COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
FRANKFORT

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ADDRESS REPLY TO
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MATERIALS RESEARCH LABORATORY
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MEMO TO: D. V. Terrell
Director of Research

The attached report, "The Design of Thin, Silica Sand-Asphalt, Wearing Surfaces for Highways and Bridges", contains a comprehensive summary of the laboratory investigation for the development of the surfaces for the Clark Memorial Bridge in Louisville and Asphalt-Coal Grove Bridge in Ashland.

The objective in this project was the development of a manufactured sand-asphalt to replace unavailable Kentucky natural sandstone rock asphalt. The desirable texture and anti-skid properties of the sandstone rock asphalt are widely recognized. Adequate initial stabilities to withstand present traffic volumes and weights in an essential requirement for pavement surfaces. Havens and Williams reported in "A Study of the Properties and Performances of Kentucky (Natural Sandstone)Rock Asphalt", the basic factors involved in highway surface course use of the rock asphalt. The sandstone in which the asphalt was deposited was studied and mixes using crushed sand from the area of the natural Kentucky rock asphalt deposits with penetration grade asphalts were prepared and evaluated. Superior anti-skid properties of the angular silica sand mixes were noted.

Stutzenberger and Havens in "A Study of the Polishing Characteristics of Limestone and Sandstone Aggregates in Regard to Pavement Slipperiness" found that the sandstones were less susceptable to polishing than the calcareous aggregates tested.

The attached report is a continuation of bituminous surface mix design studies. We believe that the silica sand-asphalt mix has considerable merit and are still observing the performance of the bridge resurfacings under dense traffic volumes. The first year's performance has been above original expectation. We recommend that a test installation of thin silica sand-asphalt surface be constructed on a primary highway or street carrying a high volume of traffic.

Respectfully submitted,

W. B. Drake

W. B. Drake
Associate Director of Research

WBD:dl
Enc.
cc: Research Committee
Bureau of Public Roads

Commonwealth of Kentucky
Department of Highways

THE DESIGN OF THIN, SILICA SAND-ASPHALT, WEARING SURFACES FOR HIGHWAYS AND BRIDGES

by

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I: INTRODUCTION

Kentucky Rock Asphalt has been recognized rather universally as a paving material exhibiting very high skid-resistance. This quality is attributed to the sharpness and hardness of the sand grains and the high void content of the compacted aggregate (2)*. The hardness of the sand grains makes the material resistant to the polishing action of abrasive grit under vehicle tires. Softer stones, such as limestones, are more susceptable to polishing under traffic and as a consequence will become slick under continued use (4).

Nearly all pavements exhibit adequately high skid-resistance when in a dry state; but when the pavements are in a wet condition, some do not retain this high skid-resistance (4). It is believed the high percentage of voids in rock asphalt surfaces enables the material to relieve hydraulic forces under vehicle tires so that the lubricating effect of the water is reduced and a relatively high coefficient of friction is retained (2). In the past, Kentucky has been fortunate to have Kentucky Rock Asphalt (natural sandstone rock asphalt) readily available for surfacing and deslicking treatment.

Although rock asphalt has excelled in skid-resistance, shipping costs from a fixed location (Brownsville, Kentucky) and the fact that the natural material has not withstood modern-day traffic when prepared

* Numbers in parenthesis refer to references at the end of the report.

and handled in the traditional manner have led to its general disuse (2). In view of the deficiency of the natural sandstone rock asphalt, this project was initiated to investigate the feasibility of manufacturing "synthetic" rock asphalt by hot, plant-mix methods. This was to be done by testing mixtures composed of silica sand and petroleum asphalt cements. The aggregates to be investigated were crushed sandstones, river and bank sands.

It was desired, of course, that the silica sand-asphalt mixtures provide a lasting wearing surface and have skid-resistance properties approaching those of Kentucky Rock Asphalt. It was also desired that the mixtures be machine laid in thicknesses of less than 1/2 in.

Historically, "sand asphalts" or "sand mats" have been utilized in several areas of the United States. The use of local sands in these areas was for economy in the absence of other suitable type aggregates. Construction practice has primarily consisted of stabilizing the sand that is in place with liquid asphalts or tars by road-mix or traveling-plant methods. When the sands were located some distance from the construction site, plant mix methods using asphalt cements have been used (3). It has been found that the stability of sand-asphalt mixtures is increased by the use of harder grades of asphalt and also by adding filler material. The surfaces were usually constructed in 2 courses, and varied in total thickness from 4-1/2 to 6 in. Sand mixtures, produced without close control, may be considered as modified sheet asphalt. Sheet asphalts are mixtures of sand, filler and asphalt cement. They may be differentiated from "sand asphalts" in that all sand used for sheet asphalt is finer than the No. 10 screen, and its grading and quality are carefully specified. Filler material may run from 10 to 20 percent of the total aggregate. Sheet asphalt is usually laid about 1-1/2 in. thick over an asphaltic-concrete binder course. This type of mix has been used extensively on city streets for over 60 years. In 1876, Pennsylvania Avenue in Washington was surfaced with a sheet asphalt using Trinidad Asphalt as the binder (2).

More recently research work on silica sand-asphalts has been done by the Virginia State Highway Department (3). Thin test sections of silica sand-asphalts were laid in 1955 after preliminary laboratory testing of the water resistance, and cohesion, of the various test mixtures. Virginia successfully applied a sand-asphalt mix at an average rate of 25 lbs. per sq. yd. (approximately 1/4 in. thick) by means of a standard Barber-Greene paver. The aggregates in these mixtures were crushed and washed sandstones or unwashed bank sand. These mixtures were manufactured by hot plant-mix methods using asphalts of 85 to 100 and 138 penetration. The tack coat was a RC-0 or RC-2 applied at a rate of 0.1 gal. per sq. yd. It was found that these pavements exhibit skid-resistant properties that compare favorably with Kentucky Rock Asphalt. The durability of this type of material can only be estimated at the present time and will be determined from further investigation.

Re-surfacing of bridges, tunnels, and airfields, in the normal course of maintenance, brings about certain problems (5). In bridges the principal problems are of increased dead weight and the necessity of raising expansion joints. In tunnels decreased headroom and drainage problems arise. The problem in re-surfacing airfields is primarily economic. The Port of New York Authority has investigated several surfacing materials that have the potentialities of meeting these special problems (5). A silica sand-asphalt mixture, similar to those used in Virginia, was the most promising of the materials studied, according to the information gathered from this investigation. Test installations of silica sand-asphalt have been placed by the Port Authority on the Goethals and Bayonne Bridges, the North Tube of the Lincoln Tunnel, and at Newark Airport.

This study was performed at the Highway Materials Research Laboratory in Lexington, Kentucky. In this study the various sands were combined with asphalt cement of penetration 60 to 70 and tested by the Marshall method to determine the physical characteristics of the mixtures. Other variables investigated were the hardness of the asphalt cement and the amount of mineral filler. A coefficient of friction was determined, by means of a laboratory testing device, for each of the mixtures.

Due to the promising results of the laboratory testing, and the successful re-surfacing of bridges with silica sand-asphalt mixtures in the New York area; the Research Division of the Kentucky Department of Highways, in June 1958, recommended silica sand-asphalt for the re-surfacing of Clark Memorial Bridge in Louisville. All laboratory testing of sands up to that time had been of crushed sandstones. The lack of sandstone in the Louisville area led to an investigation of the possibility of blending locally available bank and river sands. Various blends of the river and bank sand were tested, with and without mineral filler; and it was concluded that a satisfactory mixture could be manufactured using these sands.

Prior to letting of the contract for re-surfacing Clark Memorial Bridge, the Construction Division became interested in substituting a plant-mix, silica sand-asphalt mixture for Kentucky Rock Asphalt on the Ashland-Coal Grove Bridge. The observation, of the construction of these test sections gave valuable information as to problems which may be encountered in mixing, and laying silica sand-asphalt mixtures, in thin layers, by means of the usual paving equipment.

II: MATERIALS

In the State of Kentucky, there are great deposits of sandstone. Sandstone crops out, or lies immediately beneath the surface, in approximately 1/3 of the area of the state. The stone ranges from very hard to soft. In the past very little of this material has been used for road construction.

In this investigation, a total of 14 sandstone samples were taken from the eastern and western sandstone regions of the state. The sampling sites, and location of the sandstone areas, have been plotted on the map in Fig. 1. Samples were collected from quarries and road cuts. The sandstone was broken from the face of the outcrop so to have little weathered material in the sample. Pieces of stone were taken from the various levels of the outcrop, so far as possible, to gain a representative sample. The sandstone samples were crushed in the laboratory, by means of a small jaw crusher, to a point where the total sample would pass the No. 8 screen. This top aggregate size (0.094 in.) was chosen in view of the requirement that this material be machine laid in courses of less than 1/2-in. thickness. It was reasoned that a larger size aggregate could possibly become lodged beneath the paver screed and cause torn places in the lay.

The specific gravities and sieve analyses of the crushed sands, and of typical river and bank sands are presented in Table 1.

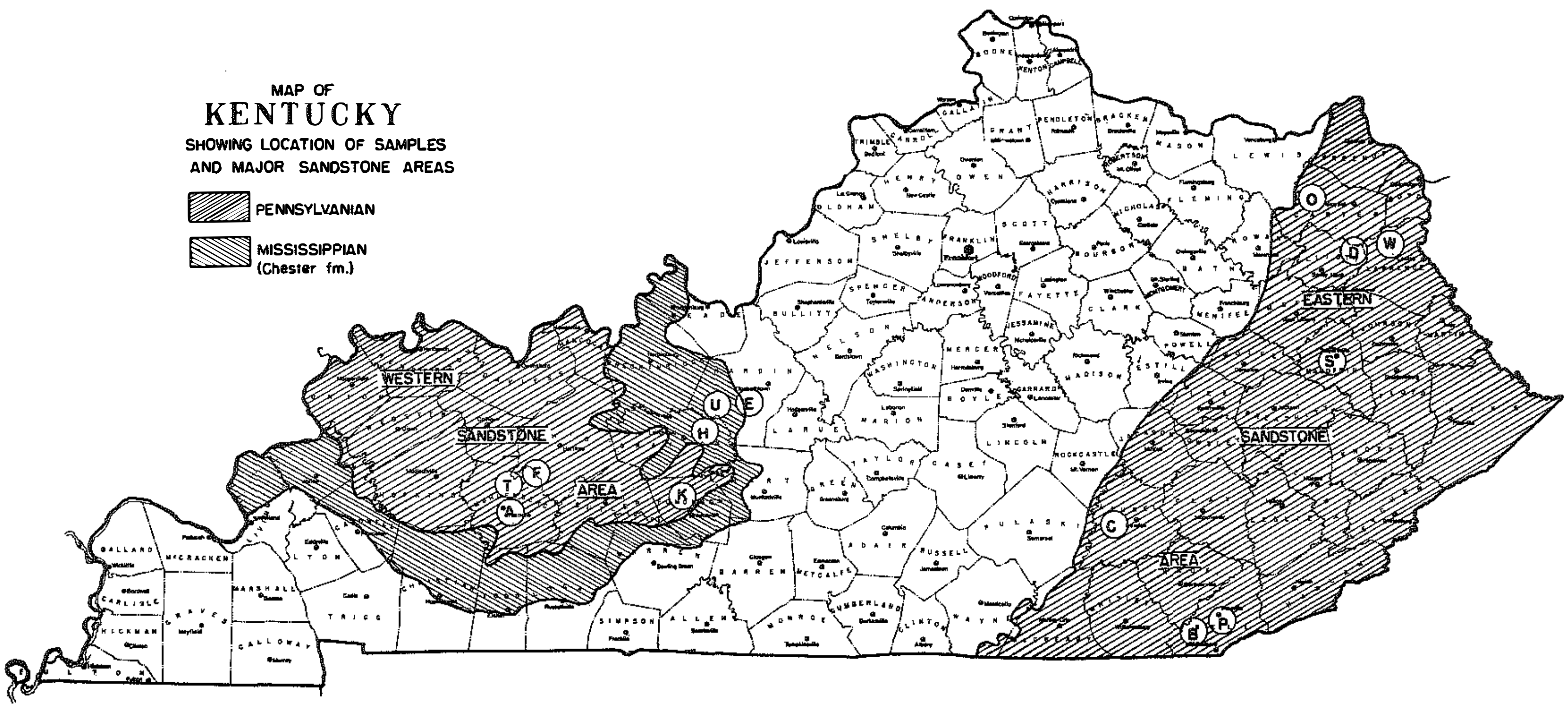


Fig. 1. Location of Samples and Major Sandstone Areas.

TABLE I

SPECIFIC GRAVITIES AND SIEVE ANALYSES OF SANDS

Sand Type and Name	Specific Gravity	Color*	Percentage Passing Sieve Number						
			8	16	30	50	80	100	200
Sandstone									
Corbin (C)	2.66	Grayish orange 10 YR 7/4	100.0	99.4	93.8	42.6	11.8	7.4	3.5
Dobbins (D)	2.69	Moderate yellowish brown 10 YR 5/4	100.0	89.5	75.2	55.0	32.4	23.1	9.7
Olive Hill (O)	2.66	Light gray N 7	100.0	91.4	78.4	52.0	29.0	20.3	10.0
Pearl Brownhill (B)	2.66	Grayish orange pink 10 R 8/2	100.0	89.9	81.9	50.2	24.6	16.5	6.3
Polly (P)	2.66	Yellowish gray 5 Y 8/1	100.0	97.0	89.7	42.1	17.7	11.5	5.2
Salyersville (S)	2.69	Light olive gray 5 Y 6/1	100.0	85.5	72.7	60.8	39.6	29.1	12.7
Webbville (W)	2.67	Yellowish gray 5 Y 7/2	100.0	85.9	70.2	31.9	17.7	14.8	7.8
Big Clifty (H)	2.66	Grayish orange 10 YR 7/4	100.0	93.6	87.4	70.8	36.4	25.9	5.6
Central City (T)	2.66	Moderate yellowish brown 10 YR 5/4	100.0	92.1	79.6	34.4	18.6	14.5	8.1
Drakesboro (A)	2.67	Pale yellowish orange 10 YR 8/6	100.0	98.2	85.2	31.7	13.9	8.9	4.7
Eastview (E)	2.67	Grayish orange 10 YR 7/4	100.0	98.9	97.1	91.4	59.2	23.6	2.9
Green (F)	2.68	Dark yellowish orange 10 YR 6/6	100.0	92.3	84.6	50.3	15.1	9.6	4.5
Ky. Rock (K)	2.65	Pale yellowish brown 10 YR 6/2	100.0	96.7	91.4	51.1	14.8	7.5	2.8
Stephensburg (U)	2.66	Pale yellowish brown 10 YR 6/2	100.0	80.5	70.3	56.9	29.3	23.2	11.0
River sand**	2.68	Combined	100.0	89.0	70.0	23.0	4.0	1.4	0.2
Bank sand	2.66	Moderate yellowish brown 10 YR 5/4	100.0	99.0	98.0	85.0	56.0	41.0	13.0

* Color names have been taken from the ISCC-NBS system. Numerical designations according to Munsell system.

** Scalped over a No. 8 screen prior to performing sieve analysis.

The designations given to the sands listed in Table 1 refer to the areas in which they were sampled. The sand designated as Kentucky Rock was obtained from the area of the bituminous rock deposits in western Kentucky. The sandstone sampled was not impregnated with any natural asphalt; however, the gradation of the crushed sand is typical of the natural sandstone rock asphalt found in the area (2).

For the greater number of the crushed sands 50 percent or more of the material lay between the No. 30 to 80 sieve sizes; this was probably due to the tendency of sandstones to crush to grain size. In general the stronger cemented sandstones yield higher percentages of material coarser than the No. 30 screen and finer than the No. 80 screen. Fig. 17 (Appendix I) is made up of photomicrographs of the sands used in testing. The Kentucky Rock and Eastview sands are examples of weakly cemented stones which have crushed to very near grain size; note the uniform size of the particles and the relatively small amounts of coarser and finer material. The Salyersville and Webbville sands are typical of the stronger cemented stones which result in longer gradations upon crushing. All of the crushed sands investigated fell within the limits shown in Fig. 2; also shown in the figure is a theoretical gradation for optimum density for a maximum size aggregate of 0.094 in. as computed by the National Slag Association's formula (7). None of the crushed sands had sufficient material coarser than the No. 30 screen to approach this theoretical gradation.

River and bank sand were obtained from various commercial sources in the Louisville and Ashland areas. Photomicrographs of typical river and bank sands are shown in Fig. 17 in Appendix I. The

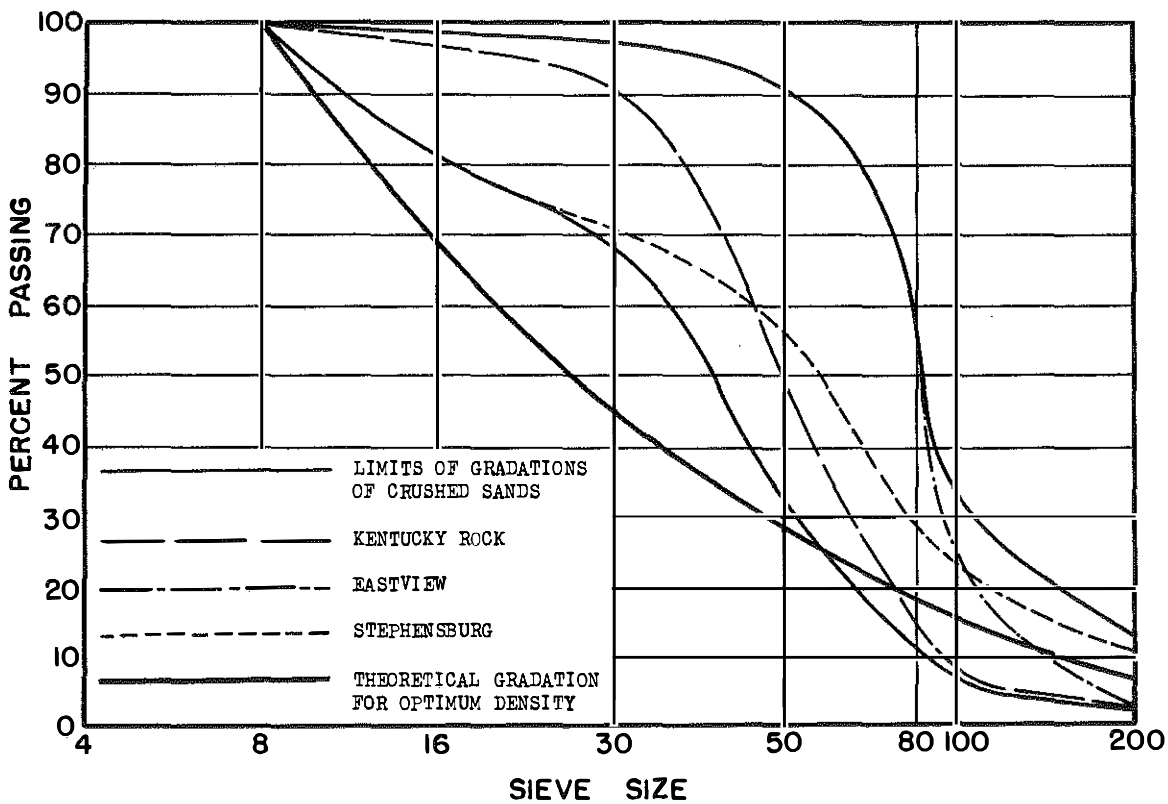


Fig. 2. Gradation Limits of Crushed Sands.

river sand consisted of rounded grains and had very little material finer than the No. 80 screen. The bank sand was fine and angular with the bulk of the material passing the No. 80 screen. The river sand was scalped over a No. 8 screen prior to performing the sieve analysis.

Filler (aggregate passing a 200 mesh screen) consisted of Type I Portland Cement, or soil, or limestone dust. Filler size materials in the crushed sands varied from 2.8 percent to 12.7 percent. The river sands contained less than 1 percent filler material. There was a large variation in the amount of filler size material in the bank sands.

III: PREPARATION AND TESTING OF SPECIMENS

The stabilities and voids analyses of the various silica sand-asphalt mixtures were evaluated by the Marshall method. Specimens were prepared from each of the crushed sandstones and from various blends of river and bank sands. The asphalt contents were in the range of 9 to 12 percent, in increasing increments of 1 percent; the asphalt cement used for all such specimens was a PAC-3. A limited amount of testing was done to investigate the influence of added filler upon the properties of the mixtures. The Marshall test was performed on lower stability sands with varying percentages of mineral filler consisting of soil, cement, or limestone dust.

The voids in the compacted aggregate were further investigated by compacting the dry sands in a graduated cylinder. The sands were compacted in successive layers until there was no further reduction in volume upon further compactive effort. The percent voids in the aggregate was then calculated.

The affect of the hardness of the asphalt cement on stability was investigated by combining the Polly sand with each of five penetration grades of asphalt cement at a constant asphalt content of 10.5 percent. Specimens were prepared according to the Marshall method and tested at temperatures of 140°F, 77°F, and 32°F. The specimens tested at 140°F and 77°F were broken by means of a Marshall testing machine. Due to the stabilities at 32°F exceeding the capacity of the Marshall machine, these specimens were broken in the Marshall testing heads fitted to a small hydraulic testing machine as shown in

Fig. 3. This effect was also investigated by combining the Kentucky Rock sand with each of the five penetration grades of asphalt at asphalt contents of 9 to 12 percent. These specimens were prepared and tested at 140°F according to the Marshall method.

Specimens for frictional testing consisted of mixtures of each of the crushed sandstones, prepared according to the Marshall method. The specimens were prepared with a binder of PAC-3 at an asphalt content of 8 percent. For comparative purposes, specimens were prepared of the Kentucky Class "I" surface mixture containing 50 percent river sand as the fine aggregate and 50 percent crushed limestone as the coarse aggregate. Frictional values for the Class "I" surface mixtures were measured at intervals of polishing against a rotating rubber annulus. Specimens of the test mixtures placed on Clark Memorial and Ashland-Coal Grove Bridges were also tested. All frictional specimens were cured for seven days in a constant temperature-air-flow oven at 80°C. The coefficients of friction were determined by rotating a rubber annulus at 180 rpm against the wet surfaces of the specimens and measuring the amount of torque converted to the specimens at normal loads of 20 and 25 psi. The coefficients of friction were computed and plotted against the total number of revolutions of the annulus at the time the measurement was made. The apparatus for testing the frictional specimens is shown in Fig. 4. A more thorough description of this testing divice is presented in reference 6.

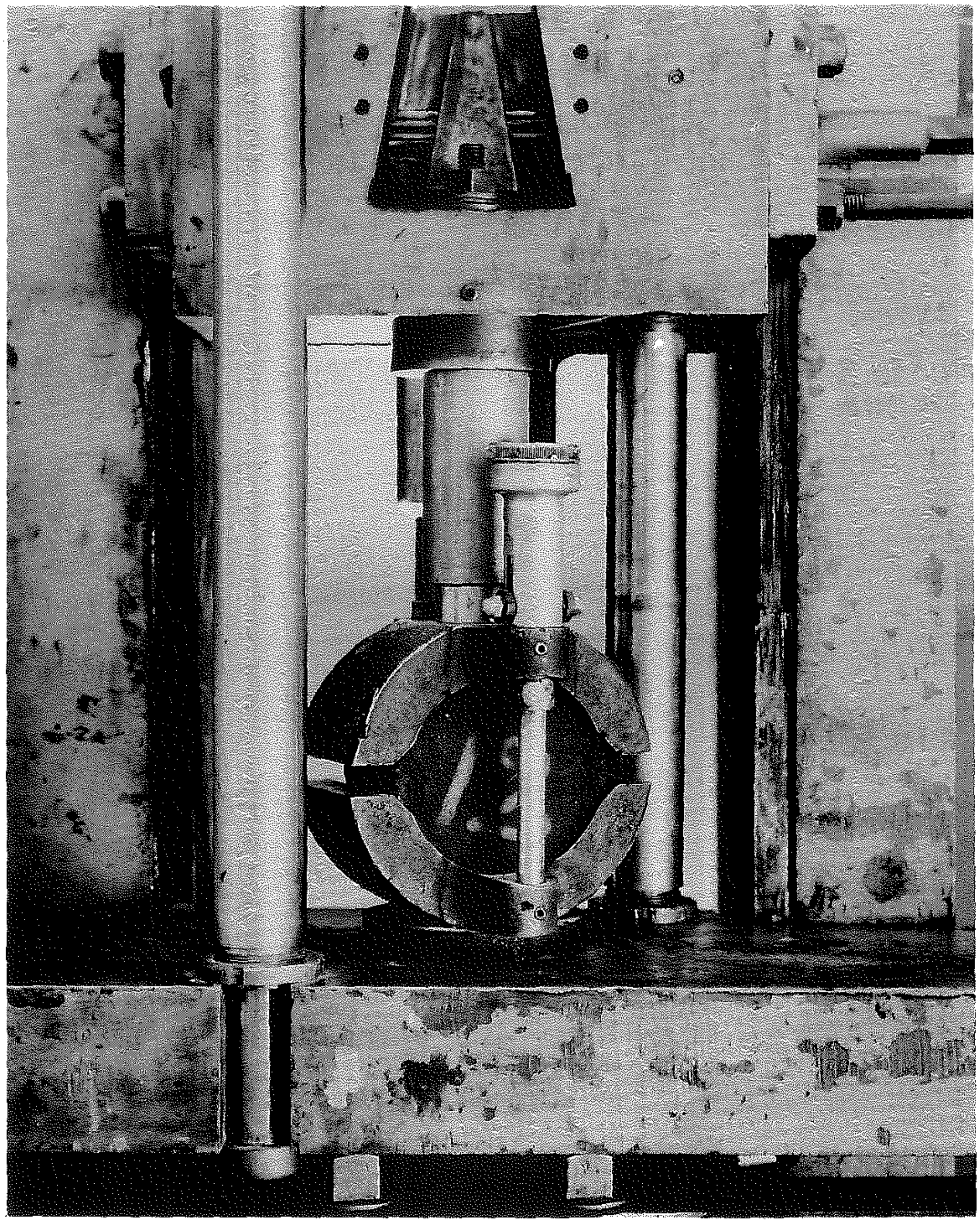


Fig. 3. Setup Used in Testing a Specimen at 32°F.

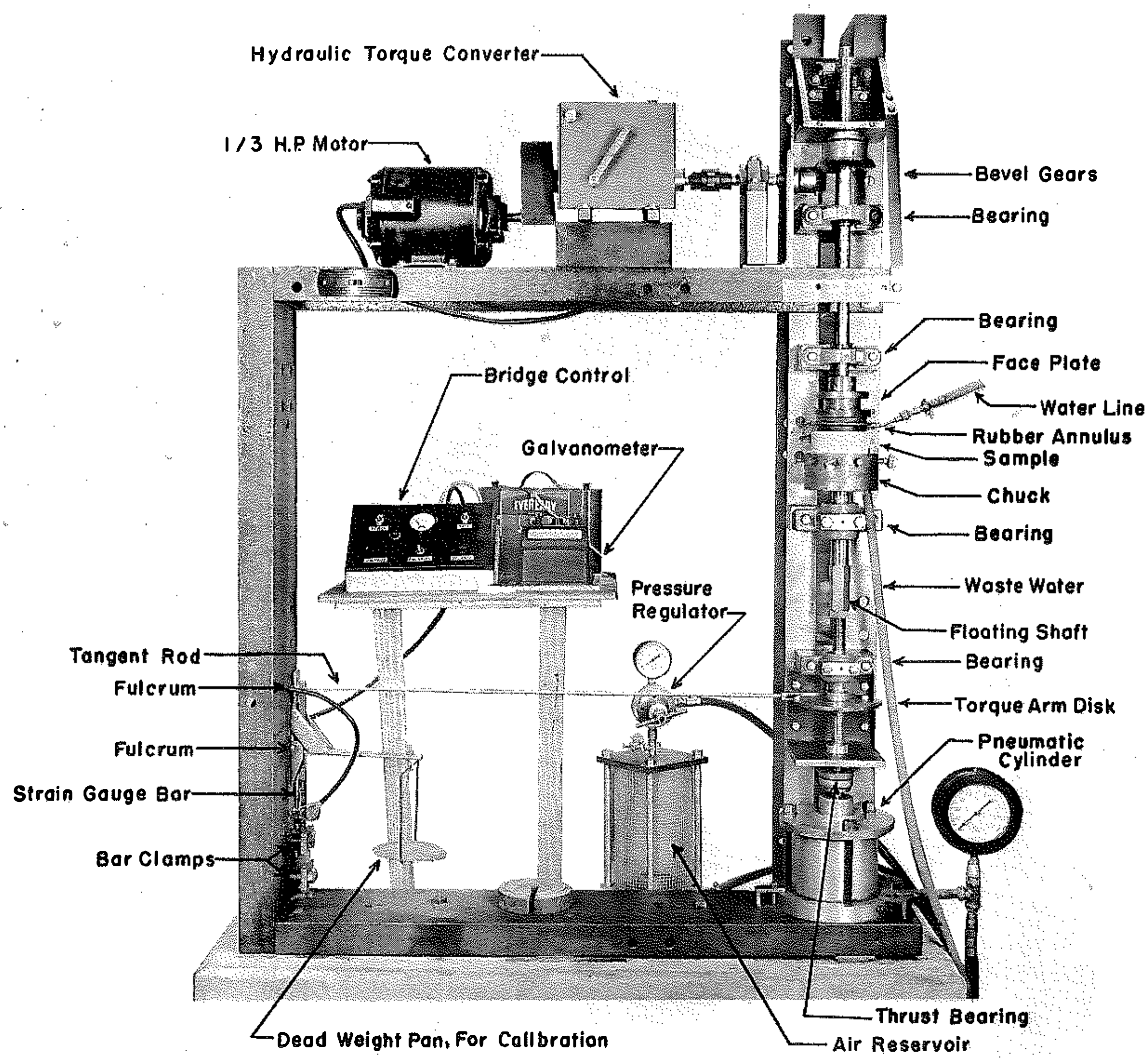


Fig. 4. Friction Measuring Apparatus.

IV: RESULTS AND DISCUSSION

The results of the study are presented in four sections. The first deals with the results of the Marshall testing of the silica sand-asphalt mixtures with crushed sandstones as aggregates, and the influence of various factors upon the properties and design of these mixtures. The second section is concerned with the frictional testing of various mixes, while the third presents the information gathered from the testing of the river and bank sand blends. The last section is a discussion of the paving of the two bridges.

Marshall Testing of Crushed Sandstone Mixtures

The stabilities of the crushed sandstone mixtures varied over a wide range. At an asphalt content of 12 percent, the stability ranged from a low 220 lbs. for the more-or-less "single sized" Eastview sand to a high of 1750 lbs. for the more densely graded Webbville sand. The results of the Marshall stability testing of crushed sandstone mixtures are presented in Table 2 in Appendix II.

The gradation of the various crushed sands had a very pronounced affect on the stability of the mixtures. The sands which had a high percentage of the material within the No. 30 to No. 80 sieve sizes yielded mixtures with low stabilities and high void contents. The stability of these "one sized" sands increased slowly with increasing asphalt content and never reached a peak value within the 9 to 12 percent asphalt content range. Fig. 5 consists of stability curves for the

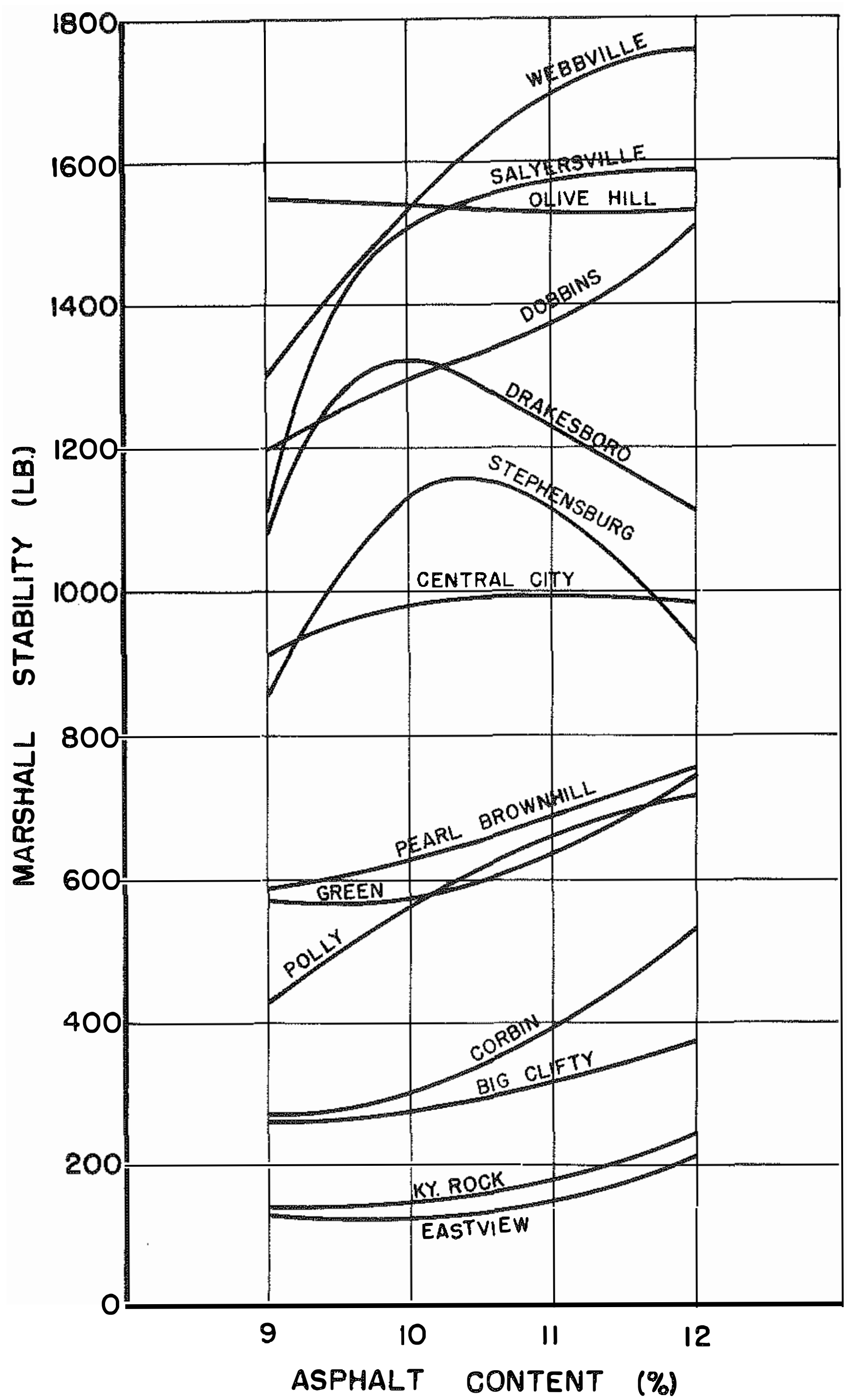


Fig. 5. Marshall Stability Curves for Fourteen Crushed Sands.

14 crushed sandstone mixtures. It will be noted that the stability curves take two characteristic shapes which depend upon the void content of the compacted aggregates. The stability values increased slowly with increasing asphalt content for the mixtures that had greater than 33.6 percent voids in the compacted aggregate. The stability increased rapidly for the more densely graded sands and in some cases reached an optimum value within the 9 to 12 percent asphalt content range. The Polly sand was comparatively low in stability even though it was one of the more densely graded sands, and conversely, the Dobbins sand was high in stability even though it had a fairly high void content in the compacted aggregate. These differences must be attributed to the texture of the sands; referring to Fig. 17 (Appendix I), it will be noted that the grains in the Polly sand are rounded and the grains in the Dobbins sand are very angular.

The characteristic that showed the most consistent correlation with stability was the percentage of aggregate passing the 200 mesh screen. Fig. 6 consists of a plot of the stability values versus the minus 200 material in the aggregate of the 14 crushed sands, at an asphalt content of 10 percent. It will be noted that the stabilities increase uniformly in magnitude with increasing percentages of filler size material even though the sands vary in gradation. Similar curves can be obtained by plotting the stability values at the other asphalt contents against the percentages of minus 200 material. The filler material serves, along with the asphalt, to fill the relatively large void spaces in the mixture to make it more resistant to deformation.

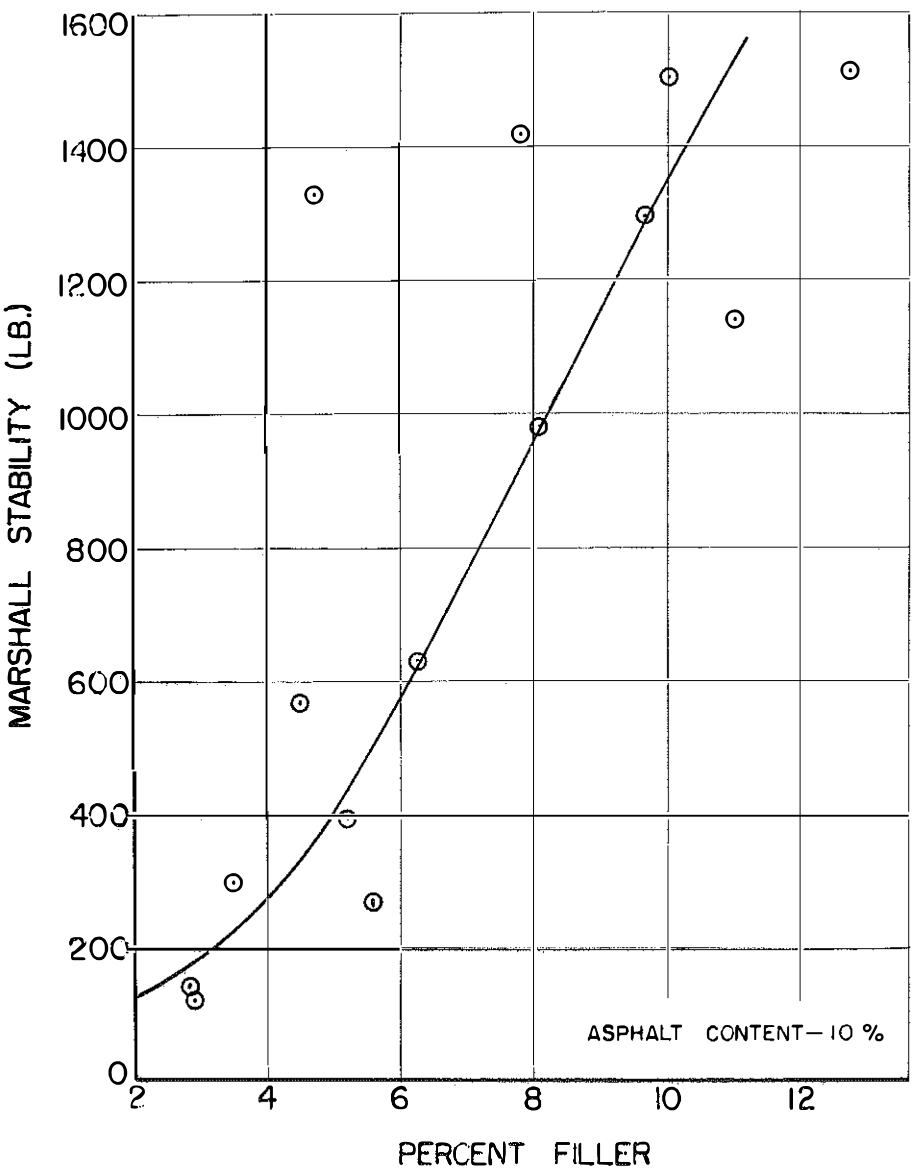


Fig. 6. Influence of Filler Material on Stability of Crushed Sand Mixtures.

The Kentucky Rock sample had low stability and a high void content. It was found that the stability of this "one size" sand could be increased by the addition of mineral filler or by blending with other sands. Referring to Fig. 7, it will be noted that the stability of the Kentucky Rock and Eastview combination is higher than the stabilities for either sand alone. This is presumably due to the slightly longer gradation of the two sands combined. The stability of the equal combination of the Kentucky Rock sand and the high stability Drakesboro sand plots in a curve of near median value. Also illustrated in the figure is the increased stability of the Kentucky rock sand when 5 percent soil filler is added.

It is doubtful that blending of crushed sands from two widely separated sources would prove to be practical from an economic standpoint due to the expense of crushing and transporting the material and in view of the fact that the stability of the material can be increased by the addition of a small amount of filler material. A stability value of 300 lbs. at an asphalt content of 9 percent was achieved for all the sands investigated in this study by the addition of mineral filler to the low stability sands. This should prove to be adequate considering the fact that the natural sandstone rock asphalt has performed satisfactorily in many instances with stability values lower than 300 lbs.

The unit weights, flow values, and the voids analyses of the crushed sandstone mixtures are presented in Table 2 (Appendix 2). It will be noted that the flow values ranged from a low of 7 to a high of 18. Assuming 10 percent voids in the mix to be the minimum

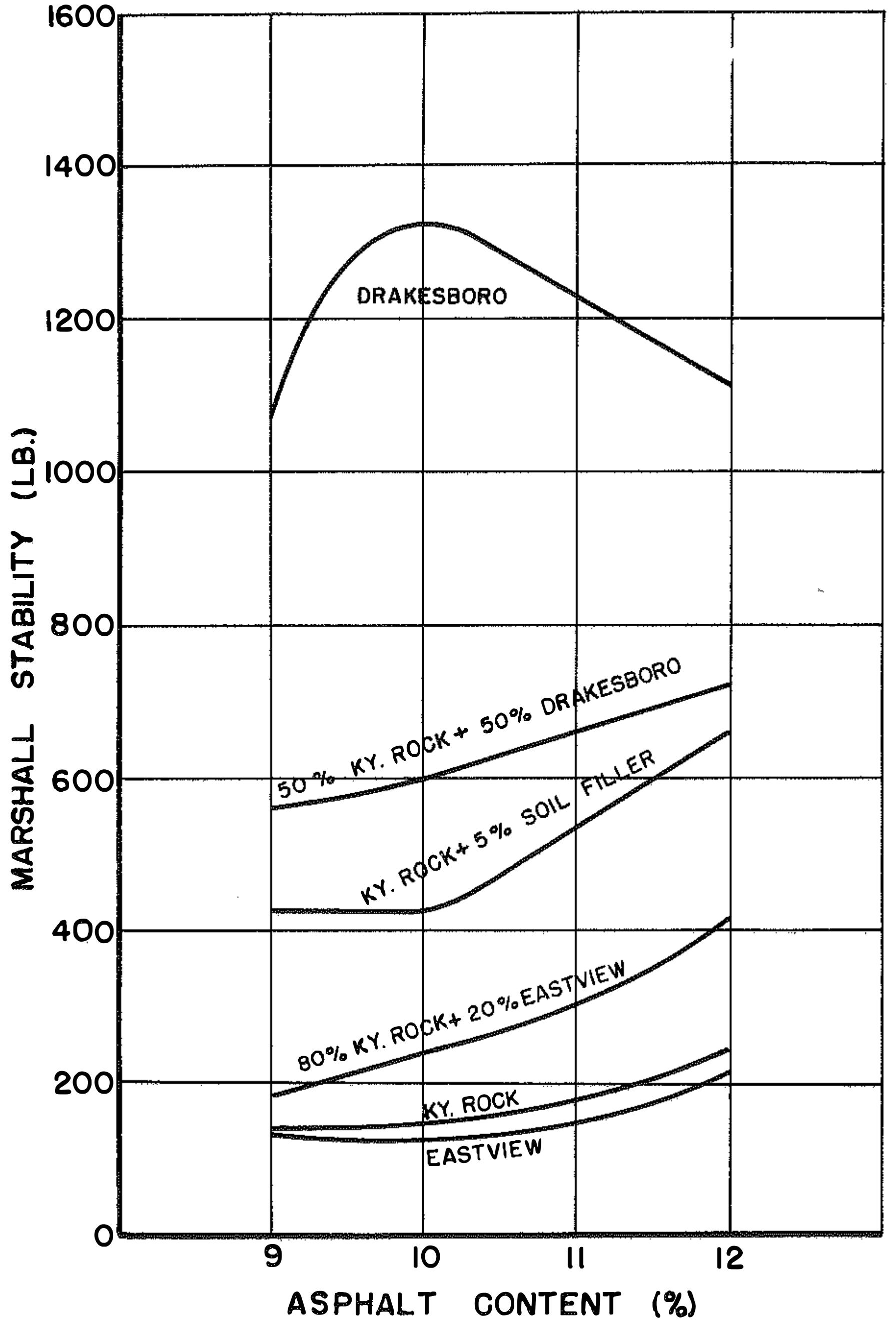


Fig. 7. Influence of Sand Combinations and Added Filler Material.

practicable design, the flow values lay within a range of 7 to 14. The voids in the aggregate, for any one crushed sand, remain fairly uniform over the range of asphalt contents investigated. The percent voids in the aggregates ranged from a high of 38.3 percent for the Eastview sand to an asphalt content of 9 percent, to a low of 28.5 for the more densely graded Stephensburg sand at an asphalt content of 11 percent.

A comparison of the percent voids in the compacted dry sands and the percent voids in the sands under Marshall compaction at asphalt contents of 9 to 12 percent is presented in Table 3, Appendix II. It may be noted there that the percent voids in the compacted dry sands are slightly higher than in the Marshall specimens; this difference is probably due to the lubricating effect of the asphalt in the mix. This small difference, combined with the fact that the percent voids remain fairly constant with increasing asphalt content, indicates that 100 blows from the Marshall Hammer resulted in near maximum density.

The result of investigating the effect of the hardness of the asphalt upon the Polly and the Kentucky Rock sands are shown in Table 4, Appendix II. The stabilities of the mixtures composed of the Polly sand and asphalts of 41 and 52 penetration were significantly higher than those mixtures prepared with asphalts of 60, 70 and 85 penetration, at each of the testing temperatures. The stabilities of the mixtures prepared with the Kentucky Rock sand and the various grades of asphalt, tested at 140°F, parallel the results obtained with the Polly sand mixtures. Flow values tended to increase with the harder grades of asphalt. Referring to Table 4, it will be noted that for the Polly sand mixture with PAC-2, tested at 77°F, the flow was 20.5 whereas the flow of the mixture incorporating PAC-5 was only 11.0. The percent voids in the aggregate tended to decrease slightly with the use of softer grades of asphalt.

Frictional Testing

The results of the frictional testing of the crushed sandstone mixtures are presented in Table 5 in Appendix II. Frictional coefficients measured at 25 psi normal pressure were slightly higher than those measured at 20 psi normal pressure. The average of the coefficients for the 14 crushed sands was 0.53 at 25 psi normal pressure and 0.48 at 20 psi normal pressure. The coefficients measured for the Kentucky Rock sand were 0.51 at 25 psi and 0.46 at 20 psi. It is indicated that the frictional properties of these sand-asphalt mixtures with respect to tire tread rubber are comparable to those of the natural sandstone rock asphalt. Included in the table are frictional coefficients for the river and bank sand blends placed on the Clark Memorial Bridge at Louisville and the Ashland-Coal Grove Bridge. For comparative purposes, specimens of the Kentucky Highway Department's Class "I", Type "B" surface also were tested in the frictional testing device. Fifty percent of the aggregate for this bituminous concrete surfacing material was river sand. Specimens were tested also in which the total aggregate was limestone which met the gradation specifications for Class "I" bituminous concrete surface.

In Fig. 8, examples are shown of the 3 types of surfacing materials tested. The scrubbing action of the rubber annulus, combined with the water used to cool and wet the specimen surfaces, stripped the asphalt from the silica sand grains in both the crushed sand specimen and the Class "I" bituminous concrete specimen containing sand. The loose sand also polished the coarse limestone aggregates in the bituminous concrete mixtures, and the polished surfaces of these aggregates can be clearly seen protruding slightly above the surrounding matrix. The frictional resistance offered by the bituminous concrete specimens decreased as the coarse limestone aggregates become worn and polished. Fig. 9 shows a plot of the frictional values for the two types of bituminous concrete specimens versus the number of revolutions of the annulus. Initially, the frictional values were very nearly the same for the two types of surfaces; however, the frictional values decreased at a faster rate for the specimens containing 100 percent limestone aggregate.

It was not possible to test the sand-asphalt specimens in exactly the same manner as the Class "I" surface samples because, after a short interval of wearing on the testing machine, the asphalt stripped from the sand grains collected in the groove worn in the sample by the annulus. The annulus rode upon this collected layer of asphalt and the loose sand grains rather than the sand grains bound into the mixture. The values presented in Table 5 are averages of the first 12 readings taken on the sand-asphalt samples. Three readings, at 20 and 25 psi, were taken on each end of two specimens. In this manner the effect of the collected asphalt was kept to a minimum.

CRUSHED
SANDSTONE
8 % PAC-3

CLASS "I" SURFACE
50 % Limestone
50 % River Sand

CLASS "I" SURFACE
Limestone Aggregate

Fig. 8. Examples of Specimens after Testing on Frictional Testing Machine.

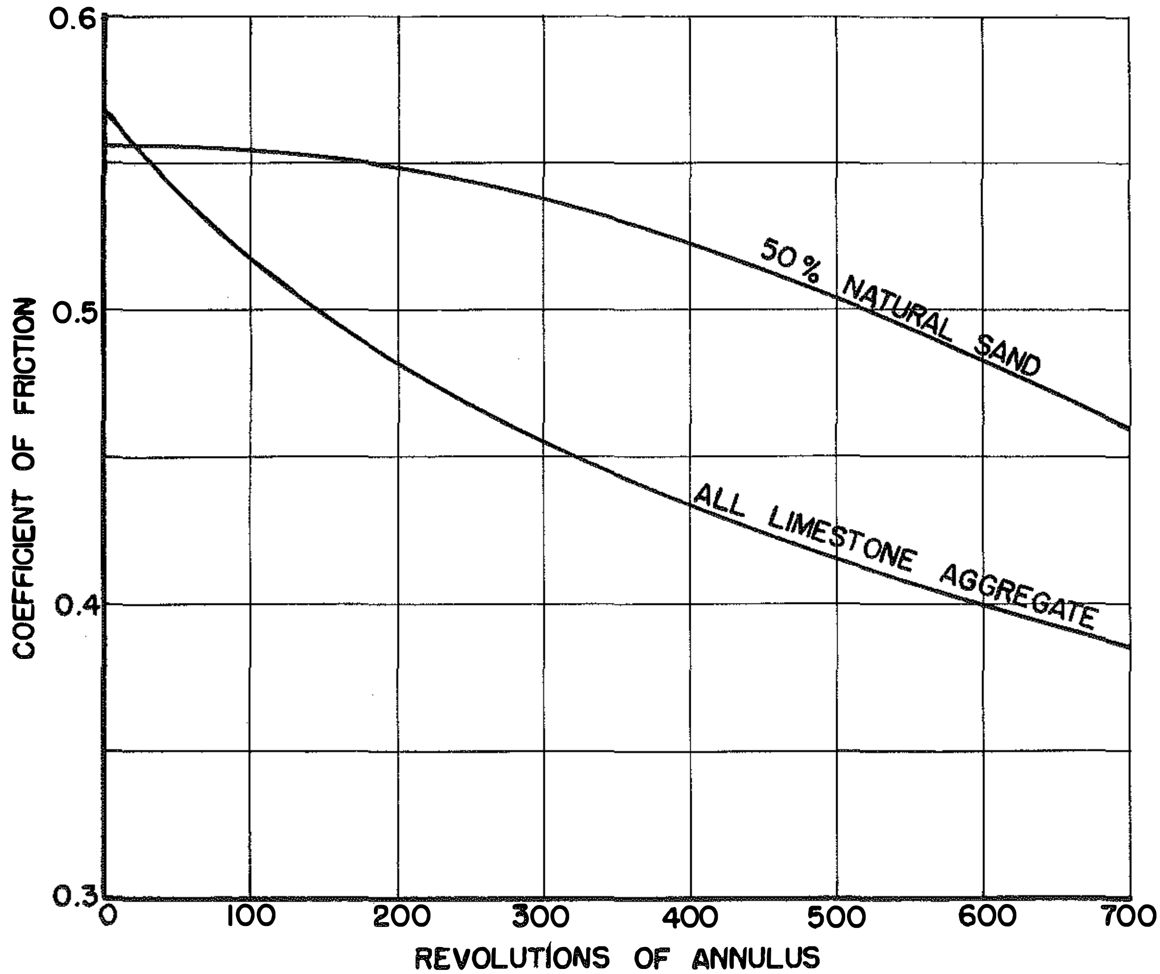
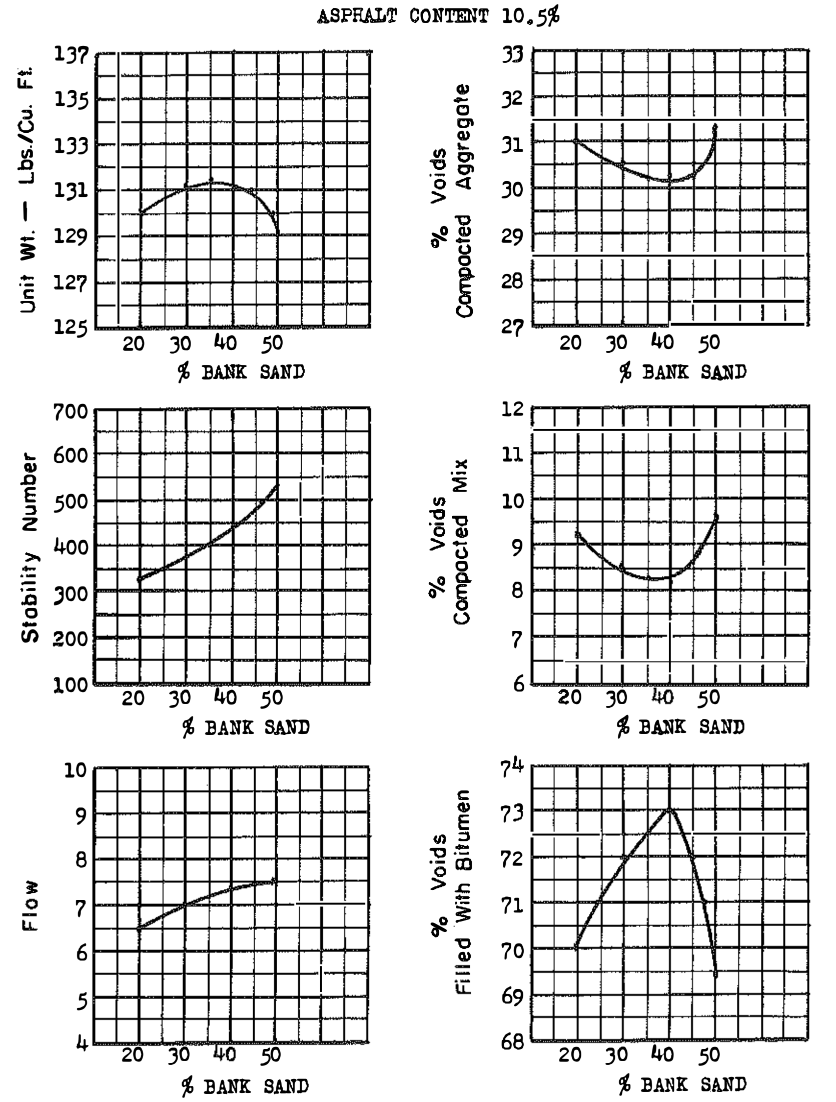


Fig. 9. Reduction of Frictional Coefficient with Polish of Limestone Aggregate of Bituminous Concrete Surfacing Materials.

River and Bank Sand Blends

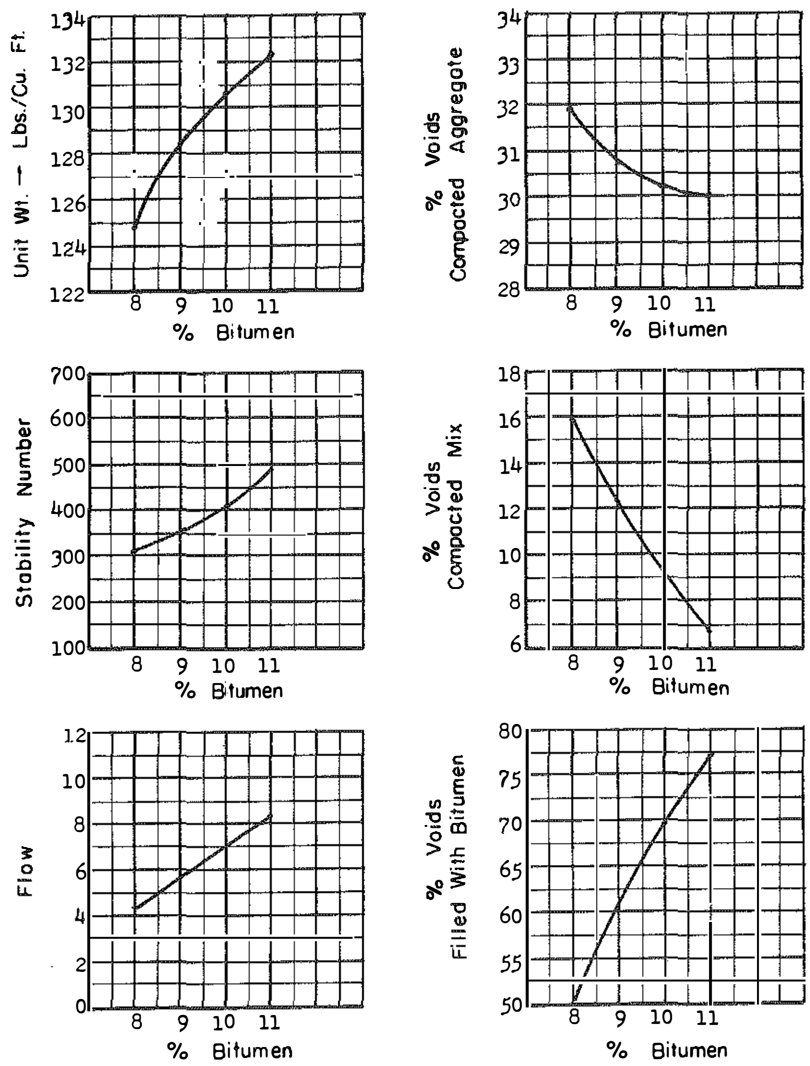
In view of the desire to establish specification requirements for the re-surfacing of the Clark Memorial and the Ashland-Coal Grove Bridges at Louisville and Ashland, various combinations of river and bank sands which were readily available in the respective areas were investigated by the Marshall method. The binder used for all river and bank sand blends was a PAC-3. The river sands were scalped over a No. 8 screen prior to blending.

The first tests were performed, at a constant asphalt content, upon mixtures with a varying ratio of river to bank sand from the Louisville area. This was done to determine the best combination of the materials for density and stability. Average gradations of the river and bank sands are presented in Table 1. The results are presented in Fig. 10. It will be noted that the stability increased uniformly with increasing percentages of the fine, angular, bank sand even though the maximum density was achieved with bank sand comprising 40 percent of the aggregate. The Marshall Test was then performed upon mixtures of equal portions of the Louisville sands at asphalt contents from 8 to 11 percent. The stability increased uniformly with increasing asphalt content as shown in Fig. 11. The percent voids decreased uniformly from 15 percent at 8 percent asphalt content, to 6.7 percent at 11 percent asphalt content. It was considered desirable to have as great a stability as possible and yet preserve a minimum of 10 percent voids in the mixtures. The equal combinations of river and bank sand at an asphalt content of 9 percent showed promise of meeting these criteria.



TEST DATA	HIGHWAY MATERIALS RESEARCH LABORATORY
	LEXINGTON, KENTUCKY
Opt. % Bit. ______ Unit Wt. ______	MARSHALL STABILITY TEST
Stability No. ______ Flow ______	Mix No. ______ Date 6-19-58
% Voids Comp. Agg. ______	Project Silica Sand-Asphalt
% Voids Comp. Mix. ______	Aggregate Varying % River & Bank
% Voids Filled With Bit. ______	Bitumen PAC-3 Penetration 65
Chart B-3 February, 1955	

Fig. 10. Influence of Varying Percentages of Bank Sand upon Properties of Mix.



TEST DATA

Opt. % Bit. 9.0 Unit Wt. 128.2
Stability No. 350 Flow 5.5
% Voids Comp. Agg. 30.8
% Voids Comp. Mix. 12.2
% Voids Filled With Bit. 60.2
Chart B-3 February, 1955

HIGHWAY MATERIALS RESEARCH LABORATORY
LEXINGTON, KENTUCKY

MARSHALL STABILITY TEST
Mix No. ____ Date 6-20-58
Project Silica Sand-Asphalt
Aggregate 50% River - 50% Bank
Bitumen PAC-3 - 65 Pen

Fig. 11. Marshall Data for Equal Combinations of Louisville Bank and River Sand. Note the percent voids in the total mix at an asphalt content of 9 percent.

In an effort to improve the stability of this combination, mixtures were prepared with 50 percent river sand, 46 percent bank sand, and 4 percent limestone filler, at asphalt contents of 9 to 11 percent. Specimens were also tested with 50 percent river sand, 47.5 percent bank sand, and 2.5 percent portland cement filler, at asphalt contents of 9 to 11 percent. The results of this testing are presented in Table 6, Appendix II. The addition of 4 percent limestone filler increased stability by approximately 60 lbs. at 9 percent asphalt content, but decreased the percent air voids to less than 10 percent. The addition of 2.5 percent portland cement, however, increased the stability 119 lbs. at 9 percent asphalt content; the percent voids in the mix was 10.4.

Considering the information gathered, material requirements were then prepared for the re-surfacing of Clark Memorial Bridge. The grading requirements for the combined aggregate was as follows:

Sieve Size	Percent Passing
No. 8	100
No. 16	85-100
No. 30	70-97
No. 50	40-63
No. 80	16-40
No. 100	10-30
No. 200	6-12

By the addition of mineral filler, this gradation requirement in most cases could be met by most of the crushed sands. The equal parts of bank and river sand could also meet this gradation requirement.

Stability tests were then run over the allowed range in gradation to insure that satisfactory mixtures would be obtained. Mixtures were fabricated of approximately equal portions of the bank and river sands, one meeting the lower limit and the other representing a median of the limits. These blends were tested at a constant asphalt content of 9 percent. Two, three and four percent portland cement filler was added to the median gradation. The results of this testing are presented in Table 6, Appendix II. The stabilities ranged from a low of 414 lbs. for the median gradation with 2 percent portland cement to a high of 553 lbs. for the median gradation with 3 percent portland cement. The percent voids in the mixture fell below 10 percent for the more densely graded lower limit and for the median gradation with 4 percent portland cement added.

Although the testing showed that the stability of most silica sand-asphalt mixtures increase with higher asphalt content up to 12 percent and in some cases even higher, an asphalt content of 9 percent was chosen for this project. As mentioned before, this asphalt content was chosen to provide 10 percent or more voids in the mixture for taking up asphalt used in tacking and for relief of hydrostatic pressure under auto tires. The specifications also provided that PAC-3 be used in the mixture, and a cutback made from PAC-3 was specified as tack. A high stability was desired due to the high traffic volume on the bridge. The specification also allowed the use of sands from single deposits, but it was not expected that such sands would be competitive with blends of river and bank sands in the Louisville area.

After the specification for Clark Memorial Bridge had been approved, but prior to letting of the contract, the Construction Division and the contractor became interested in substituting the silica sand-asphalt surface for Kentucky Rock Asphalt on the Ashland-Coal Grove Bridge. Samples of sands, believed suitable for blending in the same manner as planned for Clark Memorial Bridge, were obtained in the Ashland area. Sieve analysis of a fine bank sand obtained in Ohio and an Ohio River sand met the specified gradation requirement. Mixtures at an asphalt content of 9 percent were made with these sands in the following combinations: 60 percent river sand and 40 percent bank sand; 50 percent river sand and 50 percent bank sand; and, 50 percent river sand, 48 percent bank sand and 2 percent portland cement. The results of testing these combinations are shown in Table 7, Appendix II. The mixture consisting of 50 percent river sand, 48 percent bank sand and 2 percent portland cement was recommended for the project.

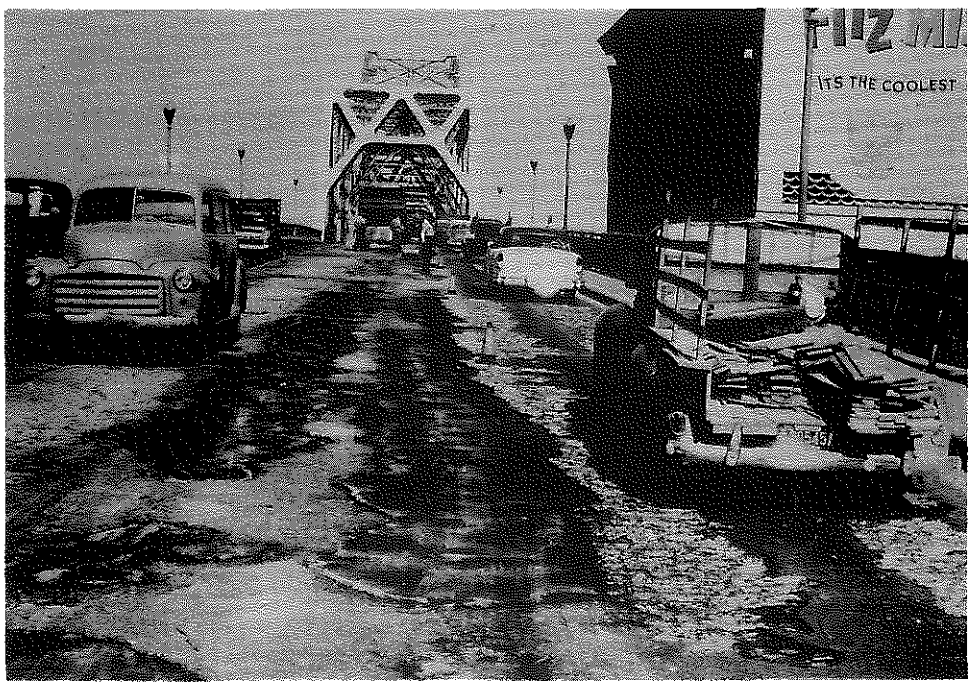
Observation of the Construction of the Test Sections

Clark Memorial Bridge. The deck of the Louisville Bridge consisted of reinforced concrete, 20 or more years old, showing rather severe damage from weathering and effects of de-icing salts. Old bituminous patches and unsound concrete were removed and repatched. The patching operation on Clark Memorial Bridge began October 8, 1958. The holes were tacked (primed) satisfactorily by placing the tacking material with a hand spray and spreading by means of a stiff broom. The mixture used for patching consisted of 50 percent medium river sand, 47 percent bank sand, and 3 percent portland cement at an asphalt content of 9 percent. A small roller was used to lightly compact the material in the patched areas, and further compaction was left to traffic (see Figs. 12 and 13). This left rough spots in the patched areas; and, to prevent the possible reflection of this roughness in the surface course, both approach ramps were machine patched full width by making the thinnest possible lay with the paver. This minimum thickness was approximately 1/8 in. (see Fig. 14).

Surfacing was started by steaking the tacking material on with the hand spray attachment and by tracking with truck wheels to gain uniform coverage. The paving mixture was prepared in a batch-type plant, laid by a Barber-Greene Paver, and compacted by a 10-ton, 2-wheel tandem roller (See Figs. 15 and 16).

The only difficulty encountered in control of the mixture was due to variation in the gradation of the bank sand. A sharp increase in the fineness of the bank sand necessitated a change in the ratio between the river and bank sand, from the 50-50 combination to a 60-40 combination, in order to stay within specifications for a portion of the project.

The only difficulty encountered in laying the material was a tendency of the material to pull under the screed. Most of the pulled places were corrected satisfactorily by roughing the pulled spot and adding material by hand. Several factors probably contributed to the pulling, among them being the fineness of the bank sand, coupled with the amount (50 percent) being used, and an incorrectly adjusted tamping bar on the paver. Variations in temperature of the mixture and in paving speed had little effect on the pulling. When the tamping bar was adjusted and the mixture change to 60 percent



Figs. 12 & 13. Clark Memorial Bridge, Views of Northbound Lanes of Louisville Approach Ramp after Removal of Old Patches. The top photo shows the extent of failure and the exposed steel. The bottom photo shows the same location after placing silica sand-asphalt patches in the inside lane.

Fig. 14. Clark Memorial Bridge, View after Machine Leveling. The thickness of the course is about 1/8 in. The streaks were caused by the screed dragging particles of crushed stone which were not cleaned from a truck bed.

Fig. 15. Clark Memorial Bridge, Appearance of Surface after One Pass of the Roller.

Fig. 16. Clark Memorial Bridge, View along Edge of New Course Showing Texture and Thickness.

river sand and 40 percent bank sand, the pulling was virtually eliminated, even though the portion of minus 200 material was higher than at any other time.

The material compresses very little when laid in thin courses. It cools very quickly and must be rolled immediately behind the paver in order to achieve compaction. Hand working of the material should be kept to a minimum. Material broadcast behind the paver will not roll smoothly into the machine laid course.

Ashland-Coal Grove Bridge. The Ashland bridge also had a concrete deck which had previously been re-surfaced with Class "I" bituminous concrete, slag aggregates; but the existing surface had been patched and was worn smooth.

Surfacing was laid on the Ashland-Coal Grove Bridge September 14, 1958, to a depth of 0.4 in., using the recommended 50 percent river sand, 48 percent bank sand, and 2 percent portland cement, and with PAC-3. No difficulty was encountered in proportioning, drying or mixing. The stockpiled sands for this project were very uniform with practically no variation throughout the stockpile. Portland cement mineral filler was added to each batch by hand; weighing and mixing were done in a Barber-Greene Batch-O-Matic plant.

The surface of this bridge required no patching. Tack was applied from the distributor spray bar and in spots appeared to be slightly heavy. The only difficulty encountered in laying was a slight amount of pulling under the screed and this occurred in only a few small isolated spots. Throwing back of the material was kept to a minimum since the surface left by the tamping bar and screed was very smooth and uniform. Rolling had to be done immediately back of the paver in order to achieve compaction. The finished product was a well-appearing, smooth, quiet riding surface.

V: CONCLUSIONS

The conclusions presented below apply specifically to the materials and combinations thereof utilized in this study and are based on the test data obtained as well as observations on the two test projects. It should not be implied that similar or superior results could not be obtained by the use of other materials or other methods of test.

(1) It is indicated that crushed sandstones when combined with manufactured asphalt cements, and in some cases with mineral filler, will provide surfacing materials with adequate stability.

(2) The stability of silica sand-asphalt mixtures may be improved by:

a. Using the optimum asphalt content for the particular sand,
b. Using harder grades of asphalt,
c. Adding mineral filler, and
d. Blending with other sands.

(3) It has been verified that the important characteristics of the sands which influence the stability of mixtures are:

a. the amount of natural filler material,
b. the angularity of the sand grains, and
c. the gradation of the particle sizes.

(4) It is indicated that the silica sand-asphalt mixtures will provide skid-resistance properties approaching those of Kentucky Rock Asphalt.

(5) Suitable silica sand-asphalt mixtures can be produced from blends of river and bank sand when combined in the proper proportions.

(6) Silica sand-asphalt mixtures offer no real problems in mixing and laying and the usual paving equipment can be used to lay these mixtures in thin courses.

VI: RECOMMENDATIONS

The following recommendations are made in consideration of the results of the laboratory testing of the various sands used in this study, and from the observations of the two projects described.

It is indicated that silica sand-asphalt mixtures offer no real problems in mixing and laying, and the usual paving equipment can be used to lay these mixtures in thin courses of less than 1/2 in. The following gradation limits are recommended in consideration of the gradations of the crushed sands used in testing:

Recommended Gradation Limits for Crushed Sands

Sieve	Percent Passing
No. 8	100
No. 16	82-100
No. 30	68-97
No. 50	33-92
No. 100	7-34
No. 200	2-12

Laboratory testing and field observations have indicated that blends of river and bank sands will provide satisfactory aggregate for silica sand-asphalt mixtures. Due to the variations which may be enounctered in the gradation of the bank sands and the roundness of the river sands, it is recommended the more rigid gradation requirements specified in the Special Provision for the silica sand-asphalt resurfacing of Clark Memorial Bridge be adhered to.

Any deficiency of filler material should be made up by the addition of limestone dust or portland cement conforming to the Kentucky Department of Highways' 1956 Standard Specifications, Article 7.1.2.

It is recommended that the asphalt content be 9 percent by weight of total mixture. Assuming that a portion of the tacking material will be taken up into the mixture, the total asphalt content after placing in a thin layer may be 10.5 percent or less, which will be less than the indicated optimum for sands conforming to the above gradation requirements. It is indicated mixtures containing sands conforming to the above requirements will provide a minimum of 10 percent air voids for the relief of hydrostatic pressures beneath vehicle tires and for taking up any excess tacking material. Mixtures conforming to the above requirements have adequate stability considering the fact that natural sandstone Rock asphalt has performed satisfactorily in many instances with much lower stabilities. A total filler content (minus 200 material) of about 7 percent by weight of the aggregate should be sufficient to provide a minimum stability of approximately 300 lbs. for mixtures conforming to the above gradation and asphalt contents.

A fairly rapid hardening of the asphalt is to be expected due to the high void contents of the sand-asphalts, and it is recommended for ordinary roadway paving that the asphalt be of 85-100 penetration grade. When the silica sand-asphalts are to be exposed to high traffic volumes and severe braking conditions, the stability of the mixtures should be improved by use of harder grades of asphalt and/ or by the addition of mineral filler.

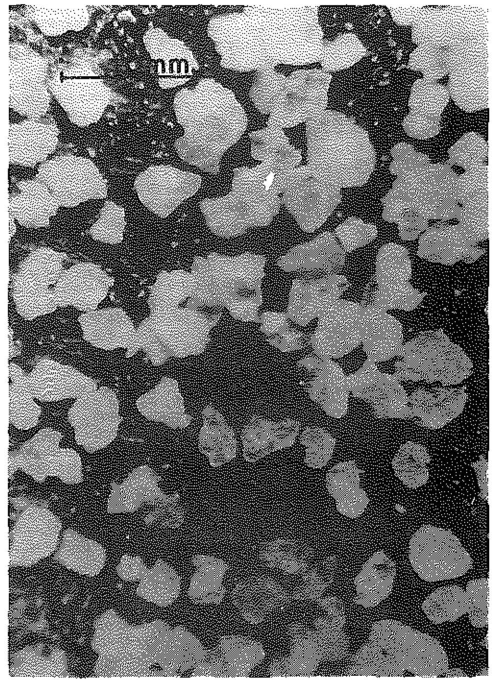
Tack is very important and should have uniform and thorough coverage. Tack shall be applied at a rate so that the total asphalt content (per cent asphalt in mix plus the percent asphalt in the tack) shall be 10.5 percent or less. When severe traffic or braking conditions are anticipated, a harder grade of asphalt may be used when cut-back with a suitable distillate to meet the viscosity requirement for a RC-2.

Throwing-back and hand-working of the mixture should be kept to a minimum as the material cools very quickly and will not "knit" as normal asphaltic concrete mixtures laid in thicker courses. Rolling must be done immediately back of the paver in order to achieve compaction.

APPENDIX I

PHOTOMICROGRAPHS OF TEST SANDS

Kentucky Rock (K)

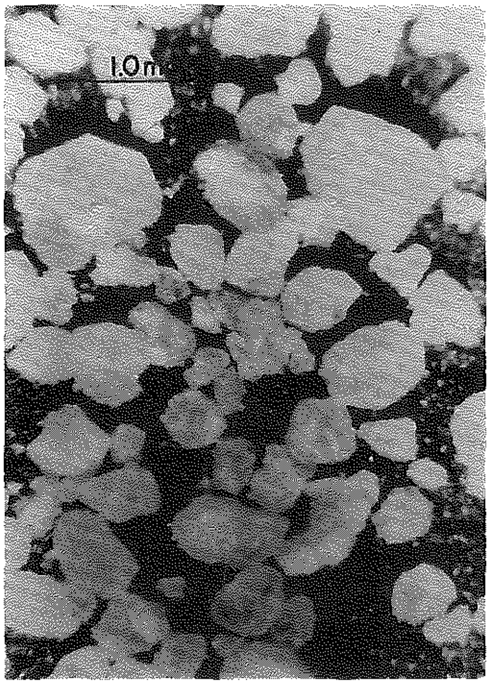


Eastview (E)

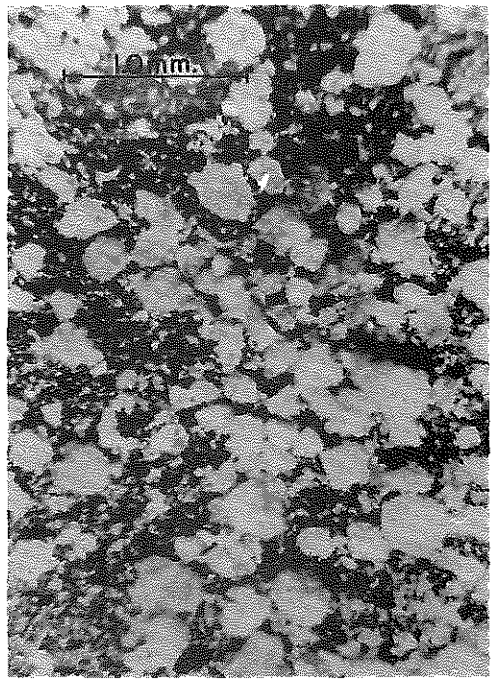
Salyersville (S)

Webbville (W)

Fig. 17. Photomicrographs of Test Sands.



Polly (P)

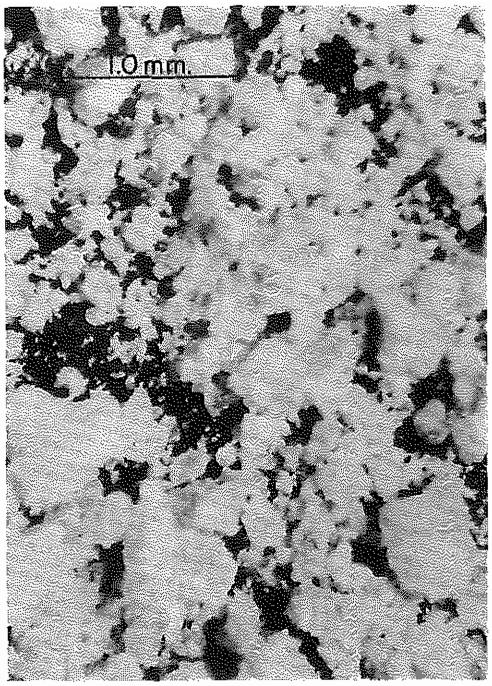


Dobbins (D)

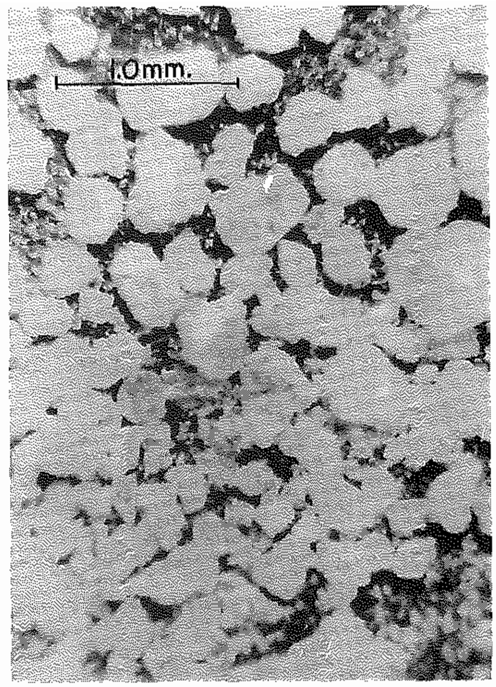
Drakesboro (A)

Corbin (C)

Fig. 17. Continued

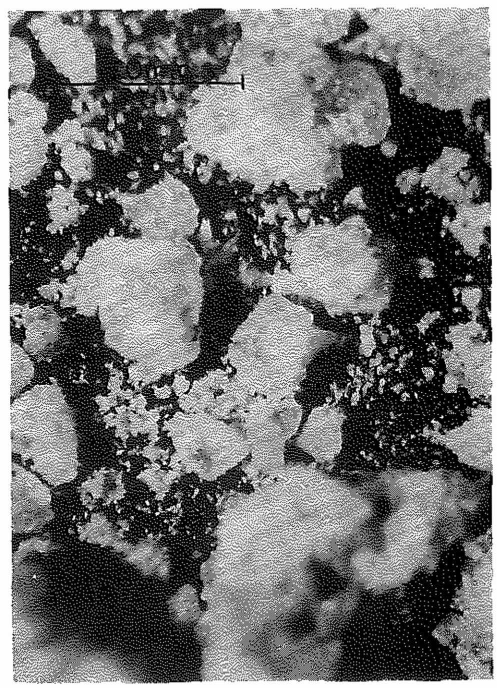


Olive Hill (O)



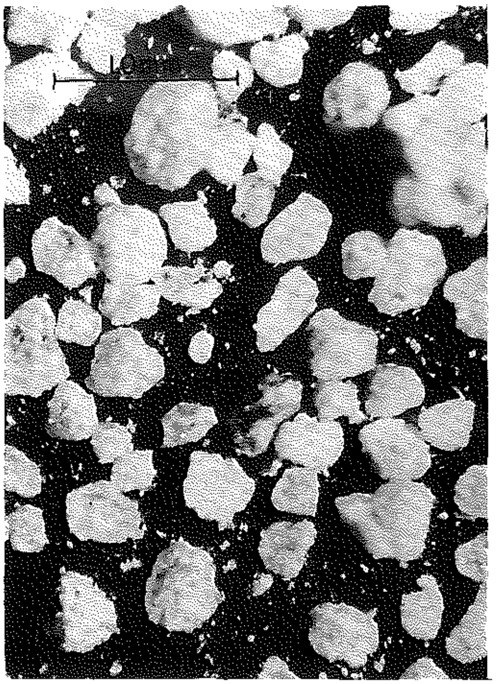
Pearl Brownhill (B)

Big Clifty (H)

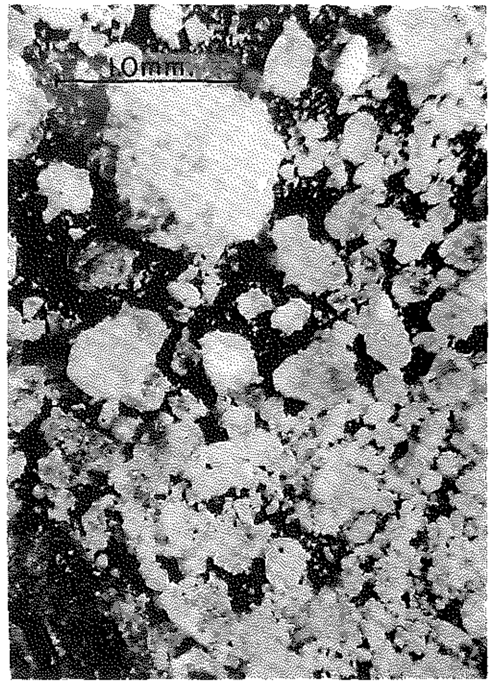


Central City (T)

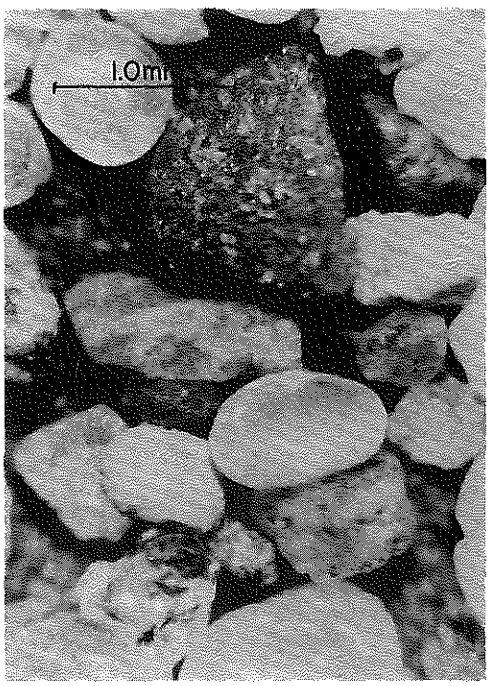
Fig. 17. Continued



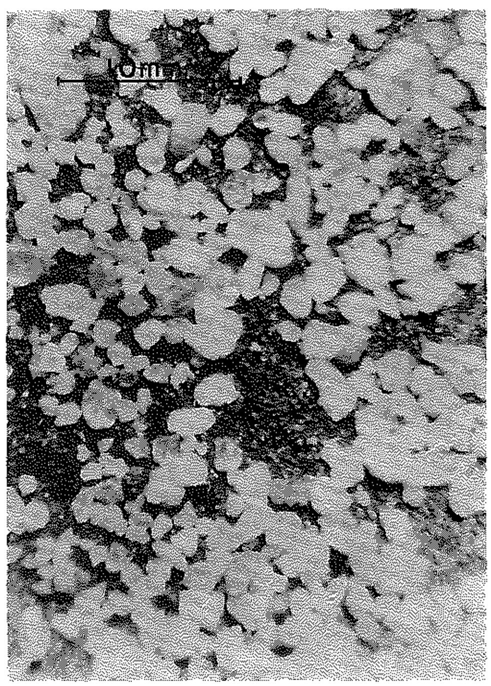
Green (F)



Stephensburg (U)



River Sand



Bank Sand

Fig. 17. Continued

APPENDIX II

TABULATION OF TEST RESULTS

TABLE 2

RESULTS OF MARSHALL TEST ON CRUSHED SANDSTONE MIXTURES

Aggregate	Asphalt Content	Asphalt Testing		Marshall Stability Test Data			Percent Voids		
		Penetration at 77°F	Softening Point in °F	Stability	Flow	Unit Weight	Aggregate Only	Filled with Asphalt	Total Mix
Eastview	9	60	126.0	128	10.5	112.9	38.3	42.5	22.0
	10			121	8.5	116.7	36.9	50.7	18.2
	11			195	9.5	116.5	37.8	54.3	17.3
	12			220	10.0	117.5	37.9	59.5	15.4
Ky. Rock	9	60	126.0	135	7.0	120.0	35.3	49.0	18.0
	10			146	7.0	121.0	35.2	56.0	16.0
	11			172	8.5	121.0	35.8	60.0	14.5
	12			247	9.0	124.0	35.3	67.0	12.0
Big Clifty	9	65	126.0	265	9.7	120.6	33.8	51.5	16.4
	10			277	9.7	120.8	34.5	56.2	15.1
	11			331	10.3	121.4	34.8	61.5	13.4
	12			367	11.0	122.6	35.0	67.4	11.4
Corbin	9	60	126.0	468	13.5	119.2	34.5	49.9	17.3
	10			299	12.8	121.2	34.2	56.9	14.8
	11			395	13.0	121.6	34.9	61.5	13.4
	12			538	15.0	123.1	34.8	68.1	11.1
Polly	9	60	126.0	429	8.5	124.0	31.8	56.2	14.0
	10			394	10.3	128.4	30.3	67.9	9.8
	11			668	11.8	127.7	31.4	71.8	8.9
	12			719	12.8	128.3	32.0	77.0	7.4
Green	9	65	126.0	570	11.7	119.9	34.7	49.8	17.4
	10			566	10.6	122.8	33.9	58.1	14.2
	11			638	12.2	124.2	33.9	64.6	12.0
	12			742	13.0	126.6	33.3	73.0	9.0
Pearl Brownhill	9	60	126.0	582	9.8	119.8	34.4	50.2	17.1
	10			625	7.8	121.9	34.1	57.4	14.8
	11			597	9.0	124.3	33.5	65.6	11.5
	12			757	10.8	126.2	33.2	72.2	8.9
Central City	9	65	126.0	902	12.7	124.2	31.5	55.3	14.1
	10			982	13.0	127.5	30.9	66.1	10.5
	11			935	14.3	129.7	30.6	74.8	7.7
	12			98[illegible]	15.3	130.8	30.7	81.9	5.6
Stephensburg	9	65	126.0	854	10.2	127.4	30.2	60.9	11.8
	10			1138	10.8	132.0	28.6	74.1	7.4
	11			1107	11.2	133.5	28.5	82.5	5.0
	12			933	18.0	130.4	31.0	81.0	5.9
Dobbins	9	60	126.0	1199	12.9	121.4	34.0	51.6	16.5
	10			1300	12.8	123.2	33.9	58.4	14.1
	11			1368	10.3	123.7	34.5	63.3	12.7
	12			1513	11.5	126.2	34.0	71.5	10.0
Drakesboro	9	69	130.1	1077	10.7	120.9	33.6	51.9	16.2
	10			1327	11.5	125.2	35.0	62.6	12.0
	11			1228	11.3	126.1	32.4	68.6	10.2
	12			1143	12.7	128.1	32.2	76.7	7.5
Webbville	9	60	126.0	1294	9.5	123.4	32.6	56.5	14.8
	10			1419	11.5	126.2	31.9	63.5	11.7
	11			1701	12.0	128.7	31.4	72.3	8.2
	12			1754	16.5	129.5	31.4	79.4	6.5
Olive Hill	9	65	126.0	1543	9.5	126.5	30.5	59.7	12.3
	10			1506	11.5	125.0	32.0	62.5	12.0
	11			1550	11.2	126.3	32.2	72.7	8.5
	12			1524	16.7	132.1	29.8	85.2	4.4
Salyersville	9	60	126.0	1097	10.5	126.5	31.6	57.8	13.4
	10			1517	10.1	128.5	31.0	66.4	10.4
	11			1573	12.5	130.7	30.5	75.7	7.7
	12			1585	15.5	130.3	31.9	78.6	6.8

TABLE 3

COMPARISON OF VOIDS IN AGGREGATE BY MARSHALL AND DRY COMPACTION

Sand	Percent Voids in Aggregate				
	Dry Compaction	Marshall Compaction Asphalt Content (%)			
		9	10	11	12
Olive Hill	34.0	30.5	32.0	32.2	29.8
Corbin	35.2	34.5	34.2	34.9	34.8
Dobbins	35.2	34.0	33.9	34.5	34.0
Pearl Brownhill	35.9	34.4	34.1	33.5	33.2
Eastview	40.6	38.3	36.9	37.8	37.9
Webbville	32.7	32.6	31.9	31.4	31.4
Salyersville	32.8	31.6	31.0	30.5	31.9
Drakesboro	36.9	33.6	35.0	32.4	32.2
Kentucky Rock	36.0	35.3	35.2	35.8	35.3
Polly	32.1	31.8	30.3	31.4	31.9
Central City	35.9	31.5	30.9	30.6	30.7
Green	37.8	34.7	33.9	33.9	33.3
Big Clifty	38.4	33.8	34.5	34.8	35.0
Stephensburg	28.6	30.2	28.6	28.5	31.0

TABLE 4

RESULTS OF THE INFLUENCE OF HARDNESS OF BINDER ON STABILITY

Specimens Prepared With Polly Sand and Tested at Lower Temperatures*

Asphalt Grade	Penetration at 77°F	Softening Point (°F)	Testing Temp. (°F)	Stability (Lb.)	Flow (1/100 In.)	Unit Weight (Lb./Cu. Ft.)	Percent Voids Agg. Only	Percent Voids Filled Asphalt	Percent Voids Total Mix
PAC-1	41	132	32	22200	19.3	127.1	31.3	68.7	9.9
PAC-2	52	126	32	23275	20.3	125.4	32.2	65.5	11.1
PAC-3	60	126	32	21873	17.3	126.0	31.9	66.5	10.7
PAC-4	70	122	32	21670	19.6	126.0	31.9	66.5	10.7
PAC-5	85	118	32	20642	18.4	129.3	30.2	72.3	8.4
PAC-1	41	132	77	5900	14.8	125.7	32.1	66.0	10.9
PAC-2	52	126	77	4612	20.5	126.7	31.6	67.6	10.3
PAC-3	60	126	77	4949	15.0	124.7	32.6	64.2	11.7
PAC-4	70	122	77	4628	11.5	126.1	31.9	66.6	10.7
PAC-5	85	118	77	3644	11.0	129.0	30.3	71.7	8.6
PAC-1	41	132	140	504	11.3	125.0	32.5	64.8	11.5
PAC-2	52	126	140	526	11.3	127.9	30.9	69.7	9.4
PAC-3	60	126	140	469	7.4	126.4	31.7	67.1	10.5
PAC-4	70	122	140	338	6.5	126.4	31.8	67.0	10.5
PAC-5	85	118	140	340	8.1	128.7	30.5	71.2	8.8

*Constant asphalt content of 10.5%

Specimens Prepared With Kentucky Rock Sand and Tested at 140°F

Asphalt Grade	Penetration at 77°F	Softening Point (°F)	Asphalt Content (Percent)	Stability (Lb.)	Flow (1/100 In.)	Unit Weight (Lb./Cu. Ft.)	Percent Voids Agg. Only	Percent Voids Filled Asphalt	Percent Voids Total Mix
PAC-1	41	132		338	9.0	118.2	35.0	48.7	18.0
PAC-2	52	126		590	11.0	119.7	34.2	50.6	16.9
PAC-3	60	126	9	134	7.0	120.0	34.3	50.4	17.0
PAC-4	70	122		127	11.0	121.2	33.4	52.4	16.0
PAC-5	85	118		111	8.5	121.0	33.7	51.6	16.3
PAC-1	41	132		318	9.0	121.5	34.1	57.2	14.6
PAC-2	52	126		370	7.0	121.4	34.1	57.0	14.7
PAC-3	60	126	10	146	7.0	121.0	34.3	56.5	14.9
PAC-4	70	122		147	9.3	122.2	33.7	58.1	14.1
PAC-5	85	118		142	8.0	123.0	33.6	58.3	14.0
PAC-1	41	132		366	9.5	124.3	33.0	66.6	11.1
PAC-2	52	126		301	7.0	122.5	34.0	63.6	12.4
PAC-3	60	126	11	172	8.5	121.0	34.9	61.0	13.5
PAC-4	70	122		205	9.0	123.1	33.7	64.5	11.9
PAC-5	85	118		177	9.0	124.0	33.2	65.8	11.4
PAC-1	41	132		328	9.5	126.5	32.6	74.7	8.3
PAC-2	52	126		406	9.0	124.7	33.6	71.4	9.6
PAC-3	60	126	12	247	9.0	124.0	34.1	69.8	10.3
PAC-4	70	122		341	11.3	124.8	33.5	71.7	9.5
PAC-5	85	118		336	11.0	126.0	33.2	72.4	9.2

TABLE 5

COEFFICIENT OF FRICTION VALUES FOR WET SURFACES

Specimen	Coefficient 20 psi	Coefficient 25 psi
Corbin	0.37	0.46
Kentucky Rock	0.46	0.51
Salyersville	0.54	0.58
Webbville	0.50	0.55
Dobbins	0.47	0.52
Eastview	0.36	0.40
Polly	0.43	0.52
Pearl Brownhill	0.45	0.51
Drakesboro	0.51	0.54
Central City	0.55	0.57
Green	0.53	0.56
Big Clifty	0.55	0.59
Stephensburg	0.56	0.62
Olive Hill	0.52	0.54
Ashland*	0.56	0.62
Louisville**	0.56	0.64

Note: All specimens were prepared at an asphalt content of 8 percent and tested at 180 rpm.

* Sample of material placed on Ashland-Coal Grove Bridge, asphalt content 9 percent.

** Sample of material placed on Clark Memorial Bridge, asphalt content 9 percent.

TABLE 6

MARSHALL TEST RESULTS FOR LOUISVILLE SAND BLENDS

Asphalt Content (Percent)	Aggregate Blend	Penetration Asphalt at 77°F	Stability (Lb.)	Flow (1/100 In.)	Unit Weight (Lb./Cu. Ft.)	Percent Voids Agg. Only	Percent Voids Filled Asphalt	Percent Voids Total Mix
7	100% River sand	69	131	6.3	122.7	32.5	42.7	18.7
8			124	6.6	123.8	32.9	48.3	17.0
9			162	6.0	123.2	32.4	52.7	15.9
10			177	7.2	126.5	32.9	61.6	12.6
9	100% Bank sand	69	238	5.5	117.8	36.2	47.0	19.2
10			228	6.8	119.2	36.2	52.8	17.1
11			223	7.2	119.3	36.8	57.1	15.8
12			327	7.0	122.8	35.7	66.3	12.1
9	50% River sand, 46% Bank sand, 4% Limestone filler	69	414	4.3	133.7	27.8	69.4	8.5
10			508	6.0	130.9	30.2	69.6	9.2
11			678	13.8	134.5	28.9	82.1	5.2
9	50% River sand, 47.5% Bank sand, 2.5% Portland cement	69	465	6.0	131.3	29.3	64.7	10.4
10			568	8.0	131.5	30.1	70.1	9.0
11			605	11.8	132.1	30.4	76.6	7.2
9	*50% River sand, 50% Bank sand	69	496	6.8	132.4	28.5	67.0	9.4
	**50% River sand, 50% Bank sand							
9	+ 2% Portland cement	69	414	8.3	129.1	30.5	61.1	11.9
9	+ 3% Portland cement		553	8.1	130.8	29.7	63.6	10.8
9	+ 4% Portland cement		473	7.6	132.5	28.8	66.4	9.7

* The aggregate is graded to meet lower limit of specification.
** The aggregate is graded to meet median gradation of specification.

TABLE 7

MARSHALL TEST RESULTS FOR ASHLAND SAND BLENDS

Asphalt Content (Percent)	Aggregate Blend	Penetration Asphalt at 77°F	Stability (Lb.)	Flow (1/100 In.)	Unit Weight (Lb./Cu. Ft.)	Percent Voids Agg. Only	Percent Voids Filled Asphalt	Percent Voids Total Mix
9	50% River sand, 50% Bank sand	65	346	9.8	126.7	30.8	59.4	12.5
10			410	10.7	127.2	31.2	65.4	10.8
11			450	11.0	129.9	30.6	74.8	7.7
9	60% River sand, 40% Bank sand	65	330	10.5	126.2	31.0	58.7	12.8
9	50% River sand, 48% Bank sand, 2% Portland cement	65	432	10.2	126.8	30.9	59.7	12.6
11			594	15.0	129.6	30.9	73.8	8.1

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