Research Report
KTC 91-14

VALUE OF RESEARCH

by

Kentucky Transportation Center Staff

Kentucky Transportation Center
College of Engineering
University of Kentucky

in cooperation with
Kentucky Transportation Cabinet

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TRANSPORTATION RESEARCH IN KENTUCKY

INTRODUCTION

Transportation research in Kentucky has been ongoing since 1914. The Road Materials Testing Laboratory was established that year at the University of Kentucky. Operation of the laboratory commenced in 1915 under the guidance of Professor D.V. Terrell who later became Dean of the College of Engineering. Dean Terrell often noted that the purpose of research was not to save money but to make it go farther. Public funding was never sufficient to accomplish all that various agency personnel considered essential nor that which the public deemed necessary and research was conducted most often for the purpose of gaining more for the money available.

The purposes of this report are: 1) to provide an abbreviated background of the evolution of transportation research in Kentucky; 2) a discussion of research and the administration of research within the Kentucky Transportation Cabinet and its predecessor agencies - the Department of Highways and the Department of Transportation; and 3) a compilation of recent and current research accomplishments which have contributed to the design, construction, maintenance, management, and operations of the highway network within the Commonwealth.

Significant benefits of research endeavors are derived through implementation of research findings and technology transfer to the users. Steps have been initiated by Transportation Cabinet and Federal Highway Administration officials to greatly enhance implementation and technology transfer. Dividends from investments in research multiply in proportion to implementation of research discoveries.

BRIEF HISTORY

The basis for transportation research in Kentucky was established in 1914 by creation of the Road Materials Testing Laboratory at the University of Kentucky. Attendees at the 1914 Road School were invited to bring samples of road building materials for tests. The laboratory was designated as the official testing agency for the Kentucky Department of Highways in that same year. Materials testing continued in that laboratory until 1928 at which time a Materials Testing Laboratory was established in Frankfort. Professor D.V. Terrell was retained as a Research Engineer and research was continued at the University of Kentucky, Department of Civil Engineering.

Officials of the University and Department of Highways entered into a bilateral agreement, in 1941, to construct and operate a Materials Research Laboratory on the University Campus. The Department of Highways erected a building at 132 Graham Avenue (campus) in 1942. The Assistant Dean of the College of Engineering was appointed ex officio Director. Organizationally, research was a branch of the Division of Design until 1949 at which time it became the Division of Research. Work within the Division was guided by a Research Committee composed of 39 individuals representing the Department and the University.

Offices and laboratories of the Division of Research were moved to 533 South Limestone in June 1967. The new facilities were located immediately adjacent to the campus across South Limestone from the main entrance. The facilities were further expanded in 1969 through construction of a structure to house and service special test vehicles with space to serve as a depository for materials samples as well as a work area for specimen preparation.

The University of Kentucky Board of Trustees established the Kentucky Transportation Center in April 1979. The Center was to serve to stimulate, coordinate, and manage efforts of the academic, private, and governmental sectors in addressing a broad range of transportation related problems on an interdisciplinary basis.

Functions of the Division of Research were transferred to the University of Kentucky in January 1981. An agreement was formalized between the then Department of Transportation and University of Kentucky Research Foundation to establish and provide for operation of a continuing program of cooperative transportation research to be known as the Kentucky Cooperative Transportation Research Program.

The Transportation Center was designated as a Technology Transfer (T^2) Center by the Federal Highway Administration in 1984. The Kentucky Cooperative Transportation Research Program and Kentucky Transportation Center functioned as separate entities within the College of Engineering until September 1988 at which time the two functions were merged. The merged units were designated the Kentucky Transportation Center which functions as a non-academic department within the College of Engineering.

RESEARCH AND ITS MANAGEMENT

Research is careful, patient, systematic, and diligent inquiry or examination in some field of knowledge undertaken to establish facts or principles. Research is the quest for new knowledge or truth. Research is obtaining answers to pressing problems for which there are no immediate solutions. Numerous attempts have been made to define research and the resultant definition may be largely dependent on the environment and psychological needs of those attempting to define it. It means different things to different people. Research could be the discovery of some fact or truth unknown to the researcher.

Attempts have been made to classify or categorize research. Research is often designated as basic or applied; or, it is termed soft or hard. Basic research is generally viewed as any systematic investigation having as its principal objective a fuller knowledge of natural or socioeconomic phenomena. Applied research is more of a systematic investigation of how existing knowledge may be used to solve a certain problem. Research relative to materials, structures, or other physical items is termed hard research; whereas, research involving planning, traffic, or the environment is designated as soft research. The classification of research would be dependent upon the goals to be achieved through the study.

Research is perpetual in that previous research has provided knowledge and data for current research and today's research will form the knowledge base for future research. Most research is evolutionary rather than revolutionary; that is, it is normally a slow and methodical process -- one step at a time. It is true that sometime discoveries are made rapidly. Someone may have an idea that proves noteworthy and valuable almost instantaneously.

Research programs should be efficiently managed. A system for management includes the following: 1) select the project, 2) design the experiment, 3) supervise the project, 4) implement the results, and 5) evaluate the benefits. Such a system of management has been implemented by the Kentucky Transportation Cabinet (KyTC) for oversight of its research program. The following briefly describes the system.

The program is administered through the State Highway Engineer's office and monitored by the Research Program and Implementation Advisory Committee (RPIAC). Direct responsibility for program management is assigned to the Assistant State Highway Engineer (ASHE) for Administration and Research who is assisted by the Research Coordinator. Responsibility for guiding, supervising, and implementing each study is assigned to a Study Advisory Committee (SAC). All studies are subject to the approval of the State Highway Engineer.

Studies funded through the Planning and Research Program (HPR) are selected annually in a somewhat formal manner. Requests for research needs statements are forwarded to all Transportation Cabinet offices. Returned statements are compiled by the Research Coordinator and forwarded to RPIAC members. Members rank proposed studies according to their conceived priorities and then a composite rating for each study is determined by the Research Coordinator. RPIAC members meet to discuss the studies

for inclusion in the upcoming work program. New studies included in the next year's program are dependent upon funds available in the coming year.

Next, a principal investigator (PI) for a new study is chosen by the Director of the Kentucky Transportation Center (KTC). The ASHE appoints a Chairman for the Study Advisory Committee. The Chairman selects members to serve on the Committee. The Chairman and members are persons having a vital interest in the study and findings. The PI prepares a Line Item for inclusion in the work program manual and then, a detailed work plan which includes time and budget items is drafted. The work plan, after review and approval by the SAC, is forwarded to the Federal Highway Administration (FHWA) for review and approval. The PI is responsible for conduct and reporting for the study under the guidance of the Director of KTC. SAC meetings are held periodically for review of study progress. Work plan changes which may be deemed desirable as the study progresses are subject to approval by the SAC and FHWA officials. Interim reports are issued as the study progresses and in accordance with the work plan or on an as-needed basis. A final report is used to document the entire study and serves to formally close out the study.

Study findings are frequently implemented as a study progresses and significant information is developed. Upon finalization of a study, the SAC prepares a statement of implementation which is included in a letter of implementation signed by the State Highway Engineer. That letter is included in the final report. Study benefits may be evaluated in numerous ways and depend upon the nature of the study. Benefits of recently completed and current studies are included in the section titled Recent and Current Studies.

Various non-HPR studies are sponsored by KyTC and FHWA as a means of obtaining quick response for projects requiring immediate attention or as a means of initiating studies which are not considered appropriate for the HPR program. These studies include Federal-Aid Research Tasks, Kentucky Highway Investigative Tasks, State Highway Quick Response Studies, Implementation Task Orders, Demonstration Projects, and Experimental Projects.

Federal-Aid Research Tasks are studies specifically related to a construction project and are funded by engineering monies allocated to the construction project. The monies are derived from federal and State funds. Kentucky Highway Investigative Tasks are similar to Federal-Aid Research Tasks except the projects and studies are 100 percent State funded. State Highway Quick Response Studies are each a special study conducted for an office within the KyTC and funds are derived form that office's account. Implementation Task Orders, Demonstration Projects, and Experimental Projects are usually initiated and funded by FHWA and are normally treated similarly to Federal-Aid Research Tasks.

PAVEMENTS SECTION

	Study Title
1.	Stability of Asphalt Concrete Mixtures
2.	Models and Strategies for Pavement Management in Kentucky
3.	Pavement Deflection Evaluations
4.	Laboratory and Field Evaluations and Correlations of Properties of Pavement Components
5.	Evaluation of Transportation Facilities for Earthquake Hazard Mitigation
6.	Pavement Investigations and Analyses
7.	Longitudinal Edge Drains
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13.	Life-Cycle Costing of Pavement Systems
14.	Longitudinal Edge Drain Effect on Pavement Performance
15.	Pavement Performance Modeling
16.	Performance of Break and Seat Concrete Pavements

~~Stability of Asphaltic Concrete Mixtures (KYHPR-84-97)~~

Description: This study was concerned with the factors that control the stability of asphaltic concrete mixtures. The mastic portion of a mixture (smaller than 3/8-inch size) was studied extensively. The factors that were studied were natural sand versus crushed lime sand, and various grades of asphalt cement. It was concluded that mixtures with crushed limestone sand and AC-20 grade asphalt cement had better rutting and fatigue characteristics. Large-stone (top sizes of aggregate greater than one inch) mixtures were also studied in this project. It was concluded that large-stone mixtures are less susceptible to rutting and should perform better on highways that carry heavy loads (such as coal haul roads).

Implementation: Partly as a result of this study, the percentage of natural sands permitted in an asphaltic concrete mixture is now severely limited. In addition, as a result of the research on large-stone mixtures in this study, these mixtures are now being used extensively statewide, and over 1,000,000 tons have been laid to date.

Cost Effectiveness: Study results indicated the large-stone mixtures could reduce rutting from two to three times the amount of rutting in a standard base mixture. Assuming that a mile of flexible pavement must be milled and overlaid four times because of rutting in a twenty-year design life, using a large-stone mixture would reduce this to two times in the twenty-year life. Using 1990 average unit bid prices, it is estimated that removal and replacement of one inch of standard base mixture cost approximately $31,900 per mile for a two-lane highway. Performing this operation four times in twenty years would cost $127,600 per mile. Removing and replacing the large-stone mixture two times in twenty years would cost only $61,000 per mile. This is a savings of $66,600 per mile. The total cost of this study was $275,000. Therefore, this study has paid for itself in only four miles of two-lane highway.

Models and Strategies for Pavement Management in Kentucky (KYHPR-85-106)

Description: A pavement management system (PMS) allows an engineering manager to make decisions on pavement maintenance, rehabilitation, reconstruction, and construction that are based on historical pavement condition information. This allows the manager to make more rational decisions. The Federal Highway Administration has mandated all state highway agencies have an approved pavement management system in operation by March 1993. This research study was an in-depth and detailed review of Kentucky's present PMS. In addition, a comparison was made between Kentucky's PMS and the mandated federal policy. The report listed the areas where further development is needed in the PMS as well as the areas where the system is well advanced.

Implementation: This review of the PMS will assist the Federal Highway Administration in their review for approval of the system. Partly as a result of this study, two new research studies were initiated to assist in the further development of portions of the PMS that are needed to receive federal approval. The report on this study is serving as a guideline to determine where further future development in the PMS is needed.

Cost Effectiveness: Some states have spent over $2,000,000 in attempting to develop a viable PMS. Although Kentucky's PMS is already well advanced, this study has helped to prevent the state from having to start from the beginning to try to develop a system. The review has clearly indicated the areas that need no further development. The total cost of this study was $240,300. This is approximately 10 percent of the possible cost of developing a completely new PMS. This is an approximate benefit-cost ratio of 10:1. Not included in that number is the savings that result from better economic decisions that can be made when using a PMS.

Pavement Deflection Evaluations (KYHPR-86-109)

Description: The structural adequacy or remaining structural life of an in-service pavement can be estimated by using non-destructive testing devices that create an impulse load on a pavement (to approximate wheel loads from trucks) and measure the amount the pavement deflects under these loads. These deflection data can be used in conjunction with mathematical models to estimate the effective thickness of a pavement. To explain the term "effective thickness," an example may be used. For instance, a particular pavement may have six inches of asphaltic concrete; however, from measured deflections it may be behaving as if there are only three inches. Therefore, the effective thickness is defined as three inches. This loss in effective inches of asphaltic concrete is due to environment and fatigue from repetitive traffic loading. The effective thickness is used to design the thickness of asphaltic concrete overlays. In the above example, the required overlay would normally be three inches. This research study developed more precise and accurate mathematical models that describe the deflection behavior of test pavements, and consequently, better estimates of effective thickness. The models developed describe the deflection behavior of Portland cement concrete (PCC) pavement, flexible pavement, asphaltic concrete over PCC pavement, and asphaltic concrete over broken and seated PCC pavement.

Implementation: These new mathematical models have been programmed for use on the computer. These models are now being used to make estimates of effective thickness for overlay design. Generally, the new models estimate effective thicknesses that are somewhat thicker than estimated by the old method. Consequently, thinner overlays are generally being required.

Cost Effectiveness: The new, more precise models are requiring overlays that are from one-half to three inches thinner. If an average of 1.5 inches of thinner overlay is assumed, this would result in approximately $26,600 in savings per mile of two-lane highway. This study cost approximately $226,200. The study has paid for itself in the rehabilitation of approximately 8.5 miles of two-lane highway.

Laboratory and Field Evaluations and Correlations of Properties of Pavement Components (KYHPR-86-115)
Federal Aid Research Task (FRT 47) -- Long-Term Pavement Performance
KYP-91-108, Subtask 3 -- Correlation of Road Raters

Description: The strength of pavement materials can be estimated from deflections obtained from in-service pavements using the falling weight deflectometer. There is a need to correlate these strength values with values obtained from laboratory tests on the same materials. These studies have chosen 20 in-service pavement sites to monitor for a minimum period of five years to determine how and at what rate these pavements deteriorate. At the same time, these sites are being sampled and tests are being performed on these samples in the laboratory to determine if laboratory tests values can correlate with changing field values. Materials engineers can use such information to assist in designing new asphaltic concrete mixtures with greater service life. Designers may be able to adjust their designs based upon the behavior of these test sites.

Implementation: These studies are just being concluded, and implementation of the results will follow in due course. Results to date indicate that correlations between field strength values and laboratory strength values may vary widely. It appears that field values probably yield better results and more accurately describe the pavement behavior. It is anticipated that this conclusion will be implemented by designers and pavement management engineers through the use of field strength values rather than laboratory values.

Cost Effectiveness: The exact cost effectiveness of this study is difficult to estimate. It is intuitively clear that more accurate estimates of pavement strength and pavement behavior will result in pavement designs and overlay designs that will provide longer service life for the estimated traffic the pavement is to carry. For example, if a pavement was under designed by one inch of asphaltic concrete because of over estimation of pavement strength, the life of that pavement could be shortened by as much as one-half. This would require an unplanned overlay of one inch of asphaltic concrete that would cost approximately $17,740 per mile for a two-lane highway. This study cost approximately $429,500. Therefore, this study will have paid for itself if just 24 miles of two-lane highway are prevented from being improperly designed.

Evaluation of Transportation Facilities for Earthquake Hazard Mitigation (KYHPR-87-116)

Description: In 1811-1812, the New Madrid Fault Zone produced the most severe earthquakes ever known in North America. Because of these quakes, it is now well documented that the central United States is highly vulnerable to damaging earthquakes. This study was initiated to choose emergency routes that would be kept open after an earthquake, to move emergency personnel and supplies into the earthquake area. Approximately 1000 miles of emergency routes were chosen and all earthquake hazards along those routes were cataloged including bridges. The 276 bridges cataloged on those routes were individually analyzed for earthquake safety. This analysis was an attempt to predict if a bridge would fail during an earthquake. It was determined that

111 bridges were susceptible to failure during an earthquake and recommendations for bridge retrofitting were presented. In addition, an outline of an emergency plan for highway personnel in each county was developed.

Implementation: As a result of this study, 11 of the most critical bridges are under contract and are presently being retrofitted. In addition, it is anticipated the remaining bridges that need retrofitting will be retrofitted over a period of five years. Other emergency agencies, such as the Kentucky Disaster and Emergency Services are presently using the emergency routes chosen in this study in their emergency response plans.

Cost Effectiveness: This study cost approximately $461,200. The cost of replacing one bridge that might collapse during an earthquake could be several million dollars. The benefit-cost ratio of this study increases dramatically for each bridge that is prevented from collapsing as a result of this study. The benefit of saving several bridges could be several hundred times the cost of this study. This also does not include the cost of lives and property that may be saved as result of maintaining passable highways in an earthquake emergency. Therefore, the ratio of benefits to cost of this study may be astronomical.

Investigative and Remedial Analysis of Various Pavements

FEDERAL AID RESEARCH TASK (FRT) 23 -- US 23, Greenup County
FRT 26 -- US 23, Lawrence County
FRT 27 -- US 31W, Hardin County
FRT 28 -- Interstate 71, Oldham-Henry Counties
FRT 36 -- US 60, Hardinsburg Bypass, Breckinridge County
FRT 39 -- US 27, Campbell County
FRT 40 -- KY 94, Fulton County
FRT 48 -- US 23, Pike County
FRT 49 -- National Turnpike, Jefferson County
STATE HIGHWAY QUICK RESPONSE STUDY (QRS) -- Assistance on Pavement Rehabilitation

KENTUCKY HIGHWAY INVESTIGATIVE TASK (KHIT) 11 -- KY 461, Pulaski County
KHIT 15 -- AA Highway, Mason-Bracken Counties
KHIT 20 -- Overlay Analysis

Description: Investigations have been performed on all types of pavements to determine their in-situ condition and to evaluate the causes of premature distress. Asphaltic concrete pavements have been evaluated to determine the causes of premature rutting and subgrade failures. Portland cement concrete pavements have been evaluated to determine the cause of settlement and premature cracking. Other evaluations have been made to evaluate the in-situ conditions of pavements and determine remedial action needed to maintain a given level of service. Investigations have been conducted to determine the causes of pavement failures which have occurred during construction.

Recommendations have been made on these projects to allow them to be constructed to their designed level of service.

Implementation: The recommendations which were provided have been utilized by the Transportation Cabinet to evaluate the best remedial action which should be used. Valuable information has been provided on the in-situ conditions of pavements in the event premature failures occur in the future.

Cost Effectiveness: The total cost of these studies was approximately $103,600. For every inch of asphaltic concrete that was saved as a result of the research analysis, approximately $17,700 was saved for every mile of two-lane highway that was rehabilitated. The research cost was recovered in only 5.8 miles of highway. The projects listed above totaled well over 100 miles of highway; therefore, the benefit-cost ratio for these studies was 20 or greater.

Longitudinal Pavement Edge Drain Studies

FRT 12 -- Interstate 64, Franklin County
FRT 33 -- Interstate 64, Fayette County
FRT 46 -- Interstate 75, Fayette County
FRT 53 -- Interstate 64, Fayette County
KHIT 5 -- US 27, Jessamine County
KHIT 16 -- Mountain Parkway, Powell County
KHIT 17 -- Western Kentucky Parkway, Grayson County
KYHPR-85-107, Subtask 3 -- Evaluation of Drainage Systems
KYHPR-85-107, Subtask 15 -- Mountain Parkway, Powell County

Description: Included in these studies was the evaluation of perforated round pipe edge drains and panel type edge drains. It was determined that the panel drain responds quicker to rainfall event than round pipe drains. Under old installation methods it was apparent that the panel drains were being damaged during construction. Inherent weaknesses were also found in some of the panel drains. Several failures were discovered in flexible outlet pipes. Most of the damage appeared to have occurred during construction. It appears that anywhere from 25 to 50 percent of the old flexible outlet pipes are damaged. Significant amount of damage had occurred during the rehabilitation of old guardrail sections. Field observations and laboratory calculations indicated that headwall distances were too great and the capacity of the edge drains were being exceeded as much as three times. Large amounts of fines were being deposited at the headwalls during break and seat operations. Platelets of calcium carbonate were found crystallizing in inverts of the drains. The platelets would break loose and become lodged behind the rodent screens and increase siltation.

Implementation: Dynamic type compaction is no longer used for compacting the fill material around highway edge drains. A sand slurry is now specified. The edge drain is also placed on the far side of the trench against the shoulder. This allows for an extra filter medium between the pavement and the filter fabric, it also allows for another means for the water to travel if the panel is damaged during installation. Headwall

distances are now installed on 250-or 500-foot intervals. For a grade less than two percent 250-foot headwall spacing is specified and anything greater than two percent 500-foot headwall spacing is specified. A larger mesh opening and a galvanized screen is now specified for rodent screens. Rigid outlet pipe are now specified for all edge drain outlets.

Cost Effectiveness: The total cost of these seven studies is approximately $120,000. Using 1990 average unit bid process, only 5.5 miles (inside and outside shoulder) of longitudinal fin drain that is installed and working properly will cover the cost of this research. Only four miles (inside and outside shoulder) of 4-inch longitudinal perforated pipe drain would pay for the cost of these studies. This does not include the increased pavement life that could result from the use of the drain. This added benefit would be many times the cost of the research.

Performance of Polyethylene Pipe

FRT 35 -- Forbes Road, Fayette County
FRT 42 -- US 68/KY 80, Warren County
FRT 43 -- Kenton County
KHIT 12 -- KY 54, Daviess County

Description: Construction inspection and long-term monitoring has and is being conducted on all the projects. FRT 43 has not been let for construction as of to date. It is apparent that the backfill specification must be closely followed during backfilling around polyethylene pipe. The pipe performs well when properly backfilled. Several contractors have elected to use crushed stone for backfill to a height approximately one foot above the crown of the pipe. This type of backfill performs well. It has been recommended that a select material of crushed stone or sand be used for backfill to a height of one foot above the pipe. This would surround the pipe in a protective envelope of material. Some rips and punctures have been found in the pipes where improper fill material was used (rocks greater than three inches and frozen clods of soil).

The pipe performs well as cross drains and longitudinal storm drains when properly installed. To date, no failures have occurred. Deflections greater than 18 percent have been recorded in entrance pipe. The bedding material around these pipes was questionable. Care must also be taken during construction to insure that the pipes are properly butted at the ends.

Implementation: The pipe is still considered experimental and implementation or routine use of these pipes is still being evaluated.

Cost Effectiveness: The cost saving in installing this type of culvert pipe over using traditional types of culvert pipe may be as much as 20 percent. During 1990, the total cost of installing concrete culvert pipe for 12-inch, 15-inch, 18-inch, 24-inch, 30-inch, 36-inch pipe was approximately $4,809,900. If 20 percent could be saved by installing polyethylene pipe, this would be a savings of $962,000. The total cost of these research

studies was $42,000. The benefit-cost ratio of these studies may eventually be approximately 23.

Studies on the Evaluation of Stone Column Reinforcement

FRT 8 -- US 42/US 127, Gallatin County
FRT 37 -- US 42, Gallatin County
EXPERIMENTAL 1B -- Interstate 65, Bullitt County

Description: Stone column reinforcement is used in soft soil foundations to strengthen the foundation and permit it to support heavier loads. In the three projects listed above, stone columns were used to support bridge approach embankments. Stone columns are installed by vibrating large diameter holes (approximately six feet in diameter) in the soft foundation. These large holes are backfilled with large-sized crushed aggregate. The stone columns are placed within a few feet of each other, resulting in a network of columns distributed over the entire area of the soft foundation that is to support the load. The results of these studies indicated when the columns were properly installed and installed in an appropriate location where they can be used to the greatest advantage, the foundation is stabilized and long-term settlement appears to be reduced. The stone columns that were installed on Interstate 65 failed during construction. Subsequent investigation indicated that a large portion of the fine-grained soil in the foundation intruded into the more open-graded stone columns and reduced the strength of the columns.

Implementation: The findings of these studies resulted in significant changes in design methods for stone columns and resulted in changes in how the stone columns were applied. In addition, changes resulted in the methods and procedures used to install or construct stone columns.

Cost Effectiveness: Calculations from the three projects listed above indicate the cost of stone columns is approximately one third the cost of removing the poor soil and replacing an equivalent amount of good soil. The total cost savings on the three projects between the two stabilization methods is approximately $1,200,000. The total research budget for these three studies was $92,300. The benefit-cost ratio for this research is approximately 13.

Studies on the Evaluation of Soil Foundation Stabilization Using Wick Drains

FRT 21 -- US 42, Carroll County
FRT 22 -- Interstate 65, Bullitt County

Description: Wick drains consist of a polyethylene core encased in a filter fabric. The core is studded on both sides and perforated. The filter is a polyester fiber fabric. Overall drain dimensions are 100 millimeters in width and 7 millimeters in thickness. The drain is shipped in large rolls and the drain material is driven into the soft soil foundation in a vertical position. Water in the soft soil flows to this drain which acts as

a channel to carry the water out of the soil foundation. This process speeds settlement of the foundation and permits construction to proceed at a more rapid rate. For example, in the second project listed above, the estimated settlement time of the foundation soil was reduced from approximately three years to approximately 100 days by the use of wick drains.

Implementation: The data and recommendations that have resulted from these studies have shown clearly the effectiveness of wick drains. Adoption of the recommendations from these studies has resulted in the routine use of wick drains at various locations in the state.

Cost Effectiveness: The total research cost of these two studies was approximately $25,200. It is difficult to assess the cost savings of these studies. The cost of the wick drains is comparable to the cost of removing and replacing the poor soil with good soil; however, the actual benefit of wick drains is the time saved in construction, and the increase in soil strength due to the effects of dewatering. The amount of money saved would vary dramatically from project to project.

Studies Evaluating Stabilization of Pavement Bases and Subgrades

KHIT 6 -- AA Highway Subgrade Stabilization with Lime
KHIT 14 -- Lime-Cement Treated Base

Description: When pavement subgrades are very soft, they will not support heavy traffic loads without excessive rutting. It is also difficult to compact granular bases sufficiently when the pavement subgrade is soft. In these studies, lime was mixed with the top six inches of the soft soil to dry and harden the soil in order to compact the soil to the proper density. The results of this study have indicated the hardened soil layer provided a good platform to compact against. In addition, it has continued to provide support for heavy loads for a number of years.

Implementation: The results of this study confirmed that lime stabilization of soil subgrades is a viable procedure for assisting in the construction of highway pavements, and that this procedure apparently extends the service life a pavement by an undetermined amount. Consequently, many additional miles of pavement subgrades have been stabilized with good success. This procedure is now a special provision.

Cost Effectiveness: It cannot be determined at present by what amount the service life of a pavement with lime stabilization may be increased. The pavements with stabilization have not been in service a sufficient amount of time to make such a determination.

Stresses on Reinforced Concrete Box Culverts,

KHIT 2 -- Ashland-Alexandria Highway

Description: In a previous research study that was concluded a number of years earlier ("Loads on Box Culverts"), design charts were developed that could be used to predict loads on reinforced concrete box culverts. Four culverts were constructed that had been designed using the new design charts on the above mentioned highway. These four culverts were instrumented with load measuring devices in an attempt to verify the magnitude of loads and to compare them with the new design charts. This was to verify the accuracy of the charts. The results showed the measured loads correlated extremely well with the loads predicted by the design charts.

Implementation: As a result of this study, the design charts were verified as accurate and were adopted as a part of the Division of Bridges culvert design procedures.

Cost Effectiveness: The total cost of this study was $76,000. Failure of one box culvert from loads that might be in excess of the assumed design load could cost $1,000,000 or more, depending on the size of the culvert. If failure of one box culvert is prevented as a result of this study, the benefit-cost ratio of the study would be approximately 14.

STUDIES IN PROGRESS BY THE PAVEMENTS SECTION

Life-Cycle Costing of Pavement Systems (KYHPR-88-118)

Description: Methods of construction and maintenance and the availability of new construction materials have proliferated in recent years. The result of this can sometimes be a bewildering array of choices of possible design and maintenance strategies from which the designer or engineering manager must choose as the best or most cost effective alternative for a particular highway section. In this study, a comprehensive computer program is being developed to permit designers and engineering managers to perform life-cycle costs analyses on pavements. This involves the development of maintenance and rehabilitation models, construction cost models, user cost models and remaining life models. All these costs are estimated and/or calculated for each possible alternative design for a particular pavement. The alternative with the most service life per dollar would normally be chosen as the best.

Implementation: It is anticipated the computer program developed in this study will be used to perform life-cycle cost analyses on each new pavement design. This includes rehabilitation and major maintenance activities. It is expected the results from these analyses will be a major determining factor in the choice of design or rehabilitation strategy.

Cost Effectiveness: The anticipated total cost of this study will be approximately $300,000. The use of the program in choosing the most cost effective design alternative will most likely result in a cost savings well above the cost of this research study on the first design project. Therefore, the cost of this study will be recovered on the first design project.

Evaluation of Longitudinal Edge Drains and their Effect on Pavement Performance (KYHPR-92-143)

Description: The objectives of this study are to verify that longitudinal edge drains improve pavement performance. To determine the lateral effectiveness of the edge drain systems across the pavement structure. To determine the cost effectiveness of longitudinal edge drains. To develop a generic specification for highway edge drains. To quantify the major in-service problems of the longitudinal edge drains and their outlets, such as blinding of fabric or clogging of panel cores or of the round pipe. Evaluate past and current construction practices and evaluate the drainage systems installed. Work is currently being conducted on Interstate 75 and Interstate 64 that will be utilized in this project. To date 234 flexible outlet pipes have been inspected. Approximately 50 percent of the outlet pipes had been damaged during installation.

Implementation: The findings of this study will impact future design and construction of highway edge drains and pavement rehabilitation in two general areas: 1.) The results of this study will likely verify the structural integrity and performance of the edge drain

system at each site inspected. These data will be useful for future rehabilitation projects. 2.) The results of this study will also impact future installation procedures and design of highway edge drains.

Cost Effectiveness: The annual resurfacing program for 1990 cost approximately $38,300 per mile. If it can be conservatively assumed that longitudinal edge drains can increase the pavement life by only 20 percent, this would have reduced the 1990 resurfacing program by $7,660 per mile. This research is estimated to cost approximately $286,000. Therefore, the cost of this research study will be recovered in just 37 miles of resurfaced highway in the first year alone.

Pavement Performance Modeling (KYHPR-92-147)

Description: An important product of pavement management systems is the ability to forecast pavement conditions at both the network and project level. The ability to forecast the future conditions of a network permits planners and those who develop budgets to determine future funding needs. Performance models also enhance the ability to develop long-term programs for rehabilitation and reconstruction. Designers also use prediction models to determine the best economic alternative from among several competing design or rehabilitation strategies. To accurately forecast pavement behavior, it is necessary to have available pavement performance models that are able to predict the condition or performance of the pavement with time or accumulated traffic.

Implementation: The results of this study may be expected to benefit the Transportation Cabinet in predicting the network level needs for rehabilitation and reconstruction. From this, funding needs can be estimated for future rehabilitation or reconstruction to maintain the network at a prescribed level of service or ride condition. These results will assist the designer in conducting a life-cycle cost analysis of pavements to determine the effectiveness of various designs. The development of these models will permit the choice of the best alternate design from an economic point of view. These models will allow the manager or designer to perform maintenance work, rehabilitate, or reconstruct at the most opportune moment in the service life of the pavement.

Cost Effectiveness: The estimated total cost of this study will be approximately $270,000. The total annual resurfacing program for 1990 was approximately $41,000,000. If the results of this study result in a better needs estimate of only five percent each year, that would equal a savings of $2,050,000 annually (assuming the annual budget remained essentially the same as 1990). Therefore, in only one year the benefit-cost ratio for this research would be approximately 7.6. However, that benefit would occur every year.

Studies on the Performance of Break-and-Seat Concrete Pavements

DEMO PROJECT 202 -- Western Kentucky Parkway, Grayson County
KHIT 19 -- Western Kentucky Parkway, Grayson County
KYHPR-85-107, Subtask 4
KYHPR-85-107, Subtask 20

Description: Portland cement concrete pavement (PCC) must be rehabilitated or reconstructed after it has reached its design service life. In the past, it was usually overlaid with asphaltic concrete. However, the asphalt layer would usually crack at the location of the joint in the old PCC pavement (reflective crack). A new technique has been developed in recent years that has tried to eliminate the reflective crack. This consists of completely breaking the old PCC pavement into various size pieces and seating these pieces (making certain the pieces are in contact with the soil subgrade or granular base below) with a very heavy roller. This technique is referred to as "breaking and seating." The broken structure is then overlaid with a thick asphaltic concrete mat. The above listed studies are currently evaluating the effectiveness of this method in reducing reflective cracking.

Implementation: Depending on the results and recommendations of these studies, it is anticipated there may be design changes and changes in construction techniques.

Cost Effectiveness: Until final results are analyzed and final recommendations are made, it is difficult to estimate the cost effectiveness of these studies.

GEOTECHNOLOGY SECTION

Study Title

1. Highway Embankment Landslides
2. Highway Pavement Subgrades
3. Computer Program for Analysis of Embankments with Tensile Elements
4. Modification of Highway Soil Subgrades
5. Geotechnical Engineering Data
6. Coolside Waste Management
7. Rockfall Mitigation Measures

Highway Embankment Landslides

Each year, the Kentucky Transportation Cabinet, as well, as other U.S. highway agencies, spend millions of dollars in repairing and maintaining highway embankments, slopes, and other earth structures. In Kentucky, the Kentucky Transportation Cabinet will spend an average of 200,000 to 400,000 dollars to repair a highway embankment landslide that occurs on the Interstate or Parkway System. However, it is not uncommon for a highway embankment to cost 1 million dollars to repair. The exact total cost of landslides on Kentucky highways is not available. However, total annual repair and maintenance expenditures are estimated to be some 20 to 60 million dollars. For example, to date (1991) some 120 million dollars have been spent on repairing embankment slope failures and unstable embankments of Interstate Highways I-71 and I-75 in northern Kentucky in the past 10 years. This amounts to about 10 million dollars per year. Additional highway landslides are developing on these roadways. However, there are numerous other areas in Kentucky where major highway embankment failures occur. For example, in any given year the Geotechnical Branch of the Division of Materials may be studying as many as 30-50 active highway landslides. Consequently, research efforts of the Geotechnology Section have been directed toward developing better design and maintenance techniques. Research studies completed in the past years pertaining to highway landslides (see Table 1) include:

- Slope stability analysis (KYHPR 84-101) study cost: $50,800
- Engineering Properties and Uses of Kentucky Shales (KYHPR-82-91) study cost: $368,200
- Three Experimental Shale Embankments (Kentucky Highway Investigative Task Number 1) study cost: $85,000
- Slope Maintenance and Slide Restoration (funded by the Rural Technical Assistance Program of the Federal Highway Administration) study cost: $65,000
- Performance Monitoring of a Highway Tiedback Wall (Federal-Aid Task Number 10) study cost: $45,000

A detailed discussion including a description of the problem; solution, benefits and implementation; and example case studies of cost benefits (when applicable) of each of these studies is presented below.

Slope Stability Analysis (KYHPR 84-101)--Research Cost: $50,800

Problem -- In designing slopes of highway embankments and excavated slopes, the geotechnical engineer must oftentimes resort to two or more methods. Methods for analyzing the stability of highway embankment slopes are somewhat limited. Some of the methods are limited to analyzing circular failures. However, in nature, the failures planes are not always circular. Although some methods analyze surfaces of irregular shapes, they are not accurate. Methods that are capable of analyzing irregularly shaped failure planes and giving accurate solutions are exceedingly complex, research oriented and time-consuming. Solution and Benefits -- Major benefits of this study were as follows:

- A new generalized mathematical, slope stability model and computer program were developed. The mathematical model and computer program are unique since the method represents a new approach to solving the equations of slope equilibrium.

- The new method analyzes slope failures involving not only irregularly-shaped failure surfaces but circular shape surfaces. Hence, failure surfaces that occur naturally may be analyzed. Moreover, solutions obtained form the newly developed program are as accurate as those obtained from the more complex and time-consuming slope stability computer models and programs. However, solutions may be generated by the newly developed program in about one-third of the time required by other slope stability computer programs. Data entry into the new program has been simplified; the program is "user-friendly" and interactive.

Example -- Case Studies of Benefits--Several guidelines for constructing embankments of soft, clay foundations were developed. The newly-developed computer program (HOPK1) solves a larger variety of complex problems than other programs and simulates more accurately certain problems that occur in nature. For example, construction of highway embankments on soft, clay foundations is exceedingly risky and very complex to design. Usually, when these types of highway embankments fail, a tension crack (a large, deep crack forms behind the slope) develops. Few, if any, methods, can simulate and analyze this situation. When such embankment failure occurs, large sums of monies must be spent repairing the failure slope. For instance, when the wall and slope failed during construction of the "Northern Ditch" in Louisville, Kentucky, one million dollars was required to repair the slope. Hence, the use of the newly developed program, which can accurately analyze such situations, and the proposed design guidelines could have (most likely) been used to prevent such an occurrence. Consequently, the benefit-cost ratio at one embankment site alone exceeds 19.

Another example of the use of the newly developed computer program involved the very risky remedial design and construction of the southern bridge approach embankment of the US 60 bridge across the Licking River. This 100-foot embankment (in height) was sliding into the river. The southern span across the river was endangered. Failure of the embankment would have closed US 60 (Lexington-Maysville Road). The situation was complicated by the fact that the toe of the slope was located at the edge of the river bank and one of the bridge piers was surrounded by the sliding embankment. Two plans

were proposed. The first plan (and one that involved minimal risk) specified decreasing the slope and extending the bridge. Estimated cost was in excess of 2 million dollars. However, implementation of this plan would have closed this two-lane roadway for several months; the detour around the site was several miles in length. The Governor's representative vetoed this plan since it would involve closing the roadway for several months. The newly developed slope stability program was used by the Geotechnology Section to devise a second option. Based on slope inclinometer data, the base of the 100-foot embankment was determined to be partly sliding along bedrock--an irregularly-shaped sliding surface. The plan specified the cutting of a shear key at the toe of the embankment (slide and front of the embankment), backfilling the keyway with rock (this material--limestone--was obtained adjacent to the site), and constructing a rock berm. This plan was exceeding risky. However, to reduce the risk, the plan was executed in stages--that is, short sections were excavated and backfilled immediately. The plan was constructed safely. Cost of the remedial plan was 750,000 dollars--a savings of 1.25 million. The benefit-cost ratio at this site alone was some 24. The program has been used at several other sites where remedial slope repairs have been required. If the savings to drivers is included (that is, the cost of lost-time to drivers), then the benefit-cost ratio would be higher than 24. If the bridge approach embankment had failed, then two spans of the bridge would have dropped into the river. Hence, several millions of dollars would have been required to repair this site.

Engineering Properties and Uses of Kentucky Shales (KYHPR 82-91) -- Research Cost: $368,200; and (a companion study)

Three Experimental Shale Embankments (Kentucky Highway Task Number 1) --Research Cost: $85,000 dollars

Problem: Because of the large quantities of shales in Kentucky, numerous highway embankments have been constructed of shales and many roadway cuts have been made in shales. Shales must be used in many areas of Kentucky to construct embankments because of their availability and the lack of more suitable and economical alternate construction materials. Numerous problems have been encountered when making highway cut and fill sections through different shale formations. Embankment failures due to slope instability and large settlements, unstable pavement subgrades, and weathering products of shales in highway cut sections that collect in ditches or cause rockfalls have occurred commonly throughout Kentucky. Enormous sums of construction and maintenance monies have been spent dealing with these problems. When shales are first excavated they have properties that resemble hard, durable rock. However, when exposed to water, may types of shales degrade rapidly into flakes or "mud" and become very weak. This was a major cause of embankment failures on Interstates I-71 and 75 in Northern Kentucky.

Solution and Benefits--Important findings obtained during the course of those studies have lead to significant changes in the manner shales are identified for engineering purposes and the way shale embankments are designed and constructed in Kentucky. Major benefits derived from these two studies are as follows:

- The concept of using the slake-durability test, as original proposed by Franklin and Chandra of England, to identify certain suitable and unsuitable engineering properties of shales was first proposed and introduced to Kentucky and the Kentucky Department of Highways during the course of this study. The first prototype of a slake-durability apparatus was designed and constructed by the Geotechnology Section of the Kentucky Transportation Center (actually, this was the first prototype used in the United States). Working drawings of the first prototype were provided to the Kentucky Transportation Cabinet, as well as geotechnical, highway, civil, and mining consultants and companies, and other governmental units. As the result of this original work by the Geotechnology Section, the slake-durability test is used widely in Kentucky (as well as in other states)to characterize and classify shales for engineering purposes by the highway and mining industries. The test is now used routinely by the Kentucky Department of Highways.

- Based on hundreds of slake-durability tests on some 40 different types of shales, guidelines were developed for classifying and characterizing Kentucky shales for engineering purposes.

- A special shale compaction provision was developed, adopted, and implemented during the course of these research studies (this provision appears now as a permanent specification of the 1991 "Standard Specifications for Road and Construction of the Kentucky Transportation Cabinet). A special research study (Kentucky Highway Investigative Task Number 1) was initiated to evaluate the long-term aspects of the special compaction specification. Three shale test embankments were constructed on KY 11. Analyses of compaction test results from these sites demonstrated that special compaction techniques were successful in achieving required compaction. Moreover, the study demonstrated that the moisture-density tests may be performed on shales and the results may be used to control field compaction. Data indicated that requiring that the shales be compacted in 8-inch loose lifts using heavy compactors, as opposed to using 12-inch or thicker lifts and light compaction equipment, added only a few cents to the cost of a cubic yard of compacted shales. Hence, it was recommended that a new compaction technique be adopted for use in Kentucky.

- Methods of predicting such engineering parameters as bearing ratios (California Bearing Ratio) of pavement subgrades and shear strength of compacted shales--values which are obtained form expensive tests--from inexpensive index tests, such as the natural water content test, particle-size determination, and the slake-durability test were developed. By using simple index tests, the practitioner may quickly predict the shear strength parameters and bearing ratios of shales in highway cuts as they would exist in a compacted state. Consequently, suitable and unsuitable shales for highway construction purposes may quickly be identified and proper use of different types of shales may be determined during the planning and design stages. Hence, engineering time is reduced during the design stage.

- Although slope stability of highway embankments constructed with shales is a major design consideration, long-term embankment settlement is also a major design consideration that, if excessive, adversely affects the performance of highway pavements. Consequently, a method of predicting long-term settlements was developed. Hence, design tools were developed for minimizing long-term settlements and instability of shale embankments.

- A cross-sectional view of the engineering properties of Kentucky shales was presented.

Example case studies of cost benefits--A major cause of slope instability and excessive settlements of portions of Interstates I-75 and I-71 that pass through northern Kentucky was identified as poor compaction of shale materials used to construct the embankments on these Interstates. These portions of I-75 and I-71 pass through and on the Kope and Fairview Geologic Formations. These formations contain interbedded shale and limestones. Some 120 large, shale embankments on a stretch of I-75 in northern Kentucky were identified as failures requiring remedial work. Some 120 million dollars have been spent with Kope and Fairview shales. Approximately 80 miles of I-71 and I-75 pass through the Kope and Fairview shales. Hence, embankment repair costs (to date) through these areas have averaged about 1.5 million dollars per mile. These old embankments were constructed under prior specifications that treated shales as sound and durable rock and permitted lift thicknesses up to 3 feet. Under these old specifications, the equipment used to compact the embankments did not consist of sufficient weight to breakdown the limestone and shale particles. Consequently, when water entered the voids of the shale embankments, the Kope and Fairview shales degraded into very weak materials. Hence, over a period of time the embankments settled excessively and failed.

Findings and knowledge acquired form the shale research studies were applied in formulating and influencing design and construction standards of the Alexandria-Ashland (AA) Highway in Northern Kentucky. A major portion of this highway passes through the Kope and Fairview Geologic Formations--the same formations that portions of I-75 and I-71 pass through. In a series of meetings held with the engineers of the prime design consultant selected to design the Alexandria-Ashland Highway and engineers of the Kentucky Department of Highways, the Geotechnology Section of the Kentucky Transportation Center discussed and made recommendations concerning four major and important, general design considerations:

- compaction of shales
- slope design
- drainage
- stabilization of pavement subgrades

At these meetings, the following recommendations were made:

- The shales of the Kope, Fairview, and other clayey shales , such as those from the Crab Orchard Geologic Formation, located in the highway corridor should be compacted using extra heavy compactors (minimum weight of 55,000 pounds) in 8-inch loose lifts (under old specifications used to

construct the I-71 and I-75 shale embankments, compaction was performed using crawler dozers in lifts of 3 feet--almost no compaction). The purpose of the heavy compaction was to breakdown the shales into a soil-like material. Also, the heavy compaction lowered the permeability of the compacted material and reduced the opportunity for water to enter the embankment and weaken the shales.

- For large embankments (over 30 feet in height), it was recommended that minimum design slopes of 2.5 horizontal to 1 vertical or 3 horizontal to 1 vertical be used. Additionally, the design shear strengths, $\varnothing'$ and c', used in slope stability analyses be set to values lower than those obtained from triaxial tests (this was based on experience gained from the shale research studies which showed that at sites where failure investigations had been made, the actual strength parameters were lower than those obtained from triaxial tests). Slopes of shale embankments on I-75 and I-71 where major problems exist were 2 horizontal to 1 vertical.

- It was recommended that good drainage be used at the bottom of the shale embankments to intercept subsurface seepage and prevent infiltration of water into the embankments.

- Finally, it was recommended that pavement subgrade stabilization techniques be used throughout the length of the AA-Highway because of the poor engineering properties of the shales and residual soils of the clayey shales of this area of Kentucky.

All of these recommendations were incorporated into the design of the AA-Highway. Some 85 miles of the AA-Highway have been constructed. Approximately 70 miles of this highway pass through the clayey shales of the Kope, Fairview, and Crab Orchard Geologic Formations. To date, no embankment failures have been reported on the AA-Highway. Considering that an average of 1.5 million dollars per mile have been spent repairing embankment failures on I-75 and I-71, and the fact that the AA-Highway was constructed through and with the same type of clayey shales as I-75 and I-71 embankments, then projected future savings are estimated to be about 105 million dollars (1.5 million x 70 miles). Hence, the benefit-cost ratio is 232. If the new measures only reduced the failure rate by 50 percent, the benefit-cost ratio would exceed 100.

Slope Maintenance and Slide Restoration (Funded by the Rural Technical Assistance Program -- RTAP -- of the Federal Highway Administration -- FHWA) --Study Cost: $65,000

Problem -- The maintenance of highway slopes and the restoration and correction of slides on highways has been identified by a number of governmental agencies as a major and continuing problem involving considerable expenditures of funds. Each year, U.S. highway agencies spend millions of dollars in maintaining highway embankments, slopes,and other earthen structures.

Solution, Benefits, and Implementation--In an effort to improve highway maintenance activities and practices, the Federal Highway Administration (FHWA) awarded a contract to the Kentucky Transportation Center in 1987 for the purpose of developing a national course on Highway Slope Maintenance and Slide Restoration. In fulfillment of this award, engineers of the Center's Geotechnology Section developed a 300-page workshop manual. The purpose of the manual was to provide reference material and a training aid to first level road maintenance supervisors who, in most cases, are not engineering graduates. Consequently, efforts were made to write the manual in nontechnical language. In addition to preparing a participant's manual, an instructor's manual was also prepared. Moreover, the one-day course includes 778, (35mm) colored slides that illustrate various slope movements and warning signs, recognition and identification of landslides, and maintenance practices that should be implemented to prevent highway landslides. A large portion of the course and 35mm, colored slides is devoted to illustrating techniques that may be used to repair highway landslides. Legal aspects of the landslides and maintenance of slopes are discussed. In addition to the course materials described above, the course was videotaped at the University of Kentucky's video classroom. These tapes are made available to instructors who may teach the workshop.

Engineers of the Kentucky Transportation Center have taught the course on twelve occasions in various states. These include Kentucky, Washington (Olympia), Alabama (Auburn University, Mobile, Montgomery, Huntsville, Birmingham and Oklahoma City). In addition, engineers of FHWA have taught the course (Texas, Colorado, Oregon, Mississippi) on several occasions. Moreover, a contractor, hired by the National Highway Institute, has taught the course on some 20 occasions and plans call for teaching the course on some 30 more occasions. Geotechnical engineers of Oregon have taught the course throughout their state. Hence, the course is being implemented.

Although exact savings cannot be calculated, or determined, if **just one** major landslide (200,000 - 1 million repair cost) was prevented at a given location by following the principles enumerated in the course, then the benefit-cost ratio would be 3 to 15. In many instances, untrained maintenance forces use methods that do not work and oftentimes are costly. Consequently, knowledge gained by participants from the course can lead to making better choices in repairing landslides, that is, selecting the proper technique to repair a given highway embankment can yield enormous savings. One agency has estimated that as much as 100 million dollars may be spent annually repairing landslides in the United States. Hence, if this course helped reduce this amount by **only** 5 percent, then the benefit-cost ratio would be over 100. Hence, the potential savings are enormous.

Performance Monitoring of a Highway Tiedback Wall (FHWA Demonstration Project 931) -- Study Cost: $45,000

Problem -- In certain situations, standard landslide repair techniques, such as berms or flattened slopes, cannot be used to repair a highway embankment failure because of space, or structural limitations at the base of the moving slope.

Solution, Benefits, and Implementation -- Tiedback walls represent a good economical approach in certain highway landslide situations involving long sloping embankments in

mountainous areas, and in situations involving down-slope geometrical constraints, such as buildings, railroads, etc. This technique involves anchoring a wall to stable soil and rock using steel rods or strands. To demonstrate the use of this technique and monitor performance, a tiedback wall was used on KY 227, in Carroll County, to correct a large embankment failure. This slide situation was complicated by the fact that a railroad and a river were located at the toe of the sliding highway embankment. Conventional solutions could not be used at this site because of the railroad and river located at the base of the slope and because of the deep foundation soils at the site. Relocation of the highway would have involved in excess of 2 million dollars. The tiedback wall cost $550,000 dollars to construct. Six years of observations show that the tiedback wall is performing as designed and has been successful in repairing the major landslide on this route. Additionally, the integrity of the railroad was preserved (certainly a condition that saved monies). Benefit-cost ratio at this site alone was over 30 ($2 million - $550,000/$45,000). Moreover, engineering data collected at this instrumented site have proven valuable in using this technique at other locations in Kentucky where structural constraints and ride-away problems exist.

Highway Pavement Subgrades

Pavement subgrades must be stable during construction and perform throughout the design life of the pavement. In the majority of cases, the subgrade is the weakest member of the pavement structure and is the most important factor influencing pavement performance. Failure to recognize this important fact has led to numerous subgrade failures during construction and premature failures after construction. For example, engineers of the Kentucky Transportation Center have performed numerous investigations of partially completed pavements that failed during construction under construction traffic loadings. From May 1986 to November 1989, the Geotechnical Branch (Division of Materials) of the Kentucky Department of Highways estimated that they were involved in some forty highway projects where subgrade problems arose and required remedial measures. Consequently, weak subgrades during construction delay the contractor because of difficulties encountered by the contractor in moving equipment on the construction site. The contractor oftentimes encounters problems in compacting the pavement base materials and the asphalt layers when weak subgrades are present. In efforts to identify the causes of poor subgrade performances and identify designs and construction procedures, and conditions that may lead to premature pavement failures during and after construction, two research studies were initiated and completed by the Center's Geotechnology Section. These are discussed below.

Bearing Capacity Analysis of Pavements (KYHPR 88-121) -- Research Cost (Estimated $165,000; Actual Cost: $145,000).

Problem -- Poor performance of pavement subgrades during and after construction was identified as a major problem in Kentucky. Numerous pavement and subgrade failures have occurred during and after construction which delayed construction on several occasions and required costly remedial measures. Pavement construction problems consisted of the following:

- Failures of weak soil subgrades under construction traffic loadings,
- Failures of granular bases under construction traffic loadings,
- Failures of partially completed pavements/bases,
- Premature failures of completed pavements shortly after construction, and
- Difficulties in achieving proper compaction of granular base and asphalt pavement materials due to inadequate bearing strength of the soil subgrade.

Solution, Benefits, and Implementation -- In examining the scope and nature of the problem, it became evident that design and construction practices needed to be changed. Moreover, it became evident that pavement design models currently in use needed to be critically examined. However, to execute this examination, a different theoretical approach was needed. Consequently, a new mathematical model that could determine the stability or bearing capacity of different construction stages of the pavement under construction traffic was developed.

Important findings, major benefits, and items that have been implemented, or that were recommended to be implemented, are as follows:

- A new generalized, multilayered pavement design, mathematical model and computer program were developed. This model gives design engineers and research engineers an alternate way and a new means of viewing the behavior of subgrades under construction traffic loadings and pavements under traffic loadings after construction. The mathematical design model is unique when compared to other pavement design models currently in use since the factor of safety against failure of a flexible pavement consisting of multiple layers is completed. Methods currently in use are not capable of calculating factors of safety against failure.
- Statistically, about 86 percent of Kentucky soils consist of clays and fat clays and silts. Hence, most highway pavements in Kentucky have been, and are being, constructed on soils of poor engineering quality. Moreover, from a statistical viewpoint, 40 percent of Kentucky soils have very low bearing strength when exposed to water--that is less than 6 percent. About 20 percent of Kentucky soils have soaked CBR values less than 3.
- To prevent failure of the subgrade under typical construction traffic loadings, the minimum CBR, as determined from the newly developed model, the value of the soil subgrade should be 6 or greater. This finding was verified and confirmed by published field data. Whenever the soaked CBR value of a soil subgrade is below 6, the bearing strength of the soil subgrade should be improved, or modified, using either mechanical or chemical means--this very significant recommendation by the Center's Geotechnology Section has been implemented by the Kentucky Transportation Cabinet.
- It was recommended that the stability of each stage of construction of the pavement be determined and designed to prevent construction failures. Hence, the question of pavement constructability was addressed.
- Analyses of the 1981 Kentucky flexible pavement design curves (which currently are used for designing flexible pavements) using the newly developed, bearing capacity model show that for low bearing soils, and in

certain situations, (CBR values equal to 2 to 4) factors of safety of 1.0 or less are obtained. Hence, based on these analyses, certain pavement design thicknesses may be obtained from the design curves that may lead to unstable pavements when constructed. Identifying design deficiency was considered significant since these situations may be avoided and since hundreds of miles of highways have been constructed on low bearing soils in past years.

- To avoid pavement failures during construction, full-depth asphalt® should not be permitted unless the subgrade(CBR) is about 9, or greater, or the subgrade CBR value is improved to a value of CBR value of 9, or greater, in cases where the untreated subgrade is below 9 percent. This requirement would avoid failure when the first lift of the pavement is constructed.
- A relationship between (weighted) 18, Kip equivalent, single-axle loads (ESAL) and factor of safety obtained form the new bearing capacity model was established by analyzing 237 pavement sections of the AASHO Road Test conducted in 1962. Based on these analyses, flexible pavement should not be designed for factors of safety of less than about 1.3, that is, a"threshold" pavement thickness must exist to avoid a pavement failure. In essence, this shows that it may take only one loaded vehicle to fail a pavement if the pavement is too thin.
- Analyses by the new model also showed that increasing the tire contact stress can cause significant decreases in pavement life. Decreasing tire contact stresses, increases pavement life.
- The design of the thickness of chemically-treated subgrades may be obtained by using the newly developed, bearing capacity model.

Example Case Studies of Benefits -- Determining the savings that would be realized if the recommendations listed above were fully implemented is difficult because it is difficult to assign cost values to such intangibles as delayed construction time, good design versus bad design, and etc. The savings depend on the conditions at any given site. However, to illustrate the savings at a selected site, the pavements "as built" on the Alexandria-Ashland Highway (AA) were analyzed using the new bearing capacity model. An analysis of the sections completed to date (1991) also illustrates the recommendations and principles listed above.

Three cost scenarios were analyzed. The total cost of the pavements including subgrade stabilization was estimated to be approximately 24.5 million dollars. The estimated cost of the pavements without subgrade stabilization methods cost some 3 million dollars. However, an analyses of the pavement sections using the newly developed model showed that the factors of safety of the pavements, without the benefits of subgrade stabilization were near 1.1, or lower; that is, the pavements would fail shortly after construction (this finding was supported by the fact that the pavements of sections 13 and 14, on untreated subgrades, of the AA-Highway failed during construction under gravel trucks). Moreover, analyses by the new model showed that about 4-6 inches (these subgrades were untreated) of pavement overlay would have been needed immediately after construction to sustain equivalent axle loads of 4 million (the value used in the original design). Based on an overlay of 6 inches, the total cost of the pavement was estimated to be about 32.3 million dollars. Hence, by treating the subgrades (a recommendation made by

Center's engineers), the estimated future savings were about 5.2 to 7.9 million dollars. The benefit-cost ratio of these sites alone is approximately 36 to 54.

Lime Stabilization of Pavement Subgrades (sponsored by the Dravo Lime Company) -- Research Cost: $2,500

Problem -- Various mechanical and chemical methods have been used to stabilize soil subgrades. Some of the methods include undercutting and backfilling with stone, mixing cement and soil in place, mixing stone and soil in place, and placing a stone blanket on some type of synthetic. Another chemical treatment method consists of mixing hydrated lime and soil in place to improve the bearing strength of the pavement subgrade. Prior to this study hydrated lime as a subgrade stabilization method had not been used in Kentucky.

Solution, Benefits, and Implementation -- The major benefit obtained from this study was to introduce the use of hydrated lime as a method of stabilizing pavement soil subgrades. Secondly, hydrated-lime stabilization is one of the cheapest methods available for stabilization of pavement soil subgrades (based on cost data compiled by the Kentucky Department of Highways in 1991). This study showed that the soils of Section AA-19 of the Alexandria--Ashland Highway could be improved by using hydrated lime. Laboratory CBR tests on the (untreated) soils from AA-14 were about 2. CBR values of soil specimens treated with hydrated lime 20-50 after treatment. Undrained strengths increased some 8 times after treatment when compared to untreated specimens (Field tests showed that in-situ CBR strengths were 20-80). Based on this study, the recommendation was made that Section-19 of the AA-Highway be stabilized with hydrated lime. Moreover, it was recommended that all subgrade soils of the AA-Highway that had similar characteristics to those of Section 19 be stabilized with hydrated lime--note: the largest manufacturer in the United States is located near Maysville, Kentucky and close to the AA-Highway (however, this technique had not been used in Kentucky). To date, 1991, approximately 30 percent of the sections completed on the AA-Highway were stabilized with hydrated line--about 28.5 miles). Section 19 of the AA-Highway was the first site in Kentucky where subgrade stabilization was used. Since this study several other sites have been stabilized with hydrated lime.

Example Case Study of Benefits -- Stability analysis of the pavement at Section AA-19, using the newly developed bearing capacity model (described previously in the study entitled "Bearing Capacity Analysis of Pavement) and the CBR strength of the untreated subgrade, yielded a factor of safety of about 0.99. Hence, this indicates that the section would have failed shortly after construction. Therefore, this pavement would have required an overlay--the only means available to repair the failed pavement (note: subgrade soils of Section AA-19 were identical to the subgrade soils of Sections 13 and 14 and the pavement designs of the sections are identical--both sections 13 and 14 and failed when the pavements were nearly completed under gravel truck loadings). Based on an analysis using the new bearing capacity model (and to sustain a design EAL of 4 million), the thickness of the overlay required to sustain the EAL design value would be 4 to 6 inches. Estimated cost of this overlay is some $300,000 to $450,000. Estimated cost of the subgrade using hydrated lime was about 100,000 dollars. Hence, the savings

ranges from 200,000 to 350,000 dollars. Consequently, the estimated benefit-cost ratio for this study at this site alone is 80 to 140.

Unstable Pavement Subgrade on Interstate 65 (KYHPR-56 -- "Quick Response Study") -- Research Cost: $4,000 dollars.

Problem -- During construction of a section of I-65 near Elizabethtown, Kentucky, a partially completed pavement failed under wheel loadings of construction traffic. Cracks and deep wheel ruts formed in the dense-graded aggregate (DGA). Large deflections under wheel loadings of portions of the partially completed pavement were observed. The problem was complicated by the fact that part of the pavement was in place.

Solution, Benefits, and Implementation -- A detailed field and laboratory investigation was performed. Geotechnical tests on subgrade samples obtained from the site showed that the subgrade soils had very low bearing strengths. Stability analyses showed that the factors of safety were near 1.0. Treatment of the subgrade was considered too costly since the partially completed pavement would have to be removed. Since the DGA has a high percentage of fines, the treatment consisted of mixing cement with the DGA that was already in place. This improved the bearing strength of the DGA to such level that the pavement could be placed and completed. Major benefits of this study were that a solution was obtained to this particular problem and this problem helped focus attention on the subgrade problems in Kentucky. Savings were realized since the partially completed pavement did not have to be removed.

Highway Embankment Landslides

Computer Program for Analysis of Embankments Reinforced With Tensile Elements (KYHPR-88-122)

Problem -- In designing the slopes of highway embankments where right-of-way or geometric limitations exist, the use of slopes reinforced with tensile elements, such as geogrids or geosynthetics, offers a good economical alternative when compared to other methods, such as concrete or metal retaining walls. In many situations, retaining walls and slopes reinforced with tensile elements can be constructed at approximately one-half of the cost of concrete or metal retaining structures, or slopes that are not reinforced. Slopes reinforced with tensile elements can be constructed at much steeper slopes than slopes that are not reinforced. The use of this technique to repair small landslides is especially economically attractive. Although this technique is economical, the method has seldom been used in Kentucky. However, a good, theoretical slope stability model that considers most design aspects of slopes reinforced with tensile elements is lacking. Methods that are currently available are limited in many aspects. For example, some of the approaches must be solved by hand calculations. Other approaches have been modeled mathematically and programmed for the computer, but are limited in the type of stability analysis that may be performed. Moreover, the problem is complicated by the fact that it is not certain how the forces due to the tensile element should be treated in formulating a mathematical model. Strain compatibility also complicates the problem. Additionally, there is a question of long-term creep of the tensile element.

Solution, Expected Benefits and Implementation -- To facilitate the design of reinforced slopes and walls, two theoretical design models and computer programs are being developed:

- The first mathematical model is based on earth pressure theory and considers only the internal and local stability of the reinforced wall or slope. The algorithms have been programmed for the IBM PC. The computer program has been demonstrated and transferred to the Geotechnical Branch (Division of Materials) of the Kentucky Department of Highways. The program eliminates the need for hand calculations and/or "looking-up" values on charts. However, this program does not consider global bearing capacity or external stability.

- The second mathematical model is a generalized approach, and when completed, will be capable of designing and analyzing the external, global, and internal stability of slopes and walls reinforced with tensile elements. The general theoretical model equations, which consider the tensile element forces, have been derived. However, the question of strain compatibility and a mathematical means of handling the direction of the tensile forces is still being investigated. Major portions of the generalized model have been programmed for the mainframe (IBM 3091).

When the generalized model and computer program are fully developed and implemented, these programs will facilitate the use of reinforced walls and slopes in Kentucky.

Expected Cost Benefits -- A sampling of the cost savings that may be realized by using a reinforced wall may be obtained by examining the costs that would be involved in repairing a small landslide. Assume, for example, that a small landslide has occurred and the failure dimensions are: 200 feet in length and 20 feet in height. Assume that a retaining wall must be used to repair the landslide. The following approximate costs would be involved for the following retaining structures (unit cost of retaining walls compiled by the California Department of Highways):

- Reinforced Concrete: $\frac{\$800}{\text{ft. of slide}} \times 200 \text{ ft.} = \$160{,}000$

- Metal Bin: $\frac{\$625}{\text{ft. of slide}} \times 200 \text{ ft.} = \$125{,}000$

- Reinforced wall: $\frac{\$350}{\text{ft. of slide}} \times 200 \text{ ft.} = \$70{,}000$

Hence, the savings at one site is $55,000. Consequently, if this reinforced slope was used to repair only 10 small landslides (similar to this hypothetical case), the savings would be over 500,000 dollars. Hence, the benefit-cost ration for this study is (500,000/140,000) 4. However, the savings would be much more if the method was used widely in the state.

Modification of Highway Soil Subgrades (KYHPR-90-132) -- Research Cost: $302,601.

Problem -- Many pavements in Kentucky, as well as other states, have been and are continuing to be constructed on soil subgrades of poor or marginal engineering properties. Most pavements in Kentucky are being constructed on clay or silts of low bearing strengths. These types of soils cause difficulties during compaction of pavement materials. Numerous subgrade and pavement failures occur during and after construction.

Solution, Benefits, and Implementation -- In an effort to improve the bearing strengths of subgrades in Kentucky and to improve pavement performance, chemical admixture stabilization has been used on several highway projects in the last few years. Chemical stabilization involves mixing some type of admixture, such as hydrated lime or cement with the soil. The major intent of this study is to determine the long-term performances and benefits of mechanical and chemical stabilization. However, chemical stabilization (prior to this study) had only been used sparingly in the past three decades in Kentucky.

Although this study is still in progress, several major benefits have already been obtained which are having a major impact on the manner in which pavements are being designed and constructed in Kentucky. These are as follows:

- The use of chemical stabilization, such as soil-cement or soil-hydrated lime, has been demonstrated as an excellent means of improving the bearing strengths of weak subgrades.

- Data being accumulated indicate that chemical stabilization is prolonging pavement life. For example on US 27 (Campbell County), portions of the subgrade had not been treated and required overlays in just three years after construction. However, on stretches of this highway where cement stabilization was used, no pavement overlays have been required and the pavement on the treated subgrade is in very good condition. Note: In these treated areas, the subgrade had failed during construction under loadings of construction prior to treatment.

- To determine the long-term benefits of chemical stabilization, a portion of this study has been devoted to locating and performing detailed investigations of old sites where chemical stabilization was used. Only three sites have been located; these sites have been investigated. For example, between Campton and Jackson, Kentucky (22 miles), the pavement was placed on a six-inch thick, soil-cement base. This pavement is some 30 years old. The long-term performance of this stretch of pavement has been very good; the overlay history averages about 12 to 14 years (this roadway has coal trucks and other truck traffic).

- As a result of this study, chemical and mechanical stabilization is being used at numerous sites when CBR values of the subgrade soils are less than 6.

- Findings of this study have lead to the development and adoption of chemical stabilization specifications by the Kentucky Department of Highways.

- A procedure for remolding laboratory specimens of chemically-treated laboratory specimens and for determining the optimum percentage of chemical admixture has been implemented. The Geotechnical Branch of the Division of Materials (Kentucky Department of Highways) is using the procedure on a daily basis. A computer program was developed and written by the Center's Geotechnology engineers to expedite this procedure. Moreover, special compaction equipment was "invented" by the geotechnical engineers to "speedup" the compaction of laboratory specimens.

- The use of waste by-products, such as kiln dust and AFBC (Atmospheric Fluidized Bed Combustion) waste, are being studied as a means of stabilizing pavement subgrades.

- The use of in-situ materials, such as the New Albany Shale, Sandstones, etc., are being studied as a means of providing a stabilized base for pavements.

Example Case Studies of Benefits -- To illustrate the benefits of this study, two case studies may be examined. The first (actual) case involves the reconstruction of KY 11 near Natural Bridge State Park near Beattyville, Kentucky. Originally, the pavement design of this 6-mile stretch of highway specified 8.5 inches of asphalt pavement on 17 inches of Dense Graded Aggregate (DGA). However, the design was modified to include chemical stabilization of the subgrade. Various types of chemical admixtures were used. These included: two hydrated-lime sections, two cement section, one kiln-dust section, and two AFBC-waste sections. One small stretch of the subgrade (1,000 feet in length was left untreated). Approximate cost of the original design (8.5 inches of asphalt resting on 17 inches of DGA) was estimated to be $3,197,026. The estimated cost of the as built pavement using subgrade chemical stabilization was $2,464,253. Hence, approximately $730,000 was saved at this site. The estimated benefit-cost ratio at this site alone was (730,000/302,601) 2.4

The second case is a hypothetical case and involves the 22-mile stretch of highway between Campton and Jackson, Kentucky. For this class of road, a normal pavement design would have involved placing 8.5 inches of asphalt surface on 16 inches of DGA. The actual constructed pavement consisted of 8 inches of asphalt concrete, 6 inches of DGA, and six inches of soil-cement. For a 24-foot roadway, the estimated cost of the assumed, typical design is $7,359,898. Based on the design that was actually built using soil-cement, the estimated cost is $6,015,539. Hence, in this hypothetical case, the savings would have been about $1,344,358. Based on the long-term history of this pavement, which has been very good over the past 30 years, the actual design with a soil-cement has performed as well, or better, than a typical design normally used for a roadway of this class. The benefit-cost ratio of this roadway is estimated to be (1,344,358/302,602) 4.4.

Geotechnical Engineering Data (KYHPR-88-126) -- Research cost: $145,000

Problem -- Over the past 40 years, the Kentucky Transportation Center has accumulated some 5,000 engineering soil data records. Since 1983 at the urging of the Center, the Geotechnical Branch (Division of Materials) of the Kentucky Department of Highways has accumulated some 15,000 records of soil engineering data. These data represent soil specimens collected throughout Kentucky. However, the soil data were not in a form that is useable to the Kentucky Department of Highways, or to others. Moreover, locations of the old records are not available. Additionally, large sums of monies are expended by the Department in obtaining soils and rock data.

Solution, Benefits, and Implementation -- Major benefits (and expected benefits) and accomplishments of this study are as follows:

- The two soil data sets have been merged into one soil data bank. The data bank contains some 20,000 records.
- The necessary computer software has been developed so that data stored in the soil computer bank may be easily retrieved.
- Procedures have been developed, in cooperation with the Kentucky Department of Highways, for locating the bore holes so that the exact locations of new soil engineering data may be known.
- The process of entering new soil data generated by the Department has been "streamlined" so that the data are entered for immediate use (reports) by the Department and KTC's soil data bank. Hence, double computer data entry is avoided.
- Work is in progress to develop computer software for storing and retrieval of rock engineering data.

When this study is completed, the following major benefits are anticipated:

- A soil data bank containing more than 20,000 engineering soil data bank will be available to the Department and others. A computer disk containing soil data for each highway district of the Department will be available. Each soil disk will contain a retrieval program using a "windows" concept for easy use.
- As the data grow each year from data generated by the Geotechnical Branch, the accumulated data will be invaluable and provide preliminary engineering soil data for highway and railroad corridor studies, (I-66 for example; Amtrak; bridge foundations, and for economical development of Kentucky). The data will be valuable in studying such problems as highway landslides. These data will be valuable to other governmental agencies, such as the Department of Natural Resources, in studies involving reclamation (mining sites, landfills) and water resources, in studies involving waterways (for example, bank erosion, etc.). Such formation can reduce the cost significantly of site-specific studies.

Moreover, when preliminary soil and rock data are available, planning of engineering projects becomes more efficient.

- A better overview of the types of soils located in Kentucky can be obtained. Such information is useful when attempting to determine the causes of highway problems. For example, data in the soil computer bank were very useful in determining the likely scope of the subgrade problem in Kentucky. For instance, from a statistical viewpoint, about 20 percent of the soils in Kentucky have bearing ratios (CBR) of less than 3--a condition that alerts engineers that subgrade problems are widely prevalent in Kentucky.

Coolside Waste Management (Two contracts: Sponsored by the United States Department of Energy and the Ohio Coal Development Board -- Research cost: $1.5 million dollars (KTC's Geotechnology Section's portion: $260,000; Principal Investigator; Dr. Tom Robl of the UK Center for Applied Energy Research Center--lead UK agency; Co-Principles: Tom Hopkins of UK Kentucky Transportation Center; Dr. Robertson, UK Department of Chemistry)

Problem -- The new Environmental Clean Air Act specifies that, by 1995, coal-fired power plants must reduce the level of SO_2 (Sulfur dioxide) in gaseous emissions. For power generating plants that are built with scrubbers, this new law may not affect such plants. However, old power plants that were built without the benefit of scrubber technology face a dilemma. Coal obtained from several regions of such states as Ohio, Kentucky (Western Coal Fields; about 25 percent of coal from the Eastern Coal Fields), Illinois, and West Virginia, burns dirty; that is, these old power plants will have difficulties complying with the Clean-Air ACT. One option for the old power plants is to import coal from the Western portion of the United States (for example, Wyoming) since this coal burns cleaner than much of the Eastern Coal. This action could significantly affect the economical well-being situation of Eastern-Coal producing states. Another option has been developed by the Consolidation Coal Company.

This technology has been labeled "Coolside". Coolside is a retrofit dry flue gas desulfurization (FGD) technology for removal of SO_2 in coal-fired power plants. In the process, hydrated lime is pneumatically injected into the power plant duct work on the "cool side" of the air preheater. However, solid waste is produced. This waste consists of coal fly ash; partially sulfated, hydrated and re-carbonated lime; and significant quantities of sodium compounds. The process is relatively inexpensive when compared to the cost of scrubbers. A successful demonstration of the Coolside technology was conducted at Ohio Edison's Edgewater Power Plant. The Coolside wastes are relatively unknown as engineering materials.

Major Benefits -- When this four-year study is completed, the major benefits will be:

- to insure that adequate environmental information is developed on the physical and chemical Coolside wastes for the design and construction of safe and stable landfills.

- to possibly develop alternative methods of disposing of the Coolside waste, other than landfill disposal. For example, research will be performed to

determine if the material may be used to stabilize highway pavement subgrades--this depends, of course, on the chemical nature of the material.

- ~~to aid in establishing the use of the Coolside technology.~~

Rockfall Mitigation Measures (new study; proposal pending) Research Cost: $300,000

Problem -- Highways in Kentucky contain numerous rock slopes and rockfalls from these slopes represent potential hazards to the traveling public. Large sums of monies are spent each year removing fallen rock from roadways and drainage ditches. Some bodily injuries and fatalities have been reported in the past years. However, the scope of this problem and the monies required each year are unknown. There is a need to develop a proactive policy in an effort to prevent, minimize, or mitigate the rock fall problem.

Solution and benefits -- This research is expected to provide the following benefits:

- Common types of rockfalls that occur in Kentucky will be identified and classified.
- The major causes of rockfalls will be identified.
- A historical record of rockfall will be collected and examined so that the scope of this problem in Kentucky may be defined.
- Litigation cases, bodily injuries, and fatalities directly related to rockfalls will be identified.
- A framework for implementing a statewide rockfall hazardous rating system will be devised.
- Certain mitigation measures will be examined.
- Guidelines will be developed for dealing effectively with rockfalls for any given locality.

MATERIALS AND TESTING SECTION

Study Title

1. Pavement and Shoulder Performance
2. Native Aggregates for Skid Resistance
3. Evaluation of Sandstone Bases and Surfaces
4. Evaluation of Procedures for Testing Aggregates
5. Construction Estimating System
6. Performance Survey of Silicone-Sealed Concrete Pavement Joints
7. Fly Ash in Highway Construction
8. Shrinkage Compensating Concrete, KY 1974
9. Analyses of Bridge Deck Cores, US 23-119 over C & O Railroad
10. Freeze-Thaw Testing of Concrete Aggregates
11. Utilization of Fossil-Fuel By-Product Materials for Highway Construction
12. Cost Effective Maintenance Contracting
13. Evaluating the Design and Effectiveness of Subsurface Drainage Layers
14. Pavement Distresses at Intersections
15. Shrinkage Compensating Concrete, I-75
16. Evaluation of Experimental Bridge Deck Using Pyrament Cement Concrete in a Full-Depth Slab
17. Analyses of Concrete Bridge Deck Cores, US 23-119 over Shelby Creek
18. SHRP Maintenance Effectiveness Study of Rigid Pavements (SPS-4) I-65 Bullitt County.
19. Preliminary Engineering, Monitoring of Construction, and Performance Evaluation: Use of Residue from Atmospheric Fluidized Bed Combustion for Highway Road Base
20. Portland Cement Concrete Pavement Joint Seals
21. Evaluation of Low Strength Concrete for Trench Backfill
22. Evaluation of Experimental Bridge Deck Containing Class "AA" Concrete and A High Range Water Reducer
23. Comparative Freeze-Thaw Testing of Aggregates for Concrete
24. Recycling in Kentucky

Pavement and Shoulder Performance (KYHPR-82-89)

Description: The basic definition of a highway shoulder requires a sufficiently stable material to support occasional or periodic loads in all types of weather without catastrophic failure. The shoulder has become an integral component of the pavement system. Safety aspects, however, generally have received more attention than structural design aspects. Performance observations support the contention that shoulders enhance pavement performance by providing lateral support to the pavement structure, providing positive drainage of surface water from the pavement, and enhance overall safety. Performance was used as the basis for the development of empirical criteria that permit the use of existing pavement thickness design procedures for the structural design of shoulders. In light of the basic definition of a highway shoulder and performance observations, it was recommended the shoulder material type be consistent with the mainline pavement material type.

Implementation: Information gained during the course of this study provided valuable insight relative to the long-term performance of various mainline pavement and shoulder materials. The advantages of highway shoulders from the standpoint of safety and improved pavement performance were demonstrated. Minimum thickness requirements for both flexible and rigid shoulders were addressed and a rational methodology for the design of shoulders was developed. Data collected and information gained during the study were used extensively in the development of interim guidelines for design of pavements.

Cost Effectiveness: Properly designed paved shoulders provide smoother and safer traffic operations, reduced maintenance requirements on both the shoulder and mainline pavements, and improved long-term performance of the mainline pavement. One must consider these factors to determine a benefit to cost ratio. The cost of this study was $143,100. If one fatal accident caused by pavement edge drop-off is prevented by providing properly designed paved shoulders consistent with the mainline pavement material type, the benefits of the study would far exceed the cost.

Native Aggregates for Skid Resistance (KYHPR-84-98)

Description: Maintaining adequate skid resistance of pavement surfaces is a concern of highway and transportation officials. Unfortunately, Kentucky aggregates, as a whole, do not exhibit desirable long-term skid resistant qualities. Hence, high quality aggregates have been imported from outside the state, introducing excessive transportation costs to the cost of placing a durable skid resistant surface. Skid resistant surfaces are evaluated by the locked-wheel trailer method (ASTM E 274). This method of testing has been used successfully to evaluate skid resistance of in-service pavements. However, this approach requires construction of pavement sections for each variable, related to skid resistance, being evaluated. As a result, experimentation with native aggregates for skid resistant

mixtures has been limited because of the availability of projects and the costs and liabilities associated with field experimentation. These factors renewed interest in the development of laboratory testing of aggregates and bituminous mixtures for evaluation of skid resistance performance.

Implementation: The KTRP Abrasion Test was demonstrated as a method to determine aggregate abrasiveness. The KTRP percent loss results used in conjunction with the area between initial and final gradation curves indicates relative abrasiveness of a group of different aggregate types. Combining results from the KTRP Abrasion Test with those of the Los Angeles abrasion test and insoluble residue test permits an assessment of performance in skid resistant mixes. A correlation between KTRP percent loss and initial skid number was not determinable. Researchers opined the KTRP percent loss would correlate better with the terminal skid number. Researchers recommended continued long-term monitoring of selected sections of the asphaltic concrete pavements containing the aggregates studied during the course of the study.

Cost Effectiveness: Although not quantified during the study, expected benefits associated with using native aggregates, in lieu of using more costly imported aggregates, for skid resistant mixtures would be much greater than the study's cost of $219,500.

Evaluation of Sandstone Bases and Surfaces (KYHPR-84-99)

Description: Sandstone is abundantly available in eastern Kentucky. There remains considerable interest in the use of locally abundant materials as an alternative source of aggregate to traditional limestone that must be imported into the area. Kentucky Route 80 and other Resource Recovery Roads in the region were constructed using sandstone in the asphaltic concrete base, shoulders, medians, and rock roadbed. Testing during the Fall of 1981 indicated significant variations in sandstone subgrade strength. A 1982 investigation revealed the presence of artesian water in the median, mainline pavement, and shoulders of KY 80. Transportation officials were concerned whether those conditions were common to all sandstone areas of Kentucky or represented only an isolated occurrence. The impetus for this study was to develop historical performance data for bituminous sandstone mixtures to understand the long-term performance as to anticipate and program for future maintenance costs or savings as a result of either the superiority or inferiority of the material and its applications.

Implementation: Historical performance data were developed relative to pavement condition ratings, pavement rutting characteristics, and structural condition using Road Rater deflection measurements. Additionally, laboratory tests were performed to characterize engineering properties of the sandstone aggregate and bituminous sandstone base mixtures. Pavement constructed using bituminous sandstone base mixtures in the pavement structure were less susceptible to the development of excessive permanent deformation, such as rutting, shoving and pushing. However, those pavements exhibited several forms of surface cracking earlier than pavements constructed using bituminous limestone base mixtures. Although there no longer are any quarries producing sandstone coarse aggregates for bituminous mixtures in Kentucky's eastern sandstone region, it was recommended that specifications for using crushed sandstone aggregates in bituminous

base, binder, and surface courses remain in the Kentucky Department of Highways' Standard Specifications for Road and Bridge Construction.

Cost Effectiveness: The principal benefit anticipated to be derived from the study was increased usage of abundantly available sandstone aggregate in eastern Kentucky. Initially, it was believed increased usage of sandstone would result in reductions in overall construction costs. However, the cost per ton to manufacture and place bituminous sandstone mixtures more than offset any cost advantage gained over importing limestone aggregates into the region. In March of 1988, the only source of sandstone aggregate available for use in bituminous mixes was phased out. The reasons cited were unreasonably high costs to manufacture quality sandstone aggregate. Factors contributing to the high production and handling costs were equipment wear, due to the abrasiveness of the sandstone, and segregation, degradation, and durability of the materials. The cost of this study, $261,500, was justified because valuable experience was gained relative to design and construction of bituminous sandstone pavements.

Evaluation of Procedures for Testing Aggregates (KYHPR-84-100)

Description: Procedures for evaluating aggregate soundness normally involve a chemical analysis such as the sodium sulfate or magnesium sulfate soundness tests. Problems were encountered relative to the reliability and repeatability of those analyses. The primary objective for this study was to determine a suitable replacement or modification of Kentucky's existing sodium sulfate soundness test that would more accurately reflect in-service performance of aggregates used in portland cement concrete pavements and bridges. Several laboratory tests were conducted by the Kentucky Transportation Center and the Kentucky Department of Highways' Division of Materials. Results of those tests were correlated with the results of the sodium sulfate soundness tests.

Implementation: Results of correlations performed on the test data indicated no observable correlations between the various test methods evaluated and the sodium sulfate soundness test for *all* aggregate types. It was recommended the Division of Materials continue stringent testing of aggregates used in portland cement concrete pavements and bridges for soundness and durability by existing Kentucky Methods and ASTM C-666.

Cost Effectiveness: The benefits of a rigorous testing program can not be diminished. The obvious benefit of this research study, which cost $271,900, is use of only the highest quality aggregate materials for constructing Kentucky's transportation facilities. It would not be impossible to quantify the benefits of a demanding testing program. Aggregate resources are matched to the applications for which they are most suited. Failure to maintain adequate testing program undoubtedly will result in premature failures and shortened life expectancies of Kentucky's transportation facilities. Premature failures resulting from the use of marginal aggregates could potentially cost consumers millions of dollars.

Construction Estimating System (KYHPR-90-131)

Description: This study was much the result of FHWA's policy on the accuracy of construction cost estimates prepared by state highway agencies. That policy states an engineers estimate should be a projection of the low bid and be within +/- 10% of the low bid for at least 50% of the projects awarded. Kentucky is one of the states that traditionally has a great number of low bids outside 10% of the engineer's estimate. Cost estimates prepared by the estimating staff of the Kentucky Department of Highways reflects what the Department considers to be a fair and equitable price for the fiftieth percentile, or average, contractor to complete the contemplated work in an acceptable manner.

Implementation: The estimating staff of the Kentucky Department of Highways utilizes an actual cost estimation method. An estimator using the actual cost approach analyzes the actual cost of the work, assigns costs to various components based on current market conditions, and develops new unit cost estimates for each project. The estimator prepares a detailed quantity take-off of material, labor, equipment and carefully considers overhead and reasonable profit. Because of the uncertainty of the amount of risk a contractor is willing to accept, there is always a chance the estimator may overstate or understate the percentage of profit. Because of these factors, an estimate of construction costs can not always be close to the low bid as desired by FHWA. The FHWA should only expect an engineer's cost estimate be relatively close to the low bid during level times (supply equals demand). The engineer's estimate will always be higher than the low bid when the supply of contractors exceeds the demand for contractors. The engineer's estimate will be lower than the low bid when prices are escalating and demand for contractors is greater than the supply.

Cost Effectiveness: Benefits stemming from this $48,000, two-year study are reasonably accurate engineer's estimates that serve as critical elements in budgetary planning and the obligation process in Federal-Aid. The engineer's estimate is the baseline reference in the construction contract letting process. When bids for a project are received, only through a carefully and accurately prepared engineer's estimate can items such as bid rigging, complementary bids, and unbalanced bids be detected. The engineer's estimate also controls construction costs by establishing a practical and reasonable price the Department is willing to pay for the work.

Performance Survey of Silicone-Sealed Concrete Pavement Joints (KYHPR-85-107, Subtask No. 2)

Description: Research personnel were requested to visually survey silicone sealant projects and make subjective and qualitative observations on the performance of the sealant. Construction techniques were considered to be the major factor in the success or failure of the silicone-sealed concrete pavement joints. The report indicated irregular saw cuts and failure to clean vertical faces of the sawed joint prior to installation led to many failures. Several pavement joints exhibited deteriorated concrete and those seals were deemed failures. In instances were proper installation and maintenance techniques were evident, silicone seals performed admirably.

Implementation: As a result of information gained during the course of this study, the Department of Highways revised Special Provision No. 63, Silicone Rubber Sealant for Concrete Pavement. It is now required that joints be blastcleaned in two passes in an effort to improve the effectiveness of cleaning and thereby improve the bond of the sealer to the concrete.

Cost Effectiveness: The cost effectiveness of this $1,200 study was demonstrated by adoption of recommended revisions to Special Provision No. 63. Proper construction, installation and maintenance techniques can extend the life expectancy of a concrete pavement, and effectiveness of silicone sealant. The expected service life of silicone sealant for portland cement concrete pavement joints is about 15 years.

Fly Ash in Highway Construction, FHWA Demonstration Project No. 59

Description: The primary objective of this study was to demonstrate the use of a pozzolanic stabilized aggregate base as an alternate base construction wherein the added structural qualities of the stabilized base material would reduce the thickness requirements for higher quality asphaltic concrete materials. Two secondary objectives of the study were generation of a data base for continued development of procedures for design and evaluation of pozzolanic base materials, and conservation of materials associated with construction of a highway pavement. The 1.7-mile experimental route was located on Man O' War Boulevard between Tates Creek Pike (KY 1974) and Nicholasville Road (US 27).

Implementation: Special Provision 70 was developed to provide information on materials and construction requirements. Design and construction procedures for utilization of a fly ash-lime kiln dust-limestone aggregate were demonstrated. No major construction problems were encountered. The development of additional information relative to design procedures would be of significant benefit.

Cost Effectiveness: The overall pavement performance was enhanced by the use of the pozzolanic base material. However, because of the lack of unit prices, researchers could not perform an economic analysis for this $20,000 study. It is perceived to be a worthy project. It is quite probable that pavement life may be extended at reduced costs (construction and maintenance) by the use of treated bases.

Shrinkage Compensating Concrete, Federal-Aid Research Task No. 16

Description: In an effort to reduce the amount of shrinkage cracking on concrete bridge decks, the Kentucky Department of Highways experimented with the use of shrinkage compensating concrete. Shrinkage compensating concrete is made with an expansive cement (Type K) in which the expansion, if restrained, induces compressive stresses that approximately offset tensile stresses induced by drying shrinkage. Concrete produced with an expansive cement will expand initially and later shrink. Complete shrinkage is obtained if expansion slightly exceeds shrinkage. The objectives of this study were to evaluate the construction and performance of shrinkage compensating bridge deck

concrete and compare the performance to conventional bridge deck concrete. The experimental bridge was located on KY 1974 (Tates Creek Road) over West Hickman Creek in Lexington, Kentucky.

Implementation: The final report summarized performance monitoring activities and evaluation in conjunction with the experimental use of shrinkage compensating bridge deck concrete (Class S). Two bridges of similar design but constructed using normal Class AA concrete were monitored for comparison purposes. Due to the absence of significant shrinkage cracking on the comparison bridge decks and the presence of minor shrinkage cracking on the Class S bridge deck, no conclusions were apparent. It was recommended that further study be undertaken to quantify the reduction of shrinkage cracking resulting from the use of shrinkage compensating concrete in bridge decks.

Cost Effectiveness: Expenditures for this study amounted to $10,000. The cost effectiveness of the experimental use of Class S concrete can not be quantified as yet. If a reduction of shrinkage cracking occurs through the use of Class S concrete, then the benefit will be longer lasting, more durable bridge decks.

Analyses of US 23-119 Deck Cores, Pike County, Federal-Aid Research Task No. 45

Description: Cores in the deck of spans 11 and 12 of the US 23-119 bridge over the C&O Railroad and Levisa Fork of the Big Sandy River in Pike County was placed during a rain. There was considerable concern that the durability of the concrete may have been adversely affected due to the excess moisture. Four cores were obtained from the deck. Petrographic analyses were used to determine the water to cement ratio near the surface and at a depth of approximately three inches from the surface. Characteristics of the air void system were determined by linear traverse method.

Implementation: A report prepared by a specialty testing laboratory confirmed the Department's suspicions. The top surface of each core was soft and friable. The top portion of each core had soft to moderately soft, beige to medium light gray paste. In contrast, the remaining portion of each core had dense, hard gray paste, indicating the water to cement ratio increased with proximity to the top surface. Air contents of the cores ranged from 4.4% to 8.5%. Entrapped air was estimated to be approximately 25% of the total air content.

Cost Effectiveness: Expenditures for this study were $4,000. The cost of the testing services was necessary to accurately assess the condition of the bridge deck concrete.

Freeze-Thaw Testing of Concrete Aggregates (State Highway Quick Response Study No. 11)

Description: In a cooperative arrangement, the Kentucky Transportation Center provided freeze-thaw testing services for the Division of Materials. American Society of Testing Materials (ASTM) Test Method C-666 Method B was performed on concrete prisms

prepared by personnel of the Division of Materials and transported to the laboratory at the Kentucky Transportation Center. Numerous specimens were tested during the three year study.

Implementation: Section 805.04.01 (B) of the Kentucky Department of Highways' Standard Specifications for Road and Bridge Construction contains provisions for testing aggregates for durability and expansion in concrete specimens.

Cost Effectiveness: Expenditures for this study amounted to $70,000. The cost effectiveness of the testing activity is guaranteed by assuring quality aggregates through extensive testing.

Utilization of Fossil-Fuel By-Product Materials for Highway Construction (KYHPR-87-117)

Description: Construction materials are becoming more difficult and expensive to produce. Costs of mining and processing crushed stone for aggregates has increased over the years. The same is true for the production of gravels, cements used in concrete, and bituminous materials used for paving materials. By-product materials have been used in highway applications on a limited basis in Kentucky. Preliminary evaluations have been favorable. This study is involved with identifying potential by-product materials for highway applications and to develop specifications and procedures for the design and construction of pavement structures utilizing those materials. Once the materials are identified, extensive laboratory evaluations are conducted to determine the engineering characteristics of the materials. After the engineering properties have been determined, a field trial is conducted wherein the by-product material is incorporated into the pavement structure. By-product materials have been utilized as an embankment fill, subgrade modifier, subbase material, stabilized base material, and as a skid resistant aggregate. Additionally, one by-product material was evaluated for use as an anti-stripping material in asphaltic concrete mixtures.

Implementation: As a result of information gained during the course of this study, specifications and procedures for the successful design and construction of pavement structures utilizing fossil-fuel by-product materials will be recommended.

Cost Effectiveness: The anticipated cost of this study will be approximately $475,000. Near the completion of the study, an economic analysis will be conducted to determine the benefits and costs of using by-product materials compared to using conventional materials. Development of procedures for utilizing by-products from fossil-fuel burning processes serves three functions: use of fossil fuels is enhanced since use of by-products from burning and pollution-control processes provides for the management of those by-product materials that otherwise would have required disposal; the economy of Kentucky benefits by the continued utilization of its ace in the hole; and, utilization of by-product materials results in conservation of other valuable resources.

Cost Effective Maintenance Contracting (KYHPR-91-137)

Description: Highway maintenance is extremely important to the function of the highway system and also to meet expectations of the motoring public. Highway maintenance should be performed as efficiently and economically as possible and in a uniform manner to provide adequate levels of service so that motorist may use may use the highway in comfort and safety. The Kentucky Department of Highways has utilized contractors to perform some maintenance activities in the past. That practice may or may not be cost effective. Because of ever increasing maintenance responsibilities and constrained resources within the Department of Highways, it is essential that all maintenance activities be cost effective whether performed by state forces or through contracts. Maintenance activities are being documented and potential cost savings quantified relative to the use of state forces versus using contracts to perform maintenance activities.

Implementation: Upon completion of the study, recommendations will be made relative to those maintenance activities that should be performed with the Division of Maintenance resources and those which should be contracted. Maintenance activities proposed to be contracted will be evaluated relative to the suitability of the activity to contracting and whether the Division is in a favorable position to manage the contracts.

Cost Effectiveness: The anticipated cost of this study will be approximately $100,200. Effective highway maintenance practices conserve capital investments in the highway system. Efficient use of Division of Maintenance personnel, equipment, and materials supplemented by practical use of maintenance contracts will yield the most cost effective means of maintaining Kentucky's highway network.

Evaluating the Design and Effectiveness of Subsurface Drainage Layers (KYHPR-92-142)

Description: Water is always present in soil and granular pavement materials in some form, but the forms that concern the pavement designer are free water, capillary water, bound moisture and water vapor. Capillary water, bound moisture, and water vapor move through soils and granular materials by various mechanisms and they are not greatly affected by gravity. Only free water conditions can be significantly altered by gravity drainage systems. The Kentucky Department of Highways is currently reviewing proposed guidelines for design of highway pavements. The guidelines propose the use of open graded, free draining, aggregate bases for controlling infiltrated surface water. However, the interim guidelines do not specifically address the design of aggregate drainage blankets. Former pavement design methods often have resulted in base courses that have not drained well, thereby resulting in some premature failures of the pavement structure. Properly designed and constructed drainage layers can be used for effective control of surface water infiltration. The purpose of this study is to develop recommendations relating to the specification, design, and construction of pavement drainage layers as an integral part of the pavement structure. The research should specifically quantify the effects and benefits of pavement drainage layers relative to long-term pavement performance.

Implementation: Upon completion of the study, recommendations for specifications relative to structural and material design and construction of open graded drainage layers, including optimum placement of collection systems, will be developed using information gained during the course of the study and presented to the State Highway Engineer for consideration of implementation.

Cost Effectiveness: The anticipated cost of this four year study will be approximately $329,700. The efficient use of pavement subdrainage, reportedly, can extend the fatigue life of flexible and rigid pavements by as much as 33 and 50 percent, respectively, demonstrating the cost effectiveness of the study. It is anticipated the benefit to cost ratio will be substantial for this study.

Pavement Distresses at Intersections (KYHPR-92-144)

Description: Pavements at intersections and approaches are subjected to a greater variety of loading conditions than for tangent sections and exhibit several types of distress in these areas. The more prominent forms of distress are manifested as deep ruts, pushing and shoving, severe washboarding, and in some cases alligator cracking. Vehicles slow, stop, idle, and start in these areas. Structural designs for pavements and paving materials are developed for pavements having moving loads without due consideration given to the high repetitive shear at locations where vehicles stop and start. Significant amounts of monies allocated for maintenance operations are exhausted each year to rehabilitate intersections that have become safety hazards as a result of simple traffic action.

Implementation: Recommendations relative to design procedures, specifications, materials acceptance criteria, and construction techniques which may be used to extend pavement service life and decrease maintenance needs at intersections and approaches will be developed using information gained during the course of this study and presented to the State Highway Engineer for consideration for implementation.

Cost Effectiveness: The anticipated cost of this three year study will be approximately $162,560. Implementation of new design procedures and rehabilitation strategies which will extend the fatigue life of pavements at intersections may save several thousand dollars in the first year alone.

Shrinkage Compensating Concrete, I-75, Federal-Aid Research Task No. 44

Description: In an effort to quantify benefits associated with using shrinkage compensating concrete to reduce the amount of shrinkage cracking on concrete bridge decks, the Kentucky Department of Highways will again experiment with the use of Class S concrete. Shrinkage compensating concrete is made with an expansive cement (Type K) in which the expansion, if restrained, induces compressive stresses that approximately offset tensile stresses induced by drying shrinkage. Concrete produced with an expansive cement will expand initially and later shrink. Complete shrinkage is obtained if expansion slightly exceeds shrinkage. The objectives of this study are to

evaluate the construction and performance of three bridge decks constructed using shrinkage compensating concrete and compare the performance to conventional bridge deck concrete. The experimental and control bridge decks are located on I-75 in northern Kentucky.

Implementation: Information gained from this study will be used to develop specifications for the use of shrinkage compensating bridge deck concrete (Class S) to offset cracking due to shrinkage drying.

Cost Effectiveness: This study has a $21,600 budget. The cost effectiveness of the experimental use of Class S concrete will be realized if a reduction of shrinkage cracking occurs. The expected benefit will be longer lasting, more durable bridge decks.

Evaluation of Experimental Bridge Deck using Pyrament Cement Concrete in a Full-Depth Slab, Federal-Aid Research Task No. 52

Description: Recent advances in the concrete construction industry appear promising for improving standard bridge deck construction practices. The Kentucky Department of Highways has proposed the use of Pyrament cement concrete in a full-depth slab, in lieu of using conventional Class AA concrete. The objective of the study is to evaluate the construction and performance of the Pyrament cement concrete bridge deck slab and to compare data obtained from the study to the historical performance of conventional bridge deck concrete. Specifically, characteristics of the concrete mix design, required compressive strength, modulus of elasticity, chloride permeability, freeze-thaw durability, workability, deck slab placement conditions, concrete placement rate, and curing conditions will be compared to historical information relative to Class AA concrete which is normally used in bridge deck applications.

Implementation: Information obtained from this study would be implemented by new design standards and special provisions that will provide guidance for the use of Pyrament cement concrete in bridge deck applications.

Cost Effectiveness: This three year study was budgeted for $29,000. The cost effectiveness of the experimental use of Pyrament cement concrete in a full-depth bridge deck slab will be realized if the materials exhibit superior performance relative to increased durability and lower permeability compared to the normal Class AA concrete.

Analyses of Concrete Bridge Deck Cores, US 23-119 Over Shelby Creek, Pike County, Federal-Aid Research Task No. 58

Description: Rain occurred during placement of a section of bridge deck on project FSP-098-0023-023.239-202B, US 23-119 bridge over Shelby Creek. The contractor did minimal finishing and covered the concrete as quickly as possible but the durability of the concrete was questioned because the water to cement ratio near the surface was affected.

Cores were taken for analysis. Petrographic analyses were requested to determine the water to cement ratio near the surface and at a depth of approximately three inches from the surface. Characteristics of the air void system also were requested.

Implementation: A report will be prepared by a specialty testing laboratory upon completion of the analyses. Corrective action by the bridge contractor may be required based on the results of the analyses.

Cost Effectiveness: Expenditures for this study are $5,500. The testing services are necessary to accurately assess the condition of the bridge deck concrete.

Strategic Highway Research Program (SHRP) Maintenance Effectiveness Study of Rigid Pavements (SPS-4), Federal-Aid Research Task No. 59

Description: The goal of the study is to develop specific performance relations as to the benefit of good concrete pavement joint sealing as opposed to routine maintenance and ineffective joint sealing. The study goal will be achieved by conducting evaluations in accordance with guidance provided by SHRP. The intent of the study is to obtain data for development of the desired performance relations. This project is located on I-65 in Bullitt County.

Implementation: Pavement maintenance effectiveness is defined as the degree to which a treatment prevents or retards the pavement deterioration process (which means improving pavement performance). Comparisons of the performance of pavements with varying maintenance techniques or strategies will provide insight very valuable to maintenance engineers in selecting the techniques to be used and the points at which the techniques should be applied.

Cost Effectiveness: The general benefit expected from this $23,000 study is improving pavement lifetime serviceability by implementing maintenance treatments offering the maximum extension of pavement service life.

Preliminary Engineering, Monitoring of Construction, and Performance Evaluation: Use of Residue from Atmospheric Fluidized Bed Combustion of Coal for Highway Road Base, Kentucky Highway Investigative Task No. 4

Description: An experimental roadway was constructed on a construction access road at the Tennessee Valley Authority's Shawnee Power Plant near Paducah wherein residue from the Atmospheric Fluidized Bed Combustion (AFBC) process was combined with aggregate and fly ash and used as the base material. Although the section was very short, preliminary research indicated considerable promise for the use of this by-product material as a pavement component. Because it was desirable to construct and evaluate a larger test section, this study was proposed specifically to identify and define the properties and long-term performance of base sections utilizing residue from the AFBC process.

Implementation: A final report will be prepared near the end of the study period that will contain conclusions and recommendations concerning the use of AFBC by-product materials for highway base and subbase materials. Information obtained from this research task may be implemented by new design procedures and special provisions that would provide guidance for the future use of AFBC by-product materials for highway base and subbase materials.

Cost Effectiveness: The cost of this six-year study is $33,500. Development of procedures for utilizing by-products from AFBC coal burning processes serves three functions: use of coal is enhanced since use of by-products from burning and pollution-control processes provides for the management of those by-product materials that otherwise would have required disposal; the economy of Kentucky benefits by the continued utilization of coal; and, utilization of by-product materials results in conservation of other valuable resources.

Portland Cement Concrete Pavement Joint Seals, Kentucky Highway Investigative Task No. 18

Description: To further quantify the effectiveness of silicone joint sealant to prevent the intrusion of surface water and incompressible material into concrete pavement joints, the Kentucky Department proposed the use and evaluation of four distinct joint sealant types. Dow Corning's DOW 888 and DOW 888 SL (Self Leveling) joints sealants are to be evaluated, and for direct performance comparison, preformed neoprene and hot-poured rubber joint seals also will be evaluated. The different sealant types are demonstrated in a new concrete pavement located on US 127, Cove Hill Road.

Implementation: Information obtained from this research task may be implemented by new design standards and special provisions that would provide guidance for the future use of joint sealants for portland cement concrete pavements.

Cost Effectiveness: The cost of this three-year study is $30,000. Proper construction, installation and maintenance techniques can extend the life expectancy of a concrete pavement. The use of self-leveling silicone sealants may provide benefits relative to the ease and effectiveness of joint sealing operations.

Evaluation of Low Strength Concrete (Flowable Fill) for Trench Backfill, Kentucky Highway Investigative Task No. 21

Description: A low strength concrete (flowable fill) was chosen for trench backfill on project SSP-056-1932-001-003 on Breckinridge Lane in Jefferson County. The Kentucky Transportation Center was requested to evaluate the material because only limited information on the cost effectiveness and engineering performance were available.

Implementation: Information obtained from this research task may be implemented by new design standards and special provisions that would provide guidance for the future use flowable fill for trench backfill material.

Cost Effectiveness: The cost of this three-year study is $55,800. Construction procedures will be documented including site and trench conditions, personnel required, placement techniques, workability of the material, quantities placed, and production rates will be documented to compare flowable fill backfill to conventional backfill. The cost effectiveness of using flowable fill as a backfill material will be determined as the study progresses.

Evaluation of Experimental Bridge Deck containing Class "AA" Concrete and a High Range Water Reducer, Kentucky Highway Investigative Task No. 22

Description: Recent advances in the concrete construction industry appear promising for improving standard bridge deck construction practices. The Kentucky Department of Highways has proposed the use of a high range water reducer in normal Class "AA" concrete in a full-depth bridge deck slab. The objective of the study is to evaluate the construction and performance of Class "AA concrete containing a high range water reducing admixture in a full-depth bridge deck slab and to compare the data obtained to similar data obtained by evaluating the construction and performance of a bridge deck constructed using normal Class "AA" concrete. Specifically, characteristics of the concrete mix design, required compressive strength, modulus of elasticity, chloride permeability, freeze-thaw durability, workability, deck slab placement conditions, concrete placement rate, and curing conditions will be compared to historical information relative to Class "AA" concrete which is normally used in bridge deck applications.

Implementation: Information obtained from this study would be implemented by new design standards and special provisions that will provide guidance for the use of high range water reducing admixtures in Class "AA" concrete in bridge deck applications.

Cost Effectiveness: This three year study was budgeted for $34,980. The cost effectiveness of the experimental use of high range water reducing admixtures in Class "AA" concrete for a bridge deck slab will be realized if the materials exhibit superior performance relative to increased durability and lower permeability compared to the normal Class AA concrete.

Comparative Freeze-Thaw Testing of Aggregates for Concrete (State Highway Quick Response Study No. 27)

Description: The Kentucky Department of Highways' Division of Materials purchased a new freeze-thaw machine. Because the Kentucky Transportation Center provided freeze-thaw testing services for the Division of Materials, it was desirable to conduct comparative testing to ensure tests results were completely reproduceable. American Society of Testing Materials (ASTM) Test Method C-666 Method B is being performed on concrete prisms prepared by personnel of the Division of Materials and transported to the laboratory at the Kentucky Transportation Center. Companion prisms are being evaluated by the Division of Materials. Approximately 175 prisms will have been evaluated by the end of the study period.

Implementation: Section 805.04.01 (B) of the Kentucky Department of Highways' Standard Specifications for Road and Bridge Construction contains provisions for testing aggregates for durability and expansion in concrete specimens.

Cost Effectiveness: Expenditures for this study will amount to $26,000. The cost effectiveness of the testing activity is guaranteed by assuring quality aggregates for concrete structures through extensive testing.

Recycling in Kentucky -- An Emphasis on Transportation, (KYP 92-56)

Description: In an era when government agencies and the general public are demanding increased efforts to recycle materials, the Kentucky Department of Highways' has a desire to promote utilization of recycled materials in the transportation area.

Implementation: The study will document findings of an extensive literature review relative to current trends for recycling highway materials and using other recycled materials in highway construction, reconstruction, rehabilitation, etc., in local, national, and international transportation markets. Current and past efforts of the department to recycle materials and use recycled materials will be documented. Preliminary recommendations will be made which will provide guidance for recycling highway materials and using other recycled materials for highway construction materials.

Cost Effectiveness: This six-month study will have approximately $5,725 in expenditures. The cost effectiveness of the study will be determined at the end of the study period.

STRUCTURES SECTION

Study Title

1. Special Problems of Metal Bridges
2. Evaluation of Bridge Performance for Construction and Maintenance
3. Evaluation of Calcium Nitrite in Bridge Deck Concrete
4. Bridge Expansion Dams and Deck Drain Systems
5. Evaluation of Structural Paint Systems
6. Effectiveness of Direct Tension Indicators
7. Computerized Bridge Management
8. Segmental Bridge, AA Highway
9. The Removal of Lead-Based Paint from Steel Bridges
10. Stress Evaluation of Welded Steel Bridges on Coal-Haul Routes
11. Evaluation of Environmentally Safe Coatings for Structural Steel

Study No. KYHPR 84-95, Special Problems of Metal Bridges (Initiated July 1, 1984; Completed October 2, 1988)

Reports Issued FY 1986 to Present:

UKTRP-86-2	"Use of Nondestructive Testing to Prevent Failures of In-Service Metal Bridges," T. Hopwood and R.C. Dean, April 1986.
UKTRP-87-21	"Acoustic Emission Monitoring of In-Service Bridges." T. Hopwood and D.W. Prine, August 1987.
UKTRP-87-27	"Reliability Assessment of High-Risk Steel Bridges by Nondestructive Test Methods," T. Hopwood, V.K. Oka, and R.C. Deen, October 1987.

Description: This study was concerned with reliability assurance and nondestructive inspection of steel bridges. Steel bridges are prone to service problems, including corrosion and fatigue cracking, that jeopardized structural integrity and possibly cause catastrophic failure. The study investigated factors that would better ensure the safety of the motoring public. Those factors included reliability requirements for nondestructive inspections, identification and development of cost-effective nondestructive inspection techniques, and the development of analytical methods for determining the susceptibility of steel bridges to fatigue cracking. During the study, acoustic emission monitoring was identified as a potentially viable nondestructive test method for detecting growing cracks in steel bridges. An acoustic emission monitoring instrument was tested successfully and test procedures were formulated from a series of bridge tests. A PC-based fatigue analysis program was developed to rapidly analyze strain gage data and determine cracking susceptibility of fatigue-prone bridge details.

Implementation: The acoustic emission monitoring device was used to monitor several locations on bridges having existing or suspected flaws. The test results provide the Transportation Cabinet with an indication of the severity of those flaws. As a result of this study the Federal Highway Administration conducted several research projects to further apply the acoustic emission technology used in this study to bridge applications. Related work by the Federal Highway Administration is on-going. The fatigue analysis program developed during this study was employed to determine the fatigue susceptibility of critical joints on the I-75 bridge at Clays Ferry. The Transportation Cabinet utilized that information in deciding whether to replace the structure as part of road widening project. The fatigue analysis program is being applied to analyze the effects of truck traffic on steel bridges of coal-haul routes in a follow-on study (KYHPR 91-139).

Cost Effectiveness : A comprehensive nondestructive inspection of a large steel bridge may cost over $ 200,000. Study results indicate that acoustic emission monitoring may

provide a 50 percent cost savings over conventional nondestructive testing. Test procedures derived during this study could provide additional savings by identifying structural members and connections that did not warrant sophisticated nondestructive inspections. That could save an extra 20 percent over indiscriminate application of nondestructive testing. In addition, the fatigue analysis could identify bridges where traffic loadings did not impose fatigue problems, eliminating the need for nondestructive inspections. The total cost of this study was $333,200. This study would pay for itself within 4 major nondestructive bridge inspections. While the Transportation Cabinet has not performed many such inspections, in the near future, the Federal Highway Administration will probably mandate that highway departments provide assurance of the structural integrity of bridges. The methods developed under this study will allow the Transportation Cabinet to meet that requirement in a cost-effective manner.

Study No. KYHPR 82-88, Evaluation of Bridge Performance for Construction and Maintenance (Initiated July 1, 1981; Completed June 30, 1988)

Reports Issued FY 1986 to Present:

UKTRP-87-1 "Bridge Decks and Overlays," J.H. Havens, T. Hopwood, and E.E. Courtney, January 1987.

UKTRP-87-5 "Summary of Experimental Bridge Features," T. Hopwood, J.H. Havens, and E.E. Courtney, March 1987.

Description: Experimental bridge features were evaluated during this study including: epoxy coated reinforcing steel, deck overlays, segmental box-girder bridges, masonry coatings, galvanized and weathering steel unpainted bridges, aluminum guardrail nuts, stay-in-place forms, and integral abutment bridges. Site inspections were conducted on bridges employing those experimental features. In the case of epoxy coated reinforcing steel and segmental bridges, extensive field monitoring was provided during the construction of experimental bridges. Follow-up site inspections were performed on those bridges up to 15 years after the experimental features had been applied. Corrosion susceptibility tests were performed on bridge decks containing overlays and epoxy coated reinforcing steel. Failure analyses were performed on masonry coatings and aluminum guardrail nuts that failed in service. A national survey was prepared on other state highway agencies's use of stay-in-place forms.

Implementation: The Transportation Cabinet continued to employ experimental features that were found to provide good service and have reasonable construction costs. Those features included: epoxy coated reinforcing steel, rigid bridge deck overlays, and integral abutment bridges. Causes of premature service failures to aluminum guardrail nuts and masonry coatings were identified and remedial actions were taken by the Transportation Cabinet. Experimental features that were not performing well or whose performance did not justify the initial construction cost were: membrane deck overlays, galvanized and weathering steel unpainted bridges and segmental box girder bridges. The Transportation Cabinet has curtailed using those features.

Cost Effectiveness: Epoxy coated reinforcing steel has been used on all bridges constructed during the last 14 years. Over 1,000 bridges have been provided with rigid deck overlays. At the time of this study, 48 integral abutment bridges had been constructed. Employment of those features constitutes a substantial investment by the Transportation Cabinet. This study provided verification of the successful performance of those features. That promoted their on-going use by the Department providing accumulated savings in lower initial construction costs or lower maintenance expenditures. The identification of features that did not perform well prevented their continued use and resulting disadvantage to the Transportation Cabinet in terms of poor performance compared to other alternatives. Identifying the causes of problems related to guardrail aluminum bolts and masonry coatings resulted in effective remedial measures being applied that has prevented the re-occurrence of those problems. The total cost of this study was $231,628. The cost savings to the Transportation Cabinet accrued by the using successful experimental features identified during this study is conservatively estimated as being $20,000,000. The cost savings by eliminating experimental features that were not cost effective also provides a significant savings. One segmental box beam bridge cost approximately $ 250,000 more than a conventional steel bridge of equivalent deck area. Galvanized steel cost over twice as much as painting. The life of galvanizing is not expected to exceed twice the life of painting, and a savings over $10,000 per bridge may be realized by continued employment of paint.

Study Nos. FRT 17 Calcium Nitrite Gose Rd over Clark's Run, Boyle County (Initiated September 25, 1985; Completed June 30, 1990) **and FRT 19, Calcium Nitrite KY 152, Washington County** (Initiated September 25, 1985; Completed June 30, 1990)

Reports Issued FY 1986 to Present:

KTC-88-2 "Calcium Nitrite as a Corrosion Inhibitor in Reinforced Concrete Bridge Decks," T. Hopwood, D.Q. Hunsucker, and E.E. Courtney, September, 1988.

Description: This study evaluated the use of calcium nitrite as a corrosion inhibitor for reinforcing steel in bridge decks. Two experimental bridges employing calcium nitrite were monitored during construction and later in service. The material caused some difficulties in finishing the bridge decks; however, those problems were not prohibitive and the material apparently is functioning satisfactorily.

Implementation: The Transportation Cabinet is planning an additional experimental bridge employing calcium nitrite.

Cost Effectiveness: The study indicated that the cost of calcium nitrite was equivalent to epoxy coated reinforcing steel. It is anticipated that the service lives of both products are similar. The study cost was $9,900. The Transportation Cabinet benefits from having a construction alternate to epoxy coated reinforcing steel. This promotes competitive bidding and prevents price increases when only one product is specified. That situation has occurred in several states where one supplier of epoxy coated reinforcing steel has a monopoly.

Study No. KYHPR-87-107, Long-Term Monitoring of Experimental Features: Subtask 8, Bridge Expansion Dams and Deck Drain Systems, (Initiated July 1, 1984; Completed July 24, 1990)
Subtask 9, Evaluation of Structural Paint Systems, (Initiated July 1, 1984: Completed April 8, 1990)
Subtask 10, Effectiveness of Direct Tension Indicators, (Initiated July 1, 1984: Completed July 24, 1990)

Reports Issued FY 1986 to Present:

KTC-89-2	"Modular Expansion Joints and Decks Drains," T. Hopwood and E.E. Courtney, March 1988.
KTC-89-55	"Load Indicating Washers," T. Hopwood and E.E. Courtney, October 1989.
KTC-90-2	"Field Inspections of High-Performance Bridge Paints," T. Hopwood, E.E. Courtney, and J.H. Havens, March 1990.

Description: The purpose of this study was to monitor experimental bridge features that required a period of service exposure to evaluate their performance. Modular expansion joints and drains impact concrete bridge deck durability, ride quality, and motorist safety. Service inspections revealed that modular expansion joints did not provide watertightness and some of the joints experienced mechanical failures. Some deck drains showed a tendency to clog. Field inspections of load indicating washers (direct tension indicators) revealed they worked properly (with a few minor service problems). Subsequent field inspections disclosed some corrosion problems with unpainted load indicating washers. Torque tests conducted several years after the load indicating washers were installed revealed that they were functioning properly. Inspections of maintenance painting operations involving high-performance paints showed those paints were not difficult to apply. Field inspections of steel bridges coated with high-performance paints revealed they were performing well.

Implementation: Based upon the findings of this study, the Transportation Cabinet decided to discontinue the use of modular expansion joints in favor of finger dams. The Transportation Cabinet elected to review the performance of deck drains on a per case basis and rework unsatisfactory drains using guidelines provided in the study. Based upon study recommendations and other factors, the Transportation Cabinet replaced the existing oil-alkyd paint systems with the high-performance paints. The study recommendation that those new paints be placed only over blast-cleaned surfaces was adopted. Additionally, the Transportation Cabinet initiated a laboratory and field trial program to qualify new paint systems (KYHPR 92-140).

Cost Effectiveness: The study revealed that modular expansion joints could experience problems necessitating repair or replacement. Typically, it costs about $60,000 to replace a modular expansion joint with a conventional finger dams. One such installation would more than pay for that study ($22,000). The study indicated that high-performance paint

systems are more durable than oil-alkyd paints. To date, none of the new paint systems have failed and therefore their service life is uncertain. Assuming a 50 percent improvement in paint durability of the new systems, the new paints would provide an additional 5 to 10 years extended service life over the 10 to 20 years presently provided by the oil-alkyd paints. The life-cycle cost of a large bridge paint job having an initial cost of $150,000 would decrease from about $7,500 per year to $5,000 per year with the savings for 10 years paying for the cost of that study ($25,000). Load indicating washers provide bridge inspectors with a practical effective means of ensuring that bolts are properly tightened. Conventional testing of bolt tightness with a torque wrench is inexact and difficult to perform safely at elevated bridge locations without extensive rigging or use of a snooper.

Study No. KYHPR-88-120, Computerized Bridge Management (Initiated July 1, 1987; Completed June 30, 1990)

Reports Issued FY 1986 to Present:

KTC-89-59 "Development of a Priority Ranking System for Bridge Rehabilitation and Replacement," T. Hopwood and V.G. Oka, December 1989.

Description: Bridge management systems are similar to pavement management systems. They allow bridge management personnel to make informed decisions regarding maintenance, rehabilitation, and replacement of bridges. This study investigated a proposed algorithm developed by the Transportation Cabinet to rank bridges for rehabilitation or replacement. The algorithms were applied to a bridge inventory data base and the resulting rankings were analyzed to determine if the algorithms were providing the Transportation Cabinet with a rational prioritization. Alternative algorithms were analyzed and a revised method was approved. The new method incorporated regional traffic data allowing optimal use of the limited necessary data that were available.

Implementation: KTC personnel prepared a PC-based program that would review bridge inventory files, extract the necessary information, and perform rankings of bridges for rehabilitation or replacement. That program was provided to the Transportation Cabinet and has been used to rank bridges selected for rehabilitation and replacement as part of the Transportation Cabinet's 6-year plan.

Cost Effectiveness: In the near future, the Federal Highway Administration plans to mandate that all state highway agencies adopt bridge management systems. The ranking system provided for the Transportation Cabinet is a key component of any bridge management system and will simplify the process of developing a more encompassing system. The development cost of the ranking system (the study cost) was only $ 51,590. Typically, ranking systems are one of six main components of a bridge management system. Development costs for complete bridge management systems has exceeded $1,000,000 in several states. Considering that a typical ranking system may cost from $150,000 to $300,000 to develop, this study constitutes a savings of at least 3 to 1.

CONTINUING STUDIES

Study No. KHIT No. 9, Segmental Bridge, AA Highway (Initiated July 1, 1988)

Reports Issued FY 1986 to Present:

KTC-90-9 "Instrumentation of the Twelvemile Segmental Bridge," (Draft) T. Hopwood and D.Q. Hunsucker, April 1990.

Description: The Twelvemile Creek bridge was intended to be a unique segmental I-beam structure employing post-tensioned splices using steel wire tendons to connect precast I beams. The Transportation Cabinet had questions about the performance of that bridge, in particular post-tensioning losses due to creep. A comprehensive study was initiated to instrument girders and the bridge deck. Additionally, concrete maturity meters were to be employed to measure strength increases during concrete curing. Field tests and instrumentation of key portions of the structure were in progress when a construction accident lead to the discontinuance of the use of prestressed I beams on that bridge. The limited data acquired prior to termination of the study were reported and are being reviewed by the Transportation Cabinet.

Study No. KYP-56, Unforseen Investigations (On-going)

Reports Issued FY 1986 to Present:

KTC-90-15 "Proposed Revisions to Kentucky Revised Statutes," (Draft) T. Hopwood, August 1990.

Description: This study constituted a review of two chapters of the Kentucky Revised Statues: Chapter 176 Department of Highways and Chapter 178 County Roads--Grade Crossing Elimination. A number of sections in the chapters of the Kentucky Revised Statutes contain archaic or ambiguous wording or do not reflect the current operational practices of the Transportation Cabinet. Those chapters are being review to detect archaic and ambiguous wording and determine sections where revisions are necessary to conform the chapters to current Transportation Cabinet operations. Proposed revisions to those statutes will be provided to the State Legislature along with justifications for updating the current revised statutes.

Study No. KYHPR 91-138, The Removal of Lead-Based Paint from Steel Bridges (Initiated July 1, 1990)

Reports Issued FY 1986 to Present: None

Description: New environmental regulations mandate strict controls on the generation, handling, and disposal of hazardous wastes. Lead, once widely used as a paint constituent, is now regulated as a hazardous (toxic) material. Maintenance painting operations necessitate the removal of old paint by blast cleaning with abrasives. Most

old bridge paints contain lead and the waste material is considered hazardous and cannot be discarded on the ground. This study involves determining new procedures to effectively contain waste paint debris generated during maintenance painting operations. Blast cleaning causes the paint debris to become airborne. That constitutes a hazard for painters and the public. The study will also investigate health regulations that must be observed to ensure safety. Additionally, the study will investigate steps the Transportation Cabinet must take to properly transport and dispose of the spent paint debris.

Study No. KYHPR 91-139, Stress Evaluation of Welded Steel Bridges on Coal-Haul Routes (Initiated July 1, 1990)

Reports Issued FY 1986 to Present: None

Description: Kentucky Statutes allow coal trucks to haul weights in excess of the normal legal maximum weight limits on roads designated as extended-weight coal haul routes. In some cases, those loads may create fatigue cracking problems in welded steel bridges. This study will examine that possibility by placing strain gages near fatigue-prone structural details and remotely measuring the resulting strains imparted by normal coal-truck traffic. Those measurements will be analyzed and compared with the safe loading capacities for those details. This study will provide the Transportation Cabinet with reliable information regarding the impact of coal-truck loads on the structural integrity of those bridges.

Study No. KYHPR 92-140, Evaluation of Environmentally Safe Coatings for Structural Steel (Initiated July 1, 1991)

Reports issued FY 1986 to Present: None

Description: In the past, the Transportation Cabinet has employed specifications for paints based on formulations (recipes). New environmental regulations affecting paint constituents are forcing most state highway agencies to abandon that practice and change to performance-based qualified products lists. That practice allows paint manufacturers to employ research to the best advantage and furnish highway departments with proprietary paints that protect well and are durable. In this study, a paint testing program will be established to evaluate paint systems which perform well and also meet current and pending environmental regulations.

TRAFFIC AND SAFETY SECTION

Study Title

1. Accident Rates Data in Kentucky
2. Safety of Geometric Features on Highways
3. Evaluation of Pavement Marking Materials
4. Lane Closures
5. Safety Belt and Child Safety Seat Usage Rates
6. Evaluation of Traffic alcohol Programs
7. Traffic Control at Rural, High-Speed Intersections
8. Guardrail End Treatments
9. Unmanned Radar Installations
10. Accidents within Work Zones
11. Allocation of Highway Costs and Revenues
12. Accidents on Shoulders
13. Truck Monitoring
14. Tort Liability
15. Highway Geometrics Related to Large Trucks
16. Work Zone Traffic Control
17. Pavement Evaluations
18. Pavement Design
19. Alexload Determinations

Accident Rates Data in Kentucky

Reports: Traffic Accident Rates in Kentucky (1984), UKTRP-86-1
Analysis of Accident Data in Kentucky (1982-1986), UKTRP-87-23
Analysis of Accident Data in Kentucky (1983-1987), UKTRP-88-7
Analysis of Accident Data in Kentucky (1984-1988), KTC-89-47
Analysis of Traffic Accident Data in Kentucky (1985-1989),KTC-90-19

Objectives: To analyze statewide accident statistics to determine the average and critical rates for highway sections in Kentucky. In addition, accident data were used to determine highway safety problem areas warranting increased funding and/or enforcement.

Benefits and Implementation: Improved safety and reduced accidents are direct benefits of the process of developing accident rates and identifying problem areas for use by the responsible agencies. The results of the research are implemented by the Transportation Cabinet's Division of Traffic as part of the activities undertaken by the Accident Surveillance Section. Additional results related to problem identification are implemented by the Kentucky State Police's Highway Safety Branch. The statistics are used to develop the problem identification portion of Kentucky's Annual Highway Safety Plan which is prepared each year to comply with Section 402, Title 23 of the United States Code.

Cost Effectiveness: The cost of the study to develop accident rates and identify problem areas is approximately $20,000 annually. The benefits derived from reduced accidents can be estimated based on the value of $1,500,000 per fatality, $11,000 per injury, and $2,000 per property damage accident. Therefore, a minor impact on the total number of accidents related to alcohol, occupant protection, speed, pedestrians, bicycles, motorcycles, school buses, and trucks should provide a very positive cost-to-benefit-cost ratio.

SAFETY OF GEOMETRIC FEATURES ON HIGHWAYS

Reports: Delineation of Horizontal Curves, UKTRP-86-4
Use of Post Delineators on Interstates, UKTRP-86-10
Treatment of Narrow Medians on Four-Lane Rural Roadways, UKTRP-86-11
Evaluation of Flexible Delineator Posts, KTC 90-24

Objectives: These studies involved evaluation of various safety or geometric features of highways. Included were an evaluation of various traffic control devices to improve safety by delineating horizontal curves; an attempt to identify the benefits and offer recommendations for use of post delineators for curves on interstates; and an evaluation of the safety benefits of narrow medians on rural interstates.

Benefits and Implementation: Results from each of these studies were offered in terms of recommendations for application of the specific safety or geometric feature. Specific traffic control plans were recommended as improvement for horizontal curve delineation. Benefits of using post delineators on interstate curves were documented and recommendations were made for application based on analyses of Kentucky data and review of accomplishments in other states. Accident analyses were performed to determine the safety benefits or disadvantages of narrow medians on four-lane roadways. Recommendations concerning the future use of flexible delineator posts were made.

Cost Effectiveness: The cost for most traffic control improvements is generally minor when compared to the benefits expected from reduced accidents. Therefore, recommendations were based on the assumption that improvements were only beneficial when there were documented accidents which could be reduced by selected improvements.

EVALUATION OF PAVEMENT MARKING MATERIALS

Reports:
Evaluation of Durable Crosswalk and Stopbar Marking Materials, UKTRP-86-13
Evaluation of Durable Lane Delineation Materials, UKTRP-86-15
Evaluation of Snowplowable Marker Installations, UKTRP-86-16
Evaluation and Application of Roadway Delineation Techniques, UKTRP-87-10
Evaluation of Construction Zone Pavement Marking Materials, UKTRP-87-11
Evaluation of Epoxy Thermoplastic Pavement Marking Materials, UKTRP-87-20
Evaluation of Extruded Thermoplastics as Lane Delineation, UKTRP-88-10
Long-Term Evaluation of Durable Lane Delineation Materials, KTC-89-57
Summary of Results of 1989 Field and Laboratory Evaluations of Pavement Marking Materials, KTC-90-13

Objectives: The general objectives were to evaluate various pavement marking materials through field tests and in some cases through accident analysis.

Benefits and Implementation: Warrants for use and recommendations for implementation were the results of the studies. The results from these studies were used in developing a statewide pavement marking policy. Comparative tests of competing marking materials has resulted in approved lists from which contractors may select materials based on price. Recommendations of various materials resulted from performance evaluations under field test conditions.

Cost Effectiveness: As with other traffic control improvements, the cost for improvements is relatively minor compared to the cost of accidents.

LANE CLOSURES

Report: I-75 Lane Closures, UKTRP-86-19

Objectives: To evaluate the effectiveness of various traffic control devices for improving the flow of traffic through lane closures on I-75 in Kentucky.

Benefits and Implementation: Various schemes and arrangements of traffic control devices were recommended for application on other sections of interstates under construction. Warrants for application based on traffic volume were recommended and implemented.

Cost Effectiveness: A formal cost effectiveness evaluation was not performed. However, the minimal cost of traffic control devices compared to the potential benefits associated with reduced accident costs suggests a high payoff for selected locations.

SAFETY BELT AND CHILD SAFETY SEAT USAGE RATES

Reports: 1986 Safety Belt and Child Safety Seat Usage Rates in Kentucky, UKTRP-86-20
1988 Safety Belt and Child Safety Seat Usage Rates in Kentucky, UKTRP-88-6
1989 Usage Rates and Effectiveness of Safety Belt and Child Safety Seats in Kentucky, KTC 89-42
Safety Belt Usage in Lexington and Opinion of a Mandatory Safety Belt Law, KTC-89-43
1990 Safety Belt Usage Survey and Evaluation of Effectiveness in Kentucky, KTC-90-18
Safety Belt Usage Before and After Enactment of a Mandatory Usage Ordinance (Lexington-Fayette County, Kentucky), KTC-90-20

Objectives: To determine safety belt usage rates statewide in Kentucky, to determine the effectiveness of safety belt usage, and to determine the effectiveness of mandatory safety belt laws.

Benefits and Implementation: Documentation of safety belt usage rates and effectiveness have been used in public information campaigns in various locations across the state as a method of increasing usage. The Lexington study was used in the process of enacting the mandatory law. The data generated by these studies will be used in the attempt to enact a statewide safety belt law.

Cost Effectiveness: The annual safety belt survey has been completed at a cost of about $20,000. The results have been used to assist in various campaigns to increase safety belt usage. The injury reduction which can be obtained through increased safety belt usage would result in a very high benefit-to-cost ratio.

EVALUATION OF TRAFFIC ALCOHOL PROGRAMS

Reports: Impact Evaluation of the Lexington-Fayette County Traffic Alcohol Program (1982-1986), UKTRP-86-28
Impact Evaluation of Louisville-Shively-Jefferson County Traffic Alcohol Programs, UKTRP-88-3

Objectives: To evaluate programs of increased police enforcement to impact alcohol-related accidents.

Benefits and Implementation: Positive results from this research were used to justify continuation of increased enforcement as part of traffic alcohol programs.

Cost Effectiveness: For the Lexington-Fayette County study, a benefit-cost ratio of 1.15 was determined when only direct income from fines and court costs were included; and increased to 3.71 when the benefits from reduced accident costs were included. For the Louisville-Jefferson County study, the benefit-cost ratio was 0.73 when only direct income was included and 2.81 when the reduction in accidents was included.

TRAFFIC CONTROL AT RURAL, HIGH-SPEED INTERSECTIONS

Report: Traffic Control and Accidents at Rural, High-Speed Intersections, UKTRP-87-6

Objectives: To determine the types of accidents that occurred at these types of intersections and recommend traffic control measures that could decrease accident potential at such locations.

Benefits and Implementation: Specific recommendations were made at 65 intersections investigated as part of the study and these recommendations could be used as a guide for implementing changes at other similar intersections.

Cost Effectiveness: The cost of the various traffic control measures recommended would be minor compared to the reduction in the costs of accidents.

GUARDRAILS AND END TREATMENTS

Reports: Performance Evaluation of Breakaway-Cable-Terminal End Treatments, UKTRP-87-14
Warrants and Guidelines for Installation of Guardrails, UKTRP-89-39
Performance of Guardrail End Treatments in Traffic Accidents, KTC-91-1

Objectives: To evaluate the performance of guardrail installed with breakaway-cable-

terminal end treatments. To develop warrants and guidelines for installation of guardrail based on accident statistics and other variables representative of Kentucky conditions.

Benefits and Implementation: Results from this evaluation provided field performance data to justify continued application of some guardrail end treatments and information concerning where specific types of end treatments should not be used. A procedure was developed and implemented to prioritize the selection of locations in need of guardrail installations.

Cost Effectiveness: The procedure developed to determine where guardrail should be installed will enable funds to be utilized with maximum benefits obtained. Development of effective guardrail end treatments will reduce accident severity.

UNMANNED RADAR INSTALLATION

Report: Evaluation of Unmanned Radar Installations, UKTRP-87-34

Objective: To determine the effects of installing unmanned radar on a section of I-75 in northern Kentucky.

Benefits and Implementation: Results were used to demonstrate that unmanned radar had potential for selected applications on sections of highway where speed had been shown to be a significant contributing factor to accidents.

Cost Effectiveness: Cost and benefit data were not available.

ACCIDENTS WITHIN WORK ZONES

Reports: Review of Work Zone Literature, UKTRP-88-5
Analysis of Accidents in Construction and Maintenance Work Zones, UKTRP-88-13

Objective: To review the literature and to document work zone traffic control devices and applications and to analyze work zone applications in terms of their relative impact on safety.

Benefits and Implementation: Devices and applications determined to be successful by others were analyzed and considered for application in Kentucky. Several traffic control schemes were evaluated and recommended to the Transportation Cabinet.

Cost Effectiveness: A cost effectiveness analysis was not performed. However, it was determined that the accident rates for most work zones did not exceed average or critical rates.

ALLOCATION OF HIGHWAY COSTS AND REVENUES

Reports: Allocation of Highway Costs and Revenues, UKTRP-88-8
Allocation of Highway Costs and Revenues, KTC-90-1

Objectives: To determine the equitable distribution of costs and revenues for highway users.

Benefits and Implementation: Results from the analysis of highway costs and revenues have been used by highway administrators as a source of information in assigning cost responsibilities.

Cost Effectiveness: A cost effectiveness analysis was not performed.

ACCIDENTS ON SHOULDERS

Report: Accidents Involving Vehicles Parked on Shoulders of Limited Access Highways, KTC-89-36

Objectives: To determine the magnitude of the problem associated with vehicles parked on shoulders.

Benefits and Implementation: Results were offered as countermeasures to reduce the problem associated with vehicles stopped on shoulders.

Cost Effectiveness: A analysis of costs and benefits was not performed.

TRUCK MONITORING

Report: Integrated Truck Monitoring System, KTC-89-60

Objectives: To develop functional specifications for an integrated truck monitoring system in Kentucky. In addition, other efforts were directed toward an evaluation of the extent of usage of the KYU numbering system for large trucks; and an evaluation was conducted to determine the extent of bypassing/avoiding truck weigh/enforcement stations.

Benefits and Implementation: Several recommendations were made to improve the usefulness and efficiency of the truck monitoring system in Kentucky. Revisions were made in audit reporting which should improve the effectiveness of field audits. A plan had been developed and funding was being sought for enhancements to the data processing capability of the motor vehicle licensing unit. Arrangements were made for the exchange of data between the planning and enforcement units.

Cost Effectiveness: The efficiency of fuel tax collection was noted as part of the research. It was estimated that heavy vehicle surtax and the normal use tax were being collected

at the rate of approximately 71 or 72 percent. Even though new revenue sources were not recommended as part of the study, the focus was on documentation of existing revenue and the efficiency with which the various taxes were being collected. Subsequent actions related to collection procedures and record keeping are areas of potential improvement; along with procedures to reduce tax evasion.

TORT LIABILITY

Report: Tort Liability Related to Highways in Kentucky, KTC-90-8

Objectives: To review and analyze claims made against the KyTC through the Board of Claims and to make recommendations relating to the establishment of an effective risk management program.

Benefits and Implementation: A list of 22 recommendations was presented to the KyTC. It was noted that nine of the recommendations were currently being performed with another ten of the recommendations considered for implementation.

Cost Effectiveness: While a specific cost-effectiveness analysis was not performed, the implementation of the recommendations will reduce the liability risk of the KyTC and provide safer highways.

HIGHWAY GEOMETRICS RELATED TO LARGE TRUCKS

Reports: Development of Turning Templates for Various Design Vehicles, KTC-91-2
Evaluation of Highway Geometrics Related to Large Trucks, KTC-91-4

Objectives: To develop the data necessary to produce the turning templates that would represent the minimum turning paths for critical design vehicles, to determine the extent of highway safety and geometric problems associated with larger trucks using Kentucky's highways, and to identify criteria which can be used in identifying roadway sections that cannot safety accommodate large trucks.

Benefits and Implementation: Plotting information was obtained to used in preparing turning templates that can be used in the design process. The turning templates include nine design vehicles including the 48-foot and 53-foot semitrailer. An accident analysis procedure was developed which can be used to investigate locations which have a high number of truck accidents. A list of criteria was given to use in formalizing truck access criteria.

Cost Effectiveness: A procedure to identify high-accident locations for trucks can result in a reduction of truck accidents and a resulting accident savings.

WORK ZONE TRAFFIC CONTROL

Guidelines: Traffic Control in Work Zones (Guidelines for Work by Utilities and Other Construction by Permit), August 1988
Guidelines for Traffic Control in Work Zones, January 1991

Objectives: To provide guidelines for traffic control in work zones to local government road and street departments, utilities, companies performing construction by permit, and any other entity providing maintenance or construction on a public roadway.

Benefits and Implementation: Over 15,000 of these handbooks have been printed with a wide distribution to various companies and local governments. Use of these handbooks will increase compliance with the proper traffic control measures in work zones.

Cost Effectiveness: Use of proper traffic control in work zones will result in a reduction in accidents which will provide a very positive benefit-to-cost ratio.

PAVEMENT EVALUATION

Reports: Evaluation of a Full-depth Asphaltic Concrete Pavement, UKTRP-86-5
Nondestructive Evaluation of Rigid Pavements Using Road Rater Deflections, UKTRP-86-7
User's Guide for Pavement Condition Surveys, UKTRP-87-12

Objectives: Document the behavior of various thicknesses of full-depth asphaltic concrete pavement thicknesses constructed on US 60, Boyd County, during 1971 and portland cement concrete pavements.

Benefits and Implementation: 1) Through the use of traffic counters and repeated nondestructive testing using the Road Rater, behavioral trends were established and verified that led to better understanding of other pavements incorporating stone bases in a statewide testing program. 2) Evaluation of pavements led to the development of a method to estimate the worth of an existing pavement for designing a minimum overlay thickness to carry the future estimated traffic. 3) While this report was designed to evaluate pavements by visual means, it did provide verification for confirming and strengthening concepts used in evaluating pavements using mechanical equipment.

Cost Effectiveness: Cost effectiveness of these studies would be of general nature. Specific data are not available to make finite conclusions.

PAVEMENT DESIGN

Reports: Thickness Design Curves for Asphaltic Concrete on a 4-inch Layer of Dense-Graded Aggregate, or on 6, 9, or 12 Inches of Stabilized Soil, or for Maximum Utilization of Dense-Graded Aggregate, UKTRP-86-14
Distributions of Strain Components and Work within Flexible Pavement

Structures, UKTRP-86-21
Evaluation of 1985 AASHTO Flexible Pavement Design Equations and Nomographs, UKTRP-87-3
Modification to Chevron N-Layer Computer Program, UKTRP-87-28
Pavement Designs Based on Work, UKTRP-87-29

Objectives: The main objectives were to determine how pavements behave and to develop thickness design curves based on that established behavior.

Benefits and Implementation: Specifically, the curves contained in the first report were used to design the pavement thickness template for the AA Highway and subsequently on other projects where the thickness of the crushed stone base was set at 4 inches. Report 5 was the first attempt to provide thickness design curves for rigid or flexible overlays on broken and seated concrete pavements.

Cost Effectiveness: A benefit-cost ratio has not been determined.

AXLELOAD DETERMINATIONS

Reports: Effects of Load Distributions and Axle and Tire Configuration on Pavement Fatigue, UKTRP-86-6
Traffic Forecasting for Pavement Design, UKTRP 87-16
Relationship Between Weights Measured by Permanent Truck Scales and Golden River Weigh-in-Motion Scales, KTC-89-31
Estimation of Equivalent Axleloads Using Data Collected by Automated Vehicle Classification and Weigh-in-Motion Equipment, KTC-90-11

Objectives: The overall objective is to understand the effects of various types of tires, the arrangement of tires, and also axleloads upon the behavior of pavement. This behavior is converted into "the number of equivalent 18,000-lb. axleloads" (EALs) which, coupled with soil strength, are the two essential beginning items in pavement design.

Benefits and Implementation: The appearance of coal-haul trucks having wide tires on steering axles was the beginning of a concentrated effort to determine the effects of normal tire and axle configurations as well as special arrangements. Since 1973, unusual arrangements have been appearing at an increasing rate and their effect on pavement performance was unknown. An attempt was made at assessing many different arrangements of tires, number of axles, and tire inflation pressures upon the pavement life. A special project was funded by the Demonstration section of FHWA and compiled in conjunction with team members from Florida, Oregon, Washington state, and Kentucky. The benefits were the inclusion of four vastly different types of traffic information and the methods used to determine the "design traffic". These data files ranged from simple to complicated in concepts.

Cost Effectiveness: Specific data to calculate benefit-cost ratios are not available.

BITUMINOUS MATERIALS SECTION

Study Title

1. Evaluation of the Effects of Asphalt Additives on Properties of Class A Surface Mixtures
2. Evaluation of Modified Bituminous Mixtures
3. Large-Stone Asphalt Mixes for Reducing Rutting
4. Louisa Bypass Experimental Project

Modified Asphalts

KTC-89-52 - "Evaluation of the Effects of Asphalt Additives on Properties Class A Surface Mixtures," Kamyar Mahboub, October 1989.

Statement of Implementation: The modified asphalts tend to remedy one mode of distress with little or no effect on other modes. The key to successful applications lies in matching potential benefits of modified systems with specific design and environmental requirements.

Statement of Research Benefits: This study provided an objective methodology by which a asphalt modifiers can be selected for optimum performance.

Benefit Cost Ratio:

- Research Cost: $74,800
- Life Cycle Cost Savings/Lane Mile for Modified Asphalt: (5280 x 12/9) x (17.09 - 14.02) = $21,613 per lane mile.

The cost of this research could be paid for through only 3.5 lane-mile of properly designed and constructed modified asphalts.

KTC-91-5 - "Evaluation of Modified Bituminous Mixtures," Kamyar Mahboub and Amy Simpson, June 1991.

Statement of Implementation: A performance-based data base is being proposed as a guide for selection of asphalt modifiers in Kentucky.

Statement of Research Benefits: An objective methodology has been developed for selection of asphalt modifiers.

Benefit Cost Ratio:

- Research Cost: $75,000
- Life Cycle Cost Savings/Lane Mile for Modified Asphalt: (5280 x 12/9) x (17.09 - 14.02) = $21,613 per lane-mile.

The cost of this research could be paid for through only 3.5 lane-mile of properly designed and constructed modified asphalts.

LARGE STONE MIXTURES

KTC-90-12 - "Large-Stone Asphalt Mixes for Reducing Rutting," Kamyar Mahboub, June 1990.

Statement of Implementation: Large-stone asphalt pavements have shown greater resistance to rutting, and are therefore recommended for heavy haul roads.

Statement of Research Benefits: This study resulted in guidelines for proper design and construction of large stone asphalts using the existing technology.

Benefit Cost Ratio:

- Research Cost: $68,000
- Life Cycle Cost Savings/Lane Mile for Modified Asphalt: (5280 x 12/9) x (17.09 - 11.93) = $36,326 per lane-mile.

The cost of this research could be paid for through only 1.9 lane-mile of properly designed and constructed large-stone asphalt pavement.

KTC-90-16 - "Louisa-Bypass Experimental Project," Kamyar Mahboub, June 1990.

Statement of Implementation: Some findings in this study were instrumental in development of Special Provision No. 87 (91) "Bituminous Concrete Mixtures, Class K"

Statement of Research Benefits: This research provided the basis for the development of new specifications dealing with large-stone asphaltic mixtures in Kentucky.

Benefit Cost Ratio:

- Research Cost - $40,000
- Life Cycle Cost Savings/Lane Mile for Modified Asphalt - (5280 x 12/9) x (17.09 - 11.93) = $36,326 per lane-mile.

The cost of this research could be paid for through only 1.1 lane-mile of properly designed and constructed large-stone asphalt pavement.

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APPENDIX
PUBLICATIONS

REPORTS PUBLISHED FROM 1981 TO PRESENT

548. "Safety Improvement Program for Toll Roads", J. G. Pigman, K. R. Agent, and J. D. Crabtree, July 1980.

549. "Evaluation of Reversible Lanes (Nicholasville Road; Lexington, Kentucky)," K. R. Agent, and J. D. Clark, July 1980.

550. "Input Guide: Kentucky Soils Data System", W. J. Pfalzer, August 1980.

551. "Overlay Recommendations for I 64: Rowan, Carter, and Boyd Counties," G. W. Sharpe and H. F. Southgate, August 1980.

552. "Statewide Survey of Skid Resistance of Pavements (1979)," R. L. Rizenbergs and J. L. Burchett, September 1980.

553. "Modulus and Damping of Asphaltic Concrete Using the Resonant Column," D. L. Allen and R. C. Deen, September 1980; also Geotechnical Testing Journal.

554. "Frictional Performance of Pavements and Estimates of Accident Probability," J. L. Burchett, and R. L. Rizenbergs, September 1980.

555. "The Need for a Schema for the Classification of Transitional (Shale) Materials," R. C. Deen, October 1980; also Geotechnical Testing Journal.

561. "The Effect of Lane and Shoulder Widths on Accident Reduction on Rural, Two-Lane Roads," C. V. Zegeer, R. C. Deen, and J. G. Mayes, October 1980; also Record XXX, Transportation Research Board.

562. "Interpretation of Dynamic Pavement Deflections," G. W. Sharpe, H. F. Southgate, and R. C. Deen, October 1980.

564. "The Operation of an Electrical Heating system for Bridge Decks," W. V. Azevedo, R. C. Deen, and J. H. Havens, October 1980.

565. "Evaluation of the FHWA Highway Traffic Noise Prediction Procedure (SNAP 1)," K. R. Agent, October 1980; also Record 789, Transportation Research Board.

566. "Interstate Safety Improvement Program," J. G. Pigman, K. R. Agent and C. V. Zegeer, November 1980; also Record XXX, Transportation Research Board.

568. "Use of Economic Analyses and Dynamic Programming in the Selection of Projects for Resurfacing," C. V. Zegeer, K. R. Agent and R. L. Rizenbergs, November 1980; also Record 814, Transportation Research Board.

570. "Frictional Performance of Pavements and Estimates of Accident Potential," J. L. Burchett and R. L. Rizenbergs, December 1980.

UKTRP-81-1 "Survey of Effectiveness of Transportation Services, "J. G. Pigman, K. R. Agent, and J. D. Crabtree, April 1981.

UKTRP-81-2 "Survey of Lane Delineation Methods," K. R. Agent, April 1981.

UKTRP-81-3 "Sprinkle-Treated Asphaltic concrete Surface Course," D. C. Newberry, Jr., April 1981.

UKTRP-81-4 "Retrieval Guide: Kentucky Soils Data System," W. J. Pfalzer and L. A. Hensley, April 1981.

UKTRP-81-5 "Problem Identification for Highway Safety Plan (FY 1983)," J. G. Pigman, K. R. Agent, and J. D. Crabtree, May 1981.

UKTRP-81-6 "Ohio River Suspension Bridges: An Inspection Report," Theodore Hopwood, June 1981.

UKTRP-81-7 "Strain-Rate Selection in the Constant Rate-of-Strain Consolidation Test," C. T. Gorman, June 1981.

UKTRP-81-8 "Evaluation of Raised Pavement Markers in Kentucky: Statewide Installation; 1975-1979," J. G. Pigman, K. R. Agent, and R. L. Rizenbergs, June 1981.

UKTRP-81-9 "Traffic Accidents in Kentucky (1978)," K. R. Agent, June 1981.

UKTRP-81-10 "Identification and Rehabilitation of High-Risk Drivers," K. R. Agent, July 1981.

UKTRP-81-11 "Evaluation of Rumble Strip Design and Usage," J. G. Pigman and M. M. Barclay, July 1981.

UKTRP-81-12 "Evaluation of Watertight Bridge Expansion Joints," W. V. Azevedo, July 1981.

UKTRP-81-13 "Vehicle Noise Emission Levels in Kentucky," K. R. Agent, July 1981.

UKTRP-81-14 "Analysis of Time-deflection Consolidation Data," E. G. McNulty, August 1981.

UKTRP-81-15 "Identification, Analyses, and Correction of High-Accident Locations in Kentucky," C. V. Zegeer, K. R. Agent, and R. L. Rizenbergs, August 1981.

UKTRP-81-16 "Mechanical and Engineering Properties of a Cherty Paleozoic Material," R. C. Deen, D. L. Allen, and T. C. Hopkins, September 1982.

UKTRP-81-17 "Design Guide for Bituminous Concrete Pavement Structures," J. H. Havens, R. C. Deen, and H. F. Southgate, August 1981.

UKTRP-81-18 "Structural Capacity of In-Place Asphaltic Concrete Pavements from Dynamic Deflections," H. F. Southgate, G. W. Sharpe, R. C. Deen, and J. H. Havens, August 1981.

UKTRP-81-19 "Evaluation of Pavement Tape as Lane Delineation," J. G. Pigman and K. R. Agent, November 1981.

UKTRP-81-20 "Development of a Thickness Design System for Bituminous Concrete Pavements," H. F. Southgate, R. C. Deen, and J. H. Havens, November 1981.

UKTRP-81-21 "Propagation of Traffic Noise," K. R. Agent, and C. V. Zegeer, November 1981.

UKTRP-81-22 "Allocation of Transportation Costs to Users," J. E. Black and J. G. Pigman, November 1981.

UKTRP-82-1 "Aggregate Shape and Skid Resistance," J. H. Havens, January 1982.

UKTRP-82-2 "Correlation of Road Rater and Benkelman Beam Deflections," R. C. Deen, G. W. Sharpe, and H. F. Southgate, January 1982 (International Symposium on Bearing Capacity of Roads and Airfields, Trondheim, Norway, June 23-25, 1982).

UKTRP-82-3 "Implementation of Road Rater Deflection Testing for Pavement Evaluation and Overlay Design," G. W. Sharpe, H. F. Southgate, and R. C. Deen, January 1982 (International Symposium on Bearing Capacity of Roads and Airfields, Trondheim, Norway, June 23-25, 1982).

UKTRP-82-4 "Pavement Testing...Before and After an Overlay," H. F. Southgate, G. W. Sharpe, and R. C. Deen, January 1982 (International Symposium on Bearing Capacity of Roads and Airfields, Trondheim, Norway, June 23-25, 1982).

UKTRP-82-5 "Problem Identification for Highway Safety Plan (FY 1983)," K. R. Agent, J. D. Crabtree, J. G. Pigman, May 1982.

UKTRP-82-6 "Triaxial Compression and Permeability Tests on Dense-Graded Aggregate," D. L. Allen, May 1982.

UKTRP-82-7 "Evaluation of Snowplowable Markers," J. G. Pigman and K. R. Agent, May 1982.

UKTRP-82-8 "Analysis of Saturation Flow at Signalized Intersections," K. R. Agent and J. D. Crabtree, May 1982.

UKTRP-82-9 "Pavement Roughness in Kentucky," G. W. Sharpe. D. H. Cain, H. F. Southgate, J. H. Havens, and R. C. Deen, July 1982.

UKTRP-82-10 "Summary of Vehicle Classification Data," J. D. Crabtree, August 1982.

UKTRP-82-11 "Traffic Accident Rates in Kentucky (1980), K. R. Agent, August 1982.

UKTRP-82-12 "Accident Rates by Vehicle Type," J. D. Crabtree and K. R. Agent, August 1982.

UKTRP-82-13 "Highway Sizing," J. D. Crabtree and J. A. Deacon, August 1982.

UKTRP-82-14 "Snow-Melting System, 9th Street and I 64, Louisville," W. V. Azevedo, September 1982.

UKTRP-82-15 "Child Restraint Usage in Kentucky (Pre-Legislation)," K. R. Agent and J. D. Crabtree, September 1982.

UKTRP-82-16 "Mechanical and Engineering Properties of a Cherty Paleozoic Material," R. C. Deen, D. L. Allen, and T. C. Hopkins, September 1982.

UKTRP-82-17 "Deflection and Evaluation of Flexible Pavements for Design of Overlays," H. F. Southgate, G. W. Sharpe, and R. C. Deen, September 1982.

UKTRP-82-18 "Effects of Construction Variations upon Dynamic Moduli of Asphaltic Concrete," H. F. Southgate, October 1982; also Proceedings, The Association of Asphalt Paving Technologists.

UKTRP-82-19 "Warrants for Left-Turn Lanes," K. R. Agent, October 1982; also, **Transportation Quarterly**, January 1983.

UKTRP-82-20	"Engineering Properties of Kentucky Oil Shales," V. P. Drnevich, T. C. Hopkins, D. L. Allen, S. S. Hale, October 1982; also Proceedings, Eastern Kentucky Oil Shale Symposium, November 1981.
UKTRP-82-21	"Mechanical Properties of Kentucky Oil Shales as Related to Mine Design Application," T. F. Fudge, Jr., D. L. Allen, and T. C. Hopkins, October 1982; also Proceedings, Eastern Oil Shale Symposium, October 1982.
UKTRP-82-22	"Review of Pertinent Contract Documents: Tennessee-Tombigbee Waterway, Divide Cut Section 3A," R. D. Hughes, R. C. Deen, D. L. Allen, T. C. Hopkins, November 1982.
UKTRP-82-23	"Strain Energy Analysis of Pavement Designs for Heavy Trucks," H. F. Southgate, R. C. Deen, and J. G. Mayes, November 1982; also TRB.
UKTRP-82-24	"Engineering Properties of Overburden Materials for the Means Project," V. P. Drnevich, D. L. Allen, T. C. Hopkins, December 1982.
UKTRP-83-1	"Sandstone as a Construction Material: KY 80, Hazard to Watergap," G. W. Sharpe, H. F. Southgate, D. L. Allen, J. H. Havens, and R. C. Deen, January 1983.
UKTRP-83-2	"Mechanical and Engineering Properties of a Cherty Paleozoic Material: A Supplemental Report," R. C. Deen, D. L. Allen, and T. C. Hopkins, January 1983.
UKTRP-83-3	"Analysis of Lost Times at Signalized Intersections," K. R. Agent and J. D. Crabtree, February 1983.
UKTRP-83-4	"Traffic Safety Analysis: University of Kentucky Area," February 1983.
UKTRP-83-5	"Development of a Thickness Design System for Portland Cement Concrete Pavements," H. F. Southgate, J. H. Havens, R. C. Deen, D. C. Newberry, February 1983.
UKTRP-83-6	"Computerized Analysis of Flexible Pavement Rutting Behavior (PAVRUT)," D. Allen, February 1983.
UKTRP-83-7	"Engineering Properties of Two Spent Shales and Minus 1/4-inch Raw Shale for the Means Project," V. P. Drnevich, D. L. Allen, and T. C. Hopkins, February 1983.
UKTRP-83-8	"Design of Oil Shale Disposal Embankments," V. P. Drnevich, T. C. Hopkins, and S. S. Hale, February 1983; also Proceedings, 1982 Eastern Oil Shale Symposium, October 1982, Lexington, Ky.

UKTRP-83-9	"Development of a Portable Retroreflectometer," K. R. Agent and J. G. Pigman, April 1983.
UKTRP-83-10	"Improved Structural Monitoring with Acoustic Emission Pattern Recognition," D. W. Prine and T. Hopwood, April 1983.
UKTRP-83-11	"Traffic Accident Rates in Kentucky (1981)," K. R. Agent, May 1983.
UKTRP-83-12	"User's Manual for Dynamic Programming for Highway Safety Improvement Program," J. D. Crabtree and J. G. Mayes, July 1983.
UKTRP-83-13	"Water under Pavements," J. H. Havens and G. W. Sharpe, July 1983.
UKTRP-83-14	"Geotechnical, Hydrologic, and Hydraulic Investigation of Mill Creek Dam -- Phase II," T. C. Hopkins, R. D. Hughes, and D. L. Allen, July 1983.
UKTRP-83-15	"Crushed Rock Bases," J. H. Havens and G. W. Sharpe, August 1983.
UKTRP-83-16	"Identification of Shales," T. C. Hopkins and R. C. Deen, August 1983; also Geotechnical Testing Journal, American Society for Testing and Materials, March 1984.
UKTRP-83-17	"Highway Skid Resistance," J. H. Havens, September 1983.
UKTRP-83-18	"Child Safety Seat Usage in Kentucky after Enactment of a Mandatory Usage Law," K. R. Agent, September 1983.
UKTRP-83-19	"Problem Identification for Highway Safety Plan (FY 1984)," J. G. Pigman and Tom Creasey, September 1983.
UKTRP-83-20	"Low-Strength (Pozzolanic) Materials for Highway Construction," G. W. Sharpe, L. E. Epley, D. L. Allen, H. F. Southgate, and R. C. Deen, September 1983; also American Concrete Institute, Fall Convention, September 1983.
UKTRP-83-21	"Structural Design and Installation Criteria for Rigid and Flexible Conduit," R. D. Hughes, September 1983.
UKTRP-83-22	"Alcohol Impact Evaluation (Interim Report)," J. G. Pigman and K. R. Agent, September 1983.
UKTRP-83-23	"Survey of Guardrail End Treatment Usage," J. G. Pigman and K. R. Agent, October 1983.

UKTRP-83-24 "Evaluation of Asphaltic Pavements for Overlay Design," R. C. Deen, H. F. Southgate, and G. W. Sharpe, October 1983; prepared for presentation to American Society for Testing and Materials Symposium on Pavement Maintenance and Rehabilitation, December 1983.

UKTRP-83-25 "Development of Pavement Thickness Designs Using Pozzolanic Base Materials," G. W. Sharpe, H. F. Southgate, and R. C. Deen, October 1983.

UKTRP-83-26 "Concrete Barrier Geometrics (US 41 Bridge in Henderson, Kentucky)," October 1983.

UKTRP-83-27 "Performance Evaluation of Experimental Paint-Stripe Beads," K. R. Agent and J. G. Pigman, November 1983.

UKTRP-84-1 "Rutting: A Case Study (US 23; 1.5 Miles North of Louisa)," J. H. Havens, G. W. Sharpe, D. L. Allen, and H. F. Southgate, January 1984.

UKTRP-84-2 "A Field and Laboratory Compaction Study of a Mixture of Retorted and Raw Oil Shale from the Means Project in Montgomery County," D. L. Allen and Bobby Meade, January 1984.

UKTRP-84-3 "Thickness Design Curves for Portland Cement Concrete Pavements," H. F. Southgate and R. C. Deen, February 1984.

UKTRP-84-4 "Periodic Nondestructive Evaluation of In-Service Metal Bridges," Theodore Hopwood and R. C. Deen, March 1984; prepared for presentation to FCP Conference Review on Project 5K, Federal Highway Administration, March 21-22, 1984.

UKTRP-84-5 "Traffic Accident Rates in Kentucky (1982)," K. R. Agent, March 1984.

UKTRP-84-6 "Thickness Design Procedure for Portland Cement Concrete Pavements," H. F. Southgate and R. C. Deen, March 1984.

UKTRP-84-7 "Specially Constructed Brides: Activities for Fiscal Year 1983," Theodore Hopwood, J. H. Havens, and G. W. Sharpe, April 1984.

UKTRP-84-8 "An Evaluation of Elastizell Concrete as a Lightweight Fill Material," D. L. Allen and B. W. meade, April 1984.

UKTRP-84-9 "Structural Evaluation of Asphaltic Pavements," R. C. Deen, H. F. Southgate, and G. W. Sharpe, April 1984; prepared for FHWA Workshop on Pavement Rehabilitation, Oklahoma City, OK, May 14-17, 1984.

UKTRP-84-10 "Vanpool Demonstration Project," (University of Kentucky) J. G. Pigman and K. R. Agent, April 1984.

UKTRP-84-11 "Variations of Fatigue Due to Unevenly Loaded Axles within Tridem Groups," H. F. Southgate and R. C. Deen, April 1984.

UKTRP-84-12 "Variable Serviceability Concept for Pavement Design Confirmed by AASHO Road Test Fatigue Data," H. F. Southgate and R. C. Deen, April 1984.

UKTRP-84-13 "Introduction to Cable Suspension Bridges," T. Hopwood and J. H. Havens, May 1984.

UKTRP-84-14 "Corrosion of Cable Suspension Bridges," T. Hopwood and J. H. Havens, May 1984.

UKTRP-84-15 "Inspection, Prevention, and Remedy of Suspension Bridge Cable Corrosion Problems," T. Hopwood and J. H. Havens, May 1984.

UKTRP-84-16 "Analysis of Accidents Involving Breakaway-Cable-Terminal End Treatments," J. G. Pigman, K. R. Agent, and Tom Creasey, June 1984.

UKTRP-84-17 "Analysis of Accidents Involving Crash Cushions," J. G. Pigman, K. R. Agent, and Tom Creasey, June 1984.

UKTRP-84-18 "An Evaluation of Pavement Drainage, Interstate 64, Rowan-Carter Counties," D. L. Allen and H. F. Southgate, June 1984.

UKTRP-84-19 "Survey of Effectiveness of Transportation Services (1984)," J. G. Pigman and K. R. Agent, June 1984.

UKTRP-84-20 "Effectiveness of Traffic Noise Barrier on I 471 in Campbell County, Kentucky," Tom Creasey and K. R. Agent, June 1984.

UKTRP-84-21 "Evaluation of Full-Depth Asphaltic Concrete Pavement," H. F. Southgate, G. W. Sharpe, Mark Anderson, and R. C. Deen, July 1984.

UKTRP-84-22 "Analysis of Loads and Settlements for Reinforced Concrete Culverts," D. L. Allen and B. W. Meade, August 1984.

UKTRP-84-23 "Pavement Thickness Designs Utilizing Low-Strength (Pozzolanic) Base and Subbase Materials," G. W. Sharpe, R. C. Deen, H. F. Southgate, and Mark Anderson, August 1984.

UKTRP-84-24 "Relationship between Kentucky CBR and Slake Durability," T. C. Hopkins, August 1984.

UKTRP-84-25 "Impact Evaluation of Traffic Alcohol Programs: Selected Locations in Kentucky" J. G. Pigman and K. R. Agent, September 1984 (for Annual Meeting of American Society of Criminology, Cincinnati, OH, November 7-11, 1984).

UKTRP-84-26 "Nondestructive Evaluation of Rigid Pavements Using Road Rater Deflections," G. W. Sharpe, Mark Anderson, R. C. Deen, and H. F. Southgate, September 1984 (for International Conference on Concrete Pavement Design, West Lafayette, IN, April 23-25, 1985.)

UKTRP-84-27 "1984 Safety Belt and Child Safety Seat Usage Rates in Kentucky and Evaluation of a Public Information Campaign," K. R. Agent and J. M. Salsman, September 1984.

UKTRP-84-28 "Jackson Purchase Parkway Pavement Study," J. H. Havens, October 1984.

UKTRP-84-29 "Water-Induced Surface Failures on I 65, Hardin County, Kentucky," E. G. Williams, H. F. Southgate, and R. C. Deen, October 1984.

UKTRP-84-30 "Estimation of Equivalent Axleloads: Computer Program Documentation," J. M. Salsman and J. A. Deacon, October 1984.

UKTRP-84-31 "Evaluation of Durable Lane Delineation Materials," (Interim Report) K. R. Agent and J. G. Pigman, December 1984.

UKTRP-84-32 "Evaluation of Durable Crossbar and Stopbar Marking Materials," (Interim Report) K. R. Agent and J. G. Pigman , December 1984.

UKTRP-84-33 "A Review and Analysis of Pile Design," D. L. Allen, December 1984.

UKTRP-84-34 "Pavement Management in Kentucky," G. W. Sharpe, R. C. Deen, H. F. Southgate, R. L. Rizenbergs, and J. L. Burchett, December 1984 (for North American Pavement Management Conference, Toronto, Canada, March 18-21, 1985).

UKTRP-85-1 "Laboratory Evaluations of Stabilized Flue Gas Desulfurization Sludge (Scrubber Sludge) and Aggregate Mixtures," Mark Anderson, G. W. Sharpe, D. L. Allen, H. F. Southgate, and R. C. Deen, January 1985 (for International Ash Utilization Symposium/ Exposition, Orlando, Fl. March 4-7, 1985).

UKTRP-85-2 "Traffic Accident Rates in Kentucky (1983)," J. M. Salsman and K. R. Agent, January 1985.

UKTRP-85-3 "Evaluation of Truck Escape Ramps," J. G. Pigman and K. R. Agent, January 1985.

UKTRP-85-4	"Comparison of Contained Rock Asphalt Mat (CRAM) with Conventional Asphalt Concrete Pavements," H. F. Southgate, January 1985.
UKTRP-85-5	"Strain Gage Installation on the I-75 Bridge at Covington, Kentucky, and Subsequent Data Analysis," T. Hopwood and J. G. Mayes, January 1985.
UKTRP-85-6	"Development of Accident Reduction Factors," T. Creasey and K. R. Agent, March 1985.
UKTRP-85-7	"Fly Ash Stabilized Bases in Kentucky," G. W. Sharpe and L. Epley, March 1985 (for Seminar on Fly Ash Utilization in Highway Construction, Atlanta, Ga. March 12-13, 1985).
UKTRP-85-8	"Truck Design and Usage Related to Highway Pavement Performance," R. C. Deen, H. F. Southgate, G. W. Sharpe, D. L. Allen, and J. G. Pigman, March 1985.
UKTRP-85-9	"Unstable Subgrade, I 65, Hardin County," T. C. Hopkins and G. W. Sharpe, March 1985.
UKTRP-85-10	"Analysis of Movements and Forces on Bridge Approaches: A Case Study (Bridge over Chesapeake Avenue on Interstate 471 in Campbell County, Kentucky)," D. L. Allen, B. W. Meade, and T. C. Hopkins, April 1985.
UKTRP-85-11	"Structural Evaluation of Asphaltic Pavements," R. C. Deen, H. F. Southgate, and G. W. Sharpe, April 1985 (Same as UKTRP-84-9) (For Workshop on Pavement Rehabilitation, Albany, NY, April 2-4, 1985).
UKTRP-85-12	"Long-Term Movements of Highway Bridge Approach Embankments and Pavements," T. C. Hopkins, April 1985.
UKTRP-85-13	"Effects of Load Distributions and Axle and Tire Configurations on Pavement Fatigue," H. F. Southgate and R. C. Deen, May 1985 (for Second International Conference on Weigh-In-Motion, Atlanta, Ga, May 20-24, 1985).
UKTRP-85-14	"Feasibility of Computerization of the Bid Item Section of Bid Proposals," J. G. Mayes and M. Isenhour, May 1985.
UKTRP-85-15	"Effectiveness of Traffic Noise Barrier on I 471 in Campbell County, Kentucky," Tom Creasey and K. R. Agent, May 1985.

UKTRP-85-16	"Summary Report of Ranking Methodologies," R. C. Deen, May 1985 (for North American Pavement Management Conference, Toronto, Canada, March 18-21, 1985).
UKTRP-85-17	"Sampling Techniques for the Collection of Vehicle Classification Data," J. G. Pigman, June 1985.
UKTRP-85-18	"Problem Identification for Highway Safety Plan (FY 1986)," J. G. Pigman and K. R. Agent, July 1985.
UKTRP-85-19	"Guidelines for the Use of Protected/Permissive Left-Turn Phasing," K. R. Agent, August 1985.
UKTRP-85-20	"Traffic Trends and Their Relationship to Highway-User Revenues," J. G. Pigman and M. Vaziri, September 1985.
UKTRP-85-21	"1985 Safety Belt and Child Safety Seat Usage Rates in Kentucky and Evaluation of a Public Information Campaign," K. R. Agent, September 1985.
UKTRP-85-22	"Latex-Concrete Overlays on Bridge Decks (I 64, MP 150 to West Virginia Line)," J. H. Havens and Theodore Hopwood, September 1985.
UKTRP-85-23	"Demonstration and Preliminary Evaluation of the Acoustic Emission Weld Monitor," Theodore Hopwood and R. C. Deen, September 1985.
UKTRP-85-24	"Evaluation of Construction Zone Pavement Marking Materials," K. R. Agent and J. G. Pigman, September 1985.
UKTRP-85-25	A Survey of the States on Problems Related to Bridge Approaches," D. L. Allen, October 1985.
UKTRP-85-26	"Impact Evaluation of the Traffic Alcohol Program in Lexington, Kentucky," J. G. Pigman and K. R. Agent, October 1985.
UKTRP-85-27	"Evaluation of Stone Column Stabilized Embankment Foundation," B. W. Meade and D. L. Allen, November 1985.
UKTRP-85-28	"Suggested Changes to Kentucky Statutes (Vehicle Weights and Dimensions)," H. F. Southgate and R. C. Deen, November 1985.
UKTRP-85-29	"Jefferson Freeway Investigation," H. F. Southgate, G. W. Sharpe, T. Hopwood, J. H. Havens, M. Anderson, D. Q. Hunsucker, and R. C. Deen, November 1985.

UKTRP-85-30 "Estimation of Equivalent Axleloads," J. A. Deacon and J. G. Pigman, December 1985.

UKTRP-85-31 "A Computerized Analysis of Flexible Pavement Rutting Behavior (PAVRUT)," D. L. Allen and R. C. Deen, December 1985 (for presentation to the 1986 annual meeting of the Transportation Research Board).

UKTRP-85-32 "The Feasibility of Draglines for Mine Reclamation," Mark Anderson, December 1985 (Proceedings, 1985 Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation, University of Kentucky, December 9-13, 1985).

UKTRP-86-1 "Traffic Accident Rates in Kentucky (1984)," K. R. Agent, January 1986.

UKTRP-86-2 "A Generalized Slope Stability Computer Program: User's Guide for HOPK-1," T. C. Hopkins, January 1986.

UKTRP-86-3 "Workshop on Roadway and Street Drainage," R. d. Hughes and D. L. Allen, January 1986.

UKTRP-86-4 "Delineation of Horizontal Curves," K. R. Agent and T. Creasey, March 1986.

UKTRP-86-5 "Evaluation of a Full-Depth Asphaltic Concrete Pavement," H. F. Southgate, G. W. Sharpe, M. Anderson, and R. C. Deen, April 1986; prepared for presentation to Sixth International Conference on Structural Design of Asphalt Pavements, Ann Arbor, Michigan, July 13-16, 1987.

UKTRP-86-6 "Effects of Load Distributions and Axle and Tire Configuration on Pavement Fatigue," H. F. Southgate and R. C. Deen, April 1986; prepared for presentation to Sixth International Conference on Structural Design of Asphalt Pavements, Ann Arbor, Michigan, July 13-16, 1987.

UKTRP-86-7 "Nondestructive Evaluation of Rigid Pavements Using Road Rater Deflections," G. W. Sharpe, M. Anderson, R. C. Deen, and H. F. Southgate, April 1986.

UKTRP-86-8 "Stability of Embankments of Clay Foundations," T. C. Hopkins, April 1986.

UKTRP-86-9 "Use of Nondestructive Testing to Prevent Failures of In-Service Metal Bridges," T. Hopwood and R. C. Deen, April 1986; prepared for presentation to 2nd International Conference on Structural Failure, Product Liability and Technical Insurance, Vienna, Austria, July 1-3, 1986.

UKTRP-86-10 "Use of Post Delineators on Interstates," K. R. Agent and J. G. Pigman, April 1986.

UKTRP-86-11 "Treatment of Narrow Medians on Four-Lane Rural Roadways," J. G. Pigman and K. R. Agent, April 1986.

UKTRP-86-12 Documentation for 1986 Weight-Distance Tax Analyses Using Lotus 1-2-3," H. F. Southgate, April 1986.

UKTRP-86-13 "Evaluation of Durable Crosswalk and Stopbar Marking Materials," K. R. Agent and J. G. Pigman, May 1986.

UKTRP-86-14 "Thickness Design Curves for Asphaltic Concrete on a 4-inch Layer of Dense-Graded Aggregate, or on 6, 9, 12 Inches of Stabilized Soil, or for Maximum Utilization of Dense-Graded Aggregate," H. F. Southgate, May 1986.

UKTRP-86-15 "Evaluation of Durable Lane Delineation Materials," K. R. Agent and J. G. Pigman, May 1986.

UKTRP-86-16 "Evaluation of Snowplowable Marker Installations," K. R. Agent and J. G. Pigman, June 1986.

UKTRP-86-17 "Performance Monitoring of a Highway Tieback Wall," B. W. Meade, D. L. Allen, and T. C. Hopkins, July 1986.

UKTRP-86-18 "Economic Analyses of Millings," H. F. Southgate, July 1986.

UKTRP-86-19 "I-75 Lane Closures," J. G. Pigman and K. R. Agent, August 1986.

UKTRP-86-20 "1986 Safety Belt and Child Safety Seat Usage Rates in Kentucky," K. R. Agent, September 1986.

UKTRP-86-21 "Distributions of Strain Components and Work within Flexible Pavement Structures," H. F. Southgate and R. C. Deen, September 1986.

UKTRP-86-22 "Design of Highway Embankments on Unstable Natural Slopes," C. S. Bishop, D. W. Armour, and T. C. Hopkins, September 1986 (also Proceedings, Ohio River Valley Soils Seminar, Louisville, Kentucky, October 17, 1986.

UKTRP-86-23 "Manual on Bridge/Culvert Maintenance," G. W. Sharpe and T. Hopwood, September 1986.

UKTRP-86-24 "Lime Stabilization of Pavement Subgrade Soils of Section AA-19 of the Alexandria-Ashland Highway," T. C. Hopkins and D. L. Allen, October 1986.

UKTRP-86-25 "Rutting and Longitudinal Cracking and Temperature Cracking: A Case Study (US 23, Greenup County, MP 6.0 to 28.8)," J. H. Havens, G. W. Sharpe, D. L. Allen, and D. Q. Hunsucker, November 1986.

UKTRP-86-26 "Shrinkage Compensating Deck Concrete (KY 1974 Bridge over Tates Creek Road)," D. Q. Hunsucker, November 1986.

UKTRP-86-27 "Investigation of Collapse of Long-Span Structure under Ky 80 in Floyd County," R. D. Hughes, D. L. Allen, and R. C. Deen, November 1986.

UKTRP-86-28 "Impact Evaluation of the Lexington-Fayette County Traffic Alcohol Program (1982-1986)," J. G. Pigman and K. R. Agent, November 1986.

UKTRP-86-29 "Status Report for Selected Projects Containing Experimental Features," December 1986.

UKTRP-87-1 "Bridge Decks and Overlays," J. H. Havens, Theodore Hopwood, and E. E. Courtney, January 1987.

UKTRP-87-2 "Automated Data Acquisition for Low-Volume Road Inventory and Management," T. Hopwood, G. W. sharpe, J. W. Hutchinson, and R. C. Deen, January 1987 (for Fourth International Conference on Low Volume Roads, Cornell University, Ithaca, NY, August 16-20, 1987).

UKTRP-87-3 "Evaluation of 1985 AASHTO Flexible Pavement Design Equations and Nomographs," H. F. Southgate, G. W. Sharpe, and R. C. Deen, January 1987.

UKTRP-87-4 "Civil Engineering Applications of Acoustic Emission," Theodore Hopwood II, February 1987 (prepared as a contribution to NONDESTRUCTIVE TESTING, The American Society for Nondestructive Testing).

UKTRP-87-5 "Summary of Experimental Bridge Features," Theodore Hopwood II, J. H. Havens, and E. E. Courtney, March 1987.

UKTRP-87-6 "Traffic Control and Accidents at Rural, High-Speed Intersections," K. R. Agent, March 1987.

UKTRP-87-7 "Acoustic Emission Monitoring of Bascule Bridge Components," Theodore Hopwood, March 1987.

UKTRP-87-8 "Design and Performance of Highway Shoulders,' D. W. Hunsucker, G. W. Sharpe, and R. C. Deen, March 1987.

UKTRP-87-9 "Evaluation of Drainage on Nicholasville Bypass," D. L. Allen, Many 1987.

UKTRP-87-10 "Evaluation and Application of Roadway Delineation Techniques," K. R. Agent and J. G. Pigman, May 1987.

UKTRP-87-11 "Evaluation of Construction Zone Pavement Marking Materials," K. R. Agent and J. G. Pigman, May 1987.

UKTRP-87-12 "User's Guide for Pavement Condition Surveys," G. W. Sharpe, H. F. Southgate, and R. C. Deen, June 1987.

UKTRP-87-13 "Allocation of Resurfacing Monies to Highway Districts in Kentucky," R. L. Rizenbergs and R. C. Deen, June 1987 (for Second North American Conference on Managing Pavements, Toronto, Ontario, Canada, November 2-6, 1987).

UKTRP-87-14 "Performance Evaluation of Breakaway-Cable-Terminal End Treatments," J. G. Pigman and K. R. Agent, June 1987.

UKTRP-87-15 "Road Base Construction Utilizing Coal Waste Materials," D. Q. Hunsucker, G. W. Sharpe, J. G. Rose, and R. C. Deen, July 1987 (for Proceedings, Eighth International Coal Ash Utilization Symposium, October 28-31, 1987, Washington, D.C.).

UKTRP-87-16 "Traffic Forecasting for Pavement Design," H. R. Desai, R. Reel, R. C. Deen, H. F. Southgate, R. Noble, V. L. Tabery, M. Hallenbeck, D. Crimmins, and W. Cunagin, July 1987.

UKTRP-87-17 "Construction and Performance Evaluation of a Geocomposite Pavement Edge Drain Including Comparison with a 4-inch Pipe Drain," John Fleckenstein and D. L. Allen, July 1987.

UKTRP-87-18 "Implementation of a Pavement Management Program in Lexington-Fayette County, Kentucky," G. W. Sharpe, R. C. Deen, and R. R. Sewell, July 1987 (for Second North American Conference on Managing Pavements, Toronto, Ontario, Canada, November 2-6, 1987).

UKTRP-87-19 "Performance Survey of Silicone-Sealed Concrete Pavement Joints," D. Q. Hunsucker and E. E. Courtney, August 1987.

UKTRP-87-20	"Evaluation of Epoxy Thermoplastic Pavement Marking Materials," K. R. Agent and J. G. Pigman, August 1987.
UKTRP-87-21	"A Chronicle of the Kentucky Transportation Research Program," R. C. Deen and R. D. Hughes, August 1987.
UKTRP-87-22	"Acoustic Emission Monitoring of In-Service Bridges," T. Hopwood and D. W. Prine, august 1987.
UKTRP-87-23	"Analysis of Accident Data in Kentucky (1982-1986_," J. G. Pigman and K. R. Agent, September 1987.
UKTRP-87-24	"Evaluation of Wick Drain Stabilization of Approach Fill Foundation (Bullitt County)," B. W. Meade and D. L. Allen, October 1987.
UKTRP-87-25	"A Survey of States' Aggregate Soundness Test Methods and Specifications," D. Q. Hunsucker, October 1987.
UKTRP-87-26	"Breaking and Seating of Rigid Pavements," G. W. Sharpe, M. Anderson, and R. C. Deen, October 1987.
UKTRP-87-27	"Reliability Assessment of High-Risk Steel Bridges by Nondestructive Test Methods," T. Hopwood, V. K. Oka, and R. C. Deen, October 1987.
UKTRP-87-28	"Modification to Chevron N-Layer Computer Program," H.F. Southgate, D. H. Cain, J.G. Mayes, and R.C. Deen, October 1987.
UKTRP-87-29	"Pavement Designs Based on Work," H.F. Southgate and R.C. Deen, October 1987.
UKTRP-87-30	"Evaluation of Asphalt Additive -- Chemkrete," L.J. Fleckenstein D.L. Allen, G.W. Sharpe, S.P. Hall, and D.W. Hunsucker, October 1987.
UKTRP-87-31	"Laboratory Analysis of Failed Asphaltic Concrete Surface -- US 23, Lawrence County," L.J. Fleckenstein and D. L. Allen, October 1987.
UKTRP-87-32	"Traffic Volume Estimates and Growth Trends," J.A. Deacon, J.G. Pigman and Ahmad Mohsenzager, November 1987.
UKTRP-87-33	"Native Aggregates for Skid Resistance," S.P. Hall, D. Q. Hunsucker, "D.L. Allen, and G. W. Sharpe, November 1987.
UKTRP-87-34	"Evaluation of Unmanned Radar Installations," J.G. Pigman, K.R. Agent, and J.A. Deacon, December 1987.

UKTRP-87-35 "Evaluation of a Polymer Asphalt Additive -- Kraton (D4460X)," L.J. Fleckenstein and D.L. Allen, December 1987.

~~UKTRP-88-1 "Shear Strength of Compacted Shales," T.C. Hopkins, January 1988.~~

UKTRP-88-2 "Earthquake Hazard Mitigation of Transportation Facilities," M. Sayyedsadr, D.L. Allen, V.P. Drnevich, and L.J. Fleckenstein, January 1988.

UKTRP-88-3 "Evaluation of ADS Polyethylene Pipe -- N-12," L.J. Fleckenstein and D.L. Allen, February 1988.

UKTRP-88-4 "Evaluation of Stability and Rutting Potential of Asphaltic Concrete Using Big Stone Gradations," D.L. Allen and H.M. Roghani, February 1988.

UKTRP-88-5 "Review of Work Zone Literature,", J.G. Pigman and K. R. Agent, February 1988.

UKTRP-88-6 "Long-Term Evaluation of the Acoustic Emission Weld Monitor," T. Hopwood, February 1988.

UKTRP-88-7 "Excessive Beam Deflections on the KY-52 Bridge over Dix River (Boyle-Garrard County Line)," T. Hopwood and V.G. Oka, March 1988.

UKTRP-88-8 "Allocation of Highway Costs and Revenues," J.G. Pigman and J.A. Deacon, March 1988.

UKTRP-88-9 "Evaluation of Lime Stabilized Road Bed, B.W. Meade and D. L. Allen, April 1988.

UKTRP-88-10 "Evaluation of Extruded Thermoplastics as Lane Delineation," K.R. Agent and J.T. Pigman, May 1988.

UKTRP-88-11 "Evaluation of Procedures for Testing Aggregates," D.Q. Hunsucker, March 1988.

UKTRP-88-12 "Laboratory Evaluation of Edge Drains," L.J. Fleckenstein and D. L. Allen, June 1988.

UKTRP-88-13 "Analysis of Accidents in Construction and Maintenance Work Zones," J.G. Pigman and K.R. Agent, June 1988.

UKTRP-88-14 "Comparison of Rigid Pavement Thickness Design Systems," Herbert F. Southgate, August 1988.

UKTRP-88-15	"Soil-Bridge Abutment Interaction," Bobby W. Meade and David L. Allen, August 1988.
UKTRP-88-15	"Evaluation of Hydraway Edge Drain on Pennyrille Parkway," Allen, Fleckenstein, July 1988.
UKTRP-88-16	"Evaluation of Stone Column Stabilized Embankment Foundation," Bobby W. Meade and David L. Allen, August 1988.
KTC-88-1	"Highway Safety Research Development, and Technology Transfer," John A. Deacon, August 30, 1988.
KTC-88-2	"Calcium Nitrite as a Corrosion Inhibitor in Reinforced Concrete Bridge Decks," Theodore Hopwood II, David Q. Hunsucker, and Edgar E. Courtney, September 1988.
KTC-88-3	"Impact Evaluation of Louisville-Shively-Jefferson County Traffic Alcohol Programs," Jerry G. Pigman and Kenneth R. Agent, October 1988.
KTC-88-4	"Asphalt Surface Treatments for Local Roads and Streets," Ellis G. Williams, Duo Services, Inc., September 1988.
KTC-88-5	"Fatigue Analysis of The I 75 Bridge over The Kentucky River at Clays Ferry," Vishwas G. Oka and Theodore Hopwood, II, October 1988.
KTC-88-6	"1988 Safety Belt and Child Safety Seat Usage Rates in Kentucky," K. R. Agent, October 1988.
KTC-88-7	"Analysis of Accident Data in Kentucky (1983-1987)," K. R. Agent and J. G. Pigman, October 1988.
KTC-89-1	"Interim Guidelines for Design of Pavements," Gary W. Sharpe, Ronald D. Hughes, David L. Allen, January 1989.
KTC-89-2	"Modular Expansion Joints and Deck Drains," Theodore Hopwood, II and Edgar E. Courtney, March 1989.
KTC-89-3	"Evaluation of Construction-Zone Pavement Marking Materials," K. R. Agent and J. G. Pigman, March 1989.
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