C and GA-A ought to do well with perhaps 26% LMS.

It is, of course, recognized that those asphalts with large amounts of LMS material cannot be thrown out of use. But it seems to make no

more sense to use them when a serious cracking problem is virtually assured. One suggestion that can be made at this point is that these asphalts be mixed with materials of lower LMS content. Such a course might enhance both materials. For example, in Georgia, mixing a "rutting" asphalt with a "cracking" asphalt might eliminate both problems. This approach requires more study but it seems worth the effort.

IIB. The Western States

Colorado, Wyoming, Utah and Idaho are united in their diversity. Each has mountainous regions which are subject to harsh winter conditions as well as lower-lying areas subject to hot, dry summers, but varying winter weather. Williams' map shows much of the region to be included in zone 16, but people living in the area recognize that there is considerably more variation in the climate. Therefore, the states will be divided into smaller geographic regions for discussion.

IIB. 1. Colorado

Samples in Colorado were received from three different regions. Most of these pavements were in the Denver area. Most of these roadways carried quite heavy traffic (20-60 thousand vehicles per day) as well. Another small group of samples came from sections in the western part of the state where the climate is judged to be approximately the same as Denver's, but where traffic volumes were considerably lower. Two samples were taken in the mountains west of Denver at 10,000 feet elevation where conditions are harsher.

The percentages of LMS from HP-GPC data are charted relative to performance for these three areas in Table 5. Representative chromatograms are shown in Figure 18 for the Denver area. The division between the excellent performers and the bad performers is rather striking. These excellent pavements were only 6 to 8 years old, however, too young to be considered as perfect models. Nevertheless, the performance patterns are encouraging and we feel they will continue to perform well.

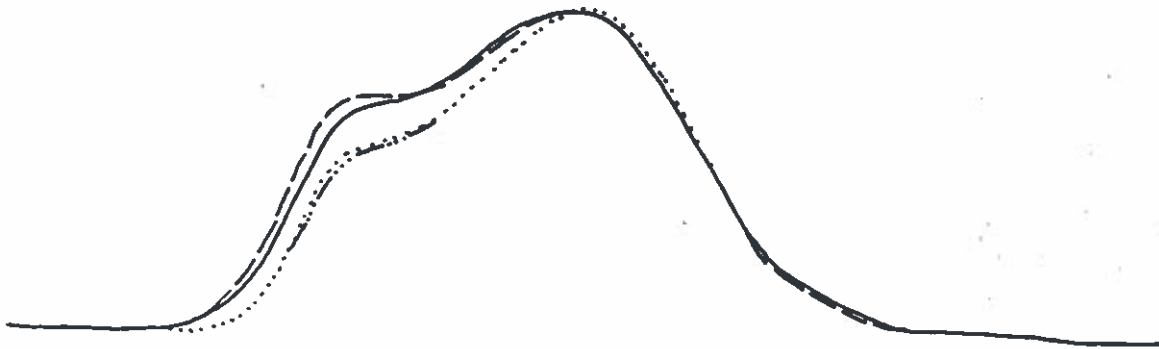


Figure 18. Denver Area Established Roadways.

- CO-10 6 years, bad (29.6-29.4)
- CO-20 3 years, poor (26.5-30.0)
- ... CO-3 8 years, excellent (23.9-32.9)
- ... CO-15 7 years, excellent (23.3-33.0)

Those pavements in the milder areas of the western part of the state are represented by chromatograms in Figure 19. CO-23 contains 26.6% LMS and was performing flawlessly after 13 years. Another road with 25.5% LMS but 3% less SMS was in bad condition after 12 years. This indicates that 25% LMS may be too high to give dependable performance in this area,

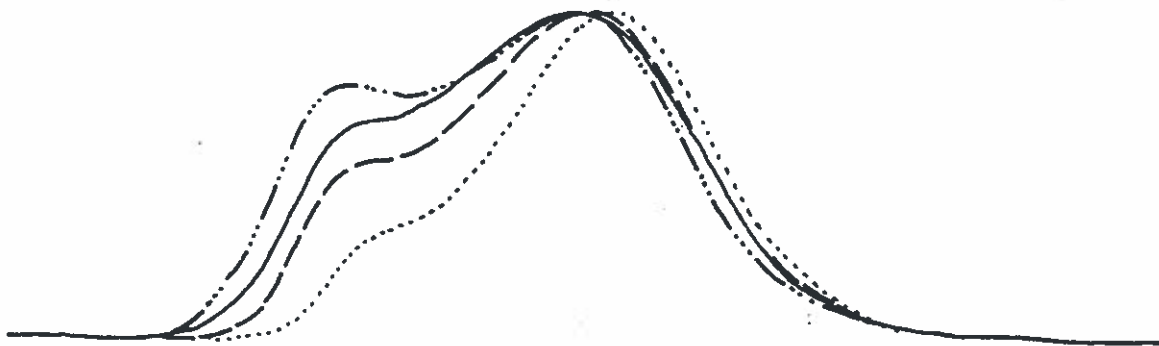


Figure 19. Established Roadways in Western Colorado.

- CO-23 13 years, excellent (26.7-31.7)
- CO-22 5 years, excellent (21.6-35.7)
- ... CO-25 17 years, bad (10.5-46.3)
- ... CO-26 4 years, excellent (31.0-27.0)

Table 5. Performance %LMS vs. in Colorado

%LMS	Zone		
	Denver 15	16	21a
48			
46			
44			
42			
40			
38			
36			
34			
32			
30	bad, cracking		
	bad		
28	bad		
	bad		
26	bad		excellent
			bad ¹
	cracking, excellent	excellent	
24	excellent	bad	
	excellent		
22		excellent	
20			
18			
16			
14			
12			
10		bad ²	

¹this pavement is constructed over a lift containing asphalt with 14% LMS similar to that in ².

even with decreased traffic loads relative to the Denver area. CO-22, although only five years old would seem to have a better chance. CO-26, on the other hand, although performing nicely after four years, is not likely to be able to continue in that fashion.

The asphalt in CO-25 is reminiscent of the very low LMS asphalts which have given poor performance in other areas (see section IIF.)

Only two samples were retrieved from the most severe mountain climate zone (zone 21a). Chromatograms for these are drawn in Figure 20. The performance of CO-16 is not surprising. Although the LMS content of the surface lift is higher than would be postulated for good performance under such conditions, it also has a very low LMS asphalt, mentioned above, as a base course. Furthermore, it lies on a cement-treated subgrade.

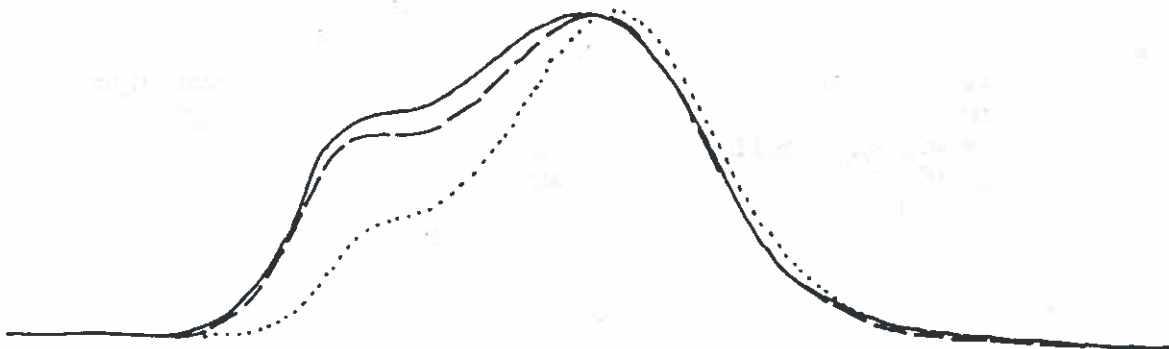


Figure 20. Established Roadways at High Elevations

- CO-17 16 years, excellent (27.4-31.1)
- CO-16 top, 10 years, bad (26.2-32.1)
- ... -16 bottom (13.2-43.3)

CO-17, on the other hand, has given superior performance for 16 years, with an LMS content of 27% - higher than would be preferred for even the Denver area. It is not apparent that this road has been recently overlaid, so, barring a mislabeling of samples, this asphalt is an exception to the pattern. It is worth noting that this asphalt is the

same as that in CO-23, a pavement which was also giving better than expected performance in zone 16. Similar asphalts have not done so well under the heavier traffic conditions of the Denver area.

Therefore, asphalts containing 24% LMS or less when finished (excepting those of very low LMS content) should be used in the Denver area. It appears that somewhat higher LMS contents can be tolerated in the mountains or the warmer western valleys. However, our sampling is rather small for these regions and we hesitate to recommend routine use of asphalts with about 25% LMS, preferring use of perhaps 20-22%. Eight virgin asphalt cements were submitted by Colorado. As shown in Figure 21, those from Refinery I are very similar and contain relatively small amounts of LMS material. Performance data for such materials in the state (in CO-25 and CO-16) are limited, but experience elsewhere has not been encouraging. It is recommended that further testing be done.

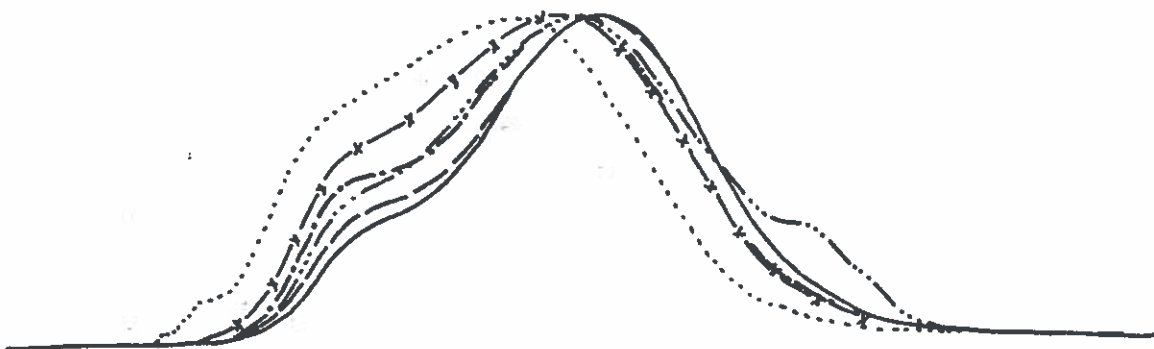


Figure 21. Colorado - Current Production Asphalts

- CO-45 - Refinery I/AC-5 (12.3-45.5)
- CO-41 - Refinery I/AC-5F, AC-10 and AC-20, 1982 (14.3-43.2)
- ... CO-40 - Refinery II/AC-20 (33.4-20.0)
- ... CO-47 - Refinery III/AC-10, 1982 (19.0-38.0)
- x- CO-46 - Refinery IV/AC-20 (22.1-32.3)
- CO-43 - Refinery V/AC-10 (18.8-35.4)

Finished asphalts of the type which would be expected to arise from CO-40 were not present in the performance-related samples we received. Similar materials have been used in Texas and New Mexico.

CO-47 also is not a precursor for roads sampled in Colorado. Similar asphalts have been used under harsher climatic conditions in Wyoming and Montana, with some reports of early failure.

CO-46 has, in its virgin state, just enough LMS to give fine performance in the Denver area and possibly other areas of the state. Care must be used not to cause too great an increase in LMS during processing. CO-43 appears to be ideal. Mixtures of such materials as CO-40 and CO-41 might also be considered as a way to use the available supplies to best advantage.

IIB. 2. Wyoming

Wyoming is divided into three climatic regions by Williams. The asphalts fall into four types as shown in Figure 22. Type D appeared in only one road, however. It was in the bottom lift of that pavement. The thin surface wearing course was just four years old and performing well. Unfortunately, the performance of the remaining lift was not known, except to say that any cracks had not reflected through the wearing course.

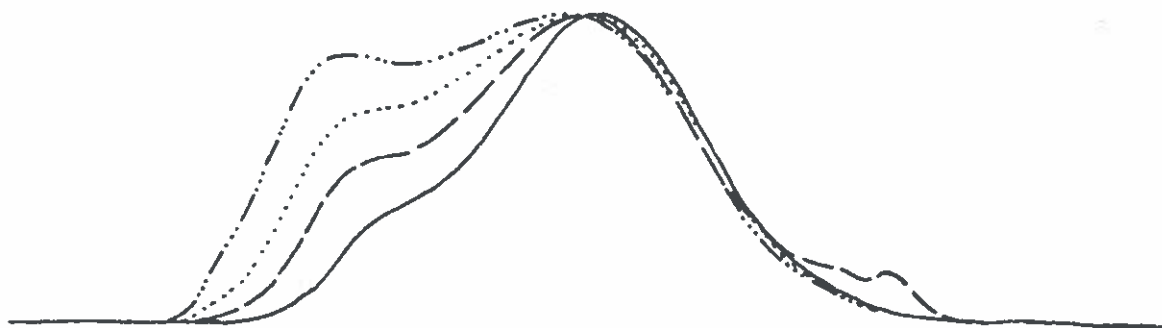


Figure 22. Wyoming - Asphalt Types.

- Type WY-A
- Type WY-B
- ... Type WY-C
- ... Type WY-D

Type A asphalts were found in six pavements. All but one of these were in poor to bad condition. Four were also severely rutted. Unfortunately, the performance of the materials is complicated by cement treated bases (which are almost always associated with cracking in the overlying pavement), by stripping (which is one potential cause for rutting) and by the presence of lifts containing other asphalt types (which is frequently associated with cracking). Therefore, it is difficult to assess the solo performance potential of this asphalt type in Wyoming. However, state officials reported that these asphalts did indeed crack. It was also reported that at least some of these were refined from a so-called "waxy" crude oil. They certainly have an

unusually low LMS content (9 to 11%). These and other anomalous materials will be discussed in Section IIF.

The type B asphalts were also difficult to assess. Based on experience in Montana, these asphalts would have been expected to perform well. However, they were cracked in cases where they were placed over cement treated bases or over type A asphalts. When in the company of a type C asphalt with 24.2% LMS, excellent performance was seen after 10 years in WY-12. Another was showing only poor performance after 28 years in zone 16. (See Table 6). A similar type B asphalt was found to be excellent but rutted after eight years in WY-31. Figure 23 shows that, although these roads share similar asphalts in the plant mix wearing courses (solid line in the figure), the lower lifts are different. These lower lifts in WY-12 contain more LMS than do those of WY-31. It is possible that the latter are related to the rutting, although some evidence for stripping was also seen in the core.

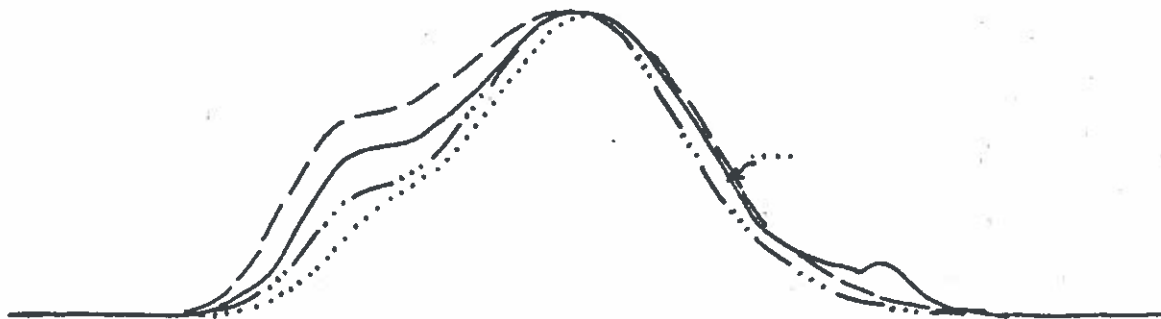


Figure 23. Rutting vs. Excellent Performance

- WY-12a and b; WY-31a (18.7-37.5)
- WY-12c (24.2-32.8)
- ... WY-31b (16.6-35.0)
- ... WY-31c (12.9-41.5)

WY-31 is 8 years old, no cracks, rutting
WY-12 is 10 years old, excellent condition

Table 6. Performance vs. % LMS in Wyoming

%LMS	Zone		
	15	16	21a
48			
46			
44			
42			
40			
38			
36			
34			
32			
30			
28			good,bad bad
26			
24	good,bad		excellent excellent
22	excellent,bad bad		
20	excellent	bad ¹	
18			
16			
14		good ²	
12			

1 - associated with a very low LMS asphalt, see pg.

2 - 28 years old

Type C asphalts with LMS contents above 22% were found in zones 15 and 21a. The data in Table 6 shows mixed performance from these asphalts. The group of samples in zone 15 deserve closer examination. Of those at 25% LMS, one was in good condition after ten years, whereas others were cracked more severely. Of those at 23% LMS, on the other hand, one is in excellent condition after 27 years, whereas, another, although in bad condition, was 45 years old. This leads us to believe that 23% is an upper limit for this region. The poor performance of that asphalt at 22% indicates that the material is not very forgiving, however.

In view of the above, we conclude that Wyoming has received questionable performance from its Type A asphalts, and more promising results from Type B, although positive data is minimal. Type C material is capable of excellent performance in zone 15 especially when LMS contents are lower. In zone 21a, it appears that asphalts with as much as 25% LMS will perform well. As in Colorado, however, we are hesitant to suggest that type of asphalt for general use, however.

Figure 24 presents the chromatograms for the current production

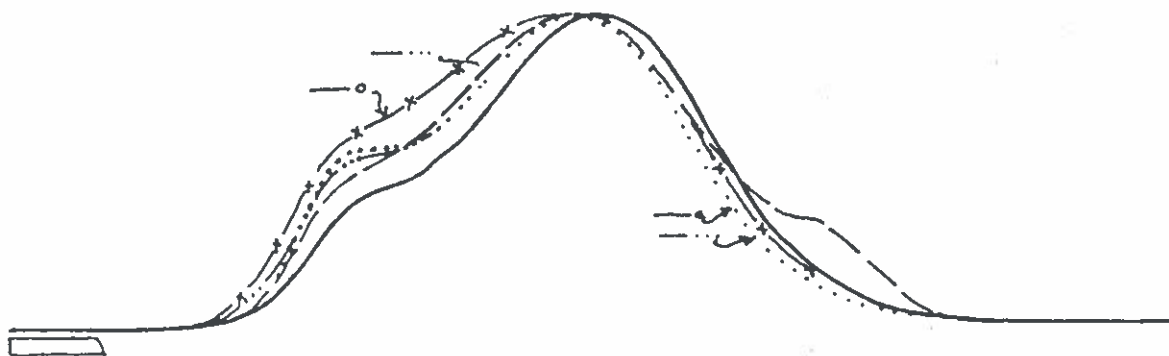


Figure 24. Wyoming - Current Production

- WY-54 - Refinery I/AC-10F* (14.7-40.9)
- WY-56 - Refinery I/AC-20F (14.6-40.0)
- WY-51 - Refinery II/AC-10F (16.3-40.0)
- ... WY-55 - Refinery III/AC-20F (20.5-32.7)
- WY-50 - Refinery IV/AC-20F (20.2-33.8)
- x WY-53 - Refinery V/AC-20F (22.2-32.4)
- o WY-52 - Refinery VI/AC-20F (22.8-30.3)

asphalts submitted from Wyoming. WY-52 and 53 are quite similar AC-20's from different refiners. They must be handled carefully to avoid pushing the LMS content too high during processing. WY-50 and -55, on the other hand, allow room for an LMS increase during processing. WY-51 should be studied further. Similar asphalts (note the presence of an unusual amount of material in the SMS region) have shown a propensity to increase LMS and crack. WY-54 and -56 from Refinery I are alike, in spite of being of different AC grades. These should also perform well, but warrant some further investigation (see section IIF.).

IIB. 3. Utah

According to the map in Figure 5, all of Utah is included in zone 16. Some differentiation must be made between the mountainous areas east of Salt Lake City and the desert areas to the west, however. A group of samples were obtained from a high area south of Provo; these have also been considered separately.

Three asphalt types were found in these samples (Figure 25).

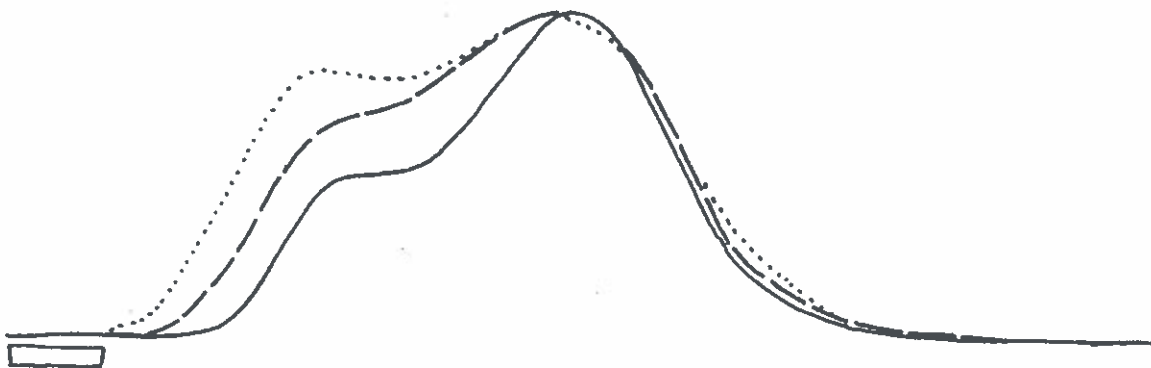


Figure 25. Utah - Asphalt types.

- Type UT-A
- - - Type UT-B
- Type UT-C

Several paving projects in the mountains, east of Salt Lake City are of interest. Construction practices in the state sometimes make it possible to see where transverse cracks existed in lower lifts of a pavement sequence. This was true in UT-8. Five lifts were discerned in the core. On the project, cracks were evident in the lower lifts to such an extent as to categorize them as "bad." The surface, at that time, showed only a few reflected cracks. The chromatograms for this series are shown in Figure 26.

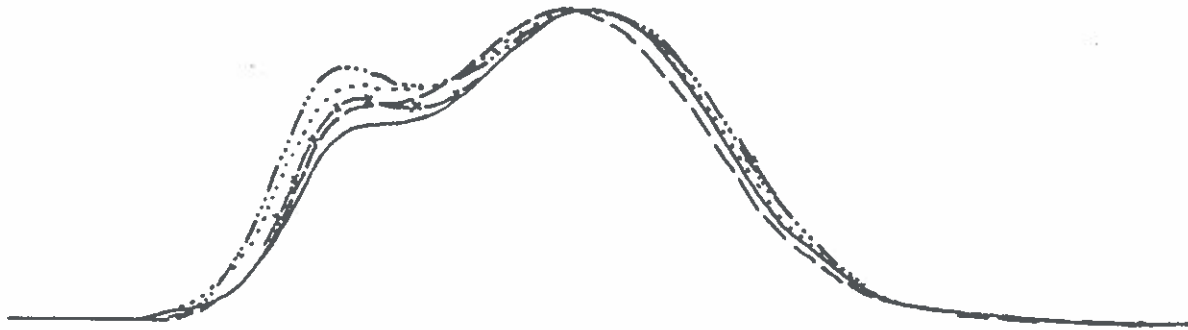


Figure 26. UT-8

—	UT-8 Top	good	(23.7-34.6)
--		bad	(25.7-31.0)
...		bad	(28.1-32.0)
-.-		bad	(29.2-32.2)
-x-	Bottom		(25.0-35.2)

Other pavements in this zone, which were in poor to bad condition, all had lifts similar to the lower lifts in UT-8 (Table 7). They contained between 26 and 35% LMS. One other pavement which was in only good condition after 5 years had a type A asphalt with 21% LMS on top of a 31.5% LMS containing lift. The performance of the surface lift cannot be faulted in this case.

In the region south of Provo, a pavement with 30% LMS in its asphalt was in good condition after 10 years. A similar section paved at the same time was in less satisfactory condition. One of its lifts contained 31% LMS.

A third pavement in that area is of interest. UT-12 was in excellent condition after 7 years. Most of the lifts in this section contained about 27% LMS. Lift C, however, showed 33.5% LMS. That lift contained a latex filler. We do not know what effect the latex may have on the performance of the asphalt, especially relative to its molecular size distribution. However, the combination was working well in this instance.

Table 7. Performance vs. % LMS in Utah.

%LMS	Zone 16		
	West	Provo	Mountain
48			
46			
44			
42			
40			
38			
36			
34	bad		bad
32			bad
30	good	bad	bad
28	bad	good	good ¹
26			bad
24	excellent		good ¹
22			good ¹
20			
18			
16			
14			
12			

¹see pg. 56 for a discussion of these pavements.

In the desert area west of Salt Lake City, seven projects were sampled. Representative chromatograms are given in Figure 27. UT-16 and UT-19 shared similar MSD profiles with about 25% LMS. Both were in excellent condition after 11 years. UT-1 was in bad condition.

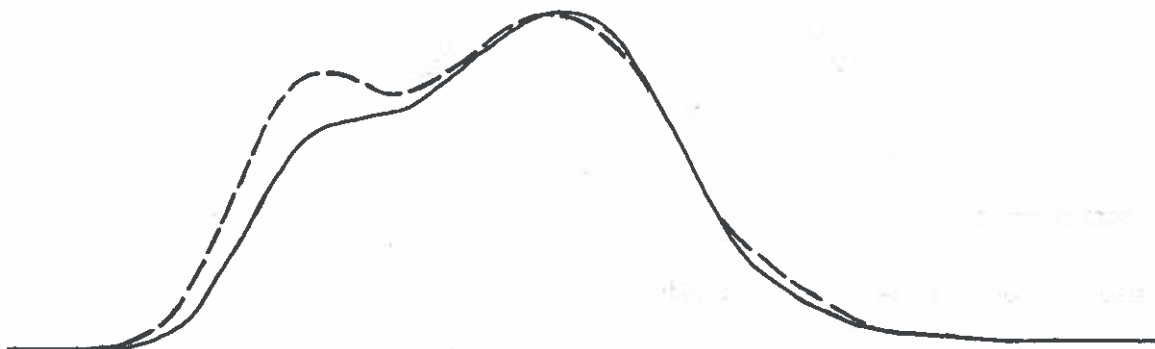


Figure 27. Utah - West of Salt Lake City

UT-19 11 years, excellent	(29.1-32.0)
UT- 1 10 years, bad	(34.9-29.7)

Table 7 shows the relationships between LMS content and performance in Utah. In summary, no positive models were obtained for the mountainous region east of Salt Lake City. It appears that asphalts with 26% LMS content or more will crack in that area. South of Provo, 27% LMS might be tolerated. In the desert west of Salt Lake City, that limit is somewhere between 25% and 29%.

Six current production asphalt cement samples were submitted, three from each of two refineries. The MSD profiles are shown in Figures 28 and 29. The differences among the three grades from refinery I are very

small as are those from refinery II. However, the products from the refineries are quite different. The asphalts from refinery II appear to be precursors for type A asphalts. Performance data for these asphalts are limited.

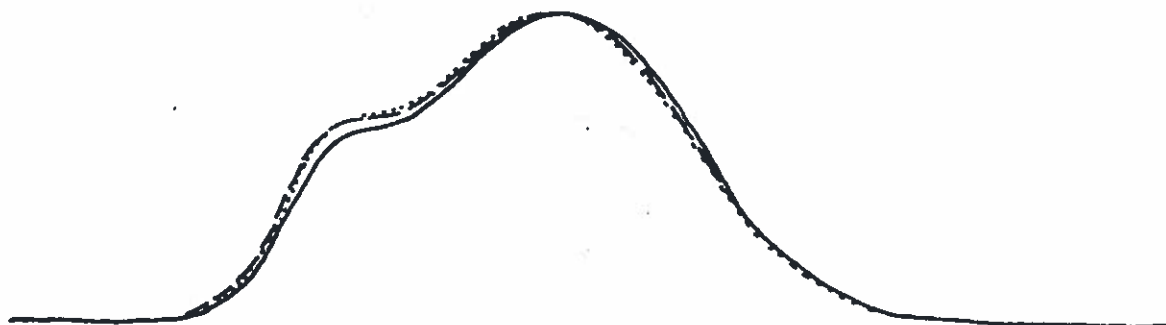


Figure 28. Utah--Current Production

—	UT-33	Refinery I/ AC-5	(22.1-34.1)
--	UT-34	Refinery I/ AC-10	(24.1-32.2)
...	UT-35	Refinery I/ AC-20	(23.8-31.9)

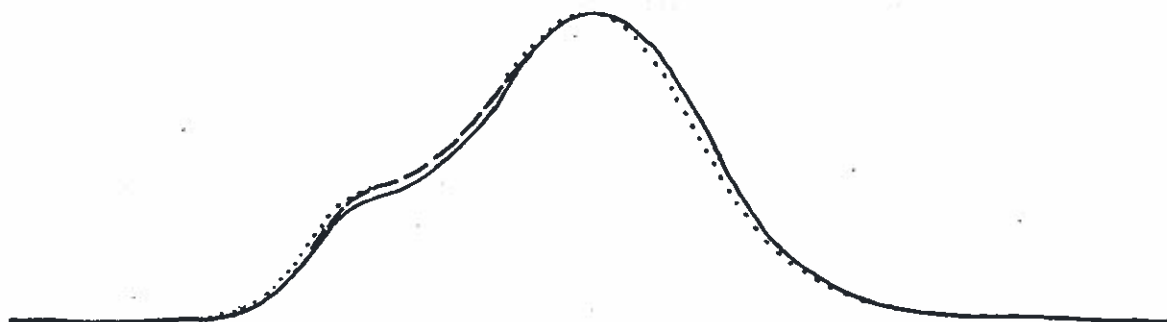


Figure 29. Utah--Current Production

—	UT-30	Refinery II/ AC-5	(14.0-42.6)
---	UT-31	Refinery II/ AC-10	(14.6-41.2)
.....	UT-32	Refinery II/ AC-20	(15.0-40.8)

Asphalts from Refinery I seem to be of the B type. Although those asphalts have given satisfactory performance in a few cases, we believe that the LMS content is at or slightly above the optimum for the climate in Utah. Therefore, we suggest care in selection of aggregate, additives and mixing temperature. Perhaps mixtures of the two refineries' products would be beneficial to both.

IIB. 4. Idaho

Two main asphalt types were found among the samples from Idaho. Chromatograms for these are shown in Figure 30.

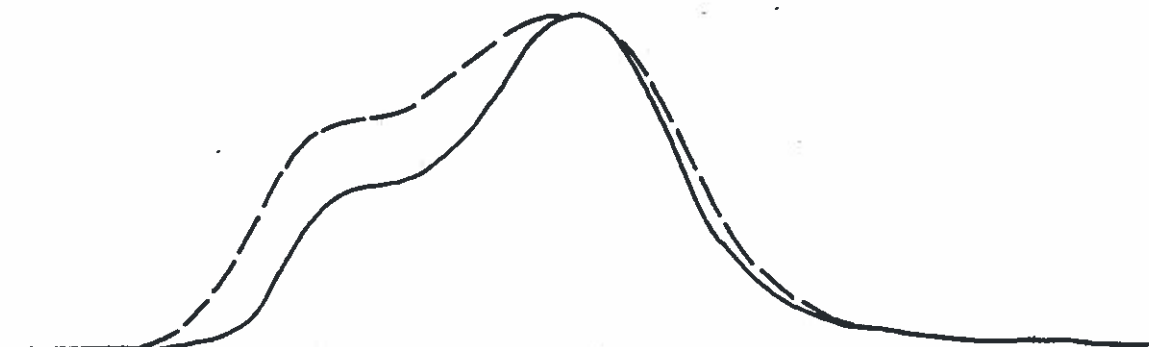


Figure 30. Idaho--Asphalt Types

— Type ID-A
--- Type ID-B

Again, the assessments of climate differ. We have divided the state into three smaller regions. The southeast probably has a somewhat harsher climate than the north; the southern section is milder with hotter summers than either of the other sampling regions.

In the southeast, the samples presented were all constructed with type A asphalts containing between 18 and 24% LMS. The asphalts came from two sources. All were in poor to bad condition after 9 and 12 years.

In the north, all samples except one were constructed with type B asphalts from at least three sources. The type A pavement had 17% LMS and was performing very well after 16 years. The type B pavements of 16 and 24 years were in poor to bad condition. One type B was performing nicely after 7 years, however. (This was the Lottman study section.)

A chart of performance at various LMS levels is given in Table 8.

In the south, type B asphalts have given mixed performances. Two 16 year old pavements are in poor to bad condition. Their LMS contents are 30 and 32%, respectively. These facts are not surprising. There

are two other pavements that are performing very well after 12 years with about 30% LMS, however. We would have expected these pavements to be cracked.

Type A asphalts in this region have also given mixed performances. One is performing well after 10 years, two others are cracking and a fourth has rutted.

Interpretation of the data from Idaho is not clear-cut. There are no positive models for the southeastern corner of the state. Based on experience in Montana we would expect that an asphalt with less than 18% LMS might be required in the southeast, whereas 19-20% might do well elsewhere in the state. The existence of excellent performers with as much as 30% LMS is exceptional. The fact that there are poor performers in that same range makes us hesitant to recommend general use of such materials.

With that in mind, observation of the chromatograms of current production asphalt cements in Figure 31 leads to the following generalizations.

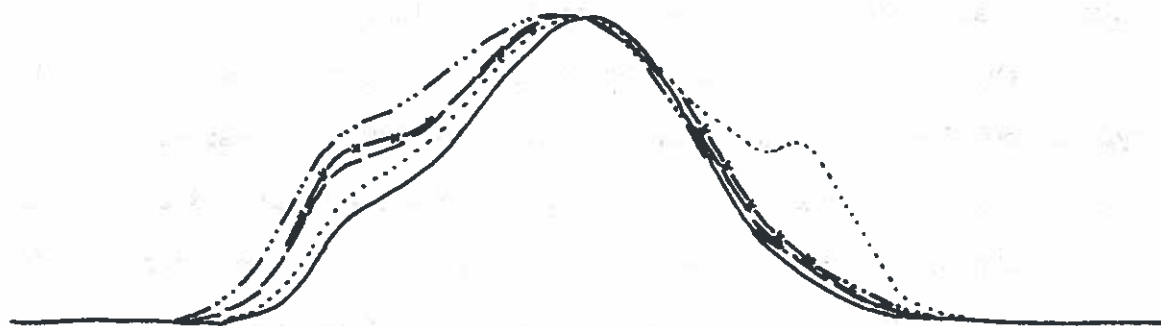


Figure 31. Idaho--Current Production

——	ID-25	Refinery I/ AC-10	(13.4-41.1)
----	ID-26	Refinery II/ AC-5	(19.7-36.3)
.....	ID-27	Refinery III/AC-2.5	(13.7-47.4)
-.-.-.-	ID-28	Refinery IV/ AC-10	(24.0-32.8)
-x--	ID-29	Refinery V/ AC-5	(20.8-37.0)

Table 8. Performance vs %LMS in Idaho

Zone 16			
%LMS	South	North	Southeast
48			
46			
44			
42			
40			
38			
36			
34			
32	bad		
30	excellent, bad	bad	
28		bad	
		excellent	
26			
24			bad
			bad
22			
	bad		
20			
	excellent		
18			bad
		excellent	
16			
14			
12			

Asphalts like ID-25 should perform well anywhere in the state provided that care is taken not to increase the LMS percentage above the model. ID-26 should, with proper caution, do well in the warmer regions of the state.

ID-27, although having a small apparent amount of LMS material, is skewed by material appearing on the far right of the chromatogram. This should be tested and used with caution until more experience can be gained.

Both ID-28 and -29 contain too much LMS to give consistently good performance, in our opinion. Neither of these appears to be a precursor of the type B asphalts that have given mixed performance in the state. That would require an increase of 10% LMS for ID-29 and perhaps 7% for ID-28, as a result of processing. Such increases would be unusually large in our experience.

IIB. 5. Summary - The Western States

Four states from the mountain west cooperated in the study: Colorado, Utah, Wyoming, and Idaho. The climate zones overlap in these states; most are fairly harsh. Tables 9 and 10 combine the data from these states and the Montana model. This is based on the available climate data, which, of course, reflects only the severity of the winter and does not consider the heat of the summer. If cracking involves, in very simplistic terms, the ability of an asphalt to relax after being contracted by cold, then the intensity of summer heat may be a mitigating influence. Samples in which cement-treated bases have influenced performance, have been eliminated, as usual.

Table 10 contains an overview of performance data from the non-mountainous regions of the cooperating western states. In the Denver area, there is a rather sharp demarcation between good and bad performance at 25% LMS. In eastern Wyoming, just to the north, this line is not quite so sharp, but occurs about 22-23%. Valleys of central Colorado presumably have a similar if not somewhat harsher climate than Denver, but surely have less traffic. Data is limited, but the separation between good and bad performance is about 22-23%, also.

Samples from the desert areas west of Salt Lake City did not include any with LMS% between 25 and 29%, but based on the above zones, the limiting value of LMS could be set below 25%.

Similar gaps occur in the samples from Idaho and western Wyoming so limits cannot be set with confidence. As stated in section IIB. 4., the excellent performance of the asphalts at 28 and 30% LMS are not thought to be typical.

Table 9. Performance vs %LMS in Western Mountains

%LMS	Zone, Increasing "harshness" ———>			
	16		21a	
	Provo UT	E UT	Mtn. CO	Mtn. WY
48				
46				
44				
42				
40				
38				
36				
34		B		
32		B		
30	B G	B G B B		
28		B		G,B
26		B	E ₂ B ²	B
24		G ¹ G ¹		E E
22				
20				
18				
16				
14				
12				

1 "holding" over badly cracked pavement

2 over "waxy" asphalt

Table 10. Performance vs %LMS in the West

Zone, Increasing "harshness" ----->									
	9	15	16						
%LMS	Den.	E. WY	Cent. OO	West UT	S. ID	N. ID	W. WY	SE. ID	MT
48									
46									
44									
42									
40									
38									
36									
34				B					
32					B				
30	Cr,B			G ³	E,B	B			
28	B			B		B			
26	B					E			
24	Cr,E	G,B	E	E					
22	E	E,B ¹	B					B	
20	E	B	E					B	
18		E				B			B
16					E				E
14						E			
12							G ²		
1 - 45 years old									
2 - 28 years old									
3 - 11 years old									

The mountainous areas of Utah, Colorado and Wyoming are also troublesome. Ideal models were not found in Utah. However, asphalts which were resisting the effects of badly cracked lower lifts give an indication that asphalts with 23-24% LMS (or less) might perform well under the conditions imposed.

In the mountains of Colorado, an asphalt with 27% LMS had survived beautifully; in Wyoming, materials with 24-25% LMS were performing well. Therefore, asphalts with up to 24% LMS should be dependable in these zones.

II. C. The North-Central States

North and South Dakota, and Minnesota are included in this group. According to William's rating system some of the most severe climate in the lower 48 states affects this region. However, those zones, particularly number 23 in northern Minnesota, are characterized not so much by a large number of freeze-thaw cycles as by the intensity of the cold. That is, the temperature tends to drop below freezing and remain there through the course of the winter. In zone 21 (the Rocky Mountains) by contrast, the landscape is subject to many more shifts through the freezing range. Just what set of conditions is more stressful to an asphalt pavement is open to question.

IIC. 1. North Dakota

All of the state falls within zone 20, although there is probably some increase in the number of freeze-thaw cycles to the southwest and some decrease in the minimum temperatures to the northeast.

No model pavement (14 years old or older and in excellent or even good condition) could be found. An eight-year-old pavement which was performing very well to date and which contained a very interesting asphalt was found. Most of the roads sampled were very old.

Three asphalt types were found among the samples (Figure 32). Type ND-A asphalts were found in all but two of the samples from the East-central region. They ranged from 18 to 21% LMS; all were in poor to bad condition. They were also quite old, 23-24 years. These are exemplified by ND-8 and ND-7 in Figure 33. However, two of those with lower LMS contents (18%) and 17 years of service showed variable performance (ND-4). That is, the extent of cracking was heavier in some parts of the project than in others. Ordinarily, uniform performance is

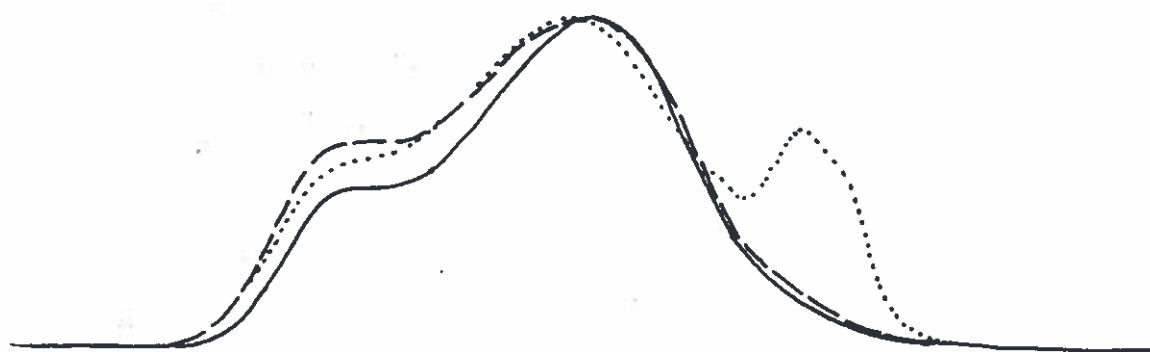


Figure 32. North Dakota--Asphalt Types

— Type ND-A
 --- Type ND-B
 Type ND-C

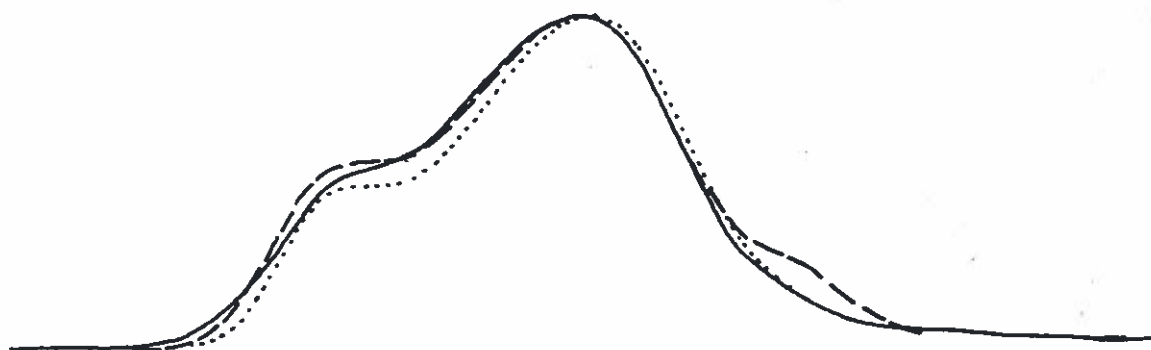


Figure 33. North Dakota--Type ND-A Asphalts in East-central Region

—	ND-8	24 years, bad	(21.3-34.6)
---	ND-7	23 years, bad	(21.2-36.8)
.....	ND-4	17 years, poor, variable	(18.0-37.8)

sought in pavements to be sampled in order to help eliminate the influence of extraneous factors. Nevertheless, in these cases, this variable performance was seen as an indication that these asphalts were on the verge of being able to perform well, if all other factors would cooperate.

Roadways containing type A asphalts in the Southwest were inconclusive. Although ND-16 had cracked severely after 7 years, it is on a lime-treated base, which, we have found, is notorious in its association with cracked pavements. ND-17 was too young to judge as a model (Figure 34).

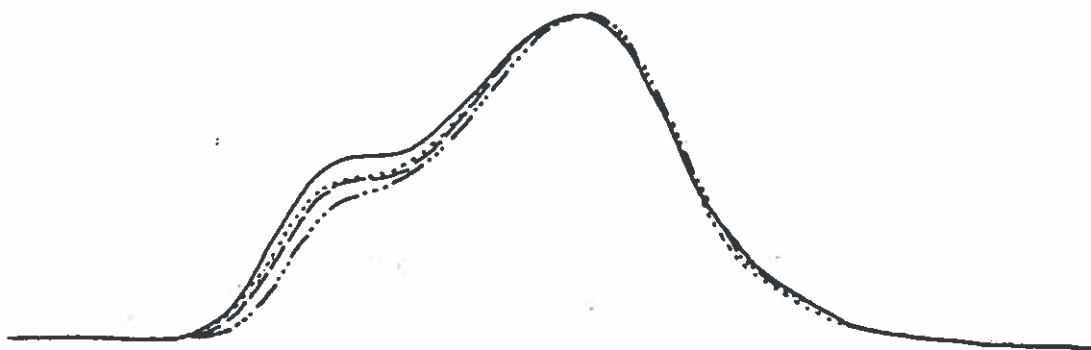


Figure 34. North Dakota--Type ND-A Asphalts in South-West Region

—	ND-16a	7 years, bad, top lift	(21.7-34.1)
- - -	-16b	8 years	(18.9-36.0)
.....	ND-17a	2 years, good, top lift	(20.0-37.9)
- ...	-17b	? years,	(16.4-37.9)

Type B asphalts have given uniformly bad performance in the roads sampled, regardless of zone.

Type C asphalt (Figure 32) proved to be quite interesting. At the time of sampling, this road was eight years old and in excellent condition. It was not old enough to be considered a model, but was old enough to invoke hope. This is an SC (slow cure)-3000 asphalt. The peak on the far right of this sample is unusual. It does not represent very small materials, because it elutes at the same time as such molecules as

toluene would elute. Toluene is, of course, much too small a material to have remained in the asphalt. The materials in this peak must have interacted with the column packing material in such a way as to elute much later than their size would suggest.

In a series of experimental sections, North Dakota tested the effects of two alternative base constructions and surface depths. These are described and the chromatograms for the asphalts are shown in Figure 35. In the two sections constructed over lime-fly ash base, asphalt concrete depth did not influence performance—both sections (ND-11 and ND-11A) had cracked at intervals of 5 to 20 feet in the 10-year life of the project. On the other hand, the 5-inch section (ND-12) on gravel base was showing better performance than the 3.5-inch section (ND-12A). Notice, however, that the latter section was constructed with a different asphalt than ND-12, ND-11 and ND-11A. Although all were constructed with SC-3000 asphalt, the nature of that in ND-12A is much different from the others. Thus the experiment has been skewed by an undetected difference in materials. Is the cracking in 12A the result of construction or asphalt?

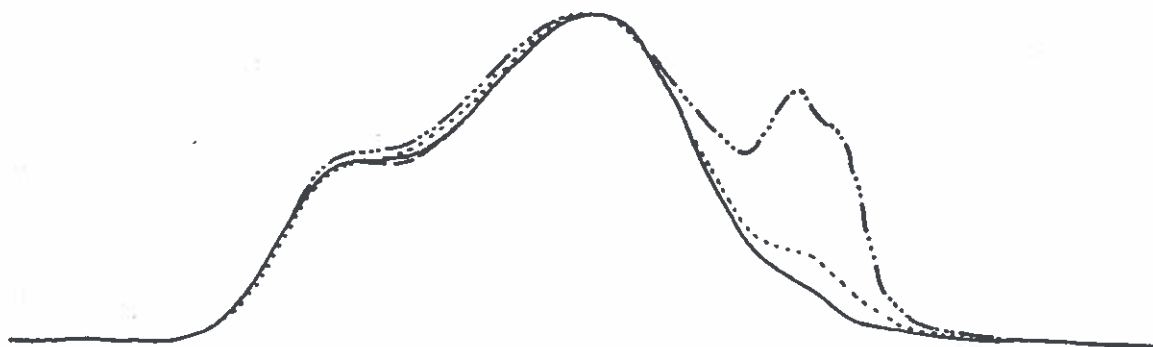


Figure 35. North Dakota--Alternative Construction Techniques
—— ND-11 10 years, bad, 1" asphalt surface over lime-flyash base
--- ND-11A 10 years, bad, 2" asphalt surface over lime-flyash base
..... ND-12 10 years, excellent, 5" full depth asphalt pavement
- · · ND-12A 10 years, good, 3.5" full depth asphalt pavement

It appears that the slow cure type asphalts have shown some promise for success in North Dakota and ought to be considered for use when environmental factors permit.

Because there were no positive models in the state, a hypothetical model based on an extension of the Montana model has been drawn. The current asphalt supplies will be compared with this "model" in several figures (36, 37 and 38). It must be remembered that the mixing process always increases the amount of LMS material in virgin asphalts. Therefore, the asphalt from Refinery I is highly likely to crack in North Dakota.

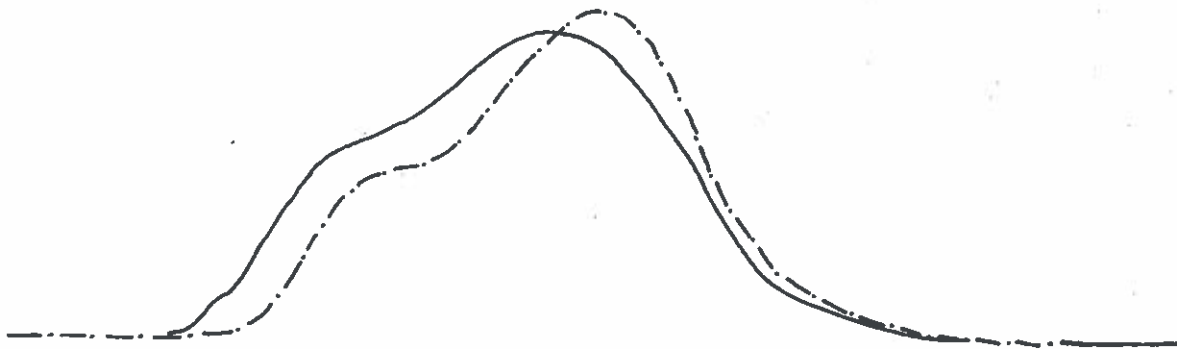


Figure 36. North Dakota--Current Production Asphalts

— · — Hypothetical model for North Dakota
—— ND-22 Refinery I/ 85-100 (26.0-29.1)

The three grades from Refinery II differ primarily in the amount of SMS material, which evidently accounts for the penetration differences rather than the amount of LMS. An increase in LMS for these asphalts would also push them beyond the model.

The products from Refinery III appear to be suitable for use in North Dakota. A caveat must be issued, however, to be certain that these asphalts are not of the type exemplified by MN-31 (see Section IIF.)

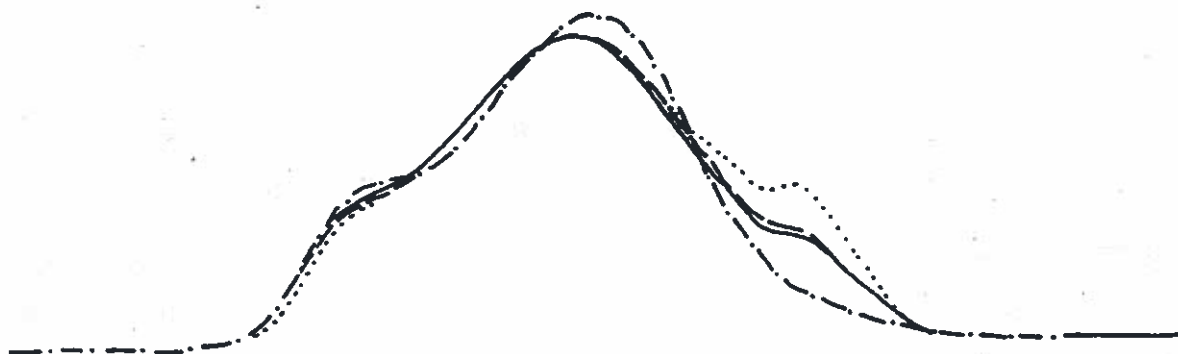


Figure 37. North Dakota--Current Production Asphalts

—	ND-19	Refinery II/ 85-100	(15.4-41.9)
- - -	ND-24	Refinery II/ 120-150	(14.9-42.4)
.....	ND-20	Refinery II? 200-300	(13.4-46.5)
- . -	Hypothetical Model for North Dakota		

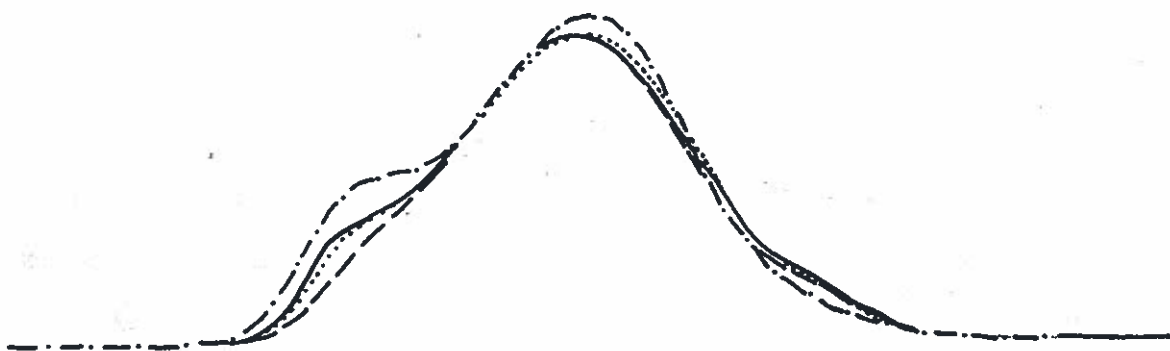


Figure 38. North Dakota--Current Production Asphalts

- . -	Hypothetical model for North Dakota		
—	ND-21	Refinery III/ 85-100, 1982	(13.3-42.0)
- - -	ND-23	Refinery III/ 120-150, 1982	(10.6-43.0)
.....	ND-25	Refinery III/ 200-300, 1982	(13.4-40.6)

One alternative for North Dakota might be to test mixtures of the products from two refineries (e.g., I and III, as in Figure 39). This sort of design has been placed in a test section in Montana with good results after two years. A discussion of the considerations is included in the Recycling section IIIC.

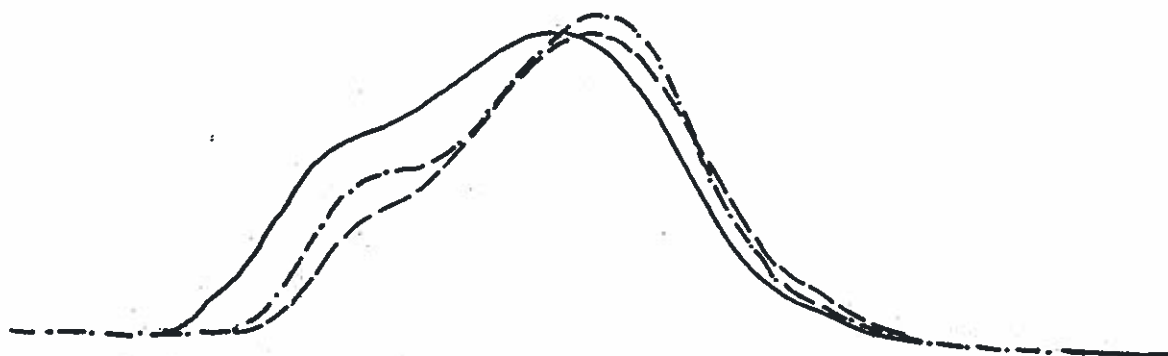


Figure 39--North Dakota--Current Production Asphalts

- — Hypothetical Model for North Dakota
- ND-22 Refinery I/ 85-100 (26.0-29.1)
- - - ND-25 Refinery III/ 200-300 (13.4-40.6)

IIC. 2. South Dakota

The state is divided into two climate zones which differ primarily in the number of freeze-thaw cycles. Three asphalt types were found in the samples (Figure 40), but types A and C were represented by only one sample each.

In the Western part of the state, type B asphalt with 23% LMS material was giving excellent performance in a 14 year old roadway (SD-15). SD-6 was in poor condition after 31 years of service, indicating that it had performed reasonably well. It contained 22% LMS. Other pavements with 24% LMS or more were in bad condition, or were cracking at very early ages. Examples are given in Figure 41.

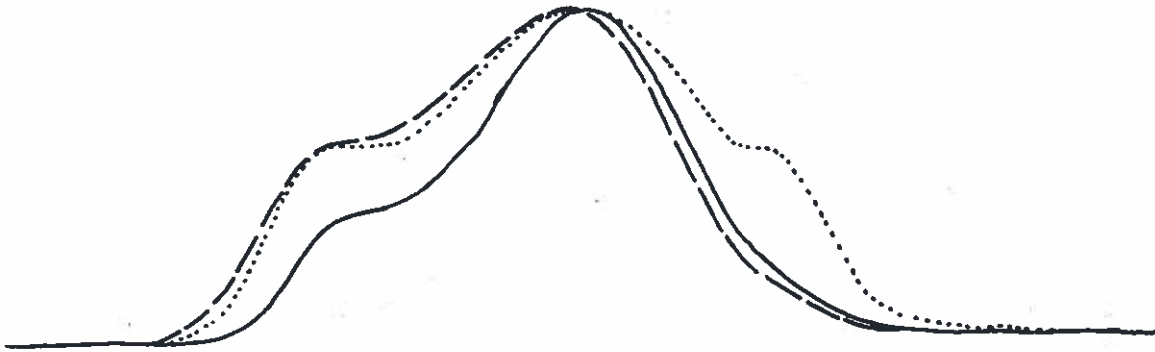


Figure 40. South Dakota--Asphalt Types

— Type SD-A
- - - Type SD-B
..... Type SD-C

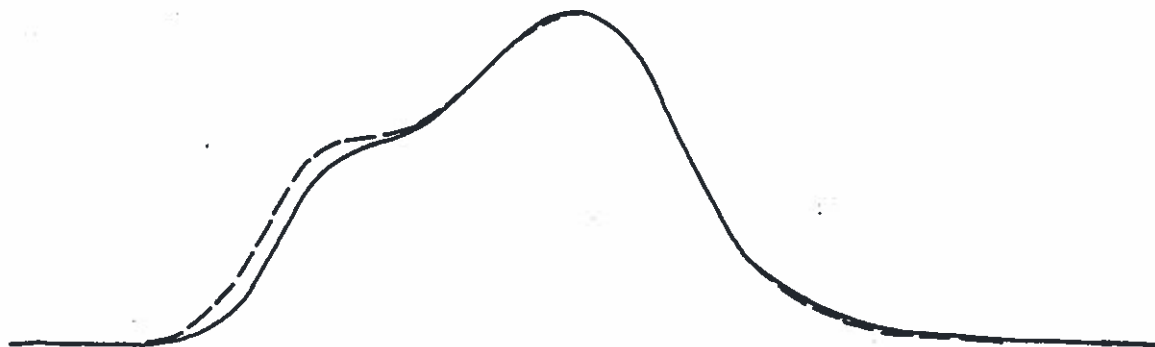


Figure 41. South Dakota--Western Region

— SD-15 14 years, excellent (23.5-33.2)
- - - SD-14 16 years, bad (26.4-31.0)

In the Central region, all pavements of type B asphalts were cracked. The LMS content of these asphalts ranged from 25% to 27%.

The one example of type SD-C asphalt was found in the Central region. That road was constructed 20 years previous to sampling and was in excellent condition. This was reported to have been a 200-300 penetration graded asphalt, but it is very reminiscent of the SC-types found in North Dakota.

The one example of type SD-A was in an eight year old pavement that was in bad condition and had cracked within a year of construction. It contained only 15.9% LMS. We suspect that it is of the same sort as MN-31 (see Section IIF.).

In 1970, South Dakota constructed a series of experimental sections near Scenic to test an observation that pavements constructed with quarried limestone performed better than those containing local gravels, the asphalt being supposedly the same. The details of the materials and rationale are given in Table 11. The HP-GPC analyses showed no significant differences among the recovered asphalts, regardless of grade or aggregate.

Table 11. The Scenic Test Sections.

Two grades or asphalt:

85-100 penetration

200-300 penetration

Two aggregate types:

local gravels

quarried limestone

Four combinations:

85-100/gravel

85-100/limestone

200-300/gravel

200-300/limestone

Constructed in 1970.

First cracking noted within 2 years.

85/100/gravel cracked first and most

85/100/limestone

- intermediate performance

200-300/gravel

200-300/limestone-cracked last and least.

All sections were cracked in 1982.

It appears that the 85-100 and 200-300 asphalts had very similar MSD's and that both aggregates had the same effect on those MSD's. Therefore, the early differences in performance may well have been directly attributable to the aggregates. However, in spite of that, all sections cracked and most had been covered by overlay and patches. We believe that the amount of LMS in the asphalt (26-27%) was too high in any case. Table 12 contains %LMS and performance data for South Dakota.

Table 12. Performance vs %LMS in South Dakota.

% LMS

48

46

44

42

41

38

36

34

32

30

28

26

cracking

bad

24

cracking

cracking, bad

excellent

22

cracking (31 years old)

excellent (SC-type?)

20

18

16

bad

14

12

South Dakota submitted no current production samples, so no statement can be made about the performance potential of its asphalts. We would recommend use of asphalts which would contain less than 22% LMS material when finished.

IIC. 3. Minnesota

This northern state has been divided into 3 climatic zones by Williams (Figure 5). Samples from Minnesota contained three different types of asphalt, which are represented in Figure 42. Type MN-A asphalt appeared in only two samples (MN-31 and 37). Both were constructed in 1982 in Zone 23 using the same grade of asphalt from one refinery. Both cracked during the first winter. These samples gave substance to our suspicions that there were some very low IMS asphalts that would crack severely. Several of these have become evident among the states involved in this study. They invariably bothered us because we did not expect such asphalts to crack. Therefore, some additional studies were undertaken, early results from which will be discussed in Section IIF.

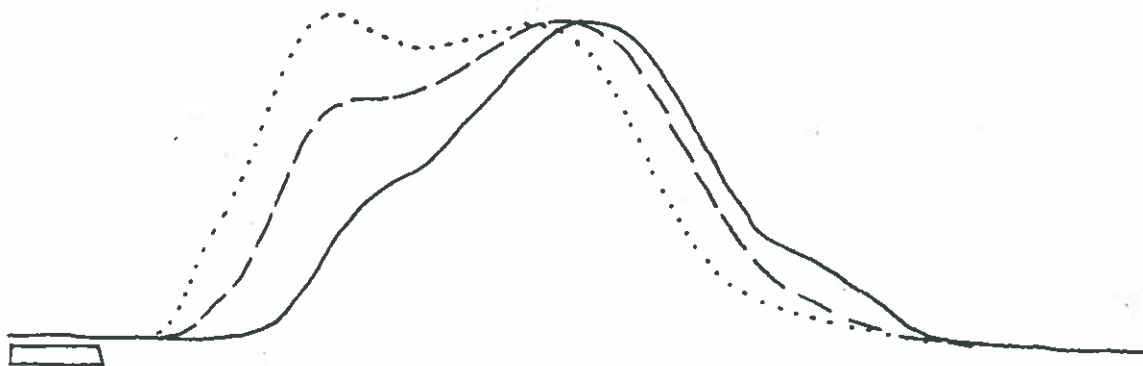


Figure 42. Minnesota Asphalt Types

—— Type MN-A
- - - Type MN-B
..... Type MN-C

Type C asphalts appeared in several samples which showed similar chromatograms but which differed in source and grade. All of these were in poor to bad condition.

The bulk of Minnesota's samples contained type B asphalts which ranged in LMS content from 25 to 36%. Table 13 shows the performance of these pavements, as well as of those type A and B pavements mentioned above, in all three zones. The best performance has been obtained from asphalts in the lower part of this range in Zone 19 (Figure 43). In Zone 20, which is somewhat harsher, even the 28-30% LMS asphalts have cracked, which indicates that even less LMS material can be tolerated in the harsher areas.



Figure 43. Established roads in Southern Minnesota

——	MN-18	9 years, excellent	(30.4-28.6)
- - -	MN-26	21 years, excellent	(25.6-32.3)
.....	MN-16	10 years, bad	(33.7-25.9)
—...—	MN- 5	14 years, bad	(37.8-24.1)

Table 13. Performance VS %LMS in Minnesota.

% LMS	Zone		
	19	20	23
48			
46		bad	
44		bad	
42		bad	
40			
38		bad	
36			
34	cracking	"good" ¹ bad	bad
32	cracking	"good" ¹	
30	good	bad	bad
28	bad ²	bad	
26	excellent		bad
24			bad
22			
20			
18			
16			bad
14			
12			

1 - 27 years, SC-type asphalt

2 - 26 years old

Some medium- and slow-cure asphalts are included in the MN-B group, but none of the good or excellent pavements contained them. There was a very interesting group of "poor" roads. They were mostly quite old, being 26-27 years of age. That they had survived as long as they had is amazing. All were constructed with SC- or MC-asphalts. The percent of LMS varies from 23.3 (in MN-4) to 31.4, but, with the exception of MN-4, range from 26.5 to 31.4%. Although these were in poor condition, they had given better performance than other asphalts with similar LMS content. As in North Dakota, the SC (and MC) asphalts have shown promise.

Minnesota submitted 11 current production samples. Four of these, which demonstrate the range of these virgin asphalt cements are represented by chromatograms in Figure 44. These asphalts are not related to any asphalts seen in Minnesota roadway samples.

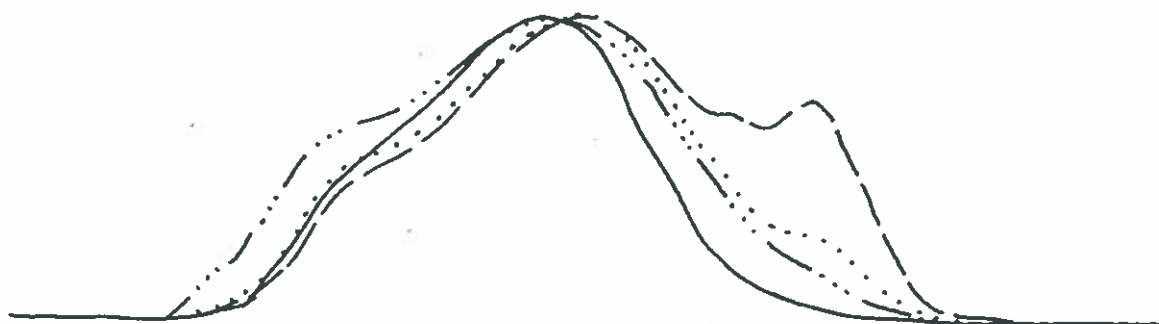


Figure 44. Minnesota - Current Production

——	MN-50	Refinery I/120-150	(21.7-24.6)
- - -	MN-52	Refinery II/SC-800	(13.5-49.3)
.....	MN-51	Refinery II/200-300	(17.9-39.1)
- . . .	MN-57	Refinery III/85-100	(26.0-30.8)

Chromatograms of the remaining samples are drawn in Figure 45. In spite of the differences in refinery and penetration grade, these materials are remarkably similar. They are likely precursors of the type B asphalts which predominate in the state's roadways. If, as we propose, an asphalt with 26% LMS is a good model for Zone 19, then only MN-50, 54 and 59 are likely to meet that requirement when finished.

Although MN 51 and 61 appear to fill the requirements of low LMS, there are, as stated earlier, some problems with this material. In another state a mixture of this asphalt with another of higher LMS content has been placed in a test section. After two years, this section is giving better performance than either of the materials alone in nearby test strips. Perhaps such an approach would be helpful in finding better asphalts for Minnesota.

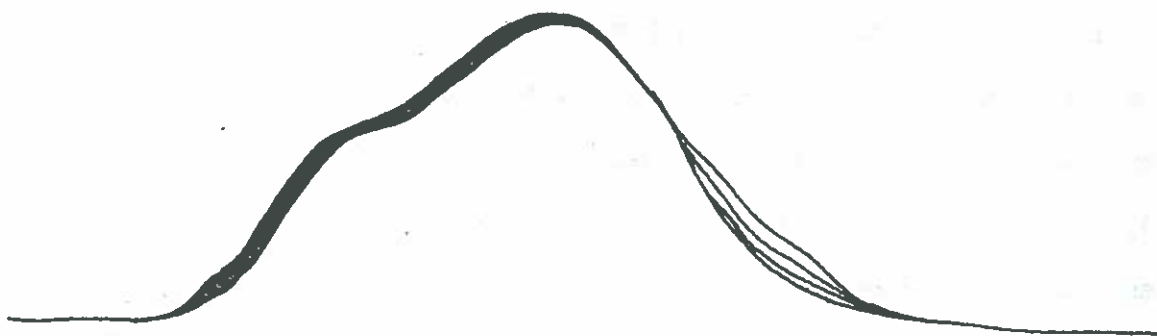


Figure 45. Minnesota - Current Production

MN-57	Refinery III/ 85-100	(26.0-30.8)
MN-58	Refinery III/120-150	(25.0-32.0)
MN-59	Refinery III/200-300	(24.1-34.1)
MN-54	Refinery IV/ 85-100	(24.1-30.5)
MN-55	Refinery IV/120-150	(26.3-29.1)
MN-53	Refinery V/120-150	(25.6-30.4)
MN-60	Refinery VI/120-150	(25.8-30.3)
MN-56	Refinery VII/120-150	(26.5-29.0)

IIC. 4. Summary of the North Central States

Three states, North Dakota, South Dakota and Minnesota are included in this region. The climate is, in general, quite harsh, particularly in terms of the intensity of cold. Throughout the region, positive models were scarce to nonexistent. In fact, except for western South Dakota and zone 19 in Minnesota, no positive models for common AC- or penetration- graded asphalts were found. As a result, it is difficult to assign limiting values of LMS percentage. Nevertheless, it is obvious that the asphalts which have been used in the past have rarely given satisfactory performance. Design and construction practices aside, it seems pointless to place asphalts with 31% LMS or more anywhere in the region. In zone 19 of Minnesota, the excellent pavement with 30% LMS was just 9 years old, whereas that at 26% had performed well for 21 years. Until the information gap between those percentages can be filled, we would recommend using materials with 26% LMS or less when finished.

In South Dakota, zone 15 (all South Dakota data has been combined for this summary), it appears that 22-23% is the maximum amount of LMS that would be viable. Somewhat less might be required in Minnesota zone 20, still less in North Dakota and in Minnesota zone 23. Further testing will be required to refine these limits.

There is a problem exemplified by MN-31, that is, very low LMS asphalts which defy the model and crack at a very early age. These should be avoided, of course, and we are working on ways to detect such materials (see Section IIF.).

Slow-cure (SC-) type asphalts were found in all three states. In Minnesota, two were in fair condition after 27 years; in South Dakota,

Table 14. Performance vs %LMS in North Central States.

%LMS	ZONE				
	MN 19	SD 15	MN 20	ND 20	MN 23
46			bad		
44			bad		
42			bad		
40					
38			bad		
36					
34	cr				
32	cr		good ² , bad		bad
30	good		good ²		bad
28	bad ¹		bad		bad
26	excellent		bad		bad
24		cr			
22		bad, cr		bad	
20		excellent		bad	
18		cr ³		bad	
16		excellent ⁴		bad, excellent ²	
14				bad, excellent ²	
12					bad

- 1 - 26 years old
- 2 - SC type
- 3 - 31 years old
- 4 - SC type?

one was in excellent condition after 20 years; in North Dakota, the lone excellent performers (7 and 10 years) had been constructed with SC-3000 asphalts. We do not have enough experience to know whether such materials can be depended upon consistently, but it appears that further investigation is warranted. The environmental concerns must be considered, of course.

IID. The Central and Eastern States

IID. 1. Illinois

Williams has divided Illinois into three climate zones. The southern most zone, 3b, is quite mild with average temperatures above the freezing mark during the winter months. However, the other zones are marked by some months in which the average temperature is below freezing and the activity is a series of thaws. Two basic asphalt types were found among the state's samples. Chromatograms for these are shown in Figure 46.



Figure 46. Illinois Asphalt Types

—— Type IL-A
---- Type IL-B

A performance vs %LMS comparison is given in Table 15. Most type A asphalts were found in the northern part of the state, Zone 19. Their LMS contents ranged from 23 to 32%; their performance was uniformly disappointing. Most were in poor to bad condition after as few as five years. Only one roadway was performing reasonably well, that was in good condition after 19 years of service. We would have expected asphalts in the lower part of such a range of LMS percentages to perform well in this climate zone. Traffic counts were not unusually heavy (1800-5000 ADT). The only unifying factor was that many medium to large voids were found in portions of these cores. Apparent stripping was noted in one

Table 15. Performance vs %LMS in Illinois.

%LMS	Zone		
	3b	14	19
48			cracking
46			bad
44			bad
42	excellent ⁴	cracking, bad	cracking
40			excellent, ³ bad
38		cracking	cracking, excellent ²
36		excellent	
34	excellent ² excellent ² , bad		
32			bad bad
30			bad
28			bad, cracking
26			bad
24			bad, cracking
22			good ¹
20			
18			
16			
14			
12			
1 - 19 years			
2 - 6 years			
3 - 7 years			
4 - 5 years			

of the samples. It is interesting to note that this group of samples was the only one in which problems with compaction were noted in Illinois.

Some type B asphalts performed quite well in the north for 6-7 years. Older examples were badly cracked, however, and some of the younger pavements were beginning to crack.

Only a few samples were obtained from zone 14. These contained type B asphalts; one pavement was performing well after eight years; two others were cracking after 6 years. The latter had more LMS material than the former.

Sampling was also light in the southern most zone, 3b. Three excellent pavements were found, all 5 or 6 years old. The maximum amounts of LMS material varied between 33.8 and 42.2%. However a 12 year old pavement with similar asphalts had deteriorated to "poor" condition. As in other areas, this asphalt type appears to perform well in the short term, perhaps better than we would expect, based on the MSD. However, the pavements do crack, having a shorter life-span than desired.

Many of the pavements in Illinois contain limestone dust, but no trends in performance could be seen.

Illinois supplied 14 current production asphalt cements which will be discussed in more detail in Section IIIA. C. Chromatograms for these are drawn in Figure 47. This rather complicated set of MSD's shows the broad range of materials available to the state. These represent AC-2.5, -5, -10 and -20 from four refinery sources. Note that some of the asphalt cements have identical or nearly identical profiles.

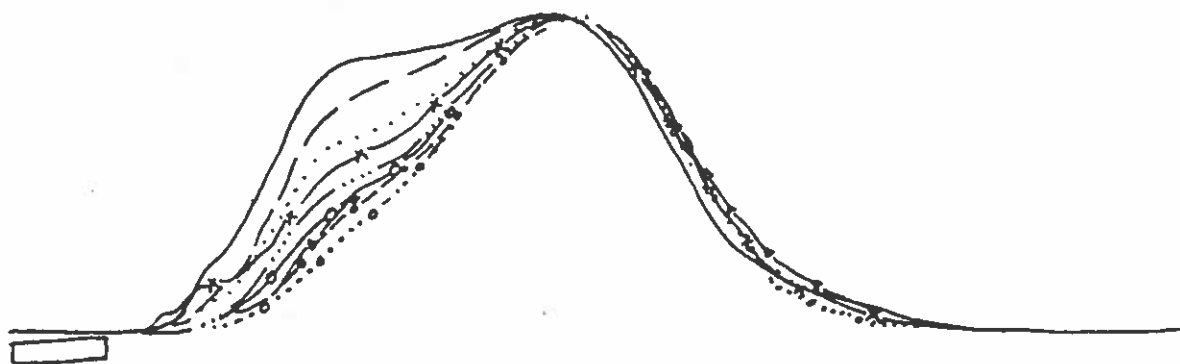


Figure 47. Current Production - Illinois

————	IL-144	(33.8-23.9)
-----	IL-141	(30.5-25.3)
.....	IL-140	(27.0-27.8)
- - - - -	IL-133, 139	(22.0-30-8)
x — x	IL-143, 136	(25.2-29.5)
o — o	IL-132, 131	(20.9-30.4)
- - .	IL-135, 138	(18.6-33.0)
—▲—	IL-134	(18.6-34.6)
...●	IL-130, 137	(16.7-31.9)

Figure 48 compares three of these asphalts with a type IL-B from a pavement. Remembering that processing always results in an increase in the amount of LMS materials, it seems possible that IL-144 could be a precursor of type B. Increases of 8-10% are not common in our experience, so IL-140 and 141 seem less likely to yield type B. There is, of course, some variation in the type B.

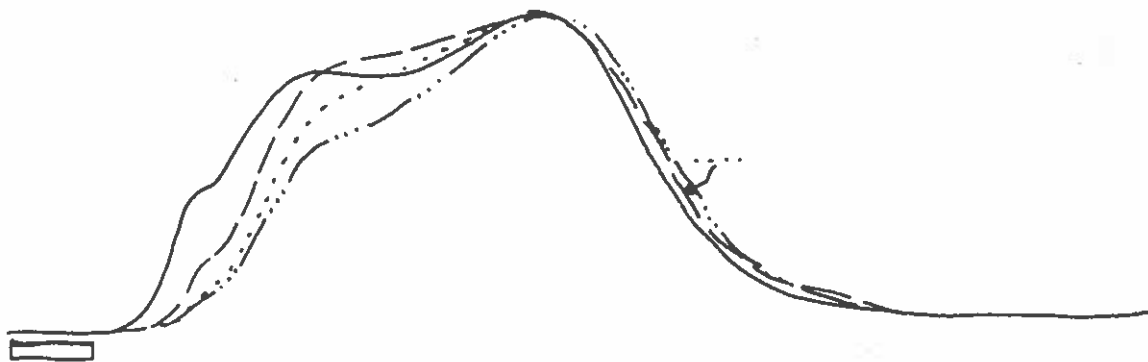


Figure 48. Current Production as Precursors for Type IL-B

——	Type IL-B	
----	IL-144 Refiner IV/60-70	(33.8-23.9)
.....	IL-141 Refiner IV/85-100	(30.5-25.3)
- ...	IL-140 Refiner I/AC-20	(27.0-27.8)

Figure 49 shows that IL-140 is the most likely precursor of the higher LMS type IL-A (type IL-A) asphalts. Figure 50 includes a similar set of chromatograms for type IL-A precursors. Most of these lower LMS virgin asphalts are possible precursors for type A, but again, typical increases in LMS on mixing seen in the past are not as large as 6 or 8% unless the materials are unusually reactive. It appears as though asphalts such as IL-130, 134 and 135 are not representative of the kinds of virgin materials received in the past. IL-136 and 143 also do not appear to be related to asphalts currently in service in the state.

IL-140, 141 and 142 could be useful in warmer areas of the state on low volume roads. Asphalts of this type presently in service should continue to be evaluated for long-term performance. Although IL-140 is not a likely precursor for type B asphalts, it does contain more LMS material than is likely to succeed in the northern part of the state. IL-133 and 139 ought to be useful in any area of the state. The same

ought to be true of IL-132 and 131. Of course, the final MSD of any of these asphalts can be determined by use of the laboratory simulation procedure (3).

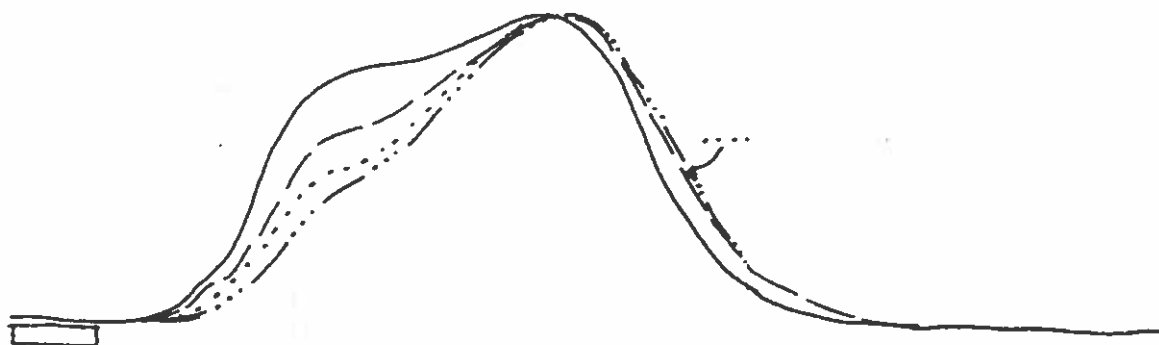


Figure 49. Current Production as Precursors for Type IL-A'

—	Type IL-A'	
- - -	IL-140 Refiner I/AC-20	(27.0-27.8)
.....	IL-133 Refiner II/AC-20	(22.4-30.9)
- . . .	IL-139 Refiner I/AC-10	(22.0-30.8)
- . .	IL-132 Refiner II/AC-10	(20.9-30.4)

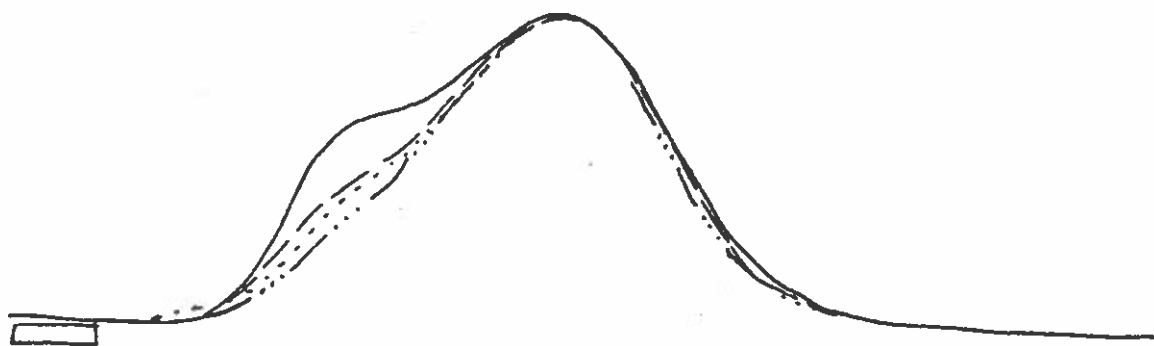


Figure 50. Current Production as Precursors for Type IL-A

—	Type IL-A	
- - -	IL-132 Refiner II/AC-10	(20.9-30.4)
- . . .	IL-131 Refiner II/AC-3	(19.6-32.2)
.....	IL-135 Refiner III/AC-10	(18.6-33.0)
- . .	IL-130 Refiner II/AC-2.5	(16.7-31.9)

IID. 2. Ohio

Williams' climate survey places all but the southern-most portion of Ohio in zone 14. The samples were obtained from four regions which experience somewhat different weather regimes; they will be discussed on that basis.

Table 16 contains %LMS and performance data in these zones. Traffic loadings, in general, are heaviest in Cincinnati, lower in the Northeast followed by North Central and, finally, the South Central regions.

Samples were particularly complicated in the northeast region of Ohio. There, asphalt concrete has been placed over a variety of bases (e.g. Portland cement concrete, bricks etc.) and in multiple overlays over many years. Blast furnace slag has been used as aggregate in some cases. Finding suitable model pavements proved to be impossible in the Northeast.

The types of asphalt found in Ohio are shown in Figure 51. This discussion will begin with the Cincinnati region and proceed through the other climate subzones.

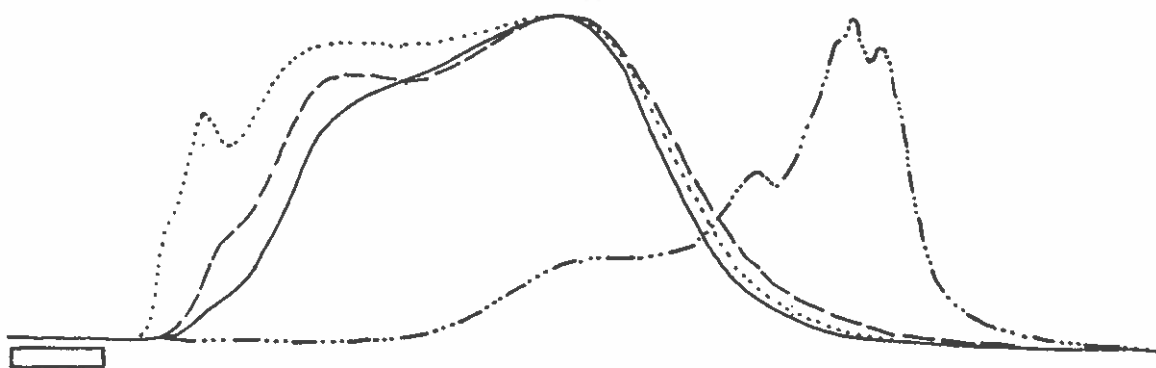


Figure 51. Ohio - Asphalt Types

- Type OH-A
- - - Type OH-B
- Type OH-C
- ... Road Tar

Table 16. Performance vs %LMS in Ohio.

%LMS	Zone			
	Cincinnati	South Central	North Central	Northeast
48		bad		
46	bad	bad		
44	cracking			
42	bad	good	cracking, bad	bad
40		good		bad
38		bad		
36	cracking good			
34	cracking excellent	bad	bad	bad bad bad
32		bad excellent	good	bad
30			bad	
28		excellent		
26				
24				
22				
20				
18				
16				
14				
12				

The best pavement sampled in the Cincinnati area was OH-41 (Figure 52). It was 14 years old at the time of sampling and in excellent condition. Three other pavements, all 10 years old and in good condition, are represented by OH-34 in that figure. Another asphalt type was found in two pavements, represented by OH-33. That roadway was in bad condition after 10 years; the other, OH-42, was an early failure, but was also over PCC base. All of these samples were in the 70-85 penetration grade.

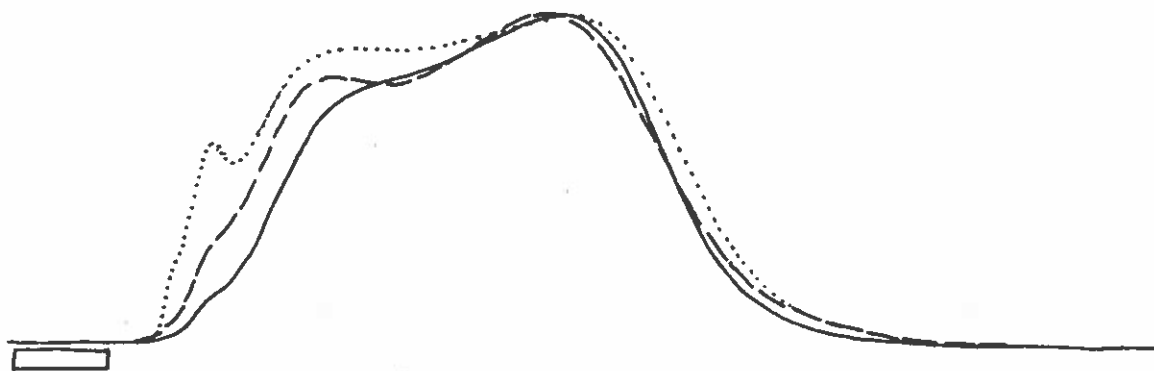


Figure 52. Ohio - Cincinnati Area

—	OH-41	14 years, excellent	(32.0-22.5)
- - -	OH-34	10 years, good	(34.9-22.3)
.....	OH-33	10 years, bad	(40.7-20.6)

In the South Central region, several of the pavements sampled had road-tar treated bases. This was reputed to be detrimental to the cracking performance of the pavement. This sampling could neither confirm nor deny that reputation. The best pavement in this region was OH-22, 10 years old, and in excellent condition (Figure 53). It was

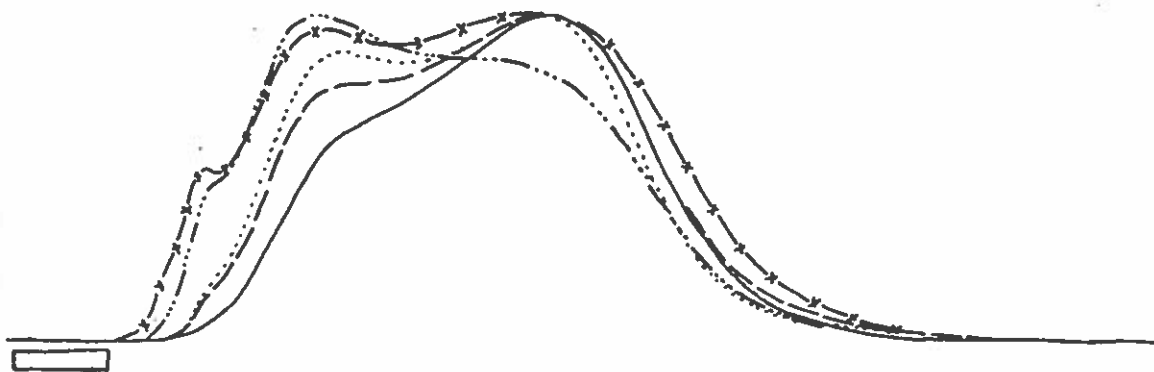


Figure 53. Ohio - South Central Region

—	OH-22 10 years, excellent	(26.7-24.2)
- - -	OH-25 9 years, bad	(33.7-23.0)
.....	OH-24 10 years, poor	(37.9-18.8)
- . . .	OH-27 4 years, bad	(48.5-15.7)
—x	OH-26 10 years, good	(40.6-22.9)

constructed with an AC-20 grade asphalt. Other samples from this area were from pavements showing fair to bad performance. Three of these are included in Figure 53. OH-24 was in poor condition after 10 years; OH-27 was in bad condition after only 4 years; OH-25 showed bad performance at 9 years of age.

Sample OH-27 is an interesting case of multiple lifts using different asphalts. Figure 54 shows that there were four materials in that pavement. The ages of the lower lifts are not known, but the newest overlay was just four years old and in bad condition. That asphalt is similar to that in OH-22 except that there is an additional amount of SMS material in OH-27a. It could not, however, withstand the influence of the lower lifts.

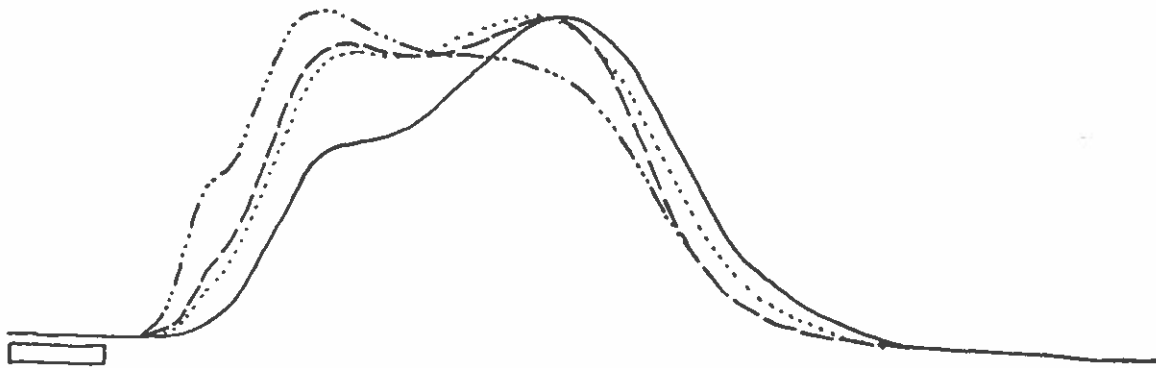


Figure 54. OH-27

—	OH-27a	4 years, bad	(25.9-30.0)
- -	OH-27b	?	(38.7-18.9)
...	OH-27c	?	(36.6-22.2)
- . .	OH-27d	?	(48.5-15.7)

The asphalt in OH-26 is type OH-C, like that in OH-33 and -42 (Cincinnati). In the South Central region it was demonstrating good performance after 10 years of service, whereas it was "bad" in Cincinnati. Although the climate is somewhat harsher in the South Central region, the traffic loads are considerably lighter than in Cincinnati (ADT of 700 as opposed to 22,000). Asphalts of this type in Pennsylvania have shown similar traits, i.e., have given better performance under lighter traffic loads.

In the North Central region of Ohio, type OH-A asphalts similar to that in OH-41 (Cincinnati) were used with mixed success. OH-20 had performed very well for 16 years; OH-15 had very few cracks after 15 years. On the other hand, OH-21 was in poor condition after 15 years and OH-16 was bad at the age of 14. All four pavements were rather deep (11-12 inch sections); traffic loading was actually lighter on the failed projects. The only obvious difference is the presence of many voids in all lifts of OH-16 and in the lower lifts of OH-21.

This same type OH-A asphalt appeared in the lower lifts of a puzzling set of samples (Figure 55). The roadway was six years old, showing excellent performance at mile post 8, poor performance at mile post 9.

Both sections were constructed at the same time. The upper lifts are different from the lower, have more LMS and would be expected to crack, eventually. Why one section should break before the other is not obvious from the available data.

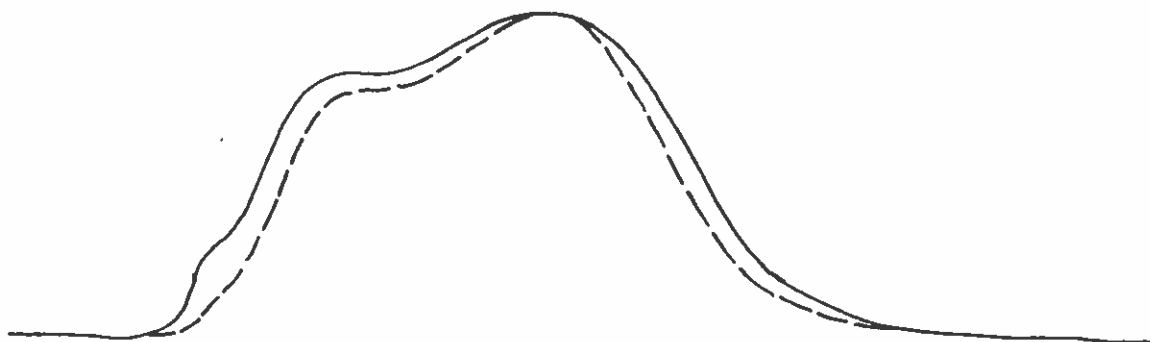


Figure 55. OH-18 Variable Performance in a Pavement

— upper lifts
--- lower lifts

The roadways sampled in the Northeast region were all constructed with type A and B asphalts with as much or more LMS material than the excellent pavements in the Cincinnati area (OH-41). Furthermore, all were in poor to bad condition. The problems in this region which were enumerated earlier notwithstanding, it is likely that the asphalt cements used could not have delivered good performance.

In summary, then, it appears that the Cincinnati area can tolerate asphalts of either type A or B with LMS percentages in the range of 30-31. The South Central region can probably use these types with as much as 29% LMS material.

Because of a lack of positive models, recommendations for the northern part of the state can not be defined except to say that asphalts with lower contents of LMS material than have been used in the past be tried, perhaps 24% or less.

Type C asphalts, based on a limited sampling, should be used only in the milder areas of the state and on low volume roads and even then, with caution.

One paving project in the Cincinnati area caused much consternation because it was reported to be 20 years old and in excellent condition in spite of being on a PCC base. Figure 56 shows that this project, OH-43, consisted of four lifts of very different asphalts, the lower two of which would have been expected to crack even without the PCC base. The second lift would have been expected to perform well, were it alone, and the uppermost lift was the only example of its type seen in the state. Further examination revealed that the lower two lifts (c,d) were 20 years old but required overlay within 5 years. That lift (b) served for an additional 10 years before a final lift (a) was placed five years before sampling. This asphalt had been performing well for five years, which makes it worthy of more attention, at least on low volume roads in the Cincinnati area.

It must be stressed that few, if any, asphalts can stand up to the stresses imposed upon them by badly cracked base materials.



Figure 56. OH-43 Cincinnati

—	OH-43a	5 years, excellent	(32.0-26.8)
- -	OH-43b	15 years	(28.4-29.5)
...	OH-43c	20 years	(44.5-17.5)
- . .	OH-43d	20 years	(40.3-22.5)

The current production, untreated samples (Figure 57) sent to us indicate that the asphalt supplies have changed considerably. OH-75, 78 and 79 have no obvious counterparts on the states' highways, even when the expected increase in amount of LMS during processing is taken into account. These asphalts show promise especially for the colder parts of the state. OH-76 is likely to be a precursor of type A asphalts for most of the state, although caution must be used in the Northeast lest processing produce too much LMS material. Asphalt 77 appears to be a precursor of one lift in sample OH-43 and should be considered for use in the warmer sections of the state.

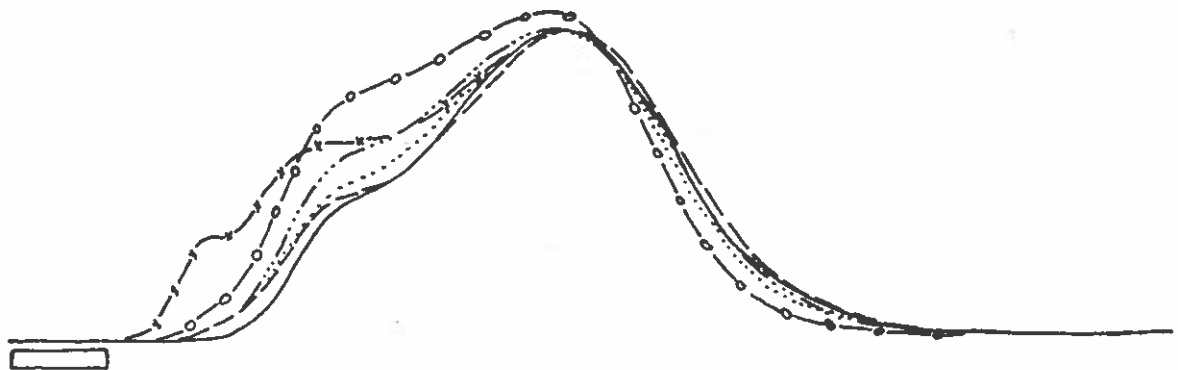


Figure 57. Ohio - Current Production Asphalt Cements

—	OH-78	Refinery	I/AC-20,	1982	(18.8-33.4)
- - -	OH-75	Refinery	II/AC-20,	1982	(20.5-32.4)
. . . .	OH-79	Refinery	III/AC-20,	1982	(22.3-30.7)
- . . .	OH-76	Refinery	IV/AC-20,	1982	(23.3-29.3)
- x -	OH-77	Refinery	V/AC-20,	1982	(25.0-28.6)
- o -	Model Type OH-A for Southern Ohio				

IID. 3. Pennsylvania

The samples from this state consisted mainly of a variety of test sections supplemented by some roadways in the Pittsburgh area. These were all relatively young; in fact, the search for old, excellent models in the state was unsuccessful. However, there is much interesting and useful information to be gleaned from the samples obtained. They will be discussed project-by-project.

Chemkrete

A set of test sections, including an AC-10 with Chemkrete and two control sections consisting of the same AC-10 and an AC-20 asphalt cement, were constructed about a year before these samples were taken. At the time of sampling, there was some cracking in all sections and no noticeable difference in performance was found.

The chromatograms in Figure 58 show several interesting points. First, there is no significant difference between the AC-10 control and

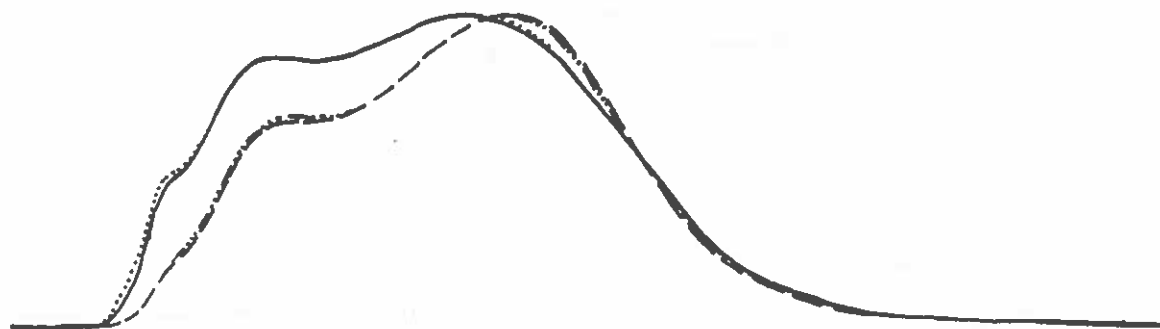


Figure 58. Pennsylvania - Chemkrete Test - PA-4

—	Refinery II/AC-10, control	(38.1-22.5)
- - -	Refinery I/AC-20, control	(29.8-26.2)
.....	Refinery II/AC-10 plus Chemkrete	(37.6-22.9)
- . .	Underlying asphalt for test sections	(29.7-28.5)

the AC-10 with Chemkrete, indicating that little, if any, chemical reaction affecting molecular size took place with the addition of Chemkrete. Second, the AC-20 control is a very different asphalt from the AC-10. Thus, this project contains one more variable than planned. Third, the pavement underlying all three sections is the same as the AC-20. Experience has shown that pavements containing lifts of widely differing asphalts tend to perform poorly, so that the Chemkrete and AC-10 control sections may be at a disadvantage.

Carbon Black

The test project for carbon black consisted of four sections using AC-20 grade asphalts: "high" pen (~80) control; "high" pen with carbon black; "low" pen (~60) control; "low" pen with carbon black. Both asphalts were from the same refiner. After four years, all sections were cracked and no significant differences in performance were noted. The pavement carried many heavily loaded logging trucks. Figure 59

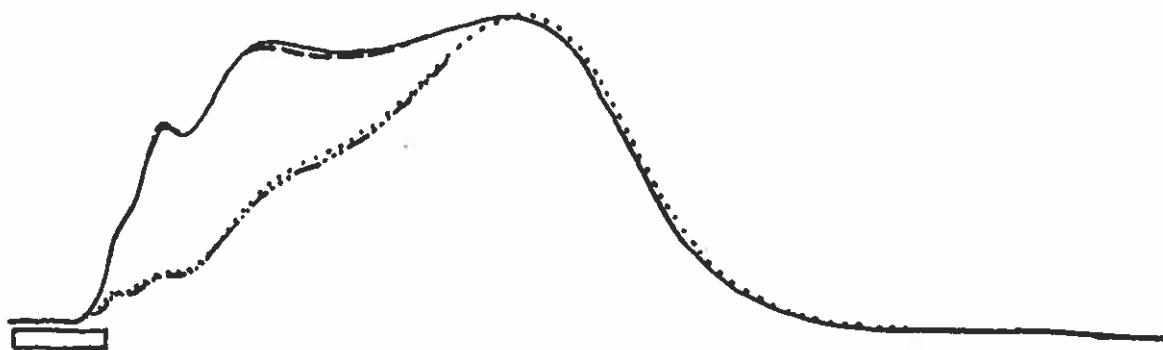


Figure 59. Pennsylvania - Carbon Black Test - PA-6

—	Refinery IV/AC-20, "high" pen (~80)	(41.6-19.7)
- -	Refinery IV/AC-20 "high" pen plus Carbon Black	(41.2-20.1)
. . . .	Refinery IV/AC-20, "low" pen (~60)	(25.7-27.8)
- . . .	Refinery IV/AC-20, "low" pen plus Carbon Black	(24.8-27.9)

compares these four sections. The most obvious point is the large difference between the "high" pen and "low" pen materials within the same asphalt grade. We believe that these sections are, therefore, more than tests of penetration differences; they are tests of different asphalts. Also noteworthy is the fact that the control sections and the carbon-black sections in each penetration category have the same MSD. That is, use of carbon black has not resulted in any overt chemical changes in the asphalt. This is typical of the results seen elsewhere.

"High" pen vs "Low" pen experiments

Three sets of test sections were constructed using AC-20 grade asphalts and comparing differences in penetration. Pertinent data is included in Table 17.

Table 17

Sample	Ref.	pen*	vis**	%LMS
8A	V	61	1780	32.8
8B	V	80	1850	32.9
9A	VI	61	—	25.9
9B	VII	73	—	33.0
10A	IV	63	2041	33.2
10B	IV	80		33.0

*77°F
**poises at 140°F

In PA-8, the asphalts were from the same refinery (V). These sections were 4 years old when sampled and were in good condition with no overt differences in performance. Although the table shows that the percentage of LMS material in each of these is about the same, the chromatograms in Figure 60 reveal that the asphalts are somewhat different.

After three years on project PA-9, cracks from PCC base (which had been marked on the curb for ease of record-keeping) had reflected through

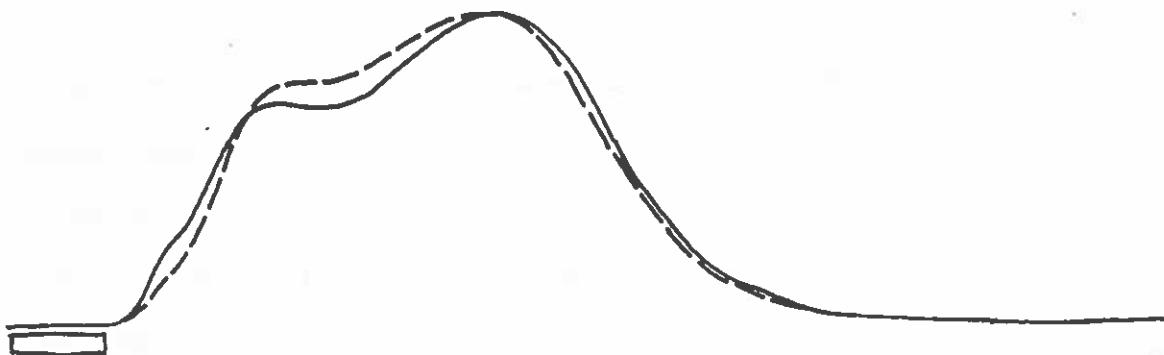


Figure 60. Pennsylvania - "High" vs "Low" pen experiments

—	PA-8	Refinery IV/AC-20 "high" pen	(80)
- -	PA-8	Refinery IV/AC-20 "low" pen	(61)

and there were a few additional cracks, but no real differences in performance could be discerned. Here the asphalts were from different sources. The "low" pen material has a much shorter MSD (i.e., a smaller range of molecular sizes) than the "high" pen and a considerably smaller LMS content (Figure 61). Much the same sorts of things may be said about PA-10 relative to performance. It is also interesting to compare the "low" pen asphalt from this pair with the "high" pen asphalt from PA-8. Although from different refineries, they are very similar (Figure 62).

Viscosity Comparison

One set of test sections was constructed to test asphalts of different viscosities. Figure 63 shows that the AC-10 from Refinery I contains much more large material than does the AC-20 (Refinery III). In fact, these are two entirely different asphalts. Moreover, the underlying pavements are different (Figure 64). This may skew the performances of the overlays.

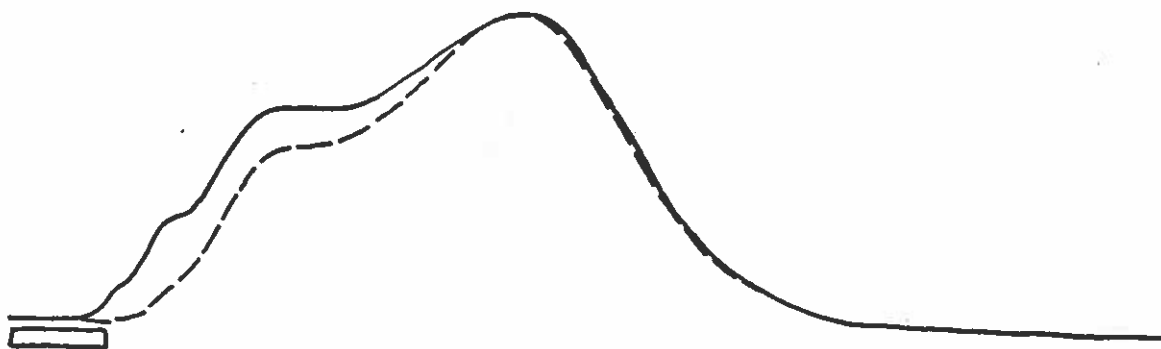


Figure 61. Pennsylvania - "High" vs "low" pen experiments

— PA-9 Refinery VII/AC-20 "high" pen (73)
 - - PA-9 Refinery VI/AC-20 "low" pen (61)

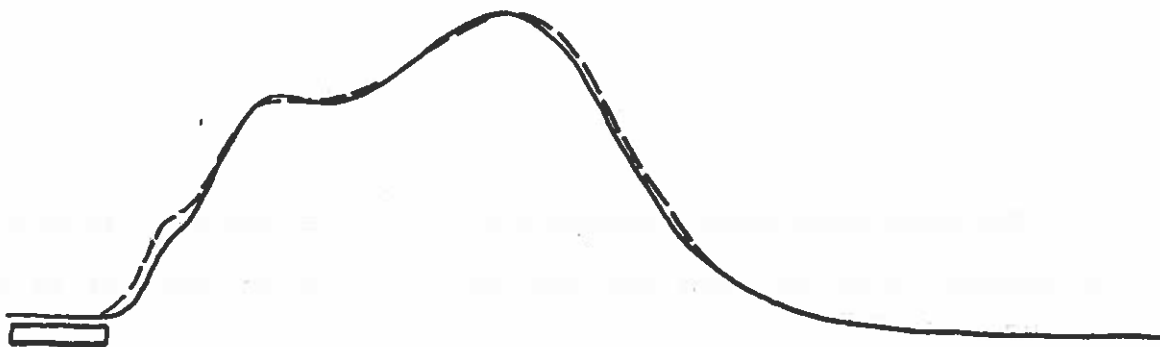


Figure 62. Pennsylvania - "High" vs "Low" pen experiments

— Refinery IV "high" pen
 - - Refinery V "low" pen



Figure 63. Pennsylvania - Viscosity Comparison - PA-19

— Refinery III/AC-20 (26.1-26.6)
 - - Refinery I/AC-10 (38.1-22.2)

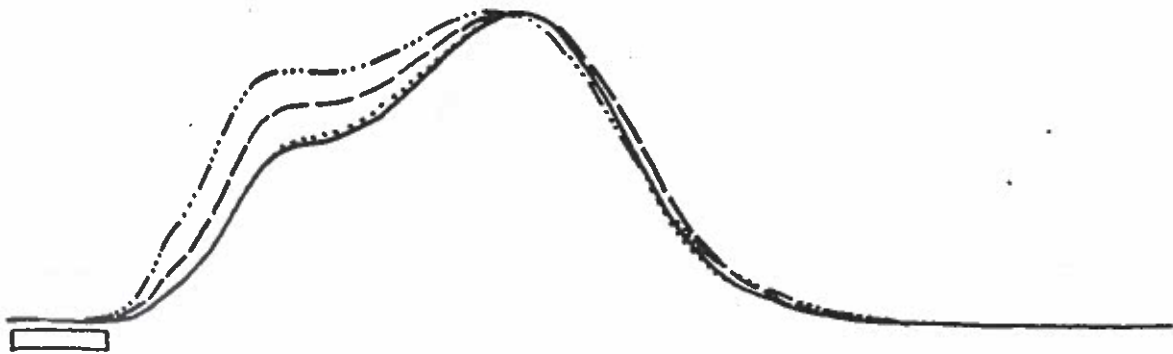


Figure 64. Pennsylvania - Viscosity Comparison - PA-19

— Underlying pavements for AC-10
 - - - Underlying pavements for AC-20

The above experimental pavements are more than tests of viscosity or penetration differences; they are tests of different asphalts as well.

Aggregate Tests

Experimental sections to study skid resistance were constructed with the same asphalt but using different aggregate combinations. Figure 65 compares three of these. Limestone alone and a limestone-gravel mixture had approximately the same effect on the asphalt. However, the fused incinerator refuse resulted in the formation of 4-5% more LMS material. After 6 years there was no difference in performance relative to cracking. But, depending on the climate, that difference in LMS content could be enough to tip the balance to poor performance. This is an example of the effects different materials may have on an asphalt - effects that are probably not anticipated or seen by ordinary testing procedures.

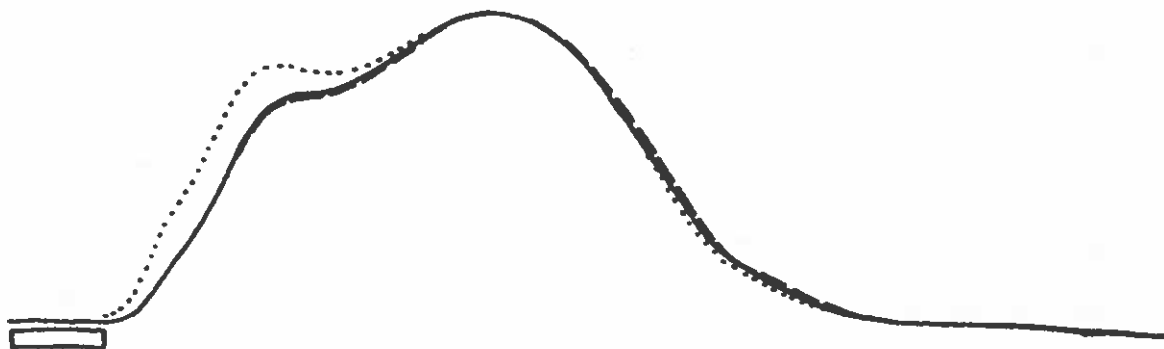


Figure 65. Pennsylvania - Aggregate Tests - PA-1

—	Asphalt "X" with limestone and gravel	(29.4-27.6)
- -	Asphalt "X" with limestone	(27.1-29.0)
.....	Asphalt "X" with fused incinerator refuse	(32.8-25.4)

Comparison of Asphalts

About six years before our sampling, Pennsylvania constructed a series of experimental sections in which the only variable was the source of the asphalt cements used. The original, untreated asphalt cements as well as cores from each test section were submitted. Pennsylvania has compiled a report (5) on this project. Some of that information will be included here in addition to data generated in this laboratory.

The performances of these test sections have varied widely. For example, sections T-1 and T-5, both constructed with asphalt from the same refinery, failed during the first winter, reportedly following a sharp drop in temperature. On the other hand, section T-3 was still performing well after six years. The other sections displayed intermediate performances.

A variety of information is available from these samples. First, they supply a rare opportunity to examine the original asphalts in comparison to corresponding established pavements. Just one set of chromatograms will be shown in Figure 66 which exemplifies the change in the MSD of an asphalt when it undergoes heating in the presence of aggregate. In all cases seen in this laboratory an increase in the size and/or amount of LMS material occurs. In the Pennsylvania samples, these changes amount to 2.3 to 4.3% more LMS material.

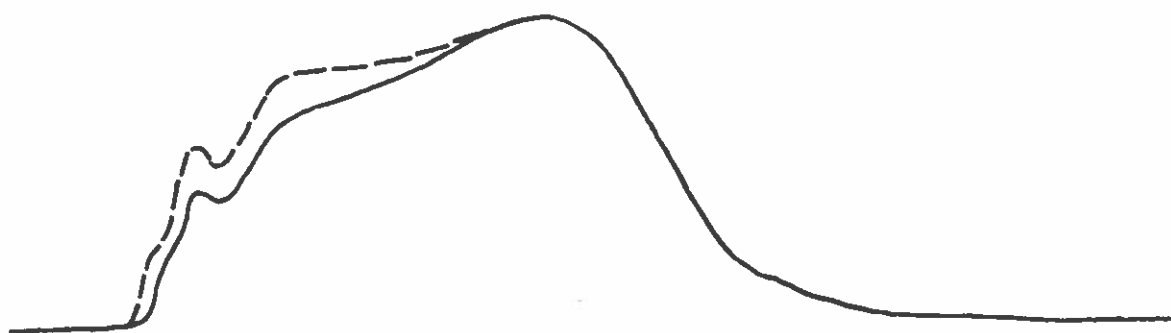


Figure 66.

———— Refinery VIII/AC-20 original for PA-5-T2
----- PA-5-T2

Figure 67 compares the original asphalt cements. Table 18 gives some data for these asphalts, which are listed in order of performance with the most successful, to date, first. Scanning this data, it can be seen that no single measurement or value could have been used to correctly predict the performances seen after six years. Unfortunately, this includes the HP-GPC data. Two samples bothered us: T-2 and T-1.

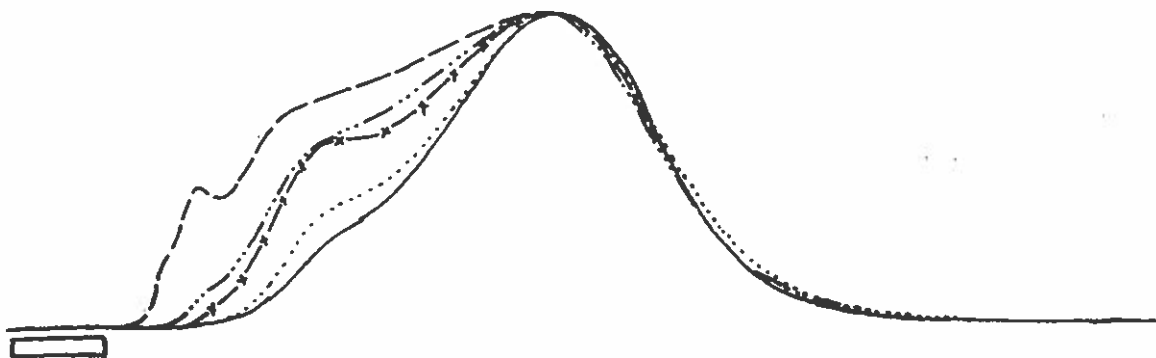


Figure 67. Pennsylvania - Tests Using AC-20 From Different Sources - Original Asphalts

- PA-38 Original for T-1
- - - PA-39 Original for T-2
- PA-40 Original for T-3
- . . . PA-41 Original for T-4
- x - PA-43 Original for T-6

Section T-2 was cracking, but, with an LMS content of about 39%, we would have expected it to have cracked more severely within six years. On the other hand, we would not have predicted that T-1 would crack, based on HP-GPC data alone, but it has cracked severely. Compared with performance-based data from New Jersey and Ohio, sections T-3, T-6 and T-4 are performing much as would have been predicted.

Asphalts similar to T-2 have given mixed performances in other states (Ohio and Illinois), depending on climate, but more especially on traffic loading. In fact, in the Pittsburgh area, similar materials have given poor to bad showings, after 8 years under an ADT of 27,000 and at 20 years with 20,000 vehicles each day. In the Cincinnati and South-central regions of Ohio, such asphalts have performed reasonably well in the short term under light traffic loads, but poorly under heavy traffic.

During the course of the study, we became aware of a few asphalts of very low LMS content which cracked, usually severely and at an early age. Such materials will be discussed further in Section II. F.

Table 18

Sec- tion	Perfor- mance	<u>SIMS</u>		<u>Pen 77°F</u>		<u>Vis 140° poises</u>		<u>Vis 275 Centistokes</u>		PVN	<u>DUC 60°F</u>		<u>DUCT 39.2° TFO</u>
		neat	core	neat	TFO	neat	TFO	neat	TFO		neat	TFO	
T-3	E	16.9	21.7	72	45	1874	3902	303	556	-0.61	150 ⁺	95.2	4.6
T-6	G	25.1	29.2	80	44	1982	5721	406	575	-0.45	150 ⁺	33.0	12.4
T-2	G	36.9	39.2	64	38	2284	6835	402	569	-0.70	29	7.0	3.5
T-4	P	26.7	30.6	65	38	1705	4694	355	527	-0.86	117	12.8	5.2
T-1	B	15.1	19.6	42	26	2710	5501	420	563	-1.04	150 ⁺	11.6	3.5

Crude Source

- T-1 - 49% Sahara, 21% W. Texas, 21% Montana, 9% Kansas - vacuum distillation and propane deasphalting
- T-2 - 66.4% Texas Mid-Continent, 33.3% Arabian, - steam distillation
- T-3 - 85% Lt. Arabian, 15% Bachaquero - vacuum distillation
- T-4 - 75% W. Texas Sour, 25% Texas and Louisiana sour - vacuum distillation
- T-6 - Blend of Heavy Venezuelan and Middle Eastern - vacuum distillation

Pittsburgh

Seven performance-based samples were selected in the Pittsburgh area. One particular project has caused a great deal of consternation. A pavement placed in 1976 failed during the first winter and was removed and replaced in 1980. Unfortunately, no samples of the failed pavement could be obtained. One other project was purported to be a "twin," however. That pavement, PA-18, was in bad condition after 6 years. Another, PA-16, was also reportedly the same, except that it was a year older. PA-16 was in poor condition after 7 years. Chromatograms for these asphalts are shown in Figure 68 along with those

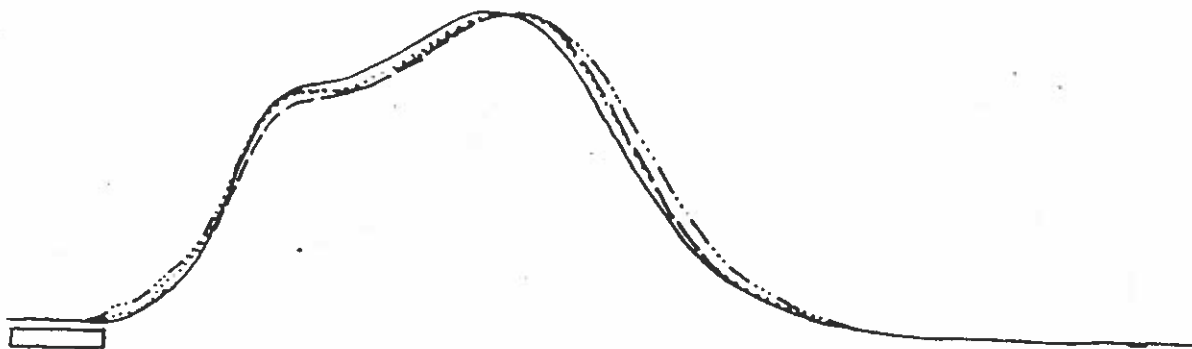


Figure 68. Established Roads, Pittsburgh Area

---	PA-18	6 years, bad, ADT-46, 715 (32.7-23.5)
--	PA-16a	7 years, poor, ADT-34,475 (29.6-25.9)
...	PA-16b	(lower lift) (32.9-24.8)
-·-	PA-14	11 years, good-ADT-26,110 (30.5-27.5)

for PA-14 which was in good condition after 11 years. Indeed these asphalts are similar. Based on area percentages, we would expect the lower lift of PA-16 to be at least partially responsible for the performance of that pavement; it also carried about 8,000 more vehicles each day than PH-14. PA-18 carried even more traffic and was on a reinforced concrete base, besides. That is, these asphalts might give moderately

good performance under the best conditions. However, we feel that better performance could be obtained from asphalts with smaller amounts of LMS material perhaps 26%. This is not to minimize the importance of good construction practices, of course. Neither does it diagnose the cause of the failure of the controversial pavement. But we believe that the asphalt is contributing to the lackluster performance of these pavements.

The chromatograms for three other Pittsburgh area pavements are included in Figure 69. Two of these (PA-17 and 13) have demonstrated poor to bad performance. The third (PA-15) was performing well after

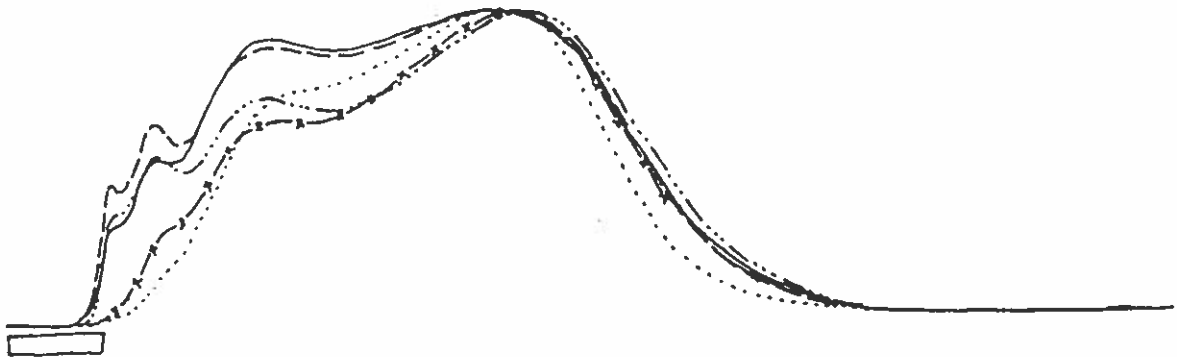


Figure 69. Established Roads, Pittsburgh Area

—	PA-17	8 years, poor, ADT-26,745	(39.4-22.5)
- - -	PA-13a	20 years, bad, ADT-19, 990	(41.0-21.4)
. . . .	PA-13b	(lower lift)	(32.3-21.0)
- . .	PA-15a	2 years, excellent ADT-31, 720	(34.8-26.5)
· -	PA-15b	(lower lift)	(29.7-26.7)

two years. However, based on the other examples as well as some in the Cincinnati area, it is not likely to give good, long-term performance. Unfortunately, this is the pavement constructed to replace the failed pavement discussed earlier.

Figure 70 contains the chromatograms of current production asphalt cements from Pennsylvania. The Trinidad natural asphalt is included for interest, since no performance data is available for this material.

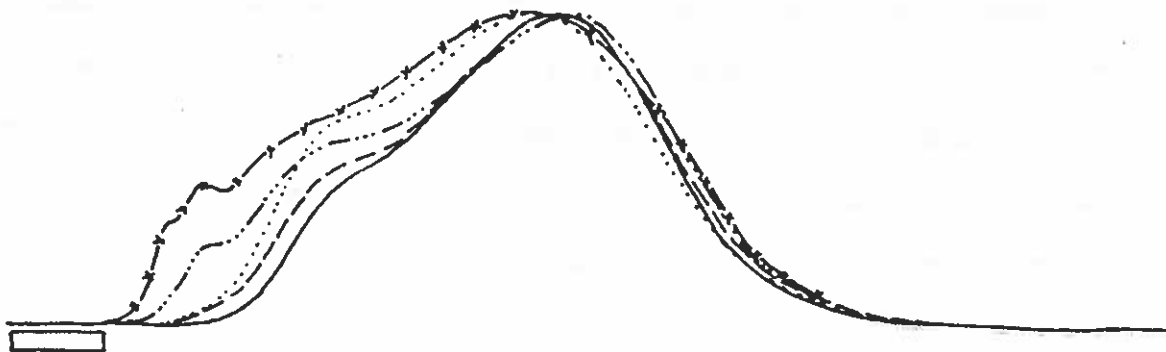


Figure 70. Pennsylvania - Current Production

—	PA-33	Refinery III/AC-20	(20.3-29.8)
— —	PA-30	Refinery IV/AC-20	(23.2-30.0)
... ..	PA-31	Refinery IX/AC-20	(28.2-25.4)
— ...	PA-32	Refinery VII/AC-20	(29.6-28.5)
— x —	PA-34	Trinidad Natural Asphalt	(34.9-25.4)

Having set tentative limits of 24% LMS in northern Pennsylvania and 26% for the Pittsburgh area, it would appear that PA-33 and PA-30 could meet those requirements. PA-32 is a likely precursor to materials such as PA 5-T2, which appear to give better performance under milder climate and lighter traffic conditions. Again, mixtures of materials might be considered to make best use of available supplies.

IID. 4. - New Jersey

Most of this state lies within region 3b as defined by Williams. The samples have been considered to have come from a single zone. Several asphalt types were found (examples are in Figure 71). Only one sample of type NJ-C was included. Most of the remainder were type NJ-B. Asphalts had come from at least seven refinery sources.

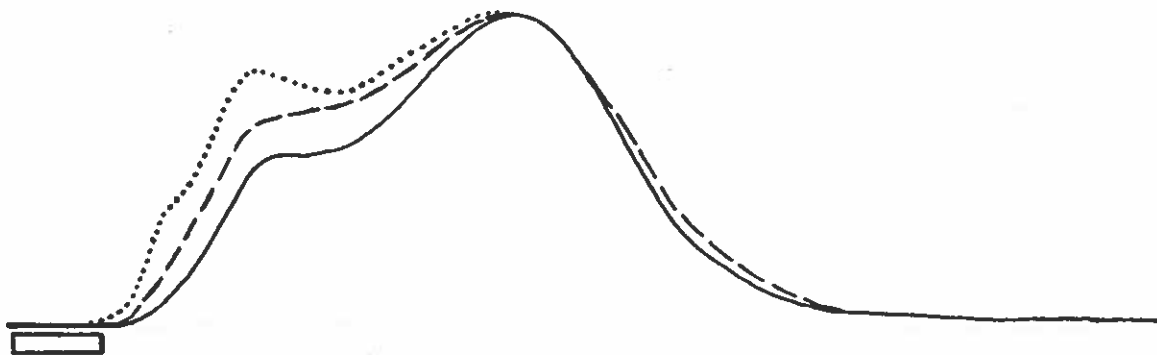


Figure 71. New Jersey - Asphalt Types

— Type NJ-A
-- Type NJ-B
..... Type NJ-C

Table 19 shows the relationship between the amount of LMS and performance. In general, excellent performance has been obtained from asphalts in the lower range of LMS percentages; mixed performance from those in the middle range; poor results with more LMS material. Some of these pavements are worth special comments. Numbers key to the table.

The pavement from which asphalt ¹ was extracted was 16 years old and in excellent condition. Furthermore, it carried about 125,000 vehicles each day, certainly one of the most heavily travelled roadways in the study. The asphalt with 28% LMS was found in a 15 year old, excellent pavement.

Table 19. Performance vs %LMS in New Jersey.

%LMS

48

46

44

2

40

38

bad

36

34

bad

cracking, excellent, bad

32

bad, cracking

bad², excellent

30

excellent

bad², excellent

28

excellent

excellent¹

26

24

22

20

18

At 30% LMS, one pavement was just 6 years old but performing well; the excellent pavement at 31% was 14 years old. The presence of poor performance in some pavements in the 29-31% range seems to indicate that these asphalts are less "forgiving". For example, pavements ² did not display classic transverse cracking but rather had extensive alligator and random cracking; although we believe that a "good" asphalt will resist stresses such as those from subgrade better than will a "bad" asphalt, these materials may not have been able to do so.

There were some asphalts with smaller LMS areas. Such asphalts were used in NJ-18 (Figure 72). After five years, this pavement was performing well in the newly constructed sections; in the section over PCC base, reflective cracking was evident. In another example (Figure 73), NJ-15 had cracked over underlying PCC joints within three months of construction. The asphalt had exhibited tender behavior during construction. There is no outstanding characteristic in the chromatograms that can be associated with the tenderness problem. In both pavements, there is a disparity between the upper and lower lifts in terms of MSD. The lower lifts contain asphalts in the LMS range in which cracking might be expected under all but the best conditions. The asphalt concrete in NJ-18 was 6" thick whereas that in NJ-15 was less than half that depth. Unfortunately, the long-term performance data from New Jersey on asphalts in the LMS range of 19-25% is not yet available.

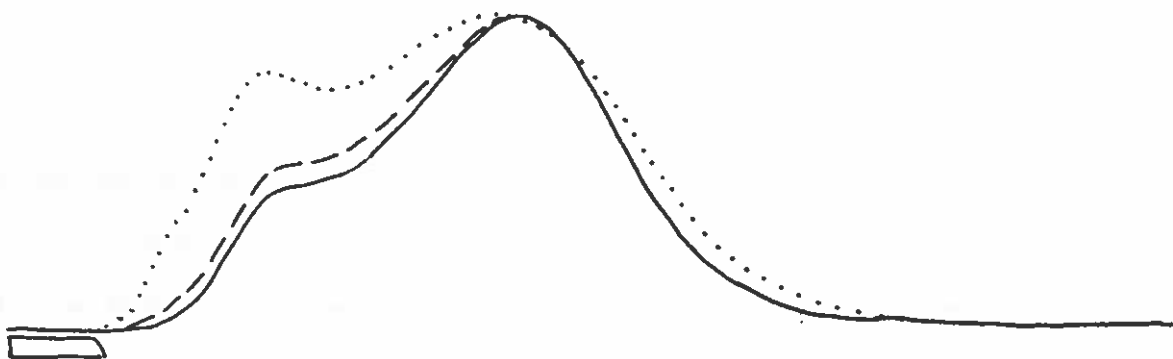


Figure 72. New Jersey - Performance of NJ-18

—	NJ-18a 5 years, excellent	(19.2-30.8)
- - -	NJ-18b	(21.8-28.5)
.....	NJ-18c	(30.8-27.2)

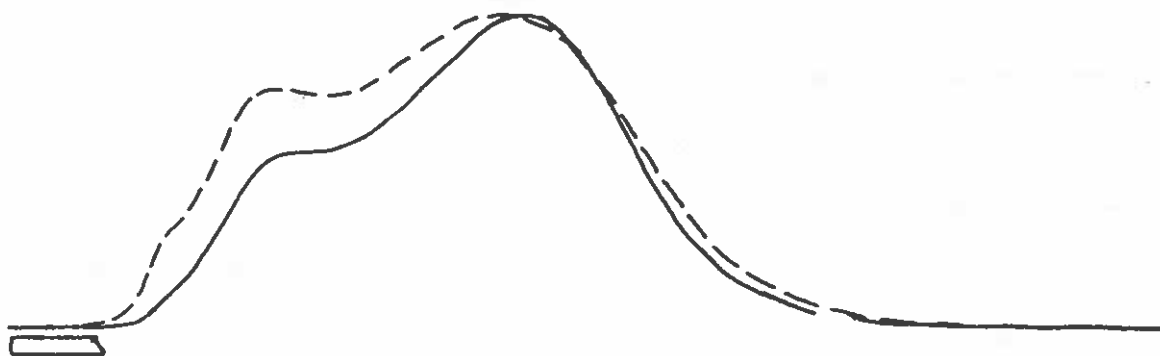


Figure 73. New Jersey - Performance of NJ-15

— NJ-15a (24.6-28.6)
 - - NJ-15b (31.7-26.1)

A series of samples was taken from sections of a four lane divided highway which, although constructed at the same time with supposedly, the same materials, were showing widely varying performance after nine years. Data for these are included in Table 20.

Table 20.

Sample	Refinery	%LMS		Performance
		top lift	bottom lift	
19A	NJ-I	32.6	33.0	excellent
19B	NJ-I	33.1	32.2	poor-random cracking
19C	NJ-II	37.4	36.0	bad, on fill, heavily cracked
19D	NJ-II	32.8	29.9	bad-a little better than 19C

The amount of LMS material in these sections puts them in the "likely to crack" category, so the performance is not surprising, except for 19A. The worst of the sections, 19C, had more LMS than the others (note that all are AC-20 grade). The fill construction may have contributed to the performance as well.

Current Production Asphalts

The asphalts supplied to us representing 1982 production were all AC-20's. They ranged in LMS content from 22.5 to 27.6%, that is, all were type A'or B (Figure 74). Unless these asphalts are unusually sensitive to aggregate and/or heat or other additives, they should yield pavements which are likely to perform well.

Based on the samples we have seen, the asphalts being supplied to the state contain less LMS material than those asphalts now in service.

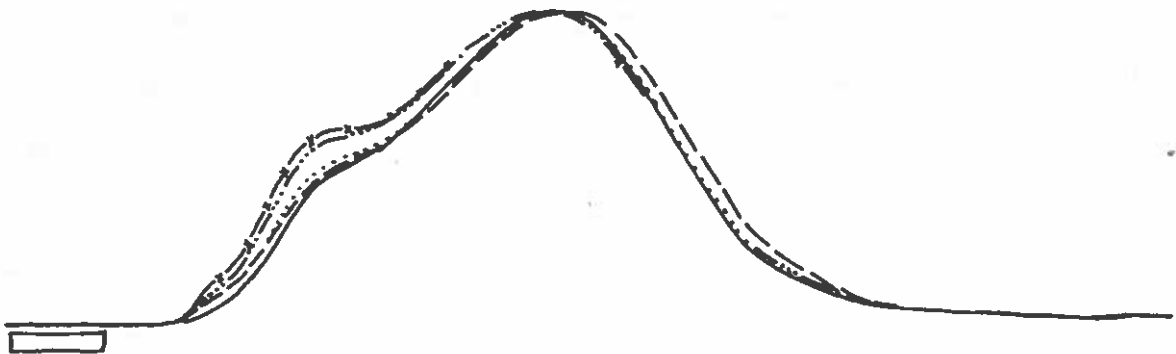


Figure 74. New Jersey - Current Production Asphalt Cements

——	NJ-27	Refinery I/AC-20, 1982	(22.5-30.7)
— —	NJ-28	Refinery II/AC-20, 1982	(23.0-33.0)
....	NJ-29	Refinery III/AC-20, 1982	(24.3-30.5)
— . .	NJ-30	Refinery IV/AC-20, 1982	(26.2-29.2)
— x —	NJ-31	Refinery V/AC-20, 1982	(27.6-28.0)

IID. 5. Summary of the Central & Eastern States

Illinois, Ohio, Pennsylvania and New Jersey are included in this geographical grouping. The climate is generally milder here than in more northern and western states. Pavements in Ohio were particularly complicated as discussed earlier. Most of the samples in Pennsylvania were from various test sections and were only 6 years old, or less, at time of sampling, so the excellent pavements are not perfect models. The same is true in Illinois.

Figure 75 shows the range of asphalt types used in these states. Not all of the types from this region are included. A summary of the performances obtained from these asphalts with respect to the percentage of LMS material is give in Table 21.

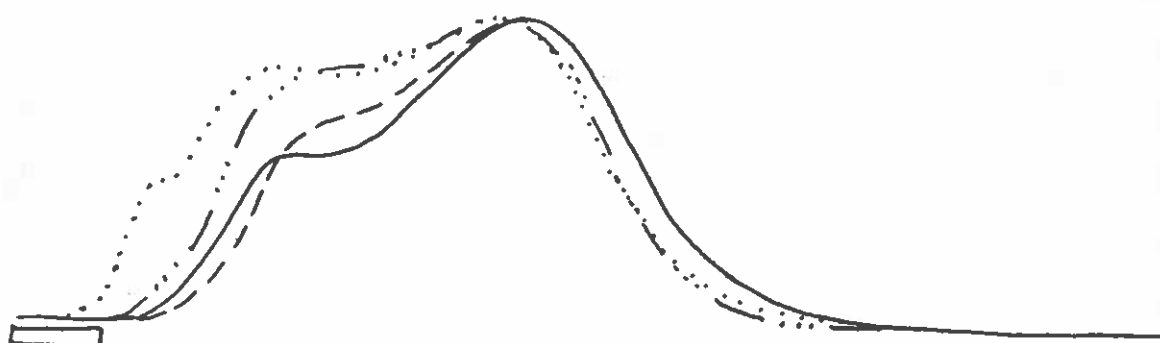


Figure 75. Asphalt Types in Central-Eastern States

- Type NJ-A
- - - Type IL-A
- ... Type IL-C
- . . Type IL-B

As expected, the LMS level at which cracking is seen drops as the climate becomes more harsh. The lack of positive models in many of these zones makes estimation of suggested MSD limits difficult. In New Jersey (column 1 of Table 21), it can be seen that excellent

Table 21. Summary of Performance, Central and Eastern States.

%LMS	3B			Zone 8		14				19	
	1	2c	3	4	5	6c	7	8	9c	10	11
48					B						
46			B								B
44						B					
42			Cr	E ^b				B		Cr,B	B
40			B		G	B	Cr,B		B		B ^d
38					G				G	Cr	E ^d B
36			Cr		B	Cr				E ^d	E ^a ,Cr
34	B		G								
32			Cr	E ^a				B			
30	B		E	E,B	B		B	B			
28	C,E,B	E ^a				B		B			B
26	C,B				B						B
24	B,E				E		G	B	B		
22	E					G					
20	B,E						B		Cr		B
18	E					Cr					B,Cr
16	E				E						
14									B		B,Cr
12									B		G ^e

1 - New Jersey

2 - Harrisburg^C

3 - Cincinnati

4 - South Illinois

5 - South Central Ohio

6 - Pittsburgh area

7 - North Central Ohio

8 - Northeast Ohio

9 - Northern Pennsylvania^a

10 - Central Illinois

11 - Northern Illinois

a - 6 years

b - 5 years

c - PA samples, 6 years or younger

d - 7 years

e - 19 years

performance can be obtained with asphalts with as much as 31% LMS. However, it appears that those at 29-31% are less "forgiving". Therefore, we would recommend use of asphalts with 28% LMS in New Jersey and similar areas and cautious use of materials with up to 31%.

In zone 8 the limit may be as high as 31% in the south central portion of Ohio, but appears to be lower in the high traffic region near Pittsburgh. In zone 14, the only positive model available is a 6 year old pavement in northern Pennsylvania with 22% LMS material. In zone 19, the only potential for a model is a 19 year old good pavement with 25% LMS.

There are a few young, excellent pavements scattered in the 35-42% LMS range. These are not considered to be excellent models first, because they are relatively young; second, because similar asphalts have been found in somewhat older pavements that were in bad condition; and third, because there appears to be a traffic dependence, ie., better results at lower traffic loads.

IIE. Alaska

Of all the states involved in this study, Alaska lays claim to the most severe climate. The interior of the state undergoes 5300 degree-days of freezing with temperature extremes of -70 to +100°F. Coastal areas are somewhat milder.

Traffic counts are not high, especially by "eastern lower 48" standards, but some portions of Alaskan roadways have been subjected to heavy loads (eg., in connection with the oil pipeline).

Alaskan construction practices call for relatively thin sections (1-3 inches in the samples received) with the goal being truly flexible pavements. Highway engineers have to contend with permafrost and a reported tendency for even dirt roads to exhibit "thermal-type" cracking. Indeed, with contributions from any or all of the possible factors, all Alaskan asphalt concrete pavements are cracked (except the newest) to a greater or lesser degree. This means, of course, that our desire to find ideal models (14-20 years old, with fewer than 15 cracks per mile) was thwarted.

Samples representing at least three refinery sources and 120-150, 200-300, AR-10, AR-20, RC-800 and AC-2.5 grades were submitted. Among these are four distinct types as shown in Figure 76.

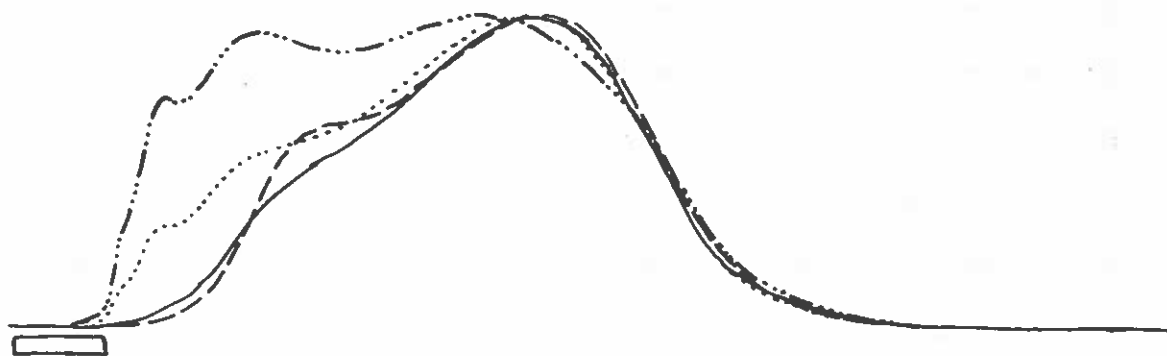


Figure 76. Alaska - Asphalt Types

— Type AK-A
 - - Type AK-B
 Type AK-C
 — . . . Type AK-D

Type AK-A asphalts appeared in 12 samples. All three refinery sources contributed; grades included AC-2.5, AR-10, AR-20 and RC-800 (some were not identified by grade). Percentages of LMS ranged from 16.1 to 22.5 (Figure 77), performances ranged from "good" at 27 years to "poor" at one year and "bad" at seven years. In fact, there were six examples of type A asphalts in roadways ranging from 25 to 29 years of age and all were still in the "good" category, ie., they exhibited some transverse

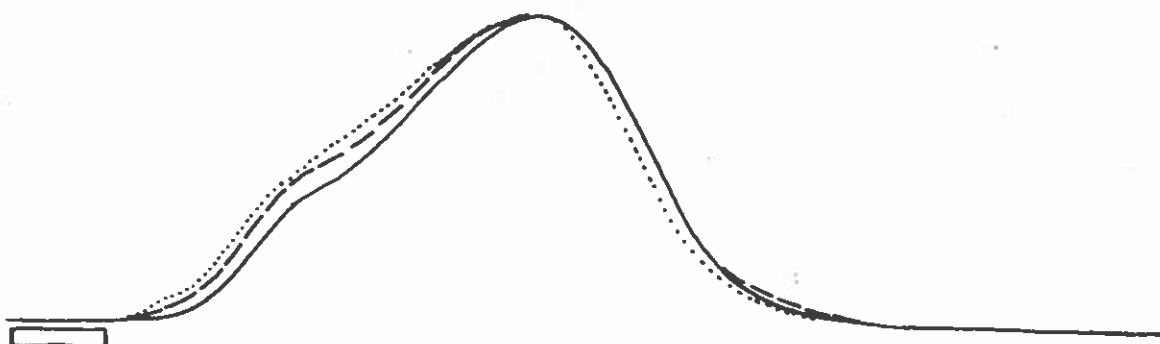


Figure 77. Type AK-A Asphalts

—	AK-27	1 year, poor	(16.1-35.1)
- -	AK-7	7 years, bad	(19.6-32.9)
. . . .	AK-15	25 years, "good"	(22.1-29.0)

cracking and little, if any map cracking. LMS content of this group was between 19.0% (for the best of these roads) to 22.5%. Grade and refinery sources of these are not known.

More recent roads of this asphalt type have not performed so consistently. Two sections were paved with an RC-800 of this type. After 16 years, one section showed alligator cracking over 100% of the surface whereas the other was in "fair" condition with some alligatoring and some transverse cracking. The LMS contents were 18.7 and 19.8%. The materials which made this a rapid-cure asphalt are not visible by this technique, if they remain in the mix to this point.

Two other sections of this asphalt type were seven years old at time of sampling and also exhibited different performances. The asphalt cements were from the same refinery but differed in grade (AR-10 vs. AR-20). As shown in Figure 78, the MSD differences were

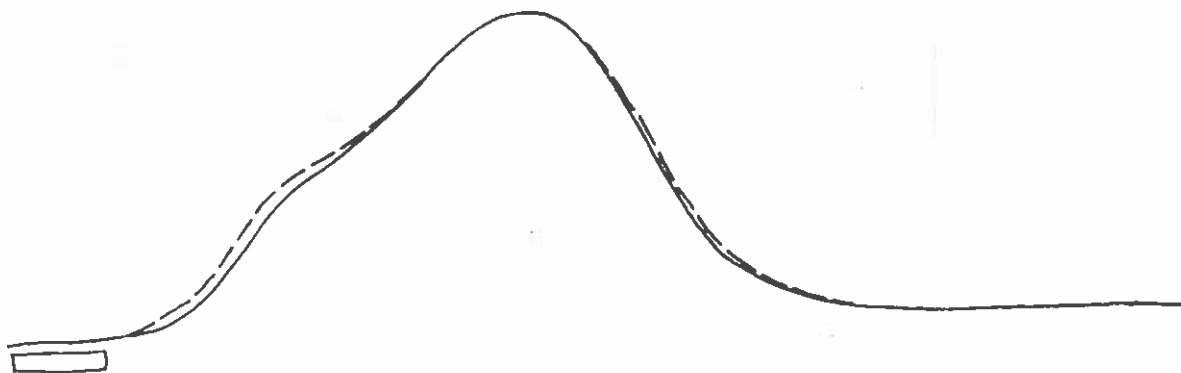


Figure 78. AR-10 and AR-20 Asphalts

- AK-7 7 years, bad, AR-20 (20.2-34.2) PVN = -2.5
- AK-24 7 years, good, AR-10 (21.7-34.3) PVN = -0.4

small. Data was available from which to calculate penetration - viscosity numbers (PVN) for these materials; these results were surprising. AK-7 (the "bad" road) had a PVN of -2.54, whereas AK-24 (the better performer) had a PVN of -0.44. Like AK-27, AK-18 was rapidly failing within a year. The PVN for AK-18, an AC-2.5, was -0.93. The LMS content for these asphalts were on the low end of the range. They apparently fall into the group represented by MN-31 (see Sections IIC. 3 and IIF.)

Alaska type "B" asphalts differ little in LMS content from type "A's", but the LMS region is more sharply defined in the chromatographic profile. Only two examples were submitted, both from the same refinery. AK-4 was constructed with an AR-10, had a PVN of -0.84 and was in bad condition after 7 years. The other section, AK-8, was constructed with 200-300 grade version of this asphalt and was in good condition after 10 years. It's PVN was -1.31.

Only one example of type AK-C asphalt was obtained. AK-20 is of uncertain age but in bad condition. LMS% was 29.5.

Type D asphalts were found in six Alaskan samples. The amount of LMS in these ranged from 35.6 to 41.1%. All were 11-12 years old and all were in poor to bad condition.

Based on the above statements, we feel that the best possibility Alaska has, using the asphalts previously available (no current production samples were submitted) is with type AK-A or -B asphalts. It appears that those with low LMS contents (17 - 18% or so) must be carefully watched, however, since the lower LMS% may result from smaller materials which adversely affect the chemistry of these asphalts. PVN's may give a clue to such potential (eg., AK-7, AK-18). However, AK-4 and

-10 show that PVN data does not always predict trends toward cracking. It also appears that AR- and RC- asphalts of type AK-A have not given very hopeful performance. Type C and D asphalts have also not performed well.

Extrapolating from data obtained from the harsher climates in other states in the study, it might be profitable for Alaska to experiment with low LMS asphalts like the Montana model or with SC- asphalts of the type found in ND-1, or with mixing asphalts of high and low LMS contents.

IIF. Exceptions

There are a relatively small but significant number of exceptions to the general pattern of the HP-GPC models. In a few cases, asphalts which would have been expected to contribute to cracking because of the large amount of LMS material, have instead performed very well. Reasons for such exceptional performance are not known but probably involve a perfect combination of design, construction, materials, climate and traffic. Nevertheless, the success rate with asphalts that contain more LMS material than the appropriate model is so small that these do not constitute a serious detriment to the HP-GPC concept.

More serious is the problem posed by asphalts with smaller amounts of LMS material which, rather than performing well, have cracked. These materials were recognized by the following characteristics:

The pavements constructed with them showed severe cracking very early, in some cases during the course of the first winter.

The asphalts met the states' contemporary specifications.

The amount of LMS was at or below the percentage that would have been recommended for asphalts in the particular climate zone.

The HP-GPC profiles are often smooth, that is, there is little if any definition of the LMS region such as has come to be expected.

Because these few asphalts apparently cannot be distinguished by HP-GPC in its' present configuration, some other means must be found to label them.

The reason for their behavior is certainly in their chemistry. They may contain materials which are not detected by either uv at 340 nm or refractive index. The differences in chemistry might be revealed by a test such as the Corbett separation. Perhaps these asphalts are

extremely temperature susceptible. In the short time available, these two factors were explored.

The Corbett analysis (ASTM D3279-81) separates asphalt into four fractions. The first, asphaltenes, is isolated by virtue of its insolubility in heptane. The other fractions, saturates, naphthene aromatics and polar aromatics, are eluted separately by solvents of increasing polarity from alumina.

The data from Corbett separations has not been extensively correlated with performance, to our knowledge. It was not our intention to establish such a correlation but rather to determine if the Corbett separation could reveal some unusual but consistent characteristic among these anomalous asphalts. Table 22 lists the amounts of each fraction determined in a few finished asphalts involved in this study along with notes about the performance of the corresponding pavement.

Table 22. Corbett Separations of Finished Asphalts.

Sample	Performance	% in Fraction			
		Asphaltenes	Polar Aromatics	Naphthene Aromatics	Saturates
MT-26-C	24/E	14.0	29.5	38.0	18.5
NJ-11	16/E	16.1	38.7	33.0	12.2
PA-T3	6/E	15.5	37.6	35.0	11.9
MN-31†	1/B	13.4	35.8	36.6	14.2
MT-T 15C†	1/B	11.9	35.9	35.3	16.9
type TX-A†	B	17.0	38.8	30.5	13.7
type WY-A†	B	12.1	34.2	31.2	22.5
PA-T1†	6/B	9.0	45.1	36.7	10.2

*age in years/condition E = excellent B = bad † anomalous, low LMS asphalt

The first three entries in this table are asphalts which have given excellent performance in Montana, New Jersey and Pennsylvania. The amounts of the various fractions in the NJ and PA samples are remarkably similar.

The last five entries are for asphalts which, although low in LMS content, have cracked. Type WY-A was reported to have been derived from a "waxy" crude. Indeed it does contain more saturates than any of the other asphalts. PA-T1 was also reported to contain a "waxy" crude among the four crudes blended in its manufacture. The amount of saturates does not reflect this; in fact, PA-T1 has fewer saturates than any of the asphalts tested. This material does contain significantly more polar aromatics than any of the other asphalts. This may constitute a solid clue in differentiating this particular asphalt. MN-31, MT-T15C, type WY-A and PA-T1 have less asphaltene content than the better performers, which may also be significant. However, the differences for MN-31, MT-T15C and type TX-A are not very large.

Some virgin asphalt cements were also subjected to Corbett analyses. Data for these are given in Table 23. The asphalts marked * have been used in test sections in Montana or Minnesota which have cracked severely within a year of construction. The remaining asphalt was used in a Montana test section which did not crack in that time. This asphalt is a precursor of the Montana model. Note that the amount of naphthene aromatics is significantly higher in the * asphalts than in MT-T01A.

Table 23. Corbett Analyses of Virgin Asphalt Cements.

Sample	% in Fraction			
	Asphalthene	Polar	Naphthene	Saturates
MN-61*	10.0	24.9	45.6	19.5
MT-T15A*	11.5	27.2	45.7	15.6
MT-T01A	17.7	28.5	33.5	20.3
MT-T06A*	12.5	28.7	45.6	13.1

These two sets of data constitute a limited sampling. However, the fact that there are significant differences between asphalts with known performance variations suggests that Corbett separations may be helpful in labeling at least some of the anomalous low-LMS asphalts. However, a considerable amount of further study would be required.

Type TX-C was also subjected to Corbett analysis. The results were: 1.9% asphaltenes; 29.5% polar aromatics; 2.3% naphthene aromatics; 66.3% saturates. This is certainly a very unusual asphalt for which more performance data and further testing is required.

It has been suggested that temperature susceptibility measurements are useful in predicting cracking tendencies. Data necessary for these calculations is very scanty for samples in this study. Data is available for PVN determinations for some Alaska pavements; these were discussed in Section IIE. Penetration viscosity numbers were available for the original asphalts used in the Pennsylvania test sections as well as in the Montana test sections. In Table 24, the examples of anomalous low-LMS asphalts are marked*. Those marked + have HP-GPC profiles that indicate that they should perform well in their respective climate zones. For these and the remaining samples, HP-GPC is a better

indicator of the observed performance than is PVN in our opinion. This very limited sampling can do no more than suggest that PVN may be helpful in tagging the anomalous low-LMS asphalts. More study is required.

Table 24. PVN vs. Performance.

Sample	Age/Performance	PVN
PA-1*	6 yrs/bad	-1.04
MT-T15A*	1 yr/bad	-0.93
PA-T4	6 yrs/poor	-0.86
MT-T06A	1 yr/cracking	-0.72
MT-T01A†	1 yr/excellent	-0.71
PA-T2	6 yrs/good	-0.70
PA-T3†	6 yrs/excellent	-0.61
PA-T6	6 yrs/good	0.45

III. Related Studies

In addition to the performance studies reported in Section II, three related areas were explored in connection with this project. The first of these involved a variety of asphalts which were being supplied to the states in 1982. This information not only gives some indication of the performance potential of those supplies (as was discussed in Section II), but also gives a broader view of the variety of materials available. Some ramifications from this wider perspective will be discussed in Section IIIA.

Section IIIB will contain a discussion of a series of test sections in Florida. These will give some information on the effect of mixing temperature and aging in service on the molecular size distribution of asphalts. This knowledge would be critical to the application of any HP-GPC model.

Recycling will be the subject of Section IIIC. The results, as shown by HP-GPC, of different approaches to the reuse of asphaltic pavements will be discussed.

IIIA. Current Production Asphalts in the Cooperating States.

Current production samples are untreated (virgin) asphalt cements, usually from the 1982 paving season. Most of the states involved in this effort submitted such samples. These new asphalts were discussed in each state's section on established pavements in terms of how they related to the older asphalts and how well they would conform to the models proposed. The fact that the amount of LMS material in an asphalt always increases upon contact with aggregate and heat in the mixing process was emphasized. (Some additives cause an additional increase in LMS content.

No known construction practices result in a decrease in this area.) It was noted that some current production asphalts have no known counterparts in service in a given state; also, some asphalt types seem no longer to be supplied.

In this section, these samples will be explored in more general terms with respect to refinery, grade, performance, etc.

There are several observations to be made about the products of any single refinery. The first is illustrated in Figure 79, ie., sometimes all the grades produced share the same MSD. In other cases, the products of a given refinery vary in such a way that the higher the viscosity grade (or lower the penetration grade), the more LMS material is seen in the asphalt. This is shown in Figure 80. In such cases, the performance - determining character of the asphalt is varying with the viscosity or penetration. One could indeed say of the asphalts in this figure that, if the model required no more than 26% LMS, the AC-20 would crack whereas the AC-10 would not (providing that care were exercised in the processing so as not to cause too great an increase in LMS content).

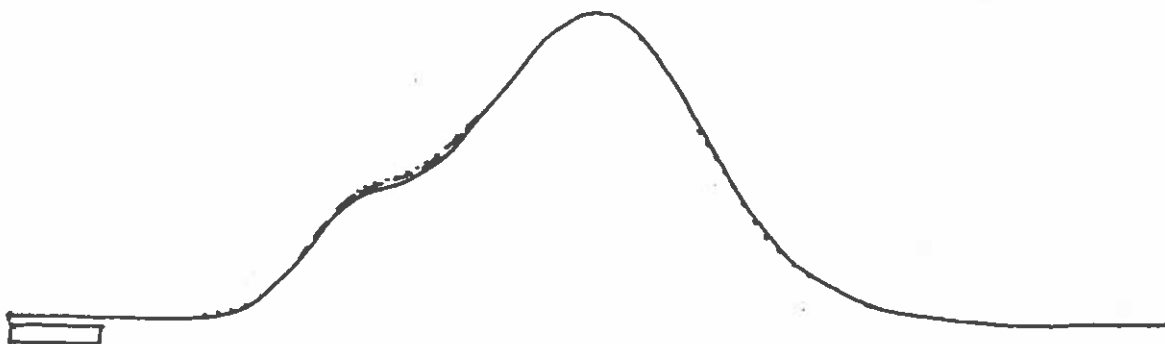


Figure 79. Similarity Among Products From a Refinery

AC-5
AC-10
AC-20

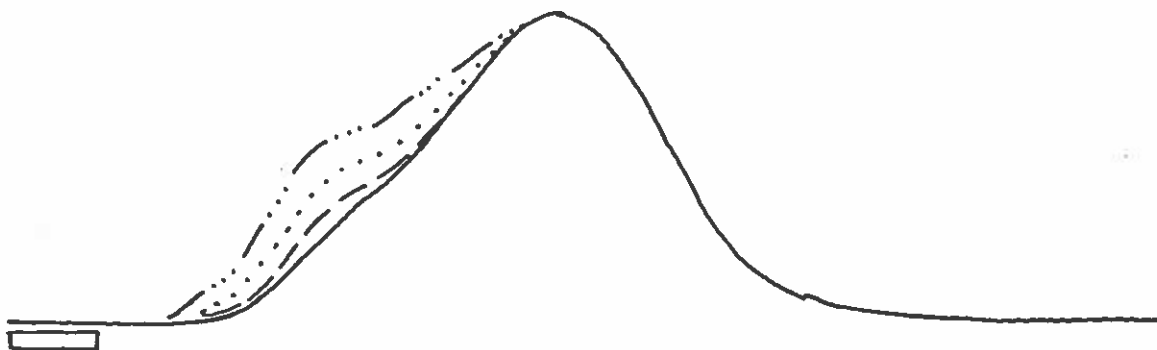


Figure 80. Variation Among Grades From A Refinery

— AC-2.5
 - - AC-5
 . . . AC-10
 - . . AC-20

In a few cases, the differences among grades from a single refinery is more nearly random, as shown in Figure 81. There the AC-2.5 and AC-10 differ by a small amount in the SMS region. The AC-5, on the other hand, appears to be unrelated to the others.



Figure 81. Variation Among Products

— AC-2.5
 - - AC-5, AC-20
 . . . AC-10

A few unusual appearing asphalts were submitted. These are represented by chromatograms in Figure 82. The SC-800 is reminiscent of the SC asphalts found in North Dakota (Section IIC. 1.). The remaining three asphalts shown are not SC types, however. They are penetration graded products from one refinery. Although the materials in the extra peaks or shoulders appear to be comparable, they probably are not.



Figure 82. Some "Unusual" Asphalts

——	SC-800
- - - -	85-100
- . - .	120-150
.....	200-300

Notice that the increase in penetration is related to very small increases in the amount of material in that shoulder. Very little of that material is required to make significant changes in the penetration of the basic asphalt. Were the amounts of this material that are indicated by the height of the extra peak in the SC-800 added to an asphalt, we believe that asphalt would be unworkable. Therefore, it is unlikely that the materials represented by the extra peak in the SC-800 are the same as those represented by the shoulders in the pen graded asphalts.

The appearance of such a shoulder in penetration or viscosity graded asphalts appears to be a relatively new phenomenon, because no examples were found in the performance related samples from around the country. Another possibility is that this is not a new phenomenon but rather that the materials in that peak which control the grade are too small to remain with the asphalt for long and so could not be found by HP-GPC after some years.

Sometimes a group of refineries produce products that are quite similar. More frequently, however, the opposite is true. In Figure 83 are drawn a few chromatograms of AC-20 grade asphalts from various refineries around the country. The amounts of LMS material in these examples range from 12.3 to 33.4%.



Figure 83. Examples of AC-20 Asphalt Cements From Various Refinery Sources.

(One might speculate that the gross differences among asphalts as shown in Figure 83 result largely from differences in crude source. More subtle differences, or lack of difference, such as are visible in Figures 80 and 79, result from variation in refinery processing. In the latter example, perhaps the difference in grade of the three asphalts results from small amounts of very light material. We know that as little as 1.5% of a light oil can raise the penetration grade of an asphalt from 120-150 to 200-300 [unpublished data]. This subject will be explored in a subsequent research effort. Considering all that has been shown in previous sections of this report about the relationship of the amount of LMS material to performance, it seems obvious that grade (viscosity or penetration) has little if anything to do with cracking performance. These grading systems do have much to do with workability, etc., and so cannot be abandoned or replaced. However, they must be supplemented if progress against the cracking problem is to be made.

III. B. Florida - Mixing Temperature and Aging.

The main contribution from Florida consisted of samples from three projects in which the effect of mixing temperature was to be studied. The pavements were constructed in different counties, using different aggregates and AC-20 asphalt cements. Sections in each project were mixed at different temperatures. The samples consisted of asphalts extracted from the sections after various amounts of time in service.

Table 25 gives LMS percentage data for some samples in FL-1, Polk County.

Table 25. Florida Temperature Studies, FL-1.

Age	%LMS at mixing temperature			
	310°	281°F	236°F	204°F
6 months	40.4	41.1	40.2	40.4
1 year	40.5		40.8	
2 years		42.5	41.6	40.5
5 years	42.0	42.0	42.0	41.7

The asphalt-aggregate combination used in this project did not respond to changes in mixing temperature in terms of HP-GPC data. A slight trend toward increased amounts of LMS material with time did occur, however. This amounted to less than 2% in 5 years.

In Table 26 are similar data for project FL-2 in Putnam County. In this asphalt, an initial difference of about 2% LMS between 240°F and 285°F

Table 26. Florida Temperature Studies, FL-2.

Age	%LMS at mixing temperature		
	285°	240°F	215°F
1 day	33.9	31.8	
1 month	33.9	33.2	34.2
6 months	35.6	35.8	
1 year	35.3	34.9	34.9

did not continue as the pavement aged. A slight increase in the concentration of LMS components was noted with time. Samples from FL-3, Jefferson County, tell a more dramatic story. Data in Table 27 show not only that more LMS material was formed as the mixing temperature was increased but also that the amount of LMS continued to increase significantly with time.

Table 27. Florida Temperature Studies, FL-3.

Age	% LMS at mixing temperature		
	317°F	284°F	243°F
1 day	29.8	28.4	27.6
1 month	29.7		
6 months	32.3	31.4	30.8
2 years	33.0		31.9
5 years	35.2	34.2	33.3

We have noted that certain asphalts as well as some asphalt-aggregate-additive combinations are more susceptible than others to LMS increases upon heating. This is a most dramatic example.

Results from some physical testing are given in a Florida report on these test sections. Some of the penetration data for the three asphalts when mixed at ~240°F are given in Table 28.

Table 28. Penetration Data for Samples Mixed at 240°F.

Project	Original pen	At construction	1 month	3 years
FL-1	90	77	78	36
FL-2	88	60	47	34
FL-3	81	72	45	26

The decrease in penetration for the FL-1 and -2 asphalts over 3 years was about 60%. A decrease of 68% for FL-3 perhaps reflects the reactivity of that asphalt.

Chromatograms for these three asphalts after mixing at 280-285°F and 6 months in service are shown in Figure 84. These are three quite

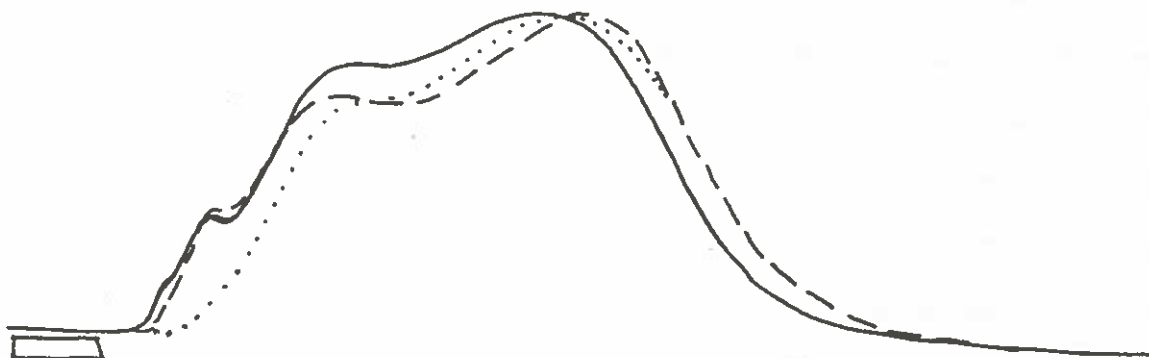


Figure 84. Florida Temperature Studies

—	FL-1C	281°F, 6 months	(41.1-20.1)
- - -	FL-2K	285°F, 6 months	(35.6-27.2)
.....	FL-3K	284°F, 6 months	(31.4-28.1)

different asphalts. These samples make several points clear:

- 1) asphalts differ in MSD within the same AC-grade;
- 2) some asphalts (or asphalt-aggregate combinations are more susceptible than others to increases in LMS percentage upon mixing;
- 3) some asphalts tend to continue to gain LMS material upon aging whereas others do not.

Current production asphalts from Florida were accompanied by samples from roads newly constructed with those asphalts. These samples provide another opportunity to observe the changes in MSD brought about by processing with aggregate. They also provide a comparison between more recent asphalts and those used to construct the test sections in 1977. Area percentage data for the new materials are given in Table 29.

Table 29. Current Production and New Roads.

Sample	%LMS	%MMS	%SMS
FL-4, Refiner I/AC-20	25.3	44.6	30.1
FL-5, Mixture using FL-4	29.2	42.4	28.4
FL-6, Refiner II/AC-20	23.9	43.9	32.2
FL-7, Mixture using FL-6	26.6	42.6	30.8
FL-8, Refiner II/AC-30	32.1	42.9	25.0
FL-9, Mixture using FL-8	34.5	41.4	24.1
FL-10, Refiner III/AC-30	25.5	44.6	29.9
FL-11, Mixture using FL-10	29.2	42.6	28.2

In all cases, the amount of LMS material increased at the expense of both MMS and SMS. This is the usual pattern.

The amount of increase varied from 2.4 to 3.9% - about 15% in terms of the LMS itself.

Figure 85 compares the chromatograms of these newer finished asphalts with those found in the test sections. Asphalts comparable to those in FL-1 and -2 were not included in the 1982 group. FL-9 is quite similar to FL-3 except that the former has more SMS material.

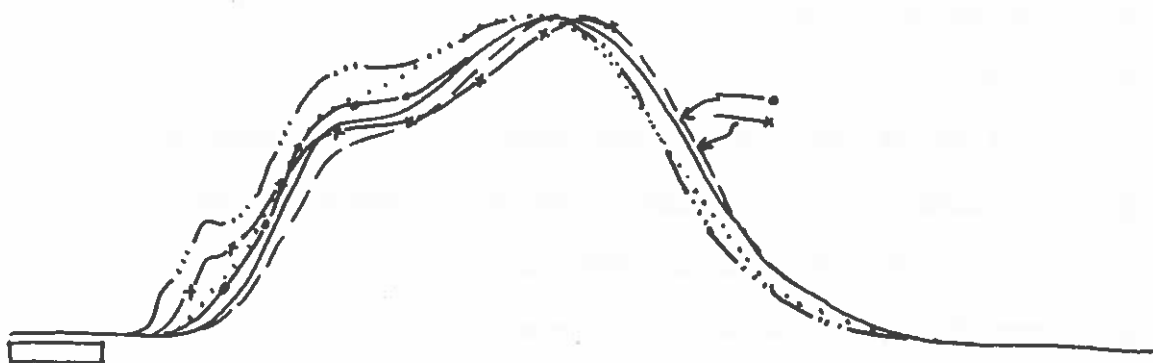


Figure 85. Comparison of New Finished Asphalts With 1977 Finished Asphalts

- FL-5 Refiner I/AC-20, 1982
- — FL-7; FL-11 Refiner II/AC-20; Refiner III/AC-30, 1982
- FL-9 Refiner II/AC-30, 1982
- ... FL-1 1977
- x— FL-2 1977
- FL-3 1977

IIIC. Recycling in Nine States

Many of the states involved in the Pooled-Fund study submitted samples from recycling projects. Samples of the salvaged material as well as virgin asphalt cement and/or recycling agent and a finished core were requested, along with a variety of other information. Supplying all of this was not possible in most cases. The story resulting from what was available, however, is interesting.

There is, of course, a great deal of discussion as to how to go about the design of recycled pavements. This arises from several factors, including:

- 1) a belief that the salvaged material may be damaged during the hot mix process in ways not duplicated in the design laboratory;
- 2) a concern that the new asphalt and/or recycling agent is not very thoroughly incorporated into the asphalt existing in the salvaged material.

In the data to follow, there is little evidence of serious damage to the asphalt in the salvaged material in terms of LMS content, except in one case.

We share the latter concern, however. Extracting the asphalt from the salvaged material and adding selected new materials may not be the best model even for hot recycling, let alone for cold processes, because the amount of mixing which actually occurs under construction conditions is not known. Until this problem can be solved, however, this part of the design process will remain.

Present design methods utilize the addition of virgin material/s until some target viscosity or penetration is reached. It has been repeatedly shown in this report, however, that these measurements

predict little, if anything, about the long-term performance of asphalts. They must not be abandoned, of course, because the characteristics they measure do contribute to the workability of the materials.

We have suggested an additional design parameter using the HP-GPC model for the climatic region involved. For example, if a high-LMS asphalt which has contributed to the cracking of a pavement is to be recycled, the amount of LMS should be reduced to conform to the model while maintaining (or restoring) the balance in the rest of the MSD. An increase in LMS might be attempted in a case in which a low-LMS asphalt is related to a rutted pavement. On the other hand, sometimes a pavement which is performing nicely must be recycled for realignment, or other reasons. In such cases, no change in the MSD is desired. These considerations will influence the selection of type and amount of virgin material to be used in the recycling process.

In the following section, the data will be discussed state-by-state.

Recycling - Illinois

Four sets of samples consisting of salvaged material, virgin asphalt cement and recycled core, were submitted. No commercial recycling agents were used. In Figure 86 is shown a set of chromatograms which are typical of these Illinois projects as well as others. In each, the chromatogram of the recycled material assumes a position between those of the salvaged and virgin materials. The MSD of the recycled material results from the MSD'S of the component materials and includes the effect of heating with aggregate on the virgin material as well as any effects on the salvaged asphalt.

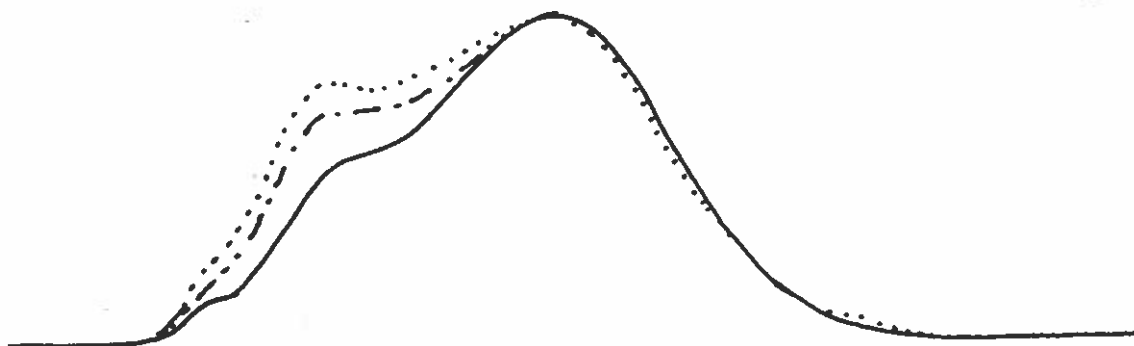


Figure 86. Recycling - Illinois IL-50,51,52

—	Virgin AC-5	(24.5-29.7)
.....	Salvaged Asphalt	(32.8-25.5)
-.-	Recycled Asphalt	(30.3-27.2)

Table 30 includes LMS and other data for the four recycling

Table 30. Illinois Recycling Data.

Sample set	%LMS salv.	%LMS virg.	%LMS recy.	LMS calc.	Ratio salv: virg.	Pen salv.	Pen recy.
50	32.8	24.5	30.3	28.4	30:70	26	22
60	27.5	18.6	25.5	23.3	35:65	21	32
70	29.4	--	25.8	--	30:70	19	35
80	29.3	24.0	28.9	27.3	30:70	26	25

projects. The calculated percent of LMS in the recycled mix is derived from the following equation:

$$(\% \text{ salv. asphalt} \times \% \text{ LMS}_{\text{salv.}}) + (\% \text{ virgin asphalt} \times \% \text{ LMS}_{\text{virg.}}) = 100 \times \% \text{ LMS}_{\text{recycled}}$$

assuming an increase in LMS of the virgin material of 2.5% on processing. (This amount could be determined more precisely by

conducting a laboratory simulation (3) with the virgin asphalt cement and the aggregate used. Time did not permit us to do that, however.) If the increase in LMS for the virgin material was no more than 2.5%, these figures indicate an increase in LMS for the salvaged asphalt of perhaps 1.6-2.2%.

Figure 87 compares the four salvaged materials; Figure 88 shows the four recycled asphalts. Notice that the salvaged materials had different MSD's but their penetrations differed by a maximum of 7 and were not correlatable with the MSD'S. However, in the recycled mixtures, the penetrations varied with the MSD so that the harder pen asphalts contained more LMS material. In terms of the model for Illinois, suggesting a maximum of 26% LMS, samples 62 and 72 fit within that range, but 52 and 82 contain too much LMS material.

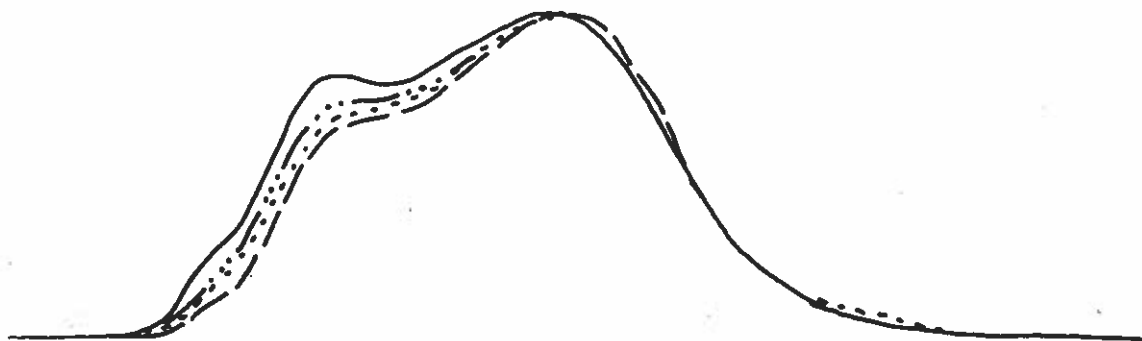


Figure 87. Salvaged Asphalts

—	IL-50	pen-26	(32.8-25.5)
- -	IL-60	pen-21	(27.5-27.8)
...	IL-70	pen-19	(29.4-27.7)
- . .	IL-80	pen-26	(29.3-27.3)

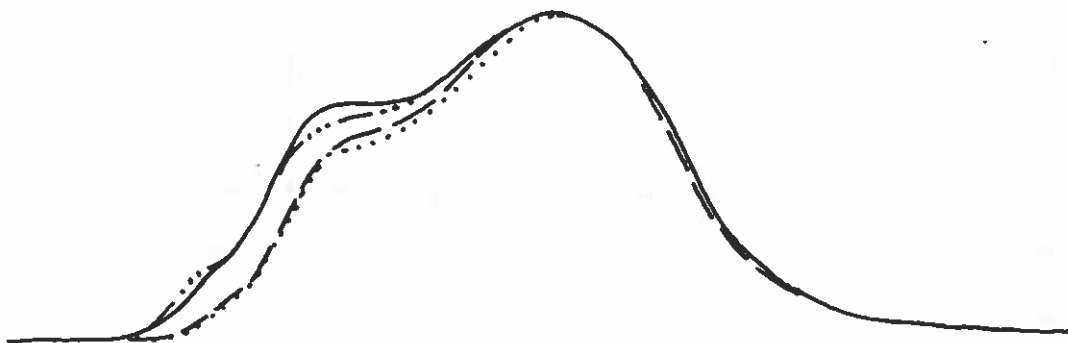


Figure 88. Recycled Asphalts From IL-50, 60, 70 & 80

——	IL-52	pen 22	(30.3-27.2)
— —	IL-62	pen 32	(25.5-28.4)
.....	IL-72	pen 35	(25.8-28.4)
— ...	IL-82	pen 25	(28.9-27.0)

Recycling - Georgia

Only one set of samples was submitted by Georgia. The chromatograms are compared in Figure 89. The LMS percentages are:

Salvaged - 34.3%

Virgin AC-5 - 32.8%

Recycled - 33.9%

These figures are of interest because so little change was effected. This fact is reassuring because it shows that no large increase in LMS amount was caused by reprocessing the salvaged material. If that had happened in this case, one might have expected to see the recycled mix exceed the salvaged material in the LMS region.

The situation seen with this sample would be ideal if the pavement to be recycled had actually been performing well but had to be sacrificed for rerouting, etc. However, had the salvaged material come from a cracked pavement, one might expect no change in the performance of the finished product. In this case, performance had been good and, considering the suggested limits of the Georgia model at 35% LMS, should continue to in the same fashion.

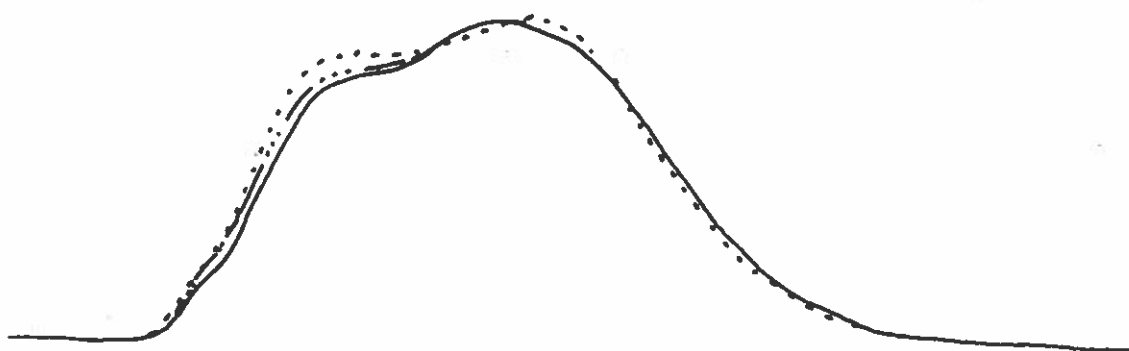


Figure 89. Recycling - Georgia

—	Virgin AC-5	(32.8-25.9)
.....	Salvaged Asphalt	(34.3-25.5)
- . .	Recycled Asphalt	(33.9-25.7)

Recycling - New Jersey

New Jersey submitted one set of samples which are unique among those seen in this study. As shown in Table 31, the virgin asphalt actually contained more LMS material than did the salvaged asphalt. In

Table 31. New Jersey Recycling.

Sample	%LMS
Salvaged	24.4
Virgin AC	28.1
Recycled	29.0

effect, the salvaged material negated the increase in LMS amount due to processing of the virgin asphalt cement. The data given in the table is for standard recycling at 310°F. Unfortunately, the temperature of the mix plant soared to 475°F at one point. The resulting asphalt contained 35.4% LMS, a clear warning that asphalt can be severely damaged if temperatures are too high. The chromatograms for the four materials are compared in Figure 90. The excessive amount of LMS in the "burned" asphalt is clear.

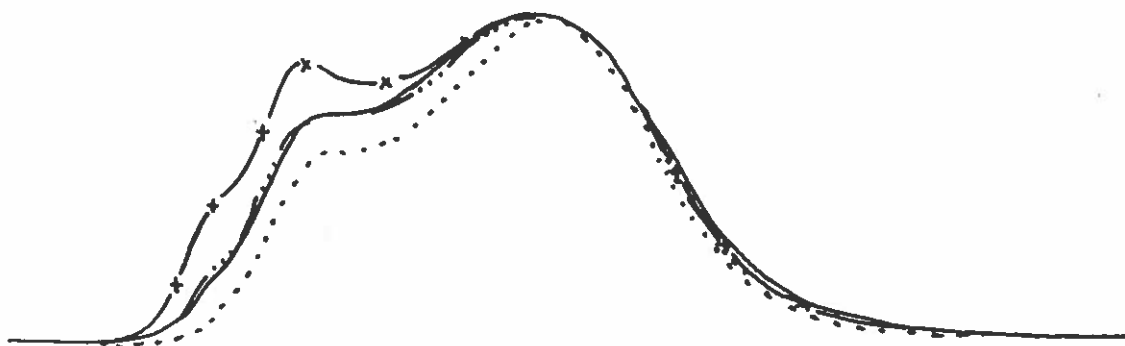


Figure 90. Recycling - New Jersey

—	NJ-26	Virgin Asphalt	(28.1-27.6)
....	NJ-25	Salvaged Asphalt	(24.4-27.8)
—	NJ-24	Recycled, ST'D Temp-310° F	(29.0-26.6)
—x—	NJ-23	Recycled, 475° F	(35.4-23.6)

Recycling - Utah

The samples sent from Utah contain an example of the use of a commercial recycling agent. Figure 91 shows the chromatograms of all components of the system. Note that the recycling agent consists almost entirely of SMS materials. Note also that the recycled mixture shows an increase in that region over both the salvaged and virgin asphalts. Area percentage data in Table 32 show that the anticipated amount of LMS material appears in the recycled mix. The amount of LMS is somewhat skewed by the additional small material.

Table 32.

Sample	%LMS	%SMS	%LMS calc.
Salvaged	27.2	32.7	—
Virgin AC-5	20.1	35.8	—
Recycling agent	0.0	98.2	—
Recycled mix (50:50 + hydrated lime)	24.7	36.3	24.9

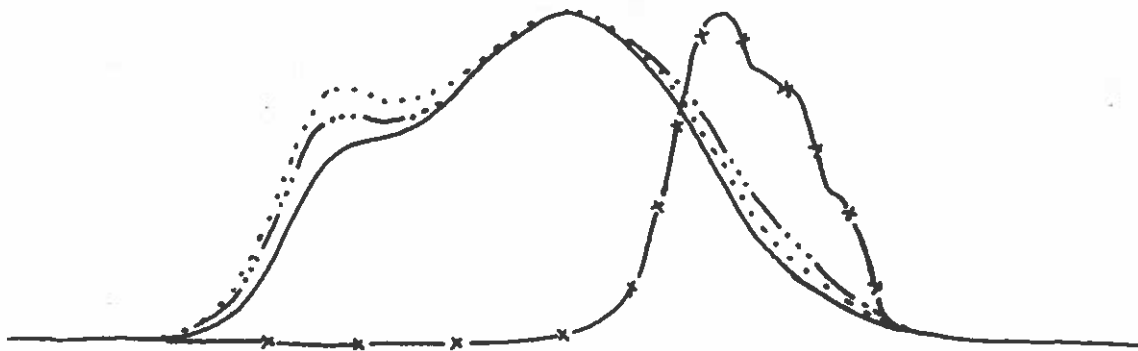


Figure 91. Recycling - Utah

—	UT-43	Virgin AC-5	(20.1-35.8)
.....	UT-45	Salvaged Asphalt	(27.2-32.7)
- - -	UT-42	Recycling Agent	(0-98.2)
- . . .	UT-47	Recycled Asphalt	(23.8-36.8)

Penetration and viscosity data are of interest. Penetration (77°) of 57 in the salvaged material was increased to 171 in the recycled mixture. Viscosity at 140°F decreased from 3823 poises to 533; viscosity at 275°F changed from 341 to 180 centistokes; ductility at 39.2°F increased from 6 cm to 123 + cm. However, the amount of LMS in the finished mix exceeds the proposed model for Utah despite the improvement in physical characteristics.

Recycling - Texas

Texas placed a series of sections in the recycling project submitted for study. The pavement had shown severe alligator cracking in the driving lane, but the performance of the passing lane was good. Therefore, the driving lane was recycled. The upper 1.5 inches were recycled and placed on the shoulder. The next 3.5 inches were recycled and returned to the driving lane as base course and subsequently received an overlay of new asphalt concrete.

A commercial recycling agent was used in the first mile of base construction (TX-8) but was discontinued when technical problems could not be solved. In the remainder of the project, differing proportions of salvaged:virgin material were used. This information along with area percentage data, is included in Table 33.

Table 33. Texas Recycling

Sample	Ratio salv:virgin	%LMS	%LMS calc.*
12b Salvaged	100	38.2	--
8b With Recycling Agent	70:30	31.2	--
9b	70:30	33.3	32.1
10b	60:40	30.7	30.1
11b	50:50	28.9	28.1

*based on amount of LMS material in finished virgin overlay (18.0%) for contribution by virgin asphalt cement.

This data indicates that no untoward increase in LMS occurred in the salvaged material upon recycling because the actual amount of LMS found is very close to that calculated by the equation given earlier.

The chromatograms of salvaged and recycled materials (Figure 93) show a significant reduction in LMS in the course of the project. The 70:30 recycled product with recycling agent shows that agent clearly on the right side of the chromatogram. One other point worth stating is that these two asphalts from the Lubbock district are very different in terms of HP-GPC data, Corbett analysis data and in performance. Nevertheless, no difficulty was experienced in mixing the two materials. It is unfortunate that the performance of the recycled mix will not be

directly observed (except in the shoulders) but, rather, will only be reflected in the surface course through an asphalt concrete with performance characteristics of its own.

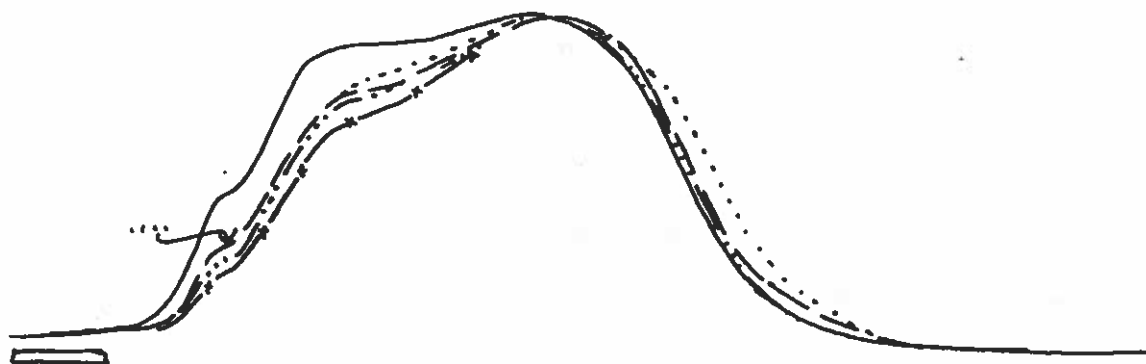


Figure 92. Recycling - Texas

——	TX-12 Salvaged Asphalt	(40.2-19.8)
— —	TX-9b Recycled - 70:30	(33.3-24.0)
....	TX-8b Recycled - 70:30 + R.A.	(31.2-27.0)
- . - .	TX-10b Recycled - 60:40	(30.7-25.0)
-x-	TX-11b Recycled - 50:50	(28.9-26.2)

Recycling - Florida

Florida submitted a series of samples in which the same salvaged material was treated with four different recycling agents. These agents are not like most other commercial recycling agents in that the latter are usually composed mainly of SMS-type materials, whereas the Florida agents are really low viscosity asphalts (Figure 94). They were "made to order" by two refineries at the state's request.

Figure 93 shows that these are distinctly different materials in terms of both HP-GPC characteristics and viscosity. Data in Table 34 shows no correlation between amount of LMS components and viscosity, however. Also shown is the fact that only recycling agent 18 (210 vis)



Figure 93. Recycling - Florida

————	FL-12	Recycling Agent, vis 904 (25.7-31.6)
- - - -	FL-14	Recycling Agent, vis 814 (25.1-28.9)
.....	FL-16	Recycling Agent, vis 256 (17.6-38.0)
- . . .	FL-18	Recycling Agent, vis 210 (28.6-28.6)

Table 34.

Sample	Refinery	vis.	#LMS	%LMS, recycled product
FL-20 - salvaged		--	37.7	--
18	FL-I	210	28.6	37.1
16	FL-II	256	17.6	31.5
14	FL-I	814	25.1	33.7
12	FL-II	906	25.7	34.5

failed to have a significant impact on the MSD of the recycled product. Figure 94 displays the chromatograms of the four recycled mixes and shows in another way the outcome of recycling. In general, the amount of material on the left of the chromatogram has been decreased and the amount on the right increased. If a model for Florida about 35 %LMS is assumed, these asphalts should perform nicely.

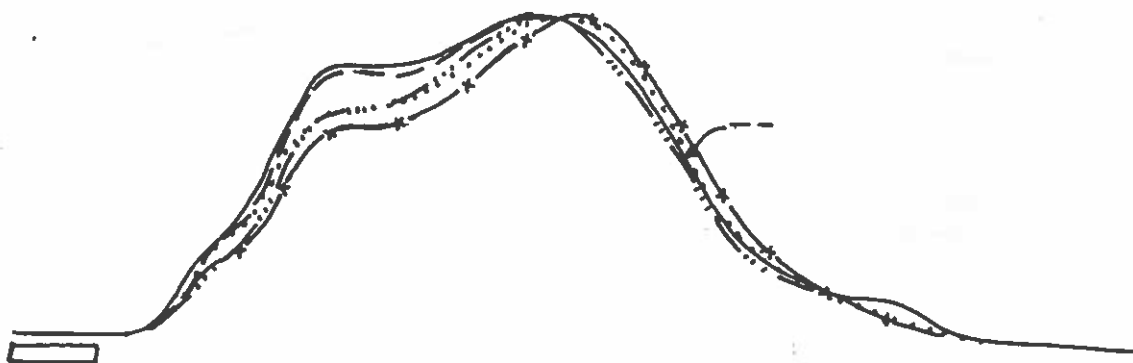


Figure 94. Recycling - Florida

- Salvaged Asphalt (SA)
- FL-19 (Mixture of SA with FL-18)
- x— FL-17 (Mixture of SA with FL-16)
- ... FL-15 (Mixture of SA with FL-14)
- FL-13 (Mixture of SA with FL-12)

Recycling - Colorado

Recycling samples from Colorado were limited to three cores from finished projects, the chromatograms of which are compared in Figure 95. These products are, obviously, distinctly different, although the designs all targeted an AC-10 grade asphalt. None was recycled because of obvious asphalt-related problems, but rather because of base failure or widening-realignment work. Based on our estimate of a model for this region with no more than 24% LMS, both CO-29 and CO-32 should be expected to crack. A LMS percentage of only 16.3 in CO-30 led us to expect rutting. Indeed, we now know that this project has rutted significantly.

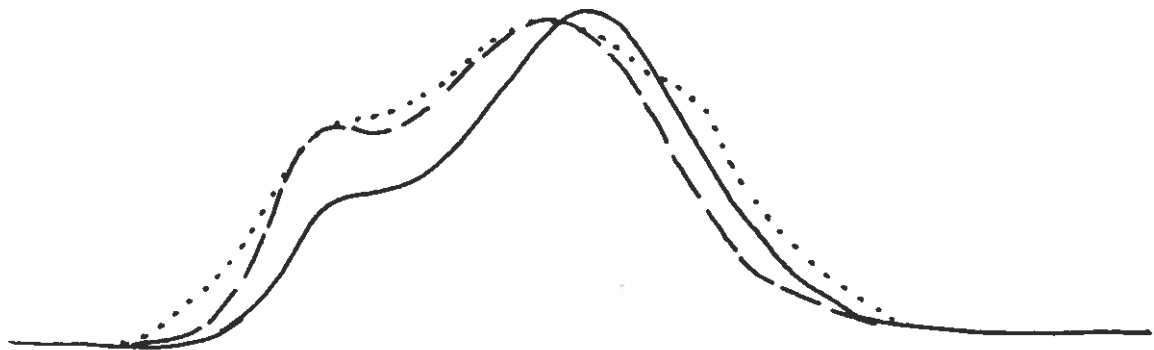


Figure 95. Recycling - Colorado

—	CO-30	(16.4-42.4)
- - -	CO-29	(25.3-31.5)
.....	CO-32	(25.8-36.2)

Recycling - Minnesota

Only cores from recycled pavements, no salvaged or virgin materials, were available from Minnesota. The recycled mixes, used in base and binder courses, vary only slightly, as shown in Figure 96; the new surface courses are very nearly the same. That is, all asphalts, recycled as well as virgin, are of the same asphalt type. Unfortunately, the LMS content of most of these asphalts is higher than required for excellent performance in Minnesota.

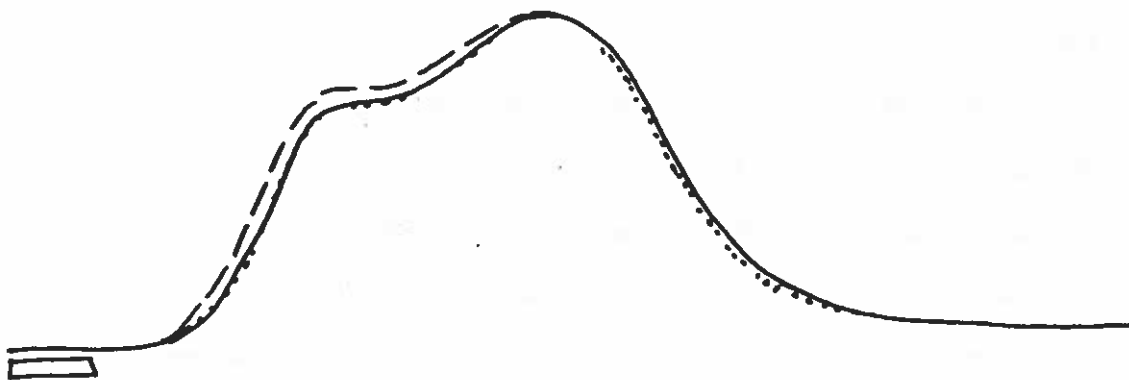


Figure 96. Recycling - Minnesota

——	MN-36 Recycled binder	(33.9-25.7)
---	MN-36 Recycled base	(35.3-25.3)
.....	MN-35 Recycled base	(34.6-24.4)

Recycling - Wyoming

Wyoming has recycled pavements which had become severely rutted. In some cases, stripping has been associated with the rutting; therefore, hydrated lime has been sometimes used in the recycling process in an attempt to eliminate stripping.

In one case both driving and passing lanes were constructed using asphalt with 24.2% LMS in the base course. The surface lift contained 18.7% LMS. The passing lane was in excellent condition after 10 years; however, the driving lane was a candidate for recycling. Recycling this surface material produced an asphalt with 20.4% LMS. This should resist cracking. However, the base of these cores showed signs of stripping, so the rutting problems may recur.

In another recycling project, hydrated lime was used in one portion. The amount of LMS was 27.2%. In the other portion without lime, asphalt contained just 24.4% LMS. (The amount of LMS in the salvaged pavement is uncertain.) Nevertheless, the addition of lime has increased the amount of large material above that likely to give crack-resistant performance in that region of Wyoming. The tendency of the two sections to rut will become evident in the future.

Still another recycled pavement was constructed with asphalt containing 26.5% LMS, an amount we would expect to contribute to cracking. Indeed the pavement had cracked: more severely where constructed over CTB, less so over plant mix base.

Recycling - Summary

The recycling projects submitted by the states show a variety of approaches. The use of HP-GPC demonstrates the nature of the materials involved. It shows that, under normal conditions, little increase in amount of LMS occurs in the salvaged material during reprocessing. Furthermore, it shows that the MSD of the recycled mix is a composite of the distributions of the components, when the normal increase in the LMS content of the virgin material on processing is considered. A combination of this simple relationship and the laboratory simulation procedure (3) can be used to aid in the design of recycled mixes.

IV. Refinement of Methods

A. "Ultra-styragel" Columns

Late in the period of the third study, Waters, Inc., from whom the HP-GPC columns had been obtained, introduced a new type of gel permeation column called "Ultra-styragel". These were intended to be more efficient and to give better separations than the " -Styragel" columns used previously. Therefore, these columns were investigated early in this study.

It was found that the "Ultra-styragel" columns did indeed enhance the analysis of asphalt by improving the differentiation of the LMS region, in particular. Furthermore, a smaller bank of columns (three versus six " -styragel") gave excellent results. Therefore, even though the new columns are more expensive, individually, the cost of a bank is considerably lower than the old type.

Because the "Ultra-styragel" columns are more delicate than the older type, some additional precautions have been taken with the analysis.

(See Analytical Procedure in Appendix A.) For example, each sample is

centrifuged before being injected onto the columns. Lower flow rates and smaller sample loads have also been instigated.

It is important to state at this point that, although changes have been made to the system to improve the quality of the data obtained, the nature of the data has not been changed. The trends, especially with regard to the LMS region, remain the same as in earlier work.

B. Effects of Water

It has been assumed that some of the material comprising the LMS region results from the association of smaller molecules. The associative forces could be those of hydrogen bonding or of the van der Waals type. Tetrahydrofuran (THF), which is used as the solvent for all laboratory procedures and as the mobile phase for HP-GPC, is fairly polar and presumably disrupts many, if not all, of the polar associations. The addition of water was used as a probe to get some idea of the extent of polar associations remaining in the THF-solubilized asphalt. These experiments would also indicate the extent to which the LMS percentage could be affected by variations in the water content of commercial THF.

Experiments indicated that indeed, the addition of water to either the mobile phase or the sample resulted in an apparent decrease in the amount of LMS material in the asphalt. However, the presence of water also contributes to changes in the packing material of the columns such that the size of the pores, which determines retention time, is affected. As a consequence, it is not possible to differentiate between the effect of water in dissociating polar bonds and the effect due to swelling of the packing material. Nevertheless, water is seen to have a

considerable effect on the apparent molecular size distribution of asphalt. In order to eliminate this effect, measures have been taken to control the amount of water in THF. These are described in appendix B.

C. Effects of Dilution

As stated in section IVB., some of the material in the LMS region may result from the associations of smaller molecules held together by hydrogen bonding or by van der Waals forces. Therefore, dilution of the sample might also have an effect on the amount of LMS material detected.

In a set of experiments, the concentration of asphalt in the injected samples was varied. The resulting data for one asphalt is plotted in Figure 97. Other asphalts react in similar fashion.

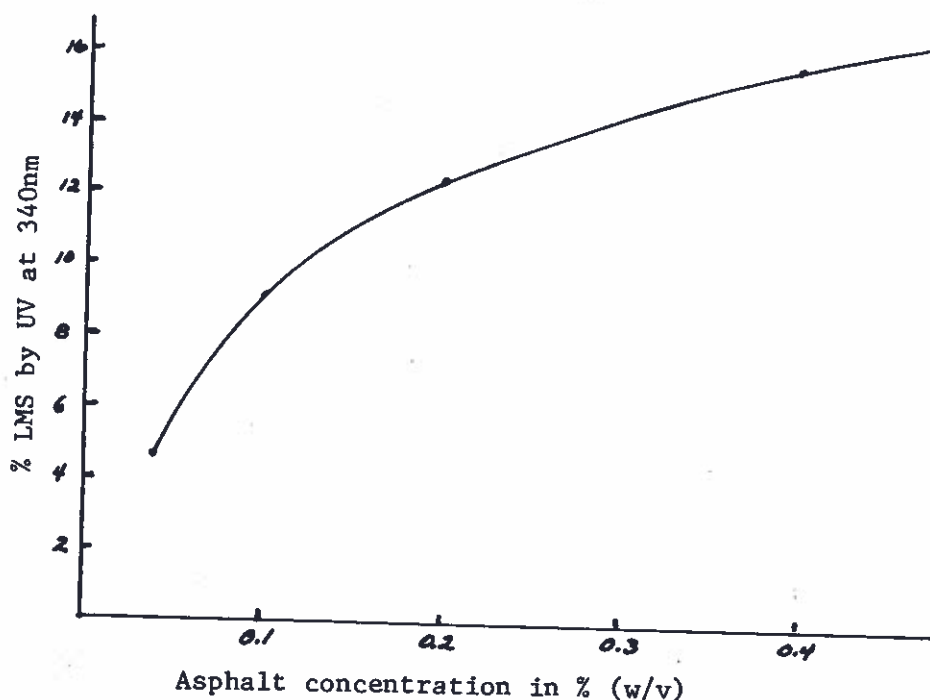


Figure 97. Effect of Asphalt Concentration on Amount of LMS by HP-GPC.

Because so much of this work is based on the amount of LMS material, it is advantageous to maximize this area. Two factors limit the practical concentrations of asphalt, however. First is column capacity: it is possible to overload the columns so that no worthwhile information can be obtained. Second, the increments of increase in apparent amount of LMS become smaller as concentration increases. A sample concentration of 0.5% w/v was selected as optimum for the analytical system used here.

D. Internal Standards and Flow Rate Control

During earlier work, one or two internal standards were added to each sample (3). They appeared as peaks on the far left and far right of each chromatogram. The standards were added to aid in monitoring the stability of the HP-GPC system, specifically, flow rate. They also aided in the comparison of chromatograms.

For this project, elimination of these standards was desired in order to avoid possible interference with the extremes of asphalts that were expected. This required some means of monitoring the actual flow of mobile phase through the HP-GPC instrument beyond the control offered by the pumps themselves. (Change in flow rate can alter the initial elution time as well as the overall elution time of a sample, thus affecting both visual and mathematical comparisons.) This was obtained easily by the addition of a digital flow meter as the last piece of equipment in the HP-GPC system. This was connected to a strip-chart recorder so that a permanent record of flow rate was available. The technicians also monitored the digital readout during the analysis as a check on system performance.

The digital flow meter was very important in a project of this size and complexity. However, the use of carefully chosen internal standards is an adequate means of monitoring flow rate.

E. Detection Sytem

In the interests of gleaning as much information as possible from the samples obtained, an ultraviolet (uv) detector was used in addition to the refractive index detector used in earlier work. The uv detector at 340 nm responds to molecules which are aromatic (eg. polynuclear aromatics) or which contain conjugated double bonds. The refractive index detector responds to molecules which change the refractive index of the mobile phase. As a result, the two detectors give different information (Figure 98). Fortunately both comparison of uv chromatograms and of RI chromatograms lead to the same conclusions.

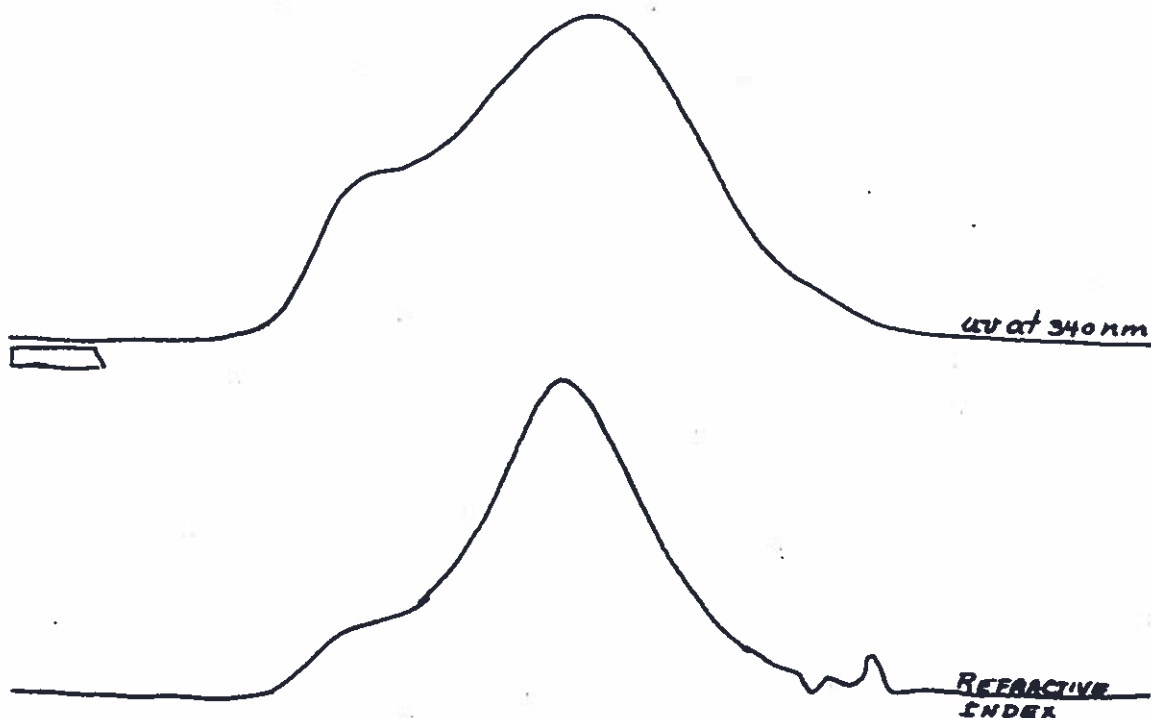


Figure 98. Comparison of Data by UV at 340 nm with that by Refractive Index for an Asphalt.

The uv detector has some advantages over the RI detector. Primarily, it is not so sensitive to fluctuations in temperature. Therefore, baselines are flat and consistent. RI baselines are subject to drift and must be closely monitored. Furthermore, the uv "sees" more material in the crucial LMS region. Also, water is not detected by uv at 340 nm, so interference by the small amounts of water that may be present in some samples is eliminated. For these reasons the data is somewhat more dependable and easier to interpret. Therefore, most of the chromatograms and numerical data used in this report have been derived from the uv detector at 340 nm.

Unfortunately, neither detection system is useful in monitoring rather small, simple hydrocarbons which may exist among the SMS materials. Small amounts of such materials may have a large effect on the penetration or viscosity of an asphalt, but cannot be detected by HP-GPC as set up here. Gas chromatography might be useful. However, the flash-point tests and losses seen in the TFOT and RTFOT can help to detect the presence of these light-end materials.

F. Computerized Data Handling

For this project a computer system capable of accepting and storing to disk data from two detectors on each of two HP-GPC instruments was obtained. This system greatly facilitated the storage and retrieval of raw chromatograms as well as the manipulation of data to yield area percentages. In fact, the system was indispensable for a project of this size.

However, the authors wish to stress that, for smaller operations, a computer system is not required. A simple strip chart recorder or recording integrator would be quite adequate for the analysis of just a few samples a day. The chromatographic profiles are most important for

interpretation of the data and visual comparisons should not be abandoned in favor of reliance on area percentage data alone. Because the areas are expressed as percentages of the whole, the amount of LMS material might be skewed by the presence of large amounts of SMS, for example. But visual comparison with another asphalt, eg., a model, would reveal the nature of the LMS region.

The computer system and software will be described in Appendix C.

V. Appendix

A. Analytical Method

Two high performance (or pressure) gel permeation chromatography instruments (Waters Associates) were used during this study. These instruments were identical except for injectors. They consisted of a solvent reservoir; a high pressure pump (Waters model M6000A); an injector (Waters U6K or Rheodyne 7125 with a 100 μ l sample loop); three "Ultrastyrigel" columns, (Waters), one 10^3Å followed by two 500 Å units; a refractometer (Waters, model R401); and a two-channel absorbance detector at 340 nm, (Waters, model 440) which was shared, one channel for each instrument. The solvent reservoir was isolated from the atmosphere by a drying tube and fitted with a tube through which helium was slowly bubbled into the solvent to remove dissolved gases.

A flow meter (Phase Separations, Inc., FLOCOB1) with an analog output was used to monitor and record the actual flow through the instruments.

Temperature of the mobile phase, columns and detectors was controlled at 26°C by means of a system of tubing and a constant temperature bath.

Tetrahydrofuran (THF, Fisher) was checked for water content (see Appendix B) and filtered through a 0.45 μ silver membrane filter (Selas) before use.

Using asphalt prepared according to the procedure in Appendix E or virgin asphalt as received, samples were prepared for injection. A small amount of asphalt (0.02 - 0.05g) was accurately weighed into a 5 dram glass vial. THF (drawn from the solvent reservoir) was added by means of a buret to prepare a 0.5% (w/v) solution. The solution was

transferred to a 5ml centrifuge tube and centrifuged in a bench-top centrifuge for 10 minutes. These steps were taken just before the sample was to be injected.

The instrument was operated in accordance with manufacturers instructions. Sample injection size was 100 ul. Flow rate was set at 0.9 ml/min.

Data was collected, stored and manipulated via a Perkin-Elmer Data system which is described in Appendix C.

Technical Notes

"Ultrastyrigel" columns are somewhat delicate; manufacturer's instructions with regard to instrument start-up, flow rates, etc. were assiduously followed to avoid damage.

Columns were cleaned weekly (after processing 30-40 samples) by injecting 2-3 ml pyridine into the system followed by continued flushing with THF.

Time required for the system to reach equilibrium was decreased and other problems, which seem to be associated with shut-down of the system over weekends or for longer periods, were minimized by maintaining slow flow of solvent through the system. When all asphalt or pyridine had cleared the system, a closed loop was set up by returning the effluent to the solvent reservoir, and a flow rate of 0.1 ml/min was maintained.

Solvents must be "degassed" to avoid troublesome bubbles in the system. This was easily accomplished with a helium purge.

Performance of the system was monitored in several ways. In addition to observing the actual flow rate and pressure, the condition of the columns was checked by periodically running a series of monodisperse polystyrene standards using the uv detector at 254 nm. In one system as configured here these standards had the following retention times:

MW	RT
2.4×10^5	16.45 min
5.0×10^4	17.38
9.0×10^3	20.38
4.0×10^3	22.85
2.9×10^3	23.77
toluene	34.68

These retention times will vary somewhat depending on the individual columns, the precise flow rate, the amount of dead volume in the system and possibly other factors. Nevertheless, when the RT's are determined when the system is set up and monitored periodically, the condition of the system can be determined. Peak broadening indicates column deterioration. Calculation of the number of theoretical plates for each column and for the bank of columns (according to manufacturer's instructions) can serve a similar purpose.

For our purposes daily analysis of a standard asphalt was the key means of monitoring the system. We expected the chromatograms of this asphalt to correspond very closely from day-to-day, and the percentage of LMS to vary no more than $\pm 0.5\%$.

V. B. Control of Water

All THF used in the HP-GPC system was monitored for water content. Solvent containing less than 0.05% water was considered acceptable. An infra-red detector (Wilkes-Miran 1A-CUF) set at a transmittance of 2.95-2.96 μ was used for this determination; transmittance of 0.5 or more indicated acceptable water content. (Each detector must be individually calibrated. Therefore, these limits cannot be used universally.)

THF which contained excessive amounts of water was dried by refluxing the THF (4 l) with sodium (10 g) and benzophenone (30 g) until the solution became deep blue in color. The THF was then distilled through a spinning band unit (B/R Instrument Corp).

The THF in the solvent reservoir was protected from atmospheric moisture as described in Appendix A.

V. C. Computer System

A Perkin-Elmer 3600 Data Station consisting of computer, two interface modules, two disk drives (5 $\frac{1}{4}$ ", double sided, double density) and a printer-plotter (Model 660) was used for the collection, storage and manipulation of the HP-GPC data. Analog data from the uv and RI detectors was fed into a chromatography interface module for temporary storage (one analysis capacity) then transferred to the 3600 computer for storage on disk.

Software used in collection and storage of data was Perkin-Elmer "Chromatographics 2 Software", 0330-0859 Revision C 5/5/83, 1982. Further manipulation (plotting, integration, etc.) was done with Perkin-Elmer "Gel Permeation Chromatography Data Processing" (GPC-5), 0254-0389, Revision B, 1983.

V. APPENDIX D. SAMPLING CRITERIA AND DOCUMENTATION



DEPARTMENT OF CHEMISTRY

COLLEGE OF LETTERS & SCIENCE

MONTANA STATE UNIVERSITY, BOZEMAN 59717



This letter is a follow-up to our recent telephone conversation regarding the Montana Pooled Fund study. We are looking forward to our association with you on this research.

Our immediate goals are to select projects for sampling in your state and to arrange a schedule for our visit with you.

Established Pavements

As I'm sure you know, our study is primarily concerned with cracking in asphaltic pavements. Therefore, we would like to have samples from established pavements of various ages and qualities so that we can determine the characteristics of asphalts that have performed well or poorly for you.

As outlined in the proposal (a copy of which is enclosed) four major variables will be used to define the samples to be selected:

- 1) the original penetration or viscosity grade;
- 2) the age of the pavement;
- 3) the extent of cracking now in evidence;
- 4) the refinery source of the asphalt cement.

Every effort must be made to eliminate from consideration roads in which cracking failure has occurred because of some other factor, such as the obvious failure of subgrade, base course or other loss of profile. On the other hand, asphalt pavements which have not cracked in spite of stresses such as profile loss, are definitely of interest. In other words, we are searching for successes or failures which are attributable to the bituminous plant mix itself. Performance should be evaluated over the whole project rather than at isolated sites.

At this time, it is most important to locate benchmark samples, that is, those roadways which began to crack at the youngest age and those which have performed without cracking for the longest period. (For example, in Montana, our best roads are more than 20 years old and are, essentially, crack-free; but some of our newer roads began to crack within a year or two.) We are also interested in old, badly cracked pavements. Sets of good and bad roads should be selected within small geographical regions so that the effects of such variables as climatic conditions and aggregate types may be minimized.

For our purposes, we have defined pavement conditions as follows:

Excellent - transverse and/or alligator cracks virtually absent (eg., fewer than 15 transverse cracks per mile).

Good - transverse cracks no more frequent than 75 feet apart with no alligator cracking.

Poor - transverse cracks 25-75 feet apart and/or alligator cracking over less than 30% of the surface.

Bad - numerous transverse cracks less than 25 feet apart and/or alligator cracking over more than 30% of the surface.

These definitions will be modified by the age of the pavement.

Each of your major refinery sources should be represented. If you have asphalts from a single refiner that have given different performance characteristics, these are of interest. Each of the penetration or viscosity grades commonly used in your state should also be represented.

Sampling sites should be selected from the Interstate system, if possible, or from heavily-travelled primary roadways (not city streets, however). Some of your test sections may be valuable.

If your state is divided by climatic extremes, look for sampling sites under each of these extremes.

When we visit your state, we want to tour these sampling sites and other nearby roads so that we can better understand your methods, problems and successes. At that time, we will photograph the roadways, mark exact sampling positions and evaluate the condition of the pavement.

After our visit, samples should be submitted as soon as possible in the form of cores taken through the full depth of the pavement. One core should be removed from the right wheel path of the driving lane at the marked sampling site. Each core should be tagged for identification with some mutually-agreeable code (arranged during visit).

A variety of additional information will be requested on a form which we will supply later (a preliminary list is in the proposal). We will appreciate receiving as much of this additional data as you have available.

If the original asphalt cement is available for any of these projects, a small sample (a few grams) would be very useful to us. Such samples are best handled by filling a container to the top and sealing.

To summarize the above notes on selecting samples from established pavements:

Climate zone . . . (as required)

Refinery I

Refinery II . . . (as required)

pen or vis grade A

pen or vis grade B . . . (as required)

Established roads, in same general area

- _____ excellent, 14 or more years old
- _____ bad, 10-20 years old
- _____ poor/bad, <5 years old
- _____ original asphalt cements from above roads, if available

Current Asphalt Supplies

Samples of the asphalt cements currently being supplied to your state should also be submitted. Those refinery sources which supplied asphalt for samples collected for the established roadways should be included. Additional refiners may be selected at your discretion. Samples should, however, be limited to pen or vis grades commonly used in your state. Again, only small amounts are required.

Recycling

Another phase of our study involves recycling. We would like to have samples of:

- _____ salvaged pavement (1 pound is sufficient)
- _____ virgin asphalt (small amount)
- _____ recycling agent, if used
- _____ recycled pavement (1 core)

for each of three projects in your state. A form requesting additional information for recycling projects will be supplied as well.

Expanded Montana Asphalt Quality Study Using High Pressure Liquid Chromatography

SAMPLE DOCUMENTATION

Established Roadway Cores

Sample ID

State abbreviation number

Location: Route # Mile post Lane

Photo number:

Present condition: excellent good poor bad

Type of cracking: transverse distance apart

 "alligator"

 other (describe)

Rutting? approximate depth

Other problems:

Average daily traffic:

Unusual circumstances or observations, performance history (dates cracking noted, etc.)

Top Lift Bottom

Construction date

Refinery Source

Pen Grade or Vis. grade

Original pen (77°F)

-PLEASE COMPLETE OTHER SIDE-

Top Lift Bottom

Original absolute vis. (140°F)

Original Kinematic vis. (275°F)

Ductility ____°F

Additives or fillers - % by weight of agg.

% Asphalt in original mix

Petrographic analysis of agg.

Max. size of aggregate

Percent voids (at construction)

Density

Prime or tack coats - kind ____

Seal coats - kind ____ date ____

Mixing plant type

Temp at plant

Remarks:

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SAMPLE DOCUMENTATION

Recycling Projects

Sample ID

Project location

Route #

Mile Posts

Reason for recycling (rutted, cracked, etc.)

Average daily traffic

Unusual circumstances or observations

Please supply applicable and available information:

	Salvaged Pavement	Recycling Agent	Virgin Asphalt	Recycled Core
Construction date		_____	_____	
Refinery source				_____
Brand name	_____		_____	_____
Pen or vis grade		_____		_____
Pen. (77°F)	before recycling	_____		after recycling

-PLEASE COMPLETE OTHER SIDE-

	Salvaged Pavement	Recycling Agent	Virgin Asphalt	Recycled Core
Absolute vis. (140°F)	before recycling			after recycling
Kinematic vis. (275°F)	before recycling			after recycling
Ductility ____°F		_____		
Additives or fillers - % by wt of _____		_____	_____	
Virgin agg. - % by wt of _____	_____	_____	_____	
Percent voids		_____	_____	
Density		_____	_____	
Prime or tack coats - kind _____ date _____		_____	_____	
Seal coats - kind _____ date _____		_____	_____	
Mixing type		_____	_____	
Remarks:				

Expanded Montana Asphalt Quality Study Using High Pressure Liquid Chromatography

SAMPLE DOCUMENTATION

Current Refinery Production

Sample ID

_____ -
State abbreviation

number

Refinery source

Pen or Vis. grade

Actual pen (77°F)

Absolute vis (140°F)

Kinematic vis (275°F)

Ductility _____°F

V. E. Sample Preparation

Pavement samples were supplied in the form of cores, usually 4 inches in diameter, although a few 8 inch and 2½ inch cores were received. These had been removed from the right wheelpath of the designated lane and station or milepost.

Each core was logged in and checked against information supplied by the state. Each was visually inspected for such characteristics as excessive large air voids, obvious stripping, general aggregate type and size etc. The demarcation between successive lifts or layers of construction in the core were marked. These were usually clearly visible. In cases where lift lines were not obvious but depth of the pavement seemed too large to have been placed in a single lift (more than 4-5 inches), an arbitrary division was made in an attempt to avoid the possibility of "hybridizing" two asphalts of different character.

The cores were halved vertically by means of a water-cooled saw with a diamond grit blade. One half of each core was wrapped in heavy plastic and placed in reserve. The top-most ¼ to ½ inch of the remaining portion was discarded to avoid interference by roadway contaminants. Chip seals and thin surface treatments were not sampled. Material from the interfaces between lifts was avoided.

The lifts were separated on the saw and treated individually. Each sample was lightly crushed. Up to 300 grams of the material were placed in a Teflon beaker and covered with 300-500 ml THF. This mixture was subjected to ultrasonification for 40 minutes (using Bronwill "Biosonik" apparatus). The mixture was filtered by suction through a glass fibre filter (Whatman GF1A). The aggregate was thoroughly washed with

additional THF. The filtrate was filtered a second time to ensure removal of sediment.

The bulk of the solvent was removed from the solution using a rotary evaporator (Buchi) at 40°C. Remaining THF was removed by continued rotary evaporation at 90-100°C for about 40 minutes. The asphalt was poured into a 5 dram glass vial and tightly covered with a polyethylene snap caps. Once the extraction procedure was begun, the above steps were taken promptly, ie., asphalt did not remain in solution for excessive periods of time.

References

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4. Llewelyn Williams, "Regionalization of Freeze-thaw Activity", Ann. Assoc. Am. Geographers, 54, 597 (1964).
5. P.S. Kandhal, "Low Temperature Shrinkage Cracking of Pavements in Pennsylvania" Asphalt Paving Technology, 47, 73 (1978).

