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# Public Roads

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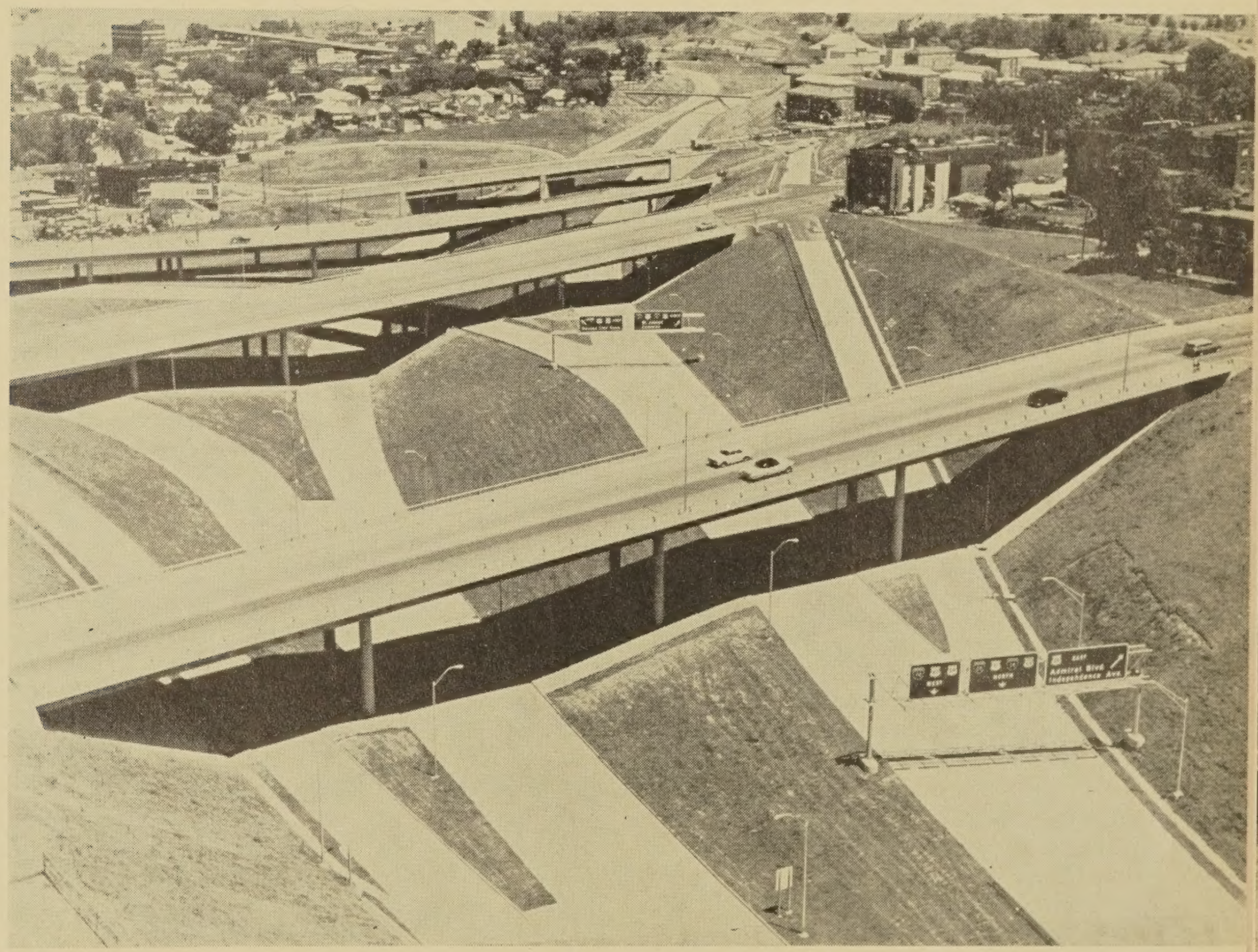

Interchange of Interstate Highways 70, 29, and 35 in Kansas City, Mo.

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**Muriel P. Worth,** ***Editor***

## IN THIS ISSUE

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# Relation of Asphalt Ductility To Pavement Performance

*BY THE MATERIALS RESEARCH DIVISION*
*BUREAU OF PUBLIC ROADS*

**Reported by**[1] **WOODROW J. HALSTEAD,**
**Supervisory Chemist**

***This article provides a critical review and restudy of published data as well as previously unpublished data concerning the relation of asphalt ductility to pavement performance.***

***The author points out that the consistency at which the asphalt begins to lose ductility rapidly and the temperature at which such consistency occurs is a significant relationship. The analysis of the data further indicates that, although an accelerated laboratory test is not available to accurately predict the ductility-penetration relationship of an asphalt in service, the ductility-penetration curve of the thin film residue provides a useful means for differentiating between asphalts and detecting those materials most likely to give unsatisfactory service. Requirements for minimum ductility, at 77° F., of the residue from the thin film oven test serve to eliminate potentially unsuitable materials.***

### *Introduction*

SINCE ITS introduction in 1903 the ductility test for asphalts has been, and still is, controversial. Some asphalt technologists believe that the test is an indication of a necessary property of asphalt related somewhat to its adhesive properties or stickiness, but others consider the present laboratory test for ductility of no value for indicating the potential quality of an asphalt as a paving material.

A review of the literature offers support for both of these divergent views. These contradictions suggest a need for a careful evaluation of the significance of the ductility test and its relation to other properties of the asphalt cement and a restudy of some of the available data to determine if there is a satisfactory explanation for the opposing viewpoints.

This article, which is part of a general symposium on the properties of asphalt that affect pavement performance, emphasizes the advantages of considering the ductility-penetration relationship of an asphalt in evaluating the effect of the asphalt characteristics on pavement performance. When available data are analyzed on this basis, there is a strong indication that the consistency at which the asphalt begins to lose ductility rapidly and the temperature at which such consistency occurs is a significant relationship. Because for some asphalts this point occurs at a relatively low penetration (or temperature) indications are that factors other than ductility, as measured in the laboratory test, control pavement performance, hence the conclusion is often reached that ductility is unimportant.

### *Summary*

The amount of hardening of the asphalt during construction and the rate of hardening in service are the primary factors affecting durability of a pavement. However, the data discussed in this article demonstrate that the accompanying decrease in ductility of the asphalt is an important secondary factor that must not be overlooked. Pavements containing asphalts having penetrations in the range normally considered satisfactory (30 to 50) but having low ductilities are likely to show poorer service than pavements containing asphalts of the same penetration but having high ductilities.

The physical characteristics of the pavements, such as void content and permeability, and the environmental factors greatly affect the hardening rate of the asphaltic binder as well as the degree of oxidation during pavement service. Consequently, an accelerated laboratory test to accurately predict the ductility-penetration relationship or the change in the ductility-penetration relationship of an asphalt in service is not available. However, the ductility-penetration curve of thin film residue provides a useful means for differentiating between asphalts and detecting those materials most likely to develop unsatisfactory characteristics. Requirements for minimum ductility of the thin film residue at 77° F. based on the critical curve illustrated in this article serve to eliminate such potentially unsuitable materials. Recently adopted limits for ductility of the thin film residues in the AASHO specifications are based on this curve. These specifications have a minimum of 50 cm. for thin film residue of the 60–70 grade, 75 cm. for the 85–100 grade, and 100 cm. for all softer grades.

Further research is needed to establish the optimum conditions of the ductility test. The conditions of the 77° F. test at 5 cm. per minute may not provide the most useful information. Other temperatures, speeds of pull, or even shapes of specimens may prove to be more useful, but, until research data are available to define the optimum condition of the test, test requirements for the ductility of the thin film residue at 77° F. should be retained.

More research is also needed to clearly define the significance of ductility in relation to pavement behavior. An asphaltic pavement is subject to extremely wide temperature changes in service and the ductility of the asphalt, as measured by the present laboratory test, can vary from zero to values exceeding the limits of the ductilometer. Therefore, it is most likely that the ability of the asphalt to undergo elongation is not the primary characteristic affecting durability but rather that the ductility test result is an indication of an internal phase relationship of the asphaltic

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[1] Presented at a meeting of the Association of Asphalt Technologists, San Francisco, Calif., February 1963.

constituents, which in turn have an important bearing on the serviceability factors of the asphalt.

### *Established Ductility-Penetration Relationships*

The general relations of the ductility test results to test temperatures and consistencies of the asphalt and the variations of these relationships according to source or method of refining of the asphalt have been shown in published reports.

Figures 1 and 2, taken from a report by Lewis and Welborn presented before the Association of Asphalt Paving Technologists in January 1940 (*1*)[2] show respectively the variation of ductility in relation to changes in test temperatures and the penetrations of the asphalts. The significant feature of these curves is the many queer shapes that were obtained for asphalts from different sources when smooth curves were drawn to fit the data points. The differences in shape could be considered as indicative that the ductility as measured by the laboratory test at 77° F. has no true significance, but closer consideration shows that essentially all the curves have some common characteristics.

The curves for each asphalt manufactured by vacuum or steam reduction show that ductility increased sharply as test temperatures or penetrations were increased until a maximum was reached; upon further increase in temperature or penetration the ductility decreased, but usually at a slower rate. Ductility of some asphalts increased more gradually than others in relation to temperature. Although information about the manufacturing processes for these asphalts is incomplete, some oxidation is believed to have been used.

When the curves are viewed separately, no significant difference is apparent between the shapes of the curves for ductility against temperature shown in figure 1 or for ductility against penetration shown in figure 2. However, the relative positions of the curves for different asphalts are different and this is important when the behavior of one asphalt is being compared with another, particularly if the materials have significantly different consistencies at the same temperature.

Lewis and Welborn in the same article (*1*) illustrated another very important characteristic of asphalt ductility that is often overlooked. They showed a plot that included data from ductility tests made at six different temperatures on each of 10 asphalts of different grades that had been steam and vacuum reduced from the same crude source. The test temperatures ranged from 50° to 95° F. and the penetrations at 77° F. ranged from 23 to 182. The total range in penetration (extrapolated) was 6 to 442. The upper curve of figure 3 shows the test results for asphalts that had penetrations of less than 70. Despite the wide differences in ductility

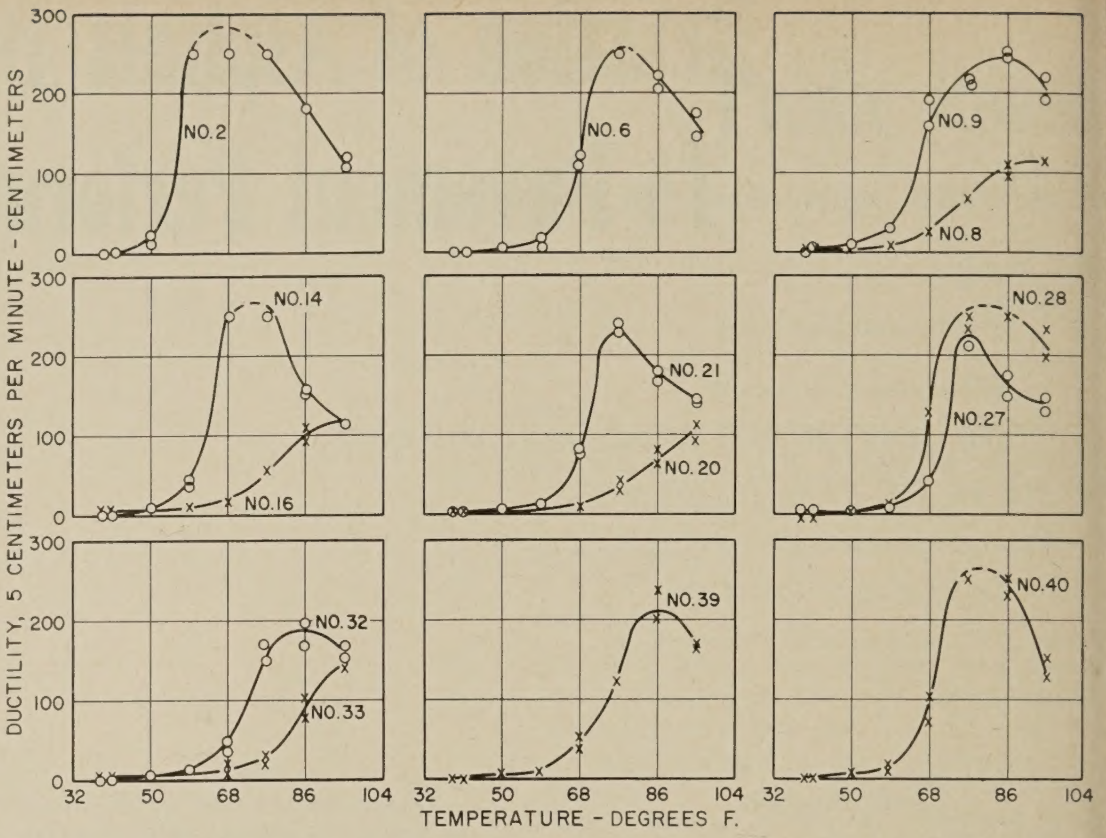

*Figure 1.—Relation between ductility and test temperatures of selected samples of 50–60 penetration asphalts.*

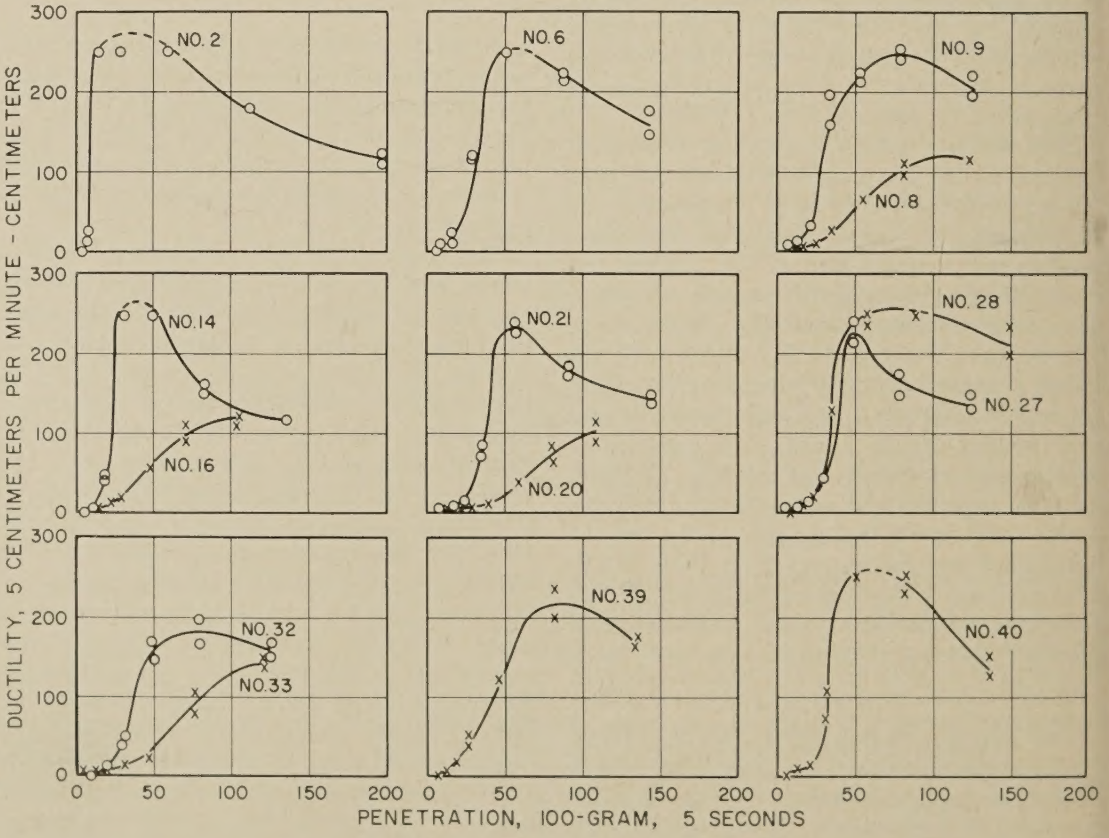

*Figure 2.—Ductility-penetration relation of selected samples of 50–60 penetration grade asphalts, tested at different temperatures.*

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[2] References indicated by italic numbers in parentheses are listed on page 230.

at the different temperatures or for the different grades of asphalt at the same temperature, the data form a single ductility-penetration curve. The lower curve in figure 3, based on data reported by Lewis and Halstead (*2*), shows that the residues from the thin film oven tests for these same asphalts also form a single curve, even though the asphalts were of different grades and tests were made at different temperatures. This same relationship is generally true for all series of steam or vacuum reduced asphalts refined from the same source. However, when oxidation (blowing), cracking, or other refinery techniques are employed, Lewis and Halstead showed that the ductility for asphalts having the same penetration may differ significantly according to the grade of the asphalt. Figure 4 shows data for the ductility-penetration relationships for original asphalts and residues from the thin film test for each of three grades of asphalts obtained from the same source and that had positive spots in the Oliensis test. The data for each grade of material form a separate curve, but each of the curves for the residue is below the curve for the original asphalt of the corresponding grade.

Additional data to illustrate the basic relations between the ductility and penetration of asphalts after different treatments are available from unpublished test results obtained in 1940 by Committee 3A of the Association of Asphalt Paving Technologists (AAPT). In this cooperative effort, several laboratories, including the Bureau of Public Roads, conducted studies of nine asphalts. Test included the determination of the penetration and ductility of (1) the original materials, (2) the asphalts after several accelerated weathering tests, including oven heating and oxidation, and (3) the asphalts after their recovery from laboratory mixtures made and aged under different conditions. Figure 5 shows the data obtained by the Bureau of Public Roads for the ductility-penetration relationship of asphalts from two sources—a California crude and a midcontinent crude; both had been refined by the steam and vacuum process. The data points shown were obtained by use of a 50–60 and an 85–100 grade asphalt from each source.

Only a limited number of definite data points are available for the California asphalts as most of the ductility results were more than 250 cm. However, the available points illustrate the extremely rapid decrease in ductility known to be typical of asphalts from this source. Different conditions of hardening the asphalts did not materially affect the penetration at which the rapid decreases in ductility occurred.

The data points for the midcontinent asphalts show that the asphalts from all tests retained approximately the same ductility-penetration relationship. However, the best agreement with the general curve shown is indicated by the data for the 5-hour, thin film test for the asphalts recovered from the pavement samples and asphalts recovered from laboratory mixtures aged under different conditions. The significant deviations from the general curve can be explained by the degree of oxidation that occurred under the different conditions. Data points for the original asphalts and residues from the standard loss test, where oxidation was very limited, generally fall above the plotted curve. Data for the 18-hour thin film and oxidation residues, tests in which oxidation can be a major factor, fall below the plotted curve.

## *Interpretation of Ductility-Penetration Relationships*

The relationships given in figures 1 through 5 provide a basis for the interpretation of ductility data from tests made on the original asphalts; on the residues from accelerated weathering tests, such as the thin film oven test; and on asphalts recovered from pavement samples. These figures illustrate that asphalts from the same source have the same ductility for equal consistencies, unless oxidation or other significant changes have occurred

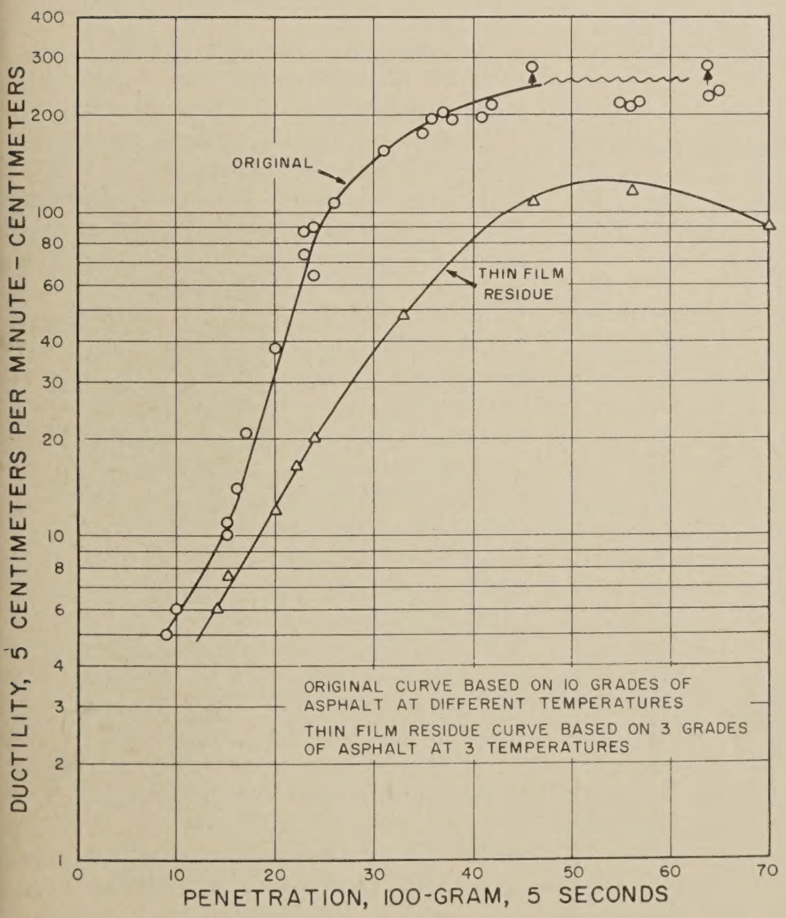

*Figure 3.—Ductility-penetration relation for asphalts of different grades refined from the same crude petroleum by steam and vacuum distillation.*

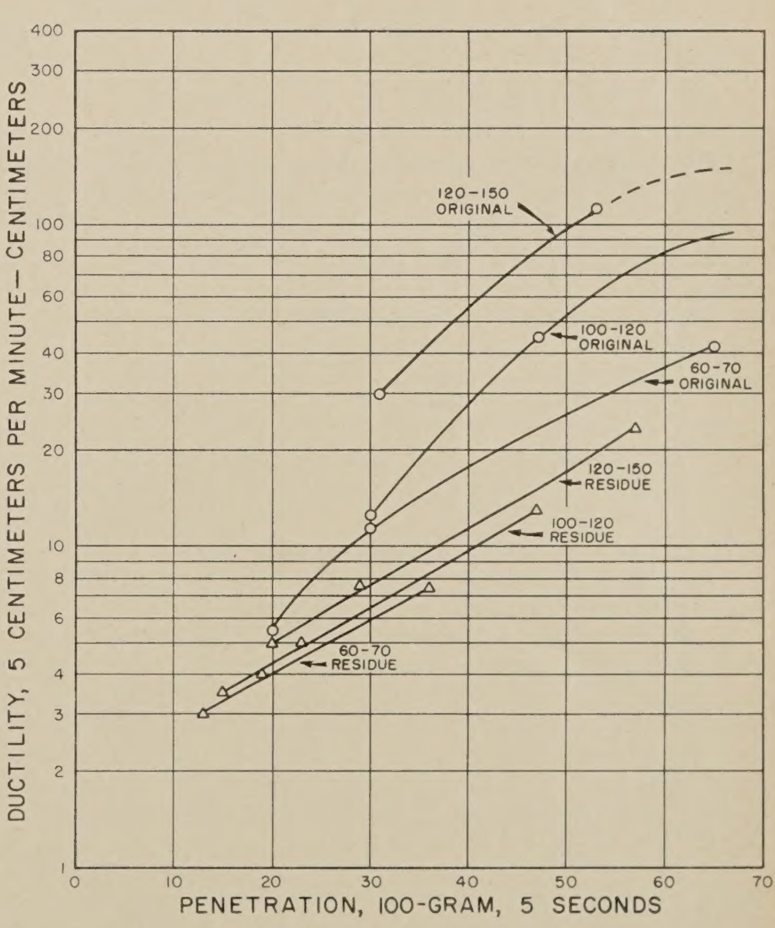

*Figure 4.—Ductility-penetration relation for asphalts of different grades prepared from the same crude that had some cracking and blowing during the manufacture.*

**Table 1.—Characteristics of asphalts recovered from Kansas Experimental Projects**

| Sample | Age when sampled | Penetration at 77° F., 100 g., 5 sec. | Ductility, 5 cm. per min. at 77° F. | Performance [2] rating at 72 months |
|---|---|---|---|---|
| | *Months* | | *Cm.* | |
| Asphalt *A:* | | | | 5 |
| Composite [1] | 10 | 62 | 200+ | |
| Do | 26 | 48 | 197 | |
| Do | 27 | 65 | 178 | |
| Do | 27 | 47 | 155 | |
| Surface | 72 | 35 | 127 | |
| Binder | 72 | 31 | 30 | |
| Asphalt *B:* | | | | 5 |
| Composite [1] | 10 | 84 | 200+ | |
| Do | 26 | 69 | 200+ | |
| Do | 27 | 62 | 200+ | |
| Surface | 72 | 44 | 250+ | |
| Binder | 72 | 48 | 250+ | |
| Asphalt *C:* | | | | 4 |
| Composite [1] | 10 | 64 | 200+ | |
| Do | 26 | 57 | 200+ | |
| Do | 27 | 65 | 200+ | |
| Surface | 72 | 48 | 250+ | |
| Binder | 72 | 52 | 250+ | |
| Asphalt *D:* | | | | 9 |
| Composite [1] | 10 | 46 | 10 | |
| Do | 26 | 40 | 8 | |
| Do | 27 | 40 | 9 | |
| Surface | 72 | 28 | 4 | |
| Binder | 72 | 29 | 4 | |
| Asphalt *E:* | | | | 5 |
| Composite [1] | 10 | 98 | 168 | |
| Do | 26 | 59 | 150 | |
| Do | 27 | 65 | 178 | |
| Surface | 72 | 43 | 71 | |
| Binder | 72 | 48 | 94 | |
| Asphalt *H:* | | | | 7 |
| Composite [1] | 10 | 63 | 194 | |
| Do | 26 | 61 | 154 | |
| Do | 27 | 43 | 62 | |
| Surface | 72 | 34 | 14 | |
| Binder | 72 | 34 | 18 | |

[1] Asphalt from both surface and binder course recovered in same sample. Data obtained by Kansas State Highway Commission.

[2] A rating of 1 is excellent; a rating of 10 denotes complete failure.

**Table 2.—Characteristics of asphalts recovered from Virginia Experimental Project**

| Sample | Test temperature | Pavement age | Penetration, 100 g., 5 sec. | Ductility, 5 cm. per min. |
|---|---|---|---|---|
| Asphalt *A*: | ° *F.* | *Months* | | *Cm.* |
| Original | 77 | ------------ | 80 | 250+ |
| Do | 60 | ------------ | 27 | 250+ |
| Do | 50 | ------------ | 13 | 191 |
| Do | 45 | ------------ | 9 | 46 |
| Thin film residue | 77 | ------------ | 47 | 250+ |
| Do | 60 | ------------ | 13 | 89 |
| Do | 50 | ------------ | 9 | 8 |
| From pavement [1] | 77 | 0 | 50 | 250+ |
| Do | 77 | 12 | 33 | 250+ |
| Do | 77 | 24 | 34 | 250+ |
| Do | 77 | 48 | 28 | 250+ |
| Asphalt *B*: | | | | |
| Original | 77 | ------------ | 71 | 250+ |
| Do | 60 | ------------ | 28 | 154 |
| Do | 50 | ------------ | 15 | 16 |
| Thin film residue | 77 | ------------ | 44 | 170 |
| Do | 60 | ------------ | 18 | 17 |
| Do | 50 | ------------ | 11 | 5 |
| From pavement [1] | 77 | 0 | 48 | 242+ |
| Do | 77 | 12 | 38 | 125 |
| Do | 77 | 24 | 33 | 64 |
| Do | 77 | 48 | 32 | 50 |
| Asphalt *C*: | | | | |
| Original | 77 | ------------ | 82 | 239 |
| Do | 60 | ------------ | 31 | 229 |
| Do | 50 | ------------ | 19 | 35 |
| Thin film residue | 77 | ------------ | 57 | 195 |
| Do | 60 | ------------ | 21 | 26 |
| Do | 55 | ------------ | 15 | 9 |
| Do | 50 | ------------ | 11 | 6 |
| From pavement [1] | 77 | 0 | 64 | 238+ |
| Do | 77 | 12 | 45 | 165 |
| Do | 77 | 24 | 39 | 135 |
| Do | 77 | 48 | 40 | 128 |

[1] Figures given are averages of results from four samples taken laterally across the pavement from each section.

in the asphalt composition. Thus, the difference between ductility at the same consistency for original asphalts and ductility of asphalts after accelerated tests or after recovery from the pavement is a measure of the ductility destroyed or lost. This ductility decrease can also be considered a measure of the degree of change caused by oxidation or other alterations in composition of asphalts. The ductilities for original asphalts at equivalent penetrations can be obtained by making tests at several temperatures to establish the ductility-penetration curve.

Because of the conditions of the thin film oven test, the change in the ductility-penetration relation occurring during the test would be expected to be equal to or less than changes in ductility-penetration occurring in the pavement in use. The loss of ductility during the thin film test may then be considered to represent the minimum change expected in service and asphalts that failed to retain adequate ductility in this test would most likely undergo rapid decreases in ductility in the pavement. For asphalts retaining high ductility at relatively low penetration after the thin film test (for example, ductility of more than 150 cm. at penetrations as low as 20) loss of ductility measured by the laboratory test most likely can be discounted as a factor in the pavement behavior. However, cracking and ravelling caused by abnormal hardness (low penetration) for such materials may still be a contributing factor in pavement performance.

## *Critical Ductility-Penetration Relationship*

The foregoing discussion implies that a critical ductility-penetration relationship exists below which low ductility would be a potential cause of poor pavement service and above which ductility would not be a significant factor affecting pavement durability. Admittedly, because of the many variables involved, a precise location for such a dividing line will be extremely difficult to determine. However, examination of the ductility-penetration relationships of asphalts used in many pavement evaluation studies, including materials from many of the more important sources of highway asphalts, indicates that most asphalts will have ductilities for equivalent penetrations that will plot above the dotted curve shown in figures 6 through 15. As will be discussed later, considerable evidence indicates that a ductility-penetration relationship that plots in the area below this curve may have a bearing on performance of an asphalt in service. The limiting values of ductility for the thin film residues included in the recently adopted AASHO specifications for asphalt generally are based on relationships shown by the dotted line in figs. 6–15.

## *Relation of Pavement Performance to Penetration-Ductility Relationship*

To determine the extent to which the penetration-ductility relationship is a factor in pavement behavior, both published and

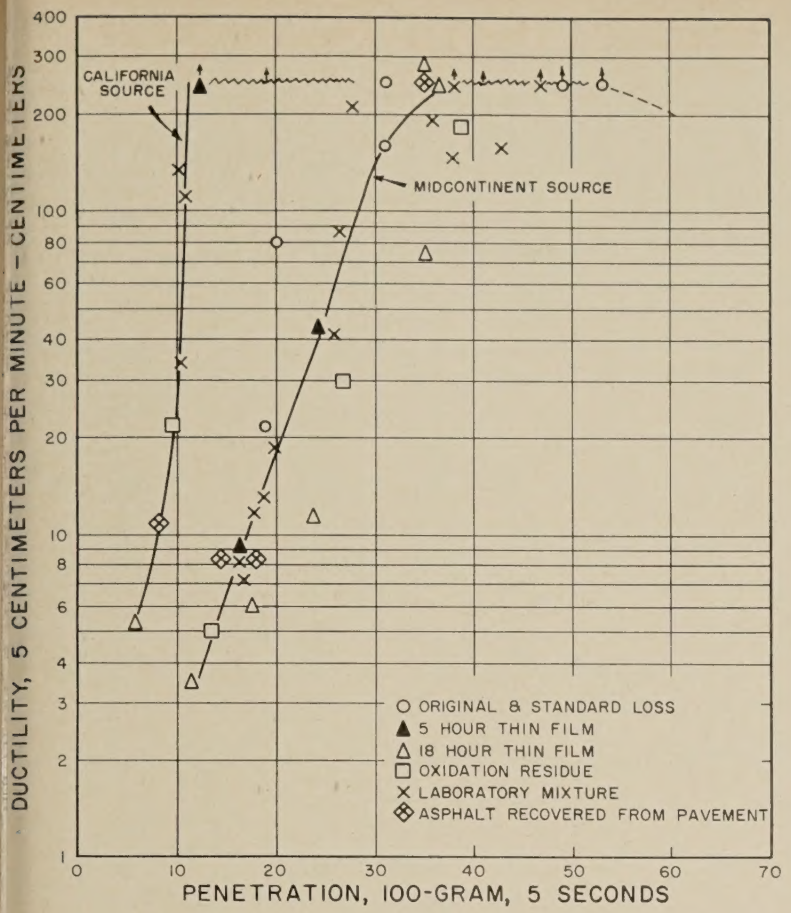

*Figure 5.—Ductility-penetration relation of residues of steam and vacuum refined asphalts from the same source after hardening under different conditions. Tests were made at 77° F.*

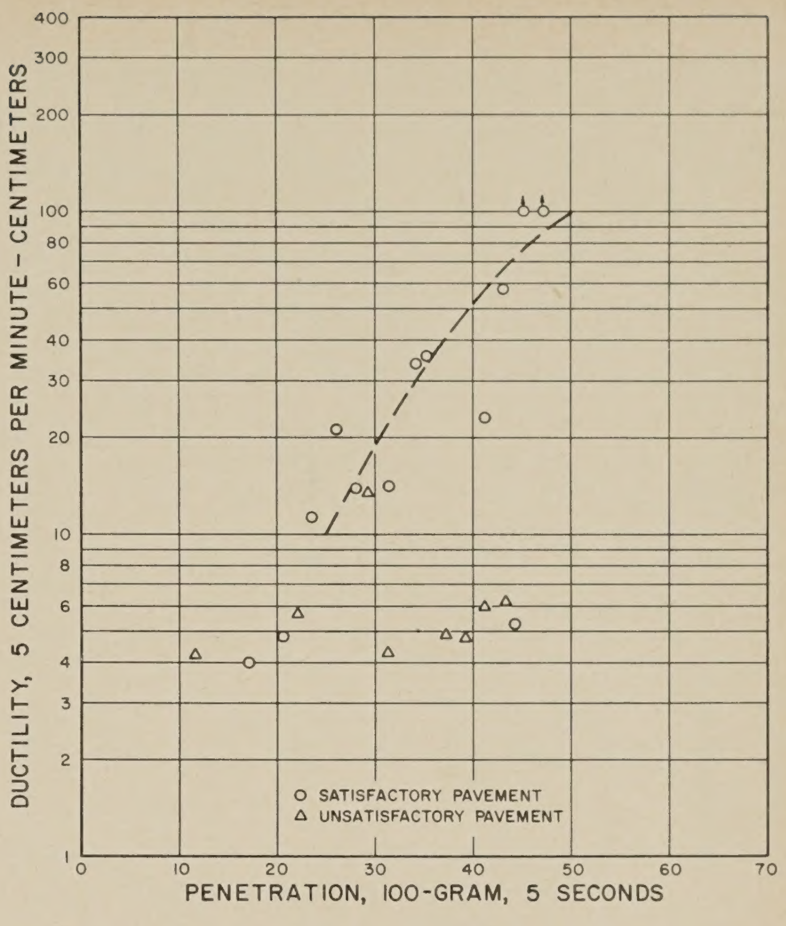

*Figure 6.—Ductility-penetration relation of asphalts recovered from Ohio pavements. Tests were made at 77° F.*

unpublished data from several pavement projects were examined.

**Ohio study**

In 1941 the Bureau of Public Roads and the Ohio Department of Highways made a joint study of bituminous concrete pavements in Ohio (*3*) in which factors affecting pavement performance were considered. One of the conclusions was that, for the 50–60 penetration asphalts used in the asphaltic concretes, satisfactory service was not likely to continue after the penetration of the asphalt had fallen appreciably below 30. The corresponding critical ductility was reported to be about 10 to 13 centimeters. The report on the Ohio pavements contains ductility and penetration data at 77° F., plotted in figure 6. As can be seen from this figure, unsatisfactory service in Ohio was generally associated with a low ductility at penetrations between 30 and 50. The only significant departure from this trend being one project that was reported to be in good condition after 35 months of service, even though the ductility was 5 centimeters for a penetration of 44. It is coincidental that the dotted line indicating the location of the critical ductility-penetration relationship appears to be the locus of the data points for the satisfactory pavement. However, the important relationship indicated is that, although several satisfactory pavements fall below the ductility-penetration boundary, no unsatisfactory pavements having penetrations greater than 25 were above the boundary.

**Kansas study**

Data given table 1 and plotted in figure 7 illustrate previously unpublished test results obtained from an experimental project in Kansas. This project involved six asphalts from different sources that were used as an overlay over old rigid pavement. The asphalts were recovered from samples cut periodically from the pavement. The curves for each asphalt were obtained by plotting the ductility at 77° F. against the penetration at 77° F. of the asphalts recovered from the pavement at different ages. The relative 6-year service rating of the sections containing each asphalt are shown in table 1. In the rating system used, a rating of 1 indicates no failure or cracking whereas a rating of 10 indicates complete failure.

The section containing asphalt *D*, for which the ductility was very low at penetrations in the range of 30–40, had the poorest service record. The section containing asphalt *H* also had low ductility after the penetration had dropped below 30, and it showed the next poorest service. Asphalts *A*, *B*, and *C* all retained ductilities of more than 100 cm. as well as relatively high penetrations, and the service records for pavements containing these asphalts were generally satisfactory. The penetration-ductility curve for asphalt *E* was approximately the same as that for asphalt *H* although the service records were significantly different. However, as indicated, asphalt *E* did not harden as much as *H* in service, thus it did not fall below the critical ductility-penetration relationship and the pavement containing it performed satisfactorily.

The data points for the ductility-penetration relationship of the thin film residues, shown as solid dots on figure 7, fall close to the curve for the asphalts recovered from the pavement except for those for asphalt *D*. The thin film data points for this asphalt fall significantly below the curve, and this low ductility indication of poor service was verified by actual performance of the pavement. Asphalt *H* would have been considered satisfactory on the basis of present criteria of ductility of the thin film residue at 77° F. but as it was a borderline material on the basis of the ductility-penetration boundary suggested in this article, its relative rapid rate of hardening apparently contributed to poor pavement service.

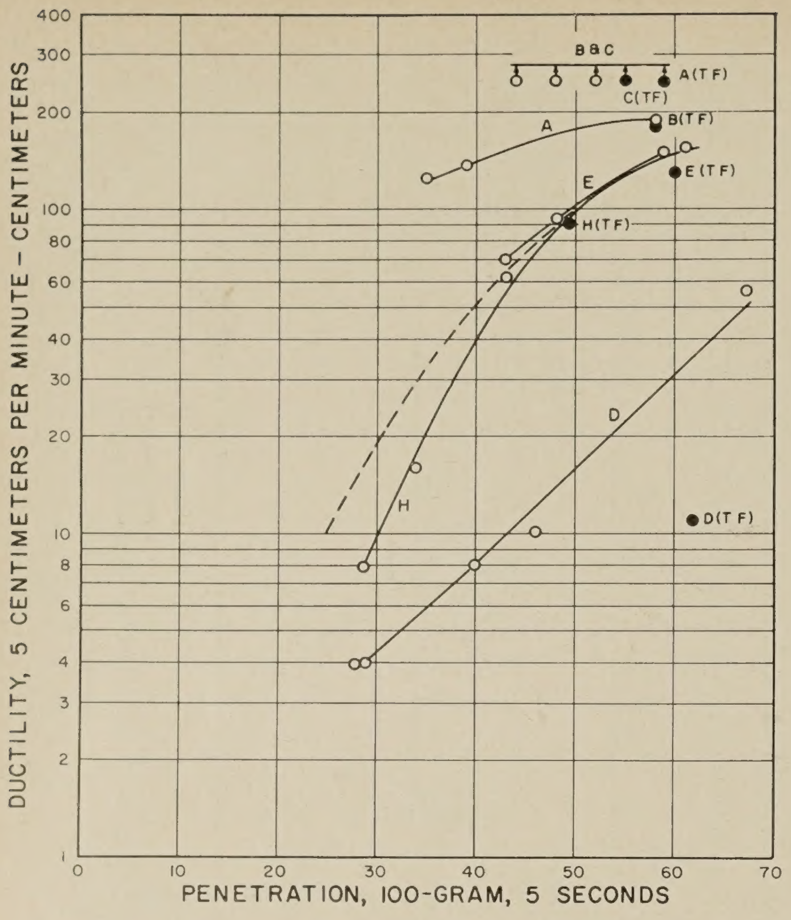

*Figure 7.—Ductility-penetration relation of asphalts recovered from Kansas pavements at different ages. Tests were made at 77° F.*

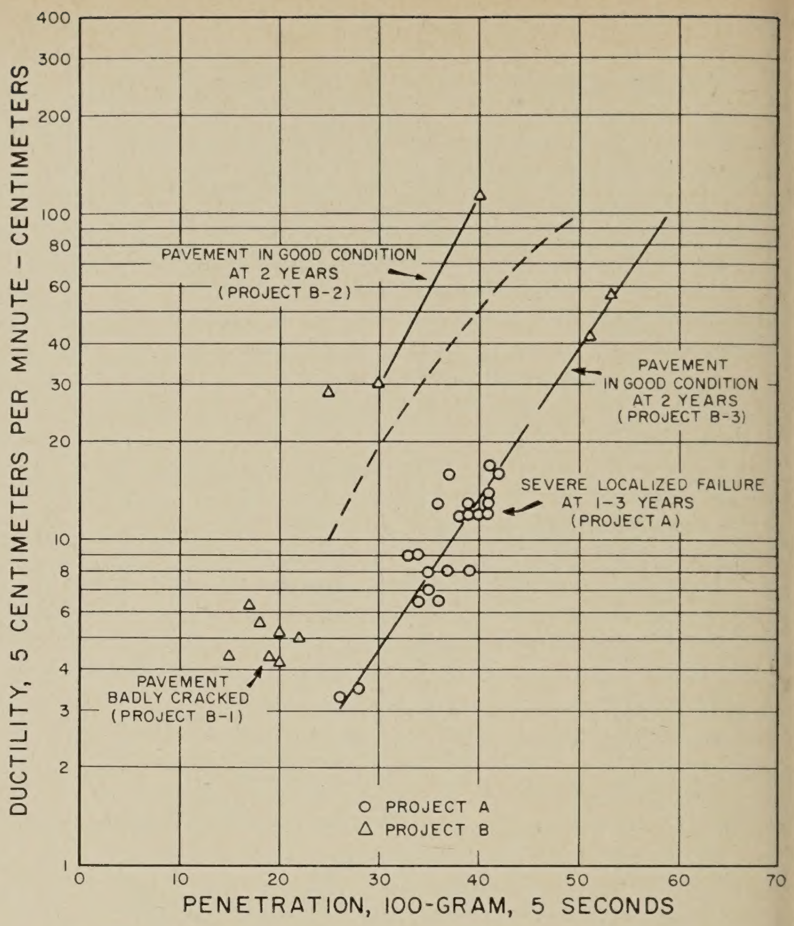

*Figure 8.—Ductility-penetration relation of asphalts recovered from pavement projects. Tests were made at 77° F.*

### Two Public Roads studies

Figure 8 illustrates data obtained by Public Roads from two extensive studies of pavements. Project A, shown by the lower curve, was subject to considerable criticism because of limited areas of severe failure that occurred between 1 and 3 years of service. The study of this project indicated a relatively low asphalt content in relation to the amount of fine aggregate present, and some localized base failures were also observed. However, the low ductility of the asphalts at relatively high penetrations is believed to have contributed significantly to the rapid failure of the pavement observed in localized areas once initial cracking occurred.

Project B indicated by the triangular data points in figure 8 was a low-traffic road built over a period of years by several contractors. The older sections of this project designated on the curve as project B–1 were badly cracked although riding qualities remained satisfactory. Each data point shown is the average of the results of several samples from each section, which represents a construction contract. For the badly cracked areas, the penetrations at 77° F. ranged from 15 to 22 and the ductility at 77° F. ranged from 4 to 6 cm. Extreme hardness of the asphalt in these sections undoubtedly was the main factor contributing to poor performance. Overheating of the asphalt during construction or the effects of relatively high voids and very little traffic could have been the cause of this hardening. The data points obtained from two newer sections of project B that are still in good condition are of interest. These sections were built with different asphalts. Although the asphalt in project B–2 has generally hardened more than that in project B–3 the ductility-penetration relation for the asphalt in project B–2 is superior to that of the asphalt in project B–3. Consequently, if the asphalt hardening in project B–3 continues, this project may fail earlier than project B–2.

### Bissett report

The data plotted in figure 9, taken from the report presented at the 1962 Highway Research Board meeting by Professor J. R. Bissett (*4*) illustrates one of the advantages of considering the ductility-penetration relationship in analyzing data obtained from pavement samples.

Professor Bissett's report included data from five projects using Brand *C* asphalt. These pavements were of different ages and differed in service performance. When the data were examined independently, greater differences in ductility for the different recovered asphalts than would be accounted for by differences in penetrations appeared to exist but, as shown in figure 9, when ductility is plotted against penetration most of the points fall close to the same curve. The data plotted in figure 9 are for four of the five projects for which Brand *C* asphalt was used and for the one project in which Brand *A* asphalt was used, except that several duplications of data points at the same location are not indicated. The curves plotted in figure 9 indicate that differences in behavior of pavements of these projects were not caused by any fundamental differences in the asphalts. Variations in construction that permitted more asphalt hardening in some instances than in others were most likely the cause. Also, all of the data for Brand *C* asphalt show relatively low ductilities for equivalent penetrations compared to asphalt from other sources; thus, accelerated pavement deterioration may occur in all of these projects once failure begins.

The data for the project in which Brand *A* asphalt was used indicate wide variations in ductility for essentially the same penetration but, as illustrated in figure 9, the data points are in the area where many asphalts show a very rapid decrease in ductility for small decreases in penetration. Therefore, the differences were most likely the normal result of greater hardening and experimental error rather than of a significant loss in ductility for equivalent penetration.

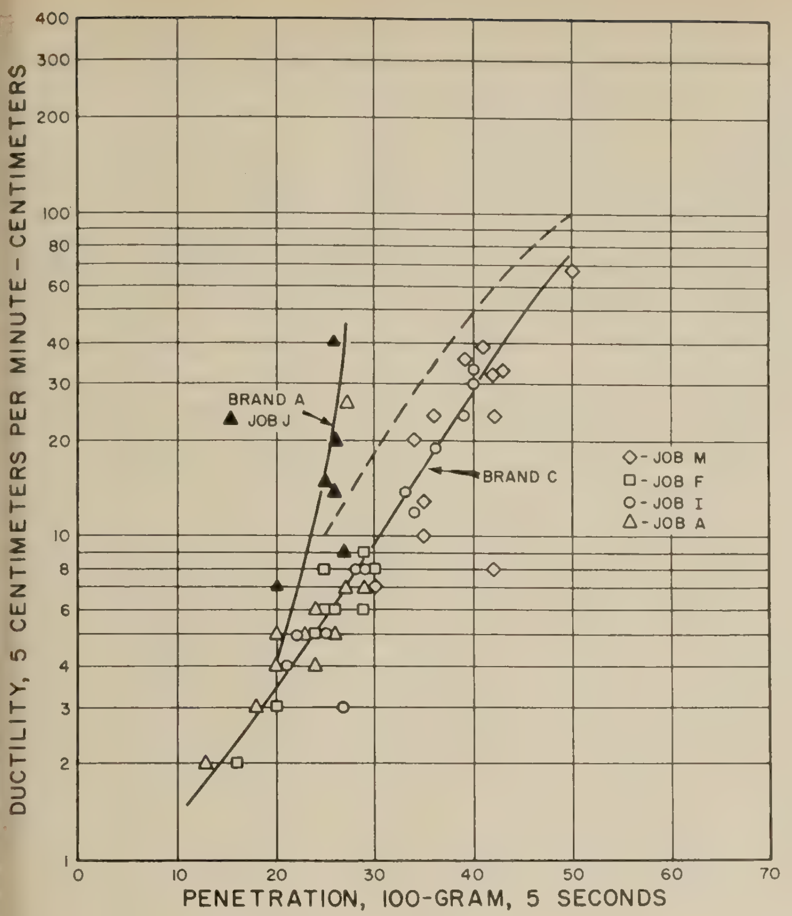

*Figure 9.—Ductility-penetration relation of asphalts recovered from pavement projects in Arkansas. Tests were made at 77° F.*

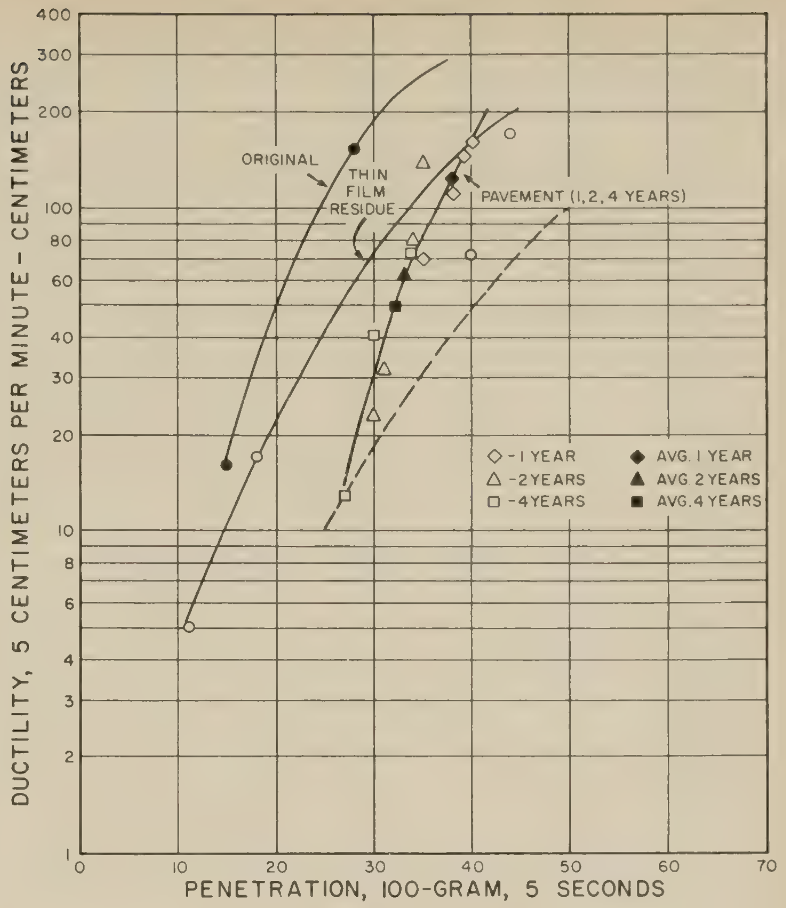

*Figure 10.—Ductility-penetration relation for asphalt B used in Virginia experimental project. Tests on original asphalts and thin film residues were made at different temperatures, and those on asphalts recovered from pavement were made at 77° F.*

The penetration-ductility relationship for the asphalts recovered from the pavement projects discussed in the preceding paragraphs are based on tests made at 77° F. only. However, the implications from data shown in figure 5 are that ductility and penetration tests made at several different temperatures for the same original material and for the thin film residue would provide data for ductility-penetration curves that could possibly be used as the basis for predictions of pavement service changes. To indicate the usefulness of this approach, the ductilities and penetrations of the asphalts being used in experimental projects now under study were determined at several different temperatures.

Table 2 shows ductility and penetration data for the original asphalts, the thin film residues, and asphalts recovered from the pavement at different ages for materials used in an experimental project in Virginia; and table 3 shows similar data for 10 asphalts used in the Zaca-Wigmore California Project. The significant ductility-penetration relationships indicated by these data are shown in figures 10–15.

**Virginia study**

Because asphalt *A* of the Virginia Project retains ductility in excess of 250 cm. after 4 years in service, trends for the relation of penetration and ductility are not illustrated. However, the data for asphalts *B* and *C* shown in figures 10 and 11 illustrate that significant changes are occurring in these asphalts. As would be expected on the basis of the principle discussed earlier in this report, the plotted curves show the ductility of the original asphalt to be greater than the ductility of the thin film residue for equivalent penetration. Although only the averages of test results for four samples—taken laterally across the road—are shown in table 2 for each pavement age, the individual results, as well as the averages, are plotted in figures 10 and 11. On the basis of the averages reported in table 2, no significant change occurred in the penetration of the recovered asphalt between 2 and 4 years, but the ductility decreased to some extent. The individual results in figures 10 and 11, however, are more informative. For example, in figure 10, all of the data points except the result for one 4-year sample are close to the plotted curve, but the points are not in sequence with respect to pavement age. This variation in rate of hardening in the same section was mostly likely caused by the differential effect of traffic at the edge of the road, in the wheel path, and between wheel paths. To date, there has been no significant failure in the pavement sections. Figure 10, however, indicates that the section containing asphalt *B* may be approaching a critical point in some areas, and further hardening and reduction of asphalt ductility may induce failure under severe weather or traffic conditions. The data for asphalt *C* plotted in figure 11 follows essentially the same trend as does the data for asphalt *A* in figure 10 except that the hardening and reduction of ductility have not progressed as far.

## *Zaca-Wigmore Project*

The Zaca-Wigmore experimental project, constructed in 1954 and 1955 in California is one of the better known projects now under study and several reports have been issued concerning the performance of the asphalts (*5, 6, 7*).

The asphalts used in this project were of the 200–300 penetration grade, thus at 77° F. the ductilities of all the materials were generally high and very little useful information is provided by the results of the ductility tests made at 77° F. on the original asphalts. However, an analysis of test data obtained by the Bureau of Public Roads for ductilities of the asphalts and the thin film residues at different temperatures, together with data for the ductility and penetration of asphalts recovered from the pavements at different ages reported in 1959 by Hveem, Zube, and Skog (*5*), provides some interesting clues to

**Table 3.—Characteristics of asphalts recovered from Zaca-Wigmore Project [1]**

| Sample | Test temperature | Pavement age | Penetration, 100 g., 5 sec. | Ductility, 5 cm. per min. |
|---|---|---|---|---|
| Section A: | ° *F.* | *Months* | | *Cm.* |
| Original | 60 | --- | 64 | 244 |
| Do | 50 | --- | 27 | 250+ |
| Do | 40 | --- | 14 | 250+ |
| Thin film residue | 77 | --- | 120 | 193 |
| Do | 60 | --- | 35 | 250+ |
| Do | 50 | --- | 17 | 250+ |
| Do | 45 | --- | 12 | 250+ |
| Do | 40 | --- | 8 | 38 |
| From pavement | 77 | 5 | 131 | --- |
| Do | 77 | 12.5 | 84 | --- |
| Do | 77 | 20 | 49 | --- |
| Do | 77 | 35 | 44 | 100+ |
| Section B-1: | | | | |
| Original | 60 | --- | 82 | 180 |
| Do | 50 | --- | 44 | 148 |
| Do | 45 | --- | 30 | 174 |
| Do | 40 | --- | 21 | 190 |
| Thin film residue | 77 | --- | 121 | 152 |
| Do | 60 | --- | 42 | 131 |
| Do | 50 | --- | 24 | 87 |
| Do | 45 | --- | 17 | 26 |
| From pavement | 77 | 3.5 | 148 | --- |
| Do | 77 | 11 | 107 | --- |
| Do | 77 | 19 | 77 | --- |
| Do | 77 | 33 | 56 | 100+ |
| Section C: | | | | |
| Original | 60 | --- | 66 | 250+ |
| Do | 50 | --- | 32 | 175 |
| Do | 40 | --- | 15 | 0 |
| Thin film residue | 77 | --- | 120 | 191 |
| Do | 60 | --- | 36 | 250+ |
| Do | 50 | --- | 18 | 250+ |
| Do | 40 | --- | 9 | 37 |
| From pavement | 77 | 5 | 132 | --- |
| Do | 77 | 12.5 | 79 | --- |
| Do | 77 | 20 | 46 | --- |
| Do | 77 | 35 | 44 | 100+ |
| Section D: | | | | |
| Original | 60 | --- | 74 | 221 |
| Do | 50 | --- | 34 | 220 |
| Do | 40 | --- | 14 | 250+ |
| Thin film residue | 77 | --- | 121 | 173 |
| Do | 60 | --- | 36 | 250+ |
| Do | 50 | --- | 18 | 250+ |
| Do | 45 | --- | 12 | 250+ |
| Do | 40 | --- | 9 | 0 |
| From pavement | 77 | 5 | 151 | --- |
| Do | 77 | 12.5 | 93 | --- |
| Do | 77 | 20 | 59 | --- |
| Do | 77 | 35 | 52 | 100+ |
| Section E: | | | | |
| Original | 60 | --- | 85 | 238 |
| Do | 50 | --- | 49 | 170 |
| Do | 45 | --- | 35 | 243 |
| Do | 40 | --- | 26 | 250+ |
| Thin film residue | 77 | --- | 65 | 201 |
| Do | 60 | --- | 25 | 138 |
| Do | 50 | --- | 15 | 21 |
| Do | 45 | --- | 11 | 9 |
| From pavement | 77 | 5 | 93 | 100+ |
| Do | 77 | 12.5 | 38 | 100+ |
| Do | 77 | 20 | 20 | --- |
| Do | 77 | 35 | 16 | 16 |
| Section F: | ° *F.* | *Months* | | *Cm.* |
| Original | 60 | --- | 68 | 216 |
| Do | 50 | --- | 35 | 174 |
| Do | 40 | --- | 20 | 171 |
| Thin film residue | 77 | --- | 85 | 224 |
| Do | 60 | --- | 32 | 122 |
| Do | 50 | --- | 16 | 22 |
| From pavement | 77 | 5 | 93 | 100+ |
| Do | 77 | 12.5 | 57 | --- |
| Do | 77 | 20 | 42 | 100+ |
| Do | 77 | 35 | 38 | 21 |
| Section G: | | | | |
| Original | 60 | --- | 80 | 186 |
| Do | 55 | --- | 60 | 209 |
| Do | 50 | --- | 44 | 103 |
| Do | 45 | --- | 32 | 137 |
| Do | 40 | --- | 26 | 60 |
| Thin film residue | 77 | --- | 90 | 141 |
| Do | 60 | --- | 36 | 41 |
| Do | 50 | --- | 24 | 11 |
| Do | 45 | --- | 18 | 7 |
| From pavement | 77 | 5 | 86 | 82 |
| Do | 77 | 12.5 | 47 | --- |
| Do | 77 | 20 | 39 | 7 |
| Do | 77 | 35 | 33 | 12 |
| Section G-2: | | | | |
| Original | 60 | --- | 74 | 242 |
| Do | 50 | --- | 40 | 225 |
| Do | 40 | --- | 21 | 200+ |
| Thin film residue | 77 | --- | 75 | 183 |
| Do | 60 | --- | 30 | 96 |
| Do | 50 | --- | 17 | 16 |
| Do | 40 | --- | 10 | 6 |
| From pavement | 77 | 7.5 | 62 | 100+ |
| Do | 77 | 16 | 52 | 100+ |
| Do | 77 | 30.5 | 34 | 96 |
| Section H: | | | | |
| Original | 60 | --- | 69 | 246 |
| Do | 50 | --- | 33 | 198 |
| Do | 40 | --- | 16 | 250+ |
| Thin film residue | 77 | --- | 107 | 142 |
| Do | 60 | --- | 36 | 250+ |
| Do | 50 | --- | 16 | 250+ |
| Do | 45 | --- | 12 | 109 |
| From pavement | 77 | 5 | 109 | --- |
| Do | 77 | 12.5 | 61 | --- |
| Do | 77 | 20 | 40 | 31 |
| Do | 77 | 35 | --- | 100+ |
| Section J: | | | | |
| Original | 60 | --- | 77 | 242 |
| Do | 55 | --- | 54 | 250+ |
| Do | 50 | --- | 40 | 250+ |
| Do | 45 | --- | 28 | 250+ |
| Do | 40 | --- | 19 | 119 |
| Thin film residue | 77 | --- | 127 | 184 |
| Do | 60 | --- | 44 | 250+ |
| Do | 50 | --- | 26 | 89 |
| Do | 45 | --- | 19 | 21 |
| From pavement | 77 | 5 | 154 | --- |
| Do | 77 | 12.5 | 95 | --- |
| Do | 77 | 20 | 58 | --- |
| Do | 77 | 35 | 70 | 100+ |

[1] Data for original asphalts and thin film residues obtained by Bureau of Public Roads Tests. Data from pavement samples taken from report by Hveem, Zube, and Skog (*5*).

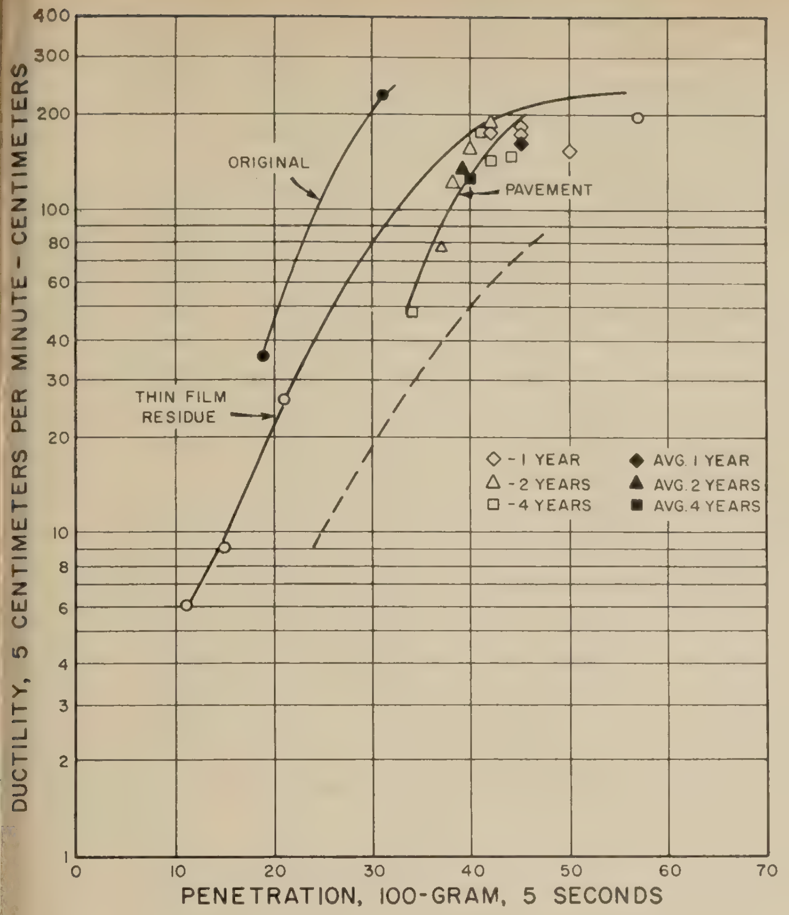

*Figure 11.—Ductility-penetration relation for asphalt C used in Virginia experimental project. Tests on original asphalts and thin film residues were made at different temperatures, and those on asphalts recovered from pavement were made at 77° F.*

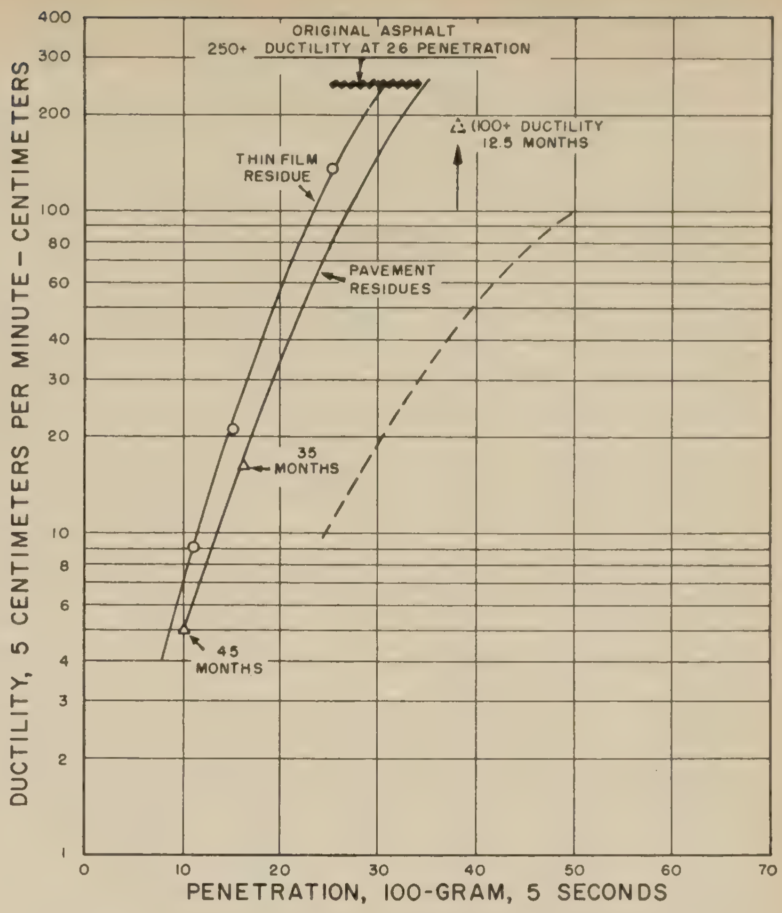

*Figure 12.—Ductility-penetration relation for asphalt E in Zaca-Wigmore experimental project. Tests on original asphalts and thin film residues were made at different temperatures, and those on asphalts recovered from pavement were made at 77° F.*

the asphalt characteristics. Table 3 shows the test data from both sources. Sections E, F, and G all showed relatively poor performance. Figure 12 shows the ductility-penetration relationships of the asphalts used in section E. This asphalt lost 4.45 percent by weight and retained only 27.7 percent of its original penetration in the thin film test, thus it would not comply with the asphalt specification now being used in California. The 1959 progress report showed that section E had failed in 1958. Figure 12 confirms the conclusion that the early failure of this section can be attributed almost entirely to the hardening caused by the high degree of volatility of this asphalt. The asphalts recovered from the pavement at 35 and 45 months had penetrations at 77° F. of 16 and 10 respectively but showed essentially the same ductility-penetration relationship as the thin film residue tested at different temperatures. It can be concluded from these test results that oxidation has not caused large changes.

The data reported for the asphalt used in section F and shown in figure 13 are more erratic. This asphalt also had a high loss (2.25 percent) and a low retained penetration (34.7 percent of the original) in the thin film test. The characteristics of the asphalts recovered from pavement samples at different periods suggest that this asphalt may be subject to rapid oxidation in the road as well as have considerable volatility. Based on the arbitrary dividing line, the asphalt recovered at 38 months had a relatively unsatisfactory ductility-penetration relationship. At 54 months the range of ductilities of the recovered asphalts was 7 to 83 cm. for 9 cores. The average penetration was 25. It is possible that the variation in penetration of the asphalt recovered from each core would account for a large proportion of the difference in ductility, but it is also possible that localized variations in conditions after construction permitted a variable amount of oxidation of the asphalt.

The ductility-penetration relationships shown in figure 14 for the asphalts used in sections G and G–2 are of interest. Hveem and his coauthors (*5*) reported that a change in the refinery methods or crude sources was made by the manufacturer of the asphalts used in these sections, but the reported differences in laboratory tests were small. However, the hardening that occurred during mixing for asphalt used in section G was considerably greater than for asphalt used in section G–2, the percentages of retained penetrations were 45.1 and 71.8, respectively.

The results of tests on the original asphalts and the thin film residue for asphalt from section G shown in figure 14 indicate that this asphalt is subject to considerable change in the ductility-penetration relationship during the thin film test and thus is also likely to undergo rapid changes in pavement service. The data for the asphalts recovered from the pavement confirm that changes in the ductility-penetration relationship had occurred. All of the ductility-penetration data points fall somewhat below the thin film residue line and also below the arbitrarily established critical boundary.

Although test results reported for the asphalt used in section G–2 indicated that it was similar to the asphalt used in section G, the test results plotted in figure 14 show that the thin film residue of the asphalt in section G–2 had a ductility-penetration relationship that was definitely superior to that of the thin film residue of the asphalt used in section G. The data point for the asphalt recovered from the pavement at 30 months shows that at this age the asphalt still retained a good ductility-penetration relationship. It is believed that a significant factor in the better performance of pavement in section G–2 reported in the 1959 progress report is this better ductility-penetration relationship as well as a slower rate of hardening of the asphalt.

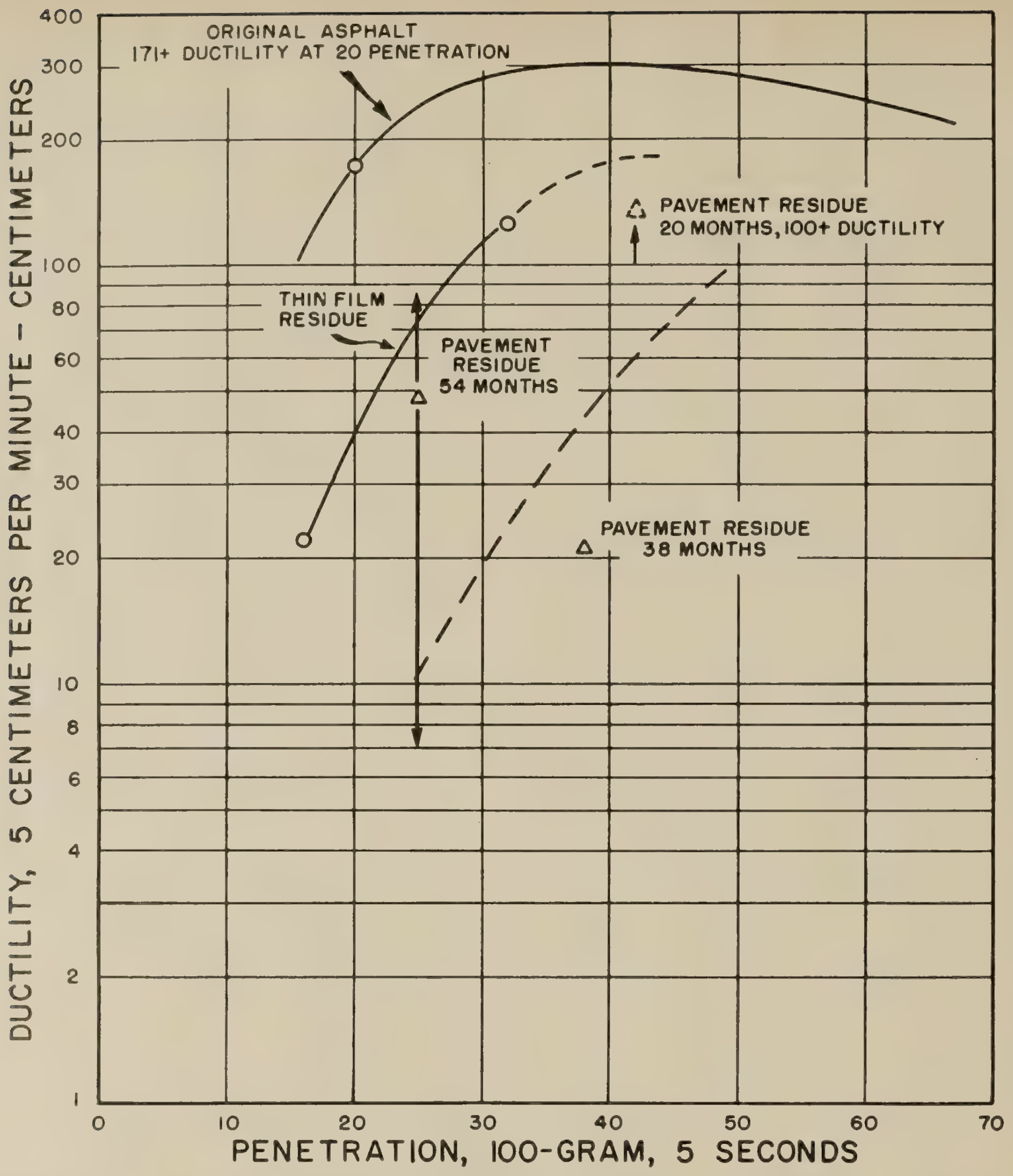

*Figure 13.—Ductility-penetration relation of asphalt used in section F of Zaca-Wigmore experimental project. Tests on original asphalt and thin film residue were made at different temperatures, and those on asphalts recovered from pavement were made at 77° F.*

### Effect of difference in asphalt content

Two sections of the Zaca-Wigmore road were designated I–2. One of these contained 5.8 percent and the other 6.3 percent asphalt. The asphalts recovered after several periods of service were significantly different. The penetrations reported in 1959 for section I–2 containing 6.3 percent asphalt were 71, 55, and 51 when recovered at 7.5, 16, and 30.5 months respectively. Ductility, reported only for the 30.5-month sample, was 96 cm. Penetrations for the asphalts recovered from the section containing 5.8 percent asphalt were 56, 38, and 25 and had corresponding ductilities of 95, 10, and 6 cm. Although data for the thin film residues and original asphalts at temperatures other than 77° F. are not available for these sections, figure 15 shows that the ductility-penetration relationship for the sample at 30.5 months from the section containing 6.3 percent asphalt was essentially the same as the relationship for the sample obtained at 7.5 months from the section containing 5.8 percent asphalt. This indicates that the lower rate of hardening in the section containing the higher asphalt content was the result of increased protection against oxidation.

The asphalt used in section J was included in the California experiment because it was considered to represent a high quality product. The service record of this section was reported to be excellent in the 1959 progress report. The ductility-penetration relationships of this asphalt, based on tests at different temperatures and shown in figure 15, show that th original asphalt retained a high ductility for relatively low penetration. All test results fo ductility were more than 200 cm., except fo the test made at 40° F. for which the ductilit was 119 cm. and the penetration was 19. Th ductility at 19 penetration for the thin fil residue was 21 cm., considerably less than fo the original but still well within the are considered satisfactory. The available dat from asphalts recovered from the pavemen section shows that at 35 months the ductilit at 77° F. was greater than 100 cm. and th penetration was 70. Thus, the ductility an penetration of this asphalt in the pavement i not likely to become critical even at relativel low service temperatures.

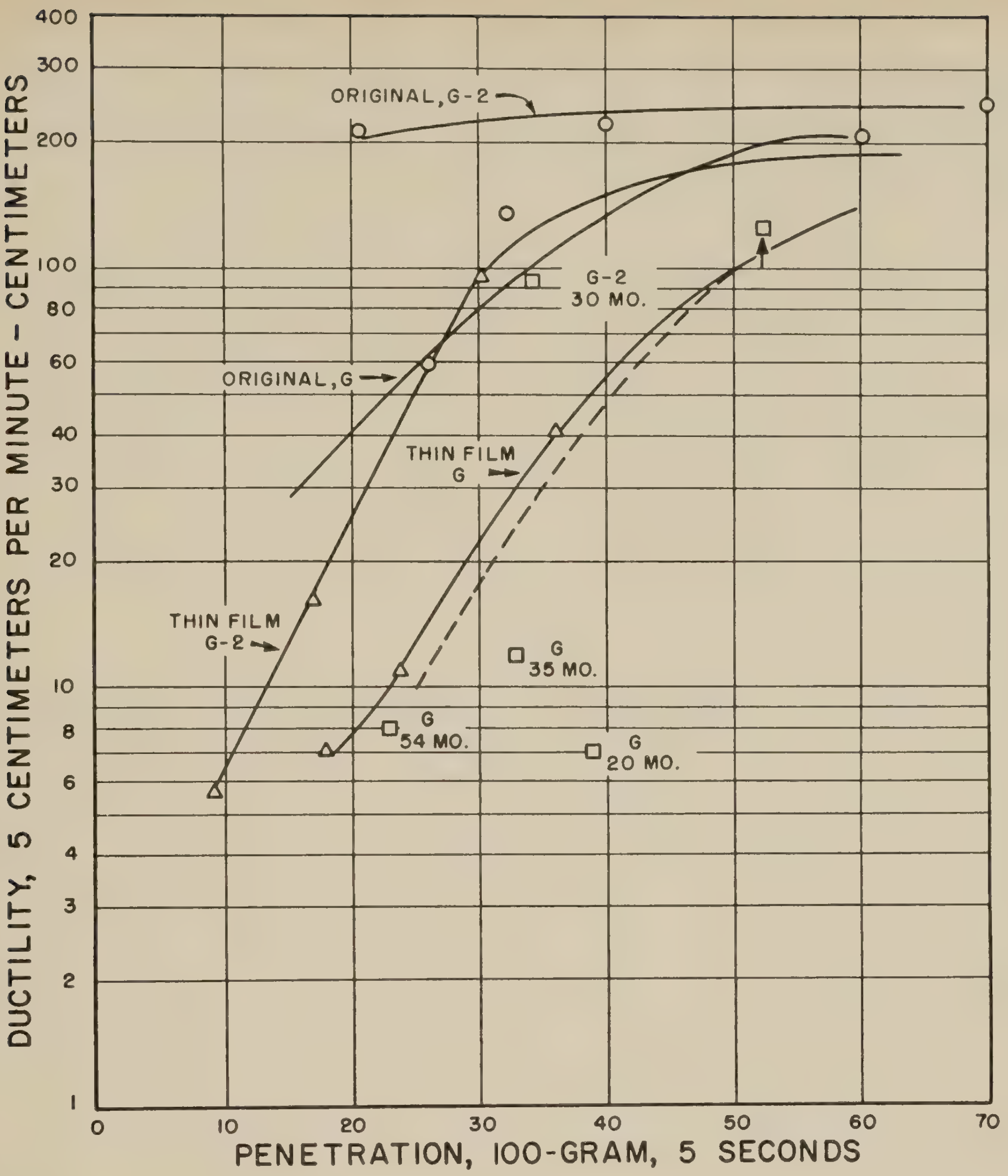

*Figure 14.—Ductility-penetration relation of asphalts used in sections G and G-2 of Zaca-Wigmore experimental project. Tests on original asphalts and thin film residues were made at different temperatures, and those on asphalts recovered from pavement were made at 77° F.*

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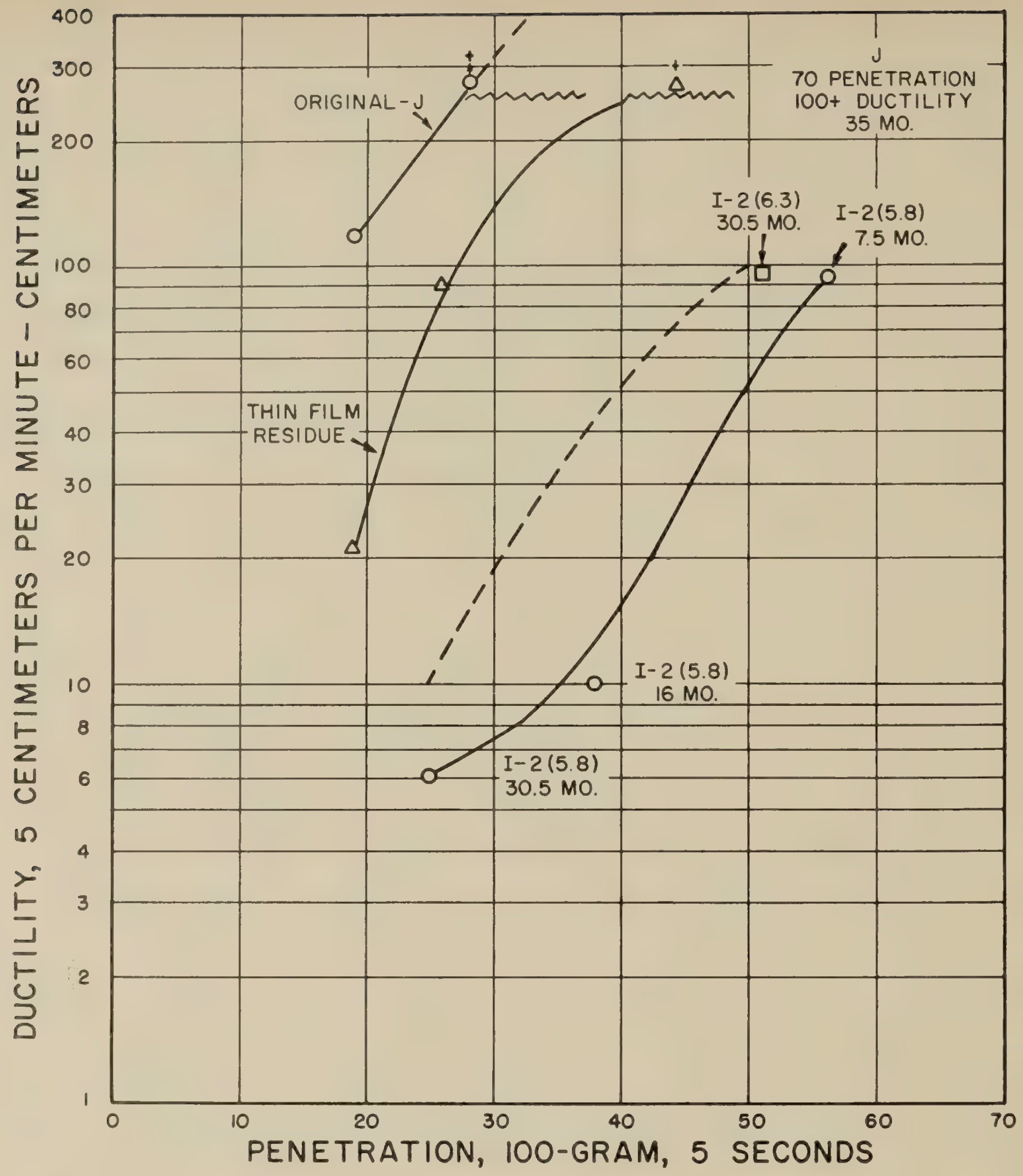

*Figure 15.—Ductility-penetration relation of asphalts used in sections J and I-2 of Zaca-Wigmore experimental project. Tests on original asphalts and thin film residues were made at different temperatures, and those on asphalts recovered from pavement were made at 77° F.*

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