Research Report
KTC-90-26

PERFORMANCE EVALUATIONS OF CRUSHED SANDSTONE AGGREGATES IN BITUMINOUS BASES

by

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in cooperation with
Kentucky Transportation Cabinet

and

Federal Highway Administration
US Department of Transportation

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COMMONWEALTH OF KENTUCKY
TRANSPORTATION CABINET
FRANKFORT, KENTUCKY 40622

DON C. KELLY, P.E.
SECRETARY
AND
COMMISSIONER OF HIGHWAYS

BRERETON C. JONES
GOVERNOR

December 20, 1991

Mr. Paul E. Toussaint
Division Administrator
Federal Highway Administration
330 West Broadway
Frankfort, Kentucky 40602-0536

Dear Mr. Toussaint:

SUBJECT: IMPLEMENTATION STATEMENT
KYHPR 84-99, Evaluation of Sandstone Base and Surfaces

Research Report KTC 90-26, entitled "Performance Evaluations of Crushed Sandstone Aggregates in Bituminous Bases" describes performance evaluations of bituminous pavements containing crushed sandstone aggregates in the base layers. The primary study objective was to develop historical performance data relative to visual distress surveys or condition ratings, pavement rutting characteristics, and structural condition using Road Rater deflection measurements. Additionally, laboratory tests were conducted to characterize the engineering properties of the bituminous sandstone base mixtures.

It was concluded that pavements constructed using bituminous sandstone base mixtures in the pavement structure do not develop excessive permanent deformation, such as rutting, shoving and pushing, under heavy traffic loadings. However, those pavements do exhibit several forms of cracking earlier than pavements constructed using bituminous limestone base mixtures. Engineers with the Kentucky Department of Highways have indicated general satisfaction with the use and performance of bituminous sandstone base and surface mixtures. The use of bituminous sandstone mixtures addresses concerns such as haul costs, rutting, skid resistance, etc.

As a result of this research study evaluating sandstone aggregates in bituminous mixtures, bituminous sandstone mixtures will be specified as an alternate paving material when sandstone aggregate is locally available.

Sincerely,

Glen M. Kelly, P. E.
Acting State Highway Engineer

Technical Report Documentation Page

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16. Abstract
The principal objective of the research effort was to develop historical performance data for bituminous sandstone pavements and bituminous limestone pavements relative to visual distress, pavement rutting characteristics, and structural condition using deflection measurements. Data relative to Road Rater deflections, pavement rutting, condition ratings based on subjective visual surveys and objective data such as skid resistance and rideability, were collected and analyzed during the course of the study.

It was concluded, based upon information gained during the evaluation period and summarized in this report, that pavements constructed with bituminous sandstone bases did not develop excessive rut depths, were more resistant to shoving and pushing, but appeared to exhibit cracking at an earlier age than pavements constructed with bituminous limestone bases. The use of bituminous sandstone mixtures addresses problems such as haul costs, rutting, skid resistance, etc. Field engineers indicated that although bituminous sandstone surface mixtures have a slight tendency to ravel, they are very resistant to rutting and applications of bituminous sandstone base and surface mixtures have been very successful in their estimation.

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EXECUTIVE SUMMARY

The objectives of this research study were A) to measure the properties of base and surface mixtures containing sandstone aggregates; B) to utilize the information obtained from Objective A for development of modifications for mix design and/or thickness design procedures if appropriate; C) to develop historical performance data relative to visual distress, pavement rutting, structural condition using deflection measurements, and other factors if appropriate; and, D) to develop guidelines and recommendations for implementation. The anticipated benefits to be derived from the research study were increased use of abundantly available sandstone aggregate in eastern Kentucky and reduced highway construction costs associated with using sandstone as opposed to importing limestone. Improved state-of-the-art design and construction techniques for use of sandstone aggregates in bituminous base and surface courses were other anticipated benefits.

A comprehensive review of available literature concerning the use of sandstone aggregates in bituminous mixtures was conducted. A majority of the literature, published by the Kentucky Department of Highways, Division of Research, was related to experience with the use of sandstone aggregates for highway construction in Kentucky. As early as the mid-1920's, Kentucky investigated the use of sandstone aggregates in portland cement concrete. The first all bituminous sandstone pavement was constructed from Paintsville to Inez in Johnson County during the 1941 construction season.

During the course of this study, information relative to Road Rater deflections, pavement rutting, condition ratings based on subjective visual surveys and objective data such as skid resistance and rideability, were gathered and analyzed. It was concluded that pavements constructed using bituminous sandstone bases in the pavement structure were not as susceptible to development of excessive permanent deformation such as deep ruts and, shoving and pushing. However, pavements constructed using bituminous sandstone bases in the pavement structure were more susceptible to cracking at an earlier age than pavements constructed from conventional bituminous limestone mixtures.

Engineers with the Kentucky Department of Highways have indicated general satisfaction with the use and performance of bituminous sandstone base and surface mixtures. The use of bituminous sandstone mixtures addresses problems such as haul costs, rutting, skid resistance, etc. Field engineers indicated that although bituminous sandstone surface mixtures have a slight tendency to ravel, they are very resistant to rutting and applications of bituminous sandstone base and surface mixtures have been very successful in their estimation. Although there no longer are any quarries producing sandstone coarse aggregate for bituminous mixtures in Kentucky's eastern sandstone region, it is recommended that Kentucky Specification 413, Bituminous Concrete Base, Binder, and Surface, Class S, remain in the Kentucky Department of Highways' Standard Specifications for Road and Bridge Construction.

INTRODUCTION

Crushed limestone is, and continues to be, the primary road building aggregate in Kentucky. The supply of quality limestone aggregate is abundant over approximately three-fourths of the state. In the remaining one-fourth however, it is necessary to use either locally obtainable aggregates or to import limestone aggregates. The latter is usually the case and transportation costs may equal or exceed the cost of the aggregate itself. The largest area so affected is the eastern Kentucky sandstone region (see Figure 1). Some of this area may be economically supplied with limestone aggregate sources along the western edge of the region; from outcrops of the Pine Mountain Overthrust; or from a few locations where streams and rivers have penetrated the sandstone strata to reach suitable limestone deposits. Also, the northern extremity of the region may be supplied with river gravels or crushed slags. This still leaves a large area in the center of the region where obtaining quality limestone for highway construction is excessively expensive.

In an effort to utilize indigenous aggregates within this area, research on sandstone has been conducted intermittently over a period of more than 60 years. Although the Kentucky Department of Highways has had specifications for the use of crushed sandstone aggregates for more than 30 years, Kentucky's experience with pavement design, construction techniques and performance concerns pavements using limestone aggregates. Performance histories for bituminous pavement mixtures using sandstone aggregates have not been developed to the degree with which bituminous mixtures containing limestone aggregates have. While sandstone aggregates have been used occasionally for several years, the construction of KY 80 utilized sandstone extensively in the bituminous base mixtures. Performance related problems for certain sections of KY 80 led to questions regarding the engineering properties of sandstone aggregates. Engineering properties which required additional investigation and definition included modulus of elasticity, permeability, stability, density, segregation during construction, and effects on other engineering properties due to variability among sandstone aggregates.

The objectives of this research study were a) to measure the properties of base and surface mixtures containing sandstone aggregates; b) to utilize the information obtained from Objective (a) for development of modifications for mix design and/or thickness design procedures if appropriate; c) to develop historical performance data relative to visual distress, pavement rutting, structural condition using deflection measurements,

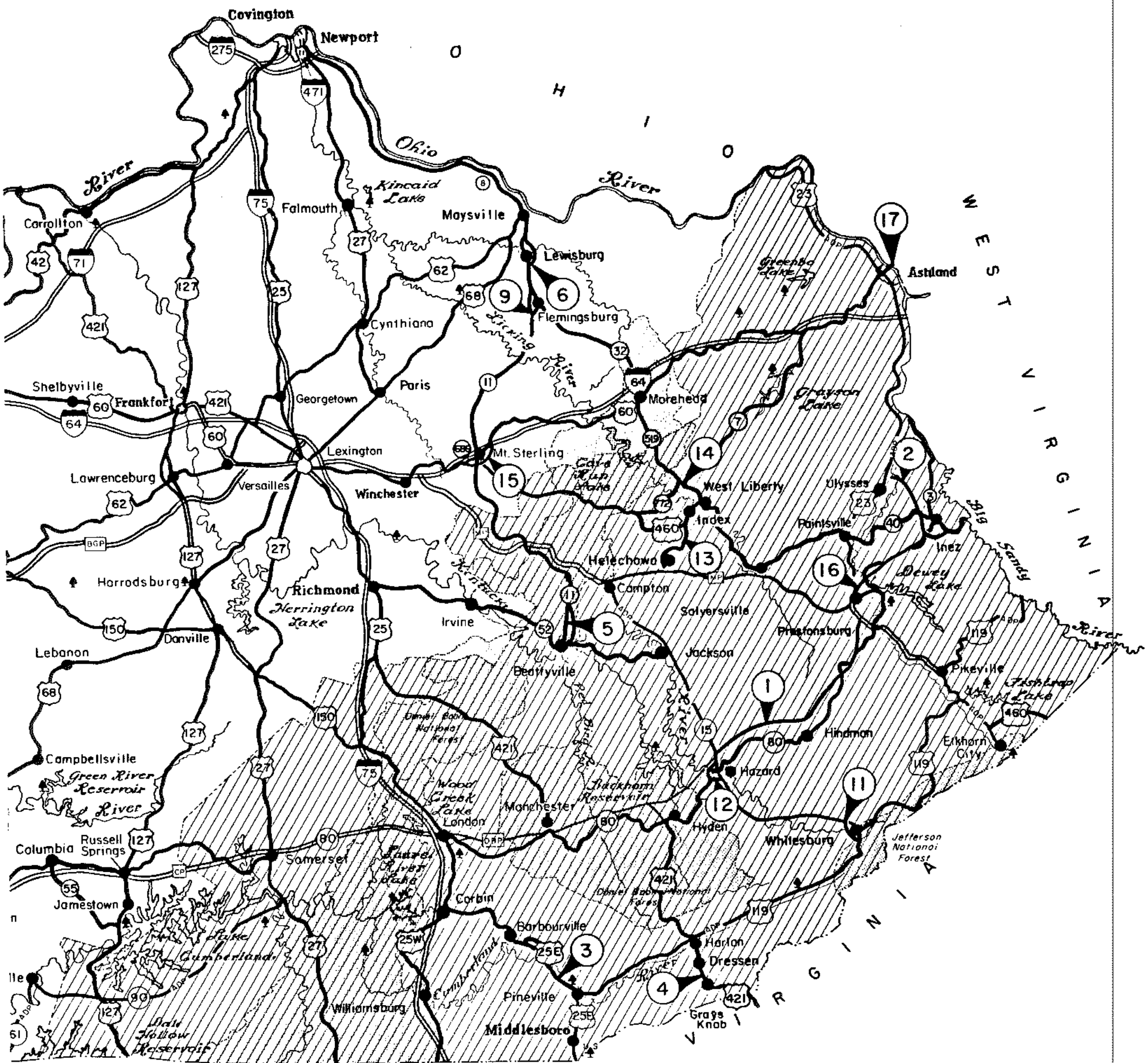


Figure 1. Eastern Kentucky's Sandstone Region.

and other factors if appropriate; and, d) to develop guidelines and recommendations for implementation. The anticipated benefits to be derived from the research study were the use of abundantly available sandstone aggregate in eastern Kentucky and reduced costs associated with using sandstone as opposed to importing limestone. Another anticipated benefit is improved state-of-the-art design and construction techniques for the use of sandstone aggregates in bituminous base and surface courses.

Phase I of the research study involved a literature search and review to adequately assess the current state-of-the-art for use of sandstone aggregates. Phase II involved field and laboratory testing. The overall objective of the field and laboratory testing program was to make comparisons of the performance of bituminous sandstone pavements to the performance of bituminous limestone pavements. To achieve this objective, the work plan called for the testing program to be separated into two areas, each being pursued simultaneously. The areas were designated as: monitor performance of bituminous sandstone and bituminous limestone pavements; and, evaluate mixtures in the laboratory to determine the effects of the variability of native sandstones on mix designs.

The field testing portion of Phase II included monitoring selected sites in eastern Kentucky where bituminous sandstone and bituminous limestone pavements were being constructed or were already in-place. The sites were chosen from Resource Recovery Road Projects, where some background data were available, including: KY 80, KY 519, KY 205, KY 645, US 119, KY 15 - Whitesburg Bypass, and KY 15 - Hazard Bypass. Data obtained during field reconnaissance surveys included: 1) Road Rater deflections to evaluate elastic moduli of the pavement layers; 2) pavement coring for visual inspection, pavement thickness determinations, and laboratory testing; 3) rut depth measurements; 4) skid-resistance and rideability data; and, 5) visual inspections for cracking patterns or signs of unusual behavior. Concurrent with the visual inspections and rut measurements, KTC personnel utilized Kentucky Transportation Cabinet and Asphalt Institute pavement rating systems to rate various deficiencies and conditions of the sites monitored.

The laboratory component of Phase II involved evaluating bituminous sandstone mixtures in the laboratory to determine the suitability of a given mix. Unfortunately, sufficient data were not obtained in the laboratory relative to asphalt content / density relationships, permeability, unconfined compressive strength, durability, modulus of elasticity, or triaxial shear strength to determine guidelines for the development of optimum mixture designs for bituminous sandstone mixes. Sonic modulus, resilient modulus, and resistance to plastic flow tests were performed on field cores. It was also intended to examine various types of Kentucky sandstones in the laboratory and determine the effects of the sandstones' inherent variability on performance. However, testing activities relative to freeze-thaw durability, abrasion or wear, and asphalt absorption of sandstone aggregates were not performed. The study required sandstone aggregates be obtained from quarries within Kentucky, and to observe the effects of contamination on performance. There are three reasons why contamination of sandstone aggregates are thought to be important: material quality control, construction quality control, and long-term performance. Material quality control involves the problem of contamination at the quarry site. As sandstone is excavated, it may become contaminated with soil, shale, coal, or other materials, thus affecting both mix designs and quality control. Construction quality control is primarily a problem of field handling, which mainly applies to its use as an unbound base material. Blasting or other construction practices may cause mixing with other materials during the construction process. Long-term performance is affected not only by material quality control and construction quality control, but also may be affected by infiltrated water in the road base system. Infiltration of water into the road base system carries finer materials into the sandstone matrix and inhibits the drainage characteristics expected from the road.

Had laboratory evaluations been accomplished, Phase III would have involved correlations between field performance observations and engineering properties and characteristics of bituminous sandstone mixtures determined from laboratory test data. But because of the limited laboratory data obtained during Phase II, the desired correlations could not be carried out as planned. Attempts made to resurrect pertinent laboratory data from old records for the routes monitored met with little success. Collection and evaluation of traffic data including volumes, classifications and vehicle loadings were required for any meaningful correlations. The implications of these correlations and analyses from the preceding phases relative to design and construction procedures and specifications were to be examined in Phase IV.

This report documents activities completed during the research study. Specifically, the report summarizes information gained from a literature search and review, historical performance data from the routes chosen for the study relative to pavement condition ratings, pavement rutting characteristics, structural condition based upon Road Rater deflection tests and analyses, and laboratory tests performed on pavement cores obtained from the chosen routes. For simplicity, this report details evaluation activities, summarizes data obtained during the course of the study, and presents conclusions and recommendations based upon the information presented herein and contained within the data appendix to this report. The data appendix report, Research Report KTC 90-26A, contains typical sections, projected traffic volumes for design, and results of field and laboratory evaluations for the various routes investigated during the study.

BACKGROUND

As early as the mid-1920's the Kentucky Department of Highways investigated the use of sandstone aggregates in portland cement concrete. A series of tests proved that sufficient strength and durability could be obtained from concrete made with sandstone aggregates (1). The initial concrete pavement was constructed in 1926 in Harlan and Bell counties (US 119) in the far eastern part of the state (2). The cost savings associated with the use of sandstone aggregate reportedly amounted to about $84,000 for the 26.2-mile road. Another sandstone aggregate-cement concrete pavement was constructed from Jenkins to Seco (US 119) in 1927. Reportedly many culvert slabs and headwalls, box culverts, and bridges had been constructed in eastern Kentucky, prior to 1930, using native sandstone aggregates in lieu of limestone aggregate.

The first all bituminous sandstone pavement was constructed by contract from Paintsville to Inez in Johnson County (KY 40) during the 1941 construction season (4). It was reported that performance characteristics were equal to conventional (limestone) bituminous pavements in the region in most respects. In 1951 and 1952, a test section of bituminous sandstone pavement was constructed on KY 30 in Magoffin and Breathitt counties with state forces and state equipment (5, 6, 7). That section incorporated a multitude of different gradations and asphalt cement binders throughout. Apparently, the test section did not perform very well. However, the failures were not in the paving materials but were associated with overall poor subgrade strength and drainage conditions.

As a result of these experimental uses of sandstone aggregates, Kentucky adopted Special Specification No. 3-56 and No. 4-56 in 1957 (8, 9). Special Specification No. 3-56 covered the material requirements for crushed sandstone aggregates in bituminous paving mixtures and bases while Special Specification No. 4-56 covered material requirements and construction methods for Class "S", hot-mixed, hot-laid, bituminous concrete pavements and bases using crushed sandstone aggregate. A 1957 memorandum from the Commissioner of Highways required "calcareous sandstones, obtained in Johnson and other east Kentucky counties, be used in base courses and bituminous pavement where it appears to be economical and wise in this section of the state." Although the use of sandstone aggregates in bituminous base and surface courses appeared to be mandated by the Commissioner of Highways, sandstone was used only occasionally again until the late 70's.

Figures from the Kentucky Department of Mines and Minerals indicated that the tonnage of coal transported by truck had increased nearly 37 percent between 1973 and 1976. During this same period, the Kentucky Transportation Cabinet reported that the mileage of highways which were used extensively for the transportation of coal had increased from 4,383 miles to approximately 6,800 miles. The Kentucky General Assembly of 1976 recognized that many highways carrying coal traffic were inadequate to meet the demands being placed upon them. Highways which were designed to serve local needs were being subjected to increasing volumes of traffic containing high percentages of trucks. The growing demand for coal as a prime energy source accentuated the need for an improved highway transportation network within the coal fields and to major marketing sites. To meet this need, the 1976 Kentucky General Assembly enacted legislation creating a program of Resource Recovery Roads financed by the sale of revenue bonds which would be retired by annual charges to the coal severance tax.

The construction of Resource Recovery Roads in rural eastern Kentucky renewed the interest in using sandstone as an alternate aggregate source. The reconstruction of KY 80 (Hazard to Watergap) utilized large amounts of sandstone aggregate in the bituminous base course, shoulders, medians and roadbed. Evaluations of KY 80 in the fall of 1981 indicated significant variations in sandstone subgrade strength. In 1982, artesian water in the median, mainline pavement, and shoulders of KY 80 were observed. During the course of the ensuing investigation, variations in the permeability among asphaltic concretes containing limestone versus those layers containing sandstone were observed. Similar variations were observed in ultimate modulus of elasticity for the various layers. Concerns arose as to whether these conditions were common to the sandstone areas or represented only isolated occurrences. The long-term utilization and performance of sandstone aggregates for use in highway construction were questioned. Researchers stressed that it was of the utmost importance to ascertain the long-term performance of any material so as to anticipate and program for future maintenance costs or savings as a result of either the inferiority or superiority of the material and its applications. The research reported herein was the effort of researchers to establish the long-term performance aspects of bituminous sandstone base mixtures.

The evaluations conducted during the course of this study involved field reconnaissance and laboratory testing of pavement materials containing sandstone aggregates in bituminous base mixtures. The laboratory study involved testing to evaluate variations in ultimate modulus of elasticity. The field study involved monitoring the performance of sandstone aggregates contained in bituminous base mixtures in actual highway applications. Field evaluations were accomplished by obtaining and analyzing the following data: 1) Road Rater deflection measurements to evaluate modulus of elasticity; 2) pavement coring for verification of constructed thicknesses, visual examinations and laboratory evaluation; 3) visual inspections and condition evaluations of pavement surfaces; 4) rut depth measurements; and 5) skid-resistance and rideability measurements.

LITERATURE REVIEW

A comprehensive review of available literature concerning the use of sandstone aggregates in bituminous mixtures was conducted. The National Aeronautics and Space Administration Technology Applications Program at the University of Kentucky was utilized to develop the literature review through the use of a computer search generated by the use of related key words. A total of 117 abstracts were identified by the computer search. Of these, only 16 were deemed somewhat useful to this study, although not all were directly applicable in defining the performance characteristics of sandstone aggregates in bituminous mixtures.

The earliest experimental use of sandstone aggregates in a bituminous pavement in the state of Kentucky apparently was a section of Kentucky Route 40 (4). The Paintsville - Inez road in Johnson County was built by contract during the construction season of 1941. The pavement structure consisted of a 1-inch insulation course overlain by a 4 1/2-inch compacted bituminous concrete base and a 1-inch bituminous surface. Crushed sandstone aggregate, both coarse and fine, from a source within the vicinity of the project, and PAC 5 (85-100 penetration asphalt cement) binder were used throughout the project. During the spring and summer of 1942, two inspections were made of the road to determine the condition of the pavement after one year's service and to evaluate the general effect of sandstone in bituminous construction. The inspections were supplemented by obtaining core specimens from the pavement. The report lists detailed notes from observations made during the inspections as well as information from asphalt extraction tests (bitumen content and gradations of the stone). The report concludes that performance of the sandstone-bituminous mixture was equal in most respects to others in the area in which conventional (limestone) aggregates had been used. Researchers recommended that any bitumen content above 9.5 percent was too high and that below 8.5 percent, the mix was deficient in bitumen content. It also was recommended that sandstone aggregate used for surface courses pass a No. 4 sieve to eliminate excessive pitting of the surface. Overall, researchers found the pavement surface to be in excellent condition relative to texture, surface pitting and bitumen content. Analyses from extraction tests indicated a bitumen content range of 7.2 percent to 10.4 percent. Where bitumen contents were lowest, the pavement surface was characterized by pitting (pop-outs) and open textures. Where excessive bitumen contents were observed, the pavement surface contained small wrinkles and showed some slight movement (shoving) under traffic action. Comments contained in the report also alluded to excellent resistance to wear and superb no-skid properties.

Additional core specimens were obtained from KY 40 and reported on in 1946 (10). The focus of that report was density and absorption analyses of the sandstone-bituminous pavement cores. During the analyses, researchers assumed a value for the specific gravity of the sandstone because there were no records located which pertained to the material at the time of construction. The 2.50 assumed value was thought to be somewhat in error as evidenced by the high percentages of solid volume densities for the base course determined by measured weights and volumes. Solid volume densities of the base course ranged from 96.5 pcf to 102.6 pcf while the solid volume densities of the surface course ranged from 80.0 pcf to 97.8 pcf. Water absorption was measured for the total sample (base and surface layers) and ranged from 0.64 percent to 1.70 percent. Apparently this work was performed prior to the time that any stability analyses were incorporated into laboratory procedures. Also, there were no asphalt extractions attempted on these cores and consequently, the percentages of bitumen reported were those representing the amounts of material scheduled for the pavement at the time of the construction.

In 1948, Metcalf and Goetz conducted a comprehensive laboratory study of sandstone covering the western and southwestern portion of Indiana (11). Results from this study indicated that on the basis of the criteria of Marshall stability tests, sandstone aggregates could be used satisfactorily in bituminous mixtures. It also was established that a relative rating of the ability of sandstones to resist degradation in use could be obtained from results of the Los Angeles abrasion test at 100 revolutions. Because sandstones degrade materially under the action of both mixing and compaction, it was suggested that the amount of fine material in the mixed and compacted bituminous sandstone pavement could be reduced by increasing the proportion of coarse to fine aggregate in the original grading. The authors determined that the optimum asphalt content of a bituminous sandstone mixture was a function of the absorptive power of the sandstone in combination with its ability to resist degradation. The amount of asphalt absorption to be expected in the bituminous sandstone mixture was approximated by direct immersion of the sandstone in heated asphalt for a controlled period of time. Based upon limited data, the researchers also indicated that a relation existed between the amount of water absorbed and the amount of asphalt absorbed by direct immersion of sandstone aggregates.

Ringo studied cementation and inherent crushing strength of eastern Kentucky sandstones during 1950-51 (12). He reasoned that the use of clastic rocks in construction is determined, in large part, by the degree and nature of cementation or the total bonding effort within an aggregate. The inherent resistance of an aggregate to crushing was recognized as the strength characteristic most important in its application to highway construction. Ringo tested 20 sandstones from eastern Kentucky for bulk and apparent specific gravity, porosity, permeability, and percent voids. Ringo also investigated mineralogical and chemical compositions, made optical determinations, and studied shear and compressive strengths of the sandstones. Cementation was defined as the sum of the percent cement and degree of interlocking. Only a slight relationship was found to exist between percent cement and strength and between interlocking and strength. Ringo inferred that inherent strength was determined by the sum of these values, rather than by either alone.

The most comprehensive study investigating Kentucky sandstones as bituminous paving aggregates was undertaken by the Kentucky Department of Highways' Highway Materials Research Laboratory during 1950 (5). The culmination of an extensive laboratory study was construction of a test section on State Route 30 in Magoffin and Breathitt counties in 1951 and 1952. The project was initiated by the Division of Maintenance of the Kentucky Department of Highways and was constructed using Department of Highways' forces and equipment.

A summary of the laboratory study concluded that sandstones having less than 30 percent Los Angeles abrasion (LAA) losses at 100 revolutions using charge B were satisfactory paving aggregates. It was determined that those sandstones having less than 30 percent LAA loss also absorbed less than 2-1/2 to 3 percent bitumen. A gradation modulus (the sum of the percents passing each series of sieves; 1-inch, 3/4-inch, 1/2-inch, 3/8-inch, No. 4, No. 8, No. 16, No. 30, No. 50, No. 100, and the No. 200) was developed, which differed only slightly from the fineness modulus concept. The gradation modulus provided an expedient method of selecting approximate bitumen contents for given gradations. For the sandstones studied, it was recommended the gradation modulus exceed 350 for binder mixtures and 450 for surface mixtures. Porosities of the sandstones also were investigated.

Porosity was determined to be very important to the study of sandstones as a bituminous aggregate because of the sandstone aggregate's capacity to absorb appreciable quantities of bituminous cement during mixing and processing. Bituminous mixtures were examined relative to the Marshall stability test. Marshall stability tests were applied to bituminous mixtures consisting of PAC-5 and PAC-8 asphalt cements and 25 different blends of sandstone aggregates. Controlling factors for stability number, flow, percent voids and percent voids filled with bitumen were established. It was determined that all controlling factors except stability had a well defined relationship with respect to gradation modulus. Also, the use of softer asphalt cements with the sandstone aggregates slightly decreased the optimum asphalt content, increased the percent voids in the compacted mix and decreased the percentage of voids filled with asphalt, but other properties remained essentially unchanged.

Field work for the study involved many variables including aggregate type, bituminous materials and paving mixture designs. Quarrying operations for the project are detailed in the report. The report also describes crushing operations and crusher products for two separate quarries and the bituminous plant operation.

Subgrade samples were obtained, classified and evaluated for maximum dry density and optimum moisture content. California Bearing Ratio values were determined to be 5.6% and the desirable pavement thickness was 8-1/2 inches, based upon a Kentucky Class II traffic classification. Prior to placing the pavement mix, most of the existing traffic bound sandstone base was primed with two applications of RT-2 with the exception of a 2.1-mile section near Gauge which was primed with MC-0. In most cases, priming was done well ahead of the paving operation allowing at least a one week curing period.

The report addresses the paving operation and equipment and difficulties experienced during placement of the sandstone-aggregate bituminous mixtures. The project contained 25 different binder mixtures and 15 different surfaces mixtures. According to the assembled data, production from almost any of the mixes was much more uniform relative to the gradation than from the bitumen content, although some variations in the bitumen content were introduced deliberately. Particular attention was devoted to the handling and working characteristics of the paving mixtures as influenced by paving and rolling temperatures, aggregate gradation, bitumen content, and firmness of the underlying base.

The project also included an Accelerated Traffic Section wherein a two-mile section of the bituminous sandstone mix was placed south of the Salyersville quarry site which allowed construction traffic to traverse over it. As a result of this arrangement, the new pavement received 7,500 seven-ton loads of quarry material in the first mile, and as much as 2,300 eleven-ton loads of plant-mix material in the second mile during the first few months of service in addition to normal traffic. By the end of the construction season, it was apparent that the pavement had been weakened. During the winter season that followed, numerous and extensive failures developed. However, from the standpoint of the sandstone and bituminous sandstone mixtures, there were no evidences of excessive deterioration under traffic. The researchers attributed the failures to the inadequate subgrade and base support. However, there also were numerous aggregate pop-outs on the surface of the bituminous sandstone mix which raveled under traffic action.

A summary of the field investigations indicates thin pavement and soft bases accounted for the majority of early failures observed. Perhaps the most significant development relative to this project occurred during production of the sandstone aggregate. The "two-aggregate" mixture was developed to utilize full crusher production and to expedite plant operations after some experience had been gained with softer sandstones found at the Quicksand quarry. The term "two-aggregate" mixture referred to bituminous mixtures which were made not only with two aggregate sizes introduced at the hot mix plant, but the aggregates themselves. Upon crushing and grading the aggregates, it was determined that approximately one-half of the material was retained on the 3/8-inch sieve. Furthermore, calculations relative to the size distributions indicated that if approximately one-third of the production stone passing the 3/8-inch sieve were combined with stone passing the 1-inch, but retained on the 3/8-inch sieve, a satisfactory binder course mix could be produced. The remaining stone passing the 3/8-inch sieve was used in the production of surface course. In this way, the entire crusher product was utilized. Because of the success and superior qualities exhibited by the "two-aggregate" mixture, the Department developed and recommended to the State Highway Engineer a specification for a "Class-S" bituminous sandstone mix, which was not accepted at that time, probably because of difficulties encountered on the Salyersville-Quicksand route.

Williams presented a paper on sandstone aggregates to the Association of Asphalt Paving Technologists during Technical Sessions held at Houston, Texas, in January 1953 (6). Paving aspects of the experimental bituminous sandstone construction of the Salyersville-Quicksand route were summarized. To prevent excessive absorption of asphalt materials, Williams recommended mixing at temperatures between 250°F and 285°F. All aggregate particles passing the No. 4 sieve apparently became completely saturated when mixed at temperatures above 265°F. Most mixtures were placed at temperatures below 250°F and there were no apparent advantages in any case when placement temperatures were above 260°F. Crushing of the sandstone aggregates occurred when aggregate was picked-up on the asphalt paver's rollers. Coarser graded mixes tended to produced greater amounts of crushed aggregate under the action of the rollers. There also was a tendency for the denser graded surface mixtures to creep under the roller unless a very light tack coat was applied between the binder and surface. A tack coat in quantities less than 0.1 gallon per square yard was recommended that practically eliminated any creep.

Short-term performance of the Salyersville-Quicksand route was reported upon during the Spring of 1953 (7). In this report, researchers again singled out weakened or inadequate base support as the primary cause of the pavement failures observed. When eliminating those causes, it was reported that only 0.3 percent of the total pavement area had failed in 17 to 32 months of service because of factors attributable to the mixes which were under test. A follow-up inspection and maintenance recommendations were requested during September, 1954 (13). The main focus of the recommendations for maintenance centered upon drainage. It was recommended that ditching and under draining be hastened to enhance the supporting strength of the subgrade and prevent further deterioration of the pavement.

At the request of the Assistant State Highway Engineer, the Division of Research developed specifications for crushed sandstone aggregates and their use in bituminous pavements and subbase applications in 1957 (14). Several difficulties, precipitated by the use of crushed sandstone aggregates in previous bituminous mixes, were anticipated by developers of the specifications including adjustments in the gradation of cold-feed aggregate due to possible degradation of the stone in the drier and the distinct possibility of overrolling the Class S mixes during the compaction process. It was recommended that the mix be rolled the minimum amount allowed under the specification.

A ten-year study conducted by West Virginia University's Engineering Experiment Station for the West Virginia State Road Commission investigated the Los Angeles abrasion test as a means of accepting or rejecting a given sandstone aggregate for base course construction (15). Highway base courses that had been constructed with sandstone, which had not passed the LAA test, had given good performance over the years. However, other highway base courses, constructed with sandstone that had passed the test, were performing poorly. A total of 106 highway specimens, divided into four phases, were tested. Phase I was directed toward determining the minimum base thickness of a sandstone having 65 percent loss in the LAA test which would effectively distribute an 11,500-pound wheel load to the subgrade. In this phase, it was determined that 9 inches of this material, compacted to its standard AASHTO T-99, Method D density, would keep subgrade motion negligibly small. Phase II was an investigation into the performance of calcareous, argillaceous and high silica sandstones, each having losses in the LAA test of 67, 77, and 87 percent. These materials were used in a 9-inch base thickness and were subjected to a load of 7,100 pounds. Results of this phase showed the LAA test did a reasonable job in rating calcareous and siliceous materials as to their load carrying characteristics. The argillaceous material gave poor performance regardless of its LAA value while the calcareous sandstone did best overall. Phase III evaluated various stabilizing agents when employed with an argillaceous sandstone having 85 percent losses in the LAA test. Results showed that portland cement yielded the most stable base. Researchers also determined that bituminous stabilizers, instead of increasing load carrying capabilities, actually "lubricate" sandstone particles in an undesirable way. Some better stabilizers did provide the expected possible results. The effects of controlled gradations on specimen performance were investigated in Phase IV. The base material included an argillaceous sandstone having 65 percent LAA losses and was subjected to a 9,000-pound wheel load. Results of this phase revealed that, in general, effects of gradation of a base course are often masked by moisture and density variations even though all three conditions are interrelated.

Petrographic examinations of samples provided useful information on the three types of sandstones. The silica sandstone tended to break into thin chips and exhibited difficulty in compaction. It usually weathered less than the other samples, however the calcareous sandstone was more absorptive of impact, but, also tended to leach and lose cement in slightly acid waters. The argillaceous sandstone weathered quickly, showing very unfavorably in direct contrast to the other two. Repeated load tests with stresses in the order of 40 to 2,000 psi gave considerable deformation. In addition to information on the varying performance of the sandstones, the repeated load test underlined the importance of keeping moisture out of crushed stone.

A study conducted by the West Virginia Department of Highways investigated the stability and permeability of base course mixes utilizing limestone and sandstone aggregates (16). The study focused upon Class I and II base course aggregates from four sources, two limestone aggregate sources and two sandstone aggregate sources. The study concluded that the Class I aggregate grading was considerably more permeable than Class II aggregates. Although the variations in actual permeability values for the different sources of Class I aggregate were almost insignificant, the sandstone aggregate was slightly more permeable than limestone aggregate. It was concluded that regardless of the aggregate type or aggregate class, stabilities of drained base courses were generally better than that of undrained base courses. It also was concluded that if the condition of the specimens (drained versus undrained) was ignored, and for the gradings used, the limestones were more stable than the sandstones tested. However, the researchers emphasized that the project was relatively small in scope and that more research in this area was needed to further quantify their conclusions.

The Kentucky Transportation Research Program investigated the performance of some experimental features contained within a section of KY 80 during the Fall of 1982 (17). Specifically, the investigation included a section of Ky 80 from Milepost 9 to Milepost 18 in Knott County. The mainline pavement of this section was constructed of 10-inches Class S, bituminous concrete base, 2-inches bituminous concrete binder (limestone) and 1-inch bituminous concrete surface (limestone). The median pavement design called for 3 inches Class S bituminous concrete base, 4-inches bituminous concrete base (limestone) and 1-inch bituminous concrete surface (limestone). The focus of the investigation was to determine causes for apparent deficiencies in the performance and behavior of this pavement section. Spalls and blisters had been reported after the 1981-82 winter. At a few sites, blistering had been induced by water bleeding through the surface. Water also had emerged from contraction joints sawed into the concrete median curb and had even overflowed the lip of the curb in numerous places. Damage to the pavement was considered only minimal, but was expected to worsen. The investigation involved; condition surveys and photologging; Road Rater testing and survey, coring, drilling, and sampling of pavement materials; and, laboratory testing of cores and samples recovered from the pavement. Cores were evaluated for permeability, density, and modulus of elasticity. The report concluded that the emergent water had no apparent relationship to the use of sandstone as a construction material, but could be attributed to insufficient drainage and geologic phenomenon within the section surveyed. Researchers recommended that the seepage of water not deter from the use of sandstone in future highway construction.

Of particular interest is the conclusion that the bituminous limestone base was much more porous than the bituminous sandstone base. The average coefficient of permeability for three bituminous limestone specimens was approximately 4,700 times greater than that found for the two bituminous sandstone specimens. Also, specimens of the bituminous limestone base and bituminous sandstone base were tested for ultimate Young's modulus of elasticity using the fundamental longitudinal frequency and the weight and dimensions of the specimen. In general, the modulus of elasticity, or stiffness, of the bituminous sandstone base mix was three to four times greater than that of the bituminous limestone base mix. It was stated that the information was derived from a relatively small data base. Researchers expected that the ultimate modulus of the two base mix designs would be similar. Densities of the two bituminous base course mixes were also investigated. Target densities were recommended at 140.0 pounds per cubic foot and 152.2 pounds per cubic foot for the bituminous sandstone and bituminous limestone base courses, respectively. During construction, the in-place density of the bituminous sandstone base mix averaged 98.1 percent of the target density while the bituminous limestone base mix averaged 94.9 percent of the target density.

EVALUATIONS

Innovative procedures and designs are subject to field trials and evaluations. The evaluations of performance are important relative to determining effectiveness of design and construction procedures and whether the method or system may become a standard. Evaluation of performance enables documentation of the experimental features, attributes, designs, and an assessment of the acceptability of those elements. Acceptability is predicated on the absence of defects and feasibility of achieving satisfactory remedies for any defects observed. The primary benefits of the evaluations of performance and efficiency of the experimental sections are greater service and potential cost savings in constructing and reconstructing highway pavements.

Phase II of the research study called for field and laboratory testing. The overall objective of the field and laboratory testing program was to compare performance of bituminous sandstone pavements to performance of bituminous limestone pavements and correlate the performance with information gained from laboratory evaluations of the engineering properties of bituminous sandstone and bituminous limestone base mixtures.

Field Evaluations

The first area of Phase II included monitoring selected sites in eastern Kentucky where bituminous sandstone and bituminous limestone pavements were being constructed or were already in place. The sites were chosen from Resource Recovery Road Projects, where some background data were available, including: KY 80, KY 15 - Whitesburg Bypass, US 119, KY 519, KY 205, KY 645, and KY 15 - Hazard Bypass. The pavements constructed on KY 80, KY 15 - Whitesburg Bypass, and US 119 contained crushed sandstone in the asphaltic concrete base courses, but none in the surface course. The remaining routes included in the study contained conventional limestone aggregates throughout both the bituminous base and surface mixtures. A brief description of the routes investigated during the study follows. Detailed information is contained within the data appendix to this report. That report, Research Report KTC 90-26A, contains typical design sections, projected traffic volumes used for design, and results of field and laboratory evaluations for the routes investigated. The data appendix report is available from the Kentucky Transportation Center upon request.

Kentucky Route 80

Kentucky Route 80 is a 42-mile section stretching from KY 15 near Hazard to US 23 at Watergap through the counties of Perry, Knott and Floyd. The KY 80 corridor is characterized by steep, rugged mountains dissected by an irregular drainage pattern typical of the East Kentucky Coal Field. The surface is underlain with rocks of the middle to lower Pennsylvanian formations consisting of shales, sandstones and coal. The western two-thirds of the route lies in the Kentucky River drainage basin, the largest stream being Troublesome Creek in Perry County. In the eastern part of Knott County the highway enters the Big Sandy drainage basin. There are several crossings of the Right Fork of Beaver near Garrett and one crossing of main Beaver Creek at Martin, all in Floyd County. Elevations vary from less than 700 feet above sea level to more than 2,000 feet above sea level. The grade of the highway ranges from approximately 700 feet to approximately 1,500 above sea level. The maximum grade encountered on KY 80 is +/- 7%. Typical sections, projected traffic volumes for design, and field and laboratory evaluations for KY Route 80 are contained in Appendix A of Research Report KTC 90-26A.

Kentucky Route 15 -- Whitesburg Bypass

The Whitesburg Bypass, Kentucky Route 15, is a 2.3-mile route which begins on existing KY 15 northwest of Whitesburg. The route extends around the southern portion of the city and terminates at the intersection of US 119, approximately 0.1 mile south of the intersection with old KY 15. The route crosses the North Fork of the Kentucky River three times. The route lies entirely within Letcher County, near the eastern edge of the East Kentucky Coal Field. The surface is underlain with rocks of the Breathitt Formations consisting of shales, sandstones, siltstones and coal. Elevations along the centerline range from 1,135 feet above sea level to 1,250 feet. The maximum grade encountered on the route is +/- 6%. Typical sections, projected traffic volumes for design, and field and laboratory evaluations for KY Route 15 -- Whitesburg Bypass are contained in Appendix B of Research Report KTC 90-26A.

United States Route 119 - Buckley Creek

United States Route 119 is a 3.5-mile section stretching from the intersection with US 23 near Pikeville eastward toward Belfry and terminates on existing US 119. The route lies entirely within Pike County, near the eastern edge of the East Kentucky Coal Field. The surface is underlain with rocks of the Breathitt Formations consisting of shales, sandstones, siltstones and coal. Elevations along the centerline range from 660 feet to 1,105 feet above sea level. The deepest cut is nearly 340 feet in depth and the highest fill is less than 115 feet in height. The maximum grade encountered on US 119 is +/- 5%. Typical sections, projected traffic volumes for design, and field and laboratory evaluations for US Route 119 are contained in Appendix C of Research Report KTC 90-26A.

Kentucky Route 519

Kentucky Route 519 is a 3-mile section stretching from KY 7 near Elk Fork north of West Liberty to the existing KY 519 east of Yocum. The entire route lies within Morgan County. The KY 519 corridor begins at the edge of the ponding easement for Cave Run Lake and is above the flood plain of the Licking River and Elk Fork. The entire route is in the Licking River watershed and there are no major stream crossings. The surface is underlain with rocks of the middle to lower Pennsylvanian formations consisting of shales, sandstones, siltstones and coal. The route crosses the Dehart Fault near the head of Sugar Camp Branch. The fault is down-thrown to the southeast with displacement of as much as 120 feet. Elevations vary from less than 770 feet above sea level to more than 1,050 feet. Cuts do not exceed 150 feet in depth and fills are less than 75 feet. The maximum grade encountered on KY 519 is +/- 7%. Typical sections, projected traffic volumes for design, and field and laboratory evaluations for KY Route 519 are contained in Appendix D of Research Report KTC 90-26A.

Kentucky Route 205

Kentucky Route 205 is an 11.9-mile section beginning at the intersection of KY 205 and KY 191 at the interchange with the Bert T. Combs Mountain Parkway and extending to the intersection of U.S. 460 approximately 0.2 mile northeast of Index. The route lies within Wolfe and Morgan counties near the western edge of the East Kentucky Coal Field. The route begins in the Red River watershed but crosses the divide at the Wolfe-Morgan County line within two miles of the beginning, and the remainder of the route is in the Licking River watershed. Major stream crossings include Salem Fork, Little Caney Creek and Caney Creek. The surface is underlain with rocks of the Middle Pennsylvanian formations consisting of shales, sandstones, siltstones and coal. Elevations vary from less than 780 feet above sea level to more than 1,200 feet. Cuts do not exceed 150 feet in depth and fills are less than 80 feet in height. The maximum grade encountered on KY 205 is +/- 6%. Typical sections, projected traffic volumes for design, and field and laboratory evaluations for KY Route 205 are contained in Appendix E of Research Report KTC 90-26A.

Kentucky Route 645

Kentucky Route 645 is a 14.0-mile section beginning at U.S. 23 just north of Ulysses and extending to the intersection of KY 3, east of Inez. The route lies within Lawrence and Martin counties near the eastern edge of the East Kentucky Coal Field. The portion of the route in Lawrence County lies in the Levisa Fork watershed. Major stream crossings are over Georges Creek, Levisa Fork, and Nats

Creek. The Martin County section is in the Tug Fork watershed with crossings of Rockhouse Fork, Middle Fork, Coldstream Fork and Blacklog Fork. The surface is underlain with rocks of the Pennsylvanian era consisting of shales, sandstones, siltstones and coal. Elevations vary from 580 feet above sea level to about 1,100 feet above sea level. Cuts do not exceed 205 feet in depth and fills are less than 80 feet in height. The maximum grade encountered on KY 645 is +/- 7%. Typical sections, projected traffic volumes for design, and field and laboratory evaluations for KY Route 645 are contained in Appendix F of Research Report KTC 90-26A.

Kentucky Route 15 - Hazard Bypass

The Hazard Bypass, Kentucky Route 15, is a 2.1-mile section which begins on existing KY 15 approximately 0.1 mile west of the Hazard city limits. The route extends around the southern edge of the city and terminates on existing KY 15 between the CSX Railroad line and Hazard High School. The location of the Bypass is roughly parallel to the North Fork of the Kentucky River with the roadway benched into the mountain side for much of its length. The only stream crossing is Messer Branch and it is crossed by a bridge which also spans KY 451 and a spur of the CSX Railroad. The route lies entirely within Perry County, near the heart of the East Kentucky Coal Field. The surface is underlain with rocks of the Pennsylvanian formations consisting of shales, sandstones, siltstones and coal. Elevations along the profile vary from 860 feet to 1,260 feet. The deepest cut approaches 300 feet in depth and the highest fill is about 175 feet in height. The maximum grade encountered on Hazard Bypass is +/- 6%. Typical sections, projected traffic volumes for design, and field and laboratory evaluations for KY Route 15 -- Hazard Bypass are contained in Appendix G of Research Report KTC 90-26A.

Field evaluations involved various methodologies to assess the overall pavement performance; rut depth measurements and condition surveys for pavement performance evaluations, Road Rater deflection surveys to determine the structural capacity of the pavement structure; obtaining core specimens for laboratory analyses, and performing in-situ testing of the subgrade. Specific information obtained throughout the course of this study for the routes monitored included: 1) rut depth measurements, 2) skid-resistance and rideability data, 3) traffic information, 4) visual inspections for cracking patterns or signs of unusual behavior, 5) Road Rater deflections to evaluate elastic moduli, and 6) pavement coring for visual inspection, pavement thickness determinations, and laboratory evaluation. Concurrent with the visual inspections and rut measurements, KTC personnel utilized Kentucky Department of Highways and Asphalt Institute pavement rating systems to rate various deficiencies of the sites monitored. Pavement condition ratings and rut measurements were obtained for each route during 1985, 1986 and 1987. Road Rater deflection surveys, at 0.1-mile increments, were performed during 1985, 1986 and 1987. Pavement coring operations were generally performed during the summer months of 1986 and 1987. Detailed data for specific routes are contained in the previously specified data appendices of Research Report KTC 90-26A.

Pavement Condition Surveys and Rutting Characteristics

Condition surveys and rutting measurements were made for each route surveyed. The condition survey utilized two systems to rate the condition of the pavement, the system employed by the Pavement Management Unit of the Kentucky Department of Highways and the Pavement Rating System for Low-Volume Asphalt Roads by the Asphalt Institute.

The Pavement Management Unit's (Kentucky System) pavement condition form is applicable to all roads except interstates and toll roads. The evaluation schema appraises route condition, rideability, rutting, skid resistance, traffic volume and travel speed, and is based on a maximum of 100 rating points. The pavement condition form allows the rater to subjectively evaluate observable distresses and conditions such as cracking, base failures, edge failures, raveling, and out-of-section in terms of extent and severity. Appearance of pavements is assessed from the perspective of the highway user in terms of good to very poor. The condition survey has a maximum of 34 demerit points. Rideability is determined from pavement roughness surveys. Pavement roughness measurements were performed by Department of Highways' personnel. The measurements were obtained using vehicles equipped with Mays Ride Meters and onboard microprocessors for rapid automated data processing. The measurements are converted to rideability index (RI) using correlation equations relating pavement roughness to highway user opinions of rideability. The rideability scale ranges from 0 to 5. Relative to the condition rating, distribution of demerit points for rideability is linear and range from one point for a RI of 3.1 or greater to 26 for a RI of 1.4 or lower. Rut depths of the asphaltic concrete pavements were measured to the nearest 1/16 inch using a stringline and a ruler. For reporting purposes, rut depths were converted to decimal format and rounded to the nearest 0.1 inch. The distribution of demerit points for rutting relative to the condition survey is curvilinear and range from three points for rut depths equal to 1/4 inch to ten points for ruts depths equal to or greater than 5/8 inch. Skid resistance measurements were made using a pavement friction tester in compliance with ASTM E 274. Distribution of demerit points for skid resistance relative to the condition survey is linear and range from one point for a skid number (SN) of 36 to 13 points for SN's less than or equal to 24. The value of the demerit points for skid resistance is adjusted according to traffic volume. Demerit points for traffic volume range from one point for average daily traffic (ADT) less than or equal to 401 to 12 points for ADT equal to or greater than 7,501. Demerit points for travel speed range from one point for speeds less than or equal to 40 mph to five points for travel speeds equal to or greater than 55 mph.

The Asphalt Institute's system was designed to be applied to relatively low-volume roads and streets, i.e., those that carry fewer than 1,000 cars and 50 trucks per day. The rating system allows the rater to subjectively assign a numerical value to each type of pavement defect, taking into account both the extent of the distress and its relative seriousness. Defects include transverse, longitudinal, alligator, and shrinkage cracks, rutting, corrugations, raveling, shoving or pushing, potholes, excess asphalt, polished aggregate, deficient drainage, and overall riding quality. The numerical sum of these values provides a fairly accurate, although subjective, index of the general condition of the roadway. Examples of the two condition assessment forms are presented in Figures 2 and 3, for the Kentucky System and the Asphalt Institute System, respectively.

Pavement Deflection Testing

Pavement deflection testing is not routinely performed but generally is conducted for pavements where subjective evaluations are inadequate to ascertain structural conditions or indicated structural inadequacies. During this study, a Model 400B Road Rater was utilized to evaluate structural conditions of the routes investigated and to compliment visual distress surveys. The deflection testing scheme used for the evaluations generally involved obtaining measurements on the pavement surface at 0.1-mile intervals within each wheel path. Deflection measurements were staggered from wheel path to wheel path to allow greater coverage of the area tested. A much tighter deflection grid pattern was established, often at 50-foot intervals, at locations where pavement cores and in-situ California Bearing Ratios (CBR's) were obtained. Load rates of 600- and 1,200-pounds force were used during the deflection surveys.

Transportation Cabinet
Department of Highways
PAVEMENT CONDITION EVALUATION FORM

TC 71-103
Rev. 4/84

District:	County:	Route No:	Road Name:

From: To:

Length:	Width:	Project No:	System:

I. CONDITION SURVEY

	EXTENT						SEVERITY					POINTS
	Few		Intermediate		Extensive		Slight		Moderate		Severe	
Cracking	1 2	3	4	5	6		1	1.5	2	3	4	
Base Failures (Faulting)	1	1.5	2	2.5	3		1	1.5	2	2.5	3	
Raveling (Spalling)	.6	.9	1.3	1.6	2		.6	.9	1.3	1.6	2	
Edge Failures	.6	.9	1.3	1.6	2		.3	.4	.6	.8	1	
Out of Section	1	1.5	2	2.5	3		1	1.5	2	2.5	3	
Appearance	Fair - 1		2		Poor - 3	4	Very Poor - 5					
											Subtotal	

			POINTS
II. RIDEABILITY	RI ________		
III. RUTTING	Depth ________		
IV. SKID RESISTANCE	SN ________	Points x Factor ______ x ______	
V. TRAFFIC VOLUME TRAVEL SPEED	AADT ________ MPH		
Raters:		Total	
Date:		CO Ranking	

ROADWAY CHARACTERISTICS

PCC AC AC/PCC
Curbs & Gutters Manholes Inlet Boxes

Shoulders High ______ Low ______
Width ______
Type ______
Industrial Haul Type ______
Patching (Percent) ______

CO RECOMMENDATIONS

Resurface - AC
Other ______

Leveling & Wedging (Percent) ______
Milling (in.) ______
Other ______

STATEWIDE RANKING:

DISTRICT RANKING:

Preparator: ______ **DISTRICT RECOMMENDATIONS**

Cost Estimate: ______

Treatment: ______

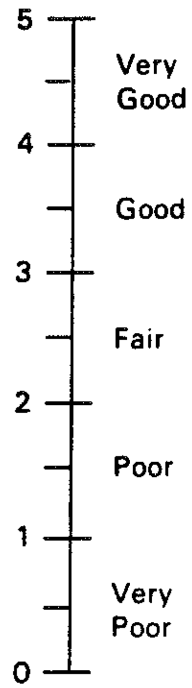
Remarks: ______

Figure 2. The Pavement Condition Rating Form used by the Kentucky Department of Highways Pavement Management Unit (front page).

II. RIDEABILITY

RI	Points
3.1	1
3.0	2.5
2.9	3.9
2.8	5.4
2.7	6.9
2.6	8.4
2.5	9.8
2.4	11.2
2.3	12.7
2.2	14.2
2.1	15.7
2.0	17.2
1.9	18.6
1.8	20.1
1.7	21.6
1.6	23.0
1.5	24.5
1.4 or lower	26.0

Rating



III. RUTTING

Inches	Points
1/4	3
3/8	6
1/2	8
5/8 or higher	10

IV. SKID RESISTANCE

SN	Points
36	1
35	2
34	3
33	4
32	5
31	6
30	7
29	8
28	9
27	10
26	11
25	12
24 or lower	13

V. TRAFFIC VOLUME

POINTS	2-Lane AADT	4-Lane AADT	MULTIPLICATION FACTOR FOR SKID RESISTANCE POINTS
1	401 - 800	401 - 850	0.1
2	801 - 1,250	851 - 1,300	0.18
3	1,251 - 1,700	1,301 - 1,800	0.26
4	1,701 - 2,250	1,801 - 2,400	0.35
5	2,251 - 2,850	2,401 - 3,100	0.46
6	2,851 - 3,500	3,101 - 3,800	0.58
7	3,501 - 4,200	3,801 - 4,650	0.71
8	4,201 - 4,950	4,651 - 5,600	0.84
9	4,951 - 5,750	5,601 - 6,600	1.0
10	5,751 - 6,600	6,601 - 7,700	1.0
11	6,601 - 7,500	7,701 - 8,950	1.0
12	7,501 or higher	8,951 or higher	1.0

TRAVEL SPEED

MPH	POINTS
40	1
45	1.5
50	3
55	5

Figure 2a. The Pavement Condition Rating Form used by the Kentucky Department of Highways Pavement Management Unit (back page).

ASPHALT PAVEMENT RATING FORM

STREET OR ROUTE ________________ CITY OR COUNTY ________________

LENGTH OF PROJECT ________________ WIDTH ________________

PAVEMENT TYPE ________________ DATE ________________

(Note: A rating of "0" indicates defect does not occur)

DEFECTS		RATING
Transverse Cracks	0-5	______
Longitudinal Cracks	0-5	______
Alligator Cracks	0-10	______
Shrinkage Cracks	0-5	______
Rutting	0-10	______
Corrugations	0-5	______
Raveling	0-5	______
Shoving or Pushing	0-10	______
Pot Holes	0-10	______
Excess Asphalt	0-10	______
Polished Aggregate	0-5	______
Deficient Drainage	0-10	______
Overall Riding Quality (0 is excellent; 10 is very poor)	0-10	______
	Sum of Defects	______

Condition Rating = 100 – Sum of Defects
= 100 – ________

Condition Rating = [ ]

Figure 3. The Pavement Condition Rating Form used by the Asphalt Institute.

The Road Rater applies a steady state vibratory load to the pavement structure and records the corresponding deflections at several radial distances from the center of the load. The magnitude of the vibratory load is a function of the loading frequency and vibrating mass. The loading limits of the Model 400B Road Rater are 0- to 2,400-pounds force. Evaluation of asphaltic concrete pavements utilizes elastic layer theory to determine, for each test location, the theoretical deflection model that best matches the measured deflection basin. Using the existing thickness of crushed stone, an effective thickness of reference-quality asphaltic concrete (modulus of elasticity of 1,200 ksi at 70°F) and a subgrade modulus are determined that reasonably match the theoretical model. A dynamic stiffness also may be determined using the deflection measurements. The dynamic stiffness is calculated by dividing the applied dynamic load by the deflection directly under the load. It may be represented in terms of pounds-force per inch. The dynamic stiffness is a measure of the structural capacity of the system.

Pavement Coring and In-Situ Testing

Pavement cores were obtained from routes monitored for performance during the evaluation period. Pavement cores were visually inspected and measured for constructed thicknesses in the field. The cores were preserved for laboratory evaluations including unit weight, Young's modulus of elasticity, and resilient modulus.

Measurements of the in-situ subgrade strengths and moisture contents were attempted. However, because a majority of the subgrades were constructed of crushed rock, the equipment used to perform the CBR test was not capable of penetrating the subgrade to the recommended depth of 1/2 inch. Results of the tests generally indicated in-situ CBR's greater than 100 percent.

Laboratory Evaluations

The second area of Phase II involved evaluating bituminous sandstone mixtures in the laboratory to determine the suitability of a given mix. The mixture design requirements used for Bituminous Concrete Base, Class S, were provided in Special Provision No. 42A [79]. The special provision required the crushed sandstone aggregate be produced as a single size, or from a blend of two or more sizes and meet the following aggregate gradation and job-mix tolerances for the Class S base course mixture:

Sieve Size	Percent Passing (by weight)	Job-Mix Formula Tolerances
2"	100	
1"	70-100	+/- 8%
1/2"	50-100	+/- 8%
#4	30-70	+/- 7%
#16	15-55	+/- 6%
#50	7-30	+/- 5%
#100	5-20	+/- 3%

Quality requirements for the sandstone aggregate were as follow:

Property and Test Method	Value
Wear (KM 64-614, 200 rev.)	55 maximum
Deleterious Material (*)	5% maximum
Water Absorption (KM 64-607)	5% maximum
Sand Equivalent (KM 64-619) (**)	25 minimum

* Shale (KM 64-604) plus coal and lignite (KM 64-615)

** A sand equivalent of 20 was permitted provided that the portion passing the No. 40 sieve was non-plastic, as determined by AASHTO T-90.

The percent by weight of asphalt cement (AC20) in the mixture was established between 5.5 and 8.0 percent. The specified Marshall Design Method Criteria were as follow:

Minimum Stability	1800 lbs	(KM 64-411)
Air Voids	2% - 6%	(KM 64-411)
Flow	20 maximum	(KM 64-411)
Minimum Retained Strength	70%	(KM 64-423)

Sufficient data were not obtained in the laboratory for bituminous sandstone mixtures relative to asphalt content / density relationships, permeability, unconfined compressive strength, durability, modulus of elasticity, or triaxial shear strength to determine guidelines for the development of optimum mixture designs for bituminous sandstone mixes by the research team. However, sonic modulus, resilient modulus, and resistance to plastic flow analyses were performed on field cores.

Upon receiving the pavement cores at the laboratory, the cores were cataloged, measured along the length and diameter, and weighed. The pavement cores were separated at the bituminous sandstone and bituminous limestone interface, if applicable, and faced off using a clipper lab saw. The cores were re-measured and re-weighed after facing. The unit weights of the field cores and the faced cores were determined using the dimensions and weight of the asphaltic concrete specimen.

The faced cores were evaluated for fundamental longitudinal frequency in general accordance with ASTM C 215-85, "Standard Test Method for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimen." The test method was adapted for the bituminous core specimen by gluing a piezoelectric accelerometer to one face of the core. The fundamental frequency was determined and Young's modulus of elasticity, in pounds per square inch, was determined using the fundamental longitudinal frequency, weight and dimensions of the test specimen. Some cores were reserved for testing in general accordance with ASTM D 4123-82, "Standard Method of Indirect Tension Test for Resilient Modulus of Bituminous Mixtures." The Standard Test Method for Resistance to Plastic Flow of Bituminous Mixtures using Marshall Apparatus also was used to evaluate a number of field cores. Data gained from these efforts are contained in the data appendix to this report, Research Report KTC 90-26A. The report is available only upon request from the Kentucky Transportation Center.

The laboratory portion of Phase II also was to examine various types of Kentucky sandstones and determine the effects of the sandstones' inherent variability on performance. However, testing activities relative to freeze-thaw durability, abrasion or wear, and asphalt absorption of sandstone aggregates were not performed during the laboratory evaluation phase of the study.

DISCUSSION OF RESULTS

Comparing the performance of routes constructed with bituminous sandstone mixtures to those constructed with bituminous limestone mixtures was not an easy task. There are many variables to be considered; variations in traffic characteristics, quality of subgrade and pavement construction, quality of the bituminous mixtures, and drainage, to name a few. Initially, it was thought that a comparison between the Whitesburg Bypass and the Hazard Bypass was appropriate. Both routes are relatively short, constructed about the same time, and utilized rock subgrades.

The thickness design for the Whitesburg Bypass included a CBR 11 rock subgrade, 8.5-inches densely-graded aggregate, 5-1/2-inches Class-S bituminous base, and one-inch bituminous limestone surface. The thickness design for the Hazard Bypass included a CBR 9 rock subgrade, 11-inches densely-graded aggregate, 5-1/2-inches conventional bituminous limestone base and one-inch bituminous limestone surface. However, traffic volumes and loadings that could be obtained indicated much higher volumes and vehicular loadings for the Hazard Bypass. The traffic volume for the Whitesburg Bypass included 7.1 percent trucks and the traffic volume for the Hazard Bypass included about 9.9 percent trucks. Data indicated a 1986 Average Annual Daily Traffic (AADT) of 16,200 for the Hazard Bypass. The AADT for the Whitesburg Bypass was only 6,730 during 1988.

Information gained during the condition rating surveys indicated performance of the Hazard Bypass deteriorated rather quickly when compared to the performance of the Whitesburg Bypass. This is supported by available traffic data. The Hazard Bypass carried more than three times the number of trucks and had nearly two and one-half times more traffic. The initial survey of the Hazard Bypass revealed very poor performance throughout the site. High degrees of rutting (as much as two inches), cracking (both longitudinal and alligator), and shoving and pushing of the bituminous limestone pavement were observed. Some portions of the route received maintenance overlays about four years after opening to traffic (between the 1985 survey and 1986 survey). The Whitesburg Bypass exhibited some cracking and only minor rutting, the majority being located at approaches to intersections. It is unfortunate that only a minimum of materials tests were completed to compare the bituminous sandstone and bituminous limestone base mixtures. Field cores from each route were tested for stability and flow using the Marshall apparatus. Although relatively few samples were evaluated, results of four bituminous sandstone cores from the Whitesburg Bypass indicated an average stability of 1,983 pounds and average flow of 0.22 inch. Results of two bituminous limestone cores from the Hazard Bypass indicated an average stability of 1,844 pounds and average flow of 0.19 inch. Field cores from each route also were evaluated using the fundamental frequency test. Those results indicated the bituminous sandstone base had a calculated modulus value of 404,000 psi and the bituminous limestone base had a modulus value of 578,000 psi. Although the tests appear to contradict one another, it certainly appears, based upon the observed rutting accumulated over the survey period, the bituminous sandstone base provides more stability than does the bituminous limestone base mixture.

Analysis of Road Rater deflections also provides some insight pertinent to this matter. The moduli values of the asphaltic concrete structure on the Whitesburg Bypass far exceed the moduli values determined for the asphaltic concrete layers of the Hazard Bypass. The analyses performed using 1987 data indicate similar subgrade moduli values for the two routes but show also the bituminous sandstone pavement of the Whitesburg Bypass to have substantially higher asphaltic concrete moduli values than the bituminous limestone pavement of the Hazard Bypass. The key to understanding this phenomenon would be to thoroughly investigate the material properties and relate them to the traffic characteristics and performance conditions of both routes.

Pavement Condition Surveys and Rutting Characteristics

The general performance of KY 80 is perplexing. Design Section F exhibited excellent performance while Design Sections B and C performed poorly. The poor performance of Design Sections B and C should not be attributed to the bituminous sandstone material however. The emerging water did not have an apparent relationship to the use of sandstone, rather the severe distresses appeared to be caused by one or a combination of things. Information gained from a review of project files alludes to the absence of tack coat material between the asphaltic concrete layers which permitted water to penetrate both from the surface down and from the subgrade up. Obviously, the major contributor to the poor performance was water getting into the pavement structure, probably around the concrete lip curbs of the raised median, and a corresponding lack of adequate drainage facilities. The water was being forced up through the pavement by hydrostatic pressure. This resulted in stripping of the bituminous limestone surface layer, and possibly the top bituminous limestone base mix. Potholes formed when the top base layer lost strength and the surface layer lost support.

The other design sections along KY 80 exhibited high degrees of both longitudinal cracking and alligator cracking. However, even the more severely distressed areas did not display the degree of rutting as might be expected. This is suggestive of stiff underlying layers that prevented excessive rutting. Demerit points for the condition ratings were primarily due to poor appearance and cracking. Much the same may be said for the two other routes, US 119 and Whitesburg Bypass, that incorporated bituminous sandstone base mixtures in their pavement structure. Most of the demerit points were attributed to cracking and poor surface appearance.

The routes that incorporated bituminous limestone base mixtures in the pavement structure generally had variable performance. Two of the routes, KY 519 and KY 205, did not change considerably over the evaluation period. This primarily was due to the lack of significant traffic or loadings on the routes. The KY 645 route is the primary route to reach US 23 and the off-loading ramps along the Big Sandy River north of Louisa. The route also contains two intersections that experience slow rolling and fully stopped coal trucks. The trucks are generally loaded when they traverse northward across KY 645. The condition ratings indicated poorer performance for the northbound lanes. The poorer performance is directly related to the amount of rutting experienced in the northbound shoulder lane. Deep rutting, in excess of one inch, and shoving and pushing are characteristic of the asphaltic concrete pavement at these locations. Rutting also was a significant difficulty on the Hazard Bypass route. This route also had intersections having rut depths typically exceeding one inch at the approaches. The Hazard Bypass exhibited substantial degrees of alligator cracking, transverse cracking and longitudinal cracking and received maintenance overlays of bituminous materials during the evaluation period.

Pavement Deflection Testing

The analysis of the Road Rater deflections was conducted using a program being developed under study KYHPR-86-109, "Pavement Deflection Evaluations." This program is based on linear elastic theory and Lagrangian interpolation. The procedure is based on a three-layer pavement system, consisting of asphaltic concrete over dense-graded-aggregate over a semi-infinite subgrade. The methodology of the program consists of comparing the field measured deflection bowls with theoretical bowls calculated using linear elastic theory. The best fit deflection bowl is determined by the minimum sum of the squared differences between the field deflections and theoretical deflections. A minimum of 5,000 deflection bowls are compared to each field deflection bowl. The result of this procedure is in-situ subgrade modulus and asphaltic concrete modulus at the test temperature.

Analyses of the data for this study were executed on mean deflections calculated from all deflections for a given design section, or route, scaled to a nominal dynamic load of 600 pounds. The mean deflections were input into the computer program developed under KYHPR-86-109 and layer moduli were back calculated. The back-calculated asphaltic concrete modulus and temperature history were used to calculate the asphaltic concrete modulus at a reference temperature. This calculation was accomplished using relationships developed by Southgate and Sharpe (18).

There is some variability in the back-calculated layer moduli over the study period. The back-calculated subgrade modulus is less variable than the asphaltic concrete modulus. This is because small changes in deflections have a greater effect on asphaltic concrete layer moduli than on subgrade moduli. It has been discussed in KYHPR-86-109 that small changes in deflection can result in considerable change in layer moduli, and lead to multiple solutions for a given deflection bowl. Because multiple solutions are possible for a given deflection bowl, results of the deflection analyses for the bituminous sandstone mixtures relative to bituminous limestone mixtures are largely inconclusive. These differences may be attributed to several factors. The variability in the subgrade modulus may be due to the moisture conditions of the subgrade. If moisture were present during deflection testing, the back-calculated subgrade modulus may decrease. In several cases, the asphaltic concrete modulus increased during the study period. This increase may be due to the presence of an additional asphaltic concrete overlay which may have been constructed between test dates. The increase also may be due to age hardening of the asphaltic concrete after placement. Analyses of deflection data are contained in the data appendix report, Research Report KTC 90-26A, for the routes investigated.

Measurements of the in-situ subgrade strengths and moisture contents were attempted. However, because a majority of the subgrades were constructed of crushed rock, equipment used to perform the CBR test was not capable of penetrating the subgrade to the recommended depth of 1/2 inch. Results of the CBR tests that were performed were considered unreliable. Therefore, subgrade modulus values obtained from deflection analyses were used in combination with a relationship between CBR and subgrade modulus values to estimate the bearing capacity of the subgrade (19).

Laboratory Evaluations

Results of the longitudinal frequency tests of bituminous specimen were erratic. Cores obtained from KY 80 represented the bulk of the laboratory testing activities. The Young's modulus of elasticity of 124 bituminous sandstone specimen averaged 987,700 psi. The unit weight of the bituminous sandstone base samples obtained from KY 80 averaged 142.3 pcf. Field cores of the bituminous sandstone base obtained at Whitesburg Bypass and US 119 also were evaluated for Young's modulus of elasticity from fundamental longitudinal frequency tests. Six samples from the Whitesburg Bypass had an average Young's modulus of 404,000 psi and 11 samples from US 119 averaged 465,000 psi. These values are considerably lower than those exhibited by specimens from KY 80. The calculated coefficient of variation (standard deviation divided by the mean) indicates much higher variations in the data obtained for the KY 80 specimens. The average coefficient of variation for fundamental longitudinal frequency tests performed on KY 80 specimens was 0.54. The coefficient of variation for Whitesburg Bypass and US 119 specimens averaged 0.38 and 0.33, respectively. The average unit weights were 141.9 pcf and 142.3 pcf for specimens obtained from the Whitesburg Bypass and US 119 routes, respectively.

Six bituminous limestone specimens obtained from KY 80 (included both base and surface courses) were tested for fundamental longitudinal frequency. The specimens had an average Young's modulus of elasticity of 2,435,000 psi and an average unit weight of 148.6 pcf. Five bituminous limestone base specimens obtained from the Hazard Bypass had an average Young's modulus of elasticity of 577,600 psi from the fundamental longitudinal frequency test. These specimens had an average unit weight of 145.5 pcf. Six bituminous limestone base specimens obtained from KY 645 had an average Young's modulus of elasticity of 548,300 psi and an average unit weight of 148.2 pcf. Again, the moduli values determined for the bituminous limestone specimens of KY 80 were considerably higher. Caution is suggested when comparing the results of the Young's modulus of elasticity determined by the fundamental longitudinal frequency of one material relative to the other due to the small number of specimen tested.

Twenty bituminous sandstone and five bituminous limestone specimens obtained from the KY 80 sites were evaluated for resilient modulus before testing was discontinued due to continual equipment malfunction. The resilient modulus of the bituminous sandstone specimens averaged 273,300 psi. The average unit weight of these specimens was 140.9 pcf. The resilient modulus of the bituminous limestone layers (included base and surface courses) averaged 346,000 psi. The unit weight of these specimens averaged 146.2 pcf. Again, because of the small number of samples evaluated by repeated load tests, caution is advised when comparing the modulus results of one material relative to the other.

Data available from project files relevant to asphalt content and asphalt density were reviewed. Laboratory mix design data for Design Section B of KY 80 recommended an asphalt content of 6.7 percent and a unit weight of 141.7 pcf. The target density at the time of construction was 140.0 pcf. Field cores of the bituminous sandstone base obtained, evaluated, and results reported by the Division of Materials in February 1982, indicated an average density of 137.3 pcf or 98.1 percent of the target density. Field specimens obtained from Design Section B by KTC personnel during 1986 had an average unit weight of 139.9 pcf, or 99.9 percent of the constructed target density. Laboratory mix design data for US 119 recommended an asphalt content of 6.7 percent and a unit weight of 142.0 pcf. The constructed target density was 142.0 pcf also. Field specimens of the bituminous sandstone base obtained from US 119 by KTC personnel during 1986 had an average unit weight of 142.3 pcf or 100.2 percent of the constructed target density. Laboratory mix design data for KY 15, Whitesburg Bypass, recommended an asphalt content of 7.2 percent and a unit weight of 138.7 pcf. The target density during construction was not determined. Field specimens of the bituminous sandstone base obtained from the Whitesburg Bypass by KTC personnel during 1986 had an average unit weight of 141.9 pcf or 102.3 percent of the design value.

CONCLUSIONS AND RECOMMENDATIONS

The objectives of this research study were a) to measure the properties of base and surface mixtures containing sandstone aggregates; b) to utilize the information obtained from Objective (a) for development of modifications for mix design and/or thickness design procedures if appropriate; c) to develop historical performance data relative to visual distress, pavement rutting, structural condition using deflection measurements, and other factors if appropriate; and, d) to develop guidelines and recommendations for implementation.

A literature search and review was performed to adequately assess the current state-of-the-art for use of sandstone aggregates. Field and laboratory testing were completed. The overall objective of the field and laboratory testing program was to make comparisons of the performance of bituminous sandstone pavements to the performance of bituminous limestone pavements. The testing program was separated into two areas; monitoring the performance of bituminous sandstone and bituminous limestone pavements; and, evaluating mix designs in the laboratory to determine the effects of the variability of native sandstones on bituminous mix designs.

The field testing portion included monitoring selected sites in eastern Kentucky where bituminous sandstone and bituminous limestone pavements were being constructed or were already in-place. Data obtained during field reconnaissance surveys included: 1) Road Rater deflections to evaluate elastic moduli of the pavement layers; 2) pavement coring for visual inspection, pavement thickness determinations, and laboratory testing; 3) rut depth measurements; 4) skid-resistance and rideability data; and, 5) visual inspections for cracking patterns or signs of unusual behavior.

Laboratory testing involved evaluating bituminous sandstone mixtures in the laboratory to determine the suitability of a given mix. Unfortunately, sufficient data were not obtained in the laboratory relative to asphalt content / density relationships, permeability, unconfined compressive strength, durability, modulus of elasticity, or triaxial shear strength to determine guidelines for the development of optimum mixture designs for bituminous sandstone mixes. Laboratory testing activities relative to freeze-thaw durability, abrasion or wear, and asphalt absorption of sandstone aggregates were not accomplished. Furthermore, laboratory examinations of various types of Kentucky sandstones to determine the effects of the sandstones' inherent variability on performance were not accomplished. Sonic modulus, resilient modulus, and resistance to plastic flow tests were performed on field cores. Because laboratory evaluations were not fully accomplished, correlations between field performance observations and engineering properties and characteristics of bituminous sandstone mixtures determined from laboratory test data could not be performed.

This report fully documents those objectives completed during the research study and provides recommendations for maintaining specifications for Class S bituminous concrete base, binder and surface mixtures. Specifically, the report documents information gained from a literature search and review, historical performance data from the Resource Recovery routes relative to pavement condition ratings, pavement rutting characteristics, structural conditions based upon Road Rater deflection tests and analyses and, laboratory tests performed on pavement cores obtained from the routes.

Information relative to Road Rater deflections, pavement rutting, condition ratings based on subjective visual surveys and objective data such as skid resistance and rideability, were gathered and analyzed during the course of the study and are reported in the data appendix to this report. It may be concluded, based on information gained during the study period presented in the data appendix to this report, and summarized herein, that pavements constructed with bituminous sandstone bases do not develop excessively deep ruts, exhibit various forms of cracking at an earlier age, and generally are more resistant to excessive shoving and pushing than the bituminous limestone pavements which were monitored.

With respect to deflection analyses of the pavement sites that were monitored, the subgrade modulus generally remained the same or decreased during the study period. This decrease was attributed to deterioration of the rock subgrades that were utilized in a majority of the test sections. However, a longer evaluation period should be used when attempting to make an accurate prediction of the performance of these pavement sections based on layer moduli values. As with all field data, there will be some variability in the collected data, therefore the performance evaluation process should involve a longer evaluation period. The same may be concluded about the condition ratings. If the evaluation period were longer and the researcher had control over the variety of designs monitored, then relative differences between the bituminous sandstone and bituminous limestone pavements would be more distinguishable. During the short evaluation period the performance of some routes remained virtually unchanged. The pavement of other routes were so highly distressed before the study began, that the pavement deteriorated to a condition which required maintenance overlays be placed during the evaluation period. The maintenance overlays artificially inflated the condition rating surveys which muddled the comparison and evaluation processes.

Although sufficient data were not obtained in the laboratory during the course of this study relative to asphalt content / density relationships, permeability, unconfined compressive strength, durability, or triaxial shear strength to establish guidelines for development of optimum mixture designs for bituminous sandstone base mixtures, there were no apparent performance difficulties in the constructed pavements as a result of the mixture design procedure in force at the time the pavements were constructed (Special Provision No. 42A [79]). Therefore, it is recommended that the Department of Highways maintain Section 413, Bituminous Concrete Base, Binder, and Surface, Class S, in the Standard Specifications for Road and Bridge Construction. Engineers with the Kentucky Department of Highways have indicated general satisfaction with the use and performance of bituminous sandstone bases and surfaces. The use of bituminous sandstone mixtures does address problems such as haul costs, rutting, skid resistance, etc. Field engineers indicated that although bituminous sandstone surface mixtures have a slight tendency to ravel, they are very resistant to rutting and their applications have been largely successful.

However, only a comprehensive laboratory investigation of the engineering properties of sandstone aggregate would guarantee that bituminous sandstone mixtures would be a practical alternative to bituminous limestone mixtures, even in eastern Kentucky. The apparent benefits of using abundantly available sandstone aggregate in the region may be lost if production and handling costs are not lowered substantially to make sandstone economically viable and competitive. Although reduced costs were anticipated initially, the cost per ton to manufacture and place bituminous sandstone mixtures, apparently, more than offset any advantages gained over importing limestone aggregates into the region. In March 1988, the only source of sandstone aggregate available for use in bituminous mixes was phased out. The reasons cited were unreasonably high cost to manufacture quality sandstone aggregate. Factors contributing to the high production cost were equipment wear, due to the abrasiveness of the sandstone, segregation, degradation, and durability of the aggregate.

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