Aggregate Shape and Skid Resistance

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Natural sands and sands manufactured by crushing larger parent materials are characterized and service tested. Singular attributes are usually confounded with other variables in service tests. Dry-bulking tests and photomicrography are used to established qualities. High-stability porous mixtures are achieved in laboratory tests. Crushing some materials to coarse chip sizes leaves many smooth facets on particles that then tend to become oriented horizontally in the pavement surface. Open-graded friction courses and sprinkle treatments are included. Damage by winter freezing of porous courses is illustrated.

Sand asphalt
Crushed sand
Bulking
Mixture design
Skid resistance

Open gradings
AGGREGATE SHAPE AND SKID RESISTANCE

by

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in cooperation with the
Kentucky Department of Transportation
and the
U. S. Department of Transportation
Federal Highway Administration

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January 1982
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INTRODUCTION

This report presents developments and advances toward greater surety in the design of skid-resistant pavements. A report of October 1970 and a commentary issued February 1971 declared sand-asphalt surfaces, as then developed and evaluated, inadequate and not fully qualified for operational status as a highly skid-resistant surfacing material. Specific recommendations concerning corrective actions were promised. The intent was to proceed expeditiously to meet that goal. The compelling objective was to eliminate intolerable degrees of slipperiness and to further provide due margins of safety.

Proof testing — that is, field testing — was necessary necessary to carry the plan forward. It seemed that only sands prepared by crushing larger parent material would meet requirements of angularity and sharpness. A few sands in production could qualify; other suppliers could produce qualifying sands by installing crushing and sizing equipment. The study remained in suspense until new sand-asphalt surfaces could be service-tested on the road. Immediate implementation of the proposed special provision in at least a few major resurfacing projects was urged. Unless performance was demonstrated and unless sand-asphalt thereby became qualified for a high order of service, emphasis on highway safety and skid resistance would have made it compelling to resort to coarse-textured, knobby (possibly imported crushed granite and other foreign aggregates) surface courses. It was contended that sand-type surface could be designed and constructed to provide sufficient internal drainage to minimize hydroplaning. Surface drainage or runoff rate remained an important factor. Knobby textures had the apparent advantage of compensating somewhat for poor surface runoff. Knobiness was to be avoided because of drumming of tires (noise) and because of hysteresis heating of tread rubber. Aggregate particles large enough to induce knobiness would be lethal if loosened and tossed and flung by traffic...

The original conception of this study embraced only sand-asphalt-type or other fine-textured surface courses. Central Kentucky is limestone country, and Eastern and Western Kentucky are largely on sandstones. Rockcastle conglomerates, Caseyville gravels, and the Buffalo conglomerate are likely sources of quartz gravels and sands. Cherts are abundant in the Purchase area; chert gravel occurs in the Ohio River west of Louisville. Carbonate gravels and some quartz sands occur in glacial outwash beds (banks and terraces) along the Ohio near Louisville and upstream. Fine sands occur in the Kentucky River Channel. Varieties of sand occur in valley fills almost everywhere. Use of locally indigenous aggregates has obvious merits. Silica and (or) quartz gravels and sands seemed to offer the greatest opportunity to achieve an abrasive renewing-type surface, dense and durable or having degrees of porosity — especially modeled after Kentucky rock asphalt (much respected for its skid resistance).

Several sands were studied, and various sand-asphalt mixtures were designed. Approximately 30 surfacing projects were envisioned for each type of sand and mixture to satisfy statistical requirements. Those projects were beginning to accumulate when open-graded plantmix seals (so-called friction courses) emerged and superseded the program (mandated by the Federal Highway Administration, Regional Administrator and Division Administrator). Thereafter, sand-asphalts were not allowed on any road having a speed limit greater than 45 mph. Statistical experiments for sand-asphalts could not be completed as planned.

To demonstrate performance of sands (from the standpoint of hardness and sharpness), it was necessary to keep the sands pure (in as many as 30 projects). Some did not understand the necessity for experimental design; others violated the plan to claim immediate economy. Thus, sands were blended (corrupted) with limestone. Specifications were changed from time to time, and continuity of name and composition was lost. Too many variables were admitted.

It was planned to monitor the skid resistance of each surface for five years or to five million vehicle passes. Only a few projects survived as planned.

A measure of success was achieved by crushing quartz gravel (Caseyville) from near Jonesville (Pikeview). Vast deposits occur near Kyrock in Edmonson County. A sand-asphalt so constructed on US 31-W, Muldraugh Hill, proved to be safe, serviceable, and attractive. The hill section was overlaid somewhat prematurely. From Tip Top to the US 60 exit, west, remains in service.

Several sands were sized and photographed. Sands made of expanded shale (crushed) were vesicular, sharp, and seemed ideally attributed. Two projects turned sour; they scaled and wore off — due to saturation and freezing (not enough asphalt). A sand-asphalt on South Limestone in Lexington and an open-graded seal on Whipp's Mill Road in Louisville were catastrophic. Incomplete drying of the aggregate before mixing was a probable cause; porosity of the surface was a major cause. Porosity of the surface mixture is favorable to skid resistance and relieves hydroplaning; porosity is detrimental to resistance to saturation and freezing.

An experimental project consisting of five sand-asphalt sections, 2 miles each on US 27 north of Somerset (1968), was spoiled by District crews placing
limestone chips at the edge of the pavement. So much limestone was scattered onto the surface and became imbedded that performance of the sands was hopelessly obscured.

The Goldbeck bulking test (1) proved to be a very effective measure of angularity of sands and a quality-control measure.

SAND-ASPHALT DEVELOPMENT

The first skid tests in Kentucky were made in 1953 (2). Comparisons at that time were made among Class I, Type B (limestone), Kentucky rock asphalt, and sandstone surfaces (then experimental). Limestone surfaces were found to be quite slippery. Rock asphalt had always been praiseworthy for its skid resistance; other problems besetting that material have not been completely resolved. Eastern Kentucky sandstones appeared to have good skid-resistance qualities; and for a few years, sandstone was listed as an alternate to limestone in some asphalt resurfacing (3). Limestones yet prevail as the predominate surfacing aggregate. Normal asphaltic concrete (Class I, Type A and Type B) surface courses, though fortified with natural sands, did not provide the desired assurances against slipperiness.

In the latter 1950's, the Department undertook the development of a more generic and inclusive surfacing mixture, sand asphalt (4, 5, 6). Full reliance for skid resistance was given to hardness, sharpness, and angularity of quartz sand, a recognizable and specific attribute of rock-asphalt and sandstone aggregates excelling in skid resistance. The surface course (nominally 0.5 inch) was regarded as sacrificial but renewable. At the outset, it seemed important to demonstrate stability and permanence. Blends of quartz sand with crushed limestone were admitted. At that time, there was persuasive evidence that some limestone in sand-sizes would not affect skid resistance significantly if the wear rate was satisfactory. Unfortunately, it appeared later that such a balance is unachievable. Some trials based on such premises proved to be inferior in skid resistance to normal asphaltic concrete surfaces containing limestone coarse aggregate. The study (7) of the skid-resistant attributes of sands indicated that the term "natural sand" and its definition given in Section 611 of the 1965 Standard Specifications ... (8) permitted but did not assure skid-resistant materials. The term "natural sand" excluded the very sands sought - that is, sands produced by crushing quartz gravels and other hard parent materials. Certain reforms were needed. Sands should be selected in terms of mineral composition, gradation, and particle shape. Limestone sands cannot be admitted - except possibly as fine mineral filler (maximum of 10 percent). Sands containing considerable proportions of carbonates would not qualify as skid-resistant materials. Some other deposits consisting predominately of quartz would not qualify if the particles were rounded or polished.

Special Provision No. 22-A (Sand-Asphalt Surface), 1967, only limited the non-quartz (SiO₂ fraction to less than 50 percent. No shape was specified. Crushed, oversized siliceous materials from conglomerate deposits were admitted.

An attempt was made in the 1970 report to define skid-resistant fine aggregate for all uses. Uncertainties in the existing definition of natural sands should not have been continued. The proposed text follows:

Skid-resistant fine aggregate for surface courses and surface treatments, when specified, shall consist of mineral quartz particles, or other materials of equal or greater hardness, which have sufficient angularity in shape and (or) roughness of texture to assure maximum tire-pavement tractive frictional resistance when wet. Fine aggregates qualifying as mineral quartz shall contain at least 90% quartz particles by visual count or 94% SiO₂ by chemical analyses. Particle shape and texture shall be evaluated visually (magnified as necessary) and in comparison to reference materials having a proven performance history. Materials produced by crushing quartz sandstones, quartz pebbles, or quartz gravels may qualify separately as fine aggregate or as blending fractions. The percentages of rounded or adversely-shaped particles in the final product shall not exceed 15%. Products of other compositions, natural or synthetic, shall be subject to pre-qualification as an equivalent alternate hereto in advance of bidding. Pre-qualification, here, means prior approval of the Engineer.

Desired particle shape was readily discernible visually (with magnification) but was not easily describable in specification terms. Until then, the only controls specified had been the insoluble residue test (mineral composition) and gradation. Prior to that, there was no test by which the shape of fine-aggregate particles could be defined.

SHAPE OF SAND

Shape and texture qualities sought in sands for sand asphalts are converse to those sought for portland cement concrete and mortar sands. River sands, glacial sands, especially glacial outwash sands, and beach and blow sands tend to be rounded, frosted, and polished. Many sandstones and conglomerates yield sharp angular sands. Crushed, manufactured, non-car-
bonate sands, altogether or blended with qualifying natural sand fractions may provide opportunities to utilize local resources and indigenous material to achieve skid-resistant pavement surfaces. Controlled wear and attrition are essential. The surface, therefore, becomes sacrificial but renewable.

Sands occur in great abundance in many localities throughout the country. Not all sands are skid resistant. Shape and texture of particles are important attributes. Shape is discernible macro- and microscopically. The Goldbeck (1) bulking test is an empirical measure of order, or conversely a measure of disorder, of shape.

A cubic packing of uniform spheres, Figure 1, regardless of size, contains 47.6 percent voids. Ordinarily packing, shown in Figure 2, yields 26.1 percent voids. The smaller spheres (0.732 D) contribute 20.5 percent of the volume of the solids. In Figure 3, a small sphere occupies the interstice in the rhombohedral arrangement. It contributes 5.3 percent to the solid volume. The rhombohedral or dense packing contains 26.0 percent voids. Although the isolation of a standard sieve size of material provides a mixture of sizes in which the smallest particles are half the diameter of the largest, there is a high probability that a random arrangement and distribution of spherical particles in the size range will yield about 41 percent voids. Goldbeck suggested a test in which excess bulking was to be avoided to assure good concrete-making qualities of fine aggregates. He suggested an upper limit of 47 percent. Kentucky has used that type of requirement in its specification for crushed limestone fine aggregate for concrete for several years. Clearly, a size fraction yielding 50 percent or more voids indicates greater disorder in shape and (or) texture (9-27). Compare figures 4 and 5 and Figures 6 and 7.

TEST PROCEDURE

Photomicrographs were taken of approximately 30 Kentucky sands, many of which have been used in bituminous concrete and sand-asphalt surfaces. Rounded and non-angular particles were found in large proportions, particularly in the coarse fractions of many sands. In general, river and terrace sands have unfavorable shapes. Sands produced from crushing conglomerates, Kentucky rock asphalt, and lightweight synthetic (expanded shale) aggregate yielded sharpness and angularity. Photographs and descriptions of the sands are in Figure 8 and Table 1, respectively.

Sands were visually arrayed according to shape; i.e., grading from angular to round. The sands were grouped into four categories: angular, subangular, subround, and round. Representative sands were chosen from each category, and dry-bulking tests were conducted in accordance with the procedure outlined in Special Provision No. 66-B, Manufactured (Crushed) Limestone Fine Aggregate for Portland Cement Concrete (March 1971). There, roundness was a preferred attribute. Six samples were washed and dried thoroughly and separated into four sizes. The testing procedure is described in Appendix A.

Four repeat determinations were made on each size of each sand. The average constituted a test value. A percentage voids was calculated for each size as outlined in the test procedure. Average percentage voids for the four sizes were also calculated for each sand. Percentage voids for each sand size, along with average voids for each sand, in order of increasing roundness, were plotted. Pictorial arrays of the sands were superimposed on percentage voids plots as shown in Figure 9. As relative roundness based on visual analysis increased (left-to-right), the percent voids as calculated from the dry-bulking test decreased. Conversely, increasing voids are accompanied by noticeable increases in angularity and sharpness of sand particles (28-30). Based on past performances of selected sands and judging the shape of the aggregates from photographs, it was concluded that 50 percent voids or greater would be required to insure that a given aggregate would be sufficiently angular to perform satisfactorily from a skid-resistance standpoint.

The test is subject to some error when the aggregate is highly vesicular. Errors arise from an inherent inability to determine the true oven-dry bulk specific gravity.

The bulk specific gravity of slag larger than the No.-4 sieve may be about 2.20. Fine slag sand passing the No.-30 or No.-50 sieve may exceed 3.00. Expanded shale fines may range between 2.59 and 2.84. Quartz grains approach 2.64. All cellular aggregates approach zero percent absorption as size diminishes. Specific gravity of powdered material is equivalent to that of a voidless mass.

A magnifying lens of 5x to 20x power is helpful to the examiner and controller of sands.

The proposed specification for a skid-resistant sand-asphalt surface was reported previously (30). It was recommended that the proposed specification replace Special Provision No. 22-A (Sand-Asphalt Surface). The changes in 22-A follow:

1. PAC-3 was designated as the asphalt cement grade. This would increase stability of the mix.
2. The minimum quartz content of the sand was increased from 50 percent to 90 percent by visual count or 94 percent by chemical analysis. This would exclude soft aggregates.
3. The maximum amount of mineral filler in the aggregate combination was decreased from five
Figure 1. Simple Cubic Packing Spheres; Ball Occupies 52.4 Percent of Volume of Box.

Figure 2. Arrangement of Spheres in a Cube.
Figure 3. Rhombohedral Packing of Spheres; Large Spheres Occupy 74.0 Percent of the Volume; the Small Spheres Occupy 5.3 Percent of the Volume.

Figure 4. Angular Particles; More Fine Particles Needed to Achieve High Density.

Figure 5. Rounded Particles; Fewer Fine Particles Needed to Achieve High Density
Figure 6. Rockcastle Conglomerate (Crushed); Mullins Station, Sinks near Livingston; Kentucky Stone Co.; 1959.

Figure 7. Ohio River Sand; Many Particles Are Rounded and Polished.
Figure 8. Photomicrographs of Size-Fractions of Various Sands.
Figure 8. Photomicrographs of Size-Fractions of Various Sands (Continued).
Figure 8. Photomicrographs of Size-Fractions of Various Sands (Continued).
Figure 8. Photomicrographs of Size-Fractions of Various Sands (Continued).
Figure 8. Photomicrographs of Size-Fractions of Various Sands (Continued).
Figure 8. Photomicrographs of Size-Fractions of Various Sands (Continued).

MINUS NO. 16 SIEVE SIZE CONT'D

SCALE: 20 DIV. X 1 INCH
Figure 8. Photomicrographs of Size-Fractions of Various Sands (Continued)
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<tr>
<th>TABLE 1. IDENTIFICATION, SOURCE, AND USES OF VARIOUS SANDS</th>
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</table>
Figure 9A. Bulking Value of Sands Associated with Particle Shape; No. 4.

- CRUSHED SANDSTONE UNCRUSHED SAND FRACTION CONGLOMERATE OF CONGLOMERATE (Caseyville)
- KENLITE JENKINS GREEN RIVER
- OHIO RIVER (Carrollton) OHIO RIVER (Pawling)
- INDUSTRIAL GLASS BEADS

Dry-bulking test

Percent voids

40 45 50 55 60 65

Expanded shale

Crushed sandstone

Conglomerate

Uncrushed sand fraction

Conglomerate of conglomerate

Average 4.80 sieve

Averaat 4.90 sieve
Figure 9(B). Bulking Value of Sands Associated Visually with Particle Shape; No. -8 to No. to No.-16 Sieve Sizes.
Figure 9(C). Bulking Value of Sands Associated Visually with Particle Shape; No. -16 to No. -30 Sieve Sizes.
Figure 9(D). Bulking Value of Sands Associated with Particle Shape; No. -30 to No. -50 Sieve Sizes.
percent to four percent, and it shall only be used when required to meet the composition limits passing the No. 200 sieve. Composition limits were changed as noted below.

4. Sand-equivalent and deleterious substances requirements were deleted. With the high quartz requirement, these are not needed.

5. A particle-shape requirement was added, this being a minimum of 50 percent voids in the aggregate as determined by the dry-bulking test. This was necessitated by the fact that rounded and sub-rounded sands were not providing necessary traction. Only sharp angular sands will meet that requirement.

6. Aggregate gradation limits were changed. More No.-8 and No.-16 and less No.-200 material were admitted as indicated below:

<table>
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<tr>
<th>SIEVE</th>
<th>PERCENT PASSING</th>
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<tr>
<td>100</td>
<td>100</td>
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<tr>
<td>No. 8</td>
<td>88-100</td>
</tr>
<tr>
<td>No. 16</td>
<td>70-95</td>
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<tr>
<td>No. 30</td>
<td>50-90</td>
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<tr>
<td>No. 100</td>
<td>5-20</td>
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<td>No. 200</td>
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**DESIGN OF SAND-ASPHALT MIXTURES**

It was recommended that 50-percent voids (later 52 percent) as determined by the dry-bulking test be taken as the lower limit. This requirement would, in essence, rule out all uncrushed river, terrace, and pit sands. Those materials had normally not proven to be skid resistant. Materials meeting requirements of this specification would be hard, angular, and siliceous. Specifications for skid-resistant sand-asphalt surfaces and skid-resistant Class I, Type A, Modified bituminous surfaces containing lightweight aggregates were proposed but not implemented.

Attached as APPENDIX B is a proposed specification for a skid-resistant Class I, Type A, Modified bituminous surface containing lightweight aggregate. Several hundred lane-miles of bituminous mixtures similar to that described in this specification have been placed in Texas and other states during recent years. Performance records indicate that they possess excellent non-skid properties for the life of the surface together with outstanding resistance against stability failures.

Lightweight aggregates in this specification are typified by ASTM C 330. The cellular structure imparts a micro-texture to the aggregate surface.

Normal guidelines and design criteria for determining the optimum combination and gradation of aggregates and optimum percentages of asphalt are based on unit weights (weight per unit volume) of typical or natural aggregates. These established weight-volume relationships are distorted somewhat when lightweight aggregates are substituted for a portion of the natural aggregates. When aggregates with widely different specific gravities are combined, conventional gradation analysis based on weight measurements of the various size fractions cannot be used. A volumetric analysis must be used to obtain a realistic analysis of the gradation of the aggregate blend. In addition, the asphalt percentage should be controlled based on volumetric analysis. Procedures for ordinary field control are contained in the specification. The procedure proposed is basically similar to practices successfully employed in some districts in Texas.

Size is relative. Densely graded sand asphalts are relatively similar to conventional bituminous concretes. Porous sand asphalts possess the same attributes as other porous bituminous mixtures. Surely, sand-asphalt mixtures can be designed to be as porous as the so-called open-graded plantmix seals. Particle shape and texture otherwise define skid resistance. Stability remains an assurance against scaling. Stability is assured by maximum utilization of an appropriate filler-bitumen ratio and stiffness of asphalt cement.

Indiana was perhaps the principal user of Kentucky rock asphalt following World War II; failures (scaling) led to almost complete rejection. Attention there shifted to sand asphalt - some made with asphalt emulsions. Sands there are largely of glacial origin and usually are not angular or sharp. Nevertheless, skid resistances have been accepted as adequate. I 65 from Louisville northward was overlaid a stretch at a time. An Indiana official expressed satisfaction to a Kentucky official; an inspection team was dispatched and a skid-testing excursion followed. Kentucky's good sand asphalts are considered to be superior from the standpoint of particle shape.

Whereas others seem to have forsaken sand asphalts in the search for skid-resistant surfaces, basic principles of relativity of particle size and packing remain as applicable to sand sizes as they are to pebble sizes. It is still possible to grade sands or silts to obtain a desired porosity. The gradation is merely shortened.

Suppose, for instance, that a relatively short-graded sand with sufficient asphalt in it to prevent bulking compacts to 33 percent voids in the mineral aggregate. Suppose, also, that 15 percent voids in the final mixture is desired. For a trial mixture, one might use 13 percent asphalt cement and 5 percent mineral filler (both by volume). For 2.64-specific gravity sand,
this would yield about 6.5 percent asphalt by weight. The proportions of asphalt-to-filler may be adjusted to obtain maximum stability. Stability is necessary to prevent scaling and stripping.

Sand is defined as aggregate passing the No.-4 or No.-8 sieves. Historically, there have been two generic types of sand-asphalt surfacing mixtures: sand asphalts and sheet asphalts. Sand asphalts have generally been long-graded sands containing 4 to 14 percent passing the No.-200 sieve and 7 to 11 percent asphalt. Sheet asphalts have generally been finer, containing as much as 98 percent passing the No.-16 sieve, 8 to 16 percent passing the No. 200, and 7.5 to 12 percent asphalt. The latter is merely a fine-sand mixture. There has been no purposeful effort to open-grade sand mixtures until now (6).

From the early 1900's, Kentucky rock asphalt (a sandstone containing natural asphalt, crushed nearly to sand sizes, heated for paving) was much admired and respected for its skid-resistant qualities. It was basically a porous sand asphalt. Voids in the mineral aggregate ranged between 28 and 35 percent. Total voids ranged between 12 and 16 percent. It had an unforgiveable weakness; it often scaled or delaminated. It had very low stability when fresh. However, a study (31) in 1955 showed an average life-expectancy of 17.3 years.

Elsewhere, sand (sheet) asphalts were used as low-cost surfacing in areas where sands were abundant. Pavement structures consisted of one or more courses of sand-asphalt or macadam base and perhaps two inches of sand (sheet) surfacing. Richardson (32) apparently sought angular, sharp, silica sands as early as 1896. Nicholson (33) published photomicrographs of prominent sands in 1926. A dilemma which yet persists in some degree was expressed by Gage (34) in 1926; his context is quoted:

A natural rock asphalt mixture seldom contains much over seven percent of asphalt, yet we are all familiar with what would happen to a sheet asphalt mixture that only contains eight percent of asphalt. I do not think there is much doubt about the durability of some rock asphalt mixtures that do not contain much over seven percent of bitumen yet there is a grave doubt about the durability of the average sheet asphalt pavement that does not contain more than ten percent of bitumen. The stability of a sheet asphalt mixture containing eight and one-half or more percent may be greater than one containing eleven percent, yet the durability of one will certainly exceed that of the other.

Gage apparently was recognizing not only the need for adequate stability but also the prerequisite need for coating thickness. A dense sand asphalt having 10 percent asphalt and a unit weight of 136.7 pounds per cubic foot contains 1.58 times more asphalt per cubic foot than an open-graded mixture having 7.5 percent asphalt and a unit weight of 115.7 pounds per cubic foot. Percentages of weight of aggregate would be 11.1 and 8.1, respectively. The ratio of the aggregate weights is 1.15:1. Surely, the ratio of specific surface area would be greater but not 1.58 times greater. Indeed, it appears there has been a tendency in the past to starve rock asphalts and other sand mixtures of their due portion of asphalt or asphalt and filler. The filler-bitumen ratio (35) appears to have been neglected, and stabilities have not been maximized. Scaling and stripping have resulted. Stabilities increase with 1) increasing angularity and texture of the sand, 2) increasing stiffness of asphalt, and 3) increasing filler-bitumen ratio to optimum. Anti-stripping agents provide precautionary assurances against loss of stability in water.

First generation sand asphalts in Kentucky were designed to be very dense and very stable. They did not scale, but they were not exceptionally skid resistant. The shape of the sand was not controlled. It seemed necessary to prove they could be designed to endure and to be as reliable in all respects as high-quality bituminous concrete.

Open-graded sand asphalts compounded to simulate Kentucky rock asphalt were first subjected to road trials in 1968 (28). Sand was selected visually and, by comparison, was judged to be similar to but not quite equal to Kentucky rock asphalt sand. Without filler material, surfaces scaled; with filler material, they did not. About two percent filler increased the stabilities from 40 to 80. Incidentally, stabilities in the range of 500 to 1,200 (Marshall) are thought to be necessary to withstand very high volumes of traffic. A simulated Kentucky rock asphalt has now equaled and slightly exceeded rock asphalt in skid resistance. The shape of sands used in the experimental project on US 27, north of Somerset (1968), was not controlled in the way proposed later. A crushed quartz conglomerate sand in a densely graded sand asphalt, constructed in 1972 and 1973, compares favorably in skid resistance with a crushed quartz conglomerate in an open-graded plantmix seal constructed in 1973 on an abutting section of the same road.

SKID RESISTANCE

Dense sand asphalts containing blends of crushed limestone sands and natural sands have performed about equivalent to bituminous concretes containing natural sands and crushed limestone coarse aggregates. All-limestone sand asphalts have performed about the same as all-limestone bituminous concretes. Sand asphalts containing all-natural sands have tended to exhibit higher skid resistance. Variability in shape, texture, and composition has affected performance.
Crushed quartz sand in a dense sand asphalt has shown very good skid resistance after 10 years under severe traffic. A porous sand asphalt containing selected quartz sand less angular than crushed sand has shown superiority over the same sands in denser mixtures. The ultimate combination of high porosity and sharp angular (crushed quartz) sands or other hard vesicular sands such as slags, scoria, or expanded shales have not been field tested. An open-graded (coarse) surface and a sand asphalt containing expanded shale aggregate failed in winter. Performance equations indicating statistical confidence limits with respect to time and accumulated traffic have been developed. Performance equations are needed to qualify types of surfaces and materials to meet minimum standards or criteria for skid resistance.

Porous sand asphalt can be considered to possess almost all of the attributes of a popcorn mix or an open-graded plantmix seal. They do not have comparable pore sizes. For instance, unless a porous sand-asphalt surface is pre-wetted before making an ASTM E 274 skid test, water sprayed in front of the test wheel does not have sufficient time to wet or be blotted into the surface. The effect on Skid Number might be about the same as if the test were made on a dense, non-wetting surface. On the other hand, a fully-wetted but unsaturated porous sand asphalt may imbibe sprayed water very quickly.

OTHER ATTRIBUTES

Sand-asphalt surfaces, especially the more porous ones, generate a minimum of tire noise and tend to damp other noises generated by a vehicle. Under-car noise caused by splash and spray in wet weather is reduced. More significantly, perhaps, spray generated by vehicles is reduced unless water is ponded or the surface is otherwise flooded. Attrition in wheel paths occurs rather uniformly — ideally before too much rounding and polishing of grains occurs.

POROSITY AND CAPILLARITY

A unique feature of sand mixtures, one which has not yet been fully explored and developed, is the strong capillarity and wicking forces that may be achieved and made useful (36). Whereas drainage of larger porous mixtures must depend on gravity flow, porous sand mixtures definitely blot and wick and may, hopefully, be designed to siphon.

Indeed, the objectives are to 1) shed water from the pavement as quickly as possible, 2) minimize hydroplaning, and 3) avoid polished or polishing aggregate particles that can be lubricated by residual films of water. Field tests remain the final proof of success; however, an intuitive and scientific skepticism toward standard methods of test, such as those now used to measure skid resistance, should be retained.

A relatively dense sand-asphalt gradation divided at the No. 30 sieve will provide a coarse and fine sand, each of which will yield about twice the voids in the mineral aggregate in asphalt mixtures as the original sand. The coarser fraction would not contain filler; the filler would have to be added. Such sorting might be accomplished in a wet classifier. All filler could be removed and proportioned back into each of the sands at the hot-mix plant. The two mixtures would be very much alike in terms of total voids (porosity) but have very different pore sizes. Capillary rise and wicking would be greater in the finer mixture if voids remain open and if internal surfaces are wettable. Both the coarse and fine mixture would exhibit wicking capabilities. Wicking is merely capillary forces at work in a porous medium.

Capillary rise, capillary siphoning, and wicking are illustrated in Figure 10. Height H must be sufficient to overcome tensions holding the drop at the tip of the tube before efflux will occur. A wick may substitute for or extend a capillary tube, as shown.

Suppose capillary rise is 10 mm in a surface course 20 mm thick. If the surface course were inundated by rain surface flow and some internal flow would carry the excess water to a lower elevation, the free-water surface would then subside into the surface course. Ordinary gravity drainage would cease at some point; shallow basins would siphon (by capillary action) into lower basins and emerge laterally or surface at low points. Water that can form concave surfaces (menisci) having shorter radii than pores causing capillary rise will not drain, and the hydrostatic law does not apply. As drying progresses, menisci recede; but blotting capacity remains high and additional water cast onto the surface is absorbed readily.

CLOGGING OF PORES

Soil and road scum intrusions affect the porosity and surface texture of various types of bituminous surfaces. Dust tends to adhere to fresh asphalt until the asphalt becomes "de-tackified;" interior surfaces also retain dust. This mineralizing process improves wettability with respect to water and gives rise to capillary action. Permanent clogging may occur, but the pumping action induced by passing tires during rainy periods tends to flush and clear pores in wheel paths.

Figure 11, left, illustrates a dense sand-asphalt surface, outside the wheel paths, that is clogged and not readily wettable. The right-hand view shows the same drop of water after addition of a wetting agent. The surface wetted, but there was no in-rush or blotting. In contrast, Figure 12 shows a drying porous sand asphalt (Kentucky rock asphalt) that has been fully wetted and flushed clean in wheel paths. Blotting occurs readily. Traffic assists the wetting process if
Figure 10. Illustration of Capillary Rise, Capillary Siphoning, and Wicking.

Figure 11. Quarter-Inch Diameter Bead of Water (left) on Dense, Clogged Sand-Asphalt Surface not Readily Wetted; Wetting Agent Induces Wetting (right) without Blotting.
the surface is somewhat hydrophobic at first and also hastens the de-saturation process.

**TACK COAT**

Porous sand asphalts have a high blotting capacity toward asphalt used in the tack coat. An abundant tack application seems necessary to prevent delaminations and to seal the underlying pavement. It is usually prudent to subtract an equivalent amount from the design asphalt content of the sand-asphalt mixture. This adjustment becomes very significant when the sand surface course is very thin.

**PARTICLE ORIENTATION AND SURFACE TEXTURE**

Particles having one or more flat sides tend to be positioned in the surface during compaction so they present a flat side rather than an acute angle or cutting edge toward the tire. In this position, the edges, if they remain sharp, contribute to tractive resistance. The micro-texture of the flat surface may be lost through wear and polishing. Certainly, micro-texture is obscured by asphalt when the surface course is new. Skid resistance should improve rapidly for a brief time and then diminish gradually to a more-or-less constant value. Attrition or loss of particles from an open-graded plantmix seal would present an impression of ravelling; attrition from a sand surface would be desirable if it occurs uniformly and at a rate commensurate with the life expectancy of the surface course. Indeed, a steady wearing away becomes an assurance against eventual polishing of sand grains at the surface. Finer sands also permit a higher size-reduction (in the crushing plant) ratio and consequently provide greater angularity when manufacturing sharp sands by crushing coarse sands or pea gravel. No.4 to No.8 sizes do not appear to be essential to the performance of sand mixtures.

Various methods of measuring and expressing surface texture have evolved. An excellent state-of-the-art summary was made by Rose in 1972 (29). A method, devised by Schonfield (37), of counting asperities from stereo-pair photographs attracted considerable interest in the interim. Correlations with skid resistance have not withstanded the test of time. An improved method has been advanced.

Whereas the Goldbeck bulking test (1) assures deviation from roundness and sub-angularity, it is an indirect measure of shape and texture. On the other hand, any measure of sharpness in sand-size aggregates should assure a high evidence of asperities in sand-asphalt surfaces. There, texture of the pavement is determined by the sharpness of its sand rather than the texture of the surface of the sand grains.

Orientation of particles of fine crushed quartz sand, oiled and compressed lightly against a flat surface, is shown in Figure 13.

**SCALING**

Scaling, illustrated in Figure 14, is attributed to a deficiency in design of the mixture — that is, instability. Usually, such mixtures are deficient in asphalt and (or) filler. Failures are accompanied by stripping of asphalt from sand particles. Coatings are thin, and...
asphalt menisci are not well formed at inter-particle contacts. Persisting water or continual wetness in conjunction with loading accelerates scaling \((38, 39, 40)\). Hard asphalts improve stability, minimize sponginess, and are more resistant to stripping. Anti-stripping agents may be needed with some aggregates. Kentucky rock-asphalt surfaces showing good durable performance contained asphalt binders (after 15 years or so in service) having penetrations of about 15. No sand asphalt or rock asphalt having stabilities (Marshall) of as much as 400 has scaled.

**RESISTANCE TO FREEZING AND THAWING**

Saturation and freezing can be devastating to porous aggregates and/or porous surface courses. There is a degree of saturation and absorption below which damage will not occur. Aggregates absorbing four percent moisture at near saturation are not likely to survive four cycles of critical freezing. Aggregates having absorption capacities of 2 percent (or, perhaps, 2.5 percent) may survive many cycles. Aggregates having capacities of 1.5 or 1.0 percent are, for all practical purposes, immunized from such damage. Porous sandstones, expanded shales, etc. may escape damage through several winters because critical circumstances do not happen concurrently. Some damage may not be recognized. Surface courses behave in a similar way. If porosities and degrees of saturation are high, damage is inevitable upon freezing. Kentucky rock asphalt and sand asphalts have suffered in this way (Figures 15 and 16). Open-graded seals (so-called friction courses) have sustained damage. Scaling and disintegration have occurred principally in wheel paths. This is where the melt-water runs and soaks in. Clogg-

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**Figure 14.** US 25, South of the Kentucky River; Insufficient Asphalt and Low Stability Caused Scaling in Wheel Paths.

**Figure 15.** Paving Dense Sand Asphalt; US 31-W, Muldraugh Hill, 1973; Special Provision 59-B.
ing of pores by road scum and "dirt" may improve resistance of porous courses to winter damage. It also renders the course less porous and thereby reduces skid resistance.

South Limestone Street in Lexington (Figure 17) suffered continuous disintegration of the porous sand asphalt. Snow was not plowed, traffic cut deep channels in the snow, and melting caused water to stand deep and long. Rutting occurred after snow and ice disappeared. Bonds were broken and black sand was scattered. It ridged outside the wheel paths and reset as weather warmed.

Much loss of an open-graded friction course occurred on US 68 in McCracken County (Figure 18) on I 24 (westbound) south of Paducah and on Whipps Mill Road in Louisville (Figure 19).

A sand asphalt scaled in warm wet weather on I 75 in Madison County. Stripping occurred; adequate stability and interfacial bond strength were not achieved. Soaked strength was low.

LABORATORY INVESTIGATIONS

In 1959, fourteen aggregates were investigated (4). They are identified in Tables 2 and 3. Their origins are shown in Figure 20. Photomicrographs are in Figure 21. In 1970, skid-resistant fine aggregates for
Figure 18. US 68, Marshall County; Open-graded Plantmix Seal; February 22, 1977.

Figure 19. Whipps Mill Road; Louisville.
### TABLE 2. RESULTS OF MARSHALL TESTS ON CRUSHED SAND MIXTURES.

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</table>
TABLE 3. COMPARISON OF VOIDS IN AGGREGATE BY MARSHALL AND DRY COMPACTION

<table>
<thead>
<tr>
<th>SAND</th>
<th>DRY COMPACTION</th>
<th>MARSHALL COMPACTION ASPHALT CONTENT (PERCENT)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Olive Hill</td>
<td>34.0</td>
<td>30.5</td>
</tr>
<tr>
<td>Corbin</td>
<td>35.2</td>
<td>34.5</td>
</tr>
<tr>
<td>Dobbins</td>
<td>35.2</td>
<td>34.0</td>
</tr>
<tr>
<td>Pearl Brownhill</td>
<td>35.9</td>
<td>34.4</td>
</tr>
<tr>
<td>Eastview</td>
<td>40.6</td>
<td>38.3</td>
</tr>
<tr>
<td>Webbville</td>
<td>32.7</td>
<td>32.6</td>
</tr>
<tr>
<td>Salyersville</td>
<td>32.8</td>
<td>31.6</td>
</tr>
<tr>
<td>Drakesboro</td>
<td>36.9</td>
<td>33.6</td>
</tr>
<tr>
<td>Kentucky Rock</td>
<td>36.0</td>
<td>35.3</td>
</tr>
<tr>
<td>Polly</td>
<td>32.1</td>
<td>31.8</td>
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<tr>
<td>Central City</td>
<td>35.9</td>
<td>31.5</td>
</tr>
<tr>
<td>Green</td>
<td>37.8</td>
<td>34.7</td>
</tr>
<tr>
<td>Big Clifty</td>
<td>38.4</td>
<td>33.8</td>
</tr>
<tr>
<td>Stephensburg</td>
<td>28.6</td>
<td>30.2</td>
</tr>
</tbody>
</table>
Figure 21 Photomicrographs of 1959 Series of Sands.
Figure 21. Photomicrographs of 1959 Series of Sands (Continued).
Figure 21. Photomicrographs of 1959 Series of Sands (Continued).
Figure 21. Photomicrographs of 1959 Series of Sands (Continued).
surface courses were defined as those consisting of quartz particles, or other minerals of equal or greater hardness, having sufficient angularity or roughness to assure maximum wet-weather traction. Investigations into the availability of sands having desired characteristics were reported in 1971 (30). The report addressed particle shape and tests. That report included an inventory of sources within or immediately surrounding Kentucky (Table 1). Thirty-one aggregates were identified. Mixture characteristics were derived in the 1959 series. Various blends of sands were evaluated. In 1975, three aggregates were used to demonstrate basic design principles. Dense mixtures were designed to minimize retention of water to hasten runoff and thereby decrease the potential for hydroplaning. Normally, voids within dense surface mixtures range between two and five percent. Experiences with Kentucky rock-asphalt surfaces indicated that mixtures should be designed to have high voids contents. Mixtures designed on that principle have voids in the order-of 12 to 16 percent. Factors considered in designs for stability were aggregate shape and texture, stiffness of asphalt, and filler-asphalt ratio (better described as C_v, ratio of volume of filler solids to the combined volume of filler and asphalt).

Stabilities of sand mixtures in the 1959 series varied over a wide range. At an asphalt content of 12 percent, stabilities ranged from a low of 220 pounds for the more densely graded Webbville sand. Results of the Marshall stability testing of mixtures are in Table 2 and Figure 22.

Gradation of the various crushed sands had a very pronounced effect on the stability of the mixtures. Sands that 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. 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. Stability curves take two-characteristic shapes that depend upon the void content of compacted aggregates. Stability values increased with increasing asphalt content for mixtures having greater than 33.6 percent voids in the compacted aggregate. Stability increased rapidly in 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.

The most consistent correlation with stability was the percentage of aggregate passing the 200-mesh screen. Figure 23 is a plot of stability versus minus-200 material in the 14 sands at an asphalt content of 10 percent. Stabilities increased uniformly with increasing percentages of filler-size material, even though the sands vary in gradation. Similar curves may be obtained by plotting the stability values at the other asphalt contents against the percentages of minus-200 material. Filler material stiffens the asphalt.

The Kentucky rock-asphalt sample had low stability and a high void content. Stability of this "one-size" sand could be increased by addition of mineral filler or by blending with other sands. Referring to Figure 24, the stability of the Kentucky rock asphalt and Eastview combination is higher than the stabilities for either sand alone. This is presumably due to the slightly longer gradation of the combined sands. Stability of the equal combination of Kentucky rock-asphalt sand and high-stability Drakesboro sand plots in a curve of near median value. Also illustrated is the increased stability of the Kentucky rock-asphalt sand when fifteen percent soil filler is added.

![Figure 22. Marshall Stability Curves for 14 Crushed Sands.](image-url)
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 pounds at an asphalt content of nine percent was achieved for all sands investigated in this study by the addition of mineral filler to the low-stability sands. This could prove to be adequate for light traffic only (natural sandstone rock asphalt has performed satisfactorily in some instances with initial stability values lower than 300 pounds).

The unit weights, flow values, and voids analyses are in Table 2. Flow values ranged from a low of 7 to a high of 18. The voids in the aggregates remain fairly uniform over the range of asphalt contents investigated. The percentage voids in the aggregates ranged from a high of 38.3 percent for the Eastview sand at 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 percentage voids in the compacted dry sands and the percentage voids in the sands under Marshall compaction at asphalt contents of 9 to 12 percent is in Table 3. Voids in the compacted dry sands are slightly higher than in Marshall specimens; these differences are attributable to the lubricating effect of the asphalt. These small differences, combined with the fact that the percentage voids remain fairly constant with increasing asphalt content, indicate that 100 blows from the Marshall hammer resulted in near maximum density.

Effects of the hardness of the asphalt upon Polly and Kentucky rock-asphalt sands are shown in Table 4. 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. Stabilities of the mixtures prepared with Kentucky rock-asphalt sand and the various grades of asphalt, tested at 140°F, parallel results obtained with the Polly sand mixtures. Flow values tended to increase with the harder grades of asphalt. Polly sand with PAC-2, tested at 77°F, had a flow of 20.5; the flow of the mixture incorporating PAC-5 was only 11.0. The percentage voids in the aggregate tended to decrease slightly with the use of softer grades of asphalt.

Table 5 shows mixture data for Ohio River sand
TABLE 4. RESULTS OF THE INFLUENCE OF HARDNESS OF BINDER ON STABILITY.

| Specimen Prepared With Poly Sand and Tested at Lower Temperatures
<table>
<thead>
<tr>
<th>Asphalt</th>
<th>Penetration at 77°F</th>
<th>Softening Point (°F)</th>
<th>Testing Temp. (°F)</th>
<th>Stability (Lb.)</th>
<th>Flow (1/100 In.)</th>
<th>Unit Weight (lb./cu. ft.)</th>
<th>Percent Voids</th>
<th>asphalt only</th>
<th>Total mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAC-1</td>
<td>L1</td>
<td>113</td>
<td>32</td>
<td>22200</td>
<td>19.3</td>
<td>127.1</td>
<td>31.3</td>
<td>68.7</td>
<td>9.9</td>
</tr>
<tr>
<td>PAC-2</td>
<td>92</td>
<td>126</td>
<td>32</td>
<td>22737</td>
<td>20.3</td>
<td>124.6</td>
<td>32.2</td>
<td>65.5</td>
<td>11.1</td>
</tr>
<tr>
<td>PAC-3</td>
<td>60</td>
<td>126</td>
<td>32</td>
<td>21873</td>
<td>17.2</td>
<td>128.0</td>
<td>31.9</td>
<td>66.5</td>
<td>10.7</td>
</tr>
<tr>
<td>PAC-4</td>
<td>70</td>
<td>122</td>
<td>32</td>
<td>21570</td>
<td>19.6</td>
<td>126.0</td>
<td>31.9</td>
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<tr>
<td>PAC-5</td>
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<td>118</td>
<td>32</td>
<td>20642</td>
<td>18.1</td>
<td>129.3</td>
<td>30.4</td>
<td>72.1</td>
<td>7.5</td>
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<tr>
<td>PAC-1</td>
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<td>112</td>
<td>77</td>
<td>5900</td>
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<tr>
<td>PAC-2</td>
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<td>129.7</td>
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<tr>
<td>PAC-5</td>
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<td>118</td>
<td>77</td>
<td>1942</td>
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<td>129.0</td>
<td>30.3</td>
<td>71.7</td>
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</table>

*Constant asphalt content of 10.5%.

TABLE S. MARSHALL TEST RESULTS FOR LOUISVILLE SAND BLENDS.

| Specimen Prepared With Kentucky Rock Sand and Tested at 110°F
<table>
<thead>
<tr>
<th>Asphalt</th>
<th>Penetration at 77°F</th>
<th>Softening Point (°F)</th>
<th>Asphalt Content (Percent)</th>
<th>Stability (Lb.)</th>
<th>Flow (1/100 In.)</th>
<th>Unit Weight (lb./cu. ft.)</th>
<th>Percent Voids</th>
<th>asphalt only</th>
<th>Total mix</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAC-1</td>
<td>L1</td>
<td>132</td>
<td>18.7</td>
<td>100% River sand</td>
<td>118.2</td>
<td>31.0</td>
<td>65.7</td>
<td>18.0</td>
<td></td>
</tr>
<tr>
<td>PAC-2</td>
<td>S2</td>
<td>126</td>
<td>15.9</td>
<td>100% Bank sand</td>
<td>119.0</td>
<td>31.0</td>
<td>65.7</td>
<td>18.0</td>
<td></td>
</tr>
<tr>
<td>PAC-3</td>
<td>66</td>
<td>126</td>
<td>12.6</td>
<td>50:1 River sand</td>
<td>111.3</td>
<td>31.0</td>
<td>65.7</td>
<td>18.0</td>
<td></td>
</tr>
<tr>
<td>PAC-4</td>
<td>70</td>
<td>122</td>
<td>9.0</td>
<td>56% Bank sand</td>
<td>117.3</td>
<td>31.0</td>
<td>65.7</td>
<td>18.0</td>
<td></td>
</tr>
<tr>
<td>PAC-5</td>
<td>85</td>
<td>118</td>
<td>4.3</td>
<td>40% Limestone filler</td>
<td>117.2</td>
<td>31.0</td>
<td>65.7</td>
<td>18.0</td>
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</tr>
</tbody>
</table>

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

**The aggregate is graded to meet median gradation of specification.
gate shape by the bulking test as described before. Open-graded sand asphalts had the No.-8 sieve and 5.5 to 11 percent asphalt. The Test data are presented in Table 8. Total air voids were held relatively constant. Balancing filler containing expanded shale of varying gradation, eight centered (expanded) shale (Solite). All three were laboratory investigation because of their resistance to polishing and sharpness upon crushing. The aggregates were Green River high-silica gravel, steel slag, and sintered (expanded) shale (Solite). All three were considered representative of locally available materials and as having the desired skid-resistant characteristics. Physical characteristics of the aggregates are listed in Table 7.

It was possible to achieve relatively good stabilities in porous (open-graded) mixtures in which all of the sand passed the No.-30 sieve. It was possible to design mixtures for relatively high percentages of voids and to supplant asphalt with mineral filler to increase stability.

Test data are presented in Table 8. Total air voids were held relatively constant. Balancing filler containing slag sands of varying gradation, seven (Louisville) blended and supplemented. Table 6 gives data on Ashland sand blended and supplemented. The 1970-1975 series included eight mixtures containing slag sands of varying gradation, twelve open-graded mixtures, and eleven containing asphalt of varying grades. The dense sand-asphalt mixtures were long-graded sands with four to 14 percent passing the No.-200 sieve and 7 to 11 percent asphalt. The open-graded sand asphalts had 100 percent passing the No.-8 sieve and 5.5 to 9.0 percent asphalt. The mixtures yielded similar results when tested for aggregate shape by the bulking test as described before.

Three crushed aggregates were chosen for the laboratory investigation because of their resistance to polishing and sharpness upon crushing. The aggregates were Green River high-silica gravel, steel slag, and sintered (expanded) shale (Solite). All three were considered representative of locally available materials and as

<table>
<thead>
<tr>
<th>Table 6. Marshall Test Results for Ashland Sand Blends.</th>
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</thead>
<tbody>
<tr>
<td><strong>Asphalt Content</strong> (Percent)</td>
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<tr>
<td>1</td>
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<tr>
<td>10</td>
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</table>

<table>
<thead>
<tr>
<th>Table 7. Physical Characteristics of Aggregates.</th>
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</thead>
<tbody>
<tr>
<td><strong>Aggregate</strong></td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Green River</td>
</tr>
<tr>
<td>Steel Slag</td>
</tr>
<tr>
<td>Expanded Shale</td>
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</table>

<table>
<thead>
<tr>
<th>Table 8. Summary of Test Data for Asphaltic Mixtures.</th>
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<tbody>
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<td><strong>Laboratory Test Mixtures</strong></td>
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<tr>
<td><strong>Asphalt Content</strong> (Percent)</td>
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</tr>
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<td>1</td>
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<tr>
<td>10</td>
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<td>11</td>
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<tr>
<td>9</td>
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<td>9</td>
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<td>11</td>
</tr>
</tbody>
</table>

36
and asphalt was necessary to maximize stability. A noticeable change in stability resulted from use of stiffer asphalts. Variations in gradation of aggregates (excluding fillers) did not enhance stability. Indeed, the filler-asphalt ratio largely controls stability. A Cv of 0.6 is about ideal. The basic aggregate gradations used in the tests were developed from sieve analyses of Kentucky rock-asphalt mixtures.

Meanwhile, open-graded friction courses came into prominence, and those mixtures were included in the study. Trial mixtures utilizing the crushed Green River high-silica gravel were prepared and tested. Other mixtures were then prepared using other sands. Results of tests on those mixtures compared favorably with trial mixtures employing the Green River gravel. All tests were performed in accordance with procedures contained in ASTM D 1559 and AASHTO T 245, and analyses were in accordance with those methods.

FIELD TESTS

OPEN-GRADED PLANT MIX SEALS: OPEN- GRADED FRICTION COURSES

An FHWA demonstration project (No. 10; DOT-FH-15-87) was done by Middle West Roads, on US 31-W north of Elizabethtown, in October 1973 (Figure 25). The aggregate was partially crushed quartz conglomerate gravel from Jonesville (Caseyville) (Green River gravel). It is shown in Figure 26. The first conception of design conveyed by FHWA alluded to short-graded aggregate nominally 3/8-inch in diameter mixed with sufficient asphalt cement to yield a "drain-down of excess" after paving (to seal the existing surface). It became known as a "popcorn" mix. No stability criterion was needed. The trial mix was spread onto a glass plate to test the "drain-down." Drain-down occurred in the trucks enroute to the paver; the trucks could not be emptied completely. Excess asphalt was curtailed; a double dosage of diluted SS-1h was applied to the road before paving.

Skid resistance persisted at skid numbers greater than 50 from the beginning. According to tests, it improved slightly at the beginning as the aggregate became exposed under traffic. Rain caused little or no splash and spray. Drainage was good. It was anticipated that clogging and ravelling would hinder the endurance and effectiveness of the surface. However, endurance exceeded expectations, and clogging was not significant. Attrition of coarse particles gave an appearance of ravelling and increased tire noise (roughness). Full-width patching ensued. Three-fourths of the open-graded seals remain in service (Spring 1981). The data are reported elsewhere (41, 42, 43, 44).

Inasmuch as the particles were only partially crushed and inasmuch as size is relative, it seemed logical that further crushing of quartz gravels would improve angularity and skid resistance. A surface composed of aggregate nominally 1/8 inch in diameter was constructed on US 62 near Clarkson. One section (1976) contained 98 percent crushed gravel, one contained 50 percent crushed gravel in combination with a high-carbonate limestone, and another contained 50 percent crushed gravel combined with a low-carbonate limestone. Eastward from Elizabethtown on US 62, sections constructed in 1975 consisted of 70 percent crushed gravel with 30 percent limestone, 40 percent gravel and 60 percent limestone, and 100 percent crushed gravel. Northward from Elizabethtown on US 31-W, 2.1 miles consisting of 70 percent crushed gravel (one face) and 30 percent limestone were constructed in October 1976. An analysis (44) indicated a...
loss of 2.0 SN’s for each 10 percent of high-carbonate limestone in the aggregate blend.

Upon review of early performance reports (skid tests), FHWA mandated use of open-graded plantmix on all new federal-aid construction and on resurfacing where the speed limit is higher than 45 mph. Failures ensued; a significant one was on US 68 (Figure 18) in Marshall County; others were in East Kentucky; some had been reported by Tennessee. An inventory and survey was made. Clogging was found on US 25-E where trucks and cars carried mud from side roads and from the shoulder onto the surface. Damage from freezing was observed generally. A section of I 24 raveled in the westbound lanes but not in the eastbound lanes. Grader blades fractured chert aggregates and scraped deeply into the course (Figure 27). Finally a moratorium was declared. Interim surfaces (staged) have been constructed, awaiting proof testing of other surfaces and the establishment of minimum requirements for skid resistance (44).

**SPRINKLE-AGGREGATE TREATMENTS**

Although light applications (25 pounds per square yard) of sand asphalts have been made with paving machines (in Virginia), as much or more material may be used in a chip seal or a variety of other treatments and produce a less desirable surface. In Kentucky, it has always seemed more desirable to level an existing surface before applying even 40- to 50-pound (0.4- to 0.5-inch) surface courses of sand asphalt. Usually, the minimum thickness of a course containing coarse aggregate that can be applied through a paver is about 1.5 times the diameter of the coarsest particles. A scratch or leveling course sometimes may be not much thicker than the coarsest particles. If the aggregate were altogether skid resistant, no further surfacing would be needed (in many instances) unless cracking and raveling were present and unless additional structure also was needed. These treatments for de-slicking could be minimal but usually are not because of practical considerations alluded to above.

To minimize the need for skid-resistant aggregate throughout the depth of the course, it was inevitable that the idea of sprinkle treatments of skid-resistant aggregates onto hot-paved surfacing would emerge. An FHWA demonstration project (No. 50, DOT-FH-15-302) was constructed on US 31-E north of Bardstown in September 1978. Four different sprinkle aggregates were employed. Partially crushed quartz gravel was the only locally indigenous aggregate. They are shown in Figures 28, 29, 30, and 31. The application rates suggested at the outset were for 50- to

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**Figure 27.** I 24, MP 12; Cracked White Surface of Chert Particles Remaining in Pavement; Dislocated Particles on Shoulder; Damage Caused by Snowplow; March 14, 1978.

**Figure 28.** US 31-E, Nelson County; Green River Gravel Quartz for Sprinkle Treatment (Uncoated); September 13, 1978.
75-percent coverage. Those rates were proven to be excessive. Practical coverage was resolved to be in the range of 30 to 35 percent.

A rippling appeared soon after paving. It was associated with the bounce of the aggregate spreader on its tires (natural frequency) and its forward speed. Loss of aggregate was progressive. Empty sockets were evidence of the loss. Skid resistance has persisted throughout -- including the control section. A report, (45) has been forwarded (KYP-79-204; DOT-FH-15-302). Excerpts and photographs follow.

Theoretical and actual spreading rates and coverages are given in Table 9. The percentage for the actual applications is by aggregate type: granite -- 62.57, gravel -- 25.0, slag -- 33.99, and quartzite -- 30.39. The crushed granite was applied at 62.5 percent coverage (Figure 32). That rate resulted in excess loose aggregate on the surface, causing throw-off to the edge of the pavement and flying particles striking automobiles following one another. Adjustments were made in the final three test sections that resulted in coverage as shown by Figure 33. That coverage was approximately 31 percent.

End results of the effort to improve skid resistance of US 31-E in Nelson County, as tested using the skid trailer at 40 mph, are reported elsewhere (45). Skid resistance of the control section has persisted at a level almost equal to sprinkled sections. On
this basis, no tangible or significant benefits have been realized from the project thus far. Loss of drop-on aggregates was greatest where the applications were heaviest (see Figure 34).

CLASS AA

Class AA dense bituminous surfacing required crushed, sharp, hard, coarse aggregate in combination with crushed hard sands. Before that, some modified Class I's required hard coarse aggregate only partially crushed. For many years, the principal coarse aggregate was limestone. Limestone coarse aggregate together with limestone fine aggregate produced certain slipperiness. However, the degree of skid resistance sought could not be achieved merely by improving the qualities of the fine aggregate.


*Density (sic, solidity) enhances strength, smoothness, and durability; but, it is believed to be somewhat diametrically in opposition to a still nobler quality of a pavement surface -- which is skid-resistance. A very solid, smooth surface is conducive to aquaplaning and other wet-weather traction-reducing phenomena. It is known that gritty, porous, sand surfaces definitely offer means of attenuating these effects; but this type of surface texture cannot, practically speaking, be expected from dense bituminous concrete-type pavement courses containing appreciable percentages of limestone coarse aggregates; it can be achieved only by topical applications of sand-type mixtures. Quartz sands incorporated into mixtures such as the Type A are surely beneficial in maintaining wet-weather traction at speeds below the aquaplaning threshold. Although quartz-type sands have been purposefully incorporated in bituminous concrete surfaces built in Kentucky since the early 1950's, all experiences seem to indicate that the ultimate degree of skid-resistance cannot be achieved by this route.

A series of skid-tests made in the spring of 1966 indicates that the Type A mixture is slightly less skid-resistant than the Type B (modified). This trend appears to be inversely related to density rather than directly related to quartz sand contents. Of course, the content of quartz sand has been altered considerably also, and the two variables are confounded until more definitive data can be obtained. New surfaces exhibited skid-resistance coefficients (30-to 20-mph deceleration) ranging between 0.65 and 0.55 -- the mean value being approximately 0.60; with time and usage, these values diminished to 0.55, 0.40, and 0.45, respectively. The influence of specific variables within these ranges is not clear. Values significantly less than 0.40 are adjudged to be critical or unsafe. Worn surfaces not containing polish-resistant sand have, according to previous studies, exhibited coefficients significantly lower than 0.40. It

Figure 33. US 31-E, Nelson County; Quartzite Sprinkle Treatment before Rolling; September 13, 1978.
would be desirable, of course, to preserve permanently the same high level of tractive resistance that is exhibited by a new surface; but such aspirations seem too demanding here. The practice of requiring polish-resistant sand in bituminous concrete mixtures is ostensibly sound, and further refinements of current specifications to require quartz or silica contents of not less than 30 percent by weight of total combined aggregate is recommended. The term "Natural Sand" as now employed does not exclude carbonate-type sands and does not provide sufficient assurance that sand so specified will be rich in polish-resistant particles. It is suggested that paragraph 306.2.1 of the 1965 Standard Specifications ... be revised as follows ... Unless otherwise provided on the plans or in the proposals, the mixture used in the final surface course shall contain not less than 30 percent silica (SiO₂) sand by weight of total combined course and fine aggregates.

Later, the amount of natural sand was advanced to 40 percent. Further striving seemed futile.

The first Class AA project was on the Watterson Expressway in Louisville, and the second was on KY 55 adjacent to Taylorsville. The coarse aggregate was a phosphate slag, and the fine aggregate was wet-bottom boiler slag. KY 55 carries only nominal traffic. Two significant projects, not Class AA but containing partially crushed gravels, are on I 75. One is north of MP 166; the other is south of MP 64. These will provide comparison with the Class AA. A third application of Class AA surface is on I 24, extending 2.5 miles from US 62 to the Cumberland River Bridge.

A basic principle commands respect even here. Aggregate particles will be worn, abraded, and (or) polished by any grit in road scum that is as hard or harder than the aggregate particle. Quartz (fine) is probably the most abundant ingredient in road scum and will polish limestone more rapidly than other quartz particles. Particles of quartz that are already rounded or are sub-angular smooth and slicken more readily than angular sharp particles. Moreover, sands and wear products attrited from a mortar matrix leave coarser particles protruding; and, eventually, the coarse particles (even hard ones) become rounded and polished. Therein is the principal attribute of sand-asphalt surfaces: that is, sand asphalts lose grains by attrition and do so rather uniformly. The rate of wear can be controlled in the design of the mixture. The wear is sacrificial, and new grit is exposed successively until the course is depleted. From the standpoint of maintaining a constant resistance to skidding, sand-type sur-

Figure 34. US 31-E, Nelson County; Crushed Quartz Gravel (Caseyville); Heavy Application in Foreground, Lighter Application in Background; Empty Sockets; March 14, 1979.
faces are ideal because they are self-renewing until used up. Unless there is some gradual attrition, even the sharp hard sands in sand asphalts will polish; and the surface can become slick. An ideal compromise may be achieved if a coarse aggregate such as porous slag or scoria (see Figure 35) or expanded shale could be matched with a fine aggregate and mortar to induce even wear and renewal as is typical of good sand asphalts.

Failures and clogging of open-graded plant-mixed seals precipitated a moratorium on the use of that type of surface until service records of Class AA could be established. The number of projects to be included in the sample was not specified; however, time allowed was too short. Meanwhile, studies to determine adequate levels of skid resistance were nearing completion. In that respect, this report is paired with and is supplemental to Reference 44.

**SANDSTONE**

Sandstone was first employed in a surface course in 1952 on KY 30 between Salyersville and Jackson. There, the entire pavement was composed of sandstone. It was quarried beside US 460 near KY 30 and near KY 15 (Quickland). The pavement was minimal and was resurfaced after five or six years. The surface was notably skid resistant (equal to Kyrick) (see Figure 36). Sandstone was then admitted as an alternate to limestone on resurfacing work until 1963 or 1964. It was also used for some chip seals. The alternate ceased to be exercised, and it was discontinued.

Interest in sandstone was renewed when KY 80 (Hazard to Watergap) was being designed. Sandstone was to be employed at all levels but the surface. Later, it came under consideration for some of the surface courses. Sandstones tend to require more asphalt than some other aggregates because they are porous and textured.

Sandstones had been employed previously in base courses on the Paintsville-Inez Road (1941, first all-sandstone bituminous road) and on the Hyden-Manchester Road (1955). Some, if not most of it, was quarried alongside the road. A limestone-sandstone was

![Figure 36. Sandstone, Asphaltic Concrete; KY 30, Salyersville - Jackson (3), 1953.](image)

Figure 35. Scoria, Cinder-like Lava from Mexico; Illustrates Vesicular, Wear-Away Fine Aggregate (Sand); Magnification ~10x; December 9, 1971.
quarried near Flatgap (Johnson County). Sandstone for building stone has been quarried at Bluestone and Freestone (near Farmers) and at Buena Vista.

Sands and sandstone gravels were worked near Crystal by the Estill Sand Company. Valley fill, there, contained sand, sandstone gravel, and coal. A hill-top sand pit was operated near Furnace.

Sandstone aggregate was used in the construction of small reinforced concrete bridges in the late 1920's. It was used in concrete pavement on the Pineville-Haran Road in 1927.

**CRITERIA FOR IDENTIFYING SLIPPERY ROADS**

Much effort has been devoted to correlating skid resistance and wet-weather accidents (41, 42, 43, 44, 47, 48, 49, 50, 51, 52, 53, 54). One must know the probabilities of accidents attributable to degrees of slipperiness. Analyses of weather records for some years have indicated that wetness persists about 12 or 13 percent of the time. A highway or section thereof showing 18 or 20 percent of the accidents in wet conditions surely would be suspected of slipperiness. Accident rates (per 100 million vehicle-miles) should be determined also. Specific rates may be compared with averages for sites of similar geometry and traffic or simply collected into categories and arrayed for regression analysis with respect to skid numbers. Accidents increase as skid numbers decrease.

Degrees of hazard are related to demands or needs for traction and therefore to speed and density of traffic, turning and stopping movements, and roadway geometrics. Indeed, there are degrees of risk associated with highway hazards. Critical skid numbers have been derived for interstate and toll roads (55) and for principal two-lane roads (US routes) (56). The critical value of $\text{SN}_{40}$ for interstate and toll roads (by interpolation) was about 40; the critical value for principal two-lane roads was between 38 and 43.

Skid numbers near or less than the critical values do not necessarily identify high-accident roads or sites; only accident records qualify as first-order identifiers (which is, unfortunately, after the fact). The ratio of wet- to dry-time accidents (excluding those on snow and ice) is a significant diagnostic factor, and it is particularly adaptable to computer searches for unsafe sections of roads. This ratio, when known and applied specifically, tends to embrace a range in skid numbers from 39 to 26. Below 26, pavements are categorically designated as very slipperly. The following guide was suggested when the speed limit was 60 mph (56):

<table>
<thead>
<tr>
<th>Skid Number</th>
<th>Skid Resistance Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above 39</td>
<td>Skid Resistant</td>
</tr>
<tr>
<td>33 to 39</td>
<td>Marginal</td>
</tr>
<tr>
<td>26 to 32</td>
<td>Slippery</td>
</tr>
<tr>
<td>Below 26</td>
<td>Very Slippery</td>
</tr>
</tbody>
</table>

Speed limits were reduced from 70 and 60 mph (31.3 and 26.8 m/s) to 55 mph (24.6 m/s) in March 1974. The relationship between accidents and pavement friction, therefore, may have been altered. A study of those after-effects has not been completed. Preliminary results from two-lane roads (about 5,000 miles (8,000 km)) are in References 44 and 54.

De-slicking of all pavements with skid numbers of 32 or less, while desirable, may not be implementable because of the large mileage of roads that would meet this criterion. A minimum skid number, however, must be set to safeguard the public from slipperiness regardless of the accident history of the highway or conditions of the pavement otherwise. Any highway section with an AADT above 1,000 should be de-slicked if the SN is 28 or less. This implies the acceptance of 45 percent greater risk of accidents in wet weather compared to an average pavement (SN of 40) in Kentucky. The public, of course, should be forewarned of road hazards. Signs warning of the hazard and signs stating a reduced speed limit: from 55 mph (24.6 m/s) to 40 mph (20.1 m/s) or 50 mph (23.4 m/s) to 40 mph (17.9 m/s) and 45 mph (20.1 m/s) to 35 mph (15.6 m/s) should be posted until the slippery conditions have been corrected.

**SAFETY ASSURANCE**

SN's at 0.1, 1, 5, 10, and 60 million vehicle passes (Table 10, 11, and 12) represent median values for each type of pavement - half of the sections had higher SN's and half lower SN's. The highest medians were for Open-Graded Friction Course, Type 1, with crushed Green River gravel. Other surfaces, except Sand-Asphalt, Type II, in urban areas have SN's of 38 or higher. SN's at minus 2.5 standard deviations represent values exceeded by 99.4 percent of the projects. Those values provide an indication of worst-case performance and a high degree of assurance against the probability of occurrence.

The criterion selected specifies that the SN of a mature surface, at minus 2.5 standard deviations (99.4 percent assurance), must exceed 32. Class I bituminous
and portland cement concrete pavements with AADT's greater than 2,500 and Sand-Asphalt (Type I) pavements have not provided this assurance. Class I bituminous (interstate and toll-road quality) and portland cement concrete, with AADT's less than 2,500 provided suitable SN's throughout their lives. Open-graded friction courses with crushed Green River gravel aggregate have provided qualifying SN's through the vehicle passes accumulated to date and, by interpolation, through the life of the pavement. Open-graded friction courses with slag aggregate provided qualifying SN's through 12 million vehicle passes. For 8-year service life, this corresponds to an AADT of 11,000 vehicles per day, the surface may exhibit SN's of 32 or less after only 6 years and may require surface renewal at that time. Open-graded friction course, with other gravel aggregate, provided necessary assurance against low SN's to one million vehicle passes; however, data were too limited to extrapolate. Sand-Asphalt, Type II, on rural roads, provided adequate SN's through 15 million vehicle passes. For 8-year service life, this corresponds to an AADT of 10,300.

Service life has been estimated on the basis of AADT. Benefit-cost analyses indicated that overlaying existing pavements having SN's less than 35 and AADT's greater than 5,000 yields benefits from reductions of wet-pavement accidents equal to or exceeding the cost of overlay. Benefits also exceeded costs for roads with SN's less than 30 and AADT's greater than 2,500 and for roads with SN's less than 24 and AADT's greater than 750. The analyses did not include increased comfort, time savings, fuel savings, maintenance savings, and reduction of other types of accidents.

A minimum SN of 28 for roads with more than 1,000 vehicles per day has been recommended to safeguard the public from slipperiness regardless of the accident history of the road. Also, as indicated from the relationship between skid resistance and cumulative traffic, the best surface does not assure mature SN's above 45. Thus, criteria for the design of surface courses concern primarily the range of SN's between 28 and 45. The percentages of pavement sections estimated to exceed those values, at 10 million vehicle passes, were determined. At least 95 percent of all pavement sections, except Sand-Asphalt, Type II (urban), provided SN's greater than or equal to an SN of 23 (44, 54).

**TABLE 10. BEST-FIT EQUATIONS RELATING SKID NUMBER AND CUMULATIVE TRAFFIC FOR VARIOUS TYPES OF PAVEMENTS**

<table>
<thead>
<tr>
<th>PAVEMENT</th>
<th>EFFECTIVE AADT</th>
<th>NO. OF SECTIONS</th>
<th>NO. OF DATA POINTS</th>
<th>MEDIAN SN</th>
<th>LOWER LIMIT**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RANGE</td>
<td>AVERAGE</td>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Class I, Bituminous:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interstate &amp; Toll Roads</td>
<td>1,000 - 2,499</td>
<td>1,560</td>
<td>43</td>
<td>45.9</td>
<td>-1.4</td>
</tr>
<tr>
<td></td>
<td>2,499 - 46,120</td>
<td>8,380</td>
<td>41</td>
<td>47.3</td>
<td>-7.2</td>
</tr>
<tr>
<td>US &amp; KY Roads</td>
<td>1,000 - 2,499</td>
<td>1,770</td>
<td>100</td>
<td>42.3</td>
<td>-4.3</td>
</tr>
<tr>
<td></td>
<td>2,499 - 34,000</td>
<td>5,680</td>
<td>130</td>
<td>40.2</td>
<td>-2.0</td>
</tr>
<tr>
<td>Portland Cement Concrete</td>
<td>1,000 - 2,499</td>
<td>2,070</td>
<td>46</td>
<td>48.9</td>
<td>-0.6</td>
</tr>
<tr>
<td></td>
<td>2,499 - 38,200</td>
<td>9,490</td>
<td>167</td>
<td>49.3</td>
<td>-7.9</td>
</tr>
<tr>
<td>Kentucky Rock Asphalt</td>
<td>1,180 - 7,590</td>
<td>2,950</td>
<td>20</td>
<td>57.2</td>
<td>-7.9</td>
</tr>
<tr>
<td>Sand-Asphalt, Type I</td>
<td>690 - 20,130</td>
<td>8,680</td>
<td>17</td>
<td>39.9</td>
<td>-1.2</td>
</tr>
<tr>
<td>Sand-Asphalt, S.P. 59B</td>
<td>4,000 - 14,550</td>
<td>8,900</td>
<td>3</td>
<td>47.3</td>
<td>-1.7</td>
</tr>
<tr>
<td>Sand-Asphalt, Type II:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Rural)</td>
<td>300 - 10,560</td>
<td>4,070</td>
<td>16</td>
<td>49.3</td>
<td>-3.8</td>
</tr>
<tr>
<td>(Urban)</td>
<td>1,040 - 18,650</td>
<td>8,060</td>
<td>9</td>
<td>36.6</td>
<td>-7.0</td>
</tr>
<tr>
<td>Open-Graded, Friction Course,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type I:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green River Gravel</td>
<td>2,220 - 19,400</td>
<td>6,610</td>
<td>10</td>
<td>46.2</td>
<td>-4.5</td>
</tr>
<tr>
<td>Slag</td>
<td>400 - 41,610</td>
<td>12,030</td>
<td>12</td>
<td>46.0</td>
<td>-3.7</td>
</tr>
<tr>
<td>Gravel</td>
<td>1,120 - 20,040</td>
<td>6,680</td>
<td>6</td>
<td>52.8</td>
<td>-4.4</td>
</tr>
<tr>
<td>Granite</td>
<td>5,300 - 11,500</td>
<td>6,520</td>
<td>7</td>
<td>48.6</td>
<td>-5.4</td>
</tr>
<tr>
<td>Type II: All Aggregate</td>
<td>2,400 - 6,900</td>
<td>3,360</td>
<td>6</td>
<td>47.1</td>
<td>-1.2</td>
</tr>
</tbody>
</table>

*Cumulative traffic in millions of vehicle passes
**At -1.5 standard deviations

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OTHER CAUSES OF SLIPPERINESS AND LOSSES OF TRACTION

Loose sands on pavements can be hazardous to traffic. Round sands will roll like ball bearings. Traction will diminish in some proportion to the concentration or coverage.

Spills onto a pavement can be very dangerous. Engine oil drippings or oil from wrecks or engine explosions should be blotted up and swept away. Spills of soil from trucks or from "ditching," soil or mud tracked onto the mainline pavement by traffic entering from sideroads or construction sites along the road, asphalt or road oil tracked onto the pavement from sideroads or paving work nearby, wet leaves, etc., cause temporary slipperiness.

Where traffic is very intense, oil slicks tend to build up (appears as a darkening or wetting, especially between wheelpaths) during summer months but diminishes with approaching winter.

Invisible (transparent) icing is an insidious hazard. "Beware!" to the unwary driver.

PAVEMENT SLIPPERINESS AND LIABILITIES

Those having authority and management responsibilities over pavements (57, 58) may not safe-
guard themselves from liabilities by mere exercise of personal and individual judgments. Only a panel of peers, a jury, or a committee is competent to judge the reasonableness of a design, a practice, or a selection. On the other hand, decision criteria based on analyzed risks, least cost, and maximum benefits are generally persuasive. The doctrine of immunity implied by the exercise of "engineering judgment" issues from the rational analysis of pertinent facts and affecting factors - such as engineers are qualified to do. It is presumed that a second and third party having sufficient facts and understanding of scientific and engineering principles would deduce the same outcome. Administrative decisions may override but not supplant; liability would gravitate upward and unshared.

Perhaps the surface providing the highest SN's may seem desirable to minimize risks. Otherwise, minimizing risks must be balanced with benefits to obtain the greatest safety with monies available. Thus, final criteria for adequacy of surface courses must include a best-good-for-all approach and priority-type programming; and the criteria may be different for various classes of roads. The term "monies available" seems inadequate in the context above. Perhaps the manager's higher duty would be to secure adequate resources. Perhaps authorities and officials need to know and to share with the administration, the legislature and, surely, with the public. Assurances of safety on the highway are concerns of each and every user and traveler. The public seems rather unforgiving if a pavement is allowed to deteriorate, roughen, or become slick. An epidemic of skidding accidents usually incites public ridicule and accusation of negligence or malfeasance.

Management loses credibility when an overlay, resurfacing, or de-slicking becomes more slippery than the pavement being resurfaced. Excess tackcoat may be blamed. To use all-limestone patching mixtures where skid-resistant surfacing is required by the criteria is misfeasance.

ACKNOWLEDGEMENTS

The work on sand asphalts began in the early 1950's when Kentucky rock asphalt was beset with lack of stability, stripping, and scaling. Ellis G. Williams and James H. Havens were the investigating team. It appeared that rock asphalt would not qualify for intense service but that it otherwise possessed admirable qualities - skid resistance, low noise, good blotting capacity. The first opportunity to use compounded sand-asphalt

| Table 12. Mean Skid Number of Pavements and Standard Deviation at Indicated Cumulative Traffic |
|-----------------------------------------------|-----------------------------------------------|
| AADT RANGE | 750 - 2,499 | 2,500 - 4,999 | 5,000 - 14,000 |
| AADT AVERAGE | 1,750 | 3,670 | 7,900 |
| HALF-LIFE (YEARS) | 7.1 | 6.1 | 4.1 |
| CUMULATIVE TRAFFIC (MILLIONS) | 2.3 | 4.1 | 5.8 |
| PAVEMENT | MEAN SN | STANDARD DEVIATION | MEAN SN | STANDARD DEVIATION | MEAN SN | STANDARD DEVIATION |
| Class I, Bituminous, Interstate & Toll Roads: | | | | | |
| AADT 1,000 - 2,499 | 45.4 | 4.3 | | | |
| AADT 2,500 - 46,120 | | | | | |
| Class I, Bituminous, US & KY Roads: | | | | | |
| AADT 1,000 - 2,499 | 40.7 | 4.9 | | | |
| AADT 2,500 - 34,000 | | | | | |
| Sand-Asphalt, Type I | 39.5 | 5.2 | 39.2 | 5.5 | 39.0 | 5.6 |
| Sand-Asphalt, Type II: | | | | | |
| (Rural) | 47.9 | 5.2 | 47.0 | 5.2 | 46.4 | 5.1 |
| (Urban) | 34.1 | 9.6 | 32.3 | 8.4 | 31.3 | 7.7 |
| Open-Graded, Friction Course, Type I: | | | | | |
| Green River Gravel | 49.8 | 4.2 | 51.0 | 4.6 | 51.6 | 4.8 |
| Slag | 47.7 | 4.3 | 46.7 | 4.5 | 46.2 | 4.7 |
| Gravel | 51.2 | 8.3 | 50.1 | 8.3 | 49.4 | 8.3 |
| Granite | 50.6 | 4.3 | 51.9 | 4.4 | 52.7 | 4.4 |

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mixtures was on bridge decks. They were designed necessarily to be dense and waterproof. The first in Kentucky was used on the Clark Memorial Bridge in Louisville. The second was on the Ashland-Coal Grove Bridge (60). G. F. Kemper was the resident engineer on the Ashland Bridge. The first mixtures were designed by Robert L. Florence (4, 5, 6, 7). Mr. Florence continued to work on sand asphalts for about 10 years.

The first road projects were in Frankfort on US 60. Some fine sands were dredged from the Kentucky River. Jerry G. Rose advanced the study of particle shape and texture. Donald C. Newberry advanced the designs of porous coarse- and fine-grained mixtures. Messrs. Rolands Rizenbergs and James L. Burchett conducted skid tests, maintained records and did the statistical analyses of performance (44).

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45. Newberry, D. C., Jr.; *Sprinkle-Treated Asphaltic Concrete Surface Course*, Research Report UKTRP-81-3, University of Kentucky Transportation Research Program, April 1981.
47. Moyer, R. A., and Shupe, J. W.; *Roughness and


APPENDIX A

DRY-BULKING TEST PROCEDURE
DRY-BULKING TEST PROCEDURE

EQUIPMENT

1. Balance -- a balance having a capacity of 1,500 grams and a sensitivity of 0.1 gram.
2. Drying Pans - at least 1,500-gram capacity, suitable for drying samples.
3. Cylindrical Cup - a rigid cylindrical cup having an inside diameter of 2-7/8 inches and a height of 5-1/2 inches.
4. Funnel - a truncated, hollow, metal cone having an overall height of 4 inches and an inside diameter of 5-1/2 inches for the large opening and 1 inch for the small opening (as shown in the sketch).
5. Sieves - the following sizes are required: No.4, No.8, No.16, No.30, and No.50.
6. Steel Straightedge - 1" x 6" x 1/16" (typical).

PROCEDURE

The sample of aggregate shall be washed thoroughly, dried to constant weight at 105° to 110°C (221° to 230°F), and separated into the following four sizes:

<table>
<thead>
<tr>
<th>PASSING</th>
<th>RETAINED</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 4</td>
<td>No. 8</td>
</tr>
<tr>
<td>No. 8</td>
<td>No. 16</td>
</tr>
<tr>
<td>No. 16</td>
<td>No. 30</td>
</tr>
<tr>
<td>No. 30</td>
<td>No. 50</td>
</tr>
</tbody>
</table>

Approximately 1,500 grams of each of the above sizes shall be required for the tests.

The test shall be conducted on only the size fractions comprising five percent or more of the aggregate by weight. The apparatus and its use are shown in Figures A1 and A2.

A sized aggregate shall be poured into the funnel while a metal plate is held against the bottom opening. The funnel shall be filled until the material is heaped between 1 and 2 inches above the top; care shall be taken not to overflow the funnel or to spill material into the cylinder below. The piece of metal used to close the bottom opening of the funnel shall be quickly withdrawn in a horizontal movement and the material permitted to flow freely into the cylinder until it overflows. Then the flow of the material onto the filled cylinder shall be cut off, and any material remaining in the funnel shall be allowed to flow into a pan.

The material in the cylinder shall then be carefully struck off even with the top of the cylinder with the straightedge. This is accomplished by holding the straightedge in both hands, edge down; starting at one side, strike off the material above the top of the cylinder. The straightedge is then placed along another diameter of the cylinder, and the material is struck off again. This is repeated in the opposite direction. Extreme care shall be taken during the striking-off operation to avoid any downward pressure on the aggregate or any jarring of the cylinder. After carefully removing any material that may be adhering to the outside of the cylinder, the weight of the contents shall be determined to the nearest 0.1 gram.

The aggregate in the cylinder shall then be recombined with the excess of the same size from the pan, thoroughly mixed, and two additional determinations made. An average of three determinations having a maximum variation of 4 grams shall constitute a test.

The percentage voids in each size shall be determined by the following formula:

\[ \text{Percentage voids} = 100 \left(1 - \frac{W}{V\cdot G}\right) \]

in which \( W \) = average weight of material in the cylinder, \( V \) = volume of cylinder in cubic centimeters, and \( G \) = bulk specific gravity (oven dry) of the aggregate as determined by the applicable portions of ASTM C127.

The arithmetical average of the percentage voids so determined for the tested size shall be reported.
Figure A1. Cup and Funnel, Dry-Bulking Test.

Figure A2. Bulking Test for Control of Aggregate Shape.
APPENDIX B

PROPOSED SPECIAL PROVISION
CLASS I, TYPE A, MODIFIED SURFACE
(SKID-RESISTANT, LIGHTWEIGHT AGGREGATE)
COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS

SPECIAL PROVISION NO. ___

FOR

CLASS I, TYPE A, MODIFIED SURFACE
(SKID-RESISTANT, LIGHTWEIGHT AGGREGATE)

This Special Provision covers the material requirements and construction methods for Hot-Mixed, Hot-Laid, Skid-Resistant, Class I, Type A Modified Bituminous Concrete Surface Course and shall be applicable to individual projects only when indicated on plans, proposals, or bidding invitations; and, when so indicated, it shall supersede all conflicting provisions of the Department's current Standard Specifications for Road and Bridge Construction. References herein are to the Department's Standard Specifications and approved addenda thereto.

I. DESCRIPTION

Hot-Mixed, Hot-Laid, Skid-Resistant, Class I, Type A, Modified Bituminous Concrete is intended to provide a skid-resistant wearing surface for pavements and bases. At least 40 percent by volume of the aggregate therein shall consist of lightweight aggregate prepared by expanding clay, shale, or slate by the rotary kiln process. The remaining portion of the aggregate shall meet the applicable requirements of Special Provision No. (Skid-Resistant Sand-Asphalt Surface). The aggregate, sand, bituminous material and the mixing and application thereof shall be in accordance with the respective requirements hereinafter described. The mixture shall be applied to the nominal, compacted thickness indicated on the plans or in the proposal; and the finished surface shall conform with the lines and grades shown on the plans or proposals.

II. MATERIALS

A. Requirements.

1. Bituminous Materials. The asphalt cement to be mixed with the aggregate shall be PAC-5 (AC-10) 85-100 penetration unless otherwise specified on plans or proposals and shall meet the particular requirements of Section 621. The quantity of asphalt cement used shall be as directed by the Engineer.

Bituminous material for the tack-coat shall meet the requirements of Section 621 for the particular type and grade specified on the plans or proposals.

2. Aggregate. The aggregate shall consist, by volume, of not less than 40 percent of lightweight aggregate. Aggregate, to fulfill this requirement, shall be obtained by expanding clay, shale, or slate at an elevated temperature in a rotary kiln. The remaining portion of the aggregate shall meet the applicable requirements Special Provision No. Unless otherwise provided, mineral filler meeting the requirements of Article 611.5.0 for quality may comprise not more than 5 percent by weight of the aggregate combination. Pre-qualifications of the aggregate sources are required. Pre-qualification, here, means prior approval of the Engineer.

The lightweight aggregate shall conform to the grading requirements for No. 8 coarse aggregate as follow:
In addition, the lightweight aggregate shall possess the following properties:

- Loose unit weight - 35 pcf minimum (ASTM Designation C 29 (shoveling procedure))
- Los Angeles Abrasion, percent loss -- 35 minimum (ASTM Designation C 131)

The remaining portion of the aggregate, including mineral filler, shall conform to the following grading requirements:

<table>
<thead>
<tr>
<th>Sieve</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8 inch</td>
<td>100</td>
</tr>
<tr>
<td>No. 4</td>
<td>85-100</td>
</tr>
<tr>
<td>No. 8</td>
<td>5-25</td>
</tr>
<tr>
<td>No. 16</td>
<td>0-5</td>
</tr>
</tbody>
</table>

In addition, the remaining portion of the aggregate shall consist of quartz (SiO\textsubscript{2}), not less than 90 percent by visual count or 94 percent by chemical analysis. Quartz, to fulfill this requirement, shall be obtained from sandstone, conglomeratic sand, bank sand, river sand, or combinations thereof.

Particle shape and texture of each aggregate type, excluding mineral filler, shall be so controlled that when subjected to the dry-bulking test, the volume of voids shall be 50 percent or greater. The dry-bulking test shall be used as a source control test and will be conducted at frequencies deemed necessary by the Engineer. The dry-bulking test shall be conducted in accordance with the procedure specified in Special Provision No.

3. **Admixture.** A moisture-controlling admixture such as silicone fluid (dimethyl siloxane polymer) shall be furnished by the Contractor to be blended with the mix when and as directed by the Engineer.

B. **Approval of Materials.** Silicone shall be of a type and from a source approved by the Department. At least one week prior to commencing production, the Contractor shall notify the Engineer that the aggregates, including blended natural sand if used, have been stocked at the plant site. Prior to notification, at least 500 tons or one-half the anticipated project requirement, whichever is least, of each aggregate shall be stocked.

III. **CONSTRUCTION METHODS**

The construction methods shall comply with the applicable requirements of Article 306.3.0, except as otherwise provided hereinafter and on the plans or in the proposals.

A. **Seasonal and Weather Limitations.** No surface as defined by this special provision shall be laid between November 15 and May 1, nor when the temperature is below 60°F, except by written permission of the Engineer, nor when the underlying course is wet, nor when other weather conditions are unsuitable.
B. Preparation of Mixture.

1. Composition of Mixture. The aggregate and asphalt cement shall be combined in such proportions that the composition of the mixture by volume shall be within the general limits for Class I, Type A Modified Surface given in the following table. A job-mix formula, within the specified composition limits, shall be established by the Engineer for each project; and the proportions and gradings so set shall be maintained within the tolerances specified hereinafter. The percentages passing all sieve sizes shall be determined by dry sieving. Once the job-mix formula has been established, it shall remain in effect until changed in writing by the Engineer. Deviations from the job-mix formula shall not exceed 0.5 percentage points in the asphalt content and 0.2 in fineness modulus of the sand gradation.

<table>
<thead>
<tr>
<th>Sieve</th>
<th>Percent Passing (Volume)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2 inch</td>
<td>100</td>
</tr>
<tr>
<td>3/8 inch</td>
<td>85-100</td>
</tr>
<tr>
<td>No. 4</td>
<td>60-80</td>
</tr>
<tr>
<td>No. 8</td>
<td>40-60</td>
</tr>
<tr>
<td>No. 16</td>
<td>25-50</td>
</tr>
<tr>
<td>No. 50</td>
<td>5-20</td>
</tr>
<tr>
<td>No. 100</td>
<td>3-12</td>
</tr>
<tr>
<td>No. 200</td>
<td>2-6</td>
</tr>
<tr>
<td>Percent, Bitumen</td>
<td>10-19</td>
</tr>
</tbody>
</table>

2. Field Control of Mixture. The relative percentages of the different aggregates in the mixture shall be controlled at the cold feeds. The "procedure for calibration and checking of cold feed flow on a bituminous hot-mix plant" as outlined in the Bituminous Manual shall be used. Aggregate samples for gradation analyses shall be taken from the hot bins. The procedure for "sampling of hot aggregate bins" as outlined in the Bituminous Manual shall be used. Samples from the bins shall be combined on a weight basis according to the particular design bin percentages. A volumetric sieve analysis of the combined aggregate shall then be performed according to the following procedure:

**TEST METHOD**

**VOLUMETRIC SIEVE ANALYSIS OF FINE AND COARSE AGGREGATES**

Scope:
This test method covers a procedure for the determination of the particle size distribution by volume of fine and coarse aggregate samples, using sieves with square openings. The method is also applicable for the sieve analysis of aggregate recovered from bituminous mixtures obtained from plant or roadway.

Apparatus:
1. Sample splitter, quartering cloth, shoveling method on clean surface, or quartering machine.
3. Mechanical Sieve Shaker.
4. Drying oven capable of attaining a temperature of 200°F or more.
5. Graduate -- a plastic cylinder with a capacity of 4,000 ml graduated in increments of 50 ml or less.
6. A wide-mouth funnel for transferring aggregates to graduate.
7. Solvent -- Benzol, trichloroethane.
8. Round pans with diameter to fit sieves.
9. Scoop, brass wire brush, and hair brush.
Preparation of Sample:
1. Select a representative portion of processed aggregate for test.
2. Place the aggregate in oven and dry to constant weight at a temperature of 140° to 300°F. Remove sample from oven and allow to cool to room temperature.
3. To quarter the material, use either the sample splitter, the quartering cloth, quartering machine, or the method of manipulating the aggregate with a large flat scoop or shovel, blending it back and forth on a smooth clean surface until blended and then quartering mechanically with some straightedge, thus reducing the dry aggregate sample to laboratory testing size. It is permissible to thoroughly blend the fine material and to take small portions from several places covering the entire area of the pan to make up the test sample. Approximately 3000 ml of aggregate shall be used.

Procedure:
1. Place the set of sieves, with the largest opening on top, into a pan and pour the aggregate onto the top sieve. Perform a sieve analysis on the aggregate sample by separating the material into a series of particle sizes using such sieves as are necessary to determine compliance with the specifications for the material. The hand sieve operation is done by means of a lateral and vertical motion of the sieves, accompanied by a jarring action so as to keep the material moving continuously over the surface of the sieves. In any case, do not turn or manipulate particles through the openings of the sieves by hand. Continue hand sieving until, by visual observation, no material continues to pass through the sieves in use. When mechanical sieving is used, shaking time should be established that will assure proper sieving of the material without degradation. Check the thoroughness of the sieving by the above described method.
2. Fill the graduate with solvent to a level to cover the entire sample of aggregate. Make an initial reading of the liquid level and record on work sheet. Place the aggregate retained on each sieve size and pan into the graduate, starting with the smallest size. After each size of aggregate is placed in the graduate, make a reading of the liquid level and record on the work sheet. For highly absorptive aggregates, each successive size of aggregates should be added at intervals of approximately 30 seconds and the liquid level reading taken approximately 15 seconds after each addition of aggregate. The same timing should be used on each test so that results will be comparable.
   Care should be taken to eliminate entrapped air in the graduate, particularly after the fine aggregate is added. This can be done by gently rolling the graduate or stirring the aggregate prior to taking a reading of liquid level. After each test is completed, the solvent may be decanted or filtered and saved for reuse.
   By subtracting the liquid reading prior to the addition of each size of aggregate from the liquid reading after the addition of aggregate, the volume of each size of aggregate may be determined. This information is to be entered in Column 3 of the work sheet. The difference in initial and final readings will be the total volume of the aggregate. Divide each volume of aggregate by total aggregate volume to determine percent retained on each sieve and enter in Column 4. This percent will be an expression of each size as a portion of the total aggregate. The cumulative percent passing each sieve is then calculated and entered in Column 5. This gradation in Column 5 is to be compared with the volumetric composition limits for compliance with the specifications.
   Asphalt content determination shall be made in accordance with the standard procedure. The asphalt content as determined by weight shall then be transformed to a volumetric percentage based on the volume of the total mixture. Sample calculations follows:
   A. Asphalt Content (by weight) by extraction = 9.4% 
   B. Specific Gravity of Asphalt = 1.026 
   C. Specific Gravity of aggregate combination = 1.867 
   \[(9.4/1.026) + (100-9.4) / 1.867 = 9.2 + 48.5 = 57.7\] 
   D. Asphalt Content (by volume) = 9.2/57.7 = 15.9%

The volumetric asphalt content is to be compared with the volumetric composition limits for compliance with the specifications.
**VOLUMETRIC SIEVE ANALYSIS**

**WORK SHEET**

Date 5-12-71  Sample No. 3  Design No. 1-D

Time 1:15  Type A-Mod.  Station No. 1519+00

Spec. Item  Project C 123-4-5

% Of Aggregate In Total Mix 90.0  (100% – % Asphalt)

Initial Reading Of Liquid Level 1000 ml.

<table>
<thead>
<tr>
<th>Aggregate Size</th>
<th>Reading of Liquid Level After Addition</th>
<th>Volume of Aggregate ml. Retained</th>
<th>Volume of Aggregate Retained % of Total Aggregate</th>
<th>Volume of Aggregate Retained % of Total Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2 inch</td>
<td>3950</td>
<td>0</td>
<td>0</td>
<td>100.0</td>
</tr>
<tr>
<td>3/8 inch</td>
<td>3950</td>
<td>150</td>
<td>5.1</td>
<td>94.9</td>
</tr>
<tr>
<td>No. 4</td>
<td>3600</td>
<td>950</td>
<td>32.1</td>
<td>62.8</td>
</tr>
<tr>
<td>No. 8</td>
<td>2850</td>
<td>500</td>
<td>17.0</td>
<td>45.8</td>
</tr>
<tr>
<td>No. 16</td>
<td>2350</td>
<td>450</td>
<td>15.2</td>
<td>30.6</td>
</tr>
<tr>
<td>No. 30</td>
<td>1900</td>
<td>350</td>
<td>11.9</td>
<td>18.7</td>
</tr>
<tr>
<td>No. 50</td>
<td>1550</td>
<td>250</td>
<td>8.5</td>
<td>10.2</td>
</tr>
<tr>
<td>No. 100</td>
<td>1300</td>
<td>200</td>
<td>6.8</td>
<td>3.4</td>
</tr>
<tr>
<td>No. 200</td>
<td>1100</td>
<td>100</td>
<td>3.4</td>
<td>0</td>
</tr>
<tr>
<td>Pan</td>
<td>1000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2950</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Place Smallest Size in Cylinder First, then Next Larger Size, etc.
2. Preparation of Aggregates. If aggregates from two or more sources are blended, they shall be metered from individual cold bins in such proportions that will yield a product having the specified composition and gradation. The aggregates shall be uniformly dried and heated to a temperature of not less than 280°F nor more than 325°F. If mineral filler is used, it shall be weighed or metered into the mix from a separate bin.

3. Temperature Requirements. Unless otherwise approved by the Engineer, the temperatures of the materials and the mixtures, in degrees Fahrenheit, shall be maintained within the ranges given in the following table:

<table>
<thead>
<tr>
<th>Material</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregates</td>
<td>280</td>
<td>325</td>
</tr>
<tr>
<td>Asphalt Cement</td>
<td>265</td>
<td>325</td>
</tr>
<tr>
<td>Mixture at Plant</td>
<td>280</td>
<td>325</td>
</tr>
<tr>
<td>Mixture When Laid</td>
<td>280</td>
<td>310</td>
</tr>
</tbody>
</table>

C. Spreading and Finishing.

1. Paver Speed. Unless otherwise directed by the Engineer, the paver when placing the surface mix shall maintain a speed of 22 feet per minute, plus or minus 8 feet per minute.

2. Continuous Paver Operation. The plant production and paver speed shall be synchronized in such a manner which will permit the paver to travel in a uniform continuous forward speed within the limits as required hereinbefore. The paver shall engage the hauling trucks while traveling forward. Every effort shall be made to keep the paver moving continuously. The paver should be permitted to stop only when a plant or paver breaks down or when some emergency or unavoidable conditions exists.

3. Entrances and Crossovers. Entrances, crossovers, and other areas inaccessible to the paver which must be spread by hand, whether constructed of this mixture or another surface mixture, shall be constructed as a separate operation. The material for these areas shall be placed directly from the trucks. The paver shall not be stopped, side plates removed, and the material for these areas allowed to spill out to the side, or the paver shall not be stopped and material for these areas shoveled from the hopper.

4. Pavement Samples. Samples shall not be cut from the pavement unless directed by the Engineer.

5. Compaction. Unless otherwise directed or permitted by the Engineer, compaction, including breakdown rolling, shall be accomplished with a 3-wheel roller or a tandem roller weighing not less than 8 tons. Entrances, crossovers, and other inaccessible areas spread by hand shall be compacted with a roller weighing not less than 3 tons.

6. Leveling and Patching. Leveling and patching shall be performed in a manner, with the designated equipment, and with the materials as prescribed on the plans or in the proposal.

IV. METHOD OF MEASUREMENT

The mixture will be weighed in accordance with Article 1.9.1. Bituminous material, except that used in the mixture, will be measured in gallons as specified in Section 621.
V. BASIS OF PAYMENT

The quantities thus measured and accepted, complete and in place, will be paid for at the contract unit price bid per gallon for "Bituminous Materials" and per ton for "Bituminous Mixture," which payment shall be full compensation for cleaning surface; for furnishing, hauling, and placing all materials, including the silicone fluid; and for all labor, equipment, tools, and incidentals necessary to complete the work.

APPROVED

STATE HIGHWAY ENGINEER
APPENDIX C

SPECIAL PROVISION NO. 58
OPEN-GRADED, MEDIUM SILICA
SAND-ASPHALT SURFACE

SPECIAL PROVISION NO. 59
OPEN-GRADED, HIGH SILICA
SAND-ASPHALT SURFACE

SPECIAL PROVISIONS NO. 59 A, B, C, D, AND E
SAND-ASPHALT SURFACE (SKID RESISTANT)

SPECIAL PROVISION NO. 60
SIMULATED KENTUCKY ROCK-ASPHALT SURFACE

SPECIAL PROVISIONS NO. 109 A AND B
OPEN-GRADED FRICTION COURSES (PLANT MIX SEALS)
This Special Provision covers the material requirements and construction methods for Hot-Mixed, Hot-Laid, Sand-Asphalt, Surface Course and shall be applicable to individual projects only when indicated on plans, proposals, or bidding invitations; and, when so indicated, it shall supersede all conflicting provisions of the Department's current Standard Specifications for Road and Bridge Construction. References herein are to the Department's Standard Specifications and approved addenda thereto.

I. DESCRIPTION

Hot-Mixed, Hot-Laid, Sand-Asphalt is intended to provide a fine-textured, skid-resistant, wearing surface for pavements and bases. Fifty percent of the sand therein shall consist of quartz (SiO₂). The remaining proportion of the sand shall consist of crushed limestone. The sand, bituminous material, and the mixing and application thereof shall be in accordance with the respective requirements hereinafter described. The mixture shall be applied to the nominal, compacted thickness indicated on the plans or in the proposal; and the finished surface shall conform with the lines and grades shown on the plans or proposals.

II. MATERIALS

A. Requirements.

1. Bituminous Materials. The asphalt cement to be mixed with the sand shall be PAC-3 and shall meet the particular requirements of Section 621. The quantity of asphalt cement used shall be as directed by the Engineer.

Bituminous material for the tack coat shall be SS-1h meeting the particular requirements of Section 621. The SS-1h shall be prepared for application by dilution with an equal volume of potable water.
2. Aggregate. The aggregate shall consist, by weight, of not less than 50 percent quartz (SiO₂). Quartz, to fulfill this requirement, shall be obtained from crushed sandstone, conglomeratic sand, bank sand, river sand or combinations thereof. The remaining portion of aggregate shall consist of limestone sand. Unless otherwise provided, mineral filler meeting the requirements of Article 611.5.0 for quality may comprise not more than 3 percent of the aggregate combination. Each aggregate, except mineral filler, shall have a minimum Sand-Equivalent value of 10 as determined by AASHO T 176, and the total combined aggregate, including mineral filler, shall have a minimum Sand-Equivalent value of 35. Deleterious substances retained on the No. 200 sieve shall not exceed the following percentages by weight of the total combined aggregate.

Percent by Weight

<table>
<thead>
<tr>
<th>Clay lumps</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>Other deleterious substances such as, but not limited to, alkali, mica, shale, coated grains, soft and flaky particles</td>
<td>1.0</td>
</tr>
</tbody>
</table>

3. Admixture. A moisture controlling admixture such as silicone fluid (dimethyl siloxane) shall be furnished by the Contractor to be blended with the mix when and as directed by the Engineer.

B. Approval of Materials.

Silicone shall be of a type approved by the Department and shall be from a source approved by the Department.

At least two weeks prior to commencing production, the Contractor shall notify the Engineer that the aggregates, including blended natural sand if used, have been stocked at the job site. Prior to notification, at least 500 tons or one-half the anticipated quantity requirement, whichever is least, of each aggregate shall be stocked.

III. CONSTRUCTION METHODS

The construction methods shall comply with the applicable requirements of Article 306.3.0, except as otherwise provided hereinafter and on the plans or in the proposals.

A. Seasonal and Weather Limitations. No sand-asphalt surface as defined by this special provision shall be laid between September 30 and May 1, nor when the temperature is below 60 degrees F., except by written permission of the Engineer, nor when the underlying course is wet, nor when other weather conditions are unsuitable.
B. Preparation of Mixture.

1. Composition of Mixture. The sand and asphalt cement shall be combined in such proportions that the composition of the mixture by weight shall be within the general limits given in the following table. A job-mix formula, within the specified composition limits, shall be established by the Engineer for each project; and the proportions and gradings so set shall be maintained within the tolerances specified hereinafter. The percentages passing all sieve sizes shall be determined by dry sieving. These permissible tolerances from the job-mix formula shall not permit the use of any mixture which will be outside the specified composition limits. Once the job-mix formula has been established, it shall remain in effect until changed in writing by the Engineer. Deviations from the job-mix formula shall not exceed 0.5 percentage points in the asphalt content and 0.2 in fineness modulus of the sand gradation.

<table>
<thead>
<tr>
<th>Sieve</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4 inch</td>
<td>100</td>
</tr>
<tr>
<td>No. 8</td>
<td>88-100</td>
</tr>
<tr>
<td>No. 16</td>
<td>80-100</td>
</tr>
<tr>
<td>No. 30</td>
<td>60-95</td>
</tr>
<tr>
<td>No. 100</td>
<td>1-20</td>
</tr>
<tr>
<td>No. 200</td>
<td>0-3</td>
</tr>
<tr>
<td>Percent Bitumen</td>
<td>7-10</td>
</tr>
</tbody>
</table>

2. Preparation of Aggregates. If sands from two or more sources are blended, they shall be metered from individual cold bins in such proportions that will yield a product having the specified gradation. The sand shall be uniformly dried and heated to a temperature of not less than 280°F. nor more than 325°F. If mineral filler is used, it shall be weighed or metered into the mix from a separate bin.

3. Temperature Requirements. Unless otherwise approved by the Engineer, the temperatures of the materials and the mixtures, in degrees Fahrenheit, shall be maintained within the ranges given in the following table:

<table>
<thead>
<tr>
<th>Mixing and Laying Temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregates.................Min. 280 - Max. 325</td>
</tr>
<tr>
<td>Asphalt Cement..............Min. 265 - Max. 325</td>
</tr>
<tr>
<td>Mixture at Plant............Min. 280 - Max. 325</td>
</tr>
<tr>
<td>Mixture When Laid...........Min. 280 - Max. 310</td>
</tr>
</tbody>
</table>
C. Spreading and Finishing.

1. Paver Speed. Unless otherwise directed by the Engineer, the paver when placing the surface mix shall maintain a speed of 22 feet per minute, plus or minus 8 feet per minute.

2. Continuous Paver Operation. The plant production and the paver speed shall be synchronized in such a manner which will permit the paver to travel in a uniform continuous forward speed within the limits as required herein before. The paver shall engage the hauling trucks while traveling forward. Every effort shall be made to keep the paver moving continuously. The paver should be permitted to stop only when a plant or paver breaks down or when some emergency or unavoidable condition exists.

3. Entrances and Crossovers. Entrances, crossovers, and other areas inaccessible to the paver which must be spread by hand, whether constructed of sand-asphalt or other surface mixture, shall be constructed as a separate operation. The material for these areas shall be placed directly from the trucks. The paver shall not be stopped, side plates removed, and the material for these areas allowed to spill out to the side, or the paver shall not be stopped and material for these areas shoveled from the hopper.

4. Pavement Samples. Samples shall not be cut from the pavement unless directed by the Engineer.

5. Compaction. Unless otherwise directed or permitted by the Engineer, compaction, including breakdown rolling, shall be accomplished with a 3-wheel roller or a tandem roller weighing not less than 8 tons. Entrances, crossovers, and other inaccessible areas spread by hand shall be compacted with a roller weighing not less than 3 tons.

6. Leveling and Patching. Leveling and patching shall be performed in a manner, with the designated equipment and with the materials, as prescribed on the plans or in the proposal.

IV. METHOD OF MEASUREMENT

The sand asphalt will be weighed in accordance with Article 1.9.1. Bituminous material, except that used in the sand-asphalt mixture, will be measured in gallons as specified in Section 621.
V. BASIS OF PAYMENT

The quantities thus measured and accepted, complete and in place, will be paid for at the contract unit price bid per gallon for "Bituminous Materials," per ton for "Sand-Asphalt Mixture;" which payment shall be full compensation for cleaning surface, for furnishing, hauling, and placing all materials, including the silicone fluid, and for all labor, equipment, tools, and incidentals necessary to complete the work.

APPROVED October 10, 1967

A. O. NEISER
STATE HIGHWAY ENGINEER
COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS

SPECIAL PROVISION NO. 59
FOR
OPEN-GRADED, HIGH SILICA SAND-ASPHALT SURFACE

This Special Provision covers the material requirements and construction methods for Hot-Mixed, Hot-Laid, Sand-Asphalt, Surface Course and shall be applicable to individual projects only when indicated on plans, proposals, or bidding invitations; and, when so indicated, it shall supersede all conflicting provisions of the Department's current Standard Specifications for Road and Bridge Construction. References herein are to the Department's Standard Specifications and approved addenda thereto.

I. DESCRIPTION

Hot-Mixed, Hot-Laid, Sand-Asphalt is intended to provide a fine-textured, skid-resistant, wearing surface for pavements and bases. At least 85 percent of the sand therein shall consist of quartz (SiO₂). No portion of the sand may consist of crushed limestone or slag sand. The sand, bituminous material, and the mixing and application thereof shall be in accordance with the respective requirements hereinafter described. The mixture shall be applied to the nominal, compacted thickness indicated on the plans or in the proposal; and the finished surface shall conform with the lines and grades shown on the plans or proposals.

II. MATERIALS

A. Requirements.

1. Bituminous Materials. The asphalt cement to be mixed with the sand shall be PAC-3 and shall meet the particular requirements of Section 621. The quantity of asphalt cement used shall be as directed by the Engineer.

Bituminous material for the tack coat shall be SS-1h meeting the particular requirements of Section 621. The SS-1h shall be prepared for application by dilution with an equal volume of potable water.
2. **Aggregate.** The aggregate shall consist, by weight, of not less than 85 percent quartz (SiO₂). Quartz, to fulfill this requirement, shall be obtained from crushed sandstone, conglomeratic sand, bank sand, river sand or combinations thereof. Unless otherwise provided, mineral filler meeting the requirements of Article 611.5.0 for quality may comprise not more than 3 percent of the aggregate combination. Each aggregate, except mineral filler, shall have a minimum Sand-Equivalent value of 10 as determined by AASHO T 176, and the total combined aggregate, including mineral filler, shall have a minimum Sand-Equivalent value of 35. Deleterious substances retained on the No. 200 sieve shall not exceed the following percentages by weight of the total combined aggregate.

<table>
<thead>
<tr>
<th>Percent by Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay lumps..........................None</td>
</tr>
<tr>
<td>Other deleterious substances such as, but not limited to, alkali, mica, shale, coated grains, soft and flaky particles...........1.0</td>
</tr>
</tbody>
</table>

3. **Admixture.** A moisture controlling admixture such as silicone fluid (dimethyl siloxane) shall be furnished by the Contractor to be blended with the mix when and as directed by the Engineer.

**B. Approval of Materials.**

Silicone shall be of a type approved by the Department and shall be from a source approved by the Department.

At least two weeks prior to commencing production, the Contractor shall notify the Engineer that the aggregates, including blended natural sand if used, have been stocked at the job site. Prior to notification, at least 500 tons or one-half the anticipated quantity requirement, whichever is least, of each aggregate shall be stocked.

### III. CONSTRUCTION METHODS

The construction methods shall comply with the applicable requirements of Article 306.3.0, except as otherwise provided hereinafter and on the plans or in the proposals.

**A. Seasonal and Weather Limitations.** No sand-asphalt surface as defined by this special provision shall be laid between September 30 and May 1, nor when the temperature is below 60 degrees F., except by written permission of the Engineer, nor when the underlying course is wet, nor when other weather conditions are unsuitable.
B. Preparation of Mixture.

1. Composition of Mixture. The sand and asphalt cement shall be combined in such proportions that the composition of the mixture by weight shall be within the general limits given in the following table. A job-mix formula, within the specified composition limits, shall be established by the Engineer for each project; and the proportions and gradings so set shall be maintained within the tolerances specified hereinafter. The percentages passing all sieve sizes shall be determined by dry sieving. These permissible tolerances shall not permit the use of any mixture which will be outside the specified composition limits. Once the job-mix formula has been established, it shall remain in effect until changed in writing by the Engineer. Deviations from the job-mix formula shall not exceed 0.5 percentage points in the asphalt content and 0.2 in fineness modulus of the sand gradation.

### Composition Limits

<table>
<thead>
<tr>
<th>Sieve</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4 inch</td>
<td>100</td>
</tr>
<tr>
<td>No. 8</td>
<td>88-100</td>
</tr>
<tr>
<td>No. 16</td>
<td>80-100</td>
</tr>
<tr>
<td>No. 30</td>
<td>60-95</td>
</tr>
<tr>
<td>No. 100</td>
<td>1-20</td>
</tr>
<tr>
<td>No. 200</td>
<td>0-3</td>
</tr>
<tr>
<td>Percent Bitumen</td>
<td>7-10</td>
</tr>
</tbody>
</table>

2. Preparation of Aggregates. If sands from two or more sources are blended, they shall be metered from individual cold bins in such proportions that will yield a product having the specified gradation. The sand shall be uniformly dried and heated to a temperature of not less than 280°F. nor more than 325°F. If mineral filler is used, it shall be weighed or metered into the mix from a separate bin.

3. Temperature Requirements. Unless otherwise approved by the Engineer, the temperatures of the materials and the mixtures, in degrees Fahrenheit, shall be maintained within the ranges given in the following table:

### Mixing and Laying Temperatures

- Aggregates..............Min. 280 - Max. 325
- Asphalt Cement...........Min. 265 - Max. 325
- Mixture at Plant........Min. 280 - Max. 325
- Mixture When Laid......Min. 280 - Max. 310
C. Spreading and Finishing.

1. Paver Speed. Unless otherwise directed by the Engineer, the paver when placing the surface mix shall maintain a speed of 22 feet per minute, plus or minus 8 feet per minute.

2. Continuous Paver Operation. The plant production and the paver speed shall be synchronized in such a manner which will permit the paver to travel in a uniform continuous forward speed within the limits as required herein before. The paver shall engage the hauling trucks while traveling forward. Every effort shall be made to keep the paver moving continuously. The paver should be permitted to stop only when a plant or paver breaks down or when some emergency or unavoidable condition exists.

3. Entrances and Crossovers. Entrances, crossovers, and other areas inaccessible to the paver which must be spread by hand, whether constructed of sand asphalt or other surface mixture, shall be constructed as a separate operation. The material for these areas shall be placed directly from the trucks. The paver shall not be stopped, side plates removed, and the material for these areas allowed to spill out to the side, or the paver shall not be stopped and material for these areas shoveled from the hopper.

4. Pavement Samples. Samples shall not be cut from the pavement unless directed by the Engineer.

5. Compaction. Unless otherwise directed or permitted by the Engineer, compaction, including breakdown rolling, shall be accomplished with a 3-wheel roller or a tandem roller weighing not less than 8 tons. Entrances, crossovers and other inaccessible areas spread by hand shall be compacted with a roller weighing not less than 3 tons.

6. Leveling and Patching. Leveling and patching shall be performed in a manner, with the designated equipment and with the materials, as prescribed on the plans or in the proposal.

IV. METHOD OF MEASUREMENT

The sand asphalt will be weighed in accordance with Article 1.9.1. Bituminous material, except that used in the sand-asphalt mixture, will be measured in gallons as specified in Section 621.
V. BASIS OF PAYMENT

The quantities thus measured and accepted, complete and in place, will be paid for at the contract unit price bid per gallon for "Bituminous Materials," per ton for "Sand-Asphalt Mixture;" which payment shall be full compensation for cleaning surface, for furnishing, hauling, and placing all materials, including the silicone fluid, and for all labor, equipment, tools, and incidentals necessary to complete the work.

APPROVED October 10, 1967

A. O. NEISER
STATE HIGHWAY ENGINEER
KENTUCKY DEPARTMENT OF HIGHWAYS
SPECIAL PROVISION NO. 59-A
SAND-ASPHALT SURFACE (SKID RESISTANT)

This Special Provision shall be applicable when indicated in the plans or proposal, and shall supersede any conflicting requirements of the Department's 1963 Standard Specifications for Road and Bridge Construction. Section and Article references herein are to the Standard Specifications.

I. DESCRIPTION

This work shall consist of the construction of one course of hot-mixed, hot-laid Sand-Asphalt Surface mixture upon a satisfactory foundation of either new or existing pavements. The thickness of the course shall be approximately 3/4 inch and the sand-asphalt mixture shall be laid at the approximate rate of 65 lbs./sq. yd. All leveling, wedging, and patching deemed necessary by the Engineer to repair an existing pavement so it will provide a smooth uniform satisfactory foundation shall be performed before the construction of this surface course is started.

This sand-asphalt mixture is intended to provide a fine-textured, skid-resistant, wearing surface for vehicular traffic. Special attention shall be given to all aspects of the work to insure that only top-quality materials, equipment, and workmanship are utilized at all times, and that the finish surface is in close conformity to the lines, grades, and sections indicated in the plans and/or proposal.

II. MATERIALS

All materials for use in this work must be sampled, tested, and approved prior to starting the production of the sand-asphalt mixture.

Since the angular high-silica sand required for this work is a select material, the Department, upon request by Contractors qualified to bid on the work, will test a reasonable number of source samples of sands furnished by the Contractors, for informational purposes only, prior to the date of the opening of bids for the contract. However, tests of the actual sand subsequently stockpiled at the plant site by the Contractor who is the successful bidder will be made to determine the acceptability of the sand for the work.

The Contractor for the work shall stockpile sand at the plant site for sampling at least 1 week before starting plant operations. Either 500 tons or enough of the sand to supply one-half of the tonnage of mixture specified in the contract, whichever is least, shall be stockpiled.

A. The bituminous material for the tack coat shall be SS-1h conforming to AASHO M 140 except that the maximum penetration shall not exceed 100.

B. The asphalt cement for the sand-asphalt mixture shall be AC-20 conforming to the current edition of AASHO M 220.

C. The sand for the sand-asphalt mixture shall be a select angular high-silica material containing at least 94 percent quartz (SiO₂) by chemical analysis in accordance with Kentucky Test Method 64-224. The quartz (SiO₂) content determination will be made on the portion of the sand retained on all sieves down to and including the No. 100 sieve, exclusive of any mineral filler in that portion. The sand shall preferably be the product of crushed siliceous material, but may be comprised either of natural materials or crushed materials, or a combination of both, provided that the gradation and angularity of the sand are consistently uniform and conform to the specified requirements. A maximum of 5 percent mineral filler may be incorporated into the sand in order for the sand to conform to the specified gradation.

The gradation of the sand by dry sieving shall be as follows:

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 4</td>
<td>100</td>
</tr>
<tr>
<td>No. 8</td>
<td>80-100</td>
</tr>
<tr>
<td>No. 16</td>
<td>65-95</td>
</tr>
<tr>
<td>No. 30</td>
<td>50-90</td>
</tr>
<tr>
<td>No. 50</td>
<td>20-65</td>
</tr>
<tr>
<td>No. 100</td>
<td>3-20</td>
</tr>
<tr>
<td>No. 200</td>
<td>2-4</td>
</tr>
</tbody>
</table>

Sand that has marginal passing values for either the quartz (SiO₂) content, gradation, or voids content will not be approved for use if the Engineer anticipates that difficulty will be experienced by the Contractor in consistently producing a uniform product in the quantities necessary to supply a continuous paving operation.

D. Mineral filler, if used, shall conform to the quality requirements of Article 611.5.0 and shall not be fly ash.

E. Silica shall be of a type and source approved by the Engineer, and shall be furnished and used as directed by the Engineer.

III. CONSTRUCTION METHODS

Every requirement contained in Articles 306.3.1 through 306.3.10 that is applicable to this type of work shall be in force except as provided herein and in the plans and proposal.

The materials, equipment, and methods for leveling, wedging, and patching shall be those designated in the proposal. The leveling and wedging shall be constructed as specified in Article 306.3.8 and shall be constructed to within plus or minus 1/4 inch of the desired elevation determined by a stringline measurement or by a template. The Contractor shall furnish any templates in accordance with Article 306.3.3. The leveling, wedging, and patching operations are particularly significant to the satisfactory performance of this type of surface mixture, and every reasonable effort shall be made to provide a uniform, stable, and even surface as a foundation for this sand-asphalt course.

A. Tack Coat. The SS-1h for tack coat shall be diluted with an equal amount of water conforming to Section 603 and thoroughly mixed prior to application. The diluted SS-1h shall be applied at an approximate rate of 0.1 gal./sq. yd. and a sufficient time and distance in advance of the paver to insure that all the water has escaped and evaporated before any of the mixture is laid on the tacked surface. The sand-asphalt mixture shall not be laid on the tacked surface until authorized by the Engineer.
B. Seasonal and Weather Limitations. The sand-asphalt mixture shall not be laid between October 15 and May 1. From May 1 to October 15 the sand-asphalt mixture shall be laid only at times when all weather conditions are very favorable in the judgment of the Engineer, when the atmospheric temperature is above 60° F., and when the underlying pavement is dry and clean except for the tack coat.

C. Preparation of Sand-Asphalt Mixture. The sand-asphalt mixture shall be prepared by combining the approved sand with asphalt cement in the percentages established by the Engineer. The percentage by weight of asphalt cement in the mixture will be established between 6 and 10 percent. The gradation limits for the mixture are the same as those specified for the sand and the Engineer will establish a job-mix formula within the specified sand gradation and asphalt content limits. Deviations from the established asphalt content shall not exceed 0.5 percent, and the fineness modulus of the sand shall not vary more than 0.2 from the value established by the job-mix formula.

1. If the sand for the mixture is a blend of two or more materials, the materials shall be supplied from individual cold bins in the proportions established by the Engineer.

2. The temperatures of the materials and the mixture, in degrees Fahrenheit, shall be maintained within the following ranges:

<table>
<thead>
<tr>
<th>Material</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>280</td>
<td>350</td>
</tr>
<tr>
<td>Asphalt Cement</td>
<td>275</td>
<td>325</td>
</tr>
<tr>
<td>Mixture at Plant*</td>
<td>280</td>
<td>325</td>
</tr>
<tr>
<td>Mixture when Laid</td>
<td>265</td>
<td>325</td>
</tr>
</tbody>
</table>

*The mixture shall be maintained within a range of ± 15°F from the temperature designated by the Engineer.

D. Insofar as practical, the paver shall be operated at a constant forward speed that will produce a smooth uniform mat free from tears, open areas, and other imperfections.

E. All intersections, approaches, entrances, aprons, mailbox turnouts, and other incidental areas that are to be surfaced as a part of the work shall be surfaced either before or after the laying of the sand-asphalt surface course on the mainline, so as not to detract from nor interfere with the paver operations in any manner while this course is being applied to the traffic lanes.

F. Tandem rollers weighing not less than 5 nor more than 8 tons shall be used for the compaction of the sand-asphalt surface mixture and the surfacing of the incidental areas.

G. Vehicular traffic shall not be permitted to use the compacted sand-asphalt mixture until it has cooled sufficiently to withstand the traffic without any damage. Intersections and any other areas which must be reopened to traffic soon after the sand-asphalt mixture has been compacted shall be thoroughly sprayed with water so as to hasten the cooling of the compacted mixture to atmospheric temperature before it is subjected to traffic. Any adjacent areas to receive the sand-asphalt course which are wetted by the water shall be allowed to thoroughly dry before the sand-asphalt course is laid.

IV. METHOD OF MEASUREMENT

The sand-asphalt mixture will be measured in tons in accordance with Article 19.9.1. The bituminous material for tack coat will be measured in gallons in accordance with Section 621.

V. BASIS OF PAYMENT

The accepted quantities of sand-asphalt mixture and bituminous material for tack coat will be paid for in accordance with Article 306.5.0 except that any silicone for the mixture and the water for diluting the SS-1h and for cooling the pavement will be considered as incidentals and will not be paid for separately.

APPROVED March 10, 1972

[Signature]
STATE HIGHWAY ENGINEER
This Special Provision shall be applicable when indicated in the plans or proposal, and shall supersede any conflicting requirements of the Department's 1965 Standard Specifications for Road and Bridge Construction. Section and Article references herein are to the Standard Specifications.

I. DESCRIPTION

This work shall consist of the construction of one course of hot-mixed, hot-laid Sand-Asphalt Surface mixture upon a satisfactory foundation of either new or existing pavements. The thickness of the course shall be approximately 3/4 inch and the sand-asphalt mixture shall be laid at the approximate rate of 65 lbs./sq. yd. All leveling, wedging, and patching deemed necessary by the Engineer to repair an existing pavement so it will provide a smooth uniform satisfactory foundation shall be performed before the construction of this surface course is started.

This sand-asphalt mixture is intended to provide a fine-textured, skid-resistant, wearing surface for vehicular traffic. Special attention shall be given to all aspects of the work to insure that only top-quality materials, equipment, and workmanship are utilized at all times, and that the finish surface is in close conformity to the lines, grades, and sections indicated in the plans and/or proposal.

II. MATERIALS

All materials for use in this work must be sampled, tested, and approved prior to starting the production of the sand-asphalt mixture.

Since the angular high-silica sand required for this work is a select material, the Department, upon request by Contractors qualified to bid on the work, will test a reasonable number of source samples of sands furnished by the Contractors, for informational purposes only, prior to the date of the opening of bids for the contract. However, tests of the actual sand subsequently stockpiled at the plant site by the Contractor who is the successful bidder will be made to determine the acceptability of the sand for the work.

The Contractor for the work shall stockpile sand at the plant site for sampling at least 1 week before starting plant operations. Either 500 tons or enough of the sand to supply one-half of the tonnage of mixture specified in the contract, whichever is less, shall be stockpiled.

D. Mineral filler, if used, shall conform to the quality requirements of Article 611.5.0 and shall not be fly ash.

E. Silicone shall be of a type and source approved by the Engineer, and shall be furnished and used as directed by the Engineer.

III. CONSTRUCTION METHODS

Every requirement contained in Articles 306.3.1 through 306.3.10 that is applicable to this type of work shall be in force except as provided herein and in the plans and proposal.

The materials, equipment, and methods for leveling, wedging, and patching shall be those designated in the proposal. The leveling and wedging shall be constructed as specified in Article 306.3.8 and shall be constructed to within plus or minus 1/4 inch of the desired elevation as determined by a stringline measurement or by a template. The Contractor shall furnish any templates in accordance with Article 306.3.2. The leveling, wedging, and patching operations are particularly significant to the satisfactory performance of this type of surface mixture, and every reasonable effort shall be made to provide a uniform, stable, and even surface as a foundation for this sand-asphalt course.

A. Tack Coat. The SS-1h for tack coat shall be diluted with an equal amount of water conforming to Section 603 and thoroughly mixed prior to application. The diluted SS-1h shall be applied at an approximate rate of 0.1 gal./sq. yd. and a sufficient time and distance in advance of the paver to insure that all the water has escaped and evaporated before any of the mixture is laid on the tacked surface. The sand-asphalt mixture shall not be laid on the tacked surface until authorized by the Engineer.
B. Seasonal and Weather Limitations. The sand-asphalt mixture shall not be laid between October 15 and May 1. From May 1 to October 15 the sand-asphalt mixture shall be laid only at times when all weather conditions are very favorable in the judgment of the Engineer, when the atmospheric temperature is above 60°F, and when the underlying pavement is dry and clean except for the tack coat.

C. Preparation of Sand-Asphalt Mixture. The sand-asphalt mixture shall be prepared by combining the approved sand with asphalt cement in the percentages established by the Engineer. The percentage by weight of asphalt cement in the mixture will be established between 6 and 10 percent. The gradation limits for the mixture are the same as those specified for the sand and the Engineer will establish a job-mix formula within the specified sand gradation and asphalt content limits. Deviations from the established asphalt content shall not exceed 0.5 percent, and the fineness modulus of the sand shall not vary more than 0.2 from the value established by the job-mix formula.

IV. METHOD OF MEASUREMENT

The sand-asphalt mixture will be measured in tons in accordance with Article 1.9.1. The bituminous material for tack coat will be measured in gallons in accordance with Section 621.

V. BASIS OF PAYMENT

The accepted quantities of sand-asphalt mixture and bituminous material for tack coat will be paid for in accordance with Article 306.5,0 except that any silicone for the mixture and the water for diluting the SS-1h and for cooling the pavement will be considered as incidental and will not be paid for separately.

APPROVED 5-10-72

J. R. HARBLON
STATE HIGHWAY ENGINEER

1. If the sand for the mixture is a blend of two or more materials, the materials shall be supplied from individual cold bins in the proportions established by the Engineer.

2. The temperatures of the materials and the mixture, in degrees Fahrenheit, shall be maintained within the following ranges:

<table>
<thead>
<tr>
<th>Material</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>280</td>
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<tr>
<td>Mixture when Laid</td>
<td>265</td>
<td>325</td>
</tr>
</tbody>
</table>

*The mixture shall be maintained within a range of ± 15°F from the temperature designated by the Engineer.

D. Insofar as practical, the paver shall be operated at a constant forward speed that will produce a smooth uniform mat free from tears, open areas, and other imperfections.

E. All intersections, approaches, entrances, aprons, mailbox turnouts, and other incidental areas that are to be surfaced as a part of the work shall be surfaced either before or after the laying of the sand-asphalt surface course on the mainline, so as not to detract from nor interfere with the paver operations in any manner while this course is being applied to the traffic lanes.

F. Tandem rollers weighing not less than 5 nor more than 8 tons shall be used for the compaction of the sand-asphalt surface mixture and the surfacing of the incidental areas.

G. Vehicular traffic shall not be permitted to use the compacted sand-asphalt mixture until it has cooled sufficiently to withstand the traffic without any damage. Intersections and any other areas which must be reopened to traffic soon after the sand-asphalt mixture has been compacted shall be thoroughly sprayed with water so as to hasten the cooling of the compacted mixture to atmospheric temperature before it is subjected to traffic.
This Special Provision shall be applicable when indicated in the plans or proposal, and shall supersede any conflicting requirements of the Department's 1965 Standard Specifications for Road and Bridge Construction. Section and Article references herein are to the Standard Specifications.

I. DESCRIPTION

This work shall consist of the construction of one course of hot-mixed, hot-laid Sand-Asphalt Surface mixture upon a satisfactory foundation of either new or existing pavements. The thickness of the course shall be approximately 3/4 inch and the sand-asphalt mixture shall be laid at the approximate rate of 65 lbs./sq. yd. All leveling, wedging, and patching deemed necessary by the Engineer to repair an existing pavement so it will provide a smooth uniform satisfactory foundation shall be performed before the construction of this surface course is started.

This sand-asphalt mixture is intended to provide a fine-textured, skid-resistant, wearing surface for vehicular traffic. Special attention shall be given to all aspects of the work to insure that only top-quality materials, equipment, and workmanship are utilized at all times, and that the finish surface is in close conformity to the lines, grades, and sections indicated in the plans and/or proposal.

II. MATERIALS

All materials used for this work must be sampled, tested, and approved prior to starting the production of the sand-asphalt mixture.

The Contractor shall stockpile sand at the plant site for sampling at least 1 week before starting plant operations. Either 500 tons or enough of the sand to supply one-half of the tonnage of mixture specified in the contract, whichever is least, shall be stockpiled.

A. The bituminous material for the tack coat shall conform to the requirements in the plans and proposal.

B. The asphalt cement for the sand-asphalt mixture shall conform to the requirements in the plans and proposal.

C. The sand for the sand-asphalt mixture shall be a select angular high-silica material containing at least 94 percent quartz (SiO₂) by chemical analysis in accordance with Kentucky Test Method 64-224. The quartz (SiO₂) content determination will be made on the portion of the sand retained on all sieves down to and including the No. 100 sieve, exclusive of any mineral filler in that portion. The sand shall preferably be the product of crushed siliceous material, but may be comprised either of natural materials or crushed materials, or a combination of both, provided that the gradation and angularity of the sand are consistently uniform and conform to the specified requirements. A maximum of 5 percent mineral filler may be incorporated into the sand in order for the sand to conform to the specified gradation.

The gradation of the sand by dry sieving shall be as follows:

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4-inch</td>
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<tr>
<td>No. 8</td>
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<td>No. 16</td>
<td>60-95</td>
</tr>
<tr>
<td>No. 30</td>
<td>45-90</td>
</tr>
<tr>
<td>No. 50</td>
<td>20-65</td>
</tr>
<tr>
<td>No. 100</td>
<td>3-20</td>
</tr>
<tr>
<td>No. 200</td>
<td>2-6</td>
</tr>
</tbody>
</table>

D. Mineral filler, if used, shall conform to the quality requirements of Article 611.5.0 and shall not be fly ash.

E. Silicone shall be of a type and source approved by the Engineer, and shall be furnished and used as directed by the Engineer.

III. CONSTRUCTION METHODS

Every requirement contained in Articles 306.3.1 through 306.3.10 that is applicable to this type of work shall be in force except as provided herein and in the plans and proposal.

The materials, equipment, and methods for leveling, wedging, and patching shall be those designated in the proposal. The leveling and wedging shall be constructed as specified in Article 306.3.8 and shall be constructed to within plus or minus 1/4 inch of the desired elevation as determined by a stringline measurement or by a template.

The Contractor shall furnish any templates in accordance with Article 306.1.2. The leveling, wedging, and patching operations are particularly significant to the satisfactory performance of this type of surface mixture, and every reasonable effort shall be made to provide a uniform, stable, and even surface as a foundation for this sand-asphalt course.

A. Tack Coat. When SS-1h is furnished for the tack coat, it shall be diluted with an equal amount of water conforming to Section 603 and thoroughly mixed prior to application. The diluted SS-1h shall be applied at an approximate rate of 0.1 gal./sq. yd. and a sufficient time and distance in advance of the paver to insure that all the water has escaped and evaporated before any of the mixture is laid on the tack surface. The sand-asphalt mixture shall not be laid on the tack surface until authorized by the Engineer. When RC-250 is furnished for the tack coat, it shall be applied at an approximate rate of 0.1 gal./sq. yd. and a sufficient time and distance in advance of the paver to insure that the volatiles have evaporated before any of the mixture is laid on the tack surface.
B. Seasonal and Weather Limitations. The sand-asphalt mixture shall not be laid between October 15 and May 1. From May 1 to October 15 the sand-asphalt mixture shall be laid only at times when all weather conditions are very favorable in the judgment of the Engineer, when the atmospheric temperature is above 60° F., and when the underlying pavement is dry and clean except for the tack coat.

C. Preparation of Sand-Asphalt Mixture. The sand-asphalt mixture shall be prepared by combining the approved sand with asphalt cement in the percentages established by the Engineer. The percentage by weight of asphalt cement in the mixture will be established between 6 and 10 percent. The gradation limits for the mixture are the same as those specified for the sand and the Engineer will establish a job-mix formula within the specified sand gradation and asphalt content limits. Deviations from the established asphalt content shall not exceed 0.5 percent, and the fineness modulus of the sand shall not vary more than 0.2 from the value established by the job-mix formula.

1. If the sand for the mixture is a blend of two or more materials, the materials shall be supplied from individual cold bins in the proportions established by the Engineer.

2. The temperatures of the materials and the mixture, in degrees Fahrenheit, shall be maintained within the following ranges:

<table>
<thead>
<tr>
<th>Material</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>265</td>
<td>375</td>
</tr>
<tr>
<td>Asphalt Cement</td>
<td>275</td>
<td>350</td>
</tr>
<tr>
<td>Mixture at Plant</td>
<td>265</td>
<td>350</td>
</tr>
<tr>
<td>Mixture when Laid</td>
<td>250</td>
<td>350</td>
</tr>
</tbody>
</table>

*The mixture shall be maintained within a range of ±25°F. from the temperature designated by the Engineer.

D. Insofar as practical, the paver shall be operated at a constant forward speed that will produce a smooth uniform mat free from tears, open areas, and other imperfections.

E. All intersections, approaches, entrances, aprons, mailbox turnouts, and other incidental areas that are to be surfaced as a part of the work shall be surfaced either before or after the laying of the sand-asphalt surface course on the mainline, so as not to detract from nor interfere with the paver operations in any manner while this course is being applied to the traffic lanes.

F. Tandem rollers weighing not less than 5 nor more than 8 tons shall be used for the compaction of the sand-asphalt surface mixture and the surfacing of the incidental areas.

G. Vehicular traffic shall not be permitted to use the compacted sand-asphalt mixture until it has cooled sufficiently to withstand the traffic without any damage. Intersections and any other areas which must be reopened to traffic soon after the sand-asphalt mixture has been compacted shall be thoroughly sprayed with water so as to hasten the cooling of the compacted mixture to atmospheric temperature before it is subjected to traffic.

Any adjacent areas to receive the sand-asphalt course which are wetted by the water shall be allowed to thoroughly dry before the sand-asphalt course is laid.

IV. METHOD OF MEASUREMENT

The sand-asphalt mixture will be measured in tons in accordance with Article 1.9.1. The bituminous material for tack coat will be measured in gallons in accordance with Section 621.

V. BASIS OF PAYMENT

The accepted quantities of sand-asphalt mixture and bituminous material for tack coat will be paid for in accordance with Article 306.5.0 except that any silicone for the mixture and the water for diluting the SS-1h and for cooling the pavement will be considered as incidentals and will not be paid for separately.

APPROVED 1-19-73

J. R. HARISON
STATE HIGHWAY ENGINEER
KENTUCKY DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS
SPECIAL PROVISION NO. 59-D

SAND ASPHALT SURFACE (SKID RESISTANT)
(Type II)

This Special Provision will apply to a project when indicated in the contract plans or proposal. Section and Article references herein are to the Bureau’s 1965 Standard Specifications for Road and Bridge Construction.

I. DESCRIPTION

This work shall consist of the construction of one course of hot-mixed, hot-laid sand-asphalt surface mixture upon a satisfactory foundation of either new or existing pavements. The thickness of the course shall be approximately 5/8 inch and the sand-asphalt mixture shall be laid at the approximate rate of 65 lbs./sq.yd. All leveling, wedging, and patching deemed necessary by the Engineer to repair an existing pavement so it will provide a smooth uniform satisfactory foundation shall be performed before the construction of this surface course is started.

This sand-asphalt mixture is intended to provide a fine-textured, skid-resistant, wearing surface for vehicular traffic. Special attention shall be given to all aspects of the work to insure that only top-quality materials, equipment, and workmanship are utilized at all times, and that the finish surface is in close conformity to the lines, grades, and sections indicated in the plans and/or proposal.

II. MATERIALS

All materials for use in this work must be sampled, tested, and approved prior to starting the production of the sand-asphalt mixture.

Since the angular high-silica sand permitted for this work is a select material, the Bureau, upon request by Contractors qualified to bid on the work, will test a reasonable number of source samples of sands furnished by the Contractors, for information purposes only, prior to the date of the opening of bids for the contract. However, tests of the actual sand subsequently stockpiled at the plant site by the Contractor for the project will be made to determine the acceptability of the sand for the work.

The Contractor for the project shall stockpile sand at the plant site for sampling at least 1 week before starting plant operations. Either 500 tons or enough of the sand to supply one-half of the tonnage of mixture specified in the contract, whichever is less, shall be stockpiled.

A. The bituminous material for the tack coat shall conform to the requirements in the plans and proposal.

B. The asphalt cement for the sand-asphalt mixture shall conform to the requirements in the plans and proposal.

C. The sand for the sand-asphalt mixture shall be either crushed slag sand or a select angular high-silica material containing at least 75 percent SiO₂. The SiO₂ determination will be made in accordance with Kentucky Method 64-224, and will be made on the portion of the sand retained on all sieves down to and including the No. 100 sieve, exclusive of any mineral filler in that portion. The SiO₂ sand shall preferably be the product of crushed siliceous material, but may be comprised either of natural materials or crushed materials, or a combination of both, provided that the gradation and angularity of the sand are consistently uniform and conform to the specified requirements.

The gradation of the sand by dry sieving shall be as follows:

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4-inch</td>
<td>100</td>
</tr>
<tr>
<td>No. 8</td>
<td>60-90</td>
</tr>
<tr>
<td>No. 16</td>
<td>55-65</td>
</tr>
<tr>
<td>No. 50</td>
<td>20-45</td>
</tr>
<tr>
<td>No. 50</td>
<td>10-30</td>
</tr>
<tr>
<td>No. 100</td>
<td>5-20</td>
</tr>
<tr>
<td>No. 200</td>
<td>2-6</td>
</tr>
</tbody>
</table>

The mixture will be designed by the Engineer in accordance with the Marshall Density and Air voids criteria in Kentucky Method 64-411.

The angularity of the sand particles shall be such that the sand will have a voids content of 49 percent or more when subjected to the Dry-Bulking Test in accordance with Kentucky Method 64-609.

D. Mineral filler, if used, shall conform to the quality requirements of Article 611.5.0 and shall not be fly ash.

E. Silicone shall be of a type and source approved by the Engineer, and shall be furnished and used as directed by the Engineer.

F. An anti-stripping additive of a type and source approved by the Engineer shall be furnished by the Contractor and shall be used as directed by the Engineer to prevent stripping of the asphalt from the aggregate.

III. CONSTRUCTION METHODS

Every requirement contained in Articles 306.3.1 through 306.3.10 that is applicable to this type of work shall be in force except as provided herein and in the plans and proposal.

The materials, equipment, and methods for leveling, wedging, and patching shall be those designated in the proposal. The leveling and wedging shall be constructed as specified in Article 306.3.8 and shall be constructed to within plus or minus 1/4 inch of the desired elevation as determined by a stringline measurement or by a template. The Contractor shall furnish any templates in accordance with Article 306.3.2. The leveling, wedging, and patching operations are particularly significant to the satisfactory performance of this type of surface mixture, and every reasonable effort shall be made to provide a uniform, stable, and even surface as a foundation for this sand-asphalt course.

A. Tack Coat. When SS-1h is furnished for the tack coat, it shall be diluted with an equal amount of water conforming to Section 603 and thoroughly mixed prior to application. The diluted SS-1h shall be applied at an approximate rate of 0.1 gal./sq.yd. and a sufficient time and distance in advance of the paver to ensure that all the water has escaped and evaporated before any of the mixture is laid on the tacked surface. The sand-asphalt mixture shall not be laid on the tacked surface until authorized by the Engineer. When RC-250 is furnished for the tack coat, it shall be applied at an approxi-
mate rate of 0.1 gal./sq.yd. and a sufficient time and distance
in advance of the paver to insure that the volatiles have evap-
orated before any of the mixture is laid on the tacked surface.

B. Weather Limitations. The sand-asphalt mixture shall
be laid only at times when all weather conditions are very
favorable in the judgment of the Engineer, when the atmos-
pheric temperature is above 60°F., and when the underly-
ing pavement is dry and clean except for the tack coat.

C. Preparation of Sand-Asphalt Mixture. The sand-
asphalt mixture shall be prepared by combining the ap-
proved sand with asphalt cement in the percentages estab-
lished by the Engineer. The percentage by weight of asphalt
cement in the mixture will be established between 6 to 10 per-
cent. The gradation limits for the mixture are the same as
those specified for the sand and the Engineer will establish a
job-mix formula within the specified sand gradation and as-
phalt content limits. Deviations from the established asphalt
content shall not exceed 0.5 percent, and the fineness modu-
lus of the sand shall not vary more than 0.2 from the value es-
established by the job-mix formula.

1. If the sand for the mixture is a blend of two
or more materials, the materials shall be sup-
plied from individual cold bins in the propor-
tions established by the Engineer.

2. The temperatures of the materials and the mix-
ture, in degrees Fahrenheit, shall be maintained
within the following ranges:

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>265</td>
<td>350</td>
</tr>
<tr>
<td>Asphalt Cement</td>
<td>275</td>
<td>325</td>
</tr>
<tr>
<td>Mixture at Plant*</td>
<td>265</td>
<td>325</td>
</tr>
<tr>
<td>Mixture when Laid</td>
<td>250</td>
<td>325</td>
</tr>
</tbody>
</table>

* The mixture shall be maintained within a
range of 25°F. from the temperature desig-
nated by the Engineer.

D. Insofar as practical, the paver shall be operated at a
constant forward speed that will produce a smooth uniform
mat free from tears, open areas, and other imperfections.

E. All intersections, approaches, entrances, aprons, mail-
box turnouts, and other incidental areas that are to be sur-
faced as a part of the work shall be surfaced either before or
after the laying of the sand-asphalt surface course on the main-
line, so as not to detract from nor interfere with the paver op-
eration in any manner while this course is being applied to
the traffic lanes.

F. Tandem rollers weighing not less than 5 nor more
than 8 tons shall be used for the compaction of the sand-
asphalt surface mixture and the surfacing of the incidental
areas.

G. Vehicular traffic shall not be permitted to use the
compacted sand-asphalt mixture until it has cooled suffi-
ciently to withstand the traffic without any damage. Interces-
tions and any other areas which must be reopened to traffic
soon after the sand-asphalt mixture has been compacted shall
be thoroughly sprayed with water so as to hasten the cooling
of the compacted mixture to atmospheric temperature be-
fore it is subjected to traffic. Any adjacent areas to receive
the sand-asphalt course which are wetted by the water shall
be allowed to thoroughly dry before the sand-asphalt course
is laid.

IV. METHOD OF MEASUREMENT

The sand-asphalt mixture will be measured in tons in
accordance with Article 1.9.1. The bituminous material for
tack coat will be measured in gallons in accordance with Sec-
tion 621.

V. BASIS OF PAYMENT

The accepted quantities of sand-asphalt mixture and
bituminous material for tack coat will be paid for in accord-
ance with Article 306.5.0 except that any silicone for the mix-
ture and the water for diluting the SS-1h and for cooling the
pavement will be considered as incidentals and will not be paid
for separately.
This Special Provision will apply to a project when indicated in the contract plans or proposal. Section and Article references herein are to the Bureau's 1965 Standard Specifications for Road and Bridge Construction.

I. DESCRIPTION

This work shall consist of the construction of one course of hot-mixed, hot-laid sand-asphalt surface mixture upon a satisfactory foundation of either new or existing pavements. Unless otherwise provided, the thickness of the course shall be approximately 5/8 inch and the sand-asphalt mixture shall be laid at the approximate rate of 65 lbs./sq. yd. All leveling, wedging, and patching deemed necessary by the Engineer to repair an existing pavement so it will provide a smooth uniform satisfactory foundation shall be performed before the construction of this surface course is started.

This sand-asphalt mixture is intended to provide a fine-textured, skid-resistant, wearing surface for vehicular traffic. Special attention shall be given to all aspects of the work to ensure that only top-quality materials, equipment, and workmanship are utilized, and that the finished surface is in close conformity to the lines, grades, and sections indicated in the plans and/or proposal.

II. MATERIALS

All materials for use in this work must be sampled, tested, and approved prior to starting the production of the sand-asphalt mixture.

A. The bituminous material for the tack coat shall conform to the requirements in the plans and proposal.

B. The asphalt cement for the sand-asphalt mixture shall conform to the requirements in the plans and proposal.

C. The sand for the sand-asphalt mixture shall be either crushed slag (blast-furnace or other approved slag); crushed quartz (silica) gravel containing at least 75 percent insolubles; or crushed granite. The sand shall meet the following quality requirements:

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4-inch</td>
<td>100</td>
</tr>
<tr>
<td>No. 8</td>
<td>90</td>
</tr>
<tr>
<td>No. 16</td>
<td>75</td>
</tr>
<tr>
<td>No. 30</td>
<td>45</td>
</tr>
<tr>
<td>No. 50</td>
<td>30</td>
</tr>
<tr>
<td>No. 100</td>
<td>20</td>
</tr>
<tr>
<td>No. 200</td>
<td>5</td>
</tr>
</tbody>
</table>

Since the angular sand for this work is a select material, the Bureau, upon request by Contractors qualified to bid on the work, will test a reasonable number of source samples of sands furnished by the Contractors for INFORMATION PURPOSES ONLY prior to the date of the opening of bids for the contract. However, tests of the actual sand subsequently stockpiled at the plant site by the Contractor for the project will be made to determine the acceptability of the sand for the work.

D. Mineral filler, when used, shall conform to the quality requirements of Article 611.5.0, shall not be fly ash, and shall conform to the following requirements for gradation:

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Minimum Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 16</td>
<td>100</td>
</tr>
<tr>
<td>No. 200</td>
<td>50</td>
</tr>
</tbody>
</table>

E. Silicone shall be of a type and source approved by the Engineer, and shall be furnished and used as directed by the Engineer.

III. CONSTRUCTION METHODS

Every requirement contained in Articles 306.3.1 through 306.3.10 that is applicable to this type of work shall be in force except as provided herein and in the plans and proposal.

The materials, equipment, and methods for leveling, wedging, and patching shall be those designated in the proposal. The leveling and wedging shall be constructed as specified in Article 306.3.8 and shall be constructed to within plus or minus 1/4 inch of the desired elevation as determined by a stringline measurement or by a template.

A. Tack Coat. When SS-1h is furnished for the tack coat, it shall be diluted with an equal amount of water conforming to Section 803 and thoroughly mixed.
prior to application. The diluted SS-1h shall be applied at an approximate rate of 0.1 gal/sq.yd. and a sufficient time and distance in advance of the paver to ensure that all the water has escaped and evaporated before any of the mixture is laid on the tacked surface. The sand-asphalt mixture shall not be laid on the tacked surface until authorized by the Engineer. When RC-250 is furnished for the tack coat, it shall be applied at an approximate rate of 0.1 gal./sq.yd. and a sufficient time and distance in advance of the paver to ensure that the volatiles have evaporated before any of the mixture is laid on the tacked surface.

B. Weather Limitations. The sand-asphalt mixture shall be laid only at times when all weather conditions are very favorable in the judgment of the Engineer, when the atmospheric temperature is above 60 degrees F, and when the underlying pavement is dry and clean except for the tack coat.

C. Preparation of Sand-Asphalt Mixtures. At least 2 weeks prior to the start of construction, the Contractor shall designate his sources of aggregate and asphalt cement. He shall also submit representative aggregate samples and a proposed job-mix formula consisting of a single whole percent passing each specified sieve. The mixture will be designed by the Bureau in accordance with Marshall stability and air voids criteria in accordance with KM 64-411.

The sand-asphalt mixture shall be prepared by combining the approved aggregate with asphalt cement in the percentages established by the Engineer. The percent by weight of asphalt cement in the mixture will be established between 6 to 10 percent except that an increase of up to 1½ percent may be required for absorptive aggregate. The Bureau will approve a job-mix formula within the specified aggregate gradation and asphalt content limits. Deviations from the approved job-mix formula shall not exceed 0.5 percent for asphalt content and 0.2 percent for fineness modulus when tested in accordance with KM 64-405 and KM 64-616, respectively.

When the aggregate for the mixture is a blend of 2 or more materials, the materials shall be supplied from individual cold bins in the proportions necessary to meet the job-mix formula and as approved by the Engineer.

The temperatures of the materials and the mixture, in degrees Fahrenheit, shall be maintained within the following ranges:

<table>
<thead>
<tr>
<th>Material</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>265</td>
<td>350</td>
</tr>
<tr>
<td>Asphalt Cement</td>
<td>275</td>
<td>325</td>
</tr>
<tr>
<td>Mixture at Plant*</td>
<td>265</td>
<td>325</td>
</tr>
<tr>
<td>Mixture when Laid</td>
<td>250</td>
<td>325</td>
</tr>
</tbody>
</table>

*The mixture shall be maintained within a range of 2 25°F from the temperature designated by the Engineer.

D. Paver Operation. Insofar as practical, the paver shall be operated at a constant forward speed that will produce a smooth uniform mat free from tears, open areas, and other imperfections.

E. Incidental areas. All intersections, approaches, entrances, aprons, mailbox turnouts, and other incidental areas that are to be surfaced as a part of the work shall be surfaced prior to or after the laying of the sand-asphalt sur-

face course on the mainline, so as not to detract from nor interfere with the paver operations in any manner while this course is being applied to the traffic lanes.

F. Rollers. Tandem rollers weighing no less than 5 nor more than 8 tons shall be used for the compaction of the sand-asphalt mixture.

G. Opening to Traffic. Vehicular traffic shall not be permitted to use the compacted sand-asphalt mixture until it has cooled sufficiently to withstand the traffic without any damage. Intersections and any other areas which must be reopened to traffic soon after the sand-asphalt mixture has been compacted shall be thoroughly sprayed with water to hasten the cooling of the compacted mixture to atmospheric temperature before it is subjected to traffic. Any adjacent areas to receive the sand-asphalt course which are wetted by the water shall be allowed to thoroughly dry before the sand-asphalt course is laid.

IV. METHOD OF MEASUREMENT

The sand-asphalt mixture will be measured in tons in accordance with Article 1.9.1. The bituminous material for tack coat will be measured in gallons in accordance with Section 623.

V. BASIS OF PAYMENT

The accepted quantities of sand-asphalt mixture and bituminous material for tack coat will be paid for in accordance with Article 306.5.0 except that any silicone for the mixture and the water for diluting the SS-1h and for cooling the pavement will be considered as incidentals and will not be paid for separately.

APPROVED 10-22-75

J. R. HARISON
STATE HIGHWAY ENGINEER
COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS

SPECIAL PROVISION NO. 60

FOR

SIMULATED KENTUCKY ROCK ASPHALT SURFACE

This Special Provision shall be applicable only when indicated on the plans, in the proposal, or in the bidding invitation and, when so indicated, shall supersede any conflicting requirements of the Department's 1965 Standard Specifications for Road and Bridge Construction and is complemented with the applicable provisions of Section 306 thereof.

I. DESCRIPTION

This work shall consist of furnishing and placing paving mixtures complying with the material requirements and processed as hereinafter described, without alternate types of materials or processes, for use in the construction of surface courses on existing bases or pavements as set forth by the plans, proposal, or bidding invitation. The mixture shall consist of crushed non-bituminous sandstone aggregate -- essentially identical to the asphalt-impregnated sandstone aggregate to be supplied under Special Provision No. 24-B on a companion section of this project, but containing no natural bitumen -- and an optimum quantity of refinery asphalt. Construction procedures and finished work shall conform with the further stipulations listed herein.

The work shall also include the surfacing of approaches at road and street intersections and approaches or aprons at entrances, when and as directed by the Engineer. If not specified and unless otherwise directed by the Engineer, the bituminous mixture for this work shall be Bituminous Concrete Surface, Class I, which shall conform to Section 306. Fine aggregate for the bituminous concrete may be natural, crushed, or conglomerate sand meeting the requirements of Section 611 for quality.

II. MATERIALS

A. Aggregate. The aggregate shall consist of crushed, non-bituminous sandstone, as described above, having uniform quality and hardness. It shall be free of dirt and debris and shall meet the following requirements:

1. Gradation: The size-gradation of aggregate samples shall comply with the following requirements:

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Percent Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2 inch</td>
<td>100</td>
</tr>
<tr>
<td>No. 4</td>
<td>40-100</td>
</tr>
<tr>
<td>No. 100</td>
<td>0-15</td>
</tr>
</tbody>
</table>
2. Silica: The aggregate shall contain not less than 90 percent Silica (SiO$_2$) as determined by chemical analysis.

B. Asphalt Binder. Asphalt cement enrichment shall consist of PAC-3 (Article 621.4.0) as specified on the plans or in the proposal.

C. Bituminous Tack Coat. Bituminous material for the tack coat shall be SS-1h meeting the particular requirements of Section 621. The SS-1h shall be prepared for application by dilution with an equal volume of potable water.

D. Admixture. A moisture controlling admixture such as silicone fluid (dimethyl siloxane) shall be furnished by the Contractor to be blended with the mix when and as directed by the Engineer. The silicone shall be of a type approved by the Department and shall be from a source approved by the Department.

III. CONSTRUCTION METHODS

A. Seasonal and Weather Limitations. No surface mixture shall be placed between September 30 and May 1, nor when the air temperature is below 60°F., except by written permission of the Engineer; neither shall it be placed when the underlying course is wet or when other weather conditions are unsuitable.

B. Plant and Equipment. Article 306.3.2, except as noted below:

1. Screens: Only one screen, a scalping screen of the necessary size, will be required.

2. Bins: The plant shall include a storage bin of sufficient capacity to supply the mixer, when it is operating at full capacity, with no undue periods of waiting for aggregate. The outlet gate on the bin shall cut off quickly and completely and shall be designed and constructed so there will be no leakage when closed.

3. Thermometric Equipment: Article 306.3.2-C-8.

4. Dust Collectors: The plant shall be equipped with an effective dust collector. Material collected must be returned to the mix unless wasting is permitted by the Engineer.

C. Preparation of Mixture.

1. Composition of Mixtures: The crushed sandstone aggregate and asphalt cement shall be combined in such proportions that the bitumen content will be not less than 7 percent and not more than 10 percent.

2. Preparation of Aggregate: The aggregate shall be deposited in the cold elevator at a rate to insure correct and uniform temperature control of the heating and drying operation. The aggregate shall be heated to a uniform temperature between 280°F. and 325°F.
3. Preparation of Asphalt Cement: Article 306.3.3-C.

4. Preparation of Mixtures: Article 306.3.3-D as applicable.

5. Temperature Requirements: Unless otherwise approved by the Engineer, the temperatures of the materials and the mixtures, in degrees Fahrenheit, shall be maintained within the ranges given in the following table:

<table>
<thead>
<tr>
<th>Material</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregates</td>
<td>280</td>
<td>325</td>
</tr>
<tr>
<td>Asphalt Cement</td>
<td>265</td>
<td>325</td>
</tr>
<tr>
<td>Mixture at Plant</td>
<td>280</td>
<td>325</td>
</tr>
<tr>
<td>Mixture When Laid</td>
<td>280</td>
<td>310</td>
</tr>
</tbody>
</table>

D. Preparation of Base. The existing surface shall be swept clean of all foreign material by means of hand brooms and mechanical sweepers. Patching, wedging, and leveling courses of bituminous concrete (Class I) shall be applied as directed by the Engineer and in the quantities as stated on the plans or in the proposal. Bituminous tack coat shall be applied in accordance with Section 301.

E. Spreading and Finishing. Spreading and finishing shall be in accordance with Article 306.3.6, except as hereinafter provided.

1. Continuous Paver Operation: The plant procedure and the paver speed shall be synchronized in such a manner which will permit the paver to travel in a uniform continuous forward speed. The paver shall engage the hauling trucks while traveling forward. Every effort shall be made to keep the paver moving continuously. The paver should be permitted to stop only when a plant or paver breaks down or when some emergency or unavoidable condition exists.

2. Entrances and Crossovers: Entrances, crossovers, and other areas inaccessible to the paver which must be spread by hand, whether constructed of this type of surface mixture or other designated surface mixtures, shall be constructed as a separate operation. The material for these areas shall be placed directly from the traveling trucks. The paver shall not be stopped to remove the side plates to allow the material for these areas to spill out the side, neither shall the paver be stopped and material for these areas shoveled from the hopper.

F. Compaction. Compaction shall be in accordance with Article 306.3.7, as applicable, except that entrances, crossovers, and other inaccessible areas spread by hand may be compacted with a roller weighing not less than three tons.
G. **Leveling and Patching.** Leveling and patching shall be performed in manner, with the designated equipment and with the materials, as prescribed on the plans or in the proposal, or as directed by the Engineer.

H. **Surface Tolerances.** Surface tolerances shall be in accordance with Article 306.3.3 as applicable.

I. **Maintenance and Protection.** Maintenance and protection shall be in accordance with Article 306.3.10.

**IV. METHOD OF MEASUREMENT**

This surfacing mixture shall be weighed in accordance with Article 1.9.1.

The bituminous tack material shall be measured in gallons as specified in Section 621.

**V. BASIS OF PAYMENT**

The accepted quantities thus measured will be paid for at the contract unit price per ton for the surface course, complete in place, and per gallon for "Bituminous Tack Material," which payment shall be full compensation for furnishing, hauling, and placing all materials; for cleaning and all necessary preparations of base; for the making of proper joints; for the disposal of all surplus materials; for furnishing, processing, placing, and rolling of the bituminous mixtures and materials; and for all labor, equipment, tools and incidentals necessary to complete the work specified.

**APPROVED October 10, 1967**

A. O. Neiser
State Highway Engineer
I. DESCRIPTION

This work shall consist of the construction of one course of hot-mixed, hot laid, open-graded surface mixture upon a satisfactory foundation provided by either new or existing pavements. The thickness of the course shall be approximately 3/4 inch. The leveling, wedging, and patching deemed necessary by the Engineer to repair an existing pavement shall be performed before the construction of this surface course is started.

This open-graded mixture is intended to provide a coarse-textured, well-draining, skid-resistant, surface for vehicular traffic. Special attention shall be given to all aspects of the work to insure that only top-quality materials, equipment, and workmanship are utilized at all times and that the finished surface is in close conformity to the lines, grades, and sections indicated in the plans and/or proposal.

All materials for use in this work shall be sampled, tested, and approved prior to starting the production of the open-graded mixture.

Since the angular aggregate required for this work is a select material, the Bureau, upon request by Contractors qualified to bid on the work, will test a reasonable number of source samples of aggregates furnished by the Contractors, FOR INFORMATION PURPOSES ONLY, prior to the date of the opening of bids for the contract. However, tests of the actual aggregate subsequently stockpiled at the plant site by the Contractor for the project will be made to determine the acceptability of the aggregate for this work.

The Contractor for the project shall stockpile aggregate at the plant site for sampling at least two weeks before starting plant operations. Enough aggregate for one day's plant operation will be considered the minimum allowable quantity of aggregate necessary to be stockpiled in order that representative samples for testing may be obtained therefrom.

A. Aggregate. Except for minerarl filler, aggregate for this mixture shall be either lightweight aggregate, crushed slag, or crushed gravel.

Lightweight aggregate shall have a maximum compact unit weight of 65 pounds per cubic foot when tested by Kentucky Method 64-613. Lightweight aggregate shall also conform to the following requirements when tested by the indicated Kentucky-Methods.

<table>
<thead>
<tr>
<th>Max. Pct. by Wt.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friable Particles (Ky 64-611)</td>
</tr>
<tr>
<td>Wear (Ky 64-614)</td>
</tr>
<tr>
<td>Loss after 5 cycles of Sodium Sulfate Soundness Test (Ky 64-610)</td>
</tr>
</tbody>
</table>

Crushed slag shall conform to the applicable requirements of the current edition of Special Provision No. 102.

Crushed gravel shall conform to the applicable requirements of the current edition of Special Provision No. 102, except that the gravel shall be a 100% crushed product with at least 95% having one or more fractured faces and at least 75% having two or more fractured faces when tested by Kentucky Method 64-603, and shall have a minimum silica (SiO2) content of 75% as determined by Kentucky Method 64-224.

Crushed limestone will not be permitted as any part of the aggregate for the open-graded mixture, except as mineral filler.

The gradation of the aggregate, including mineral filler when used, shall conform to the following requirements for either Type 1 or Type 2 when tested by Kentucky Method 64-406. Prior to the start of construction, the Contractor shall designate in writing which gradation he elects to furnish. He shall also submit aggregate samples and a proposed job-mix formula consisting of a single value for the percent passing each sieve. During the operation of the plant, tolerances from the approved job-mix formula will be permitted as indicated in the following table, except that the graduation shall be within the master graduation at all times.

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Master Gradation Range Percent Passing</th>
<th>Job-Mix Formula Tolerances</th>
</tr>
</thead>
</table>
|            | Type 1 | Type 2 | *
| 1/2 in.    | 100    | ----   |   *
| 3/8 in.    | 90-100 | 100    |   *
| No. 4      | 25-50  | 50-100 | ±6%**
| No. 8      | 3-15   | 10-30  | ±4%**
| No. 200    | -----  | 5-15   | *   |
|            | 2-5    | 2-5    | *

* Master graduation range applies.

The angularity of the aggregate particles for the Type 2 gradation shall be such that the aggregate will have a voids content of 48% or more when subjected to the Dry-Bulking Test in accordance with Kentucky Method 64-609.

B. Mineral filler, if used, shall conform to the quality requirements of Article 611.5.0.

C. The bituminous material for the tack coat may be either SS-1h conforming to AASHO M 149 except the maximum penetration may be 100, RC-250 conforming to AASHO M 81, or other materials approved by the Engineer.

D. The asphalt cement for the open-graded mixture shall be AC-29 conforming to the requirements of AASHO M 226.

E. Silicone shall be furnished by the Contractor and blended into the asphalt cement when and as directed by the Engineer. The silicone shall be of a type and from a source approved by the Engineer.

F. An anti-stripping additive of a type and source approved by the Engineer shall be furnished by the Contractor and shall be used as directed by the Engineer to prevent stripping of the asphalt from the aggregate.

III. CONSTRUCTION METHODS

Every requirement contained in Articles 306.3.1 thru 306.3.10 which is applicable to this type of work shall be in force except as provided herein and in the plans and proposal.

The materials, equipment, and methods for leveling, wedging, and patching shall be those designated in the proposal. The leveling and wedging shall be constructed as specified in Article 306.3.8 and shall be constructed to within plus or minus 1/4 inch of the desired elevation as determined by a stringline measurement or by a template. The Contractor shall furnish any templates in accordance with
Article 306.3.2. The leveling, wedging, and patching operations are particularly significant to the satisfactory performance of this type of surface mixture and every reasonable effort shall be made to provide a uniform, stable, dense, and even surface as the foundation for this open-graded course.

This open-graded course should always be constructed higher in elevation than the shoulders and gutters in order to provide for proper lateral drainage of water through the course.

A. Tack Coat. When SS-1h is furnished for the tack coat, it shall be diluted with an equal volume of water conforming to Section 603 and thoroughly mixed prior to application. The diluted SS-1h shall be applied at an approximate rate of 0.2 gallon per square yard in one or more applications for a sufficient time and distance in advance of the paver to insure that all of the water has escaped and evaporated before any of the open-graded mixture is laid on the tacked surface. When RC-250 is furnished for the tack coat, it shall be applied at an approximate rate of 0.1 gallon per square yard and for a sufficient time and distance in advance of the paver to insure that the volatiles have evaporated before any of the open-graded mixture is laid on the tacked surface. The open-graded mixture shall not be laid on the tacked surface until authorized by the Engineer.

When other tack coat materials are approved by the Engineer, they shall be applied as directed by the Engineer.

B. Seasonal and Weather Limitations. The mixture shall be placed only when the pavement surface is clean and dry and when the pavement surface temperature is 50°F or greater. The air temperature shall be at least 50°F and rising. No seasonal limitations will apply.

C. Preparation of Open-Graded Mixture. The mixture shall be prepared by combining the approved aggregate with asphalt cement in the percentages established by the Engineer. The percentage by weight of asphalt cement in the mixture will be established between 5.5 and 8.5 percent of the total mixture when either crushed slag or crushed gravel is the aggregate used, and between 9.0 and 15.0 percent when lightweight aggregate is used. The gradation limits for the mixture are the same as those specified for the aggregate and the Engineer will approve a job-mix formula within the specified aggregate gradation and asphalt cement limits. Deviations from the established asphalt content shall not exceed 0.4 percent when the mixture is tested by Kentucky Method 64-405.

When the total aggregate for the mixture is a blend of two or more materials, the materials shall be supplied from individual cold bins or stockpiles in the proportions required to meet the specified gradation and voids content.

The temperatures of the materials and the mixture, in degrees Fahrenheit, shall be carefully maintained within the following ranges:

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate</td>
<td>200</td>
<td>260</td>
</tr>
<tr>
<td>Asphalt Cement</td>
<td>250</td>
<td>300</td>
</tr>
<tr>
<td>Mixture at Plant</td>
<td>200</td>
<td>260</td>
</tr>
<tr>
<td>Mixture when Laying</td>
<td>180</td>
<td>260</td>
</tr>
</tbody>
</table>

Temperatures higher than those listed can cause the asphalt cement to drain from the mixture and should be avoided at all times.

D. Paving. The spreading of the open-graded mixture to provide the specified thickness of approximately 3/4 inch shall be at the following rates, depending upon the type of the aggregate used for the mixture.
This Special Provision will apply when indicated in the contract plans or proposal. Article and Section references herein are to the Bureau's 1965 Standard Specifications for Road and Bridge Construction.

I. DESCRIPTION

This work shall consist of the construction of one course of hot-mixed, hot laid, open-graded surface mixture upon a satisfactory foundation provided by either contractors or state. The thickness of the course shall be approximately 3/4 inch. The leveling, wedging, and patching deemed necessary by the Engineer to repair an existing pavement shall be performed before the construction of this surface course is started.

This open-graded mixture is intended to provide a coarse-textured, well-draining, skid-resistant, wearing surface mixture upon a satisfactory foundation. The Engineer shall designate in writing which gradation he elects to furnish. He shall also submit aggregate samples and a proposed job-mix formula consisting of a single value for the percent passing each sieve. During the operation of the plant, tolerances from the approved job-mix formula will be permitted as indicated in the following table, except that the gradation shall be within the master gradation at all times.

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Master Gradation Range</th>
<th>Job-Mix Formula Tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2 in.</td>
<td>100</td>
<td>*</td>
</tr>
<tr>
<td>3/8 in.</td>
<td>90-100</td>
<td>100</td>
</tr>
<tr>
<td>No. 4</td>
<td>25-25</td>
<td>5%</td>
</tr>
<tr>
<td>No. 6</td>
<td>15</td>
<td>45 **</td>
</tr>
<tr>
<td>No. 15</td>
<td>5-15</td>
<td>*</td>
</tr>
<tr>
<td>No. 200</td>
<td>2-5</td>
<td>*</td>
</tr>
</tbody>
</table>

Graded limestone will not be permitted as any part of the aggregate for the open-graded mixture, except as mineral filler, unless otherwise provided.

The gradation of the aggregate, including mineral filler when used, shall conform to the following requirements for either Type 1 or Type 2 when tested by Kentucky Method 64-406. At least 2 weeks prior to the start of construction, the Contractor shall designate in writing which gradation he elects to furnish. He shall also submit aggregate samples and a proposed job-mix formula consisting of a single value for the percent passing each sieve. During the operation of the plant, tolerances from the approved job-mix formula will be permitted as indicated in the following table, except that the gradation shall be within the master gradation at all times.

II. MATERIALS

All materials for use in this work shall be sampled, tested, and approved prior to starting the production of the open-graded mixture.

Since the angular aggregate required for this work is a select material, the Bureau, upon request by Contractors qualified to bid on the work, will test a reasonable number of source samples of aggregates furnished by the Contractors for INFORMATION PURPOSES ONLY, prior to the date of the opening of bids for the contract. However, tests of the actual aggregate subsequently stockpiled at the plant site by the Contractor for the project will be made to determine the acceptability of the aggregate for this work.

A. Aggregate. Except for mineral filler, aggregate for this mixture shall be either crushed lightweight aggregate, crushed slag, cracked gravel, crushed granite, or an approved combination of these aggregates.

Lightweight aggregate shall have a maximum compact unit weight of 65 pounds per cubic foot when tested by Kentucky Method 64-613. Lightweight aggregate or granite shall also conform to the following requirements when tested by the indicated Kentucky Methods.

<table>
<thead>
<tr>
<th>Property</th>
<th>Kentucky Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friable Particles (Ky 64-611)</td>
<td>1.0</td>
</tr>
<tr>
<td>Wear (Ky 64-614)</td>
<td>40</td>
</tr>
<tr>
<td>Loss after 5 cycles of Sodium Sulfate Soundness Test (Ky 64-610)</td>
<td>12</td>
</tr>
</tbody>
</table>

Crushed slag shall conform to the applicable requirements of the current edition of Special Provision No. 102. Crushed gravel shall conform to the applicable requirements of the current edition of Special Provision No. 102, except that the gravel shall be a 100% crushed product with at least 95% having one or more fractured faces and at least 75% having two or more fractured faces when tested by Kentucky Method 64-50 and shall have a minimum insoluble content of 75% as determined by Kentucky Method 64-223.

Crushed limestone will not be permitted as any part of the aggregate for the open-graded mixture, except as mineral filler, unless otherwise provided.

The gradation of the aggregate, including mineral filler when used, shall conform to the following requirements for either Type 1 or Type 2 when tested by Kentucky Method 64-406. At least 2 weeks prior to the start of construction, the Contractor shall designate in writing which gradation he elects to furnish. He shall also submit aggregate samples and a proposed job-mix formula consisting of a single value for the percent passing each sieve. During the operation of the plant, tolerances from the approved job-mix formula will be permitted as indicated in the following table, except that the gradation shall be within the master gradation at all times.

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Master Gradation Range</th>
<th>Job-Mix Formula Tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2 in.</td>
<td>100</td>
<td>*</td>
</tr>
<tr>
<td>3/8 in.</td>
<td>90-100</td>
<td>100</td>
</tr>
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</tr>
<tr>
<td>No. 6</td>
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<td>45 **</td>
</tr>
<tr>
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<td>5-15</td>
<td>*</td>
</tr>
<tr>
<td>No. 200</td>
<td>2-5</td>
<td>*</td>
</tr>
</tbody>
</table>

Graded limestone will not be permitted as any part of the aggregate for the open-graded mixture, except as mineral filler, unless otherwise provided.

The gradation of the aggregate, including mineral filler when used, shall conform to the following requirements for either Type 1 or Type 2 when tested by Kentucky Method 64-406. At least 2 weeks prior to the start of construction, the Contractor shall designate in writing which gradation he elects to furnish. He shall also submit aggregate samples and a proposed job-mix formula consisting of a single value for the percent passing each sieve. During the operation of the plant, tolerances from the approved job-mix formula will be permitted as indicated in the following table, except that the gradation shall be within the master gradation at all times.

III. CONSTRUCTION METHODS

Every requirement contained in Articles 306.3.1 through 306.3.10 which is applicable to this type of work shall be in force except as provided herein and in the plans and proposal.

The materials, equipment, and methods for leveling, wedging, and patching shall be those designated in the proposal. The leveling and wedging shall be constructed as specified in Article 306.3.8 and shall be constructed to within plus or minus 1/4 inch of...
the desired elevation as determined by a string-line measurement or by a template. The Contractor shall furnish any templates in accordance with Article 306.3.2. The leveling, wedging, and patching operations are particularly significant to the satisfactory performance of this type of surface mixture and every reasonable effort shall be made to provide a uniform, stable, dense, and even surface as the foundation for this open-graded course.

This open-graded course should always be constructed higher in elevation than the shoulders and gutters in order to provide for proper lateral drainage of water through the course.

A. Tack Coat. When SS-1h is furnished for the tack coat, it shall be diluted with an equal volume of water conforming to Section 603 and thoroughly mixed prior to application. The diluted SS-1h shall be applied at an approximate rate of 0.2 gallon per square yard in one or more applications for a sufficient time and distance in advance of the paver to insure that all of the water has escaped and evaporated before any of the open-graded mixture is laid on the tacked surface. When RC-250 is furnished for the tack coat, it shall be applied at an approximate rate of 0.1 gallon per square yard and for a sufficient time and distance in advance of the paver to insure that the volatiles have evaporated before any of the open-graded mixture is laid on the tacked surface. The open-graded mixture shall not be laid on the tacked surface until authorized by the Engineer.

When other tack coat materials are approved by the Engineer, they shall be applied as directed by the Engineer.

B. Seasonal and Weather Limitations. The mixture shall be placed only when the pavement surface is clean and dry and when the pavement surface temperature is 50°F or greater. The air temperature shall be at least 50°F and rising. No seasonal limitations will apply.

C. Preparation of Open-Graded Mixture. The mixture shall be prepared by combining the approved aggregate with asphalt cement in the percentages established by the Engineer. The percentage by weight of asphalt cement in the mixture will be established between 5.5 and 9.0 percent of the total mixture when either crushed slag, crushed gravel, or crushed granite is the aggregate used, and between 9.0 and 15.0 percent when lightweight aggregate is used. The gradation limits for the mixture are the same as those specified for the aggregate and the Engineer will approve a job-mix formula within the specified aggregate gradation and asphalt cement limits. Deviations from the established asphalt content shall not exceed 0.4 percent when the mixture is tested by Kentucky Method 64-605.

When the total aggregate for the mixture is a blend of two or more materials, the materials shall be supplied from individual cold bins or stockpiles in the proportions required to meet the job-mix formula.

The temperatures of the materials and the mixture, in degrees Fahrenheit, shall be carefully maintained within the following ranges:

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate</td>
<td>200</td>
<td>260</td>
</tr>
<tr>
<td>Asphalt Cement</td>
<td>250</td>
<td>300</td>
</tr>
<tr>
<td>Mixture at Plant</td>
<td>200</td>
<td>260</td>
</tr>
<tr>
<td>Mixture when Laying</td>
<td>150</td>
<td>200</td>
</tr>
</tbody>
</table>

Temperatures higher than those listed can cause the asphalt cement to drain from the mixture and should be avoided at all times.

D. Paving. The spreading of the open-graded mixture to provide the specified thickness of approximately 3/4 inch shall be at the following rates, depending upon the type of the aggregate used for the mixture.

Gravel, Granite, or Slag Aggregate: 65 lb./sq.yd.
Lightweight Aggregate: 45 lb./sq.yd.

Insofar as practical, the paver shall be operated at a constant forward speed which will produce a smooth uniform mat free from tears, open areas, and other imperfections. Any hand raking of the mixture should be kept to the absolute minimum.

E. Rolling. Normal equipment for placing and compaction will be required except that rolling shall be accomplished with a steel-wheel tandem roller of sufficient weight to adequately compact the mixture without excessive breakage of the aggregate. The amount of rolling shall be confined to only the minimum necessary for consolidating the bituminous mixture and bonding it to the underlying surface. Excessive rolling shall be avoided.

IV. METHOD OF MEASUREMENT

The open-graded mixture will be measured in tons and the bituminous material for tack coat will be measured in gallons in accordance with Article 306.4.0.

V. BASIS OF PAYMENT

The accepted quantities of open-graded mixture and bituminous material for tack coat will be paid for in accordance with Article 306.5.0 except that the silicone and anti-stripping additives for the mixture and water used for diluting the SS-1h will be considered as incidentals and will not be paid for separately.

APPROVED
J. K. HARBISON
STATE HIGHWAY ENGINEER
This Special Provision will apply when indicated in the contract plans or proposal. Article and Section references herein are to the Bureau’s 1965 Standard Specifications for Road and Bridge Construction.

I. DESCRIPTION

This work shall consist of the construction of one course of hot-mixed, hot laid, open-graded surface mixture upon a satisfactory foundation provided by either new or existing pavements. The thickness of the course shall be approximately 3/4 inch. The leveling, wedging, and patching deemed necessary by the Engineer to repair an existing pavement shall be performed before the construction of this surface course is started.

This open-graded mixture is intended to provide a coarse-textured, well-draining, skid-resistant, wearing surface for vehicular traffic. Special attention shall be given to all aspects of the work to insure that only top-quality materials, equipment, and workmanship are utilized at all times and that the finished surface is in close conformity to the lines, grades, and sections indicated in the plans and/or proposal.

II. MATERIALS

All materials for use in this work shall be sampled, tested, and approved prior to starting the production of the open-graded mixture.

Since the angular aggregate required for this work is a select material, the Bureau, upon request by Contractors qualified to bid on the work, will test a reasonable number of source samples of aggregates furnished by the Contractors, FOR INFORMATION PURPOSES ONLY, prior to the date of the opening of bids for the contract. However, tests of the actual aggregate subsequently stockpiled at the plant site by the Contractor for the project will be made to determine the acceptability of the aggregate for this work.

A. Aggregate. Except for mineral filler, aggregate for this mixture shall be either crushed lightweight aggregate, crushed slag, crushed gravel, or an approved combination of these aggregates.

Lightweight aggregate shall have a maximum compact unit weight of 65 pounds per cubic foot when tested by Kentucky Method 64-613. Lightweight aggregate or granite shall also conform to the following requirements when tested by the indicated Kentucky Method.

Max. Pen. by Wt.

Frisable Particles (Ky 64-611) 1.0
Wear (Ky 64-614) 40
Loss after 5 cycles of Sodium Sulfate Soundness Test (Ky 64-610) 12

Crushed slag shall conform to the applicable requirements of the current edition of Special Provision No. 102.

Crushed gravel shall conform to the applicable requirements of the current edition of Special Provision No. 102, except that the gravel shall be a 100% crushed product with at least 95% having one or more fractured faces and at least 75% having two or more fractured faces when tested by Kentucky Method 64-603, and shall have a minimum insoluble content of 75% as determined by Kentucky Method 64-223.

Crushed limestone will not be permitted as any part of the aggregate for the open-graded mixture except as mineral filler, unless otherwise provided.

The gradation of the aggregate, including mineral filler when used, shall conform to the following requirements for either Type 1 or Type 2 when tested by Kentucky Method 64-406. At least 2 weeks prior to the start of construction, the Contractor shall designate in writing which gradation he elects to furnish. He shall also submit aggregate samples and a proposed job-mix formula consisting of a single value for the percent passing each sieve. During the operation of the plant, tolerances from the approved job-mix formula will be permitted as indicated in the following table, except that the gradation shall be within the master gradation at all times.

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Master Gradation Range</th>
<th>Job-Mix Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent Passing</td>
<td>Tolerances</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Type 1</td>
</tr>
<tr>
<td>1/2 in.</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>3/8 in.</td>
<td>90-100</td>
<td>100</td>
</tr>
<tr>
<td>No. 4</td>
<td>5.5-10</td>
<td>10-10</td>
</tr>
<tr>
<td>No. 16</td>
<td>5-15</td>
<td></td>
</tr>
<tr>
<td>No. 200</td>
<td>2-5</td>
<td></td>
</tr>
</tbody>
</table>

* Master gradation range applies ** (Type 2 only)

The angularity of the aggregate particles for the Type 2 gradation shall be such that the aggregate will have a voids content of 48% or more when subjected to the Dry-Bulking Test in accordance with Kentucky Method 64-609.

B. Mineral filler, if used, shall conform to the quality requirements of Article 611.5.0.

C. The bituminous material for the tack coat may be either SS-1 in conforming to AASHTO M 140 except the maximum penetration may be 100, RC-250 conforming to AASHTO M 81, or other materials approved by the Engineer.

D. The asphalt cement for the open-graded mixture shall be AC-20 conforming to the requirements of AASHTO M 225.

E. Silicone shall be furnished by the Contractor and blended into the asphalt cement when and as directed by the Engineer. The silicone shall be of a type and from a source approved by the Engineer.

F. An anti-stripping additive of a type and source approved by the Engineer shall be furnished by the Contractor and shall be used as directed by the Engineer to prevent stripping of the asphalt from the aggregate.

III. CONSTRUCTION METHODS

Every requirement contained in Articles 306.3.1 through 306.3.10 which is applicable to this type of work shall be in force except as provided herein and in the plans and proposal.

The materials, equipment, and methods for leveling, wedge and patching shall be those designated in the proposal. The leveling and wedging shall be constructed as specified in Article 306.3.8 and shall be constructed to within plus or minus 1/4 inch of
the desired elevation as determined by a string-line measurement or by a template. The Contrac-
tor shall furnish the templates in accordance with Article 306.3.2. The leveling, wedging, and patch-
ing operations are particularly significant to the satisfactory performance of this type of surface
mixture and every reasonable effort shall be made to provide a uniform, stable surface, and even sur-
face as the foundation for this open-graded course.

The open-graded course should always be con-
structed higher in elevation than adjacent concrete
gutters in order to provide for proper lateral drain-
age of water through the course.

A. Tack Coat. When SS-1h is furnished for
the tack coat, it shall be diluted with an equal
volume of water conforming to Section 603 and
thoroughly mixed prior to application. The diluted
SS-1h shall be applied at an approximate rate of
0.2 gallon per square yard in one or more appli-
cations for a sufficient time and distance in
advance of the paver to insure that all of
the water has escaped and evaporated before any of
the open-graded mixture is laid on the tacked sur-
face. When RC-250 is furnished as the tack coat,
it shall be applied at an approximate rate of 0.11
gallon per square yard and for a sufficient time
and distance in advance of the paver to insure
that the volatiles have evaporated before any of
the open-graded mixture is laid on the tacked
surface. The open-graded mixture shall not be
laid on the tacked surface until authorized by the
Engineer.

When other tack coat materials are ap-
proved by the Engineer, they shall be applied as
directed by the Engineer.

B. Seasonal and Weather Limitations. The
mixture shall be placed only when the pavement
surface is clean and dry and when the pavement
surface temperature is 50° F or greater. The air
temperature shall be at least 30° F and rising.
No seasonal limitations will apply.

C. Preparation of Open-Graded Mixture.
The mixture shall be prepared by combining the ap-
proved aggregate with asphalt cement in the per-
centages established by the Engineer. The per-
centage by weight of asphalt cement in the mixture
will be established between 5.5 and 9.0 percent of
the mixture when either crushed slag, crushed
gravel, or crushed granite is the aggregate used,
and between 9.0 and 15.0 percent when lightweight
aggregate is used. The gradation limits for the
mixture are the same as those specified for the
aggregate and the Engineer will approve a job-mix
formula within the specified aggregate gradation
and asphalt cement limits. Deviations from the
established asphalt content shall not exceed 0.4
percent when the mixture is tested by Kentucky
Method 64-405.

When the total aggregate for the mixture is
a blend of two or more materials, the materials
shall be supplied from individual cold bins or
stockpiles in the proportions required to meet the
job-mix formula.

The temperatures of the materials and the
mixture, in degrees Fahrenheit, shall be carefully
maintained within the following ranges:

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate</td>
<td>200</td>
<td>250</td>
</tr>
<tr>
<td>Asphalt Cement</td>
<td>250</td>
<td>300</td>
</tr>
<tr>
<td>Mixture at Plant</td>
<td>200</td>
<td>250</td>
</tr>
<tr>
<td>Mixture when Laying</td>
<td>180</td>
<td>250</td>
</tr>
</tbody>
</table>

Temperatures higher than those listed can
cause the asphalt cement to drain from the mix-
ture and should be avoided at all times.

D. Paving. The spreading of the open-graded
mixture to provide the specified thickness of approxi-
metly 3/4 inch shall be at the following rates, de-
pending upon the type of the aggregate used for the
mixture.

Gravel, Granite, or Slag Aggregate 65 lb./sq.yd.
Lightweight Aggregate 45 lb./sq.yd.

Insofar as practical, the paver shall be oper-
at ed at a constant forward speed which will produce a
smooth uniform mat free from tears, open areas, and
other imperfections. Any hand raking of the mixture
should be kept to the absolute minimum.

E. Rolling. Normal equipment for placing and
compaction will be required except that rolling shall
be accomplished with a steel-wheel tandem roller of suf-
ficient weight to adequately compact the mixture with-
out excessive breakage of the aggregate. The amount
of rolling shall be confined to only the minimum neces-
sary for consolidating the bituminous mixture and
bonding it to the underlying surface. Excessive
rolling shall be avoided.

IV. METHOD OF MEASUREMENT

The open-graded mixture will be measured in
tons and the bituminous material for tack coat will
be measured in gallons in accordance with Article
306.4.0.

V. BASIS OF PAYMENT

The accepted quantities of open-graded mix-
ture and bituminous material for tack coat will be
paid for in accordance with Article 306.5.0 except
that the silicone and anti-stripping additives for
the mixture and water used for diluting the SS-1h
will be considered as incidentals and will not be
paid for separately.

APPROVED 10-3-76
R. HARBISON
STATE HIGHWAY ENGINEER
APPENDIX D

TEST RESULTS
FROM PROJECTS MONITORED
APPENDIX E

GEOLOGY AND OCCURRENCES
GEOLOGY AND OCCURRENCES

OHIO RIVER VALLEY

Upstream from Maysville, some 3-inch diameter gravels are dredged from bars in the river. Nearer Ashland, the former Tays River deposited sand, slits, and clays on the terraces and in the backwater valleys. The gravels are generally quartzites. Sand-bottoms occur at Vanceburg, Charleston Bottoms, and Dover. Gravels containing 40 to 56 percent carbonate-type gravels occur in the glacial outwashes of the Little Miami River (at Newtown, Ohio) and the Great Miami (clives) downstream from Cincinnati. Gravel beds are worked there, at Belview, Warsaw, and Carrollton. The carbonates tend to disappear before reaching Louisville. Outwash gravels occur in vast deposits opposite Louisvile. Sand-bottoms occur at Newtown, near Owensboro; they diminish in size toward Paducah. Only pea-gravel persists toward the Mississippi River. At the confluence, larger gravel is encountered; some granite is found. Cherty sands occur in the western Ohio River. Quartz sands persist throughout. Sands tend to be rounded and some are well polished. Some remain sharp and angular.

JACKSON PURCHASE

Chert gravels occur in abundance in the Purchase Area. They are called the Tuscaloosa and the Lafayette. The Lafayette is a brownish glassy gravel (impregnated with iron oxide in the mantle of the upper strata) and is the abundant gravel in the Purchase. It is believed to have been derived from former Fort Payne chert beds and the St. Louis. The Lafayette is equivalent to the Tennessee River gravel. The Tuscaloosa is light colored and is similar to coastal gravels in Alabama. Sands occur with the gravels (more so with the Lafayette). Gravels (dredged) were crushed at Columbus to produce Class I sands and sands for sand asphalts. Cherts were crushed to produce aggregate for open-graded plant-mixed seals. Wind-blown silts cover much of the Purchase area; they are very thick at Columbus and at Hickman; some may find use in paving mixtures (for blending) (see Figure E-2).

CASEYVILLE

The Caseyville is a sand-and-gravel conglomerate; it occurs as channel-fill trending southwestward from northern Green County (near Etna Furnace) through Edmonson County and Logan County. It is quite thick at old Kyrock, now Laurel Hill Farm. It is very pure quartz pebbles and sand. Most of the pebbles are prefractured and are crushable. It was worked by Green River Sand Company and later by Cen-Ken Stone Co. In Logan County, it is 200 feet above Mud River and is under 8 feet of soil. It is worked by Kapeo (see Figure E-3).

POTTSVILLE (LEE, ROCKCASTLE, LIVINGSTON, SHARON) CONGLOMERATES

These eastern conglomerates are similar, if not identical to the Caseyville conglomerates of western Kentucky. These outcrop along the Pennsylvanian escarpments south and east of the outer Bluegrass. A deposit at Mullins Station north of Livingston was worked by the Kentucky Stone Company in 1963 and 1964. The market then did not sustain the operation. This formation extends into southern Ohio. It was exposed along the crest of Pine Mountain (by the overthrust there) and was worked by Silica Corp. of America in the 1960's southeast of Elkhorn City. It is shown in Figure E-4. It is exposed in a large area of northeast Morgan County.

BUFFALO CONGLOMERATE

This conglomerate caps some hills in the vicinity of Webbville and Willard (Ed Waddell Farm, January 1966).

CASEY COUNTY

This is a rather large deposit of large gravel and sand perched on the top of a few hills (covered with about 15 feet of soil) and is unlike the Caseyville and Rockcastle.

IRVINE FORMATION

This formation consists of sand and gravel left perched higher and in former banks or channels of the Kentucky River. This has been correlated to the Lafayette Gravels of the Jackson Purchase Area. Some quartz gravels present are attributed to the Rockcastle and Caseyville (McFarland, A. C.; Geology of Kentucky, University of Kentucky, 1943, p 125, 126).

SANDSTONE GRAVELS

Sandstones tend to disintegrate readily in the weathering and erosion processes. Apparently few gravels persist in the Kentucky River valley at Frankfort. Some valleys feeding into the river in Eastern Kentucky may contain sandstone gravels, sand, and coal fragments (perhaps of commercial value). One such valley is near Crystal (worked by Estill Sand Co.) (see Figure E-5). These gravels have been used for base construction and as replacement aggregate on traffic-bound roads. They were designated as local creek gravels.
Figure E-1. Geological Description of the Upper Ohio River Valley near Louisville.

The diagram illustrates a) preglacial bluffs along the Ohio River at Louisville and upstream and the deep erosion of the bedrock in the channel at various locations; b) interbedded sands, silts, and gravel-fills attributed to Illinoian glacial outwashes; c) valley-fill attributable to Wisconsin glacial outwash gravels and sands; and d) recent channel-fill. Two distinct terraces are recognizable. The upper terrace is approximately 15 to 20 feet higher than the lower one in the vicinity of Louisville. The major part of the city is built on the upper terrace. The upper 15 to 20 feet of the upper terrace is usually fine sand. It is interesting to note that the valley fill is some 40 feet deeper under the heart of the city than the present river bed at the falls. This indicates that formerly the course of the river went through the present site of Louisville. The deeper valley has been filled, and the present channel is perched on the Sellersburg Limestone farther north and west than the earlier falls or scarp. The older deep channel is down into the Louisville Limestone. Where the bedrock rises toward the hills, the fill is bedded on New Albany (Devonian) Black Shale (from McFarland, A. C.; Geology of Kentucky, University of Kentucky, 1943).

Figure E-2. General Conceptual Distribution of Loessal Deposits. The area indicated was probably once covered with a mantle of loess. As a result of subsequent erosion, much of this wind blown silt has merged into valley alluviums, leaving more-or-less zonal areas of primary loess and silty residuals at the present time. Isopachs (lines of equal thickness) of the loess are shown by heavy lines. The Lafayette gravels have been reexposed or are near the surface at many locations. They comprise a mantle covering most of the area. The Tuscaloosa gravels are eastward.

Figure E-4. Rockcastle (Sharon) Conglomerate Exposed by the Pine Mountain Overthrust; Comprises Ridge Rock South of Elkhorn City. Formation was worked in the early 1960's but marketed mostly as glass-grinding sand. Many gravel-sized particles are pre-fractured and are crushable. (McGrain, P., and Crawford, T. J.; High Silica Sandstone and Conglomerate on Pine Mountain near Elkhorn City, Information Circular 1, Series X, Kentucky Geological Survey, 1959).
SANDS


SEWANEE SILICA (TENNESSEE)

A conglomerate (quartz) similar to Caseyville and Rockcastle, the Sewanee yields coarse sands that were sought for use as coarse grit for application to epoxy resin protective coatings for concrete bridge decks.

SLAGS

Blast furnace slag generated by Armco at Ashland and marketed by Standard Slag Company are usually water-quenched and are bloated (vesicular). Heavy slags (containing inclusions of iron) come from Werten, West Virginia, and from International Mills at Cairo or Carbondale, Illinois. Some phosphate slag has been blended with blast furnace slag from Birmingham and marketed out of Columbia, Tennessee. Crushed sands and chips (for open-graded seals) have been derived.

SOILS

Soils have been used for blending with aggregates. Soils have been blended with sands to achieve optimum gradation for sand-asphalt mixtures. Soils may be found that would suffice altogether or with nominal blending to produce qualifying sand-asphalt surfaces.

Figure E-5. Billey Cr., KY 52, Crystal, Kentucky, Source of Dave Cheek’s Creek Sand, 1973.
EXPANDED SHALE

Expanded shale is a lightweight aggregate manufactured by burning shale (partial fusion and bloating). New Providence shale, near Shepherdsville, was used by Kenlite. Kenlite was succeeded by Solite. The principal use was aggregate for concrete blocks. Some has been used for lightweight concrete. The aggregate is vesicular, and the absorptivity is about nine percent unless it is glazed. Sharp angular sand is obtained by crushing the coarser sizes after burning.

MORGAN COUNTY

In the western part of the county, the valleys have been cut in the upper part of Mississippian rocks, mainly in limestones and some shales. Hills are capped with the Pottsville conglomerate. A little farther east, the massive conglomerate drops towards the drainage level and becomes the predominant rock, instead of merely capping the hills, giving rise to a characteristic topography of deep steep-walled valleys and broad divides. Toward the eastern part of the county, the conglomerate again comes into prominence, having been brought nearer the surface by the Paint Creek Uplift. See 1) Rhodes, E. O.; The Paint Creek Uplift, Department of Geology and Forestry of Kentucky, Series V., Vol 3, p 243; and 2) Robinson, L. C.; Geology of Morgan County, Kentucky, Series VI, Kentucky Geological Survey, 1927.

Figure E-6. Petersburg Sand Pit, Boone County, 1977.
Figure E-7. Lewis Polley's Sand Pit.

Figure E-8. Sand Pit Atop Hill Near Furnace, Estill Sand Company.
APPENDIX F

SANDS: DEFINITIONS AND USES
SANDS: DEFINITIONS AND USES

GLASS SANDS
Quartz sands for making glass must be of high purity, at least after acid washing. Sands are fluxed with alkali, soda, lead, etc. to reduce fusion and molding temperatures. Iron tints glass red.

GLASS-GRINDING SAND
Sand, usually quartz, is used in making plate glass by grinding plates smooth and by polishing. High purity is not required.

FOUNDRY SAND
Used to make molds for molten metal castings.

MOLD SANDS
Used in foundry processes for casting metals, especially iron and steel.

CORE SAND
Mold sand used for hollow castings such as the inside of engine blocks.

SANDBLASTING SAND
Must not be too big or too fine; sometimes preferred to be not too sharp and angular.

TRACTION SAND
Used by some railroads to achieve traction upgrade or at starts; sand bites into rails and wheels and shatters.

CONCRETE SAND
Graded sand progressively smaller than 1/4 inch in diameter combined with coarser rock and cement to manufacture concrete.

MORTAR SAND
Finer than concrete sand; mixed with portland cement and water to compound mortar for masonry construction.

VEIN QUARTZ
Parent material of pebble quartz and sand.

FILTER SAND
Used in water-purifying processes.

BLOW SAND
Eolian, windblown, dune sand; rounded and frosted; corruption of "blown" sand.

CHERT
Crypto-crystalline hydrated silica.

FLY ASH
Flue ash, largely minute glass beads, cinder, and carton; from furnaces and coal-burning steam-electric generating plants.