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COMMISSIONER OF HIGHWAYS

COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
FRANKFORT

April 20, 1956

ADDRESS REPLY TO
DEPARTMENT OF HIGHWAYS
MATERIALS RESEARCH LABORATORY
132 GRAHAM AVENUE
LEXINGTON 29, KENTUCKY

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MEMO TO: D. V. Terrell
Director of Research

Approximately a year ago the Research Division prepared a preliminary report on the performance of Rock Asphalt*, analyzing the various factors that logically would be involved in the functioning of this material as a pavement surface, and making recommendations on studies that should be carried out to determine fundamental composition, treatments, specifications, and other aspects of its use on a dependable basis. As you know, the project was approved and a comprehensive study in the laboratory, at the production plant, and with full-scale pavement test sections was carried out. The results of that work to date are contained in the attached "Report No. 2 on A Study of the Properties and Performance of Kentucky (Natural Sandstone) Rock Asphalt", by J. H. Havens and E. G. Williams.

Variations in composition and consistency of the natural asphaltic binder in the rock asphalt anticipated on the basis of past observations were confirmed, and several other properties of the material important to its performance were defined. Some of the outstanding characteristics thus developed are:

1. Light oils which volatilize (and perhaps oxidize) rather readily when exposed in summer atmospheric conditions, in combination with occluded moisture, account for the softness or hardness of the asphaltic binder.
2. Separation or stripping of the asphalt from sand particles in the presence of moisture and particularly moisture subjected to agitation is facilitated by the light oils.

* See "A Preliminary Report on the Performance of Kentucky (Natural Sandstone) Rock Asphalt", dated April 12, 1955, and distributed to members of the Research Committee.

3. Curing of the rock asphalt is negligible (practically no conversion of the light oils) when the material is stockpiled in large quantities. Only a thin, hard crust is formed.
4. Steam heating of rock asphalt for placement is not compatible with low moisture contents, since the quantity of steam required to raise the temperature of the rock asphalt to the desired level is great and the volume of condensed moisture trapped within the material will likewise be great.
5. The asphalt content of the rock asphalt as quarried and crushed for delivery is lower than the value indicated for maximum stability and optimum void relationships commonly applied to compacted bituminous paving materials.
6. Additions of asphalt cement, powdered asphalt of a certain description, some antistripping agents, or the use of dry heating to volatilize the light oils and bring the binder to a more uniform and harder consistency, were effective in improving performance characteristics in the test pavement on US 31-W. Various degrees of improvement were achieved, depending on treatments and position on the road.
7. Withholding traffic from the pavement up to three days, and thus permitting the material to cure in the relatively thin layer of pavement, was beneficial in most cases when the rock asphalt was steamed in the usual way, but it was of questionable value in the case of dry heated materials.

These and many other points, including much historical background, are given elaboration in the report. The casual reader will find summaries of the laboratory data and test pavement data, with performance evaluations up to a period of six months, beginning on pages 18 and 35 respectively.

As a result of the information obtained thus far and a request from Mr. Bray that recommendations on procedures or policies best fitted to the coming construction season be developed as early as possible, a memorandum report was written on March 12 and discussed orally with Mr. Bray and others shortly thereafter. That portion of the report dealing with recommended changes in the specification governing rock asphalt was considered by the Specifications Committee, the immediate result being Special Specification No. 62, adopted March 19. I am not certain

of the provisions that went into the 1956 Standard Specifications book now in the process of printing, but I believe several features that had been proposed on the processing and laying of rock asphalt were not included probably because of the disruption that would be caused by making changes in printed copy.

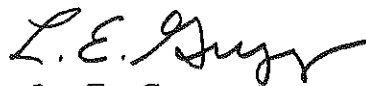
With regard to policies, it was recommended that there be different treatments of the material in accordance with traffic conditions recorded or anticipated on the road. Limitations on data applicable to size and weight of vehicles, in addition to vehicle classification, led to the use of total lane traffic in vehicles per day as a basis for separation into traffic groups, although it is recognized that volume is probably a minor factor and weight a very important factor in determining whether stripping and peeling of the rock asphalt pavement will occur. Differentiations of the traffic volumes and treatments recommended were as follows:

<u>Lane Traffic (v. p. d.)</u>	<u>Treatment</u>
0 to 1500	Natural R. A. (Steamed)
1500 to 2500	Powdered Asphalt Additive (Steamed)
2500 +	Natural R. A. (Dry Heated), or with Asphalt Cement Addition (Dry Heated).

It was anticipated that dry heating would not be feasible during the coming year because of limitations on equipment suitable for the purpose, but apparently those will be overcome in the near future through a program of development on equipment of satisfactory capacity which the Kentucky Rock Asphalt Company is conducting cooperatively with a Midwest equipment manufacturer.

The Research Division is gratified by the large amount of information developed thus far in this project, and I am sure those interested in all phases of rock asphalt will find the report worthy of detailed study.

Respectfully submitted,



L. E. Gregg
Assistant Director of Research

LEG:d1

Copies to: Research Committee
J. C. Cobb (3)

Commonwealth of Kentucky
Department of Highways

Report No. 2

on

A STUDY OF THE PROPERTIES AND PERFORMANCE OF
KENTUCKY (NATURAL SANDSTONE) ROCK ASPHALT

by

James H. Havens, Research Chemist
and
Ellis G. Williams, Research Engineer

Highway Materials Research Laboratory
Lexington, Kentucky
February, 1956

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INTRODUCTION*

Kentucky (natural sandstone) rock asphalt derives its esteem as a highway surfacing material from its uniform appearance on the road, its riding characteristics, and the fact that it affords the highest protection against skidding (slipperiness) of any of the paving materials now generally available (see Appendix IV). The usual methods of handling, steaming, laying and spreading offer some of the conveniences and advantages of a ready-to-use material. Although its service history during the past 50 years has been generally favorable, there has also been a certain amount of risk involved in its use, particularly in recent years on roads sustaining heavy loadings and high volumes of traffic.

There seems to be a rather critical period of conditioning and curing, beginning immediately after paving and extending sometimes through the first year of service, which largely determines the ultimate life of the rock asphalt pavement. The fact that a large percentage of the jobs have survived ascribes some degree of integrity to the material; but in its customary use, it has failed to overcome certain material deficiencies which in some cases have been detrimental to its performance. In the most serious cases, telltale signs of scaling, stripping, or sanding away have appeared within the first few days to a month after paving.

As a result of these uncertainties, the material has been either threatened with condemnation, or in instances actually condemned, on

* For a Historical Sketch and other related reference material see Appendices I through IV at the back of this report.

the basis of modern highway paving requirements. In some states, its use has been restricted to certain types of roads that are lightly traveled, or to maintenance operations; and in others equally distant from the source practically no use has been made of rock asphalt in recent years.

According to records furnished by the Division of Construction with regard to projects under the jurisdiction of that Division, in the six-year period, 1949-54, the mileage of two-lane road in Kentucky surfaced with rock asphalt (usually about 60 to 100 lb. per sq. yd.) ranged from 6.5 to 94.8 miles annually, with an average of 62.2 miles. Performance on these roads has varied widely, most of them having good to excellent records but some showing failures within a few days' time. In general, the pronounced failures have been on moderately to heavily traveled roads; yet, paradoxically, some of the outstanding successes have been on roads of that category.

In April, 1955, the Department requested the Research Division to survey and study the performance of rock asphalt and to prepare a preliminary report outlining in a general way whatever factors or mechanisms were thought to be responsible; and to determine the most promising courses of research leading to the solution of the problem and to ultimate corrective action. The report (1)* combined some factual aspects of performance with a somewhat hypothetical analysis or

* Numbers in parentheses refer to the list of references at the back of this report.

evaluation of the basic and essential requirements for such materials. While that report was originally intended to be a critical analysis of the problem, it also afforded pertinent introductory background to this report.

The preliminary report emphasized the need for basic design data in terms of a conventional mixture design criterion, such as the Marshall method, to establish tolerance limits on optimum asphalt content and consistency. So far as it has been possible to ascertain, these properties and relationships had never been clearly defined for rock asphalt and the material has not heretofore been governed by these conventional standards. This point apparently has been almost totally neglected in past evaluations of rock asphalt. All bituminous pavements, of course, consist of aggregate and a bituminous binding medium; and the measurement and expression of the properties of the mixture provide the basis for engineering judgement and design. Application of this method in determining the ability of the material to perform highway functions is equally important with respect to both natural and synthetic paving mixtures. Changes in proportioning, modification of the properties of one of the ingredients, or the use of an additive to beneficiate either the aggregate or the binder, are means commonly used to provide the necessary properties if a mix is deficient.

The sand in rock asphalt is essentially invariable while the asphalt is greatly variable. Variable consistency of the asphalt and its susceptibility to curing have been recognized, if not thoroughly understood, for almost as many years as the material has been quarried. For equally as many years there have been references in

the literature (see Appendix I and Ref. 2 and 3) to "free sand", "striped sand", and to "partially coated sand" in the quarried rock, in the crushed product and in the material on the road. The very first account of its use (1891) emphasized the fact that the better materials were shiny jet black and thoroughly coated. Moisture, of course, has always been regarded as detrimental to its general welfare.

In view of the angularity of aggregate particles and tendencies toward a certain gradation of rock asphalt sand, attention in the present study has centered on the bituminous binder. From that standpoint, the following expressions while rather axiomatic have been considered as guiding factors:

1. In order for the asphaltic binder to fulfill its intended function, it must be uniformly and thoroughly distributed.
2. The asphalt itself must be sufficiently "hard" or "strong" to impart a safe margin of stability to the compacted materials when it is put in service.
3. The asphalt content must be at least within the optimum range, which imparts the highest stability and strength to the compacted material. In equivalent terms this amount of asphalt provides a complete coating of all aggregate surfaces and a visible contact-point meniscus.

In recent experiences, the condition described as "shiny jet-blackness" has not always been observed. The materials when fresh are more generally grayish brown, drying and curing to a grayish black. Their brownish appearance is a telltale sign of occluded moisture, and their grayishness is a sure sign of bare sand surfaces or "free sand". These are visible evidences of material deficiencies,

or detrimental conditions at the time of construction, which could possibly explain some of the premature failures that have occurred. Evidently, the rock asphalts furnished for paving in the past have often been "borderline" materials without adequate margins of safety, having critically soft asphalts coupled with uneven distribution, thereby placing the material at the mercy of weather and curing conditions.

The initial laboratory studies provided some of the necessary basic information needed to characterize the natural material and to furnish a more reliable basis for judging actual mixture design requirements:

1. The natural material may be compacted to a maximum of about 126 lb. per cu. ft., at which point it contains approximately 30 percent voids in the aggregate structure and 15 percent asphalt by volume (7.4 percent by weight), leaving 15 percent unfilled voids.
2. The optimum asphalt content for maximum stability ranges between 10.5 and 12.5 percent. With this amount of bituminous binder, the maximum density increases to between 130 and 131 lb. per cu. ft.; and the unfilled voids reduce to a value between 5 and 8 percent.
3. Oven curing the natural material for 24 hrs. at 100°C. produces a shiny jet-black appearance, hardens the critically soft asphalt to a penetration of about 50, and produces remarkably high stabilities even at the natural asphalt content (about 7.4 percent by weight).

With these factors known, it appeared promising either to heat-treat the natural material to achieve the desired consistency and distribution of the asphaltic binder, or to heat-treat the material and at the same time supplement the asphalt content. The use of additives of various types offered still different possibilities. In any case, it was desirable to alter the finished material without causing undue embrittlement or excessive plasticity.

In order to gauge the service performance potentials of the rock asphalt when treated in various ways, comparative test sections were laid on a 2-1/2-mile stretch on US 31-W between Kosmosdale and West Point in August, 1955. Variables incorporated into different sections of the test pavement included:

1. Natural material - steamed and laid in the customary manner.
2. Natural material with antistrip additives-steamed.
3. Natural material with powdered asphalt added - steamed.
4. Natural material - dry heated to 235°F.
5. Natural material - dry heated to 300°F.
6. Natural material with 2 percent PAC-3 added - dry heated.
7. Natural material with 3 percent PAC-3 added - dry heated.
8. Natural material with powdered asphalt added - dry heated.

This work was carried out by contract, under the supervision of construction personnel, with personnel of the Research Division cooperating and making observations at the site. All the operations, including sampling for the purpose of acceptance tests by the Division of Materials, were under the supervision of Research personnel temporarily operating a field laboratory at the plant of the Kentucky Rock Asphalt Company at Sweeden, Kentucky.

In the body of this report the presentation of the details on procedures and results of tests is divided into separate sections for the laboratory and field operations, each offering correlative and parallel support to the general approach already outlined.

PART I: INITIAL LABORATORY STUDIES

In the initial laboratory studies, which immediately followed the preliminary report and preceded the road test installation, attempts were made to analyze not only the inherent properties of rock asphalt but also the general effects of different types of treatment. This work was done in conjunction with visits to the quarries and production facilities of the Kentucky Rock Asphalt Company, and to a few highway projects where new surfaces of rock asphalt were being placed. The intent was to obtain representative samples, observe the production operations, and to gain an insight into the effects of production and application methods on the material.

Samples of material for the initial laboratory tests represented six different situations, as follows:

<u>Sample No.</u>	<u>Situation</u>
1	Crust (2 in. deep) on stockpiled material, taken near the toe of a 35,000-ton stockpile exposed through one winter at the KRA plant.
2	Material from greater depth at same location as Sample No. 1.
3	Composite of material at approximately 18-in. depth in upper portion of the stockpile from which Samples 1 and 2 were taken.
4	Composite of material from a smaller stockpile at KRA plant, purportedly somewhat richer in asphaltic binder and containing a harder asphalt, stored more than one year.

<u>Sample No.</u>	<u>Situation</u>
5	Routine sample from a carload of material delivered to the contractor resurfacing Ky. 35 between Junction City and Houstonville.
6	Representative sample from a truckload of material delivered to the McConnaughay Company of Lafayette, Indiana, for trial processing in equipment considered promising for dry heating.

In a general way at least, these samples represented a fair cross-section of the rock asphalt produced by the Kentucky Rock Asphalt Company.

In making the preliminary evaluations, a great deal of emphasis was placed on relationships developed in the preparation of specimens for and results of tests by the Marshall Stability Method. This was not meant to imply that the Marshall method was considered particularly applicable to rock asphalt, nor that stability as such had any direct relation to the difficulties observed in past use of rock asphalt on certain highways. On the other hand, the Marshall method is a recognized procedure which indicates several relationships basic to satisfactory performance of bituminous paving mixes, and for that reason it offered the best means for judging the material in the light of known standards and detecting possible points of weakness that could be given more intensive study.

FUNDAMENTAL TESTS AND ANALYSES

Basic Mixture Design Requirements

Although specifications have traditionally required between 6.2 and 8.5 percent asphalt by extraction, the design-optimum has never

been established except by the inference of similarity to sheet-asphalt mixtures which normally require 10 to 11 percent asphalt or more. In order to assign comparative responsibility to the governing factors and to reveal those factors contributing to the inherent weakness of the mixture, design tests were made on rock asphalt sand (typical gradation shown in Fig. 1) which had been previously washed free of all natural asphalt. PAC-5 was used to prepare controlled mixes in which asphalt content was the only variable, and these were tested in accordance with the Marshall method. The resulting design curves and volumetric relationships are shown in Fig. 2, and the adjudged optimum as indicated there is found to be within the range of 10.5 to 12.5 percent asphalt.

While the optimum agrees with accepted criteria for surface courses, including the 6 percent maximum voids in the compacted mixture, it must be recognized that the original natural material averaging 7.4 percent asphalt and 15 to 20 percent voids had bordered on satisfactory performance for the past several years. Strict adherence to optimum requirements may, therefore, enhance its performance in some respects at the risk of vitiating other desirable features. Very dense mixtures might be more sensitive to oil slick on the surface and thus induce bleeding and slipperiness. Also, wheels seem to leave dry treadmarks on rock asphalt surfaces during wet weather. This may be due, partly at least, to a high percentage of voids and the capacity to relieve hydraulic pressures, which in turn may be related to anti-skid properties. Compromising these issues may shift the most desirable asphalt content to the lean side of the indicated optimum,

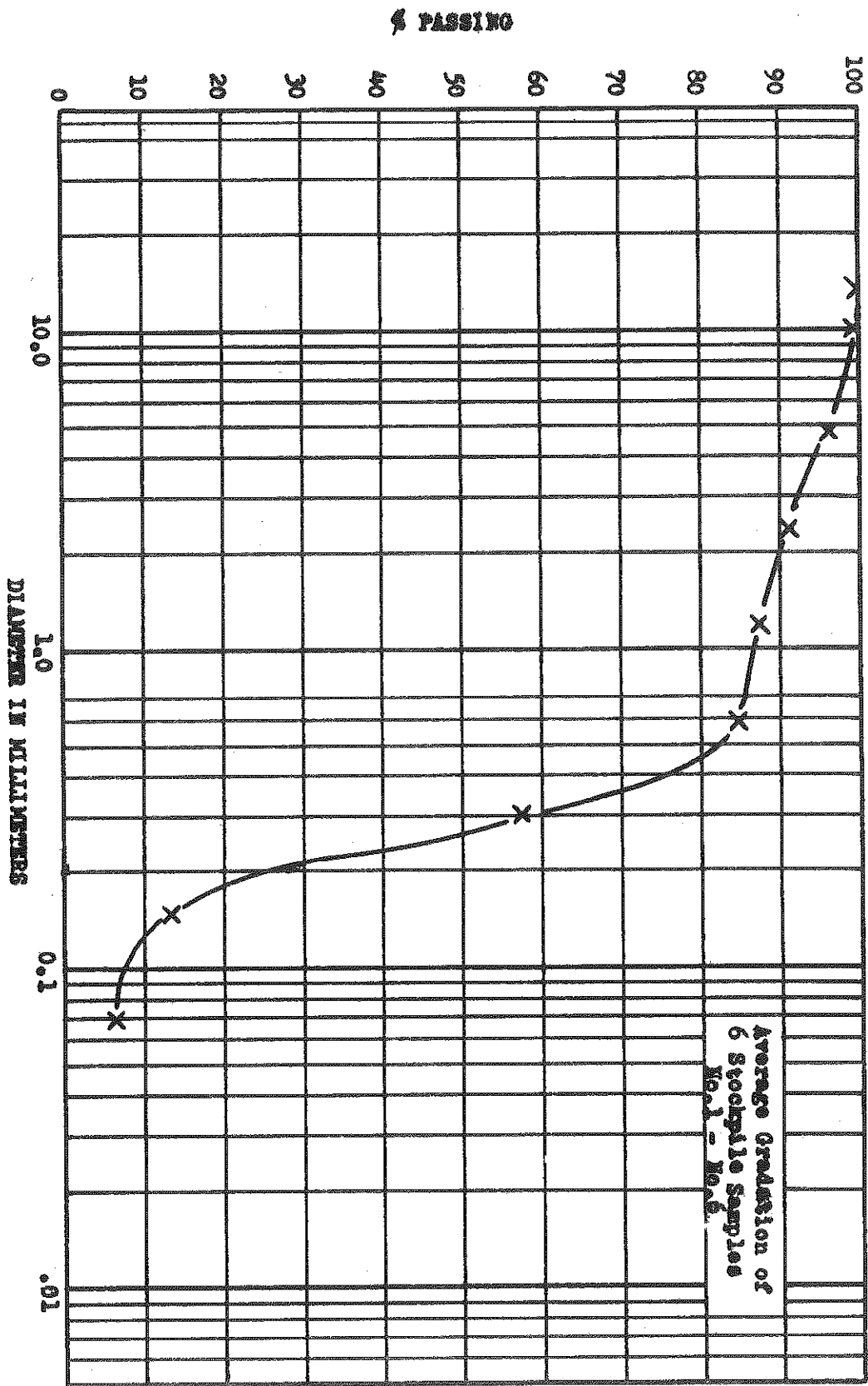
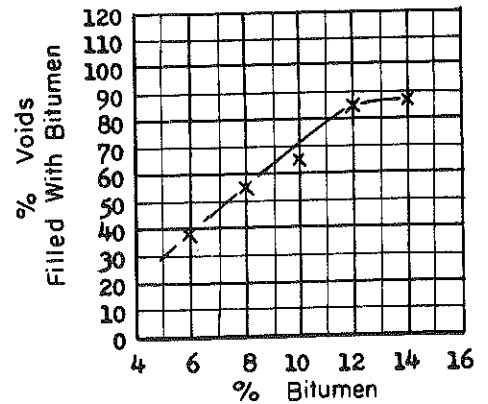
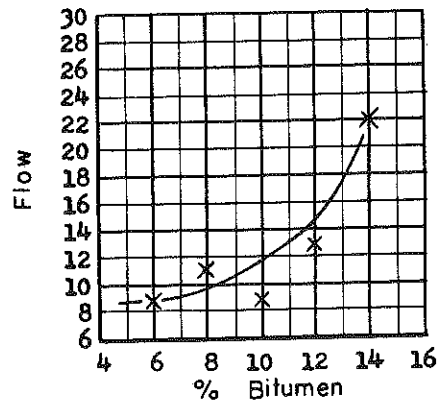
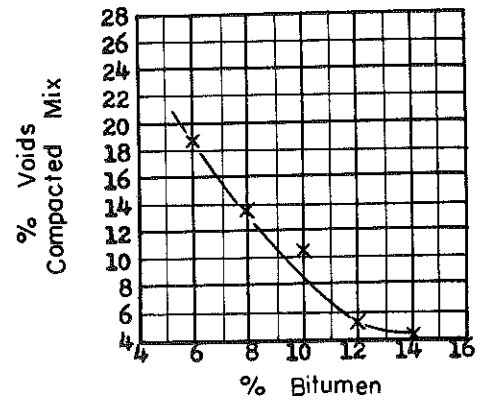
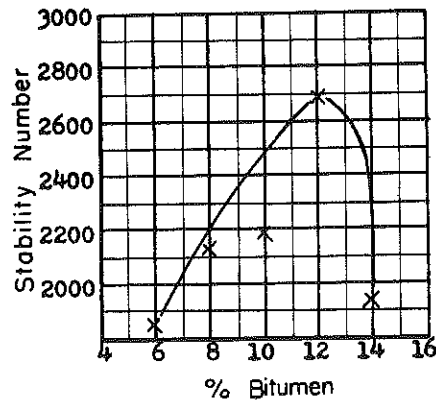
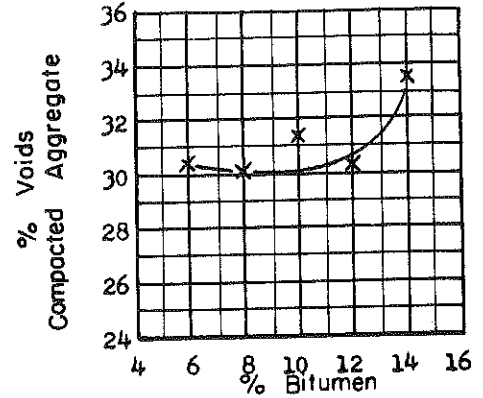
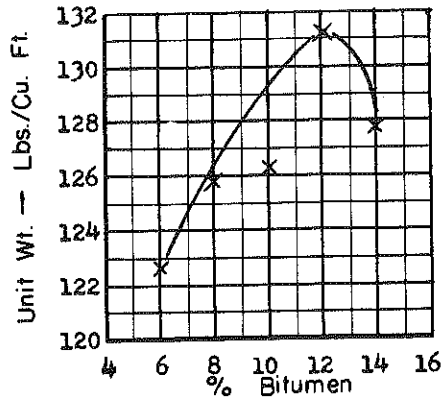


Fig. 1: Average Gradation of Six Samples Used in Laboratory Studies



Tested at 82°F.

TEST DATA

Opt. % Bit. 10 1/2 - 12 1/2 Unit Wt. 130
 Stability No. 2600 Flow 12
 % Voids Comp. Agg. 31
 % Voids Comp. Mix. 6
 % Voids Filled With Bit. 83
 Chart B-3 February, 1955

HIGHWAY MATERIALS RESEARCH LABORATORY
 LEXINGTON, KENTUCKY

MARSHALL STABILITY TEST

Mix No. _____ Date 5-4-55
 Project Laboratory Study - Rock Asp.
 Aggregate Rock Asphalt Sand
 Bitumen PAC - 5

Fig. 2

thereby preserving the highest void content commensurate with highest stability. This would place the adjusted optimum asphalt content in the neighborhood of 9.5 percent.

Effect of Asphalt Hardness on Stability and Strength

The natural asphalts in fresh rock asphalt are shown elsewhere in this report to be extremely soft but capable of curing to a high degree of hardness - extreme range: 400 to 15 penetration. Extremely soft asphalts have very little binding strength and contribute but slightly to the stability of mixtures. Assuming constancy in the gradation of the rock asphalt sand and maintaining a constant asphalt content, the influence of binder hardness may be related directly to stability measurements. Such data, when plotted on semi-logarithmic coordinates (as shown in Fig. 3) were found to yield an almost linear relationship. This is not altogether a new concept in the evaluation of bituminous mixtures, but it is extremely significant to this particular material, which has previously eluded standardization.

The data plotted were obtained from fresh stockpile materials, oven-curing tests, and heat-treating experiments, in connection with the other various phases of the laboratory part of the investigation. All the penetration data were obtained by extraction and recovery of the asphalts. The stability values shown were all measured between 76° and 82°F. This was a necessary departure from the standard method of immersion and testing at 140°F. because the softer samples fell apart in the bath at the higher temperature, indicating zero stability and very low softening points for the asphalt. The values, therefore, are not "pavement design" values in the usual sense.

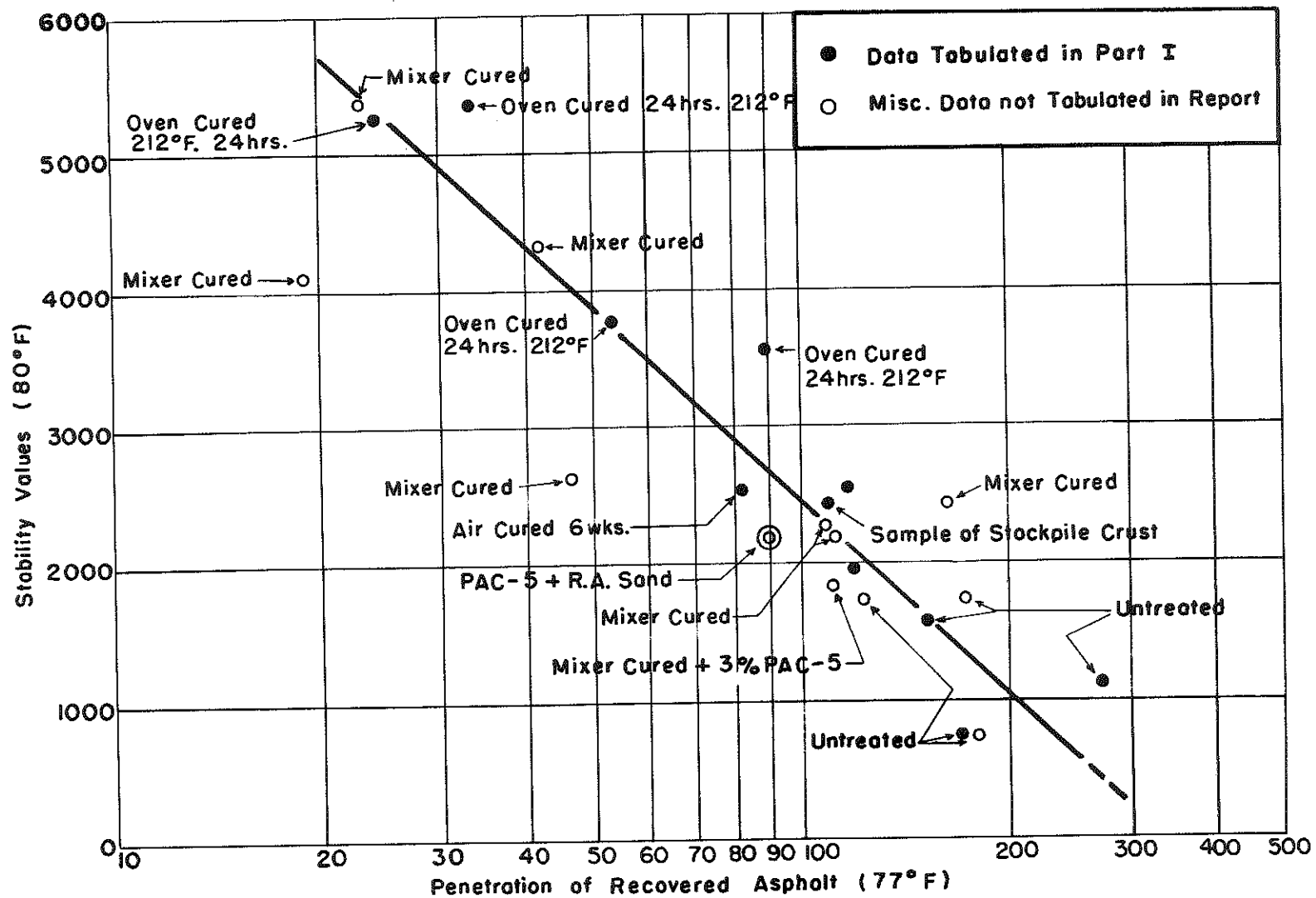


Fig. 3: Semilogarithmic Plot of Stability Values versus Penetration of Asphalt Binder

Effects of Added Asphalt

Design tests on the rock asphalt sand indicated that the natural asphalt content could be advantageously supplemented. Additions of much harder asphalt would therefore offer the twofold advantages of closer-to-optimum asphalt content and increased binder strength.

Several possible supplements, including low-penetration asphalt cements and powdered asphalts, were considered. Asphalt-cement additions would require pre-heating for both the rock asphalt and cement, while powdered asphalts could be intermixed cold. Although test samples were prepared both hot and cold, it was necessary to judge the degree of cold blending, with respect to time, simply by visual observation prior to oven-heating for compacting samples for the stability test. Stability, of course, was the only measurable physical parameter capable of reflecting any net benefit gained by such treatment. All the samples, of course, had to be heated in order to compact the specimens for test, and the effect of this heat more-or-less obscured from the test any influences attributable to autogenous blending.

Two powdered asphalts used in the tests were obtained from the Berry Asphalt Company. One (No. 1) contained 50 percent asphalt (penetration: zero) and 50 percent barium sulfate. The other (No. 2) contained 70 percent asphalt, 25 percent barium sulfate, and 5 percent clay. They were added in the proportion of 1 percent by weight of rock asphalt, giving net increases in asphalt contents of 0.5 percent and 0.7 percent respectively. Some of the test results are shown in the following table. All the samples were heated to 225°F. in an oven, compacted at 200°F., and tested after 24 hours at 75° to 82°F.

TABLE 1: Effects of Added Asphalt Powder on Stability

Sample	% Asp. (Net)	Stability (Treated)	Flow	Lb. per cu. ft.	Stability (Untreated)
No. 2 + add. No. 1	7.4	3290	14	127.3	1130
No. 3 + add. No. 1	6.8	2405	11	123.6	985
No. 5 + add. No. 1	7.0	3405	19	123.7	740
No. 5 + add. No. 2	7.2	1540	12	123.0	740
(Note: Samples below air-cured 48 hrs. prior to heating)					
No. 5 + add. No. 1	7.0	2194	16	128.5	740
No. 5 + add. No. 2	7.2	2395	17	127.3	740
No. 5 + add. No. 2	7.2	3450	18	124.2	740
(Note: Sample below air-cured 12 days prior to heating)					
No. 5 + add. No. 1	7.0	2655	14	124.9	740

After 48 hours of air-curing, powdered asphalt particles were still visible at low magnification; but after 12 days they had blended into the natural asphalt. Subsequent heating produced complete distribution of the asphalt, and all the samples were shiny jet black and thoroughly coated when compacted and tested.

Since the resulting stabilities were much higher than those obtained on the original untreated samples heated, compacted, and tested in the same way, it appears that the added powdered asphalt induced significant hardening in the natural asphalts.

Effects of Oven Curing on Natural Rock Asphalt and Recovered Natural Asphalt

Samples of the natural material taken from the stockpile were placed loosely in shallow pans and exposed for 24 hours in a forced

draft curing oven at 212°F. These materials were then compacted into Marshall specimens (200°F) allowed to set for 23 hours and then tested for stability. The asphalt was then extracted from the broken specimens and recovered for the penetration test. Data from these tests are tabulated in Table 2.

TABLE 2: Properties of Oven-Cured Rock Asphalt

Sample No.	1	2	3	4
Stabilities (80°F)	5255	3795	3540	5370
Flow	14	15	15	16
Asp. Pen., (Recovered)	24	53	88	33
Unit Wt.	121.7	122.3	122.9	119.2
% Voids (agg.)	31.2	31.2	27.4	33.2
% Voids Filled w/asp.	42.1	42.3	42.4	41.5
Voids in Total Mix	18.1	18.0	15.8	19.4
% Asp. by Extr.	6.74	6.72	5.91	7.21

Equivalent data obtained from the fresh, untreated (heated to 200°F for compaction) samples for comparison are given in Table 3.

TABLE 3: Properties of Fresh (Uncured) Rock Asphalt

Sample No.	1	2	3	4	5
Stabilities (80°F)	1590	1130	985	2435	740
Flow	9	8.5	9.5	10	11
Asp. Pen., (77°F)	151	271	Too Soft	109	179
Unit Wt.	120.4	124.5	123.3	119.9	124.2
% Voids (agg.)	32.2	30.4	30.2	32.9	29.2
% Voids Filled w/asp.	42.4	45.6	41.3	43.3	43.6
Voids in Total Mix	18.6	16.5	17.7	18.7	16.8
% Asp. by Extr.	7.07	6.93	6.30	7.40	6.5

All of the heat-treated rock asphalt samples appeared shiny jet black after curing, and there was no evidence of free, or bare, sand

surfaces. They acquired considerable toughness when cooled loose in the pans and showed marked improvement over the fresh, uncured materials.

In conjunction with these tests the natural asphalt was extracted and recovered from fresh rock asphalt, spread 1/8 in. deep in shallow pans, and placed in the curing oven at 212°F for 24 hours. The following data were obtained on the asphalt tested in this manner.

TABLE 4: Properties of Cured and Uncured Recovered Asphalt

Sample No.	1	2	3	4
Pen. (when recovered)	151	271	Too Soft	109
Pen. (after curing)	43	69	49	45
Soft. Pt. (when recovered)	112	101	99	128
Soft. Pt. (after curing)	150	130	114	128
% Loss in Wt. due to curing	4.67	5.72	11.45	4.69

Analysis of Natural Asphalt

The oven tests, already discussed, demonstrated the susceptibility of the natural asphaltic binder to curing and hardening. The fact that such changes occur under accelerated (intensified) and parallel service conditions indicate that the asphalt contained in the rock, as quarried and stockpiled, is immature with respect to its ultimate environment. Apparently the natural asphalts have never been exposed to rigorous distillation conditions, and still retain volatile constituents which would otherwise normally be recovered in petroleum refining or else reduced by air-blowing. On the other hand, the natural asphalt is apparently free of paraffin scale, which distinguishes it as truly asphaltic and capable of reduction (curing) to a consistency and quality equal to paving-grade asphalt cements.

In order to gain further insight into the true character of the natural material and to explore further the mechanisms attending curing, asphalt extracted from stockpile samples was fractionated by selective solubility, in accordance with procedures previously adapted to this type of work (15). These results are given in Table 5.

TABLE 5: Fractional Analysis and Penetrations of Cured and Uncured Natural Asphalts

Sample	Pen.	Asphaltenes %	Resins %	Oils %
Uncured (soft)	200	17.0	28.7	54.3
Cured 24 hrs. (hard)	20	26.4	28.8	44.8

For the sake of comparison similar data from refined petroleum asphalt cements (PAC-5) are shown in Table 6.

TABLE 6: Fractional Analysis of Typical Petroleum Asphalt Cements (PAC-5)

Sample	Pen	Asphaltenes %	Resins %	Oils %
A-1: PAC-5	90	15.0	14.6	66.4
Cured 7 days	21	19.3	22.0	59.7
B-1: PAC-5	89	17.8	22.9	53.7
Cured 7 days	23	25.9	23.9	47.5

(Note: Sample A-1 is a straight reduced midcontinent asphalt. B-1 is straight reduced Venezuelan asphalt.)

Curing of the soft natural asphalt for 24 hours at 100°C caused a loss of approximately 8 percent by weight; whereas the asphalt cements lost only about 1 percent in seven days at 100°C.

From these results, it seems that the curing mechanism involves a loss of oils and a conversion of oils to resins and asphaltenes. In the case of the asphalt cements the loss in weight seems insignificant; and the changes that occurred are, therefore, largely chemical. During oven curing of the rock asphalt material, there were distinct musty odors of light oils being dissipated, further evidence of susceptibility to heat treatment.

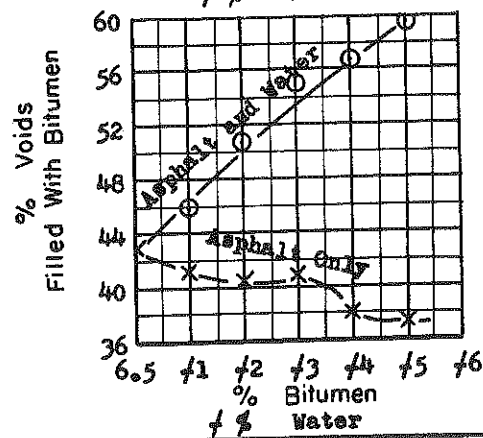
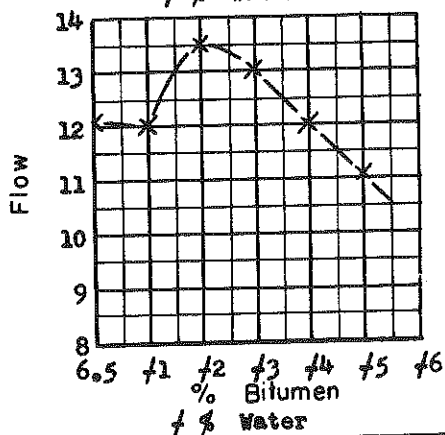
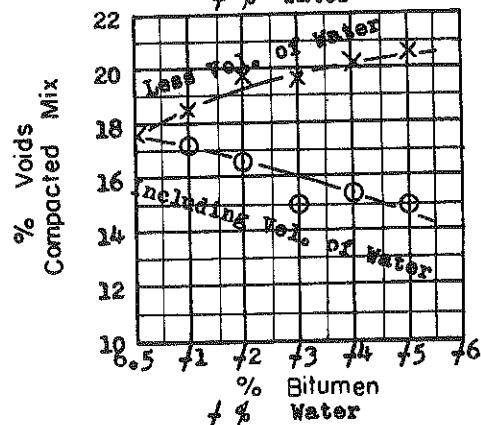
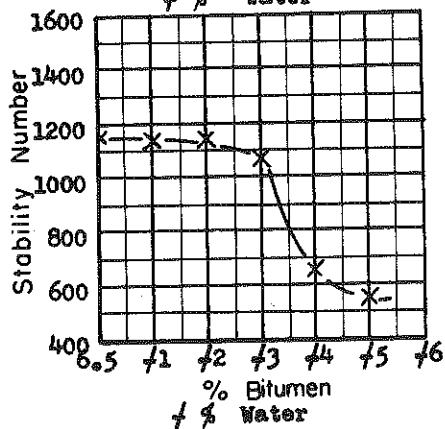
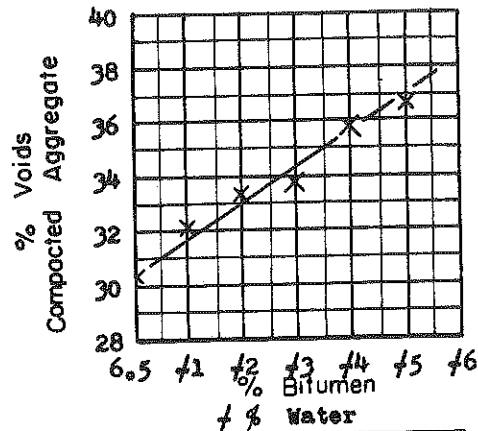
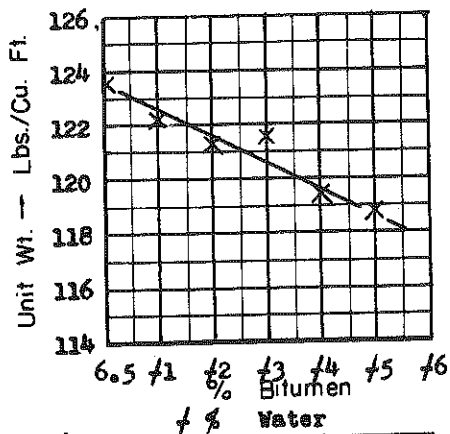
Influences of Moisture on Stability

While moisture is known to influence stripping and curing of the natural rock asphalt, it may also influence compaction and stability on the road. To examine this possibility, rock asphalt sand was recombined with extracted natural asphalt (pen. 188) to give an asphalt content of 6.5 percent. This mixture was heated to 200°F, and hot water was added, with mixing, in increments of 1 percent until a maximum of 5 percent moisture was obtained. Samples were compacted after each increment of moisture, and these were tested in the Marshall apparatus. The results of the stability test and the compacted volumetric relationships are plotted in Fig. 4.

The additions of moisture caused the material to assume a progressively brownish color, and the combined effect of the water and the mixing caused very noticeable stripping.

The decrease in densities of the compacted samples may have resulted from free sand inducing additional intergranular friction or from some more obscure influence of the occluded moisture

Compaction Temperature 175°F. / Moisture



TEST DATA

Opt. % Bit. _____ Unit Wt. _____
 Stability No. _____ Flow _____
 % Voids Comp. Agg. _____
 % Voids Comp. Mix. _____
 % Voids Filled With Bit. _____
 Chart B-3 February, 1955

HIGHWAY MATERIALS RESEARCH LABORATORY
 LEXINGTON, KENTUCKY

MARSHALL STABILITY TEST

Mix No. _____ Date 5 - 12 - 55
 Project Laboratory Study of R.A.
 Aggregate Rock Asphalt Sand
 Bitumen Natural - 188 Pen.

Fig. 4

on the asphalt. The loss of stability, therefore, may have resulted from the loss of density as well as from deterioration of the asphalt's cohesive strength.

Effects of Quarry Water on Stripping

During the past few years, since scaling and stripping of rock asphalt surfaces has become rather critical, there has been some conjecture about the possibility of natural mineral acids and salts in the quarry waters and the rock deposits inducing a susceptibility to stripping and, possibly, scaling. While, it is true that the adhesive bond may be weakened or destroyed by obscure chemical agents acting on the interface, it is also true that a normal asphalt film may strip away when stressed beyond its fundamental bonding strength. Considering that the quarried and crushed material has been in contact with ground water and moisture for quite a long time, it is quite possible that the interface has never been completely free of moisture (dehydrated) since the petroleum first infiltrated the sandstone. Logically, though, a very definitely improved ionic bond fixation, as well as a mechanical one, may be induced by heating and drying the interface of absorbed moisture, thereby securing it against subsequent invasion of moisture. Material that has achieved a "fixation" by any means would be less susceptible to any action due to salts and acids because it would be more tightly sealed against water. Both the quartz sand and the asphalt are rather inert to mineral acids, and it is somewhat doubtful that salts or acids could exert a very significant influence on the material unless it were already weakened by absorption of moisture under the asphalt film.

During the month of June, 1955, water samples for analysis were taken from the Kentucky Rock Asphalt Company's No. 5 Quarry (recently opened) and of the rainwater effluent from the stockpiles. Some test results on these samples are shown in Table 7.

TABLE 7: Result of Tests on Quarry Water and Stockpile Effluent

Test	Quarry No. 5	Stockpile
Acidity (pH)	6.4	3.1
Sp. Resistivity	8000 ohms	700 ohms
Pos. Qual. Test for	Ca ⁺⁺	Ca ⁺⁺
Pos. Qual. Test for	SO ₄ ⁼	Fe ⁺⁺
Pos. Qual. Test for	--	Fe ⁺⁺⁺
Pos. Qual. Test for	--	SO ₄ ⁼

Water impounded in this quarry was turbid and the suspended matter was a red, difficultly soluble, ferrous mineral. The stockpile effluent was clear. Sulfides and possibly hydrated iron oxides in the sandstone deposits apparently undergo oxidation and dissolution on exposure to the atmosphere, resulting in calcium and iron sulfates and sulfuric acid within the stockpile. Actually, traces of these salts and acids might be considered more common than uncommon in ground waters for at least half the area of the state, and they would seem to have a greater tendency to produce insoluble organic soaps and to favor adhesion rather than disrupt it. The possibilities of alkali soaps or water-soluble sulfonates being present seem rather remote, but cannot be completely discounted.

Another point of interest in this connection is the formation of white salt on a freshly laid rock asphalt surface as it dries out. Many

experienced pavers regard the appearance of this salt as a good omen. However, it should be more properly interpreted as a sign that the material is drying out rather thoroughly, leaving all the dissolved salts deposited on the surface. They are subsequently washed away by rain and do not reappear.

Effects of Antistripping Additives

Since the normal approach to a stripping problem is often through the use of appropriate antistripping agents, such as amines and water-insoluble soaps, which are known to promote adhesion and facilitate coating, it would have seemed remiss not to examine the benefits that might be gained by their use with rock asphalts, which have an inherent susceptibility to stripping arising from certain deficiencies in adhesiveness. Adhesiveness, or ultimate bonding strength, in an asphalt is generally considered to depend upon the concentration of polar molecules acting as linkages between the liquid-solid boundaries. Antistripping agents are intended to compensate asphalts otherwise deficient in these polar molecules. In rock asphalt, however, the adhesiveness may not depend so much upon the concentration of the polar molecule linkages as upon the electro-chemical structure of the aggregate. Quartz, which comprizes the rock asphalt sand, has very little surface bonding energy in comparison with other mineral aggregates. It is inherently weak in this respect. Thus, even when the maximum adhesive bond strength of a rock asphalt has been obtained, by drying and curing, stripping may be produced by cold-kneading. It was, therefore, by no means a certainty that the adhesiveness of the asphalt would be increased by the use of antistripping agents.

Also, antistripping additives are normally used most advantageously in coating wet aggregates with liquid asphalts in preparing cold mixes. Normally, too, the additives have been either incorporated into the asphalt prior to mixing or else used to pre-heat the aggregate. There seems to be no precedence for adding them to a material such as rock asphalt in which the aggregate and asphalt are already combined. Hence, the only recourse was to dilute the additive with naphtha and to spray the solution into the rock asphalt with vigorous mixing. While this presumably achieved thorough distribution of the agents, the solvent naturally altered the consistency of the asphalt. Subsequent heating for compaction dispelled the solvent, leaving the material fairly well coated.

While it is customary to evaluate stripping resistance by laboratory tests, it is difficult to judge comparative degrees of stripping or of resistance to stripping; and the tests do not provide the realism of long-range service tests. In anticipation of actual field service tests, mixtures prepared as previously described were evaluated in terms of stability and the influence of the additives on the penetration of the asphalt. The data, of course, do not attempt to reflect any direct enhancement of stripping resistance. The results are shown in Table 8, which follows.

Additions shown in the table are expressed as percent by weight of the natural asphalt. In the case of Sample 2 receiving 5 percent additions, significant softening of the natural asphalt resulted; but subsequent heating for compaction evidently compensated for losses in stability otherwise expected. Sample No. 5 showed an improvement in stability with all additions; however, this can not be attributed entirely to the effect of the agents, because the processes by which they were added obviously enhanced the distribution of the natural asphalt.

TABLE 8: Properties of Rock Asphalt Treated with Antistripping Agents

Sample	% Asp.	Pen.	Stab.	Flow.	Unit Wt.
No. 2 (orig. stored 6 wks.)	6.9	82	2510	11.0	121.7
No. 2 (+5% add. No. 2)	6.9	116	2545	11.0	126.0
No. 2 (+5% add. No. 3)	6.9	119	1960	10.0	124.2
(Note: 5% additions undiluted, 0.5% additions diluted 80%)					
No. 5 (orig. from Ky. 35)	6.5	169	740	11.0	124.2
No. 5 (+.5% add. No. 1)	6.5	-	1195	11.5	127.0
No. 5 (+.5% add. No. 1)	6.5	-	1675	13.5	127.3
No. 5 (+.5% add. No. 2)	6.5	-	1355	13.5	127.3
No. 5 (+.5% add. No. 3)	6.5	-	1090	10.5	123.2
(Note: Above samples heated at 225°F, compacted at 200°F, and tested after 24 hrs. Samples below were allowed to cure 48 hrs. in air prior to heating and compacting, test temperatures: 82-85°F)					
No. 5 (+.5% add. No. 1)	6.5	-	990	12.5	124.5
No. 5 (+.5% add. No. 1)	6.5	-	940	14.5	124.2
No. 5 (+.5% add. No. 2)	6.5	-	1095	12.0	124.2
No. 5 (+.5% add. No. 3)	6.5	-	1125	12.5	125.1

Additive Identification: No. 1 - KlingXX, No. 2 - Pave 100, No. 3 - McConnoughay

Effects of Temperature on Compactive Density

Sample No. 5, as used in other tests, was heated to various temperatures and compacted immediately (modified Marshall method) to determine the relative influence of a given compactive effort on the degree of consolidation or density achieved. The results are given in Table 9.

TABLE 9: Properties of Rock Asphalt Compacted at Various Temperatures

Temp. °F	Lb. per cu. ft.	Stability	Flow	Asp. Content %
100	125.4	560	12	6.5
150	123.6	990	15	6.5
190	122.9	1310	10	6.5
225	123.6	1325	10	6.5
275	122.3	1800	15	6.5

Quite contrary to the general concept of stability, the data show a very obvious gain in strength in inverse proportion to density. There is also an inverse relationship between temperature and unit weights obtained. Both factors are probably subordinate to the influence of temperature on the asphalt. The higher temperatures are favorable to an advantageous distribution of the asphalt and to drying and curing the material. The data, therefore, fail to offer a relationship capable of indicating an optimum temperature for compaction. Considering the evanescent character of the natural material and the number of variables involved in its sensitivity to heat-treatment, there seems to be little, if any, possibility of establishing such a relationship by this method.

Effects of Sample Storage

Storage of the samples in the laboratory in cloth and paper bags was attended by progressive curing with respect to duration of storage. While indicating the evanescent character of the material, this greatly complicated the testing. To illustrate this, the penetrations of the re-recovered asphalts at various times up to six weeks are shown in the following table:

TABLE 10: Penetration of Asphalt Recovered From Samples Stored for Various Periods.

Sample	1	2	3	4	5
Pen. as Sampled	169	270	Too Soft	146	179
Pen. after 2 wks.	127	188	152	146	-
Pen. after 6 wks.	96	82	126	66	-

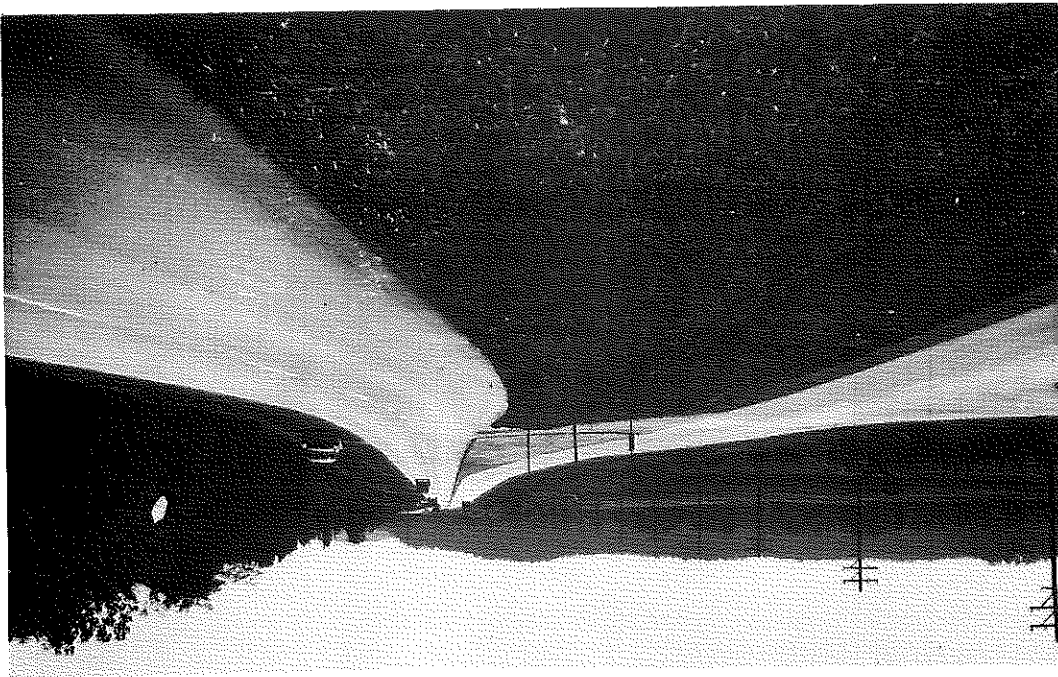
Also, in addition to cases above, a 1-ton stock sample stored outside for a period of four years and originally as soft as the materials above reduced to an average penetration of 45 and an average softening point of 132 °F.

SUMMARY OF LABORATORY TESTS

The most significant development in this phase of the work was the establishment of basic mixture design relationships more favorable to higher and safer margins of stability - by increasing both asphalt contents and binder strengths - and the establishment of favorable effects from heat-treating the natural asphalt to achieve improved binder distribution and cohesive strength. Other results emphasize certain deficiencies in the natural rock asphalt: softness of the asphalt, partially stripped and free sand, lack of stability, curing difficulties, and the detrimental influences of moisture.

The various stability tests do not establish minimum values of stability that would assure satisfactory performance under various traffic loadings and intensities; but they were used here to gauge the improved qualities of the treated materials in terms of over-all serviceability. Collectively, the results did furnish some insight into the mechanisms controlling the physical properties of the materials and provided some of the background necessary to a more decisive appraisal of the materials in actual service tests.

PART II: FIELD PERFORMANCE TESTS (TEST ROAD)



PART II: FIELD PERFORMANCE TESTS (TEST ROAD)

PROJECT DESCRIPTION

While the various tests and results described in Part I capably reflect improved or optimum properties, they fail to establish minimum pavement design standards that would more-or-less guarantee satisfactory performance on the road. In order to establish these design standards and to differentiate between satisfactory and unsatisfactory levels in the controlling properties, recourse was made to a full-scale field service test.

On the assumption that rigorous conditions would permit the earliest and most decisive differentiation between the better materials and the very poor ones, a 2.5-mile section of US 31-W (Kosmodale to West Point) was allocated as a test project for comparative experimental rock asphalt surfaces. This was one of the most heavily traveled roads in the state, carrying close to 20,000 vehicles a day (17,186 by 24-hr. count November 1, 1955).

The location of the project is shown by the map in Fig. 5. The road is approximately 72 miles from the source of the material, near Brownsville. Because the job would require special handling and processing of the rock asphalt, it was elected to truck the hot material from the plant to the paver - about a 2-hr. haul. The job estimate called for 2,785 tons (actual quantity used: 2,763 tons - 288 loads) of material.

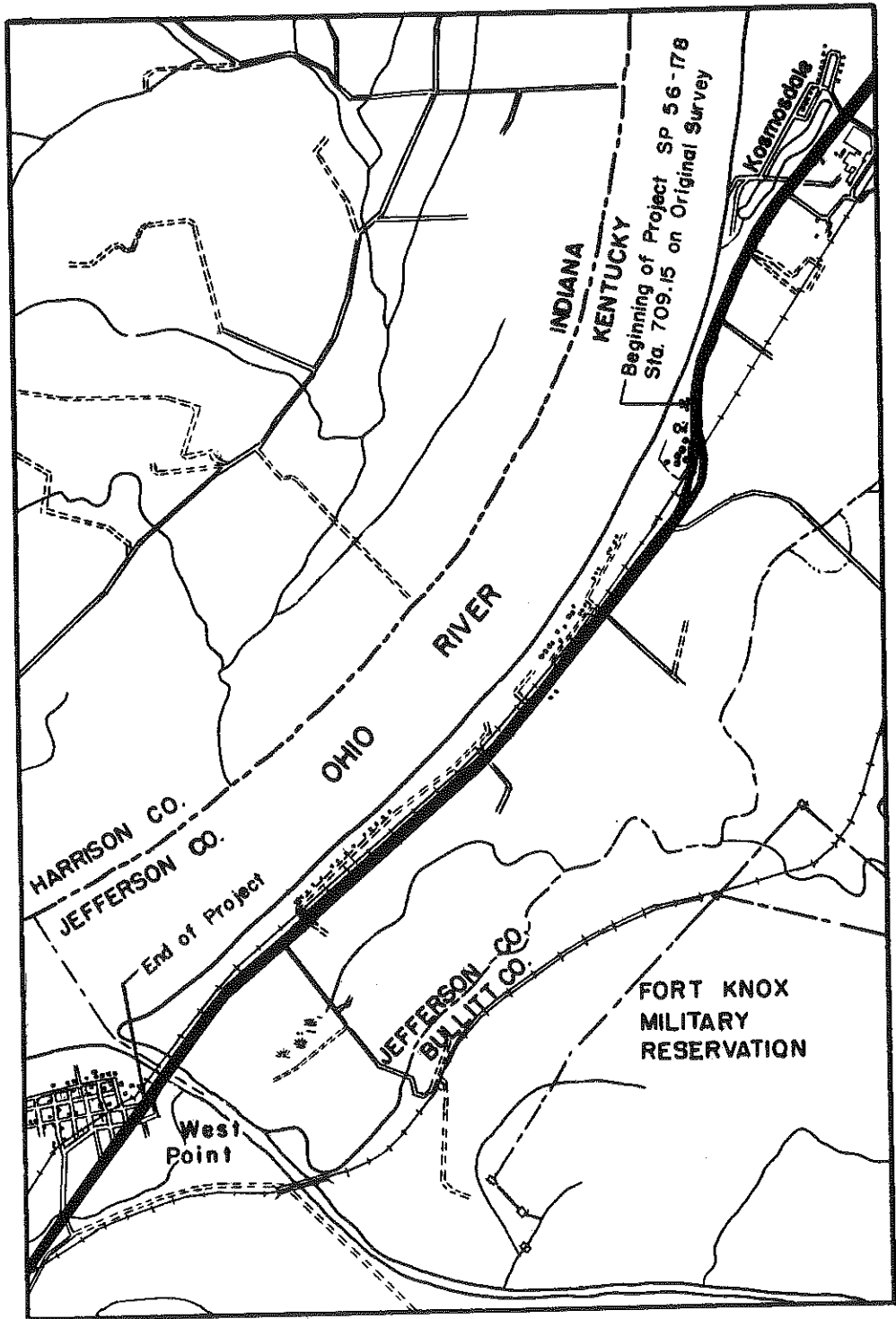


Fig. 5: Map Showing Location of Rock Asphalt Test Project

The original pavement included four 10.5-ft. traffic lanes with a raised median strip 2 ft. wide. The existing pavement consisted of 8 in. of Portland cement concrete with a light rock asphalt de-slicking treatment. The underlying soil was recent alluvium (silty river terrace) and there was some faulting in the concrete pavement. The contract provided for 1.25 in. of Class I, Type-B binder course with a 1-in. rock asphalt surface. The only feature of the existing pavement expected to influence the performance of the rock asphalt surfaces was the faulting joints, which might produce "reflection cracking".

Variables Selected

The variables included in the test road were essentially those included in the preliminary laboratory studies. They are re-enumerated as follows:

<u>Section</u>	<u>Composition and Treatment</u>
I	Untreated R. A.; steamed to 200°F and applied in customary manner.
A	Blend from three quarries; stockpiled 6 months.
B	Blend from three quarries; fresh-quarried material.
C	Selected material (Black Gold), stockpiled three months.
II	Blend from three quarries; fresh-quarried material plus antistripping additives (1 percent by weight of asphaltic binder) steamed to 200°F.
A	Additive No. 1 - Kling XX
B	Additive No. 2 - Pave 100
C	Additive No. 3 - McConaughay
III	Blend from three quarries; fresh-quarried material plus 1 percent powdered asphalt by weight of the R. A., inter-mixed cold; combination steamed to 200°F.
A	Additive No. 2 - 50 percent asphalt (penetration 0), and 50 percent barium sulfate.
B	Additive No. 1 - 70 percent asphalt (penetration 0), 25 percent barium sulfate, and 5 percent clay.

<u>Section</u>	<u>Composition and Treatment</u>
IV	Blend from three quarries; fresh-quarried material, dry heated.
A	Heating temperature 235°F.
B	Heating temperature 300°F.
V	Blend from three quarries; fresh-quarried material, dry heated to 235°F. and asphalt cement (PAC-3) added.
A	PAC-3 addition, 2 percent by weight of R. A.
B	PAC-3 addition, 3 percent by weight of R. A.
VI	Blend from three quarries; fresh-quarried material plus 1 percent powdered asphalt additive No. 2, combination dry heated to 235°F.

The original intent was to allocate equal quantities of material to each of the major sections, paving the full four-lane widths to their proportionate length of the project. It was also intended that the order of paving should provide various curing periods ranging from less than one hour to three days. Other incidental variables were more-or-less unavoidable or expedient to the operation.

PREPARATION OF MATERIALS

Quarrying and Crushing Rock Asphalt

Fresh-quarried material used in control section I-B and in all the treated sections was a blend from three different quarries: Kyrock's Black Gold Quarry (Figs. 6 and 7), their No. 5 Quarry (Fig. 8), and their Dismal Quarry (Fig. 9). The Black Gold has been worked for a great number of years and normally contains a harder type of asphalt than the others. The two quarries were opened within the last two years. The Dismal Quarry product tends to run higher in asphalt content, but it is a much softer grade. Selected rock hauled alternately from the



FIG. 6: West Face of the Black Gold Quarry. Usable rock is shown under the pipe line at the left of picture.



FIG. 7: Close-up View of Freshly Blasted Rock. Pipe is lying on top of the usable ledge.

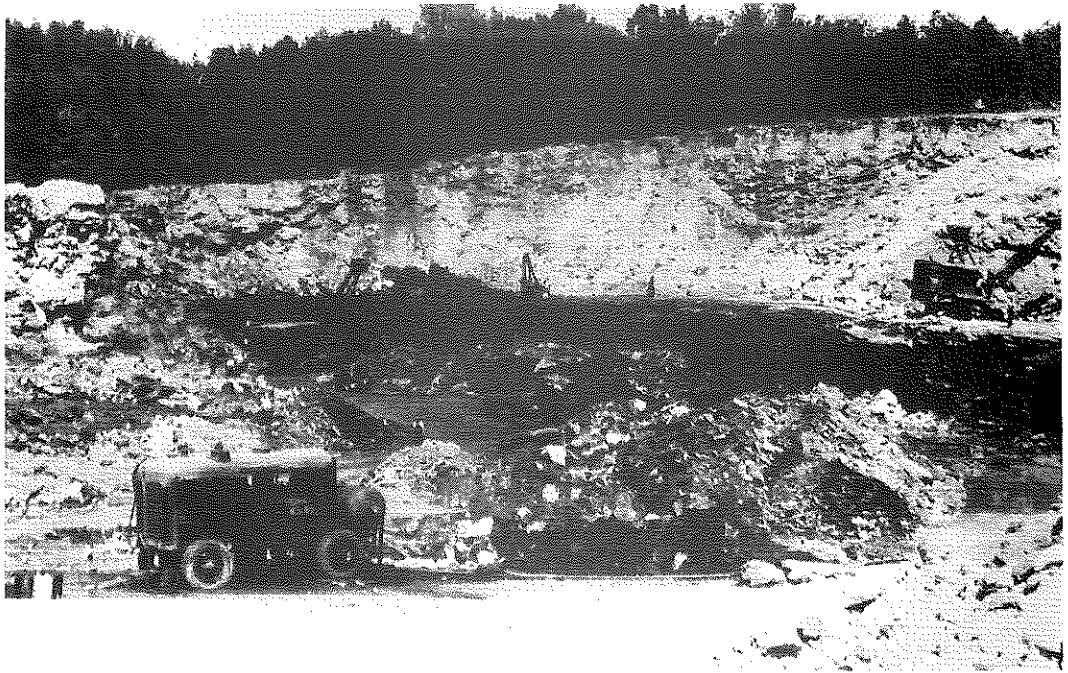


FIG. 8: Kentucky Rock Asphalt Company Quarry Opened About 2 Years Ago. Here the heavy overburden is being hauled away. Shovel is loading usable rock from the quarry floor.



FIG. 9: Recently Opened Dismal Creek Quarry. Photo was taken in early spring prior to the quarrying season.



FIG. 10: Kyrock's Indian Creek Quarry, now Abandoned. About two years ago, material was quarried here by tunneling. The bituminous material here was reported to be rather soft.



FIG. 11: Delivering Asphalt Rock from the Quarry to the Primary Crusher.



FIG. 12: Steaming and Loading Rock Asphalt at the Stockpile.

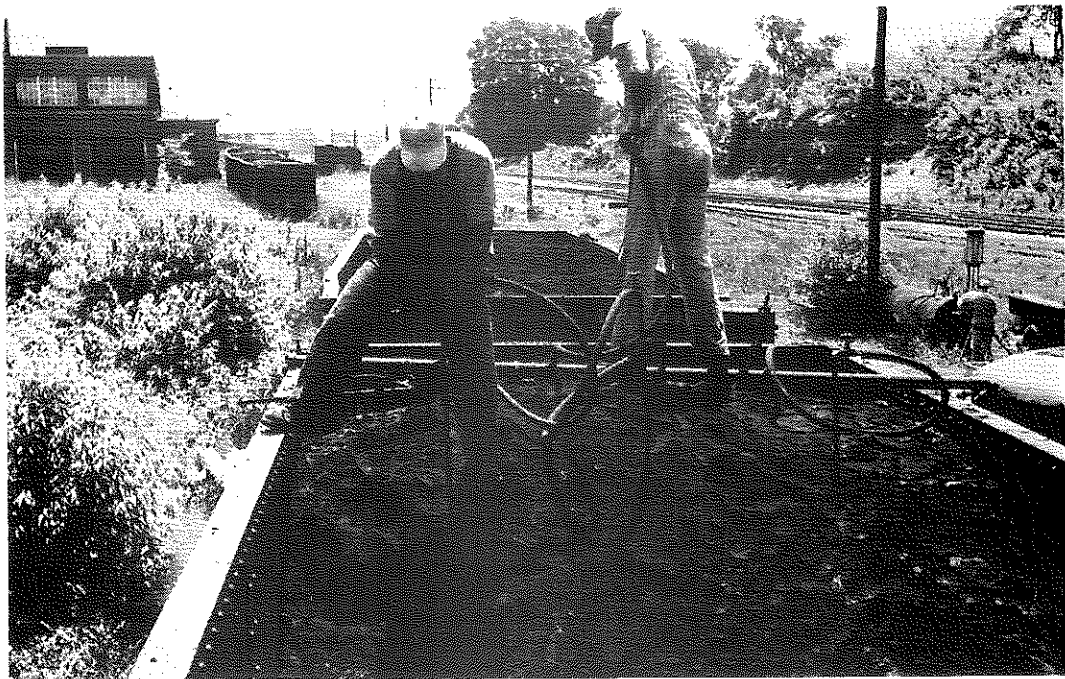


FIG. 13: Steaming Rock Asphalt in Railroad Cars.

three sources supplied material to the primary crusher. Following primary reduction (to about 8-in. maximum size), the material passed by conveyor through a series of rollers to a scalping screen diverting coarse material to a hammer mill for final reduction. Following final screening, the material was either scattered over the stockpile or diverted onto another conveyor and carried to the hopper above the pug mill for mixing the additives.

For the 1955 production season, the average asphalt content by ignition was about 7.45 percent (according to the company's daily records), and there was very little variation from day to day. Experienced quarry men purportedly select only the best rock to be processed and leave a considerable amount of the material on the quarry floor as waste. Where the overburden is heavy, this is stripped and hauled away (Fig. 8). Light overburdens are simply blasted onto the quarry floor to uncover the usable material. The usable material in the Black Gold Quarry (about 15 ft. in depth) is overlaid by about 5 ft. of lean rock, containing approximately 4.5 percent bitumen, which is wasted as overburden. The vast waste piles present a rather awesome spectacle and attest to the expense of the operation. Yearly production may range from 75,000 to over 175,000 tons depending upon the demand for the material.

The rock is moderately cemented quartz sandstone and is crushed to its unit sand sizes. The extracted sand analyzes about 85 percent SiO_2 or about 95 percent insoluble silica. On ignition, the residual sand varies in color from a reddish brown to white, depending on the deposit from which it is taken. The reddish sands may be acid washed to equivalent whiteness.

While it is known that the characteristics of the deposits vary from place to place and from top to bottom of a particular quarry, the purpose of the investigation was not to conduct a critical analysis of the production operations. Rather, the intent was to process normal production material in whatever manner thought necessary to achieve certain properties, or controlled variables, for use in comparative service testing - leading to the establishment of fundamental engineering requirements for the material, regardless of the route or process by which it may be recovered and compounded.

Steam Heating and Its Effects on Rock Asphalt

Most rock asphalt used for machine-spread paving in the past has been preheated by injecting live steam into the stockpiles or railroad cars. This practice has been fairly convenient, rapid, and has eliminated the necessity for other handling of the material. At the same time, there has been a concerted effort to maintain a low moisture content in the material delivered to the job. Specification limitations on moisture have ranged from about 4.0 to 0.5 percent. The general experience shows, of course, that moisture is detrimental to satisfactory performance. The Department's 1945 Standard Specifications required that the material be heated to 180° - 200°F, and have a uniform temperature of not less than 170°F when delivered to the job, and contain not more than 2.5 percent moisture. Indiana's 1946 Standard Specifications required steaming to 200° - 235°F, in 3 hours, using 16 jets per railroad car, and permitted 4 percent moisture.

In selecting various materials to be used for service tests on US 31-W, it was decided that one control section would be laid in the conventional manner and steam heated to about 200°F in the usual way. It was also decided that a second section would be heated to about 235°F by steaming, thereby eliminating practically all moisture. The idea seemed feasible enough because 235°F had appeared in earlier specifications as maximum permissible temperature. Obviously, this was a misconception because it neglected to consider the basic thermodynamic properties of steam. In attempting to achieve this temperature, a 50- or 100-ton stockpile of material was easily heated to 200° or 205°F in 3 or 4 hours of steaming (boiler pressure 125 psi and steam temperature about 350°F). Continued heating, up to 6 or 8 hours, failed to raise the temperature noticeably above 212°F. The reason for this is explainable, of course, by some cursory calculations.

Steam heat is most efficient when it is possible to utilize its latent heat of vaporization - that is, the heat given up due to condensation (212°F). Thus, the sensible heat of steam in going from 350°F to 212°F is very small in comparison to its latent heat of vaporization. Consequently a much greater mass of superheated steam is required to raise the temperature of a body one degree Fahrenheit at any temperature above 212° than at any temperature below 212°F. If steam is being delivered at a constant rate to a mass of rock asphalt, assuming the specific heat for rock asphalt to be about 0.23 btu per lb. per degree Fahrenheit, and neglecting the sensible heat of the condensed steam, it would take approximately 70 lb. of steam (350°F) to heat a ton of rock asphalt from 60° to 212°F. On reaching 212°F, 70 lb. of moisture would have condensed within the mass. Roughly 3.5 percent moisture

would have been added to the material. To dry this moisture out by continued heating with 350°F steam and to raise the temperature of the mass to 220°F would take about 1700 lb. more steam and perhaps 20 times longer.

Of course, the case above has been simplified greatly by the assumption that all of the useful heat of the steam is ideally transferred to the mass and that no losses have occurred. These general relationships are portrayed graphically in Fig. 14.

In steaming bulk quantities of rock asphalt to temperatures below 212°F a layer of condensed moisture is deposited on all surfaces. Even though the asphalt is softened by the heat, it will not effectively displace this moisture from its bare surfaces without the aid of a coating agent; and, therefore, steaming alone is not an effective means of obtaining a uniform distribution of the asphalt or of drying the material. It leaves these two significant factors too dependent upon favorable curing weather and construction techniques. For instance, steamed material delivered to the paver on a warm, dry day is more likely to give satisfactory service than material laid on particularly humid days. Moisture that has not evaporated prior to rolling would be compacted into the pavement and might or might not dry out with time. This circumstance would be aggravated by cool or rainy weather. Under the most favorable circumstances conceivable, there could be sufficient aeration after spreading to permit thorough drying and still preserve sufficient heat to keep the asphalt soft enough to permit compaction by rolling. However, the occurrence of such conditions would be quite rare.

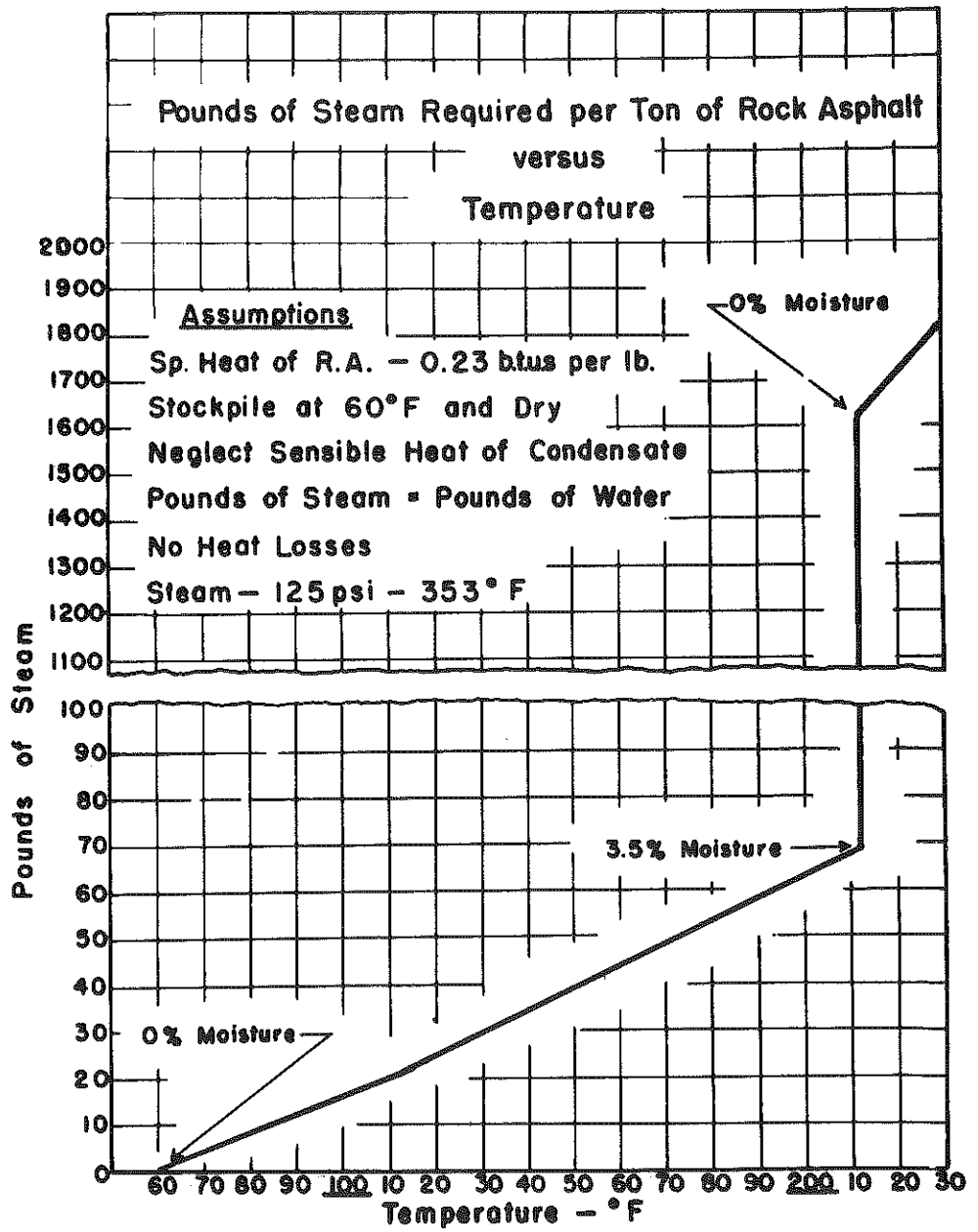


Fig. 14: Theoretically Estimated Relationship Showing the Quantity of Steam Required to Heat 1 Ton of Rock Asphalt to a Given Temperature.

Cold Mixing and Its Effect on Rock Asphalt

Admixtures of powdered asphalt and antistripping agents were added to freshly crushed rock asphalt by mixing cold in a batch-type pug mill. These processed materials were stockpiled and steam heated prior to delivery to the paver. Mixing methods are illustrated by Figs. 15 through 18.

During the processing of the powdered asphalt admixtures, it was noted that the stockpile had several light, grayish streaks and there was a noticeable margin in blackness between each load dumped. At first, it was suspected that the lighter materials had higher than ordinary moisture contents, yet, testing revealed these to be only 1.25 percent. Microscopic examination showed an alarming amount of bare surfaces and stripped sand grains. It had previously been observed that fresh material from the crusher plant was light gray to brownish, and it darkened somewhat after a few days on the stockpile. This same material mixed cold in the pug mill became even lighter in color if mixing continued very long. The addition of powdered asphalt did not noticeably darken these batches. Other batches receiving less mixing came out darker than the normal material already cured in the plant stockpiles. The cold mixing evidently agglomerated the loosely adhering asphalt - which was more cohesive than adhesive - and produced mechanical strip-ping. It is very possible that the freshly crushed rock was more susceptible to this action than cured material, or there may have been a moisture barrier on the silica surfaces which interfered with adhesion.

None of the materials processed in this manner ever quite duplicated the high uniformity of coating and blackness obtained by dry

heating. After two months of service on the road, materials containing powdered asphalt additives (steam heated) were rather variable in this respect, although they were generally tougher and more stable than untreated materials.

Antistripping agents, added in the approximate proportions of 1 percent by weight of the asphalt, were diluted 1 to 3.6 with gasoline, requiring 8.4 lb. of solution for each 2000-lb. batch of material. Mixing the additive, in this case, had a slight darkening effect which doubtless resulted from the presence of the gasoline and its tendency to dilute and liquify the non-uniformly distributed asphalt. Subsequent curing in the stockpile greatly darkened the materials containing antistrip additives No. 1 and No. 2, but not material containing No. 3. The blackest material contained additive No. 2. Odors of gasoline dissipated from the surface of the stockpile within two days and were not detected at all after the material thus treated was steamed for delivery to the paver.

Processed materials containing additives No. 1 and No. 2 remained alarmingly soft for several days after they were put in service on the road, but they were generally shiny black and much more uniformly coated than untreated materials. Additive No. 3 failed to produce the same degree of redistribution of asphalt, resulting in a more harsh material - possibly with a harder asphalt, but less uniformly coated (see Table 14).

Dry Heating and Its Effects on Rock Asphalt

The objectives sought in dry heating were twofold: (1) to dry the material thoroughly, and thereby eliminate moisture as a variable and (2) to raise the temperature sufficiently to "flash off" any lighter petroleum

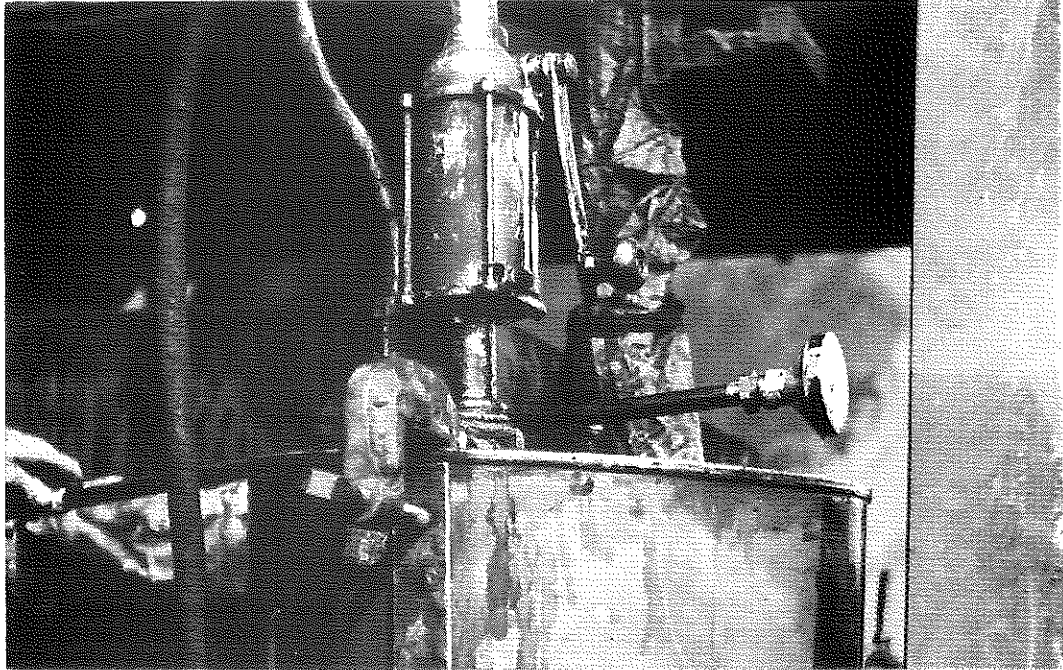


FIG. 15: Barrel Pump and Spray Nozzle Used for Adding Antistriping Agents at the Pug Mill.

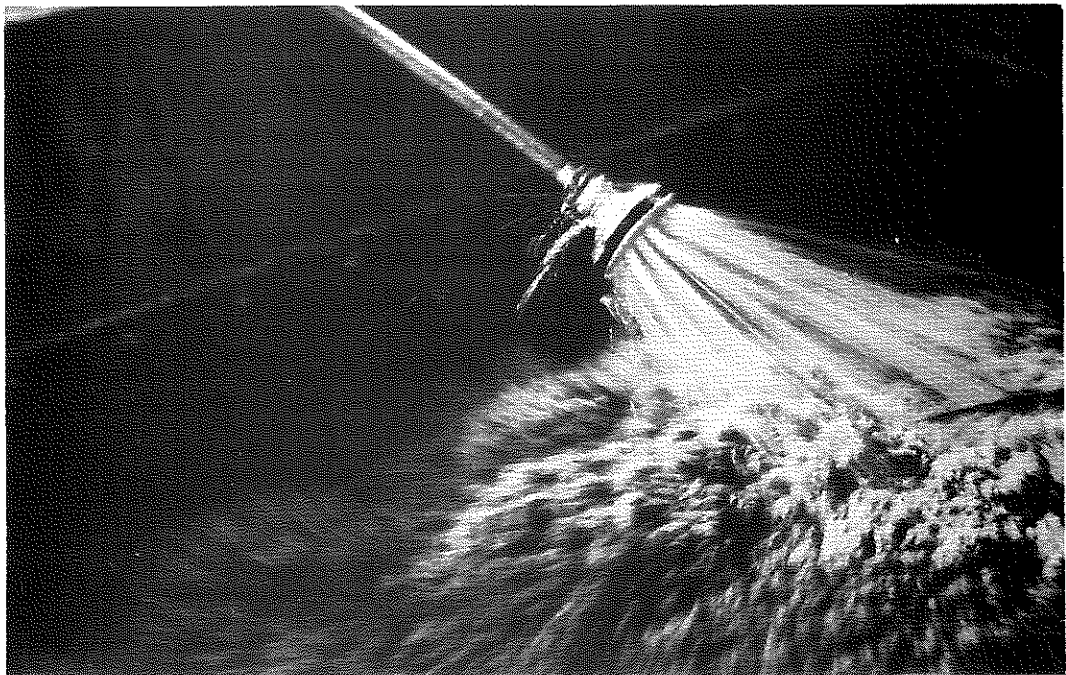


FIG. 16: Spraying Cut Back Antistriping Agents into the Pug Mill.

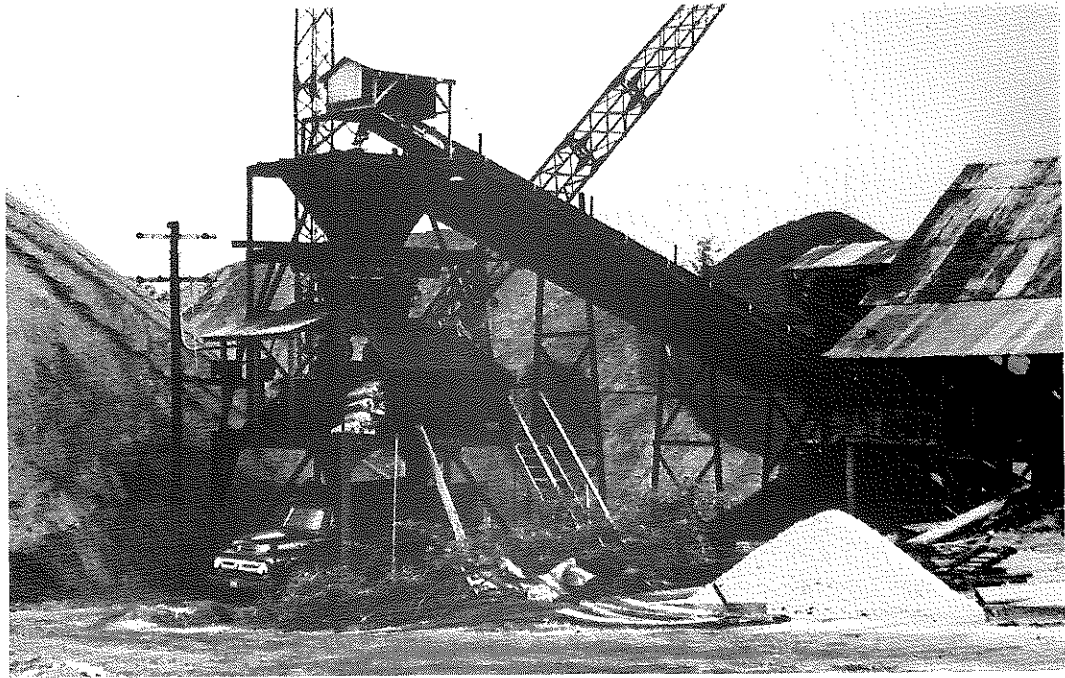


FIG. 17: Pug Mill with Conveyor from Crushing Plant.

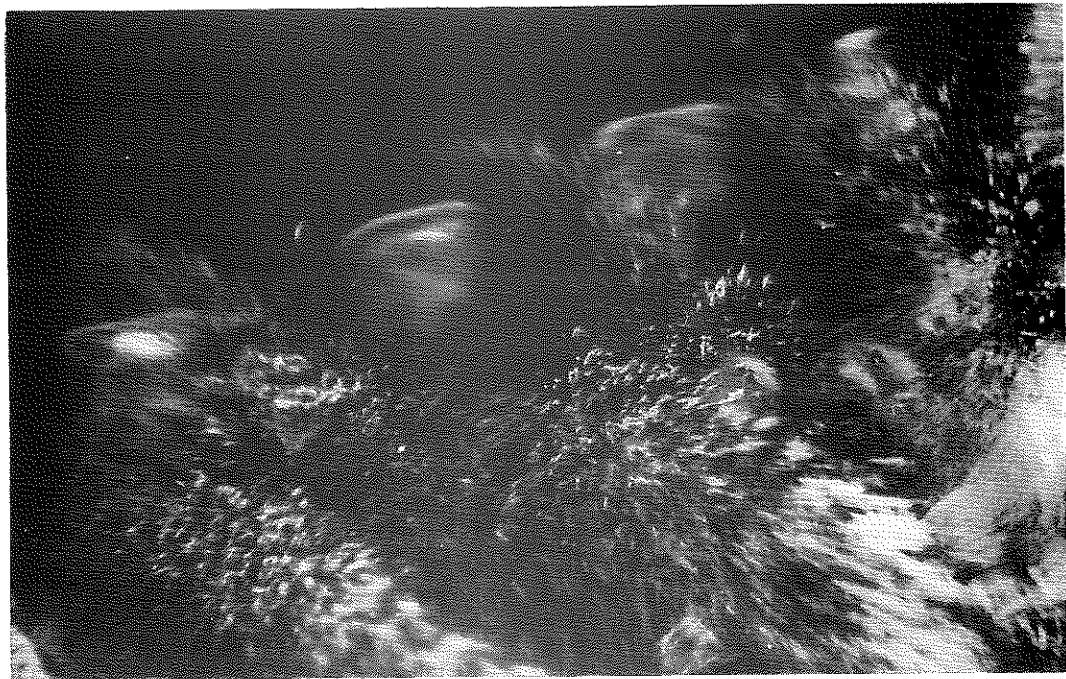


FIG. 18: Mixing Cold Rock Asphalt with 1 Percent Powdered Asphalt.

oils of greater volatility than normal asphalt cements. This would reduce the natural asphalt to an equivalent paving-grade material, or at least more-or-less pre-cure the material prior to spreading on the road.

Some time between 1930 and 1936 some dry heating was done with an aggregate-type rotary drying kiln, and the Department's 1945 Standard Specifications included provisions for dry heating with similar equipment. These cautioned against any direct contact of a flame with the material and against overheating or burning. Temperatures were limited to between 150° and 200°F. Information available implies considerable difficulty in feeding the material through this type of equipment without having it cake and clog the kiln. One instance of record, resulted in failure of Processed Sandstone Rock Asphalt - Hot Mix, used for resurfacing Broadway in Louisville, Barrett to Baxter Streets, in the fall of 1935. The material raveled and had to be removed. The lean rock was heated to 250°F in a kiln-type dryer, and then carried to a twin-pug mixer where asphalt cement was added. Because of the seeming similarity in materials and processing used then as compared with those used in this test project, reports dealing with the construction in 1935 have been reproduced and are included in Appendix III of this report as pertinent information. Apparently, some of the mixtures obtained then were equal in physical properties to mixtures sought in the current test installations on US 31-W. Unfortunately, a full account of the details and circumstances attending the failures was not given in the older report.

As an alternative in planning the new test installations, it was decided to make some trial runs on a direct-flame-heated pug-mixer

(portable patch-mixer) manufactured by K. E. McConnaughay of Lafayette, Indiana. This equipment is illustrated schematically in Fig. 19. It is fired by metered fuel and air, the flame being directed downward into the pug mixer. The rotation of the pug throws the material up into contact with the flame and the hot combustion gasses. Being freely dispersed, the material being treated heats quickly and thoroughly. This particular equipment was of the batch-feed type, handling about 225 lb. of rock asphalt per batch, and requiring about 45 sec. to heat the charge to well over 200°F. Continued heating above 200°F was attended by the evolution of a great volume of white smoke. If heating was continued too far above 350° or 400°F, the asphalt ignited, evolving great quantities of black smoke. Mixing times and temperatures were recorded and samples of the processed materials were taken for laboratory study. The results of the various tests made during trial runs at the McConnaughay Plant in April, 1955, are given in Tables 11 and 12.

TABLE 11: Results of the Trial Runs on HTB Mixer

Heating Time Sec.	Temp Obtained °F	Pen. of Recov. Asp.
(Original untreated material, Sample No. 6, Part I)		172
30	170	164
40	247	111
60	330	109

In a small laboratory pilot model, the following results were obtained:

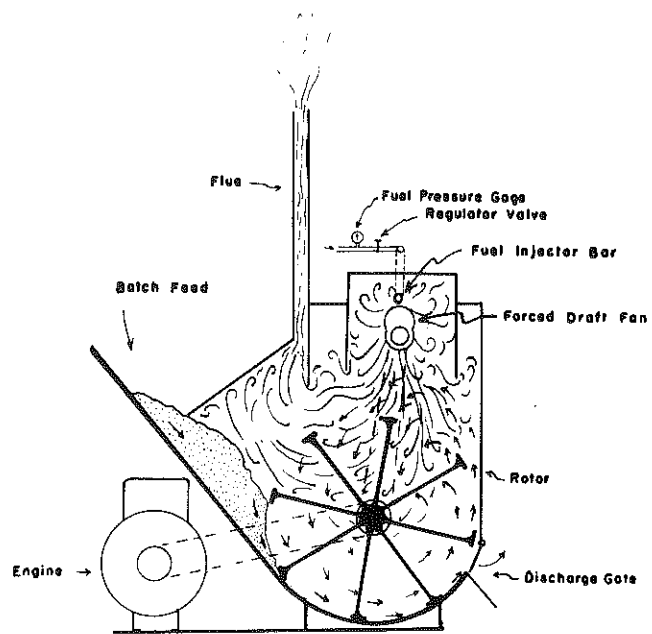


FIG. 19: Schematic Drawing of Dry Heater.

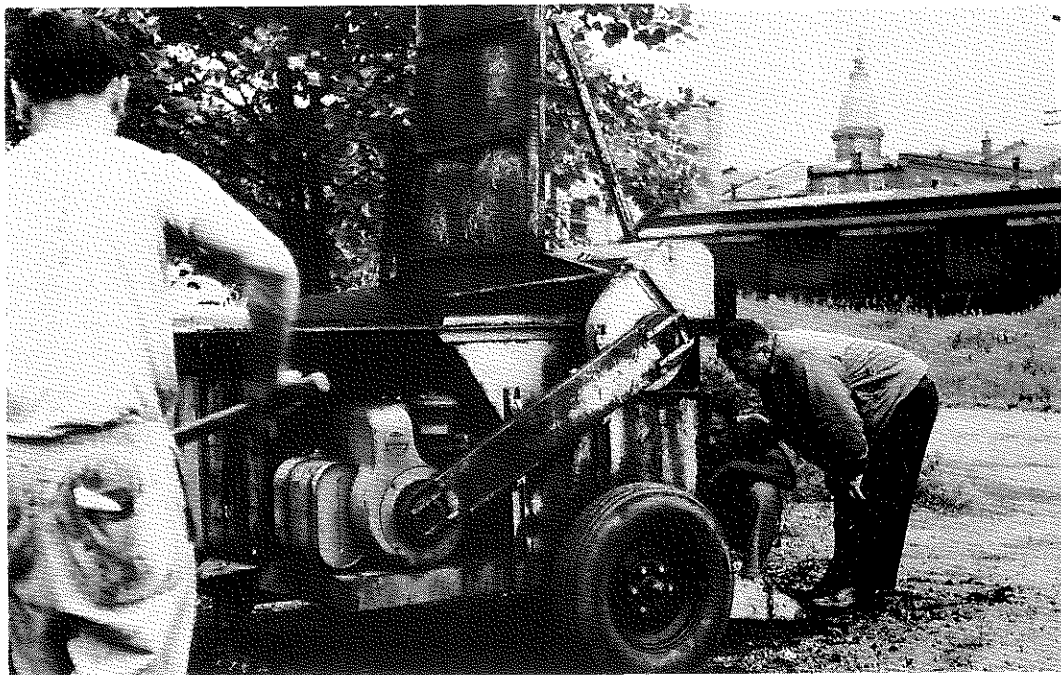


FIG. 20: Side View of McConnaughay HTB Mixer.



FIG. 21: HTB Mixer Heating Rock Asphalt in Trial Runs.

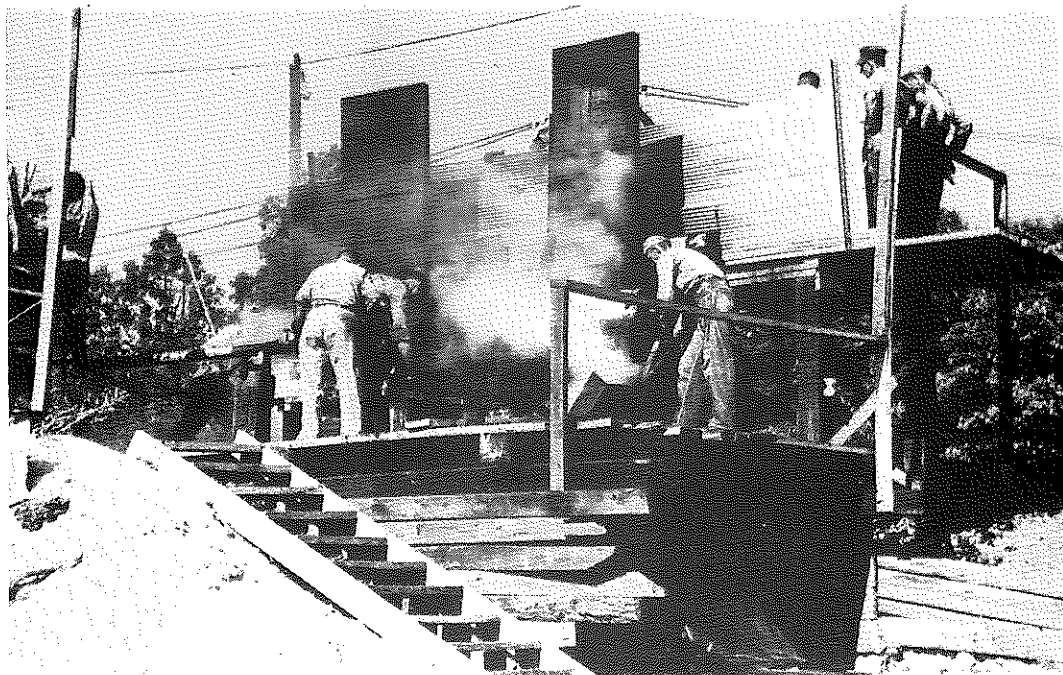


FIG. 22: Improvised Installation of HTB Mixers for Producing Dry Heated Rock Asphalt.

TABLE 12: Results of Trial Runs on Pilot Model Mixer

Heating Time Sec.	Temp. Obtained °F	Pen. of Recov. Asp.
(Original untreated material, Sample No. 6, Part I)		123
45	192	23
60	239	46
75	304	27
90	355	19
90	357	42

Two machines were obtained by the Kentucky Rock Asphalt Co. and installed at their plant near Brownsville (see Fig. 22). One machine had a rated capacity of 5 cu. ft. and the other 3 cu. ft. In preliminary trial runs there, various temperatures were obtained from individual batches of rock asphalt under different operating conditions. These are given in Table 13.

Table 13: Results of Preliminary Runs on Heating Equipment Installed at KRA Plant.

Mixing Time Sec.	Fuel Pressure psi	Temperature °F
45	100	205
45	100	215
45	100	185
45	100	215
45	100	220
45	130	275
45	130	270
45	130	205
30	130	200
30	130	200
30	130	250
60	130	250
60	130	300

The most serious objection to the dry heating process was the formation of clinkers, which resulted from incomplete scavenging of the heated pug mill after each batch was discharged. When the feed material was cold and chunky, it would not feed uniformly and tended to disrupt the timing of the cycle, causing overburning of part of the batch and underheating of the remainder. It was a very common occurrence for the discharging batch to ignite momentarily and then to smother out. This was especially so when the cycle was delayed or interrupted by improper feeding. So far as it was possible to determine, however, this did not damage the material, and this type of burning did not contribute to clinker formation. It seemed that all the hard crusty clinkers were formed inside the machine, where the material caked, coked, and later scaled off. If clinkers went undetected to the paver, they tended to lodge under the screed and to scar the surface being laid. Later, under traffic, they eroded out, leaving an otherwise unblemished surface pitted.

Approximately 1150 tons were dry heated for paving on the test project. Asphalt cement (PAC-3) in amounts of 2 and 3 percent was added to approximately half the dry processed material; and approximately 100 tons of material containing 1 percent powdered asphalt, previously added by cold mixing, were dry heated. All of the materials processed by dry heating were shiny jet black, very sticky; and contained no uncoated sand surfaces or free sand. On cooling, they set rapidly and became unworkable. Moisture contents were practically negligible and none exceeded 0.6 percent. The over-all average asphalt content of the dry heated materials containing no additives was approximately 0.5 percent less than the over-all average asphalt content of the straight-run steamed materials. This value may be taken as the loss in asphalt content due to dry heating.

All of the dry heated materials exhibited a tendency to pull under the screed; but this was most pronounced in those containing added PAC-3. All of them compacted well under the roller.

FIELD CONTROL: SAMPLING AND TESTING

While the preliminary laboratory tests described in a general way the effects of various treatments and guided the planning of the field tests, it was necessary to obtain similar data on the actual materials processed by the various methods prior to delivery to the paver. These tests would not only provide records for the actual properties achieved in the production of the materials, but would also provide a necessary link in the correlation of performance with measured physical properties.

Facilities were improvised at the rock asphalt plant to make the following tests:

1. Moisture Content - Samples were taken from alternate loads, sealed immediately in cans, weighed, and dried in an oven at 220°F for 2 hr. The loss in weight was computed as the percentage of moisture.
2. Densities and Stabilities - Samples were taken usually from every fourth load (at least 2 per test road section), dried in an oven for 2 hr., and compacted for density and stability tests. These were made for comparison with the relationship between stability values and the penetration of the asphalt previously developed from preliminary laboratory tests (Fig. 3). In conjunction with alternate samples, or from at least 2 per section, additional material was taken; and stability specimens were compacted using the material as samples (without drying). These additional specimens were set aside and allowed to cure 24 hr., 3 days, 10 days and 30 days before testing.

At the same time the samples last mentioned were taken, a 1-gal. container of each material was taken and sealed immediately. Altogether

there were 37 of these samples which were returned to the Research Laboratory after completion of the construction work, for subsequent testing, which included the following:

1. Extraction and recovery of the asphalts
2. Penetration tests on the recovered asphalts
3. Softening point tests on recovered asphalts
4. Asphalt content by extraction
5. Asphalt content by ignition
6. Sieve analyses of aggregate

These tests could not be made concurrently with the field stability tests.

TABULATION AND ANALYSIS OF FIELD DATA

All of the test data pertaining to the various materials produced and delivered to the job are compiled in Table 14. The data are grouped according to the type of material, type of processing, and the individual loads sampled within each group. The grouped data, therefore, may be readily associated with their respective sections of the strip map or project layout in Fig. 25, and with similar charts on which the progressions of failures have been recorded, as in Figs. 26 and 45.

The data have been further condensed into a tabulation of sectional summaries or averages which is intended to express more concisely the general character of each type of material and the properties achieved by the different processing methods. Table 15, then, also affords a more generalized link in the evaluation, or correlation, of certain test values with respect to performance on the road.

Table 14: Summary of Field and Laboratory Data For Materials Used For Paving.

Load No.	Identification of Material	Moisture content (at departure)	Asphalt Content		Recovered Asphalt*				Temperature when		Curing Time (days in air)		Marshall Stability Test Data							
			by Extract.	by Ignit.	Pen.		Soft. Pt.		Compact.	Tested	1st. Break	2nd. Break	Stability Values			% Voids				
					200F	300F	200F	300F					Flow	1st. Break	2nd. Break**	% Change	Unit Wt.	Filled	Total	Agg. Only
2	Section I -	5.88																		
4	Control A, Stand-	7.87																		
6	ard Blend Material, Stockpiled 6 mos.	6.58									33	13.5	638							
8	Steam Heated,	4.79	7.2	7.7	264	165	100°	104.3°	200	85	0.2	33	13.5	788	1244	+36.7	116.4	39.2	21.4	34.3
8	(North-bound Lanes),	4.79	7.2	7.7					190	75	1	33	10.5	558	792	+29.5	113.8	36.3	23.0	36.1
8	Cured 3 days.	4.79	7.2	7.7					190	72	3	33	15.0	607	854	+28.9	121.7	44.2	17.0	31.7
8		4.79	7.2	7.7					175	70	10	90	16.5	1042	866	-16.9	122.6	45.3	17.1	31.3
8		4.79	7.2	7.7					165	85	30		13.0	653			119.8	42.1	18.9	32.7
10		4.20																		
12		5.19																		
14		5.59																		
16		5.49	6.7	7.8	223	146	97°	122°	200	85	0.2	33	10.0	788	1333	+40.9	117.0	37.4	21.2	33.6
16		5.49	6.7	7.8					150	75	1	33	12.5	387	766	+49.5	121.6	41.5	18.4	31.4
16		5.49	6.7	7.8					150	72	3	33	13.5	457	730	+37.4	120.4	40.2	19.2	32.2
16		5.49	6.7	7.8					150	70	10	33	15.5	832	704	-15.4	123.5	43.6	17.1	30.4
16		5.49	6.7	7.8					145	85	30	90	8.5	747	963	+22.4	124.8	45.1	16.3	29.7
18		5.29																		
20		7.45																		
22		4.94																		
24		4.62	7.6	7.8	271	173	96.3°	116.3°	200	85	0.2	33	14.0	804	1440	+44.2	117.6	42.6	22.8	34.2
24		4.62	7.6	7.8					175	75	1	33	19.0	266	523	+49.1	119.2	43.7	18.7	33.2
24		4.62	7.6	7.8					175	72	3	33	14.0	431	678	+36.4	117.3	41.7	19.5	34.3
24		4.62	7.6	7.8					165	70	10	33	14.5	865	810	-6.6	122.6	47.7	16.3	31.2
24		4.62	7.6	7.8					145	85	30	90	11.5	635	864	+26.5	121.5	47.0	16.8	31.6
26		7.19																		
28		7.84																		
30		6.78																		
130	Section I - Control B, Fresh	5.34																		
134	Crushed Blend	2.78	7.0	7.9	191	f	98°	105°	200	80	0.2	24	13.0	319	580	+45.0	123.0	44.5	17.3	31.1
134	Material, Stock-	2.78																		
134	piled 1 Mo.,	2.78																		
134	Steam Heated,	2.78																		
134	(Southbound Lanes)	2.78																		
134	No Curing.																			
138		3.66																		
142		1.94																		
284	(Southbound)	3.75																		
286	Patch Material	2.70																		

* Natural asphalts recovered at maximum temperatures of 200° F and 300° F for comparison because some materials (steamed) had no prior history of temperatures much greater than 200° F.

** Same samples rotated 90° to original plane of failure and re-tested after approximately 30 days storage in laboratory air.

Table 14 : Cont'd.

Lead No.	Identification of Material	Moisture content (at departure)	Asphalt Content by Extract. Ignit.		Recovered Asphalt*				Temperature when Tested		Curing Time (days in air)		Marshall Stability Test Data								
					770 Pen.		Soft. Pt.		Compact.	Tested	1st. Break	2nd. Break	Stability Values			% Voids					
					200F	300F	200F	300F					Flow	1st. Break	2nd. Break**	% Change	Unit Wt.	Filled	Total	Agg. Only	
145	Section I - Control C.	3.73																			
147	Select Quarried Material.	3.72	7.5	7.8	155	115	111°	105.5°	200	80	1	24	14.5	1226	801	-34.7	121.4	45.4	17.6	32.2	
147	Stockpiled 3 Mos., Steam Heated, (Southbound Lanes), No Curing.	3.72							165	75	3	24	16.5	546	503	-7.9	119.5	40.7	19.6	33.0	
147		3.72							165	75	3	24	12.5	448	531	+15.6	118.3	39.4	20.4	33.7	
147		3.72							155	70	10	24	13.0	738	609	-17.5	117.6	40.7	20.1	34.8	
147		3.72							145	85	30	76	8.5	679	715	+5.0	116.0	39.9	21.2	35.1	
151		4.65	7.4	7.7	152	132	110.3°	108.5°	200	80	1	24	14.0	1103	1140	+3.2	121.4	45.0	17.6	32.0	
151		4.65							150	75	3	24	11.0	297	577	+48.5	122.0	43.5	17.9	31.5	
151		4.65							150	75	3	24	11.5	315	551	+42.8	122.4	43.9	17.7	31.4	
151		4.65							135	70	10	24	13.5	738	638	-16.3	121.4	45.0	17.6	32.0	
151		4.65							135	85	30	76	8.5	679	1004	+32.4	118.8	42.3	19.7	33.0	
153		2.14																			
155		4.50																			
32	Section II - Antistrip No. 1.	3.91																			
36	Fresh Crushed Material + 1% Antistripping Agent, Steam Heated, (Northbound Lanes), Cured 2 days.	3.24	7.9	8.1	199	144	99.5°	114°	200	75	0.2	32	12.0	332	843	+60.6	116.4	42.2	20.3	35.1	
36		3.24							175	75	1	32	16.0	290			117.9	44.2	19.7	33.7	
36		3.24							175	72	3	32	13.0	507	580	+12.6	116.5	41.7	20.5	35.2	
36		3.24							165	75	10	32	15.0	450	615	+26.8	120.7	47.1	17.3	32.5	
36		3.24							165	85	30	89	10.0	530	699	+24.1	122.9	49.7	15.8	31.4	
40		3.89											7.5	311	930	+66.5					
44		3.24	7.9	8.1	199	170	99.5°	114°	200	75	1	32	14.5	974	613	-37.1	114.8	40.5	21.4	35.9	
44		3.24							185	75	1	32	12.0	272	412	+34.0	114.5	40.6	21.6	35.7	
44		3.24							185	72	3	32	12.5	338	411	+17.8	116.6	42.4	20.0	34.8	
44		3.24							175	75	10	32	13.5	405	480	+15.6	121.3	47.8	16.8	32.7	
44		3.24							175	85	30	89	11.5	413	678	+53.0	121.0	47.4	17.1	32.4	
160	(Southbound Lanes), Cured 1 day.	3.65																			
162		3.97																			
164		4.00	8.2	7.8	178	177	105.5°	118°	200	75	1	21	15.0	1305	771	-40.9	124.8	53.0	14.6	31.0	
164		4.00							145	65	1	21	11.0	341	379	+10.0	122.9	50.6	15.8	31.9	
164		4.00							145	65	3		14.5	739			119.2	45.8	18.3	33.9	
164		4.00							135	85	10		11.5	675			120.1	46.9	17.7	33.4	
164		4.00							125	85	30	73	9.0	613	697	+12.1	118.6	45.0	18.8	34.2	
48	Section II - Antistrip No. 2.	1.25											14.0	861	779	-9.5					
50	Fresh Crushed Material + 1% Antistripping Agent, Steam Heated, (Northbound - Lanes) Cured 2 days.	4.54	7.4	7.6	209	186	101°	110.5°	200	75	1	32	11.5	755	650	-13.9	116.1	39.4	21.2	35.0	
50		4.54							190	75	1		12.0	176			118.6	42.0	19.5	35.6	
50		4.54							190	72	3	32	12.0	217	394	+44.9	115.1	38.5	21.8	35.4	
50		4.54							180	75	10	32	13.5	304	403	+24.6	122.9	46.9	16.5	31.1	
50		4.54							165	85	30	89	14.5	376	883	+57.4	119.8	43.3	18.6	32.8	
54		3.59											17.5	1217	920	-24.4					
58		3.10	8.3	8.0	193	184	101°	113.3°	200	75	1	32	14.0	828	770	-7.0	117.6	45.1	19.1	34.8	
58		3.10							155	75	1	32	11.0	212	482	+56.0	114.1	41.3	21.4	36.5	
58		3.10							155	72	3		12.0	325			114.8	41.3	21.0	36.3	
58		3.10							145	75	10	32	14.0	375	533	+29.6	121.5	48.3	18.7	32.9	
58		3.10							125	85	30	89	11.0	365	606	+54.7	120.1	47.9	17.4	33.4	

Table 14: Cont'd.

Load No.	Identification of Material	Moisture content (at departure)	Asphalt Content by Extract. Ignit.		Recovered Asphalt*				Temperature when		Curing Time (days in air)		Marshall Stability Test Data				% Voids			
					77° Pen.	Soft. Pt.	Compact.	Tested	1st. Break	2nd. Break	Stability Values			Unit Wt.	Filled	Total	Agg. Only			
					200F	300F					200F	300F	Flow					1st. Break	2nd. Break**	% Change
170	(Southbound Lanes), Cured	5.04																		
173	8 hrs. to 1 day.	4.27	7.6	8.6	55(1)	81	129°	129.5°	200	75	1	72	14.5	1149	2073	44.6	125.5	51.4	15.5	29.7
173		4.27							135	65	1	72	10.5	362	2900	487.5	125.4	51.4	14.4	29.7
173		4.27							125	65	3	72	15.5	621	2525	475.4	122.0	47.0	16.7	31.7
173		4.27							125	85	10	72	12.0	772	3161	475.6	122.9	48.1	16.1	31.1
173		4.27							110	85	30	72	13.5	819	2773	470.5	119.8	44.4	18.3	32.9
176		4.85																		
178		3.68																		
181	Section II - Antistrip	3.85																		
183	No. 3, Fresh	3.87	7.7	7.6	114	132	116°	119.5°	200	75	0.2	71	11.5	388	1803	478.5	123.6	48.9	15.8	30.8
183	Crushed Material	3.87							150	65	1	71	13.5	358	1590	477.5	119.8	44.4	18.3	32.9
183	+ 1% Antistrip-	3.87							150	65	3	71	12.5	644	1804	464.3	116.8	41.8	20.0	34.3
183	ping Agent, Steam	3.87							150	85	10	71	10.5	629	2175	471.1	120.7	45.5	17.6	32.3
183	Heated, (South-	3.87							145	85	30	71	14.5	680	1465	453.6	119.8	44.4	18.2	32.8
183	bound Lanes), Cured 6 hrs.	4.71																		
62	Section III - Powdered Asp.	5.00	8.2	8.6	178	119	108.5°	117.3°	200	70	0.2	30	13.5	726	1128	435.6	116.7	43.2	20.2	35.4
62	No. 2, Fresh	5.00	8.2						150	70	3	30	16.5	807	799	- 0.99	121.1	42.5	18.5	32.1
62	Crushed Material	5.00	8.2						150	70	3	30	12.0	756	887	414.8	120.8	42.1	18.7	32.3
62	+ 1% Powder, Steam Heated, (Northbound Lanes) Cured 8 hrs.	2.16							135	80	30	87	11.0	1129	586	-48.0	118.9	45.4	18.6	34.1
70		1.14	7.1	8.2	154	107	107.8°	119.5°	200	70	0.2	30	11.5	758	1079	429.7	119.8	41.7	19.0	32.6
70		1.14	7.1						150	70	3	30	15.5	902	1098	417.8	120.5	41.9	18.9	32.4
70		1.14	7.1						150	70	3	30	16.5	824			122.6	44.2	17.4	31.2
70		1.14	7.1						150	70	10	30	13.5	874	1139	423.3	119.5	41.4	19.2	32.7
70		1.14	7.1						135	80	30	87	11.5	995	1438	430.8	117.6	39.4	20.5	33.8
74		1.49										30	13.0	526	865	439.2				
191	(Southbound Lanes) Cured 8 hrs.	3.00																		
194		3.03	7.7	8.6	128	104	114.3°	116.5°	200	75	1	71	15.0	1476	2175	432.1	125.5	52.2	14.3	29.8
194		3.03							140	63	1	71	14.0	661	1356	451.3	123.6	48.7	16.1	31.4
194		3.03							140	65	3	71	19.5	1204	1305	477.7	119.5	44.4	18.5	33.3
194		3.03							135	85	10	71	15.5	1189	1524	422.0	119.8	44.7	18.3	33.1
194		3.03							125	85	30	71	15.5	990	957	- 3.3	119.8	44.7	18.3	33.1
200		4.47																		
202		5.14																		
272		2.86																		
275		3.17																		
278		2.34																		
279		3.89																		
281		6.12																		

For Closure

Table 14: Cont'd.

Load No.	Identification of Material	Moisture content (at departure)	Asphalt Content		Recovered Asphalt*				Temperature		Curing Time		Marshall Stability Test Data						
			by Extract.	by Ignit.	77° F.		Soft. Pt.		when Compact.	Tested	days in air		Stability Values			Unit Wt.	% Voids		
					200F	300F	200F	300F			1st. Break	2nd. Break	Flow	1st. Break	2nd. Break**		% Change	Filled	Total
76	Section III - Powdered Asp.	2.60	8.2	8.5	149	84	110°	122°	200	70	3	30	13.0	1038	1121	123.1	51.1	15.6	31.8
76	No. 1, Fresh Crushed Material + 1% Powder, Steam Heated, (Northbound Lanes), Cured 3 hrs.	2.60							142	70	3	30	14.5	955	946	122.7	44.2	17.5	31.3
76		2.60							142	70	3	30	13.0	786	946	119.5	40.8	19.5	32.9
76		2.60							135	70	10	30	11.5	816	1112	122.3	49.7	15.9	32.3
76		2.60							120	70	30	87	14.5	1121	1468	119.5	46.9	18.2	33.9
80		3.01										30	18.5	1687	1355				
84		1.64	7.7	8.4	170	104	108.5°	117.3°	200	70	3	30	14.0	2168	283	126.4	53.0	13.9	29.5
84		1.64							200	75	3	30	15.0	896	1098	121.1	42.4	18.5	32.1
84		1.64							200	75	3	30	14.5	884	1113	122.6	44.2	17.4	31.2
84		1.64							185	70	10	30	15.5	1287	1144	122.6	47.5	16.7	31.8
84		1.64							175	80	30	87	11.5	1297	1317	123.2	48.8	15.9	31.1
86		2.76										30	16.5	1477	1617				
206	(Southbound Lanes) Cured 2 hrs.	3.39																	
209		3.82	7.9	8.1	194	121	112°	116.3°	200	75	1	71	14.0	851	1298	123.3	50.0	16.0	31.6
209		3.82							165	63	1	71	12.5	821	893	122.0	47.6	16.8	32.1
209		3.82							165	65	3	71	13.5	821	902	119.5	44.8	18.5	33.5
209		3.82							150	85	10	71	13.0	958	1001	119.2	44.3	18.7	33.6
209		3.82							145	85	30	71	12.5	794	913	118.9	44.0	18.9	33.8
214		3.09																	
217		3.14																	
90	Section IV - Dry Heat, 235°F, Fresh Crushed Material (Northbound Lanes), Cured 3 days.	0.52	6.6	8.0	198	104	104.3°	123.5°	200	70	0.2	28	15.5	1233	1456	120.2	39.2	19.7	32.3
90		0.52							200	70	1	28	14.0	1225	966	120.4	39.8	19.2	32.0
90		0.52							190	68	3	28	18.0	1007	825	120.7	40.1	19.0	31.7
90		0.52							190	65	10	28	19.0	1649	950	119.8	39.2	19.7	32.4
90		0.52							180	80	30	81	8.5	960	1208	121.5	41.5	18.2	31.1
94		0.21										28	12.0	822	1174				
98		0.00	6.8	8.3	175	125	100°	117°	200	70	1	28	15.5	1596	1023	119.5	40.1	19.5	32.6
98		0.00							215	70	1	28	13.0	1014	818	123.2	44.1	17.0	30.4
98		0.00							215	70	3	28	15.0	810	879	121.7	42.3	18.0	31.3
98		0.00							195	65	10	28	14.0	1421	798	123.9	44.9	16.6	30.1
98		0.00							175	80	30	81	9.5	769	723	120.7	41.2	18.7	31.8
100		0.61										28	19.5	1436	1103				
220	(Southbound Lanes) Cured 8 hrs.	0.00																	
223		0.00	6.9	7.7	200	150	104.5°	116.3°	200	80	0.2	70	13.5	717	1093	119.8	40.7	19.3	32.6
223		0.00							150	65	1	70	17.0	898	758	120.4	41.3	18.9	32.2
223		0.00							145	65	3	70	15.5	1119	700	123.2	44.5	17.0	30.6
223		0.00							130	85	10	70	16.5	811	920	123.0	44.7	17.3	30.5
223		0.00							125	85	30	70	14.0	599	606	123.9	45.2	16.6	30.3

Table 14: Cont'd.

Load No.	Identification of Material	Moisture Content (at departure)	Asphalt Content		Recovered Asphalt*				Temperature when		Curing Time [†] (days in air)		Marshall Stability Test Data							
			by Extract.	by Ignit.	270° Pan.	300° Pan.	Soft. Pt.	300° Pan.	Compact.	Tested	1st Break	2nd Break	Flow	1st Break	2nd Break**	% Change	Unit Wt.	Filled	Total	% Voids
227	(Cont'd)	0.55	6.8	7.9	198 [†]		100.5°	113.3°	200	80	1	70	15.5	1471	1196	-18.7	121.4	42.0	18.3	31.6
227		0.55						180	65	1	70	18.0	1165	892	-23.4	120.1	40.7	19.1	32.2	
227		0.55						180	65	3	70	15.5	1301	812	-37.6	121.7	42.1	18.1	31.4	
227		0.55						170	85	10	70	14.0	1059	1015	-4.2	123.3	44.2	17.1	30.5	
227		0.55						165	85	30	70	12.0	855	1005	+14.9	121.7	42.4	18.1	31.4	
105	Section IV - Dry Heat,	1.07	6.6	7.8	134	93	112°	119.5°	225	70	0.2	26	17.0	1886	2688	+29.8	123.0	42.5	17.6	30.6
105	3000° F. Fresh	1.07						230	70	1	26	15.5	1647	1395	-15.3	121.4	40.8	18.6	31.4	
105	Crushed Material	1.07						210	70	3	26	20.0	1730	1407	-18.8	122.0	41.4	18.2	31.1	
105	(Northbound Lanes), Cured	1.07						210	65	10	26	18.0	2692	1089	-59.5	122.0	41.0	18.2	31.1	
105	2 days.	1.17						190	80	30	78	12.5	1223	1855	+34.0	123.5	43.0	17.1	30.4	
109											26	16.0	1239	1020	-17.7					
111		0.57	6.7	7.8	155	116	107.5°	122.5°	200	80	1	26	15.0	1475	1025	-30.5	119.2	38.4	20.1	33.4
111		0.57						220	70	1	26	15.5	890	808	-9.2	124.2	44.3	16.7	30.9	
111		0.57						220	70	3	26	15.0	938	763	-18.7	124.1	44.0	16.7	30.0	
111		0.57						195	65	10	26	16.5	1925	892	-53.7	121.1	40.9	18.8	31.8	
111		0.57						195	80	30	78	10.0	947	1473	+33.5	122.9	43.0	17.5	30.7	
231	(Southbound Lanes) Cured 3 hrs.	0.00	6.8	8.4	211 [†]	175	102.5°	118.3°	200	80	1	70	19.0	1371	1288	-6.1	122.7	43.4	17.5	30.8
231		0.00						210	65	1	70	16.5	1101	682	-38.1	122.3	43.1	17.7	31.0	
231		0.00						205	65	3	70	18.5	1411	538	-61.9	121.0	42.7	17.9	31.2	
231		0.00						190	85	10	70	16.0	1099	1097	-0.2	122.0	42.7	17.9	31.2	
231		0.00						185	85	30	70	12.0	800	610	-23.8	121.7	42.3	18.1	31.3	
235		0.62																		
237		0.62	6.7	7.8	185 [†]	104	103.5°	122°	200	80	1	68	16.5	2158	1340	-37.9	121.1	40.4	18.8	32.2
237		0.62						210	65	1	68	19.0	1855	1301	-29.9	120.5	40.3	19.3	32.2	
237		0.62						210	80	3	68	15.5	1208	1601	+24.5	122.6	42.7	17.8	30.9	
237		0.62						205	85	10	68	10.5	756	1560	+51.5	123.9	44.0	17.0	30.3	
237		0.62						200	85	30	68	15.5	1577	1240	-21.4	124.8	45.1	16.4	29.8	
114	Section V - 2 1/2 PAC-3 Add.,	0.00	8.3	9.4	176	135	106.8°	110.5°	200	85	1	26	15.5	752	1368	+45.0	123.6	52.0	15.1	31.7
114	Fresh Crushed	0.00						210	70	1	26	15.5	1069	1139	+6.1	123.4	51.4	15.4	31.8	
114	Material, Dry	0.00						200	70	3	26	17.0	1141	1080	-5.3	124.8	53.9	14.2	30.8	
114	Heated, 250° F.	0.00						200	65	10	26	18.5	2165	1177	-45.6	127.3	57.6	12.4	29.3	
114	(Northbound Lanes), Cured	0.00						190	80	30	78	10.5	1154	1749	+30.2	127.6	58.6	12.2	29.1	
118	8 hrs.	0.00	8.4	9.6	132		112.3°	118.5°	200	85	0.2		14.0	738			124.2	53.5	14.6	31.4
118		0.00						215	70	1	25	16.0	898	1080	+16.9	123.3	52.1	15.2	31.8	
118		0.00						215	75	3	25	16.5	878	1131	+22.4	123.2	52.0	15.2	31.8	
118		0.00						190	70	10	25	17.0	1484	1218	-17.9	122.6	51.2	15.7	32.2	
118		0.00						185	85	30	77	10.5	1094	1889	+42.1	125.4	55.2	13.7	30.5	
241	(Southbound Lanes) Cured 8 hrs.	0.60	8.3	9.3	94	79	116.5°	129°	200	80	0.2	68	17.5	1660	2782	+40.3	122.3	50.6	15.9	32.2
241		0.60						200	80	1	68	16.0	1959	2833	+16.0	121.4	49.5	16.5	32.7	
241		0.60						200	80	3	68	16.5	2222	2559	+13.2	125.1	54.4	14.0	30.6	
241		0.60						200	85	10	68	12.5	1618	2646	+38.9	124.8	54.0	14.2	30.8	
241		0.60						190	72	30	68	13.5	3292	2881	-12.5	125.7	55.4	13.5	30.3	

Table 14: Cont'd.

Load No.	Identification of Material	Moisture content (at departure)	Asphalt Content by Extract. Ignit.		Recovered Asphalt*				Temperature when		Curing Time (days in air)		Marshall Stability Test Data							
					77° F.		Soft. Pt.		Compact.	Tested	1st. Break	2nd. Break	Stability Values			% Voids				
					200F	300F	200F	300F					Flow	1st. Break	2nd. Break**	% Change	Unit Wt.	Filled	Total	Agg. Only
245	(Cont'd)	0.00	8.7	9.8	200	121	104.5 ^o	116.5 ^o	300	80	3	68	19.5	4186	5392	+22.4	125.2	56.3	13.6	31.1
245		0.00						230	80	1	68	16.0	1197	1365	+12.4	123.6	53.9	14.5	31.9	
245		0.00						220	80	3	68	17.0	1368	1693	+19.2	124.2	54.9	14.3	31.6	
245		0.00						210	85	10	68	11.5	854	1776	+51.9	125.5	56.8	13.4	30.9	
245		0.00						200	72	30	68	14.0	1794	1463	-18.5	125.2	56.3	13.6	31.1	
122	Section V - 3% PAC-3	0.00										25	14.0	1157	902	-22.0				
126	Add., Fresh	2.01	9.3	9.4	159	92	109.8 ^o	122.5 ^o	200	85	1	25	14.5	1516	1459	- 3.8	126.4	61.3	12.0	30.8
126	Crushed Ma-	2.01						215	70	1	25	14.5	1082	1213	+12.4	126.0	60.8	12.1	30.9	
126	terial, Dry	2.01						215	75	3	25	15.0	828	1288	+35.7	127.3	62.2	11.3	30.3	
126	Heated, 250° F.	2.01						190	70	10	25	16.5	828	1322	+37.4	124.2	57.6	13.4	31.7	
126	(Northbound Lanes), Cured 3 hrs.	2.01						185	85	30	77	10.0	1243	2407	+48.4	124.2	52.6	13.4	31.7	
128		0.53	9.2	8.3	120	107	113.8 ^o	121.8 ^o	200	85	1	25	14.0	1844	1773	- 3.9	124.5	58.0	13.3	31.7
128		0.53						240	70	1	25	14.5	1312	1316	- 0.5	122.9	55.9	14.3	32.4	
128		0.53						240	75	3	25	15.5	1248	856	-31.4	129.2	56.3	14.1	32.3	
128		0.53						220	70	10	25	17.0	1641	1406	-14.3	123.2	56.3	14.1	32.3	
128		0.53						195	85	30	77	9.0	1698	1667	- 1.8	123.4	55.6	14.3	32.3	
252	(Southbound Lanes) Cured 3 hrs.	0.00	9.0	10.1	161	101	109.3 ^o	120.3 ^o	330	80	0.2	65	19.5	4162	6439	+35.4	126.7	60.2	12.1	30.4
252		0.00						250	65	1	65	20.9	1773	2121	+16.4	124.5	56.7	13.7	31.7	
252		0.00						245	85	3	65	21.5	2208	2338	+ 5.6	124.2	56.4	13.9	32.8	
252		0.00						235	85	10	65	12.0	1737	2602	+33.2	124.8	57.3	13.5	31.5	
252		0.00						210	75	30	65	13.5	2331	2505	+ 6.7	126.1	64.2	12.6	30.8	
256		0.00	8.4	9.6	140	102	110.5 ^o	120 ^o	200	80	1	65	14.0	2334	2984	+21.8	126.7	57.1	13.4	29.9
256		0.00						240	65	1	65	15.0	2007	2522	+20.4	123.3	52.0	15.3	31.8	
256		0.00						240	85	3	65	19.0	2553	3020	+20.0	123.6	52.5	15.0	31.6	
256		0.00						220	85	10	65	12.0	1665	2330	+28.5	123.9	53.0	14.8	31.5	
256		0.00						205	75	30	65	13.0	2635	2626	- 0.3	124.2	53.4	14.6	31.3	
260	Section VI - 1% Powdered Asp. No. 2, Add., Dry Heated 250° F.	0.00	7.5	8.9	195 ⁺	159	105 ^o	116.8 ^o	200	80	1	65	13.5	1143	1722	+33.6	127.0	52.8	13.8	29.1
260		0.00						175	65	1	65	14.0	887	1147	+22.7	125.4	50.5	14.9	30.0	
260		0.00						175	85	3	65	14.0	1162	1382	+15.9	125.1	50.0	15.1	30.1	
260		0.00						175	85	10	65	10.0	947	1306	+27.5	125.1	50.0	15.1	30.1	
260	(Samples represent materials in both Northbound and Southbound Lanes)	0.00						170	75	30	65	13.0	1783	1330	-25.6	126.4	51.8	14.2	29.4	
264		0.00	7.2	8.3	78	60	126.5 ^o	126.5 ^o	200	80	1	63	17.0	2385	2937	+18.8	123.0	45.7	16.9	31.1
264		0.00						190	65	1	63	16.5	1965	2499	+20.1	127.0	50.9	14.2	28.8	
264		0.00						190	85	3	63	12.5	1326	2255	+41.2	125.5	48.9	15.2	29.7	
264		0.00						190	85	10	63	12.0	1643	2952	+44.3	123.3	45.9	16.7	30.9	
264		0.00						175	75	30	63	12.0	2797	2461	-12.0	126.7	50.5	14.4	29.0	

Table 15: Cont'd.

Identification of Material	Moisture content (at departure)	Asphalt Content		Recovered Asphalt*				Temperature when Tested		Curing Time (days in air)		Marshall Stability Test Data							
		by Extract.	by Ignit.	77° F.		Soft Pt.		Compact.	Tested	1st. Break	2nd. Break	Flow	Stability Values		% Change	Unit Wt.	% Voids		
				200F	300F	200F	300F						1st. Break	2nd. Break**			Filled	Total	Age. Only
Section IV - Dry heat 235°F (Oven dried for compaction)	0.27	6.8	8.0	192.8	126.3	102.3	117.6	177	73.4	1-30 .6	55.6 42.0	14.5	1042 1213	942 1174	-10.6 -3.3	121.8 120.3	42.3 40.6	18.2 19.2	31.2 32.3
Section IV - Dry heat 300°F (Oven dried for compaction)	0.60	6.7	8.0	171.3	122.0	106.3	120.6	199	74.8	1-30 .8	54.0 43.2	15.7	1363 1626	1142 1472	-19.4 -10.5	122.5 121.5	42.5 41.2	17.7 18.6	30.9 31.8
Average (Dry heat only)	0.44	6.8	8.0	182.1	124.2	104.3	118.6												
Section V - 2% PAC Add. (Oven dried for compaction)	0.15	8.4	9.5	151.0	112.0	110.0	118.9	205	77.5	1-30 1.1	55.1 46.8	15.2	1537 1834	1716 2656	+10.6 +30.9	124.6 123.9	14.3 53.2	31.0 14.9	31.6
Section V - 3% PAC Add. (Oven dried for compaction)	0.60	9.0	9.4	145.0	100.5	110.8	121.2	220	77.0	1-30 .75	51.5 45	15.0	1674 2203	1975 2711	+15.2 +13.7	124.7 126.1	13.7 59.2	31.6 12.8	30.8
Average (Dry heat + PAC-3)	0.38	8.7	9.5	148.0	106.3	110.4	120.0												
Section VI - 1% Powd. Asp. No. 2 (Oven dried for compaction)	0.00	7.4	8.6	136.5	104.5	115.3	121.7	178	78.0	1-30 1.0	64 64	13.5	1565 1764	1912 2329	+13.1 +24.3	125.5 125.0	14.9 49.3	29.7 15.4	30.1
Average (Dry heat + Powder 2)	0.00	7.4	8.6	136.5	104.5	115.3	121.7												

* Natural asphalts recovered at maximum temperatures of 200° F and 300° F for comparison because some materials (steamed) had no prior history of temperatures much greater than 200° F.
 ** Same samples rotated 90° to original plane of failure and re-tested after approximately 30 days storage in laboratory air.

The first objective in the field work was to produce materials having the same or comparably improved properties as those developed in the initial laboratory studies; i.e., in regard to drying and curing the asphalt, promoting better distribution of asphalt, enrichment of asphalt contents, and improved strength. Collectively these factors should be reflected in an enhancement of stability as measured by the Marshall method. The relationship between stability and penetration of the asphalt, as previously shown in Fig. 3 (Part I), should therefore apply and suffice to gauge the amount of curing (hardening) actually achieved in full-scale production. Therefore, all the stability-penetration data from Table 14 have been plotted (superimposed) on the earlier graph, and the combined plots are shown in Fig. 23. It is readily apparent that the amount of curing actually obtained by the dry heating process was considerably less than expected or desired; but even so, the treatment produced about a threefold increase in stability and decreased the penetration by as much as 50 to 150 points. All of the dry-processed materials yielded penetration values conspicuously above 100, which was rather contrary to expectations, particularly for materials heated to 300°F and above. The approximate penetration range sought by high temperature treatment was 20 to 100. This simply means that the production treatment was not of sufficient intensity to bring the materials within that range of hardness*.

* Subsequent aeration of these high temperature materials after spreading on the road may have induced additional hardening to penetration values well below 100; however, data from pavement samples are not yet available to confirm this.

Weight data were not employed because available information applied to the entire roadway and could not be accurately assigned to individual lanes.

Paving

No special or unusual equipment was employed in construction. Major items consisted of a Barber-Greene Paver, serviceable but in poor condition ; a 10-ton, 3-wheel roller; an 8.5-ton tandem roller; a distributor, and the usual covered trucks. The only small tool not usually encountered was the lute, which is quite necessary for proper finishing of hand-spread material.

To facilitate future evaluation of all mixtures, it was necessary to maintain very complete records of all paving data. Each load was individually identified and its position located. Data consisted of the following:

1. Identification of mixture
2. Load number
3. Station location
4. Lane in which placed
5. Tonnage
6. Temperature at point of origin
7. Temperature when spread
8. Temperature when rolled
9. Any pertinent comments, such as location of faulty spots in the base, oil drippings, changes in weather which might affect the pavement, etc.

Actual surfacing started in the northbound traffic lanes of Section I, at Sta. 0+00 (Sta. 709+15 on original survey) on the Kosmosdale end of the project and continued southward until all except Section VI were in place. Then the southbound lanes were started at Sta. 0+00 and paving continued in these lanes until the first five sections were completed.

An emulsified asphalt (RS-2) tack was employed in all sections at the rate of approximately 0.1 gal. per sq. yd. between binder and surface courses. This was applied several hundred feet in advance of paving and the uniformity of coverage was improved by tracking - an operation performed primarily by the distributor.

The paver was operated with the screed both heated and unheated; however, the latter method resulted in scouring and stripping of surface sand and thus was adjudged inferior to the former. Especially when the screed was cool, asphalt accumulated on the screed plate until the deposit was thick enough to be displaced by material sliding underneath. This resulted in alternately stripped surface areas and thin, wavy, rich deposits distributed transversely at intervals (see Fig. 28). Probably no serious damage was done to the surface, since the stripped sand layer appears to be no more than one grain in depth. It does, however, leave an undesirable appearance and a slight openness of texture in the scoured areas. This appears to be characteristic of the wide screed employed in this particular type of paver.

Steam Heated Materials

All of the materials used in Sections I, II, and III (see Fig. 25) were steam heated to temperatures ranging from 185° to 210°F and trucked 72 miles to the job. Temperature losses during the haul varied

from 10° to 40°F with an average loss of approximately 20°F. Moisture contents of all steamed materials were high; most being in excess of the current specification limit of 3 percent. Table 14, previously presented, summarizes temperature and moisture data for all materials used in the project.

Workability was good when a heated screed was employed and spreading temperatures were above 170°F. Control materials, because of their lack of "stickiness", were unique in this respect. As a result of observations at the beginning of the project, a minimum rolling temperature of 140°F was selected. Rolling at or above this value appeared to produce better compaction and to minimize roller pickup. This choice, however, had the disadvantage of not permitting aeration and consequent drying prior to rolling. Since the tamping screed of the paver actually prevented exposure of the material in a loose state, very little aeration would have been possible in any case.

Response of steam heated rock asphalt to roller compaction differed with each of the three variations involved in these tests. At the beginning of construction an attempt was made, on control material, to determine optimum compactive effort. Heavy rolling was first attempted and then progressively reduced to a minimum of one coverage by each of the two rollers. On the basis of mixture behavior during these trials, minimum coverage was selected as the standard for steamed materials. Heavy compaction resulted in frequent shear failure, as evidenced by lateral movement of the mix and the appearance of hair cracks. All steamed materials showed the same effects from overrolling; however, the amount of rolling necessary to produce failure increased when

additives were used. Mixtures containing antistrip compounds moved readily beneath the roller, but hair cracking and formation of horizontal shear planes developed only when rolling was extreme. Very little movement was observed in sections containing powdered asphalt until four or more passes were made. Since none of the sections appeared to benefit from additional coverage, a standard of one coverage by each roller was established.

Back rolling was done at some locations but was soon discouraged because lateral movement of the cold mixture, indicating the formation of horizontal shear planes, sometimes occurred.

Failures Originating During Construction - These mixtures could be , and in some cases were, damaged during construction and prior to any traffic exposure, by overrolling. When spread, moisture contents were high; and, consequently, cohesion was very low. Compactive effort was opposed primarily by the sand itself, and the material compacted rapidly to a more-or-less stable state. Thus when additional force was applied in excess of this resistance shear occurred. The condition was initially observed as a slight movement (occasionally pronounced) in front of the roller wheels, which additional rolling emphasized by producing hair cracks in the surface. The observed failures caused by overrolling were of three types: (1) lateral movement only, (2) ripple patterns, and (3) hair cracking.

Failures of types 1 and 2 were both horizontal shear failures of the scale type. Type 1 could be detected only by close observations and by digging into the pavement (see Fig. 27). Scale thicknesses varied from 1/8 to 1/2 in. Type 2 could be readily observed; however, it was

not widespread and could be easily overlooked. This scale rarely was more than 1/8 in. thick.

Both these types resulted from differential horizontal movement. Prominent striations indicated scaled material had moved or slipped over the underlying mixture along a well established horizontal shear plane. The interface along these failure planes was also identified by stripped sand which undoubtedly resulted from scour during movement. The observed condition was virtually identical to that always observed in older pavements suffering from scale-type failures.

Hair cracking (Type 3) near the edge usually indicated only lateral movement. Otherwise it was occasionally associated with horizontal scale, but more often it indicated wedge-type failures extending downward at angles of from 20 to 40 degrees. Rolling of these areas after cracks appeared caused the damaged sections to shove throughout the full course depth, and the entire failure assumed a roughly rectangular shape. Traffic rapidly obliterated all surface evidences of the damage, but the planes or zones of weakness, of course, remained.

Because of these failures, roller coverage was reduced to eliminate the formation of hair cracks. This did not wholly eliminate the horizontal shear planes; but cracking served as a warning sign to the roller operator and greatly reduced the damage caused by overrolling. The actual compactive effort, employed as standard, virtually eliminated this condition.

Failures Induced by Traffic - Several types of failure developed from early traffic. These may be generally classified as: (1) sanding, (2) rutting and shoving, (3) pickup by vehicle tires, (4) scaling, (5) oil or solvent spots (6) pitting, and (7) tire tracking. Most of these failures

are shown in the grouped illustrations that follow (Figs. 28 through 42).

Sanding resulted from surface abrasion of mixtures having very low cohesion and usually occurred when moisture contents were quite high and cohesion at a minimum. If it progressed uniformly over the entire surface little apparent damage occurred; however, any unevenness resulted in the formation of holes and ruts. Saturation was frequently caused by concentration of roller water and, if these locations were exposed to traffic before drying, localized sanding invariably resulted. All steamed mixtures were susceptible to this action but only the untreated materials suffered appreciably.

Rutting and shoving were induced by loading in excess of the inherent ability of the materials to resist. In some cases the shear was along a horizontal plane and in others along a concave surface. These failures were also primarily associated with high moisture content in the pavement; however, they can occur at any time if the asphaltic binder is sufficiently fluid.

Pickup by vehicle tires occurred principally when moisture contents were high. It was observed in a few instances when the mixture was dry and vehicles were required to stop in one place for even a few minutes. After the surface had hardened slightly the condition no longer existed.

Scaling resulted from differential movement of the crust which formed as a hardened layer 1/8- to 1/4-in. thick on most of the steamed rock asphalt. The hardening itself apparently results from exposure to air and light; consequently, underlying material is insulated by the surface crust and tends to remain soft and uncured. Whether produced

during construction or by traffic afterwards, a weakened plane highly susceptible to scaling failure is created, and the entry of water along the planes of separation fulfills the requirements of scaling failure. These requirements have been described in "A Preliminary Report of the Performance of Kentucky (Natural Sandstone) Rock Asphalt" (1).

Oil or other heavy solvents caused localized softening of the cementing material; this usually resulted in sanding of the type shown in Figs. 30 and 42. Well cured materials were least susceptible to this damage, but all were affected. Highly volatile solvents such as gasoline evaporated without appreciable damage to areas protected from traffic.

After considerable traffic exposure, pitting - in the form of small concave shear failures - sometimes developed. Once begun, this progressed rapidly in the direction of traffic, the progression undoubtedly resulting from the bouncing of vehicle wheels. In some cases an initial bump sufficed to explain the condition; but in others there was no apparent roughness at the point where the failure began. In at least one place the pavement appeared saturated, suggesting that hydrostatic pressure created by wheel impacts aggravated the failure.

Tire tracking of the surface under early traffic is not in itself a failure, but was classed as such because it was severe enough in a few cases to cause permanent damage. This occurred on very soft pavements in the early stages of curing under traffic. It caused some sanding but the pavement was usually re-smoothed and re-compacted by the traffic without appreciable damage.

Dry Heated Materials

These materials, consisting of freshly quarried rock asphalt, dry heated only and also containing PAC-3 and powdered asphalt supplements, Sections IV, V, and VI respectively, were all heated to a significantly higher temperature (235° to 300°F) than the regular steamed materials. Each load consisted of the accumulation of numerous individually and successively heated batches (approx. 250 lb. per batch). Temperatures of batches varied somewhat but were generally within the desired range. Temperature losses while enroute to the job averaged 20° to 30°F. When spread at temperatures well above 200°F, the materials gave off bluish vapors, indicating further volatilization of light oils. Although moisture was generally less than 1 percent, numerous vapor bubbles formed under the freshly spread materials; and, in some cases, these were punctured and deflated. Clinkers, resulting from coking, plagued the spreading operation by lodging under the screed and scarring the surface. When observed, they were removed, but many went undetected and showed up later as "pop-outs" (Fig. 40).

Due to the method of processing, the supply of dry heated material to the paver was slow (actually about one load per hour). During the interim time between loads, the paver often stood idle and the hot screed tended to overheat the material underneath and caused it to coke rather severely (Fig. 39). Most of these spots were subsequently cut out and replaced, but a few were left for observation. Generally they tended to deteriorate under traffic. Other spots occasionally showed up which were apparently attributable to overheated batches.

Unless the screed was heated, all of the dry heated materials tended to pull and tear (Figs. 35 and 36). Correcting this required excessive hand finishing, which could not be easily accomplished if they were allowed to cool below 200°F. However, since virtually all these sections were laid at temperatures well above 200°F and with the screed heated, this presented no particular problem.

Response to the roller was typical of ordinary hot-mixed paving materials. Heavy rolling had no apparent beneficial or harmful effects. Compaction, therefore, was usually limited to one coverage by the roller. About 160°F was the lowest temperature at which surface irregularities could be rolled out. Above 225°F the material tended to pick up on the rollers. In some cases, it was necessary to roll farther back in order to take advantage of the interim temperatures.

Section IV temperatures ranged between 200° and 270°F, averaging 236°F, for the low-heat half; and between 270° and 305°F, averaging 288°F, for the high-heat half. Although parts of the section were allowed to cure variously from one hour to three days, curing did not seem to be necessary or to offer any particular benefit; and the materials were sufficiently stable to support heavy traffic immediately after cooling. They were characteristically black and thoroughly coated, and there were no evidences of crust formation or tendencies to scale. No failures other than those attributable to overheating (coking) or improper processing have occurred (as of February 7, 1956).

Section V temperatures averaged fairly close to 250°F. The extra 2 percent and 3 percent PAC-3 made the material a little more difficult to work below 225°F (Fig. 35). Traffic was deferred for 1 and

2 days; but here again no additional advantages seemed to be gained by subsequent curing. There have been no indications of crust hardening although some scaling has occurred.

Section VI averaged 290°F, ranging from 250° to 300°F. The combined effect of the powdered asphalt supplement and dry heating made the materials difficult to work below 230°F. They appeared equally as black but not as shiny as in the other dry heated sections. This section was laid at the rate of 60 lb. per sq. yd. and was not allowed to cure any longer than would be normal in actual practice. Scaling and pitting (Fig. 44) have developed at several locations, and the section has required patching at least twice since construction.

Second-Month Inspection

(Including Construction Features)

October 7, 1955

The relative performance of the various sections and the extent of damage within each are recorded on the following strip-map. The succeeding photographs present a visual record of the otherwise general details shown on the strip-map.

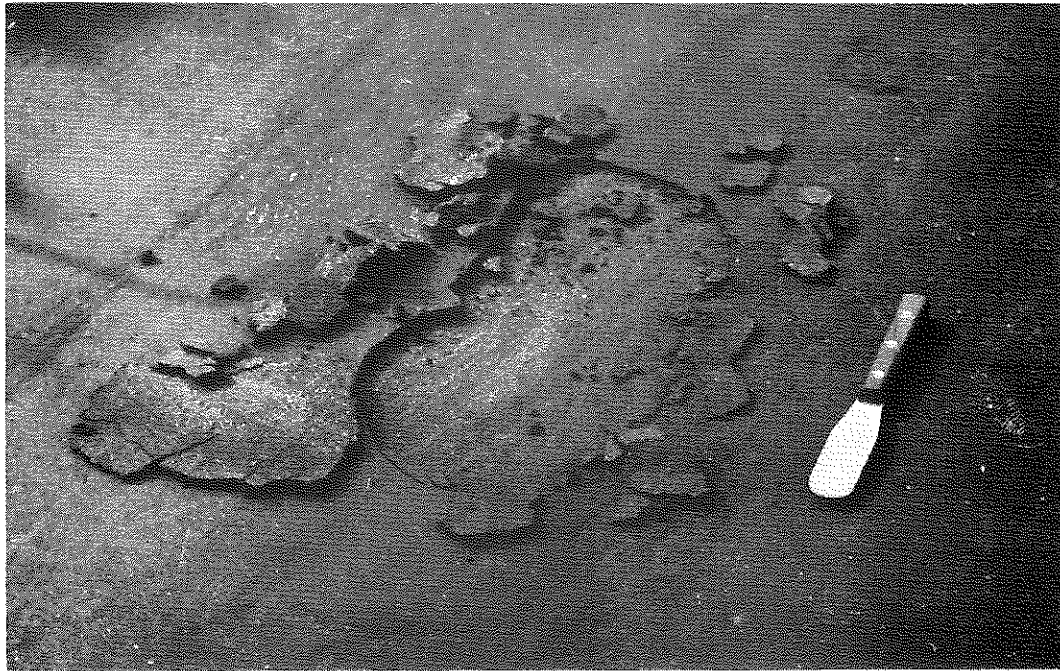


FIG. 27: Section I: Typical Horizontal Shear Failure Caused by Over-rolling. There were no breaks in the surface and the condition was detected only by movement in front of the roller wheels. Striations on the sheared surfaces are evidences of scouring and stripping caused by differential movement along the shear plane. This condition is very similar to that observed in older pavements suffering from scaling.



FIG. 28: Section I, Control B: Example of Streaks Caused by the Scouring Action of the Paver Screed Tending to Strip Asphalt from the Sand. The asphalt accumulated on the screed and was sloughed off at intervals, leaving alternately enriched and stripped sand on the surface. This condition was minimized when the screed was hot.

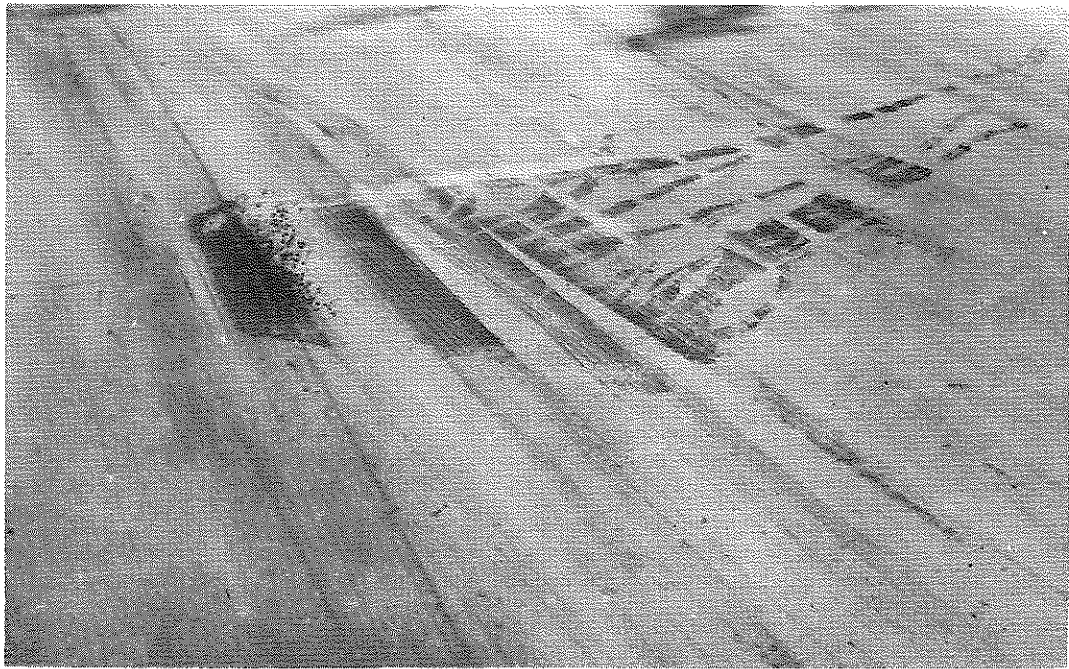


FIG. 29: Section I, Control B, Steam Heated. The dark pattern outlines an area saturated with water from a roller standing idle. Note that the material is easily marked and loosened by traffic.

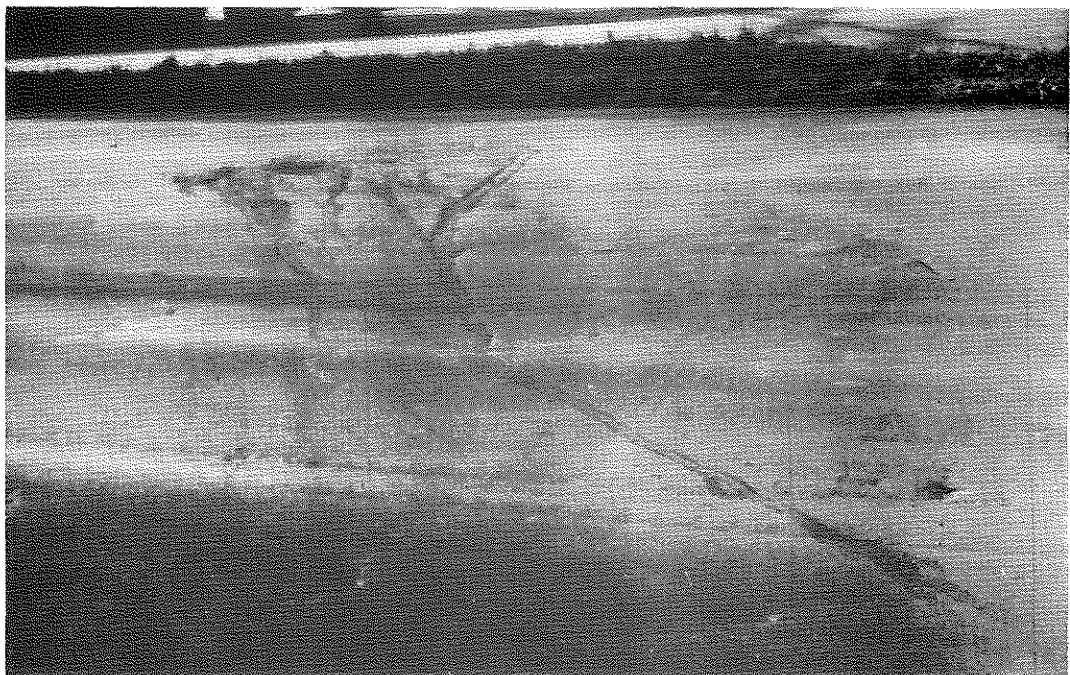


FIG. 30: Section I, Control B, Steam Heated: View of the same area above after 3 days under traffic. The depth of these water-marks is about 1/4 in. Dry heated materials were apparently not susceptible to damage from roller water.

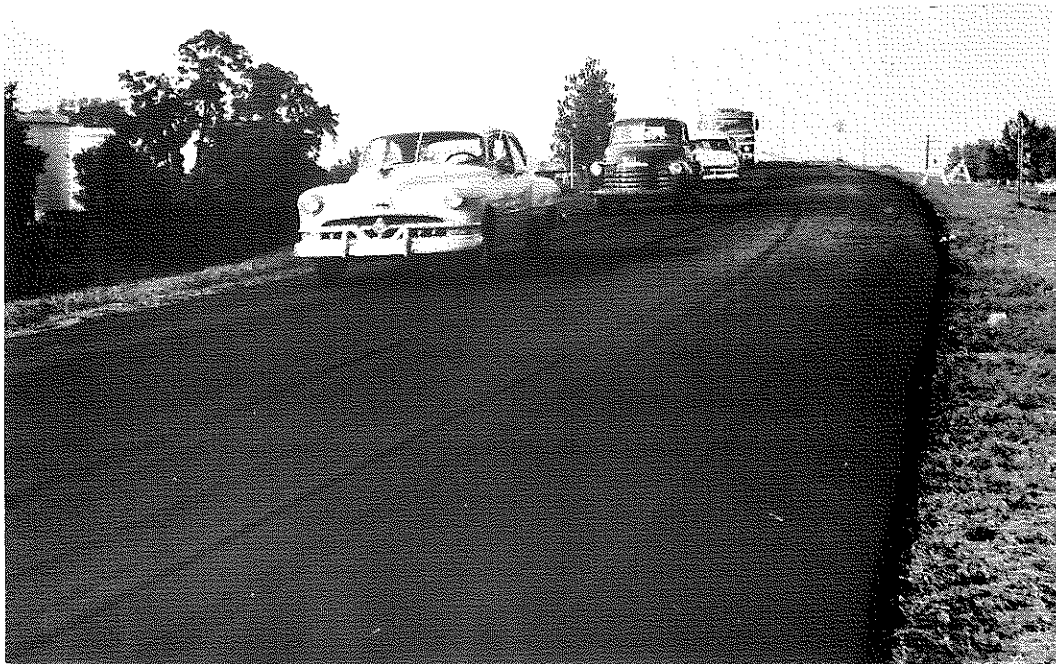


FIG. 31: Section I, Control B (Southbound Lanes). This section was opened to traffic almost immediately after final rolling. The material obviously had not achieved sufficient stability to support the traffic. Actually the condition was aggravated by paver breakdown which interfered with the normal flow of traffic. Decelerating, standing, and accelerating vehicles imposed rather severe tractive as well as static loads on the material.



FIG. 32: Section I, Control B (Same as Above) Showing Severe Shoving and Displacement. At some locations as much as 4 in. of the surface was shoved off the edge of the pavement. The wheel tracks were rather deeply furrowed, and some material picked-up on the tires.



FIG. 33: Section I, Control B (Same as Figs. 31 and 32). After about three days, traffic had fairly well compacted and stabilized the material; but the earlier condition left the surface rough, deeply furrowed and in need of correction.



FIG. 34: Section I, Control B. Same section after resurfacing with a thin overlay spread with the paver, and after about two months of service.

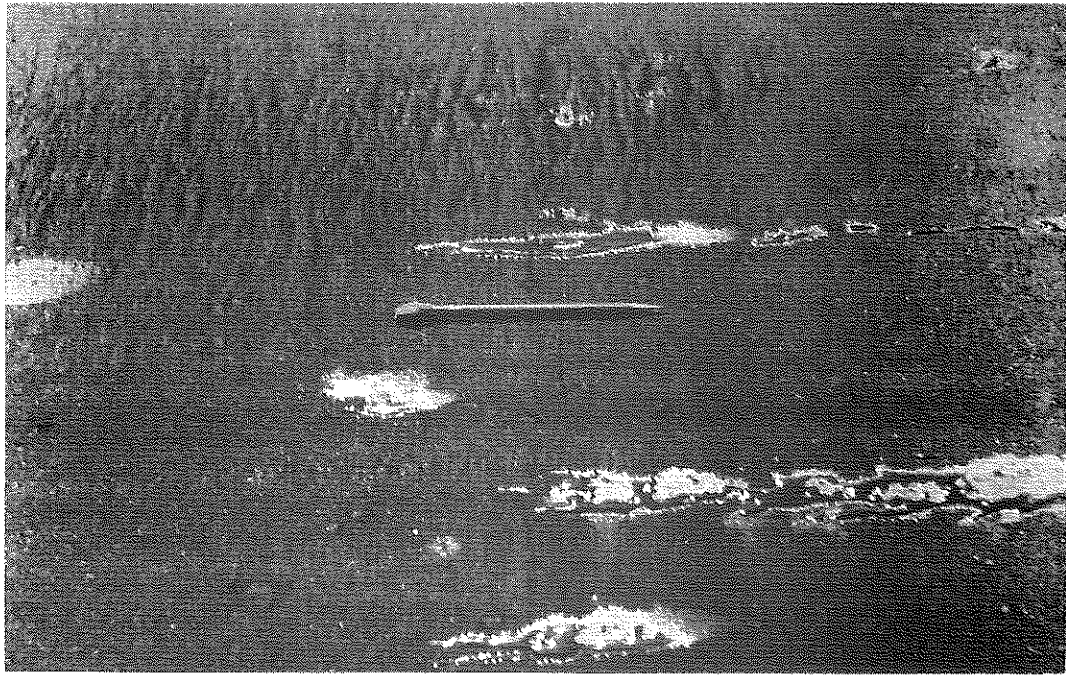


FIG. 35: Section V, Containing PAC-3, Dry Heated. Shows tendency of the material to tear under the screed in localized spots, due to excessive enrichment and non-uniform distribution of the added asphalt. Other portions of the same load spread and finished satisfactorily. This condition was more prevalent in mixtures containing 3 percent added asphalt than in those containing only 2 percent.

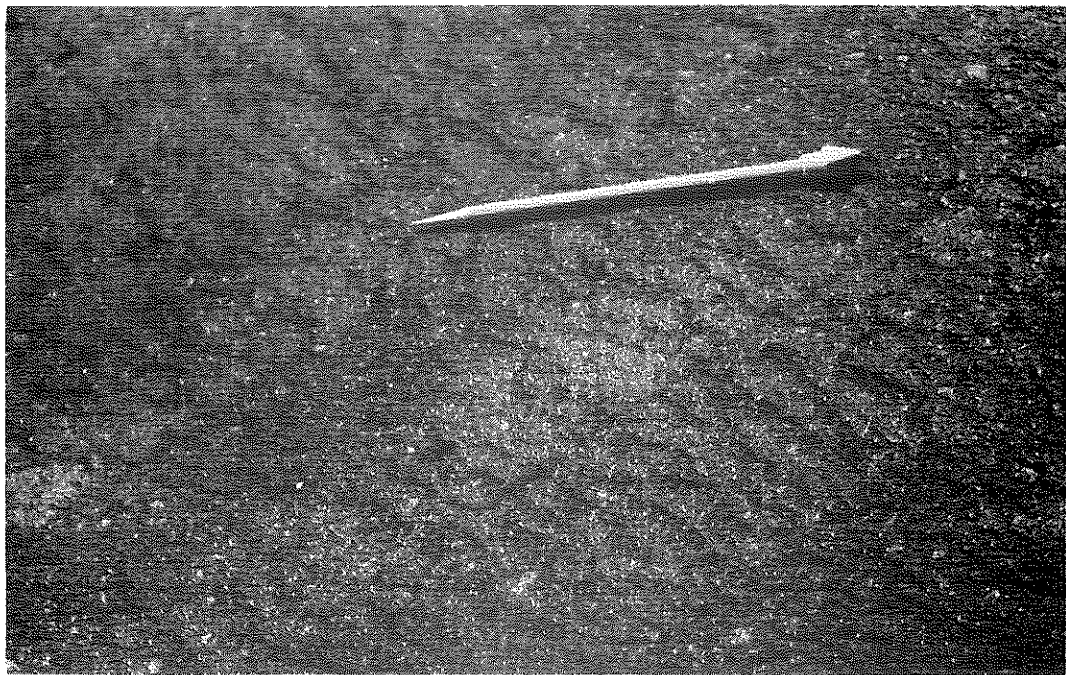


FIG. 36: Section I, Containing Powdered Asphalt, Dry Heated. Shows typical rough appearance when spread. Temperature was 250°F or above and the screed heated. Rolling eliminated any surface evidence of this condition.



FIG. 37: Paving with Dry Heated Materials. The vapor rising from the pavement had a bluish color which presumably indicated volatilizing oils. This was common to all dry heated materials, particularly above about 220°F. Note raker at left removing a clinker. The particular mixture here contained 2 percent PAC-3.



FIG. 38: Typical Example of Bubble Formation in Dry Heated Materials. Most of these seemed to occur near the middle of the lane and in material which had been in contact with the hottest part of the screed.



FIG. 39: Section IV, Dry Heated. The small area shown was overheated and partially coked by the hot screed while paver stood idle between deliveries of material. Usually these were removed and replaced; but a few spots were left for observation, and later patched.



FIG. 40: Section VI, Containing Powdered Asphalt, Dry Heated. Cinders, or clinkers, due to overheating and coking show up as pop-outs. This section was not paved to the full 1-in. depth. Actually about 60 lb. per sq. yd. were used and clinkers were less likely to be submerged. These seemed to encourage scaling around their perimeter.

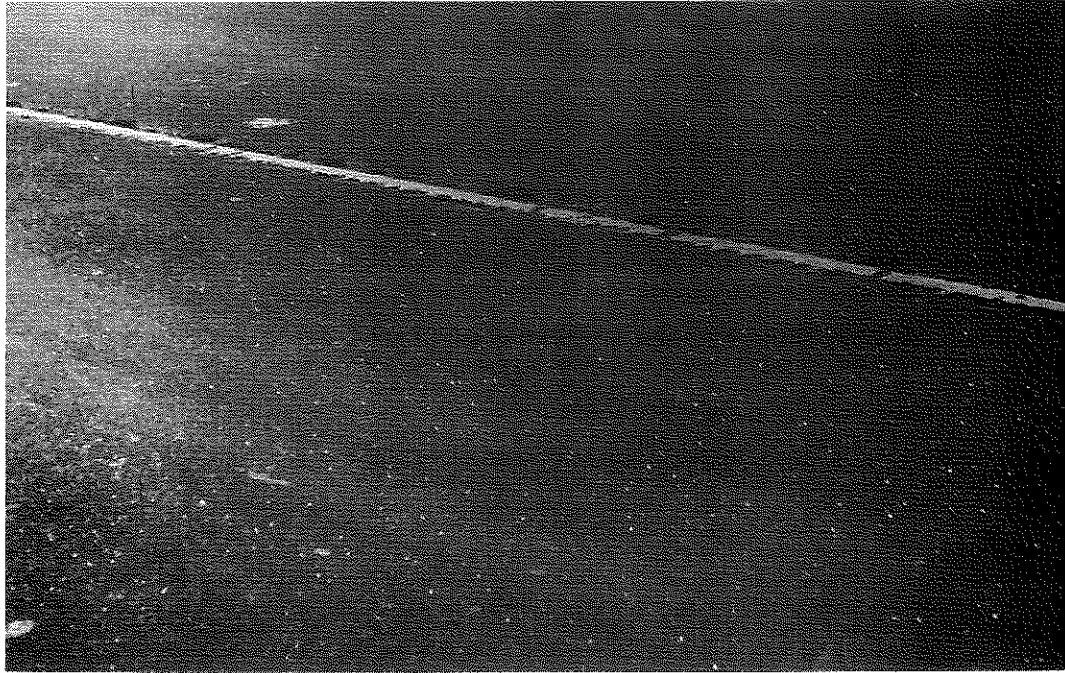


FIG. 41: Typical Example of Damage Caused by Painting Lane-Separation Lines. Apparently the material had not been sufficiently cured and the paint and solvent softened the asphalt, allowing it to sand away.



FIG. 42: Example of Very Severe Damage Resulting From Fuel Oil Spilled During the Construction of the Raised Median Divider Strip. Fuel oil was evidently used to clean shovels, etc. This photo was taken after patching. Oil was tracked a considerable distance in the direction of traffic, and softened the surface, showing as bright spots, but caused no damage requiring patching.



FIG. 43: Unscheduled Section Containing Powdered Asphalt No. 2, Steam Heated. During construction, hydraulic fluid from the paver leaked onto the roadway. Although this was mopped and broomed away, the material quickly rutted out of the wheel tracks. Accordingly, this section has been eliminated from further consideration in the evaluation of performances. The undamaged section in the foreground is dry heated material containing 3 percent PAC-3.



FIG. 44: Section VI, Containing 1 Percent Powdered Asphalt No. 2, Dry Heated. Only 60 lb. per sq. yd. were laid on this section. Continuous pitting and loss of material from the wheel tracks are evident in the outside lane. Heater-planer is shown in the background attempting to re-smooth the section.

Sixth-Month Inspection

February 7, 1956

As in the preceeding portion of this report the relative performance of the various sections and the extent of damage within each section are recorded on the following strip-map which serves to summarize, in a general way, the features considered pertinent to performance evaluations.

The succeeding photographs present a visual record of the otherwise general details shown on the strip map.



FIG. 46: Section I, Control A, Northbound Lanes. This general view looking southward from Sta. 0+00, shows severe rutting in the outside lanes. Damage began approximately six weeks after construction. Since then the damaged areas have been patched twice. The bright areas are remnants of patch material enriched by heavy applications of prime coat.



FIG. 47: Section I, Control B, Southbound Lanes, Looking Southward from Sta. 0+00. Rutting is practically continuous throughout the entire section but has been confined almost exclusively to the outside lane. This section has also been patched twice previously.



FIG. 48: Section I, Control A, Northbound Lanes. Showing Scaling in Wheel Tracks of Outside Lane. The bright areas are patches. This area was reworked with the heater-planer after 2 months because of the development of small hairline cracks. Treatment apparently retarded but did not prevent scaling.



FIG. 49: Section I, Control B, Southbound Lanes. Extensive rutting is confined to the outside lane. This area was patched, soon after laying, with a thin overlay.



FIG. 50: Section I, Control A, Northbound Lanes. The southern end of the section is shown, with joint at arrow between Control A and section containing Antistrip No. 1. Meandering track down center of outside lane was caused by heater-planer in reworking, during October. Obviously, attempts were unsuccessful in effecting permanent restoration. Traffic tends to avoid these areas because of roughness.



FIG. 51: Section I, Control C, Southbound Lanes: A General View Showing Scaling and Sanding of Overlay Patch. Failure extends only to original surface, which was apparently strengthened and toughened by priming material. Note that inside lanes are still undamaged.



FIG. 52: Section II, Antistrip No. 1, Northbound Lanes. Scaling has developed in the outside lane while the inside lane is undamaged. Section containing Antistrip No. 2 is similarly affected but to a lesser extent.



FIG. 53: Section II, Antistrip No. 1 and No. 2, Southbound Lanes. Scale here is 1/4 to 3/8 in. deep. Joint between No. 1 (foreground) and No. 2 (background) is indicated by arrow. No. 2 has not suffered in these lanes but has scaled in the northbound lanes.



FIG. 54: Section II, Antistrip No. 3, Used in Southbound Lanes Only. This view shows the transition from Antistrip No. 2 (foreground), undamaged, to Antistrip No. 3, damaged. Only the outside lanes with No. 3 show appreciable failure.



FIG. 55: Section III, Steamed, Containing Powdered Asphalt No. 1. Foreground shows well developed scale in outside wheel tracks. Inside lanes are undamaged. Section IV, dry heated to 235°F. Background is practically free of damage except for a few isolated spots of scale. Similar materials in opposite lanes are only slightly damaged.



FIG. 56: Unscheduled Section Containing Powdered Asphalt No. 2 Similar to Section III Near West Point, Sta. 107+08 to 115+66. This section was seriously affected by oil from a broken hydraulic cylinder on the paver. Rutting occurred in the wheel tracks almost immediately. These were cut out and replaced in October, 1955. Patches are practically intact but failure continues around them.



FIG. 57: Section IV, Dry Heated to 235°F, Southbound Lanes, Showing Only Isolated Scaling in Outside Lanes. Similar material in opposite lanes also shows only very slight amount of failure.



FIG. 58: Section V, 2 Percent PAC-3 added, Dry Heated, Northbound Lanes. Some scaling is evident in outside wheel tracks. Scale is very thin, and affected locations do not appear to be associated with any factor apparent at the time of construction.



FIG. 59: Section VI, Containing Powdered Asphalt No. 2, Dry Heated, Northbound Lanes. Failure seems to be rather general throughout this section, but again only in the outside lanes.

SUMMARY OF FIELD DATA AND PERFORMANCE

The field data are simply a record of the measureable physical parameters of the various materials at the times they were delivered to the paver. The data inadequately portray such visible features as color, free sand, stickiness, and workability. Subsequent performance under traffic requires visual and judicious evaluation. Here, the adjudged interrelationships between these factors are summarized and enumerated, as follows:

1. The natural steam heated materials were characterized by mealy workability, practically comparable to that of "loose sand". This is attributed to the softness of the asphalt and non-uniformity of coating. They gained strength with curing, but were initially immature and inadequate for medium to heavy traffic.
2. Antistripping additives tended to soften the natural asphalts. Materials so treated remained alarmingly soft even after several weeks on the road. Stability samples air cured for 30 days showed a progressive gain in strength. Performance on the road indicated that the treatment failed to enhance the material sufficiently to sustain heavy traffic.
3. Powdered asphalt supplements improved initial stability, but cold mixing of the additive and subsequent steaming tended to strip asphalt from the sand surfaces.

This was apparent by the progressive grayness of batches excessively mixed. Other batches appeared even blacker than the raw or untreated material. Generally, the performance on the road was considerably improved over that of untreated materials.

4. Dry heated materials containing no supplements had superior test values, improved strength, uniform coating and distribution of asphalt, blacker appearance, "stickiness" comparable to that of ordinary hot-mixed materials, and a firm "set" on cooling. While containing considerably less than optimum percentages of asphalt, their service performance has thus far been superior to that of all other sections, including even dry heated materials containing asphalt supplements. Clinkers contaminated these materials and showed up as "pop-outs" or small blemishes on the road but these were attributable to inadequate scavenging of the heating equipment. The materials exhibited high initial strength, adequate for heavy traffic.
5. Materials containing supplements of asphalt cement (PAC-3, dry heated) exhibited high stabilities and other characteristics suggestive of a designed, hot-mixed, sheet asphalt. Enrichment of the asphalt made the material more difficult to spread and work, but it also gave the material a "setting" quality, and immediate strength on cooling. While the over-all

test properties were superior to those of plain dry heated materials, performance under heavy traffic has proven to be slightly inferior. This seeming disparity, however, is attributable in part to a lack of control over the mixing and processing and also to the particular location of the material on the road.

6. Dry heated materials containing supplements of powdered asphalt gave test values as high as or higher than those of the plain dry heated materials and the dry heated materials containing supplements of PAC-3; yet the performance of these materials has not been equal to that of the other dry heated materials.
7. Practically all of the failures have occurred in the outside, heavy traffic lanes (approx. 7000 v. p. d.) while the inside lanes (approx. 2000 v. p. d.) have sustained only slight damage regardless of the material. In other words, it seems that all of the various materials might prove to be adequate within or below this lower traffic limit. On the other hand, only the plain dry heated materials seem to be entirely adequate under the severest traffic. Next in order according to apparent resistance to failure are the other dry heated materials, then the steam heated materials containing powdered asphalt, steam heated materials containing antistrip compounds, and then untreated steamed material. The greatest improvement, of course, was within the dry heated sections.

8. In general, the order of performance parallels the increased stability as measured by the Marshall method, and the heat-treated rock asphalts respond normally to all of the basic mixture design principles. When moisture and uneven distribution of asphalt in the natural materials are eliminated, the only factors controlling stability, and consequently performance, are the amounts of asphalt and its cohesiveness or binding strength.

The field performance tests, at this time, have not yet run their full course. As of February 7th, after six months of service, including the greater part of a winter season, the test sections have already sustained severe damage. While the conditions of the test have exceeded expectations in severity and intensity, such extensive damage was not anticipated - or at least not so early in the test. Yet for such a test to fulfill its intent, there should be decisive failures as well as a decisive margin of invulnerability, with a full gradient of performance within these limits. The first condition, of course, has been fulfilled both with respect to the materials involved and volume of traffic. The second condition is not yet in jeopardy since the sections of plain dry heated materials still show considerable promise of survival. Assurance of this is time dependent and can not be accelerated. Continued observations are therefore necessary and unavoidable. Interim progress reports are being contemplated, and these will of necessity involve conclusions regarding the surviving materials.

HISTORICAL SKETCH

APPENDIX I

HISTORICAL SKETCH

I-1

Although natural rock asphalt was known in Kentucky as early as 1890, the peak production occurred concurrently with the great "road-building era" in the state and other parts of the country (1923-1932). Peak production reached almost 400,000 tons annually and was valued at almost 3-million dollars. At one time it was estimated, perhaps a little too optimistically, that there was enough rock asphalt in Edmonson and Grayson Counties to pave all the roads in the United States. It has been advertised by such cliches as "Natures Own Paving Material", "Black Gold", and "Kyrock", or "Kentucky Rock Asphalt."

In 1888 and 1889, Dr. W. J. Breyfogle, of Louisville, explored the outcroppings in several counties in western Kentucky and gained possession of the more promising deposits. Under his direction, in 1889, trial blocks (streets) were laid in various cities (Louisville, and Columbus, Ohio), and companies were organized to quarry the material and to promote its use. As a matter of interest, an original account of these developments is quoted, in part, from a report to the Kentucky Geological Survey made by Edward Orton, State Geologist of Ohio, in 1891, (2):

"In Ohio, streets have been laid with the Kentucky rock asphalt, as the new material is designated in several cities. Two streets, and one or two sample blocks beside, have been laid in Columbus, most of the work having been done in the last three months of 1890. The most conspicuous sample is laid in front of the United States Government Building, in which the post-office and other public offices are established. The test afforded by this block will be a fair one when completed. While the travel upon it is not of the heaviest sort, it is fairly constant, and horses are left standing upon the pavement at frequent intervals through the day. The charge has been made that this sample has been tampered with in spots by pouring coal oil upon it. The present year (1891) will probably demonstrate

the character of the new material and its adaptation to street-making in its native state. As to the streets that have been laid in the city, different opinions are entertained, both by property-owners along their lines, and also by experts. The principal criticism is directed to the want of hardness in the asphalt surface.

The reader will perceive that even if California rock asphalt were proved to be a thoroughly successful street-paving material, we should have no right to assume that Kentucky rock asphalt would also serve equally well for this use. The Kentucky asphalt has a coarse sand for its base, while the California rock, as shown in the preceding statements, consists in the main of clay and very fine-grained sand. Whether the asphalt or the paraffine base predominates in the Kentucky rock has yet to be determined. In other words, this new material must establish its claims independently. The molasse of Switzerland is a coarse sandstone, which is sometimes impregnated with a notable percentage of asphalt, but Neale rejects it entirely from his list of road-making material.

I append the careful statement of Mr. Charles B. Palmer, of Columbus, as to the work done on one of the two streets named above. Mr. Palmer was appointed superintendent of the improvement on Woodruff avenue, in the interest of the property-owners, by the Board of Public Works. He brought to his duties not only personal interest and good judgement, but also habits of careful observation. His opinion is, on the whole, favorable as to the possibilities of the new material. His statement bears date January 25, 1891.

STATEMENT OF CHARLES B. PALMER, ESQ.

'The paving of Woodruff and Ninth avenues, in this city, during the past season, was an interesting event, as being the first instance of the use of Kentucky rock asphalt, or bituminous sandstone, for paving purposes, in Ohio. The new material has attracted a great deal of public attention, and produced an animated discussion among our citizens as to its merits.

In the construction of these pavements, the wearing surface was laid on a six-inch foundation, made in the usual manner, the road-bed having been first properly graded and rolled with a sixteen-ton steam roller. The road-way was 30 feet wide with a six-inch crown. The proportion of materials used in the concrete was one part cement to two parts sand, and four of broken stone. Upon this was laid the wearing surface of rock asphalt, two inches in thickness after compacting. The material was prepared by being finely ground, heated by steam, spread on the street and rolled, the intention being merely to change the form, leaving it on the street as nearly as possible in its natural state. The grinding and heating were done by

machinery specially constructed for the purpose. The heating was done in a large revolving steam cylinder. On being received from the heater, the material was hauled to the street in gravel beds covered with canvas, dumped on the street, spread with shovels, and raked down to proper thickness. It was first rolled with a light, hot roller, and then with a 500-pound hand roller. The material compacts by rolling about two-fifths, requiring considerably over three inches of loose material to make two inches after rolling.

Naturally, with a new material, new company, new machinery and inexperienced workmen, a good many difficulties were encountered, which can be avoided in future work. The contractors made every effort to secure the best results; but, as might be expected, there were some imperfections in their work.

Judging from my limited experience, the most important points to be guarded are-

1. Quality of Material. - Like most natural products, the bituminous rock varies in quality, shading off from the best to the worthless, depending upon the proportion of bituminous matter which it contains. The best quality is jet black in color, and adheres like putty, when pressed between the fingers. If brownish in color, and inclining to crumble apart rather than adhere, it should be rejected.

2. Grinding. - It should be finely granulated. Lumps of unground material the size of hickory nuts are objectionable, especially if left near the surface of the work.

3. Heating. - The specifications under which the contract was executed required a temperature of 250 degrees F. when placed on the street, and, in my judgement, this is a very proper and necessary requirement. It is true that this material can be compacted to a certain extent when cold, and when left in piles after being ground it speedily consolidates into a mass which can, with difficulty be separated with a pick. From this it is argued that a high degree of heat is unnecessary; but in practice this idea is found to be erroneous. The hot material makes by far the smoothest and most compact pavement, and will undoubtedly be the most durable. The imperfectly heated material remains rougher and more porous, and will not compact by rolling to the required thickness, or rather thinness. Worst of all, such portions of the work show indications of crumbling with use, while the rest remains smooth and tough. I am, therefore, led to believe that the heating of the material is a point of very great importance in making a good pavement with this product. I think that a temperature of at least 200 degrees F., when actually spread on the streets, is necessary to secure the best results. For various reasons

it was found impossible to maintain a satisfactory temperature, chiefly on account of the street and the heater being three miles apart, with cold fall winds blowing a large part of the time. It seldom exceeded 150 degrees, and often fell below 100. A great many loads were sent back to be reheated. None of the work is, therefore, a really fair sample of what may be expected of the material when handled in the best manner.

4. Rolling. - After being spread on the street very hot, it should be thoroughly compacted. It will require further experiment to determine the best way to do this. In the present case, nothing heavier than a 500-pound hand-roller was used in compacting the material at the time of laying. A few days later, a corrugated iron horse roller was used, consisting of ten cast iron wheels, each three inches wide, with alternate spaces of the same width. This machine was said to weigh about three tons. As it seemed to have but little effect upon the cold pavement, it was, at my suggestion, weighted with over two tons of pig iron. In this condition, it produced a decided effect, and was evidently beneficial, working and kneading the pavement-which, though cold, was still somewhat plastic-smoothing out inequalities, and making it more compact. I was strongly impressed, however, with the idea that it should be more thoroughly compressed while soft, than can be done with a 500-pound roller. This opinion was sustained by the City Engineer and the Board of Public Works, and the contractors, therefore, ordered a five-ton steam roller. But, much to my regret, it could not be obtained in time to test it before our street was finished. It was claimed by the contractors that a five-ton roller is too heavy; that it will crush the material out of place, if used while the work is soft. A very short trial would have settled the question; but it was not done. If five tons is too heavy, it should be determined by experiment what is the greatest weight that can be used without injury to the work, and a roller constructed to meet the case. It is interesting to note in this connection that tamping and ironing seem to produce better results than rolling, and the idea has been suggested of a tamping machine to take the place of a roller.

In conclusion, it may be said that while it is too much to expect that the first attempts to use a new material will be satisfactory, the results so far obtained are, on the whole, sufficiently encouraging to warrant the prediction that Kentucky rock asphalt will be extensively used for street paving. If the present methods of manipulation are not the best, better ones will be found. If it should be found desirable to produce a slight modification in quality by the addition of some substance, there is no reason why it should not be done. It took years of careful experiment to bring the

mixture, known as "Trinidad asphalt," to its present state of efficiency; and it will be strange if a material, which exists in great abundance near the center of population of the United States, and which comes from the hand of nature so nearly what is required for a pavement of the best class, shall not, by a little skillful treatment, be perfected and made to supply this important demand!

Note. - The year that has passed since the above statements were prepared has given a fairer opportunity to judge of the merits of the rock asphalt than had been afforded up to that time. It is a pleasure to report that the streets of Columbus, which were surfaced with it, present a much more favorable appearance than they did one year ago. The asphalt has grown harder and more compact in this interval, while still retaining a measure of elasticity. It now appears to the writer that the rock-asphalt, when properly handled, is likely to become a paving material of great value."

E. O.

Two other documents or reports of a similar but more technical nature, dated 1913 and 1924, have been reproduced and included in the appendix for convenient reference (4) (5).

According to Orton's report, Dr. Breyfogle was the first to recognize the similarity or analogy between the Kentucky rock and a natural rock asphalt in California which has been used with some success between 1880 and 1890 for paving streets. The Californians fashioned their work after older natural (limestone) rock asphalt pavements in Europe. The earliest records of natural rock asphalts being exploited commercially go back to about 1802 when such materials were mined as building stone or masonry stone at Seyssel, on the Rhone River, in France, and at Val de Travers in Switzerland. These materials were first used for paving floors, bridges, and walk-ways. Then, a Swiss engineer noted that waste material compacted under traffic hauling the rock from the mines. He interested the French authorities in his discovery and in 1854 a test-pavement of compressed (compacted) pulverized limestone rock asphalt

was laid in Paris on Rue Bergere. This pavement was maintained in good condition for sixty years.

The following abbreviated chronology covers the interim period(6)(7):

1852 - First modern asphaltic road - of the modern macadam construction, used Val de Travers asphalt rock, from Paris to Perpignon, France.

1854 - First compressed (compacted) pulverized rock asphalt roadway (discussed above).

1858 - First large stretch of rock asphalt surface, Palais Royal and Rue St. Honore, in Paris, consisted of 6 inches of concrete foundation surfaced with 2 inches of Val de Travers rock asphalt.

This same year, the steam roller was invented in France, replacing horsedrawn rollers; and the rock crusher was invented by Eli Whitney Blake in New Haven, Conn.

1869 - First compressed asphalt pavement in London, Threadneedle St; using Val de Travers rock asphalt.

1870 - First asphalt roadway in the U. S., opposite City Hall, Newark, N. J.; used European rock asphalt.

1871 - A mixture of coal tar, crushed rock, and sand was laid in Washington, D.C., following a favorable appraisal of the material by a Congressional Committee.

1876 - Congress directed that comparative service tests be made on Pennsylvania Avenue in Washington to settle controversial claims made by two intensely competitive materials. The section between Capitol and 6th Street was surfaced with Val de Travers rock asphalt and the remainder was surfaced with sheet asphalt using Trinidad asphalt. The Val de Travers rock asphalt was subsequently pronounced "too slippery" and the sheet asphalt was acclaimed a "success".

(Note: This decision apparently spelled the "doom" of European rock asphalt in the U. S.)

After 1876, the use of Trinidad, Bermuda, and other natural asphalts, and tars became customary. It also became customary for paving contractors to furnish maintenance-free guaranty of the pavement

for five years. There followed an era of reckless experimentation. Intensive competitors offered as much as fifteen years guaranty. The petroleum industry was then in its infancy, but began to develop rapidly between 1890 and 1900. The development of the air-blowing process in 1894 made it possible to reduce a greater variety as well as greater quantities of petroleum residues to a consistency and quality suitable for paving. About 1890, or earlier, the Barber Asphalt Paving Company, spearheaded by Clifford Richardson (later a notable authority on asphalts and asphalt pavements), began working with dense-graded macadam-type mixtures very similar to our modern asphaltic concretes. In 1899, Frederick John Warren began experimenting with similar gradations, and two years later succeeded in obtaining a patent on his mixture. A later modification of the mixture in 1910 was called "Warrenite" and was recommended for use on country roads. About this time, the "Topeka" mix successfully circumvented the Warren patents.

The history of rock asphalt first preceded and then paralleled the evolution of the modern asphaltic concrete pavement. The availability of natural rock asphalt doubtlessly provided convenient relief from the seemingly endless controversies connected with the various proprietary bituminous concrete mixtures.

In 1905, the Public Square in Bowling Green, Kentucky, was paved with rock asphalt; and by 1920 or 1924, it was claimed that all the streets in that city were paved with rock asphalt.

Between 1890 and 1945 more than fifteen different companies were variously engaged in quarrying and processing rock asphalt for highway use. Since 1945, the Kentucky Rock Asphalt Company has been the only producer. Although definite records are not available, the following list of companies that have been in operation at one time or another has been compiled from fragmentary references and verbal accounts offered by persons (8) having some knowledge of the earlier history of the industry. Approximate dates and locations of the quarries are given for most of the companies listed:

1. American Bituminous Rock Company started buying mineral rights in the vicinity of the Big Clifty in Grayson County in 1891 and later acquired additional mineral rights in Hardin and Edmonson Counties. This company did not actively engage in quarrying the material. Although the records do not show any definite connection, this may have been the sponsoring company organized by Dr. Breyfogle, mentioned at the beginning of this treatise.
2. Pioneer Asphalt Company assembled equipment and produced rock asphalt in Logan County near Russellville; believed to have operated intermittently from 1894 to 1905.
3. Wadsworth Stone and Paving Company (or Wadsworth Stone and Mining Co.) of Pittsburgh, Pa. started operations near Asphalt in Edmonson County, on the Green River, in 1903; legally succeeded by the Kentucky Rock Asphalt Company in 1917.
4. Federal Asphalt Company acquired the mineral rights and land of the American Bituminous Rock Company and assembled machinery near Big Clifty, and started production in 1910, (1900 according to Dr. Jillson's 1924 report).
5. Kentucky Rock Asphalt Company was chartered as a Kentucky corporation in 1917. During that year, the company acquired the land, mineral rights, and machinery of the Wadsworth Stone and Paving Company and also acquired land and mineral rights to some 40,000 acres from the Bee Springs Land and Mining Company (or the Bee Springs Coal and Mining Co.) (a holding company not actively engaged in quarrying rock asphalt). Production started in 1918 at the old Wadsworth plant near Asphalt. About a year later, the company moved

the plant to Kyrock on the Nolin River. Materials were shipped largely by barge to various rail points. In 1946, the plant was moved to its present location at Sweeden near Brownsville.

6. Ohio Valley Rock Asphalt Company, organized by Mr. Fred Wood and associates, started production at Summit in Hardin County in 1922 and operated there until 1940 when the plant was moved to Black Rock, Kentucky (in Grayson County west of Leitchfield). In 1940, the company also acquired the mineral rights, land, and equipment of the Diamond Rock Asphalt Company. Operations continued at Black Rock until 1946 when the company went out of business.
7. American Rock Asphalt Company (or Rock Asphalt Co. of America) started operations near Asphalt, Kentucky in Edmonson County in 1922, was succeeded in 1927 by the United Rock Asphalt Company which produced material during that year and through 1928. The holdings of this company were acquired by the Diamond Rock Asphalt Company in 1936 which relinquished its holdings in 1940 to the Ohio Valley Rock Asphalt Company.
8. Natural Rock Asphalt Company acquired land and equipment for production on Bear Creek about three miles from Huff, in Edmonson County. Operations began in 1920 and discontinued in 1935. At one time, the company maintained crushing equipment at or near Rockport.
9. Continental Rock Asphalt Company started production at Big Clifty in Grayson County in 1923. The company operated until 1925 and disposed of its holdings to the Crown Rock Asphalt Company.
10. Crown Rock Asphalt Company purchased mineral rights, land, and equipment from the Continental Rock Asphalt Company in 1925 and continued operations intermittently until 1940. The Crown Company "processed" lean rock to achieve the desired asphalt content.
11. Garfield Rock Asphalt Company produced rock asphalt during 1927, 1928, and 1929 near Garfield in Breckinridge County.
12. American Standard Asphalt Company acquired mineral rights in Logan County. No further information available.

13. Black Rock Asphalt Company, an organization operating under this name assembled equipment, produced, and stock-piled a limited amount of material in the vicinity of Black Rock in Grayson County in 1936, 1937, and 1938. The venture proved unsuccessful because the material failed to meet specifications.
14. Church Asphalt Company produced a limited amount of material at a location five miles north of Shrewsbury in Grayson County during 1926 and 1927. Apparently this was also an unsuccessful venture.
15. Seneca Petroleum Company, principally engaged in marketing fuel oils in Chicago, produced limited amounts of rock asphalt between 1939 and 1945 at a location near Huff, possibly on properties or at the same location operated by the Natural Rock Asphalt Company between 1920 and 1935. The equipment was sold to the Kentucky Rock Asphalt Company which operated the site during the 1945 season. The operation was then discontinued and the equipment dismantled.

About 1937, a Mr. Fowler erected a small crushing plant at Leitchfield and produced and sold limited amounts of rock asphalt until about 1940. Also, Dr. Jillson referred to a rather extensive operation contemplated by a company which he listed in 1926 as the Silica Asphalt Company to be located south of Leitchfield on Conoloway and Bear Creeks. It is not known whether the venture ever materialized. Some other companies, such as the Premier Asphalt Company, and individuals have been variously engaged through the years in buying and selling mineral rights.

Several photographs showing early methods of handling and using rock asphalt are appended hereto. Other fragments of historical interest appear in the Appendices and in the body of the report.



Fig. I-a: Unloading Rock Asphalt from Railroad cars (about 1920).



Fig. I-b: Dumping Rock Asphalt for Hand Spreading: 14th Street in Chicago, about 1920.



Fig. I-c: Spreading Rock Asphalt, 14th Street,
Chicago, about 1920.



Fig. I-d: Rolling Macadam Base, Midland Trail,
in Shelby County, about 1920.



Fig. I-e: Spreading Rock Asphalt, Midland Trail, Shelby County, about 1920.

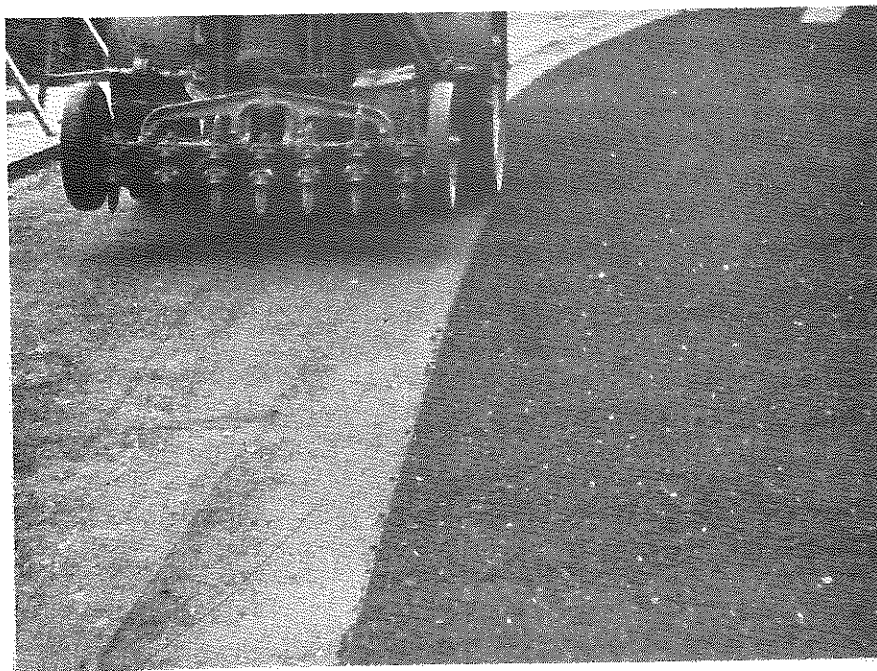


Fig. I-f: Rolling Rock Asphalt Surface, Midland Trail, Shelby County, 1920.

APPENDIX II

SOME GEOLOGIC AND COMMERCIAL (HISTORIC) ASPECTS
OF KENTUCKY ROCK ASPHALT DEPOSITS

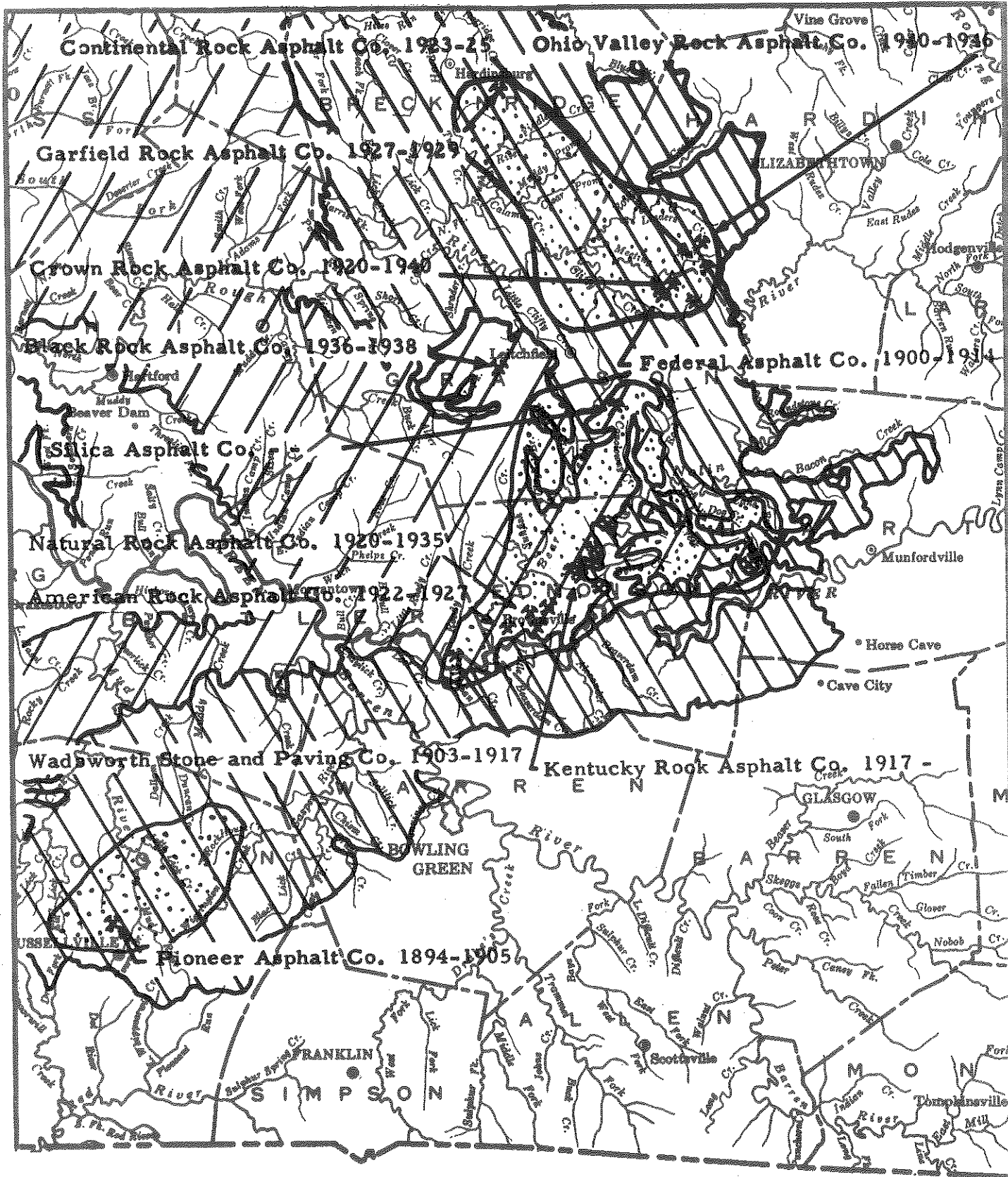
GEOLOGY OF KENTUCKY DEPOSITS

According to MacFarlan (9), the deposits in Edmonson County (the only area now being worked) are mainly in the basal sandstones of the Caseyville and higher Bee Spring which forms the base of the Pennsylvanian (Pottsville) formations. The Cypress and Hardinsburg sandstones are locally impregnated but heavily overburdened. The deposits in Grayson, Breckinridge, and Logan counties are in the Cypress and those in Warren County are in the Bee Spring sandstone. These are the same sandstones and formations that produce gas and oil in the Owensboro oil field. In Eastern Kentucky, deposits of rock asphalt occur near Soldier in Carter County in the same (or similar) basal Pottsville formations.

Geologically these deposits are regarded as "defunct" oil pools estimated to have contained a billion barrels of crude oil. Erosion of upper strata from the Cincinnati arch exposed the material to ground waters and subsequent exposure to air completed the evaporation of the lighter petroleum hydrocarbons (a natural distillation process, which in marginal localities has progressed far enough to leave a more or less asphaltic residue approaching the consistency of paving grade asphalts.) The amount of cover and other localized conditions undoubtedly influenced the "maturity" of the asphalts.

Essential features of the areas in which rock asphalts have been produced are illustrated by the map shown in Figure II-a.

Additional information of more than historical interest is contained in the following papers taken from the report of the Kentucky Geological Survey in 1913, and the Pan American Geologist of May 1924.



Pottsville fm.
(Penn.)



Chester fm.
(Miss.)



Fig. II-a: Composite Map showing some of the Geologic Features and Areal Locations of Bituminous Rock Deposits in Western Kentucky which have been of Commercial Importance.

Kentucky Geological Survey

KENTUCKY ROCK ASPHALT *

By

Malcolm H. Crump

Kentucky Rock asphalt is found principally along the southern and eastern outcrop of the western coal field of Kentucky. It has been opened and commercially developed in the counties of Edmonson, Warren, Logan, Breckinridge and Grayson. It is known to outcrop in Hancock and Hardin and is reported to be in Hopkins. It is also found to a limited extent in Northeastern Kentucky, notably near Soldier on the C. & O. R. R. in Carter county.

Geologically, it appears in the Chester sandstones and in the lower sandstones of the coal measures, including the Conglomerate sandstone. The rock is very generally a sandstone which has been, more or less, saturated with petroleum, the latter (which completely coats each face of every individual grain of sand and thus forms a cementing material) being oxidized and the lighter oils driven off by exposure to the air. It is in fact, an "oil sand" which has been brought to the surface and which after exposure to the elements, forms a mass which can be separated only by crushing and grinding. The percentage of bituminous matter contained varies from 5% to 21%, 7% is the amount required for commercial uses, this amount having been found best for its use as a practical road or surfacing material. The thickness of the beds runs from 3 to 30 feet, though it is reported as high as 40 feet in bored wells. It is usually worked on the outcrop, where the stripping of earth and shale or sandstone may run from nothing to a thickness equal to that of the asphalt bed. It is more or less irregular in thickness with a tendency to pockets of variable extent and thickness; the quality is also irregular to some extent, as is usually the case with natural products. It is quarried in open cut with steam or hand drills and blasted with the usual explosives, either powder or dynamite. Stripping is done at one of the quarries, with a steam shovel. Asphalt rock has been successfully worked in several places - such as Garfield, Breckinridge Co. - less successfully at Big Clifty, Grayson Co.; near Russellville, Logan Co., Young's Ferry, Warren Co., and above Lock No. 4, at Asphalt, Edmonson Co., several miles below Brownsville, the county seat of Edmonson. Here it is found at the base of the conglomerate and also in the Chester. The beds run from 5 feet to 15 feet in thickness. It is quarried in open cut after the stripping, which latter runs from one to ten feet in thickness and consists mainly of earth and sand, is removed by means of a steam shovel. This plant is owned and operated by the Wadsworth Stone and Paving Co., of Pittsburg, Pa., and is immediately on Green River, which has slack water navigation and is navigable every day in the year, and has as much as ten

* As published in Kentucky Geological Survey, Series 4, Vol. I, Part II, 1913.

to twenty feet of water. The plant is readily accessible to the L. & N. R. R. at Bowling Green, Ky., and to the Illinois Central R. R. at Rockport, Ky., the first 50 miles away and the second 80 miles. The property consists of 300 acres in fee, and a still larger amount of mineral rights.

The boiler capacity of the plant is 275 H. P. The rock after being quarried, is broken to crusher size and carried on tram-cars a distance of one mile, to a jaw crusher, where it is reduced to the size of a walnut. It then passes through three pairs of rolls, about 18 inches in diameter and 24 inches long. It is here reduced as nearly as possible to individual grains of sand; every face, of every grain, is permanently coated with asphalt, and in this condition it is ready for use, as it is laid cold, without heating, or the admixture of any substance whatever. The above is a gravity plant from the quarry to the crusher, and thence to the barges on the river. The crusher is about 600 feet from the waters edge. To properly and economically load the material on the barges, a solid concrete dock 8 feet thick at the bottom, and 11 feet above low water mark, has been constructed on piles driven 30 ft. into the river bed. On this dock there is a tipple 12 feet in height at the waters edge and running back to level ground 200 ft. from the river, where a permanent chute is fixed to receive the loaded dump cars from the plant, the material from which goes from either one or two tracks into this chute which delivers it to the barge. It is then towed to Bowling Green, where it is transferred by means of a clam shell elevator directly into the L. & N. cars, or into storage as occasion demands. The capacity of this plant is 300 tons in 24 hours.

Mastic. In addition to the crushing, and grinding plant there are heaters and mixers for manufacturing Mastic. There are two heaters which are loaded, and discharged, four times in 24 hours, with a capacity of 50 tons for that time. This mastic is composed of about 75% of pulverized limestone, 20% of Ky. Rock Asphalt, and 5% of liquid asphalt, or bitumen. It is moulded into 50 lbs. blocks for convenience in shipping and hauling. The mastic is reheated at the place where used and properly seasoned to suit the needed requirements. It is used for water proofing floors of breweries, packing houses, ice houses, cold storage rooms, subways, and wherever a watertight and waterproof floor is needed. As stated above, the crude rock is found out cropping on the hills at least 150 ft. above the river and is a simple quarrying proposition, which usually carries an overburden of 5 to 15 ft., the rock asphalt being of about the same thickness. The overburden is removed by the use of steam drills and steam shovels after being first loosened by dynamite which effectually shatters the rock. The asphalt rock is also drilled with steam drills and shot with dynamite the same as any ordinary rock quarry. The material from this quarry has been and is being extensively shipped as far north as London, Canada, and west as far as Topeka, Kan., while large quantities go to New York for state highways, as well as to Pennsylvania, Cleveland and Columbus, Ohio, Detroit, Mich., and many other points.

Specifications. - The following specifications are for a roadway, having a 6 inch stone foundation and a 2 1/2 inch wearing surface of Rock Asphalt, but they can be changed to suit local conditions and to comply with the engineer's standard requirements.

Sub-Grade. - The sub-grade shall be brought to an even uniform surface parallel with the proposed finished surface. The entire sub-grade shall be rolled with a steam roller of ten tons or more until it is thoroughly compact, and firm. Any portion not accessible to the roller shall be tamped.

Foundation. - Upon this sub-grade thus prepared shall be spread clean, sharp hard limestone of the proper size and of such thickness that it will measure three inches after being thoroughly rolled. Upon this will be placed a three-inch layer of similar stone. After proper rolling this top layer shall be filled with limestone screenings or sand and also well rolled. The resulting surface shall present a true and even appearance 2 1/2 inches below the proposed finished roadway and shall be sufficiently compact to sustain traffic without showing any depressions or ruts.

(Note). - Sandstone, trap, or furnace slag may be used in place of limestone, provided they are properly bound together with suitable material. A Telford base can also be used provided it gives a similar surface.

Final Stone Layer. - On the foundation thus prepared there shall be spread a 2 1/2 inch course of limestone. This course shall be given one rolling only. Just sufficient to smooth the surface to receive the asphalt.

Asphalt Wearing Surface. - The roadway is now ready for the first layer of cold asphalt, which shall be dumped on working boards and not directly on the final stone course. Before spreading all lumps shall be broken or cut up so that it can be uniformly spread over the stone. It shall be spread with shovels, using about 20 lbs. per. sq. yd. for the first layer. This layer is intended to partly fill the voids and hold the stone in place, while the second layer will fill the remainder of the voids, in addition to forming the wearing surface.

When sufficient area has been covered the asphalt shall be forced into the voids by rolling the area twice. After the first cover has been laid care should be taken to prevent any foreign matter being carried on this course before the second, or final course of asphalt has been spread. This is to insure the proper bond between the two courses. When a reasonable amount of the first layer has been completed the second, or final layer, shall be spread and raked to a uniform thickness of one inch in a loose state, using 60 lbs. to the sq. yd. The surface is now ready for the final rolling, but care must be taken not to roll the surface too much immediately after laying. Two rollings are sufficient for the first day, after which it shall have one rolling each day for three successive days and the roadway shall be closed to traffic during that period. None of the completed first layer shall be left uncovered by the second layer over night. The rock asphalt used shall be equal to that quarried in the State of Kentucky, containing an average of 7% of natural bitumen and in no

case shall the average be less than 6% and the material shall be ground as fine as possible, every grain separate and distinct being the ideal condition. Since it is of a sticky or viscous nature it cannot be screened, therefore a small percentage of coarse or lumpy material cannot be avoided; this is not particularly objectionable as during the rolling the lumps are either crushed or incorporated with surface material.

Test for the Bitumen. - Five samples shall be taken from different parts of a given quantity (approximately one pound) which shall be thoroughly mixed and from which a test sample equal to 5 grains shall be taken and the bitumen removed by the ignition test. Carefully weigh the material before testing, and then the residue, which is silica sand. The difference represents the total amount of pure bitumen, which divided by five, will show the percentage of bitumen present. In selecting the test samples only finely ground material should be used.

Quantity Required. - The asphalt shall be spread in the two layers, so that one short ton (2,000 lbs.) will not cover more than 25 square yards of completed roadway.

Proper to Lay. - This should be done in warm, dry weather, but may be done in cool weather if clear and the temperature is not under 60° F., and if additional time is allowed for the asphalt to settle and compact itself before opening the road to travel. If during the rolling of the final layer on a hot day, the asphalt sticks to the roller, the rolls should be greased with a thin coat of lubricating oil which will prevent further sticking. While a ten ton roller is necessary for the sub-grade and foundation, an eight ton tandem asphalt roller is preferable for rolling the asphalt surface, and it is further suggested that the speed of the roller be cut down one-half to prevent the asphalt from creeping in front of the roller. All the rolling connected with the entire construction of a roadway, shall be started along the edges, and worked to the center or crown of the roadway. While it is natural for this material to cup and pick up in its early stages, after two weeks, or three at the most, this will cease and produce a smooth, dustless, mudless and noiseless roadway, which is waterproof and practically automobile proof."

Specification for Resurfacing an Ordinary Macadam Roadway. - "When possible, raise the crown of the road, clean the surface by removing all dust and loose material. The ruts and holes must be filled with stone, and the surface smoothed over, and thoroughly rolled. On this prepared surface there shall be spread a new top coat of limestone and asphalt in the manner specified under "Final Stone Course," and "Wearing Surface," which completes the roadway. When it is impossible to raise the grade or crown of the road to be resurfaced, all mud, dust and loose material shall first be removed and the surface of the old road shall then be loosened by using spikes in the steam roller, or by other practical means. The old wearing surface thus loosened shall be removed and the foundation shall be reshaped, so that the surface will be similar to that hereinbefore specified. "For Foundation," thence proceeding as for a new roadway."

A sample section of this material was put down in Bowling Green, Ky., August, 1907, by B. F. Heidel of the office of Public Roads, under the supervision of Vernon D. Pierce of the same department. Circular 89, Office of Public Roads, Department of Agriculture, Washington, D. C., April 20, 1908, says: "As soon as one-half of the roadway had been surfaced and properly rolled, it was opened to traffic, in the hope that the asphalt would be further worked into the voids, of the stone by the action of the wheel and hoofs. At first the coating rutted badly, under the weight of the heavy loads of gravel and logs to which it was subjected, and the smooth surface given by the roller was seriously cut by the hoofs. This effect decreased visibly after three or four days. At the end of a week no trace remained of the deepest ruts, and the surface had become smooth and compact. It then presented an appearance not unlike that of an asphalt pavement, which has been opened for traffic for sometime. Practically little impression was made on the surface by traffic after a week, except on very warm days, and this was not sufficient to impair its appearance or value. After four months the appearance of the roadway had undergone no appreciable change, but particles of limestone were exposed to view. This was undoubtedly due in large measure to the effect of forcing the asphalt into the voids of the stone, as a large part of the traffic is confined to the center of the pavement. The axis of the roadway had been more or less disturbed while the asphalt was being laid, and it is possible that the few protruding stones were those which had been raised above the general plane of the rock surface and were not covered to the same depth by the rock asphalt as the surrounding rock.

Incisions into the asphalt surface at this time revealed no perceptible loss by drying or hardening of the bitumen, as the sand particles showed their normal inclination to move when warmed in the hand. The permanence of macadam construction depends largely on the nature of the binder used, and the ability of traffic to supply by attrition the material removed by wind and water. It was to test the adaptability of rock asphalt as such a binding material, that the piece of construction was undertaken. The pavement is dustless, there is no appreciable wear of the surface material to be raised and carried away by the wind as dust, and such dirt as may be carried upon it is readily removed by sweeping or flushing with water. There is sufficient adhesive power in the bitumen to serve as a cement to hold the stone of the wearing surface in place - giving at once a smooth, and water-proof surface. It is resistant to deformation under a load, yet sufficiently plastic to break the severity of the blow from a horse's hoof, and thus in a measure avoid the harmful effects of a rigid pavement on animals. In 1910 another inspection showed the surface clean, smooth and compact, with no ruts, and having the appearance of a first-class asphalt city street. The individual crushed stones were tightly bound together, and not a single loose stone was found; the surface was everywhere hard and well compacted, and a small specimen of the rock asphalt, when dug out and warmed in the hand showed that the surface bitumen still had considerable life.

Today the surface presents a good appearance, firm and generally smooth, and the asphalt is apparently as alive as when first laid. Some of the white spots of limestone are still seen, but the individual stones are firmly held in place. There has been no raveling; some uneven places have appeared due to irregular scattering and spreading, together with slight defects in the foundation. It has passed the sixth winter and is found in excellent condition, though there have been no repairs. One of the recent U. S. Highway Inspectors when asked his opinion as to cost of maintenance, replied that one man with a motor car, and the crushed asphalt properly distributed along the road could maintain 25 miles indefinitely for ordinary traffic. The same material when used at Columbus, Ohio, showed, after several months of steady traffic, a surface as smooth as the best finished asphalt street, with no waves or cracks, and entirely free from dust. It is much like ordinary street asphalt and it is constructed without artificially heating the material, as well as without the admixture of any foreign substance; but just as it comes from nature. The experiment of the Federal Government at Bowling Green was made at the suggestion of the writer, and in his presence; hence he is prepared to substantiate everything stated.

It is very difficult to have the general public and the users of artificial asphalts understand that a natural material, or any other asphaltic substance can be laid cold and without mixing it with some liquid material such as oil, tar, or artificially prepared asphalt. Substantiating this statement, B. F. Heidel, in a letter July, 1912, says:

"Speaking of Kentucky Asphalt which was laid on the Cemetery Pike at Bowling Green, Ky., Aug., 1907, this material was from the quarries of the Wadsworth Stone and Paving Co. on Green River, where it was prepared for use on the road by crushing. No other material, either sand or bitumen was added to change the consistency of the crushed, native product. The rock asphalt was applied to the wearing surface of the stone at atmospheric temperature and at no time during the construction was artificial heat applied, either to the wearing course of stone, or to the rock asphalt.

Annual inspection has been made since that time by engineers from the Office of Public Roads in the Department of Agriculture. The reports show "that the pavement has remained practically unchanged in appearance, with little evidence of wear, and the bitumen has retained its life to the present time."

The same material is found in the Chester sandstone, north of Russellville, Ky., and in parts of Logan county in the same geological horizon, as that of Edmonson, Warren and Grayson. It is described by a mining engineer, as "as a natural combination of asphalt or bitumen, with sand, and is of an unusual and remarkable nature. The asphalt is of the finest quality and the sand of a degree of hardness and sharpness unknown in this country or elsewhere, and is wonderfully adapted to street and road surfacing."

"It refines to 99% of its total bitumen at a cost not exceeding \$5.00 a ton. For this high degree of purity, samples from both Edmonson and Logan counties yield 8 to 21% of bitumen and 92% to 79% of clean, hard

white sand. The highest grades are too rich for road, and street work and must be reduced by mixing with a leaner material until a composition as follows, is reached: Asphalt 7% to 8%, Sand 93% to 92%, Quarrying is in open cut and is done by means of steam drills, and dynamite. Under some circumstances black powder is used to advantage. The bitumen or asphalt is equal to that found anywhere and the combination makes a high class durable surface for street and highways and is always laid without artificial heat or the use of limestone, or other material." At one quarry the average cost of quarrying and carrying to the crusher is 45 cents per ton, while the cost of crushing, grinding and putting on the cars is 80 cents. An opening on the Dismal Fork of Nolin in Edmonson county some ten miles West of Mammoth Cave is thus described by M. W. Venable, a distinguished civil and mining engineer of Charlestown, W. Va. "After an exhaustive examination the geological character of the country and locality seems to be regular, with no faults or displacements. The asphalt deposit lies about 90 feet below the top of the ridge and consists of a heavy stratum of very pure sandstone saturated with bitumen. The sand is held together entirely by the latter. When the impregnated sandstone is exposed to heat, the pitch, or bitumen collects on its surface. Therefore it may be expected that the out-crop indications only approximate the thickness, and richness of the stratum under the hill, yet the outcrop is from 15 feet upwards in thickness and rich enough to warrant its use on streets and road surfaces. The outcrop may be traced along the foot of the hill over the entire property and at every point its character remains constant. It is estimated that 9,000,000 tons of commercial material are found on an area of 350 acres. By a crude process of boiling 2240 lbs. of average rock asphalt, produced 80 gallons of crude bitumen, which was boiled down to 65 of refined material.

As a paint it appears to possess the consistency of refined caout-chouc. Spread on tin, no amount of bending or percussion breaks or cracks it. Exposed to the weather it neither cracks or peels. From its location and character, it can be mined very cheaply in open cut. This is the most valuable mineral property I have ever reported on."

There are more than one hundred openings in Grayson and Edmonson counties, from Grayson Springs along, and on both sides of the divide between Bear Creek and Nolin river, where it is readily accessible to water transportation to the Ohio and thence throughout the Mississippi Valley. After a careful personal inspection, Dr. Edward Orton, late State Geologist, of Ohio, said:

"It may be stated that, while it is too much to expect that the first attempts to use a new material will be entirely successful and satisfactory, the results so far obtained are on the whole, sufficiently encouraging to warrant the prediction that Kentucky Rock Asphalt will be extensively used for street and highway surfacing. If the present methods of manipulation are not the best, better ones will be found. It took years of careful experience to bring the mixture known as Trinidad Asphalt to its present state of efficiency, and it will be

strange if a material which exists in abundance so near the center of population of the U. S. (150 miles) and which comes from the hand of nature, so nearly what is required for a pavement (or surface) of the best class, shall not by a little skillful manipulation be perfected and made to supply this important demand."

The above prediction has been fully verified and substantiated by the numerous experiments and reports of U. S. Highway Engineers and contractors in many parts of the Union. Kentucky Rock Asphalt has passed the stage of experiment and is a recognized commercial product second to none for surfacing highways and streets. The fact that it can be used cold, without artificial cooking, or heating, and without the use of any outside material, such as liquid asphalt, oil or tar, and also without the use of pulverized limestone, greatly enhances its economic value. It has a very promising future; in this day of highway improvements, especially when it is considered that one short ton will surface one square rod about two inches deep, which amounts to 320 tons per mile for a roadway sixteen feet wide. At a cost of \$5.00 per ton, this means \$1,600.00 for an ideal boulevard which is practically waterproof, noise-proof, dust-proof, automobile-proof, and well night indestructible. One man and a motor car can maintain indefinitely 25 miles, when the material is suitably distributed along the roadway.

A sample or specimen section has been laid on the Lincoln way at St. Helens, south of Louisville in Jefferson county, Kentucky, and it is the hope and expectation that the entire Lincoln-Jackson way from Louisville via the Lincoln Home at Hodgenville, thence by the Mammoth Cave and Bowling Green to Nashville, Tenn., a distance of 200 miles will be surfaced with this material. No roadway in the United States would equal this. As an automobile boulevard it could not be excelled. The Kentucky Rock Asphalt deposits parallel this highway for 120 miles and at no point are they more than 20 miles distant.

It is now being transported many hundred miles for streets and highways in far off states and Canada. It is a promising material and only needs such exploiting as an official report will give it.

It may well be considered the coming highway surface material for durable and economic construction. As before said the crushed and ground material, containing not less than 7% bitumen is used as a top dressing or surfacing material in the place of limestone or other screenings and produces a dustless, noiseless and inexpensive surface, which required less work for construction than an ordinary water bound macadam. It is used raw, no artificial cooking or heating being necessary. The latter statement is repeated, because it is almost impossible to make the average highway contractor and some highway engineers understand that any asphalt, natural or artificial, can be used for surfacing without heating or cooking, by raising the temperature to 250 or more degrees. The only machine needed is the ordinary 10 ton steam roller, the asphalt being of such a nature that the rolling and later travel is amply sufficient to pack the roadway as smooth and

hard as a regular pavement. The best results are obtained when the weather is warm on account of the fact that the asphalt is then in a better condition to pack. It should not be laid when the temperature is below 60° or while raining, but the warmer the day the better.

From this fact the material can be used in the far south all winter and in the far north during the heated summer months. A steam roller will permit it to be used everywhere at all seasons. The rock asphalt system of road construction is simpler and requires less labor than ordinary macadam, as less metal is needed and the hauling of several grades or sizes of stone is unnecessary, also one or two rollings are saved.

After the traffic is turned upon the road it beats down much harder and quicker than the water bound macadam and is never dusty, muddy or slippery. It approximates sanded rubber more nearly than anything else. The reason it is never dusty is that the asphalt from its oily, viscous nature cannot form dust and quickly settles any outside dust that may fall upon it. This asphalt surface will greatly outwear any macadam surface because the asphalt wearing surface does not grind up and blow away, and therefore remains a long time in good condition. It is well known that there are only two ways by which a stone or macadam road wears out, one by the action of water, the other by wind. The dust that forms from the grinding up of the stone is either washed away or blown away. Neither of these conditions can affect Rock Asphalt as it is both water-proof and dust-proof. Excellent samples of this material as a street surfacing material are seen at Bowling Green, Ky., on the public square, where it was laid in 1905, also at Birmingham, Ala., Belle Isle Park, Detroit, Mich., Sewickly, Pa., Emmett St., Evansville, Ind., (1907); Williamsville road, East Buffalo, N. Y. (1908); Euclid road, Cleveland, Ohio (1908); Nelson road, Ohio State Department, Columbus, Ohio (1909); U. S. Experimental road, Ithaca, N. Y. (1909); Seminary Ave., Greensburg, Pa. (1909); New York State road, No. 481, Pittsford road (1909); New York State road, No. 750, Clarence Center, N. Y. (1909); New York State road, No. 645, Orchard Park to Jewettsville (1909), New York State road, No. 642, Angola to Evans Center (1909); New York State road, No. 480, Churchville, N. Y. (1909); driveways, tennis court and athletic field, Belle Isle Park, Detroit, Mich. (1909); Staunton Military Academy, Staunton, Va. and many other places.

KENTUCKY ROCK ASPHALT *

By Dr. Willard Rouse Jillson

Director of Kentucky Geological Survey, Frankfort

The occurrence in Kentucky of bituminous sandstones naturally impregnated with petroliferous residues has been a matter of scientific record for over seventy-five years. Dr. David Dale Owen, in executing the first Geological Survey of this State, noted them and their "tar springs" at many points. References to them are to be found in many of his reports.¹ In the work of geological explorations which followed under the direction of Nathaniel S. Shaler, and later under Robert Proctor, bituminous sandstones and limestones were frequently found, analyzed and described.² The great commercial future of these very extensive deposits at this time, was, however, hardly surmised and consequently little more than passing attention was given to them.

In the report published by the Third Kentucky Geological Survey, under Prof. Charles J. Norwood, little appears concerning them; but during the Fourth Geological Survey, under the direction of Joseph B. Hoeing, they suddenly sprang into prominence and were described specifically and regionally in two separate reports.³ During the progress of the Fifth Geological Survey these deposits received but casual consideration; but in the publications of the Sixth Geological Survey, they again received special and state-wide attention.⁴

At the present time the Kentucky Geological Survey is engaged in very extensive and detailed examinations of the rock-asphalt deposits of the entire State. The reason for the present widespread interest and startling development in Kentucky rock-asphalt is found in the strong upward economic trend of the market during the past five years. The future demand, backed by large road-building programs, now under way in all adjoining commonwealths, appears actually unlimited. When properly quarried, mined, milled and used in superior highway construction, Kentucky rock-asphalt is by far the most attractive surfacing material yet developed. Noiseless, dustless, and almost everlasting, it finds warmhearted approval wherever introduced. As a result of its many outstanding virtues as a road-surfacing material, its market has extended itself automatically with the astonishing results, that although the number of commercial operators has now increased to four in Kentucky, each plant shipping a mill capacity, the market is greatly underproduced.

The term "Rock Asphalt," in Kentucky, has become standard

1 Kentucky Geol. Surv., (1), 1854-7.

2 Ibid., (2), 1873-92.

3 Ibid., (IV), 1912-18.

4 Ibid., (VI), Vol. II, 1921.

* As published in Pan Amer. Geologist, Vol. XLI, May 1924.

with reference to bituminous sandstones sufficiently impregnated with petroliferous residues of an asphaltic nature, to exhibit upon careful analysis a total content of bitumen ranging from about five to fifteen per cent. Leaner and richer natural mixtures occur, but these are excluded in the common acceptance of the term.

Limestones impregnated with petroliferous residues also occur, notably in Nelson, Madison, Marion, Bell, and some other counties, but these fall outside of the consideration. In its strict sense "Rock Asphalt" is a natural mixture of silica sand, known as the mineral aggregate, and natural residues of petroleum, that will bond as a road surfacing material and withstand long and continued heavy traffic. Standard specifications 5 call for from 7 per cent to 9 per cent of natural bitumen, in the mineral aggregate, finely pulverized and free from lumps and foreign matter. The rock asphalts of Kentucky are well exemplified in type deposits ranging from 20 to 50 feet thick in western-central Kentucky, in Edmonson, Hart, Grayson, Hardin, Breckinridge, Warren, Logan and some adjacent counties. Stratigraphically these deposits fall into two groups: (1) the Chester (Upper Mississippian), and (2) the Pottsville (Lower Pennsylvanian).⁵ The rock asphalts of the Chester rocks are the older and more widely distributed of the two groups and will here receive the first consideration.

An investigation into the use of Kentucky rock-asphalt as a road material indicates that it has been in use, sporadically for upwards of 25 to 35 years. The old Federal Asphalt Company, about 1900, operated mines and quarries in the Cypress formation, an asphalt-impregnated sandstone of the Chester near Big Clifty, Grayson County. A very satisfactory product was made, and many city streets and park-ways in Ohio, Kentucky, Pennsylvania and New York were laid with the material. Illustrations of this old mining operation are given herewith. Other operations less extensive, and one at least much larger, that the old Wadsworth Stone and Paving Company on Green River, occur in Hardin, Grayson, Breckinridge, Logan, Warren, and Edmonson counties. Chester and Pottsville rock-asphalt taken from various openings thus located during the past twenty years, has been shipped to points in New York, Pennsylvania, Ohio, Indiana, Missouri, Tennessee and Kentucky, and has been used for streets, highways and sidewalks with complete satisfaction in all cases where it was laid on a sound base. Though it is difficult to trace the movements of this rock-asphalt, it is known that all of the material thus used was not shipped from any particular section, though it is probably that the major portion of it was produced from the Big Clifty (Chester sandstone), in eastern Grayson County.

The Chester formation in Kentucky exhibits two bituminous sand-

⁵ Standard Specifications for State Road and Bridge Construction: Missouri State Highway Comm., pp. 84-89, Jefferson City, 1922.

stones. These are in ascending order the Cypress sandstone, 70 to 80 feet in thickness, and the Tar Springs sandstone, 40 to 50 feet in thickness. The Tar Springs sandstone is not regarded as of commercial importance as a rock-asphalt source, due to the fact that its bituminous content is high in volatiles and relatively low in asphalt base. Its occurrence as a thinner member and higher in the Chester succession is resultant in a smaller areal outcrop than in the case of the Cypress sandstone, which is nearly twice as thick and which occurs at some little distance below it. For this reason, although a number of asphalt outcrops of the Tar Springs sandstone is known to occur, particularly in northwestern Breckinridge County, this stratigraphical member will not receive further consideration.

The Cypress sandstone, broadly outcropping from the Ohio River through the middle portion of Breckinridge County, northern and eastern Grayson County, southwestern Hardin County, Hart County, southern Edmonson, northern Warren, southern Butler, and northern Logan County, and on to the west, is the largest bituminous sandstone in outcrop in Kentucky. Although highly petroliferous at a number of points, particularly in Breckinridge, Grayson, Hardin, Warren and Logan counties, it is not continuously so, and there are broad areas where it is absolutely barren of petroliferous matter.

In Breckinridge County, in and about Garfield, on the L. H. & St. L. Railroad, are extensive deposits of possibly commercial importance. The same is true for northeastern Grayson County, in the vicinity of Big Clifty and Grayson Springs Station. The Continental Rock Asphalt Company, with a milling capacity of 500 tons a day, is now operating at Big Clifty and a few miles to the northeast on the Illinois Central Railroad at Summit, in southwestern Hardin County, the Ohio Valley Rock Asphalt Company is operating, with a capacity of 1,000 tons a day. Plans now under way contemplate commercial operations at Garfield, in Breckinridge County, and near Russellville, in Logan County. Each of these plants will operate rock asphalt coming from the Cypress, or Big Clifty, sandstone of the Chester section.

Since the market is apparently destined to receive a very large amount of rock-asphalt from the Chester horizon during the next few years, it is worth while to make comparisons of this rock-asphalt with that produced from deposits of the Pottsville sandstone, in Edmonson and Grayson counties. The following table showing such comparison of typical analyses brings out concretely the fact that the rock-asphalts produced from the Cypress sandstone have a somewhat finer mineral aggregate, but on the other hand a somewhat higher bituminous content. This is as it should be, since a finer mineral aggregate may be interpreted to constitute a somewhat larger material surface to be covered with bituminous matter. Each of the representative samples here referenced was collected by the writer. Analysis was made by the State Chemist, Dr. A. M. Peter.

Comparison of Kentucky Rock-Asphalts

Chester (Big Clifty) Sandstone					Pottsville Conglomerate				
Hardin, Grayson, and Logan Counties					Edmonson County				
Lab. No.	Bit.	Cont.	%		Lab. No.	Bit.	Cont.	%	
4146	-	Bit.	9.96%		4102	-	Bit.	8.98%	
"	"	4132	"	"	4112	"	"	6.83%	
"	"	4036	"	"	4113	"	"	8.49%	
"	"	4068	"	"	3968	"	"	8.00%	
"	"	4150	"	"	3890	"	"	7.35%	
"	"	4149	"	"	3968	"	"	8.00%	
Average total bituminous content of Chester Asphalts								8.19+%	
Average total bituminous content of Pottsville Asphalts								7.94+%	
								.25+%	

The slightly larger bituminous content of rock-asphalt produced from the Cypress sandstone, may not be taken to mean that roads produced from this material will slip, or slide, or corrugate, or in any way be defective, except where standard specifications for the laying of this rock-asphalt have not been followed. Oppositely to such a contention a slight increase of 1/2 % to 1 % above the general grading of 7 1/2% bituminous matter is, and particularly in this rock-asphalt, a positive advantage since it tends to bind the material aggregate much closer, and render it more impenetrable to the eroding influence of wind and water. The writer has personally inspected a number of roads and highways surfaced during a period of years with rock-asphalt produced from Cypress sandstone and has yet to know the first instance of dissatisfaction in the service rendered by the material, particularly with reference to the bituminous content where standard specifications were followed. Where this rock-asphalt shows a bituminous content of from 7 to 9% there can be no doubt but what it is the equal of any other Kentucky-produced rock-asphalt, including that of the Pottsville conglomerate, which will now be discussed.

In northern Edmonson, southern Grayson and western Hart counties, large deposits of rock-asphalt occur as the Pottsville rocks (Pennsylvanian). In comparison to their extent these deposits are at present but slightly operated. The largest operation, owned by the Kentucky Rock Asphalt Company, is situated on the Nolin River, six miles above its juncture with Green River in central Edmonson County, at Kyrock post-office. In western Edmonson County, on the lower waters of Bear Creek, near the Butler county-line, and near Green River, the Natural Rock Asphalt Company has an extensive operation. Rock-asphalts here operated are bituminous sandstones in the conglomerate portion of the Pottsville formation. These sandstones are somewhat coarser and more irregular than those of the Chester rock-asphalts. Pebbles of the size of a pea, or somewhat larger, are not infrequently found. The mineral aggregate is roughly irregular and angular, and the bituminous content of operated lenses stands well within the standard specifications of 7 to 9 per cent of bituminous matter.

In this field there are a number of outcrops which are somewhat richer in bituminous matter, running up to 10, 12 and 14 per cent, and in these localities natural "tar springs" are of common occurrence.

Edmonson County rock-asphalt, as produced by the Kentucky Rock Asphalt Company from 1918 to date, has become standardized as a road-material in this and adjoining states, and well deserves the recognition given it by road enthusiasts everywhere. A large field here awaits the projection of new rail and river transportation which all signs indicate will be brought about within the next few years. Plans are now already under way for the operation of a large boundary by the Silica Asphalt Company, southeast of Leitchfield, on the waters of Conoloway and Bear creeks. Other operations are contemplated near Black Rock post-office a few miles southwest of Leitchfield.

The uniformity of the product now produced in Edmonson County by the Kentucky Rock Asphalt Company and the Natural Rock Asphalt Company; in Hardin County by the Ohio Valley Rock Asphalt Company, and in Grayson County by the Continental Rock Asphalt Company, leads to the conclusion that this highgrade road-surfacing material will find a continually broadening market, and one in which satisfaction will continue to develop an increasing demand. The possibilities of rock-asphalt development in Kentucky from a quantitative standpoint are almost unlimited, and with the qualitative requirements of standard specifications satisfactory met by the rock-asphalts of both the Pottsville and Chester formations, an interesting prospect for the development of this great mineral resource of Kentucky, is assured.

APPENDIX III
REPORT OF TESTS ON SAMPLES OF ROCK ASPHALT
MATERIALS USED IN THE RESURFACING OF A
LOUISVILLE STREET

1936

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS
WASHINGTON D. C.

FRANKFORT, KENTUCKY
June 7, 1937

Mr. T. H. Cutler
Chief Engineer
Department of Highways
Frankfort, Kentucky

Dear Mr. Cutler:

We are enclosing herewith a report made by the Division of Tests, Bureau of Public Roads in Washington, on samples of rock asphalt and completed processed rock asphalt pavement on Kentucky U. S. Works Program Highway Project WPMH 117 section H, Broadway in Louisville from Barrett to Baxter. We are also enclosing a copy of our letter which we sent to the Division of Tests with the samples submitted.

You will note from this report that there is apparently some coking or carbonizing of the bitumen in the dryer and also some loss of asphalt oils. The report also points out that it would be difficult to mix two lean rock asphalts with different characteristics and expect to obtain a uniform mix.

It is suggested that you read this report as it contains a considerable amount of worthwhile information.

Very truly yours,

(SIGNED) Mack Galbreath
Senior Highway Engineer

COPY

Frankfort, Kentucky
December 12, 1936

Testing Laboratory
U. S. Bureau of Public Roads
Washington, D. C.

Gentlemen:

We are enclosing herewith specifications for processed sandstone rock asphalt used for surfacing Kentucky U. S. Works Program Highways Project WPMH 117 Section H, and are sending you under separate cover samples of materials used in the construction of this pavement. A part of the work done was not in accordance with the specifications, but we are not so much concerned about this fact as we are to learn something in regard to why the processed surface did not give the expected results.

The processed sandstone rock asphalt surface was constructed on a sheet asphalt binder course which was in good condition. About 56 tons of the processed rock asphalt surface was laid on November 21 and was supposed to be prepared strictly in accordance with the specifications. The material when delivered to the pavement was supposed to have a temperature of 190° to 200° but cracked and checked under the roller. The material appeared to lack binding qualities and some additional asphalt cement was included in the 55 tons laid on November 23. Slightly better results were obtained but the material still appeared to lack binding qualities and additional asphalt cement was used for the mix laid on November 24, which was 43 tons. Apparently satisfactory results were obtained on this date as the mix appeared to bond under the roller and this section is in good condition today.

The pavement was opened for traffic on November 25 and the first two sections laid immediately began to wear off and to pot out over considerable areas. On December 1, when I made the first inspection, one or two spots were noted where the wearing surface had worn through to the binder. On December 8 I again inspected this project and found that there had been some additional loss of processed rock asphalt but that this loss had almost entirely stopped, probably due to warmer weather.

The rock asphalt wearing surface was processed in a new hot mix pug mill plant recently constructed in Louisville which apparently is quite modern. The lean rock asphalt was first run through a dryer and heated up to 225°. This dryer was designed to handle stone, gravel, sand, etc., and no special effort was made to keep the hot gasses from coming into direct contact with the material being handled. The lean rock asphalt was then carried to the pug mill and mixed with the asphalt cement material in accordance with the specifications.

The State Testing Laboratory had a representative at the processing plant and the pavement was laid under the direction of the State Construction Department. Records obtained from these two departments are somewhat conflicting and we are unable to obtain a sufficient amount of information to tell exactly what happened. In an attempt to improve the binding qualities of the mixture, the Construction Division slipped some additional asphalt cement into the mix which was not known by the plant inspector. For this reason my records in regard to the amount of asphalt cement added would not be accurate.

The samples being sent you by express and identified by a statement enclosed in each sample, are as follows:

Sample No. 1: An equal mixture of lean rock asphalt as indicated by samples nos. 2 and 3 after passing through the dryer but before mixing with asphalt cement.

Sample No. 2: Lean rock asphalt probably obtained from the quarry of the Crown Rock Asphalt Company at Big Clifty, Kentucky.

Sample No. 3: Lean rock asphalt probably obtained from the Kyrock quarry in Edmonson County.

Sample No. 4: A section of processed rock asphalt surface obtained from pavement laid November 21, which was supposed to be prepared strictly in accordance with the specifications and with 100% lean rock from the Kyrock plant as represented by sample No. 3.

Sample No. 5: A section of pavement laid on November 23, made from lean rock asphalt composed of 50% Sample No. 2 and 50% Sample No. 3 and also containing some additional asphalt cement.

Sample No. 6: This sample is the same as No. 5 except that it is supposed to contain additional asphalt cement.

We were unable to obtain a sample of the asphalt cement used but a test made by the St. Hwy. Dept. is listed as follows:

% soluble in CCl ₄	99.9
Spec. Gr. 25°C/25°C	1.00
Ductility, 25°C	110+cm.
Penetration, 25°C	181
Loss, 163°C., 5 hours	0.4%
Characteristics of Residue	
Penetration, 25°C	152
Ductility 1/4cm. per sec. at 39.2°F	20+
Oliensis Spot Test	Negative
Paraffin Scale	0.4%
Ductility equipment not available for 150 cm. Ductility.	

The pavement is not satisfactory and will be removed but as this is the first processed rock asphalt project constructed in Ky. with federal funds, I would like to know more about why the pavement failed. The bituminous material in natural rock asphalt contains a considerable amount of light oils which are no doubt responsible for the quick binding qualities of this material. We would like to know if the lean rock asphalt, in passing through the dryer and being subjected to direct contact with very hot gasses, if not direct flame, loses an appreciable amount of these light oils or if there is any carbonizing or coking of the asphalt. We would also like to know, if possible, if the characteristics of the asphalt binder in lean rock asphalt are materially different from those of the richer rock asphalt used in the construction of a natural rock asphalt pavement. We would also like to know the percentage of bitumen contained in samples 4, 5 and 6 obtained by the ignition test and also by some extraction test such as the cold carbon disulphide test.

What we would like to have is some light on why this material constructed in accordance with the specifications, would check and crack under the roller and not bond as might be expected from the natural rock asphalt.

Very truly yours,

Senior Highway Engineer

COPY

May, 1937.

Report of the laboratory study of rock asphalt samples
submitted from Kentucky U.S. Works Program Highway
Project W.P.M.H. 117, Section II

Reported by the Division of Tests

This report contains tables giving results obtained on the above mentioned samples, and a discussion of the results. For comparative purposes test results on a sample of normal Kyrock received in connection with the construction of another project are included. This sample is designated as laboratory number 41898.

Table 1 shows that the organic matter present in the two lean rocks is somewhat less soluble in carbon disulphide than the organic matter present in the normal Kyrock. The organic matter present in the normal Kyrock contains a greater proportion of bitumen.

The test results on the extracted bitumens indicate that the bitumen from the lean Kyrock is not materially different from that extracted from the normal Kyrock. It is slightly harder as measured by the penetration test and the softening point determination, but the slight difference in the percentage of bitumen insoluble in 86°B naphtha would seem to indicate that oxidation or weathering had not proceeded very far in this particular sample.

Tests made on other samples of lean Kyrock have given extracted bitumens with penetration as low as 95 and as high as 200 so that it may be assumed that there is a wide variation in the consistency and other characteristics of the contained bitumen in these lean rocks.

The extracted bitumen from the lean Crown Rock is decidedly different from that obtained from the two Kyrocks, but is very similar to that obtained from other samples of lean material received from the same quarry. We have not tested a rich Crown Rock. If the bituminous binder in the Crown Rock deposit was ever similar to that in the normal Kyrock deposit, the low penetration and high softening point, as well as the high percentage of matter insoluble in naphtha in the extracted bitumen from the lean Crown Rock, would indicate that loss of volatile matter and weathering had altered to a great extent the characteristics of the contained bitumen.

Table 1. - Comparison of lean rock asphalts
and normal Kyrock asphalt

B. P. R. no.	43233	43234	41898
Identification	2	3	
Material	Lean Crown rock	Lean Kyrock	Normal Kyrock
Used on	Ky. W. P. M. H. 117-H	Ky. W. P. M. H. 117-H	
Loss on ignition (%)	3.59	5.80	7.09
Bitumen (soluble in CS) (%)	3.22	5.24	6.92
Ratio of bitumen to loss on ignition	.897	.903	.976
Tests on extracted bitumen			
Penetration, 25°C	19	141	220
do 0°C.	9	38	41
Softening point (C°)	68.5	42.5	37.8
Ductility, 25°C. (cm.)	9.5	107.5	87
Bitumen insol. in 86°B. naptha (%)	38.13	20.81	19.12

The test data in Table 2 indicate that sample 1 (43232), which is supposedly a 50-50 blend of samples 2 and 3 (43233 and 43234) that has been passed through the dryer, has an extracted bitumen with properties that are not in agreement with the calculated theoretical characteristics of a blend of samples 2 and 3, but closely approximate those of the lean Crown Rock. The addition of the lean Kyrock containing more and softer bitumen has not offset the properties of the lean Crown Rock. The low ratio of bitumen to loss on ignition in the heated blend indicates some loss of volatile matter and shows that some oxidation or coking has occurred during the passage of the crushed rock through the dryer. The characteristics of the extracted bitumen from the heated blend indicate that this method of preheating the crushed rock asphalt before blending with

hot asphalt materially alters the contained bitumen and, unless the alterations were always of the same magnitude they might lead to a very non-uniform product from the mixing plant.

Table 2. - Comparison of lean Crown Rock asphalt and lean Kyrock with the mixture of the same after passing through the dryer

B. P. R. No.	43233	43234	43232	
Identification	2	3	1	
Material	Lean Crown rock before heating	Lean Kyrock before heating	Blend of Crown Rock 50%, and Kyrock 50% after passing through dryer	Theoretical blend of 43233 & 43234, 50% of each before heating
Loss on ignition (%)	3.59	5.80	4.22	4.70
Bitumen (soluble in CS ₂) (%)	3.22	5.24	3.23	4.23
Ratio of bitumen to loss on ignition	.897	.903	.765	.900
Tests on extracted bitumen				
Penetration, 25°C.	19	141	20	94.6
do 0°C.	9	38	11	27.0
Softening point (°C.)	68.5	42.5	65.2	52.4
Ductility, 25°C. (cm.)	9.5	107.5	(1)	
Bit. insol. in 86°B. naptha (%)	38.13	20.81	35.29	27.40

(1) Not sufficient material for test.

Table 3.

In Table 3 it is seen that while the extracted bitumen of the lean Kyrock had a penetration of 141, and the added bitumen had a penetration of 181, the extracted bitumen of the blended mix is only 59. Undoubtedly there is considerable loss of volatile matter and resultant hardening of the

contained bitumen in the lean Kyrock in the dryer, and the consistency of the bitumen in the finished mix results in a product which, from the standpoint of plasticity and workability, is quite dissimilar to normal Kyrock surfacing, and under comparable weather conditions doubtless would not spread or compact as readily as normal Kyrock.

The theoretical penetration of 154 is calculated from the penetration of the extracted bitumen of sample 3 and the penetration of the added asphalt cement, on the assumption that the resultant penetration of a mixture of two asphalts is the weighted average of the two asphalts. This theoretical penetration of 154 is the highest possible obtainable penetration for mix 4 even if no hardening of the bitumen in sample 3 or in the added asphalt cement had occurred during the preparation of the mixture. Consequently there is no possibility of this blended mixture having as soft a contained bitumen as that of the normal Kyrock, sample 4189, Table 1.

Table 3. - Comparison of unblended
and blended lean Kyrock

B. P. R. No.	43234		43235
Identification	3		4
Material	Lean Kyrock before passing through dryer	Asphalt cement as report- ed by Ky. St. Hwy. Dept.	Lean Kyrock No. 3 plus asphalt cement samples after blending and laying
Loss of ignition (%)	5.80		8.27
Bitumen (soluble in CS ₂) (%)	5.24		7.55
Ratio of bitumen to loss on ignition	.903		.913
Tests on extracted bitumen			
Theoretical penetration, 25°C.			154
Penetration, 25°C.	141	181	59
do 0°C.	38		26
Softening point (C°.)	42.5		55.4
Ductility, 25°C. (cm.)	107.5	110+	55
Bit. insol. in 86°B. naptha (%)	20.81		27.75

Table 4.

From the results given in Table 4 it is seen that the bitumen contents of samples 5 and 6 have been increased considerably by the addition of asphalt cement, and that the contained bitumen has been materially softened as shown by the higher penetration and lower softening point results on the extracted bitumen as compared with the results obtained on the extracted bitumen of sample 1. However, the properties of the bitumen extracted from the two mixes are widely different from those of the normal Kyrock material.

Table 4. - Comparison of the heated mixtures of lean rock asphalts before and after addition of asphalt cement

B. P. R. No.	43232	43236	43237
Identification	1	5	6
Material	Blend of 50% Crown rock and 50% Kyrock through dryer	Blend No. 1 plus asphalt cement surface	Blend No. 1 plus additional asphalt cement surface
Loss on ignition (%)	4.22	9.65	11.07
Bitumen (soluble in CS ₂) (%)	3.23	8.05	10.23
Ratio of bitumen to loss on ignition	.765	.834	.924
Tests on extracted bitumen			
Theoretical penetration at 25°C.		120	134
Penetration, 25°C.	20	87	88
do 0°C.	11	38	36
Softening point (C°)	65.2	50.1	49.9
Ductility, 25°C. (cm.)		89	85
Bit. insol. 86°B. naphtha (%)	35.29	26.34	25.90

Table 5.

The stabilities at 60 degrees C. and 25 degrees C. are probably indicative of the compressibility and workability of the mixtures. The normal Kyrock having the lower stability at these two temperatures would probably spread better and get a greater initial compaction than the three processed mixtures. The effect of the harder bituminous binders in the three blended products is also indicated in the higher stability of these materials at the two higher temperatures. At the low temperature the stability of the normal Kyrock is highest due perhaps to greater temperature susceptibility of the contained binder.

Table 5. - Comparison of the stability of processed rock asphalts and normal Kyrock

B. P. R. No.	43235	43236	43237	41898
Identification	4	5	6	
Material	Kyrock plus asphalt cement	50-50 blend plus asphalt cement	50-50 blend plus asphalt cement	Normal Kyrock
Bitumen (soluble in CS ₂) (%)	7.55	8.05	10.23	6.92
Pen. of ex. bit. at 25°C.	59	87	88	220
Stability (pounds)				
at 60°C.	725	425	480	280
25°C.	2,850	2,540	2,510	2,070
0°C.	8,500	7,650	6,750	10,000
Density (Ave.)	1,929	1.921	1.921	1.906

Conclusions

The test data on the extracted bitumens, as well as the stability values, indicate that it would be difficult to produce a blended rock asphalt mix having properties comparable to those of normal Kyrock.

There are definite data to show that the rock asphalts are altered during their passage through the dryer and, unless temperature conditions are accurately controlled and all contact with heater flame removed, it does not seem that uniform batches could be turned out.

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS
WASHINGTON, D. C.

REPORT ON SAMPLE OF ROCK ASPHALT

Laboratory No. 43232

Date May 19, 1937

Name - Mixture of lean rock asphalts

IDENTIFICATION MARKS - # 1

SUBMITTED BY - Mack Galbreath, Sr. H. E. Frankfort, Ky.

Sampled

Received Dec. 18, 1936

Samples after passing through dryer

Quantity represented

Source of Material - Equal mixture of # 2 Crown R. A. Co., Big Clifty -

(#3 Kyrock,

Location used or to be used - Kentucky WPMH 117-H (Edmonson Co.

Examined for Special research work on rock asphalt mixtures.

TEST RESULTS

Loss on Ignition 4.22%

Bitumen (soluble in CS₂) 3.23%

Tests on extracted bitumen (recovered by Abson Method)

Penetration at 25° C. 20

do 0° C. 11

Ductility at 25°C. (cm.) Insufficient Material for test.

Softening point (°C.) 65.2

CS₂ soluble, % 99.84

Organic insoluble, % 0.10

Ash, % 0.06

Bitumen insoluble in 86°B. naptha, % 35.29

E. F. KELLEY,
CHIEF, DIVISION OF TESTS
PER H.M.M.

(COPY)

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS
WASHINGTON, D. C.

REPORT ON SAMPLE OF ROCK ASPHALT

LABORATORY NO. 43233 Date May 19, 1937
 NAME - Lean rock asphalt
 IDENTIFICATION MARKS - # 2
 SUBMITTED BY Mack Galbreath, Sr., H. E., Frankfort, Ky.
 SAMPLES RECEIVED Dec. 18, 1936
 SAMPLED FROM Stock
 QUANTITY REPRESENTED
 SOURCE OF MATERIAL (Quarry) Crown Rock Asphalt Co., Big Clifty.
 LOCATION USED OR TO BE USED Kentucky WPMH 117-H
 Examined for Special research work on rock asphalt mixtures.

TEST RESULTS

Loss on ignition	3.29%
Bitumen (soluble in CS ₂)	3.22%

Tests on extracted bitumen (recovered by Abson method)

Penetration, 25°C.	19
do 0°C.	9
Ductility, 25°C. (cm.)	9.5
Softening point (°C.)	68.5

CS ₂ soluble, percent	99.87
Organic insoluble, percent	0.07
Ash, percent	0.06

Bitumen insoluble in 86°B. naptha, percent	38.13
--	-------

E. F. KELLEY
 CHIEF, DIVISION OF TESTS
 PER H. M. M.

(COPY)

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS
WASHINGTON, D. C.

REPORT ON SAMPLE OF ROCK ASPHALT

LABORATORY NO. 43234

Date May 19, 1937

NAME - Lean rock asphalt

IDENTIFICATION MARKS - # 3

SUBMITTED BY - Mack Galbreath, Sr. H. E., Frankfort, Ky.

SAMPLED

RECEIVED Dec. 18, 1936

SAMPLED FROM - Stock

QUANTITY REPRESENTED

SOURCE OF MATERIAL - Kyrock quarry, Edmonson Co.

LOCATION USED OR TO BE USED - Kentucky WPMH 117-H

EXAMINED FOR-SPECIAL RESEARCH WORK ON ROCK ASPHALT MIX-
TURES.

TEST RESULTS

Loss on ignition 5.80%

Bitumen (soluble in CS₂) 5.24%

Tests on extracted bitumen (recovered by Abson Method)

Penetration, 25°C. 141

do 0°C. 38

Ductility, 25°C., (cm) 107.5

Softening point (°C.) 42.5

CS₂ soluble 99.88%

Organic insoluble 0.09%

Ash 0.03%

BITUMEN INSOLUBLE in 86°B. naptha, percent

20.81

E. F. KELLEY
CHIEF, DIVISION OF TESTS
PER H. M. M.

(COPY)

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS
WASHINGTON, D. C.

REPORT ON SAMPLE OF BLENDED ROCK ASPHALT

LABORATORY NO. 43235

NAME - Processed rock asphalt surface

IDENTIFICATION MARKS - # 4

SUBMITTED BY Mack Galbreath, Sr. H. E., Frankfort, Ky.

SAMPLED

RECEIVED Dec. 18, 1936

SAMPLED FROM Section laid November 21, 1936

QUANTITY REPRESENTED

SOURCE OF MATERIAL Lean Kyrock, Sample # 3, plus asphalt cement

LOCATION USED OR TO BE USED - Kentucky WPMH 117-H

EXAMINED FOR - Special research work on rock asphalt mixtures

TEST RESULTS

Loss on ignition	8.27%
Bitumen (soluble in CS ₂)	7.55%

Tests on extracted bitumen (recovered by Abson method)

Penetration, 25°C.	59
do 0°C.	26
Ductility, 25°C. (cm.)	55
Softening point (°C.)	55.4
CS ₂ soluble, %	99.82
Organic insoluble, percent	0.15
Ash	0.03

Bitumen insoluble in 86°B. naphtha, % 27.75

H. F. stability (on material as received) molded at 93°C.,
3000 pounds per sq. inch, double plunger method.

Average density	1.929
Stability, 60°C.	725 pounds
do 25°C.	2850 "
do 0°C.	8500 "

E. F. KELLEY,
CHIEF, DIVISION OF TESTS
PER HMM

(COPY)

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS
WASHINGTON, D. C.

REPORT ON SAMPLE OF BLENDED ROCK ASPHALT

LABORATORY NO. 43236

Date May 19, 1937

NAME - Processed rock asphalt surface

IDENTIFICATION MARKS - # 5

SUBMITTED BY - Mack Galbreath, Sr. H. E., Frankfort, Ky.

SAMPLED

RECEIVED Dec. 18, 1936

SAMPLED FROM Section laid November 23, 1936

Quantity Represented

SOURCE OF MATERIAL - Made with 50% lean rock # 2 and 50% lean rock # 3, plus additional asphalt cement.

LOCATION USED OR TO BE USED - Kentucky WPMH 117-H

Examined for Special research work on rock asphalt mixtures.

TEST RESULTS

Loss on ignition	9.65%
Bitumen (soluble CS ₂)	8.05%

Tests on extracted bitumen (recovered by Abson method)

Penetration, 25°C.	87
do O°C.	38
Ductility, 25°C. (cm.)	89
Softening point (°C.)	50.1
CS ₂ soluble, percent	99.71
Organic insoluble, percent	0.09
Ash, percent	0.20%
Bitumen, insoluble in 86°B. naptha, percent	26.34
H. F. stability (on material as received) Molded at 93°C., 3000 pounds per square inch, double plunger method.	
Average density	1.979
Stability at 60°C.	425 pounds
do 25°C.	2,540 "
do 0°C.	7.650 "

E. F. KELLEY
CHIEF, DIVISION OF TESTS

(COPY)

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS
WASHINGTON, D. C.

REPORT ON SAMPLE OF BLENDED ROCK ASPHALT

LABORATORY NO. 43237

Date May 19, 1937

NAME - Processed rock asphalt surface

IDENTIFICATION MARKS - # 6

SUBMITTED BY Mack Galbreath, Sr. H. E. Frankfort, Ky.

SAMPLED

RECEIVED Dec. 18, 1936

SAMPLED FROM Section laid November 23, 1936

Quantity represented

SOURCE OF MATERIAL Made same as # 5 except additional asphalt

LOCATION USED OR TO BE USED - Kentucky WPMH 117-H

EXAMINED FOR Special research work on rock asphalt mixtures

TEST RESULTS

Loss on ignition	11.07%
Bitumen (soluble in CS ₂)	10.23%
Tests on extracted bitumen (recovered by Abson method)	
Penetration, 25°C.	88
do 0°C.	36
Ductility, 25°C. (cm.)	85
Softening point, (°C.)	49.9

CS₂ soluble, % 99.90%

Organic Insoluble 0.10%

Ash 0.00%

BITUMEN INSOLUBLE in 86° B. naptha, percent 25.90

H. F. stability (material as received) molded at 93°C.,

3000 pounds per square inch, double plunger method.

Average density	1.921
Stability at 60°C.	480 pounds
do 25°C.	2,510 "
do 0°C.	6,750 "

E. F. KELLEY
CHIEF, DIVISION OF TESTS
PER HMM

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APPENDIX IV
OBSERVATIONS ON THE SKID RESISTANCE
OF
KENTUCKY ROCK ASPHALT PAVEMENTS

SKID RESISTANCE OF KENTUCKY ROCK ASPHALT

Current emphasis on skid resistance and slipperiness of pavements, in the interest of safety, has drawn considerable attention to Kentucky rock asphalt as a material offering particularly good resistance to skidding. In most of the skid-test work that has been published on Kentucky rock asphalt surfaces, these pavements have exhibited as high or higher coefficients of friction than other surfaces. In general, they are equal to fresh chip-seal coats and do not polish under traffic as softer surface-course aggregates often do. Generally, however, the material has been regarded more as a proprietary product than as a category of paving mixtures reflecting inherent characteristics of the sharp quartz sand comprising the aggregate.

The factors imparting high skid-resistance to this particular material are thought to be: 1) the sharpness and hardness of the sand, and 2) the ability of the surface to relieve hydraulic pressures under the tires. Resistance to polishing is attributed to the fact that quartz is seventh in the scale of mineral hardness while calcite (limestone) is only third. Only topaz, corundum, diamond, etc. (all rather rare minerals) are classified as harder minerals. From this point of view, about the only commonly abundant abrasive sufficiently hard to wear and polish the sand in rock asphalt is the quartz itself. Calcite (limestone), being only third in the hardness scale, is vulnerable to polishing by almost any grit that might be found in the "road scum" or imbedded in tire treads.

While most of the actual skid-tests have been made only on surface courses laid with a paver, rock asphalt has been used rather extensively

as a deslicking treatment over existing surfaces, both as spinner and hand-spread applications. Very thin treatments, reportedly less than 25 lb. per sq. yd., have been successfully laid by a paver. Rock asphalt seals and de-slicking treatments have frequently provided an expedient means of correcting hazardous conditions arising from bleeding in fat pavements or from wear in curves (polishing).

These non-skid features were first recognized during the horse-and-buggy days when appropriate inference was made to its advantageous tractive resistance afforded shod hoofs. In former eloquence, the material was described as dustless, noiseless, and non-skid.

Skid-testing, as such, seems to have paralleled the advent of four-wheel and hydraulic brakes, and became of national interest sometime around 1934. Moyer (10) published some data on sandstone rock asphalt in 1934, and presented values for friction coefficients ranging from 0.59 to 0.77. Some advantageous features were attributed to sand-paper type surfaces (typified by rock asphalt). Measurements were made with a towed-trailer essentially similar to equipment now in use in Tennessee.

Recent, post war, studies on skid-resistance in Virginia (11), Tennessee and Kentucky (12), and very recently in Indiana (13) have included rock asphalt surfaces. The tests made in Kentucky in 1953 were conducted cooperatively with the Tennessee Highway Research Program using equipment developed by that organization (see Fig IV-a). It consists essentially of a towed trailer, one wheel in line with the draw bar and the other wheel acting as an out-rigger. The main wheel is equipped with



Fig. IV-a: Skid-test Equipment used by the Tennessee Highway Research Program in Cooperative Tests on Kentucky Roads.

a brake to skid the wheel, and the skidding resistance is measured by the "pull" on the draw-bar. Towing the trailer at various speeds makes it possible to evaluate skid resistance, or coefficients of friction, at different speeds. The tow-truck carries a water tank and spray for wetting the pavement in front of the braking wheel. Coefficients of friction may be calculated from the basic equation:

$$f = \frac{F}{W}$$

Where F = tangential force (pull) to produce sliding
 w = Total downward force on the wheel

Coefficients tend to decrease with increasing speed and vary with respect to other conditions of the tests. Because of differences in methods and equipment, coefficients are generally considered as relative and serve only for comparisons of roads and surfaces tested with the same apparatus and under equivalent conditions.

The work done in Virginia was by the "stopping distance method" in which a car is accelerated to a particular speed, braked to lock all four wheels, allowed to skid to a stop, and the skidding distance measured. In this case, the friction coefficient is evaluated from the following equation:

$$f = \frac{V^2}{30 S}$$

where V = initial speed in m. p. h.
 S = stopping distance in feet.

Both methods yield coefficients in the same comparative order, but values may not be used inter-changeably unless properly validated by comparative

tests. Values obtained by the stopping-distance method seem to be considerably higher and are perhaps more realistic over a wide range of speeds.

Insofar as it has been possible to ascertain, the measurements made with the Tennessee equipment in July, 1953 represent the only skid-testing that has been done in Kentucky or on Kentucky roads. Some of the results were presented at the 1955 Kentucky Highway Conference and, in a more abbreviated form, at the 34th Annual Meeting of the Highway Research Board in 1955 (14). However, the pertinent comparisons within Kentucky roads and between various types of surfaces have not heretofore been recorded. These data have been abstracted and re-drafted into a condensed graphical form and are presented in Fig. IV-b.

The report on the Kentucky tests summarized these results in the following manner:

"In most skid-test work which has been published, the Natural Rock Asphalt (Ky-Rock) surfaces have exhibited the highest coefficient of friction. Tests were made in Kentucky to verify this and the results on three Ky-Rock surfaces are shown in Fig. 9, (included here in Fig. IV-b). These curves tend to confirm the general belief that the Ky-Rock surfaces are relatively non-skid as the coefficients are in general higher than on most surfaces — especially when the age variable is considered. This seems to indicate that the surface wears (sands away) as it becomes older and does not polish as do many of the limestone surfaces."

While skid resistance should be recognized as an inherent feature of sharp angular quartz sand, it should not be assumed categorically that all deposits of rock asphalt or sandstone would yield sands of equal angularity and hardness. However these properties may be evaluated comparatively, at least, with the aid of a low power microscope.

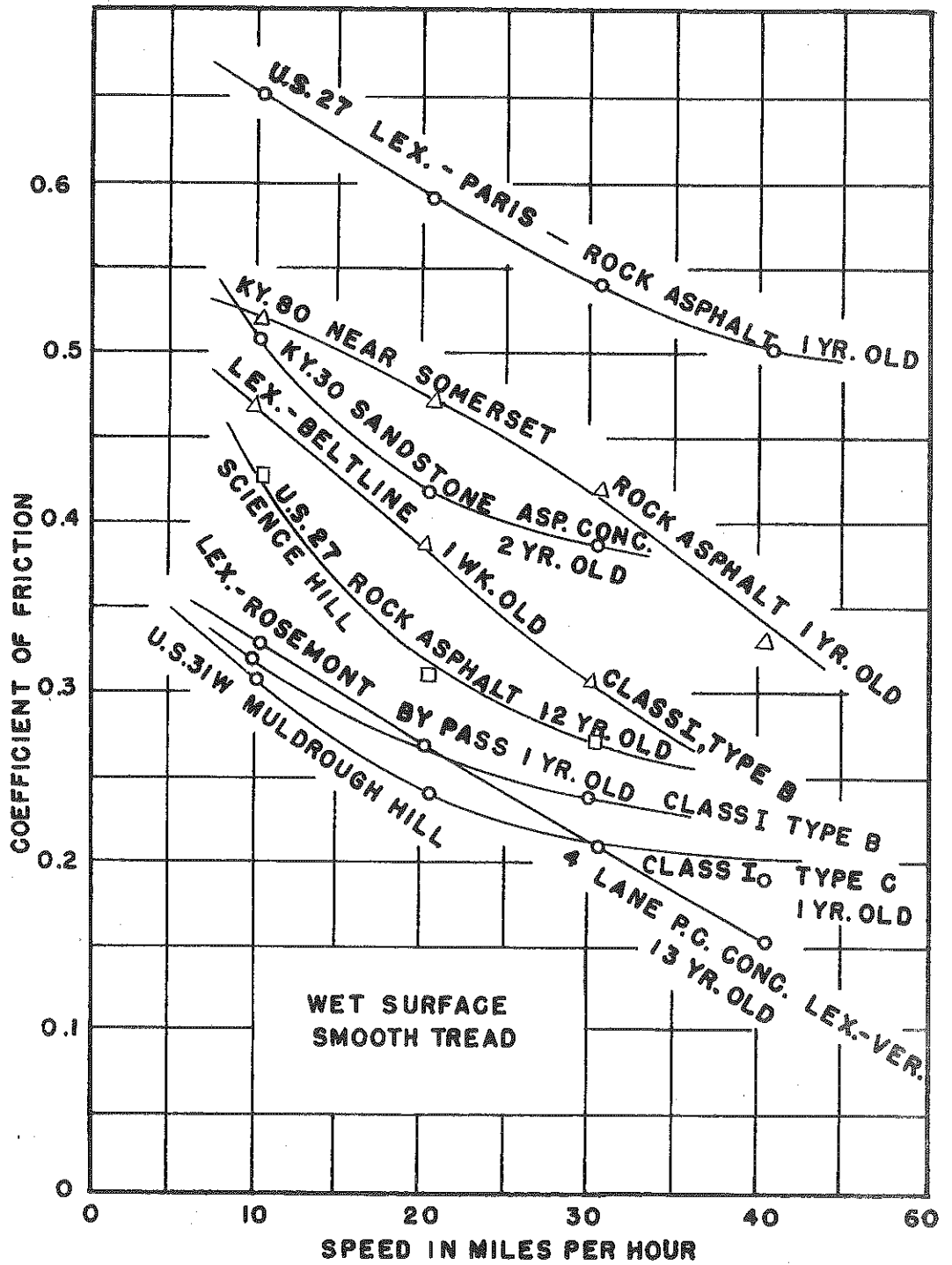


Fig. IV-b. Results of Skid Tests on several Kentucky Roads by Towed-Trailer Type of Equipment used in Tennessee.

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