Research Report
UKTRP-88-4

# EVALUATION OF STABILITY AND RUTTING POTENTIAL OF ASPHALTIC CONCRETE USING BIG-STONE GRADATIONS

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Considerable interest has been generated in recent years in using big stone gradations to reduce rutting and shoving in asphaltic concrete. This report documents mix design procedures and a laboratory testing program to determine the stability and rutting potential of a big-stone gradation.

A series of creep tests was performed on a big-stone gradation and the results were compared to creep tests performed on a Class I base mixture. The big-stone mix average approximately 50 percent rutting potential as compared to the Class I base. One creep specimen of the big-stone mixture was compacted using polymer-modified AC-20 grade asphalt cement. This specimen performed with less strain than the big-stone specimens compacted with an unmodified AC-20 asphalt cement (at loading times greater than 4000 seconds. One specimen was compacted using an AC-40 asphalt cement. This specimen failed at a short loading time (approximately 1000 seconds), indicating a brittle mixture.

PREVIOUS REPORTS ISSUED UNDER THIS STUDY

None

REPORTS ANTICIPATED IN THE NEAR FUTURE

Roghani, H. M., and Allen, D. L., "Determination of Resilient Modulus and Stability of Asphalt Mastics (Aggregate sizes less than 3/8 inch)"

# INTRODUCTION

In recent years, increased wheel loads and tire pressures have led to increased stresses within pavements. The resultant effects have been more obvious in flexible pavements. Thicker pavement structures may be constructed to withstand larger numbers of equivalent axleloads; however in the case of flexible pavements, elevated temperatures in the upper layers of the asphalt-bound materials make those layers highly susceptible to rutting or shoving.

This study was initiated with the general objective of quantifying some parameters that govern the stability and rutting characteristics of asphalt-bound mixtures. There has been considerable interest in recent years in big-stone mixtures (top aggregate sizes greater than 1.0 inch). It appears these mixtures have potential for higher stabilities and less rutting. Also, considerable attention has been given to composition of the mastic portion of mixtures (all aggregates smaller than 3/8 inch). This study focused on both areas of interest. This report includes information on the big-stone portion of the research.

A paving project located in eastern Kentucky is to be completed in the spring and summer of 1988. The particular site has a high concentration of heavily loaded coal trucks and will potentially be subject to rutting and shoving. It was decided to pave this project with a big-stone mixture. As a consequence, an in-depth research study was conducted to determine an optimum mixture design and to determine the rutting behavior of the optimum design.

## AGGREGATE INVESTIGATION

The coarse aggregates used in this study were from Plum Run, Ohio. All were crushed limestone from the same quarry. Three coarse aggregate gradations (No. 4, No. 56, and No. 78) were blended to obtain the coarse fraction of the various gradations tested. The average gradations for these aggregates were supplied by the quarry and are listed in Table 1. The coarse aggregate gradations are based on a dry-sieve analysis.

Two sand fractions were used in the mixtures. The first was a washed block (natural) sand from Plum Run, Ohio. The gradation, based on a dry-sieve analysis, is also listed in Table 1. The second sand was a crushed limestone sand from Kenmore, Kentucky. The wet-sieve analysis of that sand is shown in Table 1.

## LABORATORY MIXTURE GRADATIONS

Initially, 12 gradations were considered for testing. Those gradations were designated as Mix 1, Mix 1a through Mix 6, Mix 6a. Gradations identified with only a numerical value were made with Plum Run sand. Gradations identified with the letter "a" were made with Kenmore sand. Gradations for the 12 mixtures are shown in Table 2. Each gradation was made by blending two or three coarse aggregates and one sand. The blended proportions for each gradation are listed in Table 3.

All laboratory gradations could be identified as a Class K base material. Specification limits for a Class K base are coarser than for a Class I base. Specification limits for both classes are compared in Figure 1.

After discussions with representatives of the asphalt industry and with personnel of the Kentucky Department of Highways, it was decided to test only Mix 1, 1a, 2a, and 5a. Gradations of those mixtures are shown in Figure 2.

## MARSHALL MIX DESIGNS

Because of the large aggregate size, 6-inch Marshall specimens were compacted using a 22.5-pound Marshall hammer. Based partially upon work conducted by the Pennsylvania Department of Transportation (1), the target height of the specimens was 3.75 inches. The ratio of volumes between 6-inch specimens and a conventional 4-inch specimen (2.5 inches in height) is approximately 3.37. Based upon that volume ratio and using the 22.5-pound hammer, the compactive energy for the 6-inch specimen would be 112 blows per side. This is equivalent to a 75-blow mix using the 4-inch specimen.

Gradation 5a was tested initially. In an effort to obtain high stability, the first specimen was compacted using 135 blows per side. This is equivalent to 88 blows per side for a 4-inch specimen. That compaction resulted in a high density (approximately 150 pounds per cubic foot) and a low void content. In addition, considerable particle crushing occurred. Therefore, all remaining specimens were compacted using 112 blows per side. The Marshall mix design results at optimum asphalt contents are summarized in Table 4 for all test gradations. All mix design results are listed in Appendix A. Mix 1a had the highest percentage of air voids of the three mixtures that contained Kenmore sand (Mix 1a, 2a, and 5a). For this reason, Mix 1a was chosen as the gradation to use on the potential paving project in eastern Kentucky.

To develop a correlation between the 4-inch and 6-inch Marshall specimens for Mix 1a, the U.S. Army Corps of Engineers' method of Marshall mix design for large-stone mixtures was used. In this method, all aggregate particles greater than 1 inch in size are scalped off and the weight of material scalped off is replaced with material greater than 3/4 inch but smaller than 1 inch. The Corps of Engineers' method was used for both the 6-inch and 4-inch specimens. Results are listed in Table 4.

The stability for the test performed using the 6-inch mold, Corps of Engineers' method, Mix 1a, was 18 percent less than the normal method, Mix 1a. The density, flow, and air voids were essentially the same for the two methods. However, the voids in the mineral aggregate (VMA) was 0.9 percent higher in the Corps of Engineers' method. The stability from the 4-inch mold, Corps of Engineers' method, was 57 percent of the stability of Mix 1a using a 6-inch mold normal method. The density dropped by two pounds to 145.3 pounds per cubic foot. The VMA increased 1.7 percent and the air voids decreased 0.2 percent.

## CREEP, UNCONFINED COMPRESSION, AND RESILIENT MODULUS TESTS

The Asphalt Institute (AI) at College Park, Maryland, and Chevron U.S.A., Inc., Richmond Research Center, Richmond, California, participated in a laboratory testing program to determine the mechanistic properties of Mix 1a. Test aggregates were shipped to both agencies. Chevron investigators compacted specimens that were 6 inches in diameter and 3.75 inches in height. Chevron personnel performed the indirect splitting tensile test on the specimens to determine the resilient modulus. A summary of their testing conditions and results is given in Table 5.

The Asphalt Institute personnel tested laboratory compacted specimens that were 6 inches in diameter and 6 inches in height. Three methods of compaction were used for three asphalt contents. AI investigators performed unconfined compression tests at 77°F and creep tests at 104°F. Table 6 is a summary of their compaction methods, test conditions, and results.

The Transportation Research Program performed 18 creep tests. Ten tests were performed on Mix 1a, four were performed on a Class I base, and four were performed on cores from an in-service pavement that contained a large-stone mix similar to Mix 1a. Gradations of the Class I base and the pavement cores are shown in Table 7.

All creep tests were performed at a temperature of approximately 104°F. Six tests were performed on Mix 1a at a static stress of 29 pounds per square inch and four tests were performed at 80 pounds per square inch. One test was attempted at 150 pounds per square inch; however, such large loads broke the equipment. All remaining creep tests were performed at a stress of 29 pounds per square inch.

## DATA ANALYSIS

Table 9 is a tabulation of creep moduli obtained from Sample 1 (Mix 1a) and values obtained by AI under the same test conditions. In addition, creep moduli from a Class I base used on KY 627 in Clark County, Kentucky, are compared in Table 9. The gradation for this material is listed in Table 7. Tests on the material from KY 627 were performed approximately 12 years earlier under a different study. The moduli for Mix 1a obtained by the two testing agencies compare quite well. The Class I base from KY 627 yielded considerably lower values than Mix 1a.

Figure 3 is a summary of the permanent deformation data (rutting potential) from all creep tests performed by this agency at a stress level of 29 pounds per square inch. The average permanent strain for the big-stone mix (Mix 1a) at 1,000 seconds of elapsed loading time is approximately 56 percent of that of the Class I base. The permanent strain for the big-stone mix was only 11 percent of that obtained from the Class I base used on KY 627, at 1,000 seconds of elapsed time. The curve in Figure 3 representing the big-stone mixture bends upward more sharply (from 1,000 seconds to 4,000 seconds) than the curve representing the Class I base. This indicates the big-stone mixture is somewhat more brittle than the Class I mixture.

Laboratory compacted Samples 9, 12, 15, and 16 were made with a asphalt cement from the same source (Ashland Oil Company, Ashland, Kentucky) as Samples 1 through 8; however, the two cements were from different batches. Viscosities were determined for both asphalt cements using a Brookfield cone-plate viscometer. The first asphalt cement (Samples 1 through 8) had an average viscosity of 1,400 poises at 140°F. The second asphalt cement had an average viscosity of 1,990 poises at the same temperature. The higher viscosity of the second asphalt cement would appear to make the Class I base behave more like the big-stone mixture. In actuality, if the same asphalt cement had been used for both mixtures, there would have been an even greater difference between the rutting potential of the two mixtures.

Laboratory Sample No. 17 (Mix 1a) was compacted using an AC-40 grade asphalt cement The viscosity of the asphalt cement at 140°F was 4,100 poises. Figure 3 shows the permanent strain curve for this test. In the early portion of the test, strain values for the AC-40 test were approximately 11 percent less than for Mix 1a using an AC-20 asphalt cement. However, the AC-40 specimen failed much more quickly in a very brittle mode of failure.

Sample No. 18 was Mix 1a compacted using an AC-20 grade asphalt cement modified, 6 percent by weight, with a polymer designated as Kraton D4460X. The polymer was manufactured by the Shell Oil Company. The viscosity of the modified AC-20 was very high at 9,340 poises at 140°F. The permanent deformation curve for this material is shown in Figure 3. The response of the material was very flat. At less than 4,000 seconds of loading time, the permanent deformation was greater than for the unmodified AC-20 samples. However, at loading times greater than 4,000 seconds (up to 9,000 seconds) the modified AC-20 performed better. The sample would have taken considerably more strain before failure.

Results of creep tests on pavement cores from the big-stone project in Pikeville, Kentucky, also are shown in Figure 3. The permanent strains are similar to those exhibited by the Class I base (laboratory compacted specimens) used on KY 627. Pavement cores usually exhibit higher strains than laboratory compacted specimens because the methods of compaction differ between the field and laboratory. Therefore, it is not unexpected that the pavement cores composed of a big-stone mixture would yield higher strains than the laboratory compacted big-stone mixture (Mix 1a).

Figure 4 shows the permanent strain as a function of loading time for the creep tests performed on Mix 1a at a stress of 80 pounds per square inch. These results are compared with permanent strain obtained from tests on the Class I base used on KY 627. Strains from the Class I base are in the range of 2 to 2.5 times greater than strains from Mix 1a (at loading times less than 60 seconds). The Mix 1a curves bend upward more quickly than the Class I base curve. Again, this indicates Mix 1a is less susceptible to rutting, but it is somewhat more brittle than the Class I base.

## CONCLUSIONS AND RECOMMENDATIONS

It is concluded the big-stone mixture (Mix 1a) is considerably less susceptible to rutting than a Class I base. Based upon the results of this study, it is recommended that Mix 1a be used for locations where heavy loads and high tire pressures might produce rutting in a Class I base. Mix 1a or a similar big-stone gradation would be expected to reduce the potential for rutting.

Using an AC-40 grade asphalt cement is not recommended for use with the big-stone mixture. It did not significantly reduce strains in short loading times, and, in fact, failed much more quickly than specimens containing AC-20 grade asphalt cement. However, it should be noted this conclusion is based upon results of only one test. It is recommended that more testing of this material be performed.

Based upon results of only one test, the specimen compacted using the polymer modified AC-20 performed considerably better than the unmodified AC-20 at load times greater than 4,000 seconds. From these results, it is recommended that a polymer modified AC-20 asphalt be used in conjunction with a big-stone mixture on a paving project that will be subject to heavy wheel loads.

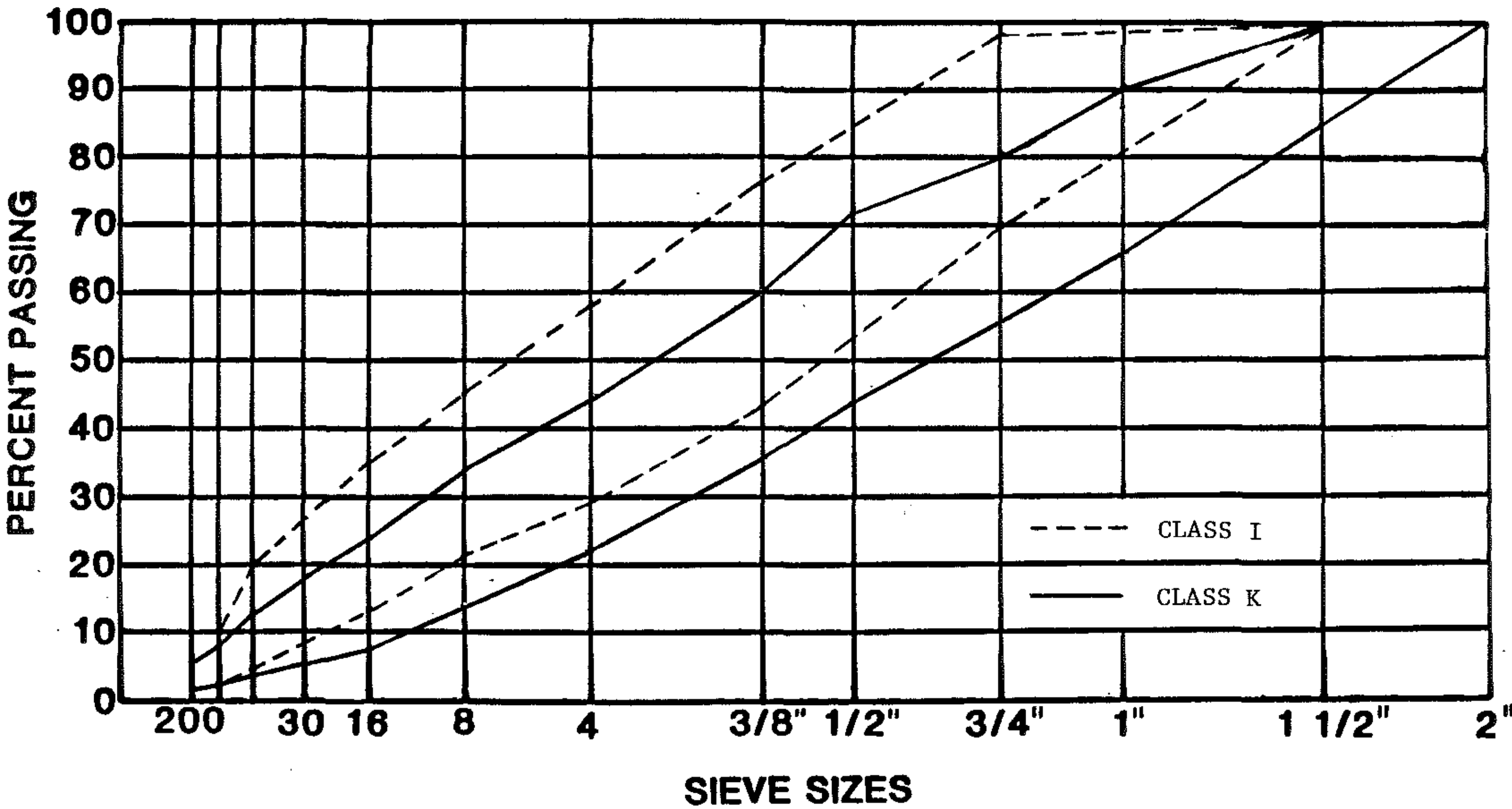


Figure 1. Gradations of Class I Base and Class K Base.

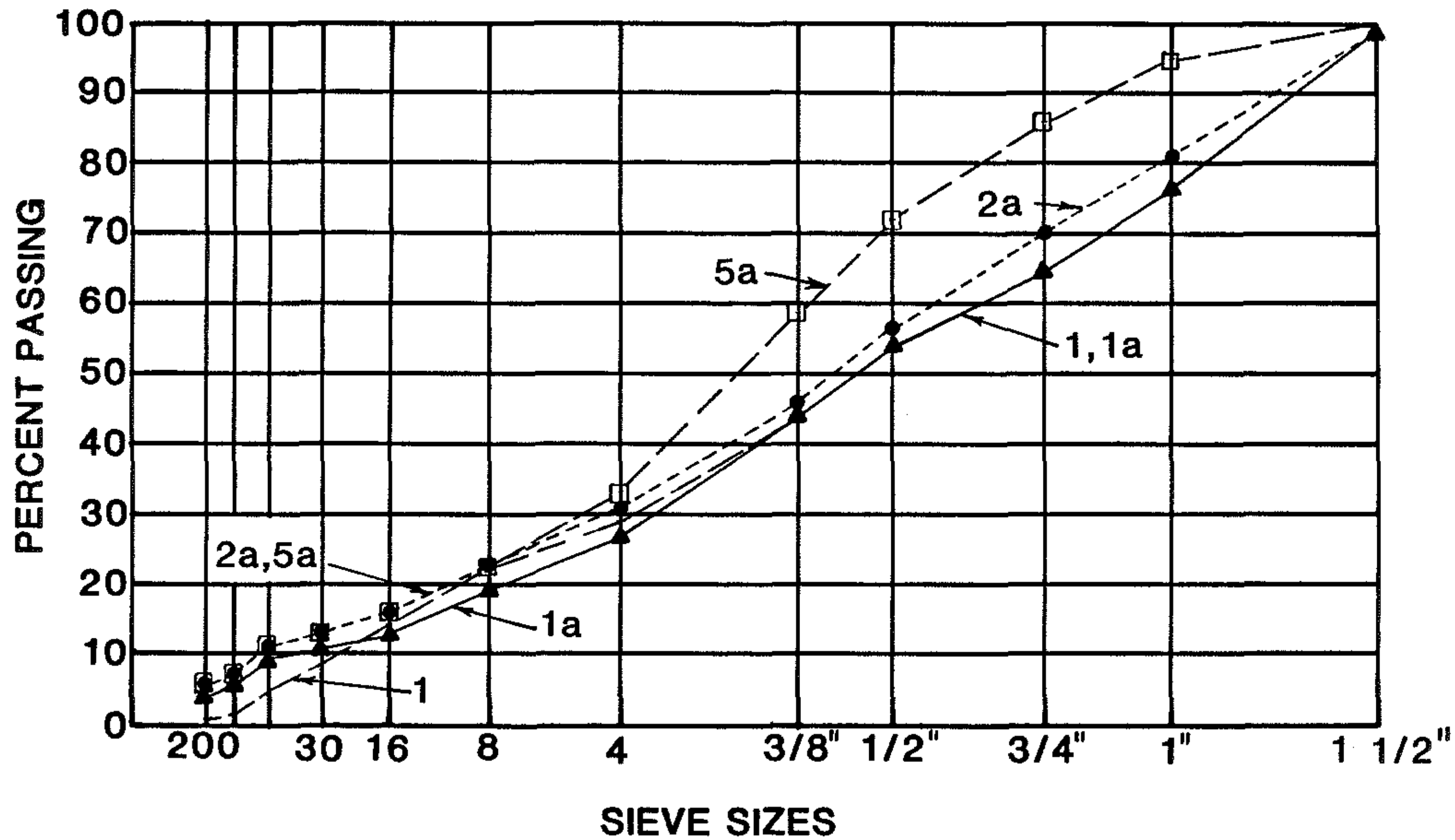


Figure 2. Gradations of Laboratory Test Mixtures.

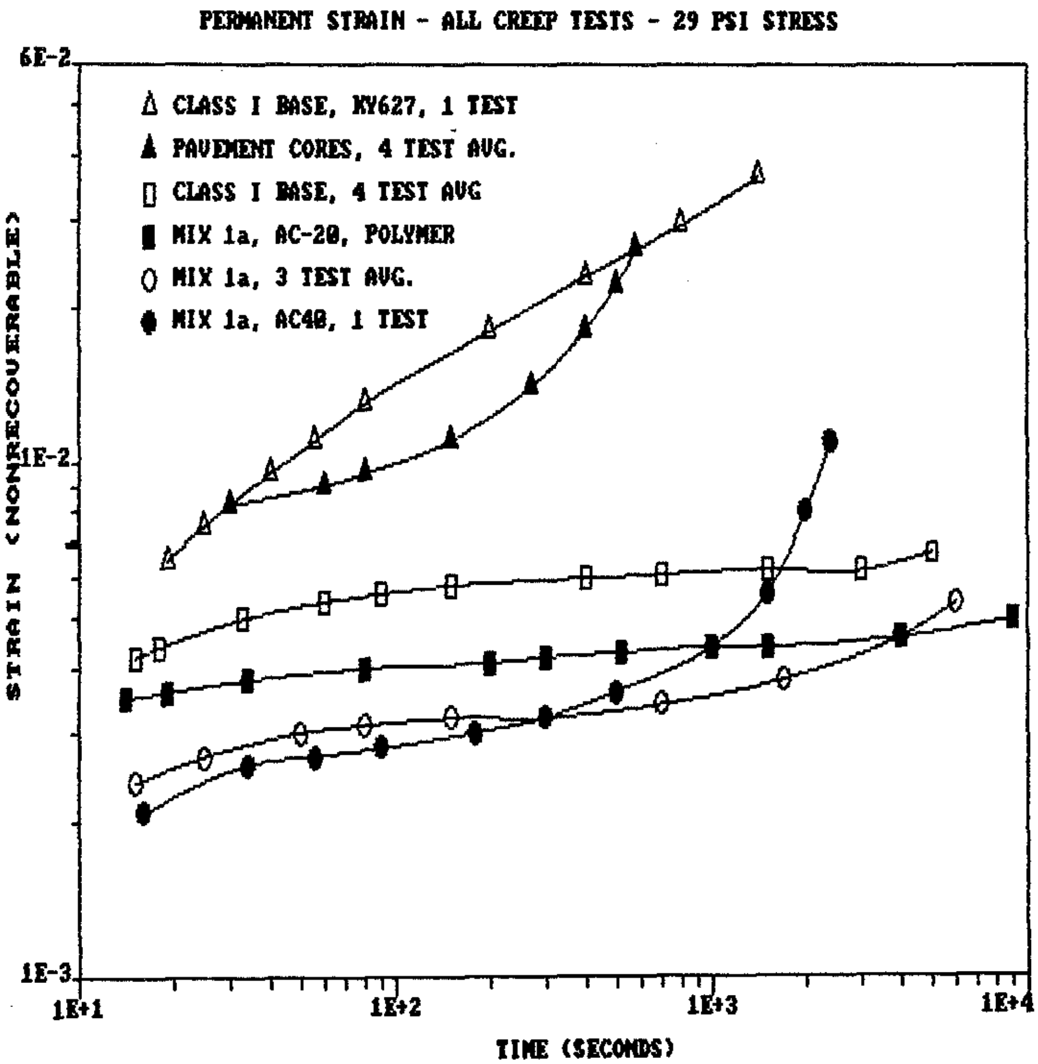


Figure 3. Permanent Strain for All Creep Tests at 29 PSI Stress.

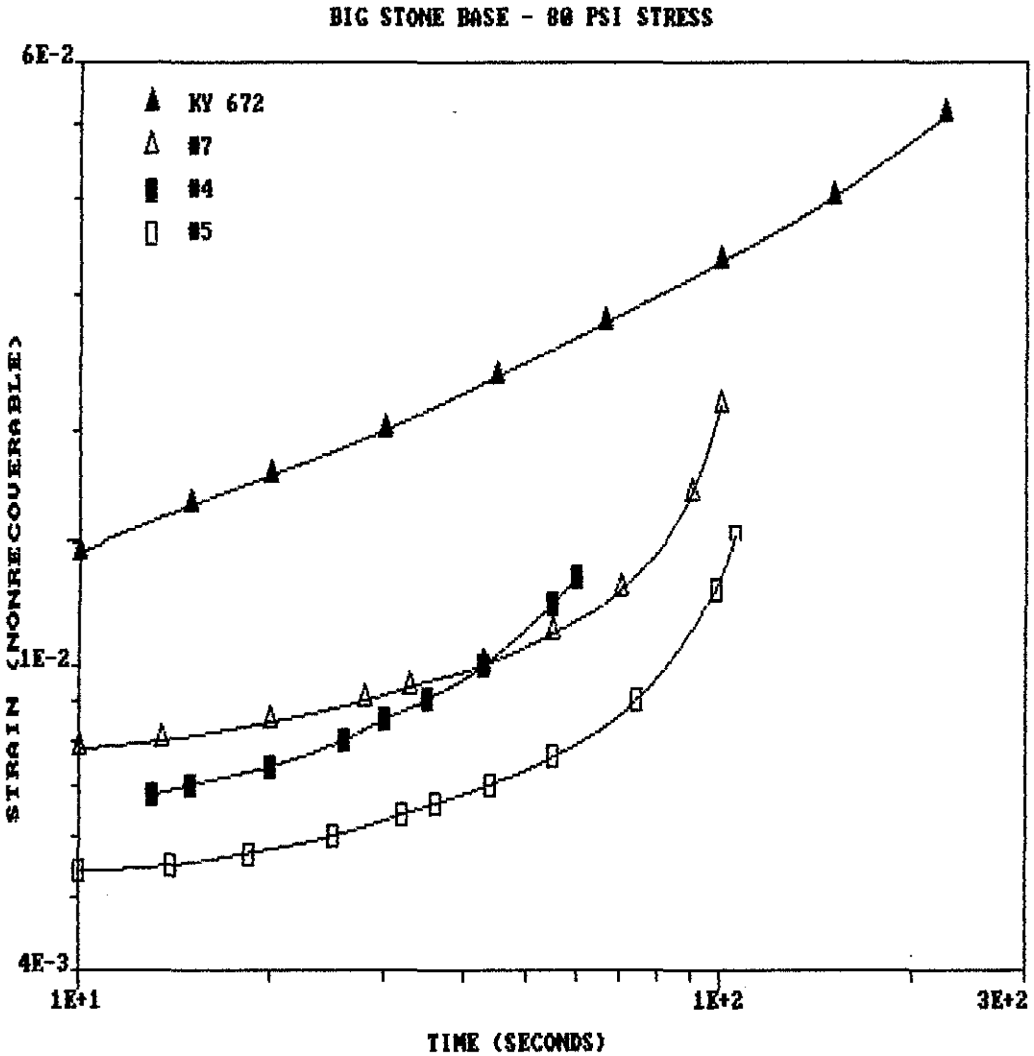


Figure 4. Permanent Strain for All Creep Tests at 80 PSI Stress.

TABLE 1. SUMMARY OF AGGREGATE GRADATIONS

| | PERCENT PASSING | | | | |
|---|---|---|---|---|---|
| SIEVE | NO.4 | NO.56 | NO.78 | PLUM RUN SAND | *KENMORE SAND |
| 2" | 100 | | | | |
| 1 1/2" | 95 | 100 | | | |
| 1" | 26 | 87 | | | |
| 3/4" | 9 | 61 | 100 | | |
| 1/2" | 2 | 25 | 94 | | |
| 3/8" | 1 | 7 | 70 | | |
| 4 | | 3 | 11 | 100 | 92 |
| 8 | | | 3 | 88 | 72 |
| 16 | | | | 58 | 52 |
| 30 | | | | 34 | 44 |
| 50 | | | | 19 | 36 |
| 100 | | | | 8 | 25 |
| 200 | | | | 4 | 16 |

* Wet Sieve Analysis

TABLE 2. GRADATIONS OF LABORATORY MIXTURES

| | PERCENT PASSING | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SIEVE | 1 | 1a | 2 | 2a | 3 | 3a | 4 | 4a | 5 | 5a | 6 | 6a |
| 2" | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | -- | 100 |
| 1 1/2" | 99 | 99 | 99 | 99 | 100 | 100 | 100 | 100 | 100 | 100 | -- | 100 |
| 1" | 77 | 77 | 81 | 81 | 94 | 94 | 95 | 95 | 95 | 95 | -- | 95 |
| 3/4" | 65 | 65 | 70 | 70 | 82 | 82 | 86 | 86 | 86 | 86 | -- | 86 |
| 1/2" | 54 | 54 | 57 | 57 | 62 | 62 | 73 | 73 | 72 | 72 | -- | 72 |
| 3/8" | 44 | 44 | 46 | 46 | 48 | 48 | 61 | 61 | 58 | 58 | -- | 59 |
| 4 | 29 | 27 | 33 | 31 | 34 | 32 | 44 | 41 | 35 | 33 | -- | 36 |
| 8 | 23 | 19 | 27 | 23 | 27 | 23 | 36 | 30 | 27 | 23 | -- | 26 |
| 16 | 15 | 13 | 17 | 16 | 17 | 16 | 23 | 21 | 17 | 16 | -- | 18 |
| 30 | 9 | 11 | 10 | 13 | 10 | 13 | 14 | 18 | 10 | 13 | -- | 15 |
| 50 | 5 | 9 | 6 | 11 | 6 | 10 | 8 | 14 | 6 | 10 | -- | 13 |
| 100 | 2 | 6 | 2.4 | 7.5 | 2.4 | 7.5 | 3.2 | 10 | 2.4 | 7.5 | -- | 8.8 |
| 200 | 1 | 4 | 1.2 | 4.8 | 1.2 | 4.8 | 1.6 | 6.4 | 1.2 | 4.8 | -- | 5.6 |

TABLE 3. AGGREGATE BLENDS USED TO MAKE LABORATORY GRADATIONS

| AGGREGATE IDENTIFICATION | PERCENT (BY WEIGHT) OF EACH AGGREGATE TYPE USED IN GRADATION | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 1a | 2 | 2a | 3 | 3a | 4 | 4a | 5 | 5a | 6 | 6a |
| No. 4 | 30 | 30 | 20 | 20 | -- | -- | -- | -- | -- | -- | -- | -- |
| No. 56 | 20 | 20 | 30 | 30 | 50 | 50 | 35 | 35 | 35 | 35 | -- | 35 |
| No. 78 | 25 | 25 | 20 | 20 | 20 | 20 | 25 | 25 | 35 | 35 | -- | 30 |
| Plum Run Sand | 25 | -- | 30 | -- | 30 | -- | 40 | -- | 30 | -- | -- | -- |
| Kenmore Sand | -- | 25 | -- | 30 | -- | 30 | -- | 40 | -- | 30 | -- | 35 |

TABLE 4. SUMMARY OF MARSHALL MIX DESIGN RESULTS

| MIX NO. | MAXIMUM STABILITY (pounds) | MAXIMUM UNIT WEIGHT ($lb/ft^3$) | MAXIMUM SPECIFIC GRAVITY | FLOW (0.01 in) | VOIDS IN AGGREGATE (Percent) | AIR VOIDS (Percent) |
|---|---|---|---|---|---|---|
| 1 | 5,100 | 145.9 | 2.524 | 22.0 | 12.6 | 5.0 |
| 1a | 5,000 | 147.3 | 2.521 | 20.5 | 11.5 | 4.7 |
| 2a | 5,200 | 147.6 | 2.530 | 26.5 | 12.2 | 4.3 |
| 5a | 4,500 | 147.8 | 2.541 | 23.0 | 14.5 | 4.0 |
| *1a | 4,100 | 147.4 | 2.521 | 20.0 | 12.4 | 4.3 |
| **1a | 2,850 | 145.3 | 2.518 | 14.0 | 13.2 | 4.5 |

* U.S. Army Corps of Engineers´ Method, 6-inch mold, 112 blows

** U.S. Army Corps of Engineers´ Method, 4-inch mold, 112 blows

TABLE 5. SUMMARY OF RESILIENT MODULUS TESTS PERFORMED BY CHEVRON

| Temperature ($^oF$) | Stress (psi) | Resilient Modulus (psi) |
|---|---|---|
| 76 | 29 | 1,050,000 |
| 76 | 29 | 828,000 |
| 76 | 29 | 1,040,000 |
| 76 | 29 | 917,000 |
| 76 | 29 | 899,000 |
| 76 | 29 | 992,000 |
| 76 | 29 | 922,000 |
| 104 | 29 | 172,000 |
| 104 | 29 | 219,000 |
| 104 | 29 | 188,000 |
| 104 | 80 | 44,200 |
| 104 | 80 | 63,000 |
| 104 | 80 | 49,000 |
| 104 | 80 | 87,400 |

TABLE 6. EFFECT OF COMPACTION TYPE AND ASPHALT CONTENT ON CREEP MODULUS AND UNCONFINED COMPRESSIVE STRENGTH (TEST PERFORMED BY THE ASPHALT INSTITUTE)

| COMPACTION TYPE | KNEADING | | | VIBRATORY | | | MARSHALL | | |
|---|---|---|---|---|---|---|---|---|---|
| Percent Asphalt | 3.6 | 4.1 | 4.6 | 3.6 | 4.1 | 4.6 | 3.6 | 4.1 | 4.6 |
| UNIT WT (pcf) | 143.2 | 142.7 | 143.4 | 142.5 | 143.5 | 143.1 | 143.0 | 142.5 | 142.4 |
| Percent Air Voids | 8.7 | 8.4 | 7.2 | 9.2 | 7.9 | 7.4 | 8.8 | 8.5 | 7.8 |
| Percent VMA | 13.2 | 13.9 | 14.3 | 13.3 | 13.4 | 14.1 | 13.2 | 14.0 | 14.5 |
| Unconfined Compressive Strength (psi) (2) | 340 | 320 | 346 | 304 | 289 | 281 | 384 | 387 | 369 |
| Creep Modulus (psi) (3) | | | | | | | | | |
| 1 min | 41,615 | 39,167 | 63,625 | 58,750 | 83,036 | 130,781 | 64,625 | 70,857 | 58,750 |
| 10 min | 28,612 | 26,406 | 36,172 | 23,605 | 59,446 | 116,250 | 37,209 | 41,823 | 35,250 |
| 60 min | 20,735 | 20,531 | 24,914 | 18,089 | 37,366 | 422,348 | 32,313 | 32,216 | 29,580 |

(1) Specimen prepared using Kentucky 1-A aggregate gradation.
(2) Measured at 77°F temperature using loading rate of 0.05 in/in of specimen height.
(3) Measured at 104°F temperature using static load of 29 psi.

TABLE 7. GRADATIONS OF CLASS I BASES AND PAVEMENT CORES ON WHICH CREEP TESTS WERE PERFORMED

| | PERCENT PASSING | | |
|---|---|---|---|
| SIEVE | PIKEVILLE PAVEMENT | CLASS I BASE | CLASS I BASE (KY 627) |
| 2" | 100 | 100 | 100 |
| 1 1/2" | 94 | 100 | 100 |
| 1" | 83 | 100 | 100 |
| 3/4" | 74 | 92 | 88 |
| 1/2" | 59 | -- | 75 |
| 3/8" | 50 | 62 | 66 |
| 4 | 32 | 46 | 47 |
| 8 | 19 | 32 | 33 |
| 16 | 12 | 20 | 21 |
| 50 | 6 | 10 | 8 |
| 100 | 5 | 7 | 5 |
| 200 | 3.5 | -- | -- |

TABLE 8. SUMMARY OF CREEP TESTS RESULTS PERFORMED BY THIS AGENCY

| SAMPLE NO. | DESCRIPTION | STRESS (psi) | TEMPERATURE (°F) | TIME (min) | PERMANENT STRAIN ($10^{-3}$) |
|---|---|---|---|---|---|
| 1 | Big Stone (Mix 1a) | 29 | 101 | 100 | 5.6 |
| 2 | Big Stone (Mix 1a) | 29 | 104 | 100 | 4.1 |
| 3 | Big Stone (Mix 1a) | 29 | 104 | 100 | 5.8 |
| 4 | Big Stone (Mix 1a) | 80 | 102 | 1 | 13.2 |
| 5 | Big Stone (Mix 1a) | 80 | 105 | 1 | 14.5 |
| 6 | Big Stone (Mix 1a) | 80 | 104 | 1 | 14.4 |
| 7 | Big Stone (Mix 1a) | 80 | 104 | 1 | 22.3 |
| 8 | Big Stone (Mix 1a) | 150 | 104 | -- | -- |
| 9 | Class I Base | 29 | 102 | 100 | 4.5 |
| 10 | Pavement Core No. 4 | 29 | 103 | 10 | 39.1 |
| 11 | Pavement Core No. 6B | 29 | 103 | 10 | 12.0 |
| 12 | Class I Base | 29 | 104 | 300 | 9.3 |
| 13 | Pavement Core No. 11 | 29 | 104 | 10 | 15.9 |
| 14 | Pavement Core No. 4B | 29 | 105 | 10 | 23.1 |
| 15 | Class I Base | 29 | 104 | 30 | 4.1 |
| 16 | Class I Base | 29 | 104 | -- | 8.3 |
| 17 | Big Stone (Mix 1a),AC-40 | 29 | 106 | 40 | 16.0 |
| 18 | Big Stone (Mix 1a),AC-20S | 29 | 104 | 90 | 4.8 |

TABLE 9. COMPARISON OF CREEP MODULUS VALUES

| SAMPLE NUMBER | IDENTIFICATION | CREEP MODULUS (psi) 1 min. | 10 min. | 60 min. |
|---|---|---|---|---|
| 1 | Mix 1A (29 psi) | 59,627 | 48,979 | 33,449 |
| | Asph. Int. (Mix 1A) (Marshall) | 70,857 | 41,823 | 32,216 |
| | KY 627 | 40,000 | 25,000 | 14,000 |