



COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS
FRANKFORT

HENRY WARD
COMMISSIONER OF HIGHWAYS

April 3, 1964

ADDRESS REPLY TO
DEPARTMENT OF HIGHWAYS
MATERIALS RESEARCH LABORATORY
132 GRAHAM AVENUE
LEXINGTON 29, KENTUCKY

D. 1. 7

MEMORANDUM

TO: W. B. Drake, Assistant State Highway Engineer
Chairman, Kentucky Highway Research Committee

SUBJECT: "Kentucky Highway Research Program," by
J. H. Havens, and R. C. Deen; presented at
the 16th Annual Kentucky Highway Conference,
University of Kentucky, March 10, 1964.

The above referenced report, attached hereto, was presented at the 16th Annual Kentucky Highway Conference in response to an invitation from the program committee to review the past and current research activities of the Kentucky Department of Highways. Of course, we were pleased to have an opportunity to describe our work, but we were mindful of our inability to condense many years of history into a brief speech. However, we were motivated by a somewhat broader commitment to prepare a rather complete history and annotated bibliography* of highway

*Reference: KYP-64-1; HPS-HPR-1(25), Part II, p. 124.

research in Kentucky in connection with our 1964 schedule of research projects. This report, therefore, provided an opportunity to draft a preliminary version of the more complete history and bibliography previously planned. Although the report in its present form will appear in the proceedings of the Conference, which will be published as a bulletin by the Engineering Experiment Station, University of Kentucky, this transmittal will serve as a record of both the Conference report and a report of progress on the above mentioned project. This report requires

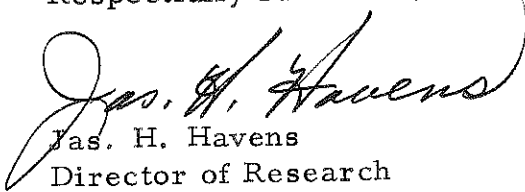
W. B. Drake

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no action at this time although comments and suggestions are invited.
Informational copies will be forwarded to the Bureau of Public Roads.

Respectfully submitted,


Jas. H. Havens
Director of Research
Secretary, Kentucky Highway
Research Committee

JHH:afj

Encl.

cc: Research Committee

R. O. Beauchamp

R. L. Campbell

T. J. Hoggood

A. O. Neiser

J. C. Moore

D. V. Terrell

INTRODUCTION

How encompassing and yet how sinister are the words "In the beginning...." The phrase implies that in the beginning there was nothing but disorder, whereas now a high degree of orderliness and development prevails. The Kentucky Highway Research Program, as it is today, is deeply rooted in the past. Its early history closely parallels that of the Annual Kentucky Highway Conference. Some of the early history of the Conference was reviewed by D. H. Bray, State Highway Engineer, in a paper presented at the renewal of the annual meetings in 1949*. A brief interim history of research was presented by Dean D. V. Terrell at the 14th Annual Kentucky Highway Conference**. However, to preface this report, a brief review of events which have a significant bearing on the over-all development of the present research program will be presented:

- 1912 - Kentucky Department of Highways was organized.
- 1914 - First Kentucky Highway Conference (A two-week Road School).
- 1914 - American Association of State Highway Officials was founded.
- 1914 - Kentucky Legislature passed the so-called State Aid Road Law (5-cent property tax); inter-county seat road system plan prepared.
- 1914 - Road Materials Testing Laboratory established at University of Kentucky; began operation in 1915 under Professor D. V. Terrell. Inspectors were required by law to be on all state aid works.
- 1915 - Kentucky Rock Asphalt (Reference: Col. C. M. Crump).
- 1916 - Rural Post Road Bill (H. R. 7617) submitted to Congress.
- 1917 - Oiled macadam and water-bound macadam roads.
- 1918 - Inauguration of Federal Aid.

* Bray, D. H. "Highways and Highway Engineering in Kentucky," "Proceedings of the Kentucky Highway Conference," Bulletin No. 12, Engineering Experiment Station, University of Kentucky June, 1949.

** Terrell, D. V. "Highway Material Research Laboratory -- 1942 - 1962," Bulletin No. 64, Engineering Experiment Station University of Kentucky, June, 1962.

- 1918 - Bulletin 949, Bureau of Public Roads, U. S. Department of Agriculture, on materials and tests was issued. Superseded by AASHO.
- 1919 - Last of first series of Highway Conferences.
- 1919 - Ashland - Cannonsburg Road, FA-1 (Brick); Lexington - Winchester Road, FA-2 (Concrete).
- 1920 - Highway Research Board (National Academy of Sciences) was organized (Advocated by Mississippi Valley Conference of State Highway Departments and Bureau of Public Roads).
- 1920 - Enactment of 1-cent gasoline and 60-cent horse power tax in Kentucky.
- 1921 - Federal Aid Act revised.
- 1927 - Experiments in concrete paving using sandstone aggregate (Pineville - Harlan Road).
- 1928 - Material Testing Laboratory established in Frankfort; was previously at the University of Kentucky in the basement of Pence Hall; V. P. Ligon, Engineer of Tests; D. V. Terrell retained as Research Engineer.
- 1930 - Sandstone used in several reinforced concrete bridges in Eastern Kentucky.
- 1933 - Beginning of hot-mix bituminous concrete paving; hot-mix bituminous concrete in prior use for streets (raked); first use of paver in Kentucky was for laying Kentucky rock asphalt.
- 1934 - Congress authorized use of 1.5% of Federal Aid for Highway Planning Studies.
- 1937 - First soil-cement base in Kentucky, in Daviess County.
- 1937 - Early experimental work in air entrainment in concrete; by D. V. Terrell, using Ivory Flakes. First use of air entrainment (N.V.X.) in concrete pavement; U. S. 31-W (Fort Knox)*.

* Gregg, L. E. - "Experiment with Air Entrainment in Cement Concrete," Bulletin No. 5, Engineering Experiment Station, University of Kentucky, September, 1947.

- 1940 - Experimental concrete pavement; U.S. 27 Cynthiana - Falmouth Road, including air in natural cement, gravel and limestone aggregate and experimental joints.
- 1940 - Experimental joint-spacing concrete pavement; Owensboro - Hartford Road.*
- 1941 - Bilateral agreement between the Department of Highways and the University of Kentucky to construct and operate a Materials Research Laboratory on the campus of the University. This action envisioned a facility unequalled anywhere in this country, and the original estimate of cost of the facility was \$50,000. Professor D. V. Terrell was Director of Research.
- 1941 - 1946 - World War II. Research facility remained understaffed; Curtis Cantrill, Research Engineer.
- 1945 - L. E. Gregg appointed Associate Director of Research.
- 1946 - Staff of the Research Laboratory: Robert F. Baker, W. B. Drake, S. T. Collier, J. H. Havens.
- 1949 - Renewal of Annual Highway Conference.
- 1949 - Experimental concrete pavement without transverse joints; U.S. 31-W, Franklin-Tennessee Line.
- 1957 - W. B. Drake succeeded L. E. Gregg as Associate Director of Research.
- 1958 - D. V. Terrell, Dean Emeritus, retired as Director and was succeeded by W. B. Drake.
- 1963 - W. B. Drake was advanced to Assistant State Highway Engineer and was succeeded by James H. Havens as Director of Research.
- 1963 - July 1 - Inaugurated a new era of research involving full participation and utilization of Federal Aid HPS-HPR funds for research and development.

With the beginning of federal aid highway work in Kentucky, the necessity of specifying the quality of road building materials and the enforcement of specification requirements through testing became increasingly apparent throughout the country, and the testing facilities available at the University of Kentucky under Professor D. V.

* Evans, M. and Drake, W. B. "17-Year Report on the Owensboro - Hartford Cooperative Investigation of Joint Spacing in Concrete Pavements," Proceedings, Vol. 38, 1959.

Terrell were rather widely known. The mandatory control of the quality of road material by the Bureau of Public Roads alarmed some of the neighboring States, and it appeared for a time that some would subscribe to testing services available at the University of Kentucky. Professor Terrell was appointed to an ad hoc committee in 1918 to establish material requirements and appropriate test methods. These requirements and methods were issued as Bulletin 949, U. S. Department of Agriculture, and remained in effect until after 1920 when AASHO became a specifications and tests organization. By and large, these early efforts inaugurated research in highway materials and was perhaps instrumental in the organization of the Highway Research Board in 1920.

Testing of road materials and research were continued jointly under Professor Terrell until 1928 when the testing services were transferred to Frankfort where a testing laboratory was provided, (adjacent to the Ann Street garage). Some research, however, continued at the University in the Department of Civil Engineering. Professor Terrell devoted his summers to research, and an attempt was made to utilize the Frankfort forces and facilities during the winter seasons. These arrangements continued until about 1939 when it became apparent that a more intensified, more productive research program was needed. Realizing from previous experience that research was a completely separate entity from testing, the Commissioner of Highways attested to the Board of Trustees of the University, July 23, 1941, as follows:

"During the past two years, this Department has explored and studied the important problem of conducting exhaustive research on highway materials ... Such studies as we have thus far made disclose the possibility of great savings and the advisability of separating the pure research program from the standard procedure of testing road construction materials."

"Therefore, we have reached the definite conclusion that the surroundings on the Campus of the University will tend to greatly facilitate pure research and that the association with the College of Engineering in this endeavor will be advantageous to all parties concerned..."

Other communications concerning early negotiations lamented the dependency of the Highway Department upon organizations such as the Portland Cement Association and Purdue University to provide basic information.

A building was erected in 1941; but, because of the onset of World War II, the facility remained under-staffed until 1946. Prior to 1945, the staff consisted principally of Curtis Cantrill, Carey Burns, and S. T. Collier. In 1945, L. E. Gregg, formerly with

Purdue University, became Associate Director of Research. Assistant Dean of Engineering, D. V. Terrell was ex officio Director. Under Gregg's influence and leadership, the laboratory expanded into five sections, each headed by a capable person. Mr. Robert F. Baker, who is now Director of Research and Development for the U.S. Bureau of Public Roads, joined the staff early in 1946. Both Gregg and Baker had specialized in soil mechanics at Purdue and in the beginning devoted their talents to this important field. James L. Young, Jr., a geologist, was added to the staff. The principal staff at that time consisted of James H. Havens, the present Director; W. B. Drake, former Director and now Assistant State Highway Engineer; E. G. Williams, who is now the Asphalt Institute's representative in Kentucky; S. T. Collier, now Engineer of Specifications; and Carey Burns, deceased. Research was then a branch of the Division of Design. In 1949, it became the Research Division.

In the subsequent 18 years or so, possibly as many as 1000 people have come under the supervision of the Division - either as a student trainee, part-time employee, or full-time staff member. The attrition rate has been rather high inasmuch as qualified, dedicated researchers are hard to find and even more difficult to retain. Research is a tedious occupation and few have the fortitude to pursue it. Many, who have developed a reputation as an authority in some specialty, have commanded better positions elsewhere.

In the eighteen years since 1946, the Division has amassed and indexed some 240 research reports and papers dealing with various studies and investigations. This rate of productivity averages slightly more than one per month. However, these statistics cannot possibly imply the significance or importance of these studies to the Department. Perhaps, in retrospect, some of the studies appear trivial or inconsequential whereas, at the time, they were of considerable importance. Many of them were no more than are impromptu investigation and required only a few days or weeks to complete. On the other hand, a majority of them required one to three years to complete. A large portion of the effort on a project goes into the documentation and reporting of the work. Anything less than a full discourse describing the need for the work, the objectives, methods, analyses, and conclusions is disdained.

Practically everything that man knows is recorded in literature somewhere. Perhaps many discoveries have been made and lost because they were not properly documented; this means that they must be discovered again. By the same token, those who ignore the past by failing to research the literature are doomed to repeat what others have already done. Retrieval of information from the literature is in itself a major task confronting the meticulous researcher;

this aspect of research in any field is not unlike the problems confronting a historian.

Somehow, there is always a lingering suspicion that research is not really an essential activity; on the other hand, it is a type of activity which must continually reprove its worth. In its abstract sense, research implies an ability to discern the significance of a problem, accumulate all of the facts bearing thereon, and to rationally analyze the situation. The strength of this ability reverts to individuals and personalities and to team efforts. The ability to accomplish work in various categories, as well as productivity are measures of functional potentialities. The actual value of research depends, to a great extent, upon the importance of the problem to which the effort is consigned - that is, if the effort were expended solely on trivial problems, the rewards would indeed be trivial. From this point of view, research efforts should be selective and directed toward problems offering the greatest potential reward and toward areas of the greatest need. Dean Terrell has commented on many occasions that "the purpose of research is not to save money but to make it go farther;" and the researcher would like to say demurely that each dollar that has been invested in research has been returned many times. However, this has been one aspect of the program to which a somewhat callous laxity must be confessed.

The purpose of this historical review of the Kentucky Highway Research Program is to provide at least a brief compilation of accomplishments which have contributed in various degrees of importance to the main business of the Department of Highways - that is, the design, construction, and maintenance of roads. We, who are involved in research, may tend to overrate the importance of our work; but, on the other hand, our work has been and is rather diversified; and everyone may not be familiar with it in its entirety or recall work done beyond the immediate past. The report today is actually in three tenses - past, present, and future - and is, in fact, the beginning of a research project in itself. In the program for the current fiscal year, a project (KYP-64-1) entitled "Annotated Bibliography and History of Highway Research in Kentucky" was planned. This report today is in the nature of a preliminary outline or draft of that project report. Of course, it would not be prudent at this time to even mention as many as 250 items; however, this opportunity to present some of the highlights from the over-all program is welcomed.

RECAPITULATION OF SOME SIGNIFICANT RESEARCH

From the very beginning, 1. the quality, soundness, and durability of road aggregates (see Figures 1 and 2), 2. the design and control of concrete mixes, 3. the durability of concrete, 4. bituminous materials and mixes, 5. curing, 6. and effects of freezing on concrete (see Figure 3), 7. soils, 8. construction methods, etc have been researchable problems and have been under continual surveillance. The first freezing tests on concrete were made in 1929, and the specimens were transported to a local ice-cream plant for freezing. Without doubt, these have been the most researched items in the whole history of highways, and even now a large portion of the research effort here and elsewhere is channeled toward physical research. This is not to say that progress has not been made; many problems have been solved whereas many new ones have been disclosed; and so, many things become subject to perpetual study. Nevertheless, these are the substances of which roads are built, and it is toward the proper and efficient utilizations of materials that physical research is aimed. This point has again been emphasized to explain why so much research is concerned with materials and specifications. All other functions involving design, construction, and maintenance of roads emerge or evolve from a knowledge of materials.

Thickness Criterion for the Design of Bituminous Pavements

In 1941 California inaugurated a scheme for determining the thickness of a pavement structure that would be needed to withstand a given quantity of mixed traffic. Bradbury* had previously demonstrated that each 1000 pounds of load added to a 5000 pound wheel load almost doubled the damaging effects of each application of the load to a portland cement concrete pavement. These equivalency factors were used to reduce mixed traffic to an equivalent number of repetitions of a 5000 pound wheel. By sampling traffic and determining the number of trucks and the number of wheels in the various weight classes and by using Bradbury's equivalency factors, a daily or yearly accumulative index of traffic was obtained. For projected design, the existing truck traffic was expected to double in 10 years. By knowing the original

* Bradbury, R. D. Reinforced Concrete Pavements, Wire Reinforcement Institute, 1938.

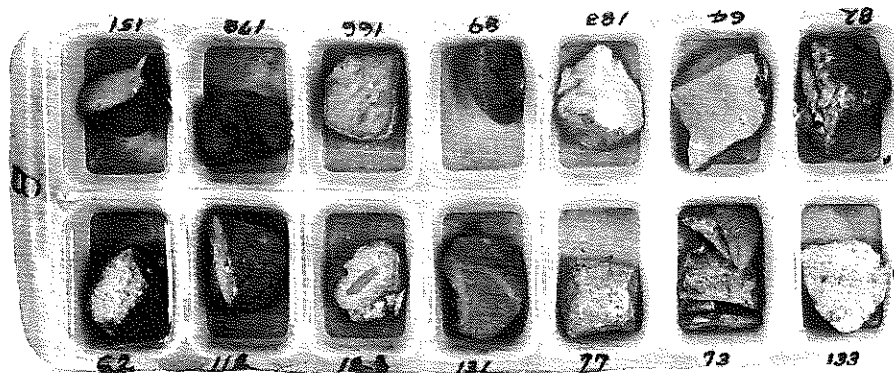


Figure 1. Photograph Showing Various Aggregate Particles Before Freezing.



Figure 2. Photograph Showing Various Aggregate Particles (Same Particles Shown in Figure 1) After Freezing and Thawing.

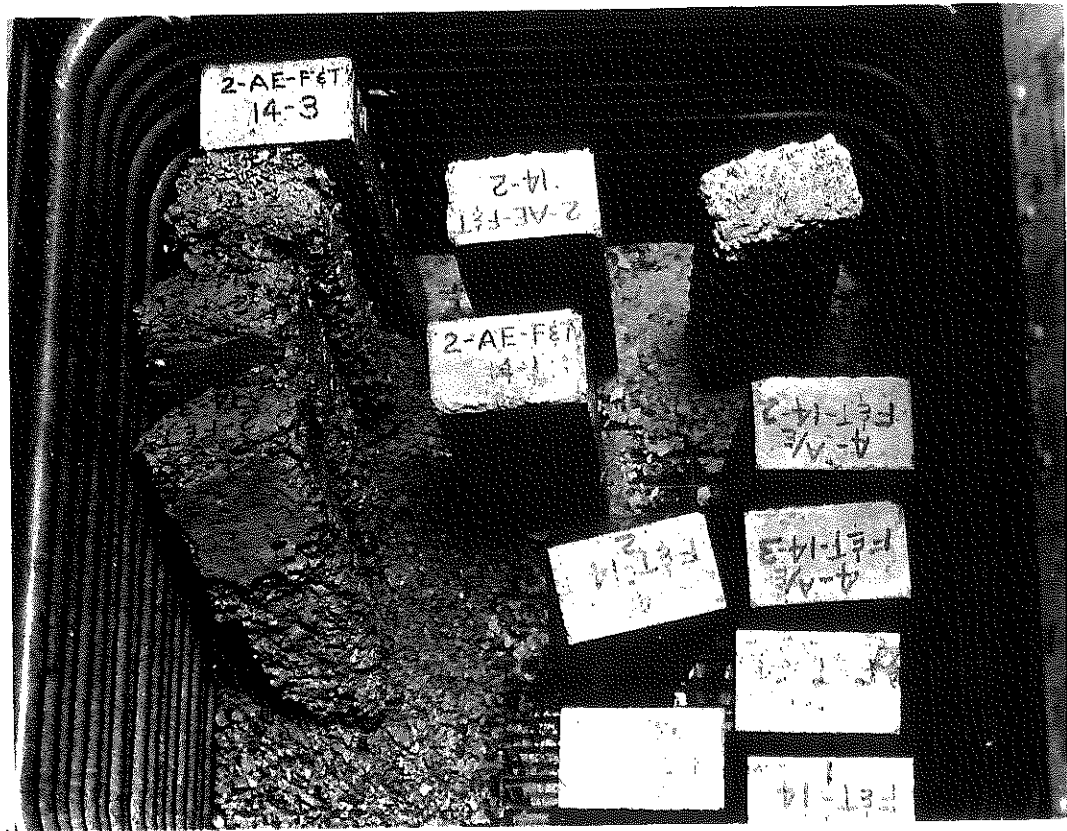


Figure 3. Illustration of the Improvement in the Durability of Concrete as a Result of Air-Entrainment.

current traffic counts, etc on existing roads, the accumulated 5000 pound equivalent wheel loads (EWL) could be estimated. This meant that existing roads could be studied in relation to the traffic, thickness of the pavement structure, and the strength (California Bearing Ratio or CBR) of the supporting soil. This was an empirical scheme whereas some of the earlier methods of design were quasi-rational. California developed a design chart relating traffic, thickness, and CBR. Kentucky adopted their method as a guide for design. In 1946 an extensive study of existing pavements was made to develop design criterion for Kentucky that was based on the California scheme. Several hundred miles of road were studied; some 250 test pits were opened in the pavements; bearing tests were made on the subgrade soil; samples were taken for laboratory testing and classification. Traffic counts were obtained and temporary loadameter stations were set up to supplement permanent ones and estimates were made of the accumulated EWL's. Correlation charts (see Figure 4) were drawn to give the best separation between poorly performing pavements and adequately performing pavements. In using these curves, the EWL used for design was estimated as that which would accumulate over a period of 10 years. This design system was adopted by the Department in 1948.

In 1958 the whole system was re-evaluated and refined.* About 80 roads designed according to the 1948 criterion were studied. Only minor changes in the curves (see Figure 5) were made at that time. This re-study was completed before AASHO Road Test was built; and we have since made a detailed comparative analysis of our design chart in relation to findings from the Road Test and find that they are essentially in agreement. Some nominal modifications are foreseen, but our present designs and practices are perfectly valid.

Perhaps the principal contribution derived from the AASHO Road Test was the establishment of more precise load-equivalency factors. The Road Test largely confirmed Bradbury's approach, and the principle of fatigue implies more clearly that pavement structures can be economically designed to support a given finite number of applications of EWL's during its lifetime. This principle may be paraphrased as follows:

The relative damaging effects of loads of different magnitudes is proportional to the number of applications of each load that will cause failure. Thus, if N_1 applications of load P_1 will cause failure, and if N_2 applications of P_2 will cause failure, then one application of P_2 is equivalent to N_1/N_2 applications of P_1 .

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- * Drake, W. B. and Havens, J. H. "Kentucky Flexible Pavement Design Studies," Bulletin No. 52, Engineering Experiment Station, University of Kentucky, June, 1959.
 - * Drake, W. B. and Havens, J. H. "Re-Evaluation of Kentucky Flexible Pavement Design Criterion," Bulletin No. 233, Highway Research Board, 1959.

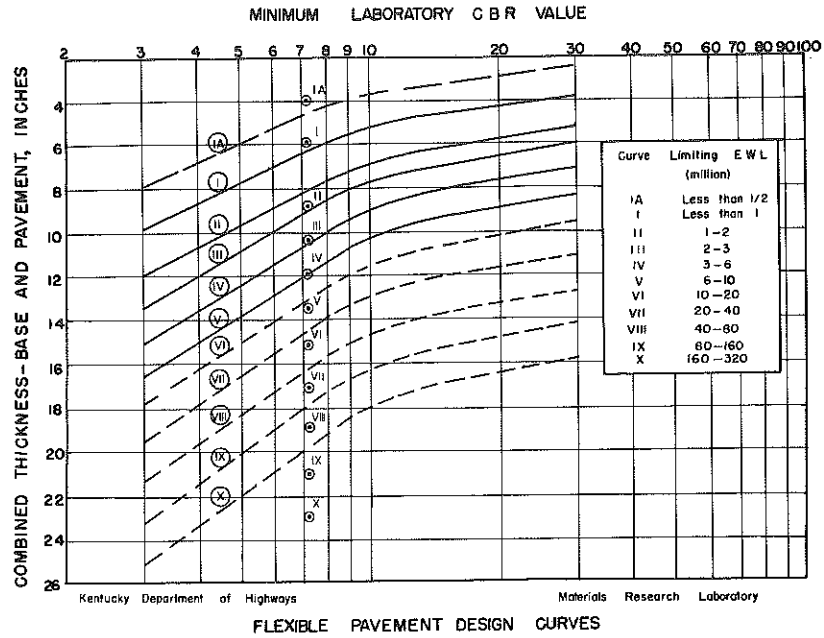


Figure 4. Kentucky Flexible Pavement Design Chart Developed in 1948; Shows Control Points Derived from the 1958 Re-evaluation Study.

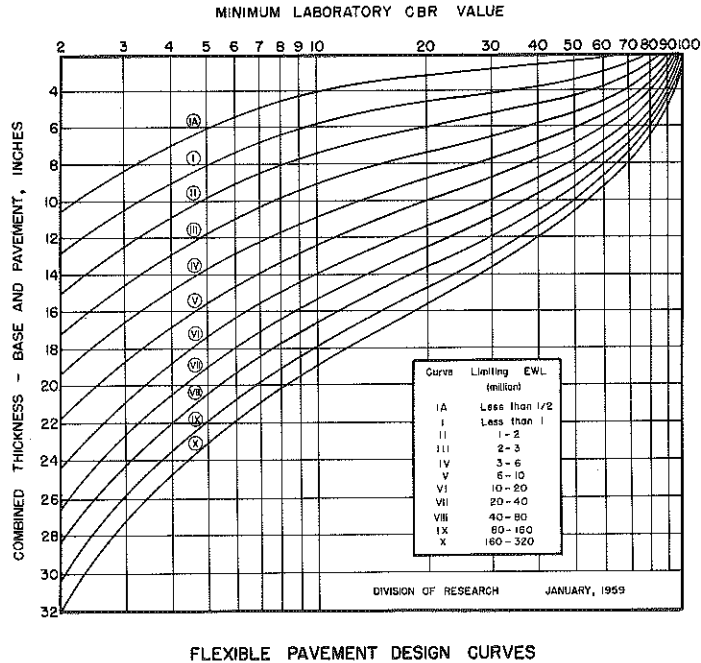


Figure 5. Revised Kentucky Flexible Pavement Design Chart, 1958 Re-evaluation Study.

Using the above principle, Kentucky's EWL's are convertible into AASHO, equivalent 18-kip axles.

The basic Kentucky load is a 5000 pound wheel (or a 10-kip axle) whereas the basic AASHO load is an 18-kip axle. The original California factor for equating the damaging effect of a 9000 pound wheel (18-kip axle) to a 5000 pound wheel load was 16. To convert from a 5000 pound EWL to an 18-kip basis the 5000 pound EWL is merely divided by 16. Inasmuch as the Kentucky EWL includes two-direction traffic and is now computed for a 20-year period, the daily, AASHO equivalent number of 18-kip axles is obtained approximately by dividing the Kentucky EWL by $20 \times 365 \times 2 \times 16$. These conversions have permitted a direct comparison between Kentucky designs and the AASHO Road Test. A set of precise conversions for both flexible and rigid pavements is shown in Table 1.

Table 1.
Summary of Conversions of Kentucky EWL's to AASHO Traffic Basis

Ky. Traf- fic Curve	Ky. EWL 20- Year (10 ⁶)	Ky. Daily Equiv. 10-kip Axles	20-Year AASHO EWL (10 ⁶)				Equivalent Daily AASHO 18-kip Axles			
			Flexible		Rigid		Flexible		Rigid	
			P _t *		P _t		P _t		P _t	
			2.0	2.5	2.0	2.5	2.0	2.5	2.0	2.5
IA	0.25	17	0.0072	0.0078	0.0076	0.0078	1	1	1	1
I	0.50	35	0.0144	0.0155	0.0152	0.0156	2	2	2	2
II	1	69	0.0287	0.0310	0.0303	0.0311	4	4	4	4
III	2	137	0.0575	0.0620	0.0607	0.0622	8	9	9	9
IV	4	274	0.1150	0.1240	0.1214	0.1244	16	17	17	17
V	8	548	0.2299	0.2479	0.2428	0.2489	32	34	34	34
VI	16	1,096	0.4599	0.4958	0.4855	0.4977	63	68	67	68
VII	32	2,192	0.9197	0.9916	0.9710	0.9954	126	136	133	137
VIII	64	4,384	1.8394	1.9832	1.9420	1.9908	252	272	266	273
IX	128	8,767	3.6788	3.9664	3.8840	3.9816	504	544	532	546
X	256	17,534	7.3476	7.9328	7.7680	7.9632	1008	1087	1064	1091

*P_t - Terminal Serviceability Index

The 1958 Kentucky design curves for bituminous pavements are shown in Figure 5. These curves give only the total thickness of the pavement; however, they are based on the past performances of actual pavements in which, on the average, one-fourth to one-third of the thickness consisted of bituminous concrete. It can be noted that each successive curve doubles the EWL. This implies that an error of one to two inches in thickness could double or halve the life of the pavement. To illustrate how critical such an error might be, suppose that the traffic accumulated twice as fast as it was predicted. This would reduce the life of the pavement to one-fourth of its design life. Of course, an extra inch of thickness would have just balanced the error in the traffic estimate. This example further illustrates the importance of having reliable traffic data. An increase of 2000 pounds in average axle load, holding the number of repetitions constant, is almost the same as doubling the EWL and would require approximately one additional inch of thickness to sustain the pavement through its design life. Traffic is estimated and projected 20 years ahead, and the pavement is designed to withstand this 20 year accumulation. If the traffic develops more rapidly, then the life of the pavement is commensurately shortened. Since 1948, the average accumulations of traffic have been in close agreement with the estimates. However, as far as individual roads are concerned, the deviations have been great. As an example, in three years, one road accumulated 70% of its 10 year estimate.

Thus, it can be seen that a pavement might be designed very accurately to carry the amount of traffic predicted for it and still last only a few years. The error would not lie in the design curves but would be in forecasting of traffic. Forecasting the total accumulation of traffic 20 years hence is probably about as reliable as forecasting the weather. Nevertheless, it is an essential part of pavement design. The Planning Division has been making traffic counts since about 1934, and samplings of axle loads are taken yearly. In-stream counting methods have been developed to a rather high degree of perfection. Everyone is more conscious of the need for total counts inasmuch as they are needed to establish the class and geometrics of a roadway. From the standpoint of pavement design, the need is to know the axle weights as well as the total traffic.

Thickness Criterion For the Design PCC Pavements

Prior to the AASHO Road Test Kentucky had not tackled the problem of thickness design for concrete pavements inasmuch as the Portland Cement Association and the Bureau of Public Roads had provided rational criteria which appeared to be reasonably valid but was somewhat limited to static load concepts. In 1947, an extensive study of "pumping" under concrete pavements was undertaken in Kentucky. The results from this work strongly favored the use of a granular insulation course under concrete pavements and this practice continues to the present time.

The AASHO Road Test confirmed the advantages of an insulation course; but, more importantly, it also provided a method of dealing with composite or mixed traffic on the same basis as used in the design of bituminous pavements. Through this equality in traffic, the thickness of the two main types of pavements may be compared. From another point of view, this implies that for a given traffic condition, equal designs may be made.

Several experimental concrete pavements were built around 1940,* and these have been evaluated and reported on from time to time.

Road Roughness

During World War II there was a severe restriction on the speed of vehicles on the highways. After the close of the War and after the restrictions were removed, people resorted to their favorite rate of travel. About 1950, after a few new roads had been built, the traveling public became conscious of waves and undulations in the pavement. This sort of thing could develop into a safety hazard at high speeds causing motion sickness and fatigue. These were waves that would not normally be detected with a 10 foot straight edge and were, in fact, in the order of 80 to 150 feet or more in length. A similar type of roughness was detected on resurfacing projects as well.

Pavements to be resurfaced very frequently needed wedge courses to bring them up to a smooth grade and crown. It seemed that water-bound macadam bases could not be built to the precise tolerances desired. Pavers had short wheel-bases and normally reproduced the profile of the base on which they traveled. Coarse stone bases, of course, could not be reshaped or disturbed. Wedge courses or leveling courses seemed to be needed in case of these bases. At that time, it seemed that long wheel-based grading machines were the logical answer. In several cases, graders were used to spread hot-mixed bituminous concrete leveling courses, and in each case the riding quality of the final surface was improved.

The possibility of setting forms and rails for the paver to ride was considered as a possible recourse. However, the thinking invariably reverted to the idea that a paving machine would do a satisfactory job if it had a smooth base on which to ride. This line of reasoning led to the conclusion that a fine-graded granular base could be shaped with a long planning machine and be compacted to provide a more suitable foundation.

Subsequently, a method of monitoring the accelerations experienced by a passenger riding in a car at normal driving speeds was developed by the Research Division and thus made it possible to rate pavements in terms of their riding qualities. This system

* Gregg, L. E. "Experiments with Air Entrainment in Cement Concrete," Bulletin No. 5, Engineering Experiment Station, University of Kentucky, September, 1947.

has continued under development; and, for several years now, newly constructed pavements have been rated from the standpoint of workmanship and from the standpoint of subsequent annual rate of deterioration under traffic.

The AASHO Road Test introduced the concept of rating pavements according to their serviceability. Roughness is the most significant factor in a serviceability rating and Kentucky's roughness indexes correlate nicely with the more general indexes. This serviceability index is important from the standpoint of pavement design because it indicates how well a pavement is performing its designed function and how much additional traffic it can carry before it deteriorates to a point where resurfacing or reconstruction will be needed.

Within the past two or three years, industry has contributed electronically controlled leveling devices for paving machines, and these units have significantly improved the smoothness of new pavements where they have been employed. Sawing joints in concrete pavements has contributed greatly to the smoothness of the finished pavements. Good riding quality has come to be expected in all kinds of paving, but this is especially so on turnpikes and interstate roads. Not only is it desirable to build good riding quality into these roads but also to forestall troublesome settlement and distortions.

At the 14th Highway Conference in 1962, a detailed report on Kentucky's studies of riding qualities and pavement roughness was presented.

Pavement Slipperiness

Throughout much of the past history of roads in Kentucky, Kentucky Rock Asphalt served as one of the principal surfacing materials. When a pavement became slick--through bleeding, wear, or polishing--the cure prescribed was resurfacing or deslicking with Kentucky Rock Asphalt. In fact a large portion of the road mileage in Kentucky was at one time or another surfaced with this material and many of them are still in service. These rock asphalt surfaces were notoriously skid-proof, but the material was more expensive than bituminous concrete and had a tendency to scale making a rough, unsightly pavement (see Figure 6). Because of this, it fell into disfavor and disappeared from the scene.

Until about 1953 or 1954, when rock asphalt demised and post-war traffic really began to flood the roads, the highway engineer was not fully conscious that a serious slipperiness problem existed in Kentucky. However, an intensive study was being carried on in Tennessee where a towed-trailer skid-tester had been built. The neighbors from Tennessee were interested in calibrating their device on some of Kentucky's rock asphalt and sandstone surfaces. As a matter of interest comparison tests were made on several bituminous

concrete surfaces composed largely of limestone aggregate. Many were found to be critically slippery. These tests led to a recommendation to the Department suggesting that aggregate for bituminous surfaces, for medium and high traffic, contain 50% quartz sand.

Kentucky's studies relating to slipperiness stem from that time. Some of the qualities of rock asphalt were admired but its deficiencies were also recognized; attention then was directed to the design of sand-asphalt mixtures to supplant rock asphalt. Virginia had already undertaken a similar endeavor and had achieved considerable success in applying thin sand-asphalt surfaces to existing pavements. They were laying them as thin as 1/4 inch whereas rock asphalt had traditionally been placed in thicknesses ranging from one-half to one and one-fourth inch. Kentucky's interest in a thin, skid-resistant surfacing course arises from the fact that in limestone areas, natural quartz sands have to be shipped in and are much more expensive than crushed limestone sand. Therefore, the structural part of the pavement is more economically constructed with limestone aggregate. Whereas present practices require that the aggregate in the top one and one-half inches be composed of 40% silica sand, it seemingly would be more economical to reserve the premium sand for a thinner top course. As mentioned before, the presence of exposed limestone particles larger than sand-size in the surface are offensive from the standpoint of skid resistance whereas a blend of limestone sand and silica sand in a thin wearing course might provide the degree of skid-resistance desired. These thoughts and enabling provisions are being embodied in specifications.

The Research Division has attacked this problem from several flanks -- that is, from the standpoint of measurement and detection of slipperiness and from fundamental mechanical theory.* A few interesting observations are offered:

1. All clean dry pavements have about the same skid resistance (coefficient of friction of 0.80 to 0.85).
2. Smooth, glassy surfaces become the most slippery when wet.
3. Sand-paper textures retain the highest skid-resistance when wet.
4. Tires tend to hydroplane at speeds of about 85 mph; significant loss of traction begins to occur at about 40 mph.

* Stutzenberger, W. J. and Havens, J. H. "A Study of the Polishing Characteristics of Limestone and Sandstone Aggregates in Regard to Pavement Slipperiness," Bulletin No. 186, Highway Research Board, 1958.

Havens, J. H. "Skid Prevention Studies in Kentucky," Proceedings, Part II, First International Skid Prevention

5. A vehicle traveling 60 mph has enough kinetic energy to cause it to hurtle 121 feet upward if it underwent a change in direction without loss of energy. This is the same distance it would skid horizontally if it were sliding on a pavement where the coefficient of friction was 1.0. If the coefficient of friction were 0.14, such as might be expected on snow or ice, the sliding-stopping distance from 60 mph is 875 feet.
6. Coefficients of friction less than 0.4 are critically hazardous.
7. The maximum horsepower that can be utilized in accelerating to a given speed is limited by the coefficient of friction between the tires and the pavement. If the coefficient of friction were 1.0 (maximum conceivable value) and if only the rear wheels are in traction, only 310 h.p. could be utilized in accelerating a 3850 pound vehicle to 60 mph.
8. The reason that trailer trucks tend to jack-knife on slippery roads is because the load of the cargo is concentrated near the front of the van rather than over the rear axle.

Sandstone

As already inferred, Kentucky has had a long-standing interest in sandstone as an aggregate. In 1927 sandstone was used in some 30 miles of concrete paving between Pineville and Harlan. About 1940 a portion of the Paintsville-Inez road was surfaced with bituminous concrete with sandstone aggregate. The Salyersville-Royalton road was also paved with sandstone about that time. About 1950 the problem was attacked anew. After about a year of laboratory work, a test road was constructed on Ky 30 between Salyersville and Jackson. This work transcended more than three years and was nominally successful in achieving its objective. It proved again that sandstone could be utilized as a bituminous paving aggregate when and if the need arises and other circumstances become favorable.



Figure 6. Illustration of Poor Performance Exhibited by Kentucky Rock Asphalt.

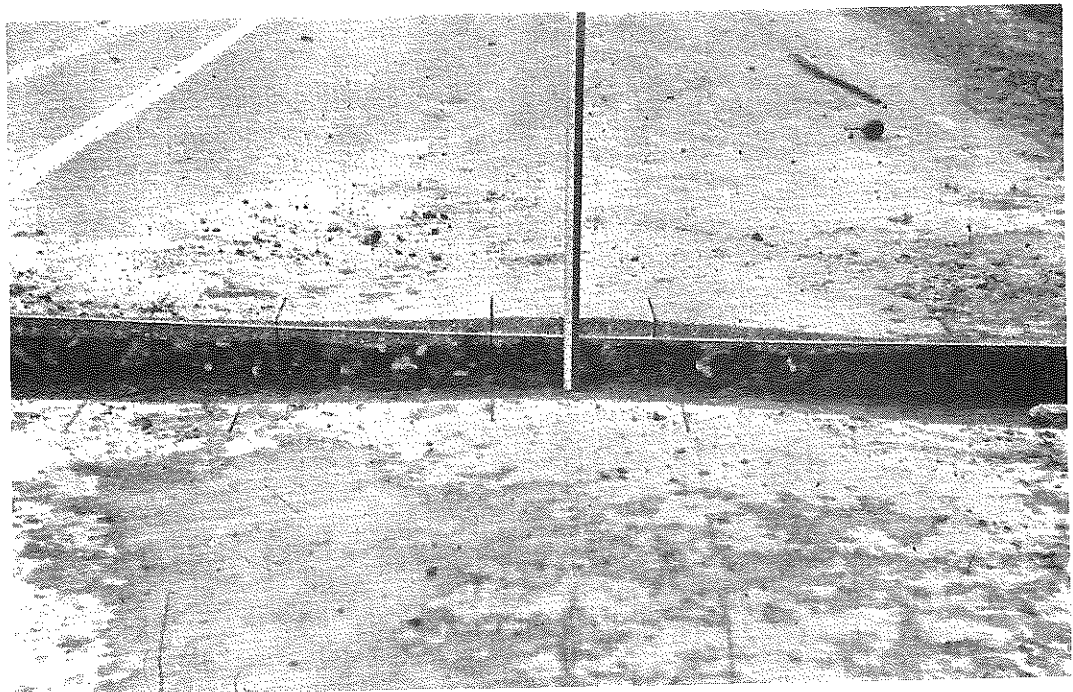


Figure 7. Water-Bound Macadam Base Showing Rutting of Pavement in Wheel Tracks and Intrusion of Soil.

Drainage

Research relating to highway drainage has dealt with three major subjects, two of which are contiguous to each other, the third is concerned with the durability of culvert materials.

Hydrology and Hydraulics. About 1950, the Division of Design expressed some dissatisfaction with their practices for sizing culverts. They were concerned about the possibility that the criterion at that time frequently led to extravagancies and overdesigns, whereas in some cases new culverts flooded and overflowed the roadway (see Figure 8). The Research Division undertook an analysis of the situation and an evaluation of the criterion.

Rainfall records were analyzed and intensity-duration curves were developed for the various areas of the State. These data provided a statistical basis for determining the run-off and discharge needed for the hydraulic design and sizing of the culverts. These data, combined with basic hydraulics, provided the foundation for the Department's present design practices and were condensed in the form of a Drainage Manual by the Division of Design. A staff team spent some three years on this project.

Subsequently, the team directed its attention to basic hydraulics and a number of reports dealing with entrances and head-discharge relationships were prepared.*

Durability of Culvert Materials. In September of 1949, the research staff was requested to investigate the premature failure of galvanized corrugated metal entrance culverts on US 60 north of Princess, Kentucky. Water carried by the side ditch on the east side of the road had corroded the bottom out of a series of 40-inch diameter pipe, whereas, on the opposite side of the road, the water had not damaged the pipe at all. The corrosive water emanated from a strip-mine area. During 1950 and 1951, an extensive survey of culvert conditions throughout the State was made and the problem areas were delineated. As an outgrowth of these surveys, the Department adopted certain policies or practices restricting the use of some types of culverts in these localities. Also, in extremely severe situations, special means of protection were recommended. In 1951 a culvert test site (see Figure 9) was established at Morton's Gap on US 41, south of Madisonville where a source of highly acid water was found. Various kinds of concrete pipe and coated and uncoated metal pipe were installed. Plain galvanized pipe (see Figure 10) lasted only 28 days. After some

* West, E. M. "Model Study of Flow Through Culverts," Bulletin No. 40, Engineering Experiment Station, University of Kentucky, June, 1956.

West, E. M. and Hughes, R. D. "The Development and Use of Hydraulic Models in a Study of Culvert Performance," Bulletin No. 41, Engineering Experiment Station, University of Kentucky, September, 1956.



Figure 8. Illustration of the Importance of Hydrological and Hydraulic Criteria in the Design of Highway Drainage.

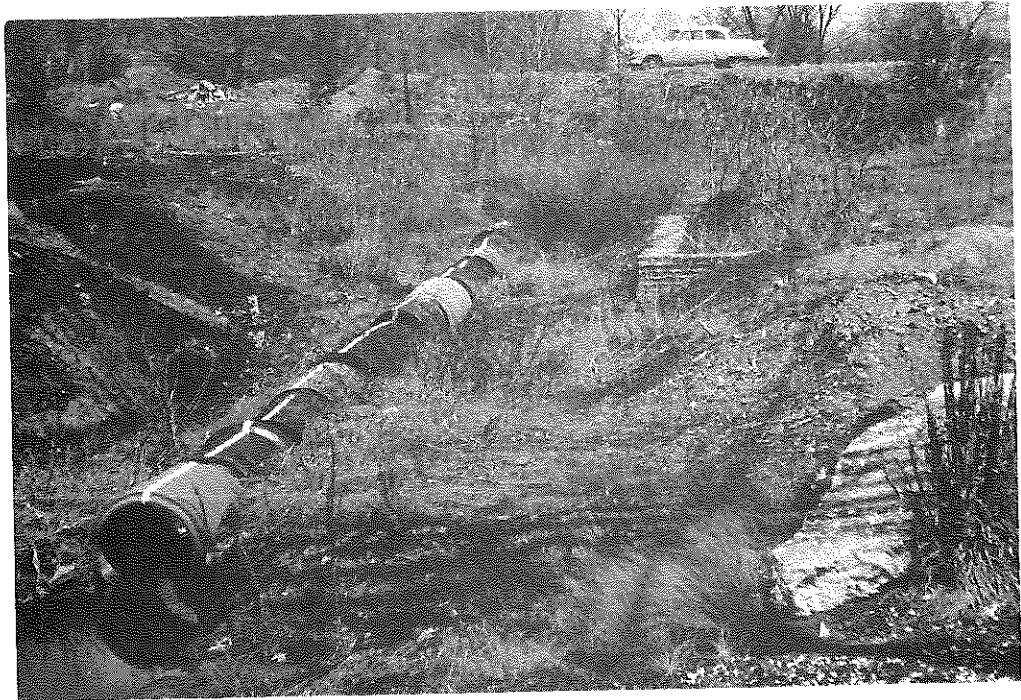


Figure 9. Test Installation at Mortons Gap where Various Types of Culvert Materials are Evaluated According to Their Resistance to Corrosion.

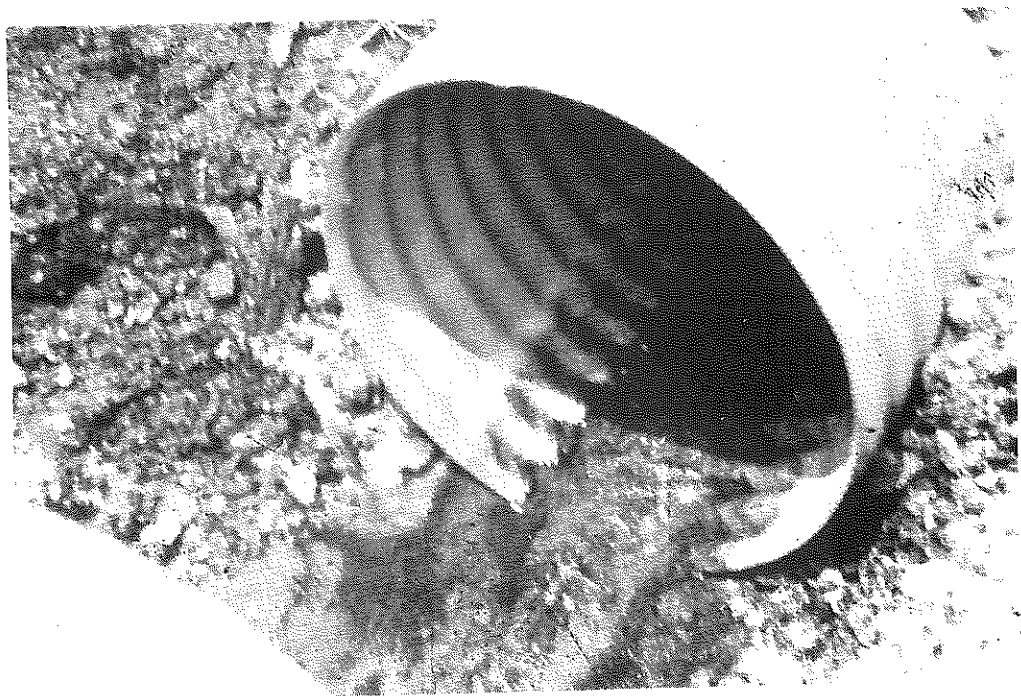


Figure 10. Galvanized, Corrugated Metal Pipe After 28 Days in Test at Mortons Gap.

13 years, concrete pipe (see Figures 11 and 12) is showing rather severe damage and some of the bituminous coated metal pipe have failed. This experiment has demonstrated a need for consideration of the life expectancy of culvert materials in all highway construction. In reconstructing US 41 south of Madisonville, acid resistant liners were cast into concrete pipe and box culverts at several locations. Also on the Western Kentucky Parkway, special protective measures were employed where the water was found to be highly acid.

Traffic Paint

In some years prior to 1951, the Department had paid as much as \$3.50 per gallon for traffic paints. Prior to World War II, traffic paints consisted largely of linseed oil and natural resins and were usually slow drying. Just prior to World War II, glass beads were dropped on the paint for night-time reflectorization (see Figure 13). Following the war premixed paints containing glass beads became available. Some highway departments relied predominately on formulation-type specifications whereas others merely specified a particular proprietary product (by brand name) or an equal. Practically all of the pre-war formulations became obsolete when post-war synthetic resins became available. When the Research Laboratory began to study formulations, it became progressively obvious that a different approach was needed. Various formulation types of paints as well as proprietary paints were obtained and subjected to a comparative road test. The Department continued to buy paint by formulation for another year but also continued the road tests. It became obvious that considerable savings could be realized by purchasing paints on the basis of performance testing (see Figure 14). A strong preference was indicated toward premixed beads, and the testing of drop-on beads was discontinued. After two or three years, the entire procurement program was transferred to the Division of Materials.

The Department has since been beset by other problems concerning traffic paint. It is known that a snowy winter such as the one just experienced destroys the paint markings. Snow is very abrasive, and the type of resin which is being used in these paints is not very resistant to the sustained moisture conditions attending the melting of snow and ice. Paints do not perform well on new concrete, but part of the trouble there arises from the fact that the concrete scales off. However, there are some specific ideas on how to overcome this problem and it is hoped that some experimental applications of primers and special paints can be made early this spring.

Perhaps mention should be made of a current project involving so-called hot-melted plastic stripes. These materials were applied on portions of the Watterson Expressway in Louisville, I-64 in Franklin and Shelby Counties, and I-64 in Clark and Montgomery



Figure 11. Concrete Pipe After 28 Days in Test at Mortons Gap.

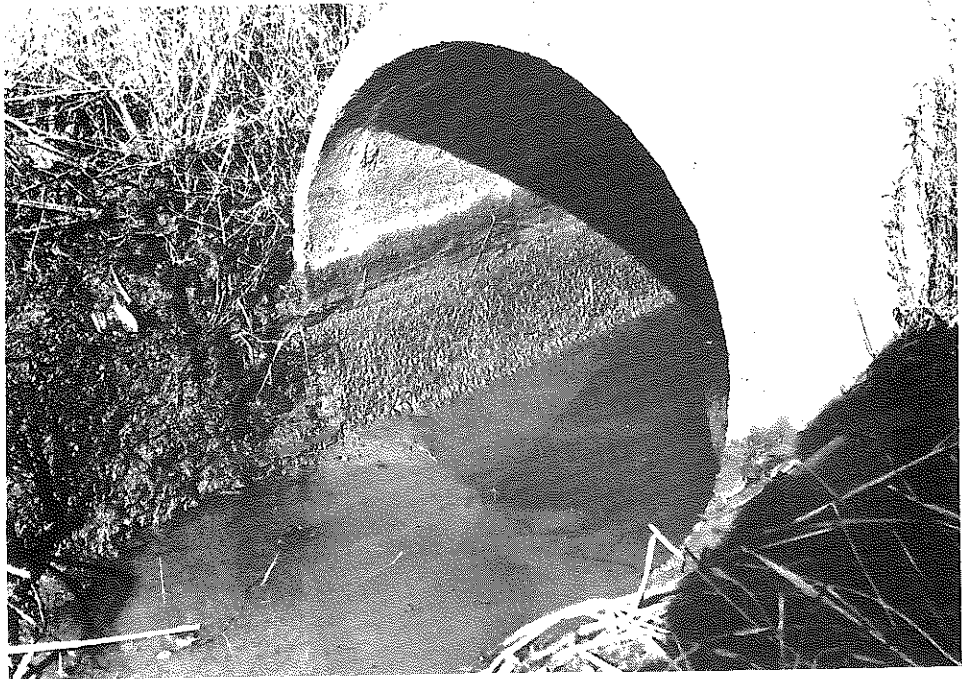


Figure 12. Concrete Pipe After Approximately 10 Years in Test at Mortons Gap.

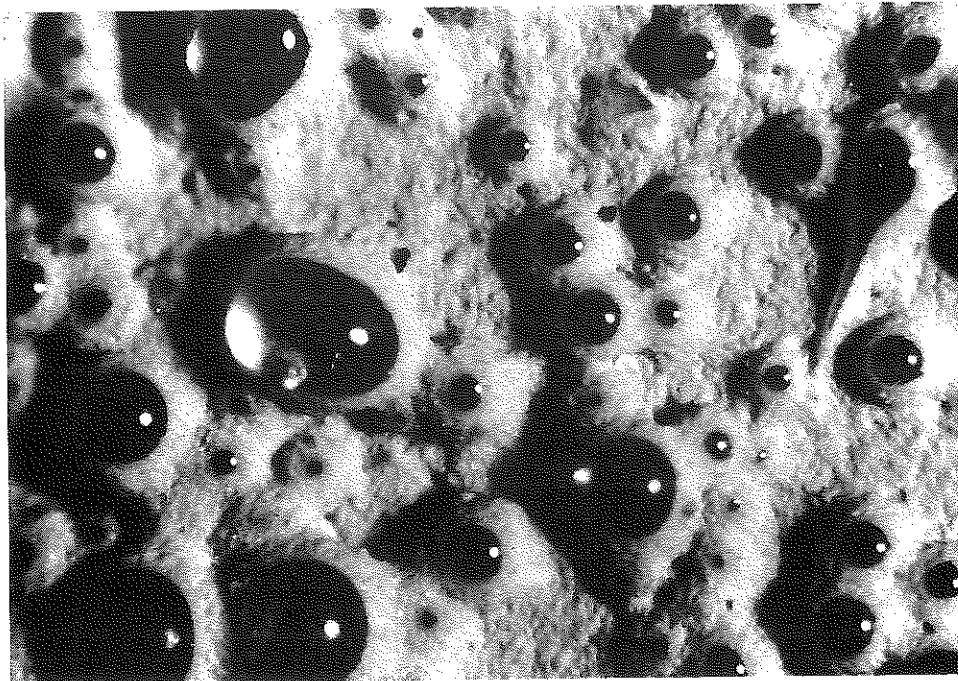


Figure 13. Photomicrograph of a Traffic Paint Stripe Showing Reflectorizing Glass Beads Ideally Anchored in Paint.

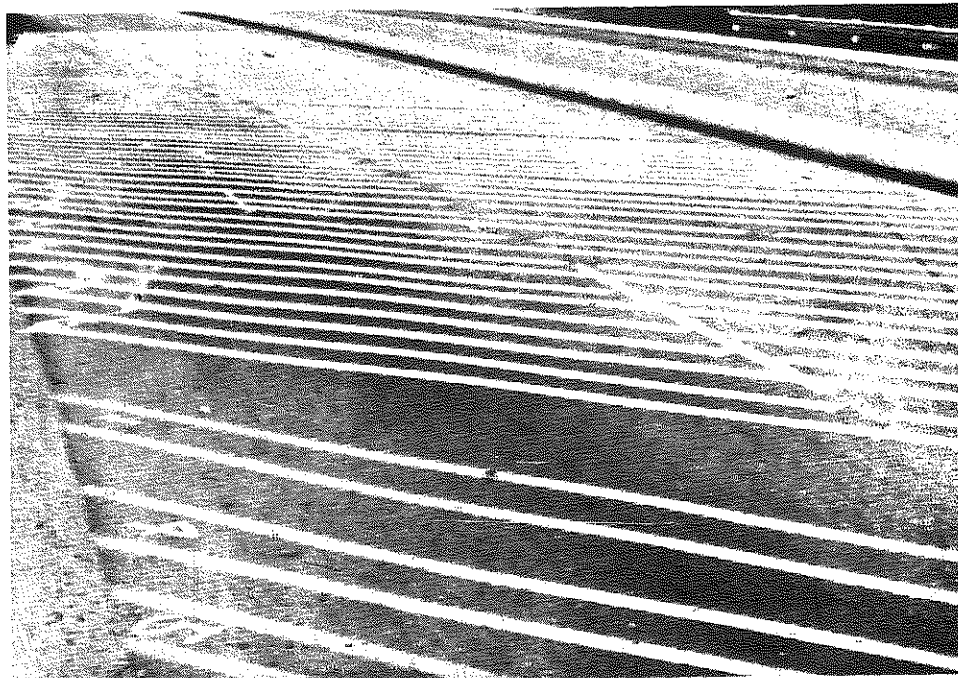


Figure 14. Test Site for Evaluating the Performance of Traffic Paints. Samples Submitted by Manufacturers are Applied Annually; Evaluations of Performance Provide a Basis for Procurement.

Counties (see Figures 15, 16, and 17). They are now in their second winter. This kind of strip costs almost 40 cents per lineal foot whereas ordinary paint costs about one cent per lineal foot. This means that a high degree of performance and permanence from the plastic lines should be expected if this material is to be economically feasible. The deterioration during the past winter was somewhat alarming.

Reflectorized Sign Materials

Another post-war innovation which has commanded much attention through the years is the reflectorization of highway signs (see Figure 18). In 1948 the Research Division was assigned the responsibility of evaluating these materials and preparing suitable specifications for their purchase and use. Special Specification No. 50 was prepared in 1949. Subsequently, a field study (see Figure 19) of the amount of reflectivity needed to recognize letters of different sizes at various distances has been made. Permission was obtained from the Fayette County Road Engineer to erect test signs on the Avon Road. Some 20 people were used as night-time observers and recorded the distance from the signs at which they could accurately declare the identity of the letters.

At this same time the Research Laboratory became interested in a polarizing headlight system which offered considerable possibility of alleviating the glare problem from on-coming headlights. Comparison pictures (see Figures 20 and 21) were made to illustrate the advantages. The system has never been put into use because of conversion difficulties.

Later the sign study had to be abandoned because the signs were confusing to the people traveling the road. However, the test installation had served its purpose and the information needed was obtained. Work has continued with a study of the optical characteristics of beads and the weathering resistance of the materials. Special Specification 50 was revised in 1954 and has continued in effect to the present time. It was renumbered in 1956 as Special Specification 5-56. All of the reflective sign materials used by the Department since 1949 have been specified according to those requirements.

Deterioration of Concrete Bridge Decks

Kentucky, like many other states, is confronted with the alarming problem of bridge deck deterioration. This is really a part of the more general problem of concrete durability. Bridge decks freeze and thaw more often than pavement concrete, and the same quality of materials is used in bridge concrete as is used in pavements. Excessive manipulation, over-finishing, and dissipation of air, cannot be held blameless. It seems that

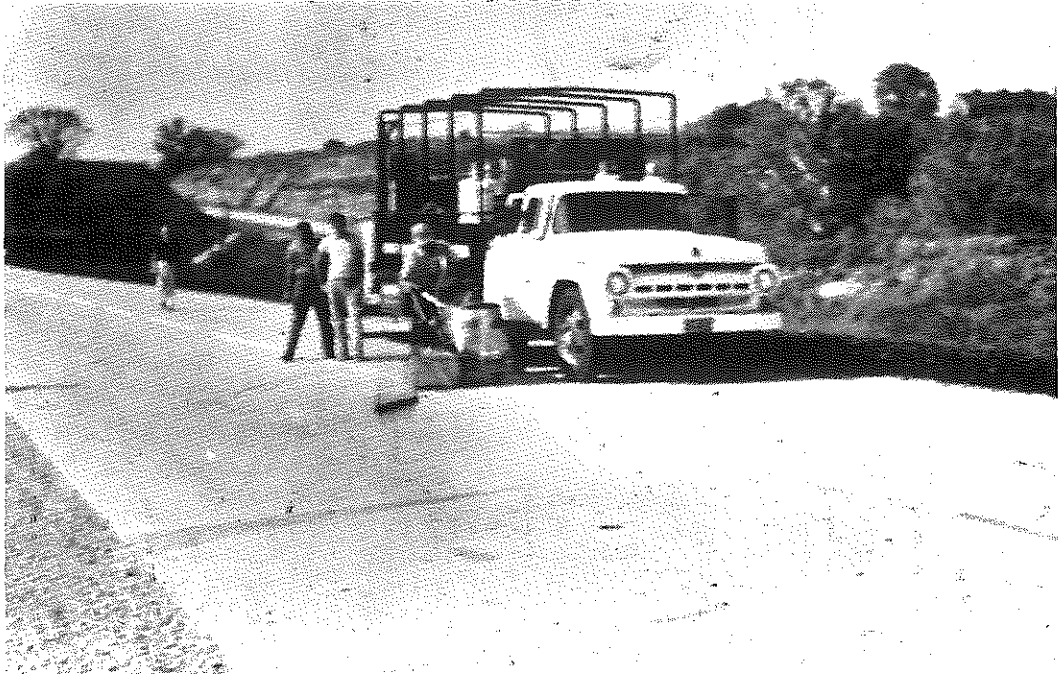


Figure 15. Application of Experimental Thermo-Plastic Stripe.

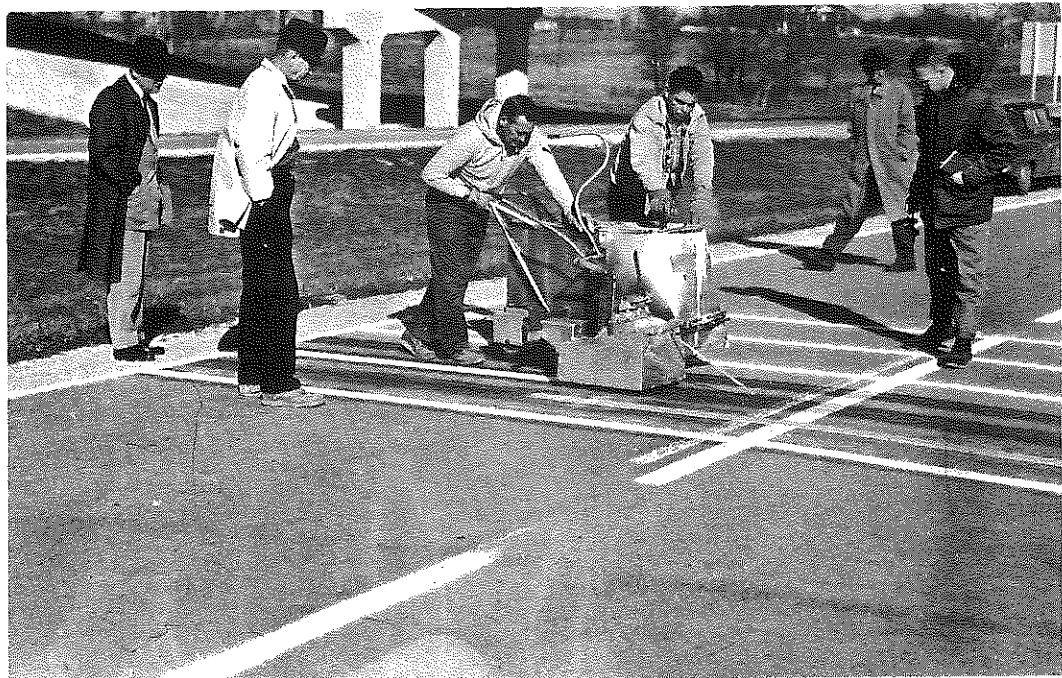


Figure 16. Application of Experimental Thermo-Plastic Cross-Stripe at a Location Where the Performance of Various Striping Materials May be Viewed Comparatively.

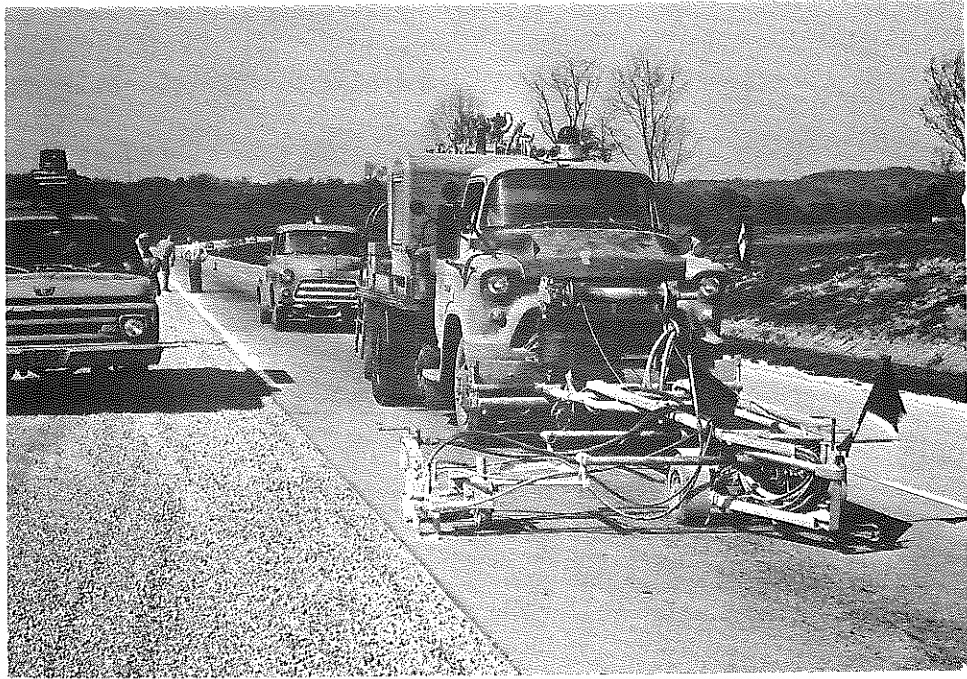


Figure 17. Paint Striper Currently Used by the Highway Department.

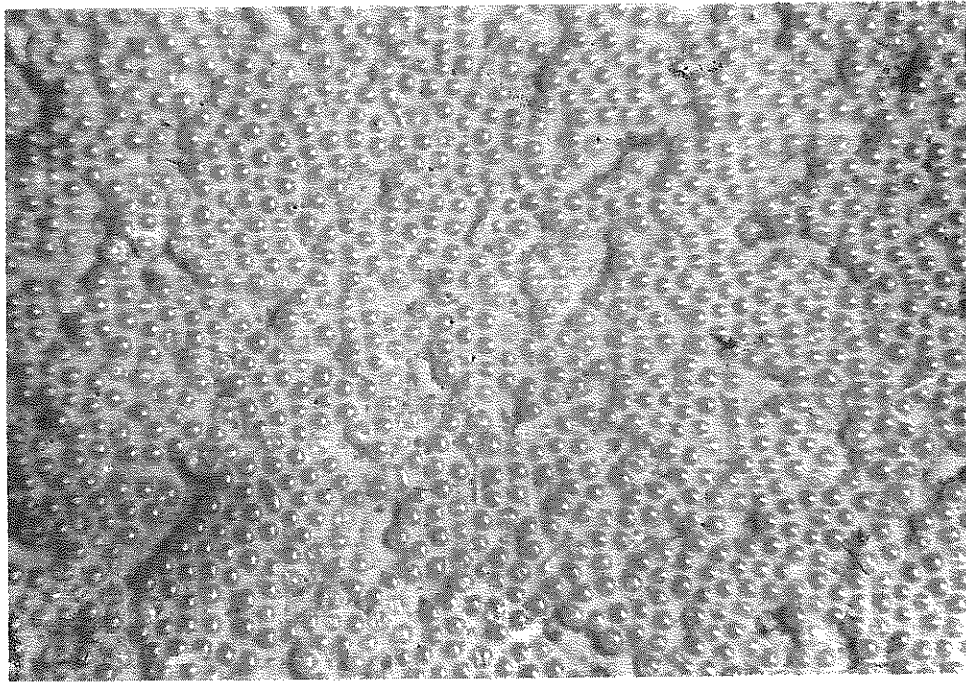


Figure 18. Photomicrograph Showing ReflectORIZING Glass Beads in Sign Surfacing Material. Approximately 200,000 Beads are Used on Each Square Inch of Sign Surface.

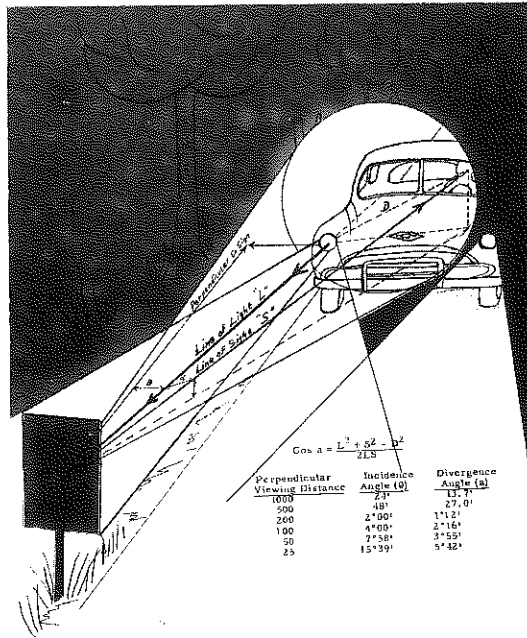
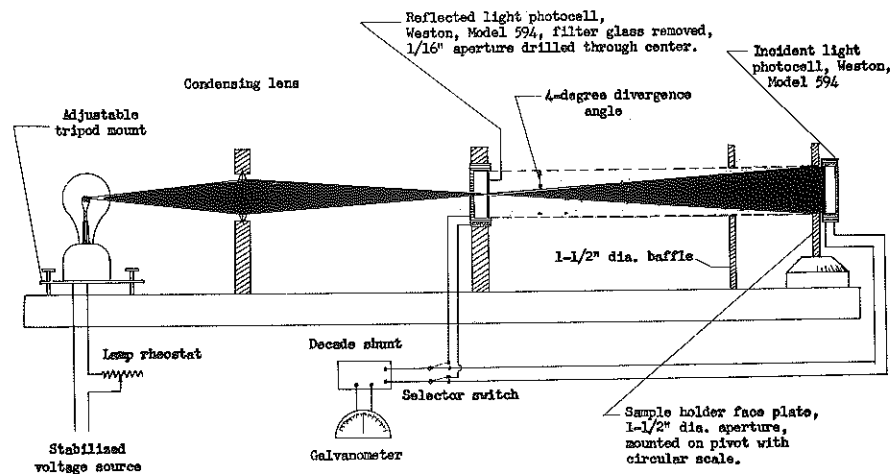


Figure 19 a. Sketch Illustrating the Path of Light with Respect to Night-Time Vision of Highway Signs.



Note: For 4-degree divergence, cell-to-sample distance is 10.7"
 Effective divergence angle decreased to 1-1/2 degrees by placing 1/2" dia. aperture mask over reflected light photocell.

SCHEMATIC DIAGRAM OF REFLEX PHOTOMETER

Figure 19 b. Sketch Illustrating an Optical Reflectometer in which the Conditions of Night-Time Vision of Highway Signs is Simulated and Measured.



Figure 20. Night Photograph Illustrating Ordinary Headlight Glare.



Figure 21. Photograph Illustrating Night-Time Approach in which Both Vehicles are Equipped with Polarized Headlights and Windshields.

new bridges very often deteriorate more rapidly than older ones. On the other hand, many small bridges built in the 1920's and 1930's are now deteriorating rapidly.

The State of New York made a claim recently that they were completing an average of one bridge per day. If these bridges have to be repaired at that same rate some years hence, imagine the seriousness of the problem. Kentucky is probably completing a bridge or so per week and should be equally concerned.

The Research Division first became a party to the problem when the Maintenance Division requested assistance in repairing the deck on the Clark Memorial Bridge in Louisville. Since then some real progress (see Figures 22 and 23) has been made in the use of protective coatings for new bridges, better concreting practices, and in the repair of deteriorating decks. Epoxy resin patches and sand-epoxy seals have been employed on a major bridge on Ky 80 crossing Lake Cumberland and on the Ohio River Bridge at Owensboro. Other bridges are to be treated this spring and summer, and the Division of Research will continue to assist the Maintenance Division in this kind of work. We compiled an extensive report last year on experiences and case studies thus far.

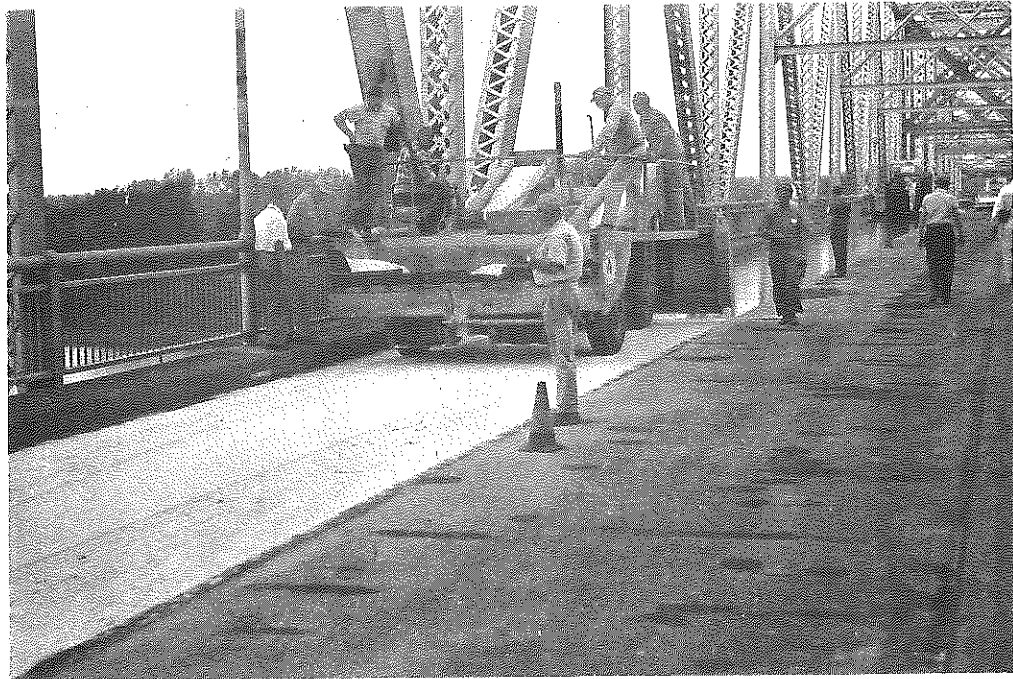


Figure 22. Application of "Epoxy" Protective Coating and Skid-Resistant Sand to a Concrete Bridge Deck Which Has Been Repaired by Patching.



Figure 23. Bridge Deck Which Has Been Partially Restored by Patching with Tar-Modified Epoxy Resin.

CURRENT RESEARCH PROGRAM

Before July, 1963, the activities of the Division of Research were financed almost wholly by state funds. However, federal aid funds were available to finance approved planning and research functions of the Department. A change in the federal law on July 1, 1963, has resulted in a balanced program of planning and research functions to be financed by federal-aid funds.

A number of research studies or projects pursued on the former basis are of a continuing and recurring nature and have been included in the cooperative work plan since each one has been adjudged to be worthy and beneficial to Kentucky's highway program. The current research program is founded upon the needs of the Department and has been reviewed and endorsed by principal staff engineers. The program is further strengthened and supported by the Department's Research Committee, which is charged with responsibilities for guidance, review, and effective use of research reports. The committee is composed of the following staff members:

- Assistant Commissioner, Program Management
- Assistant State Highway Engineer, Construction and Materials
- Assistant State Highway Engineer, Design, Bridges and Roadside Development
- Director, Division of Maintenance
- District Engineer, District 7
- Consultant for Research and Training
- Director, Division of Research - Secretary
- Assistant State Highway Engineer, Planning and Research - Chairman

The committee is authorized to call other staff members into consultation as specific needs arise.

Soil Mapping

It has long been recognized that soil maps, and particularly engineering soil maps, are useful in the planning and design stages of many civil engineering structures and land developments. Problems associated with foundations, drainage and soil behavior may be recognized at a very early stage during the preliminary location and site selection through the use of adequate soil maps.

There are two general approaches to making engineering soil surveys and/or maps. Both approaches have been used extensively by various agencies throughout the United States. One approach, and the only recourse in cases where no prior information is available, is to prepare engineering maps from actual field exploration. Pedological and geologic maps are sometimes used as a guide in selecting areas for detailed exploration. Generally, in this approach only "origin-texture" maps are prepared wherein

each origin-texture classification gives some indication of the engineering characteristics of the soil. The agricultural soil scientists have developed a classification and mapping system which is largely concerned with the agricultural productivity of the soils. Many areas have been mapped by such methods and many more are in the process of being mapped. These soil maps and surveys contain a wealth of descriptive information that would be useful to engineers. Hence, the second approach to obtaining engineering soil maps is to utilize the pedological maps and descriptions and to add the necessary engineering data. This approach has an advantage in that the mapping work has already been done. All that is needed is to obtain samples from the various soils and perform engineering tests.

In about 1955, the Research Division began a program* of adapting the existing US Department of Agriculture soil maps for engineering purposes by adding engineering data to the pedological soil series classifications. An outgrowth of this work has been the preparation of three departmental reports. The first was made in August, 1957, and contained a summary of basic information on soils and their classification as well as specific engineering data pertaining to pedologically mapped soils in Fayette County.** The second report contained similar types of engineering data for Mercer County soils. In 1962 the third report was prepared to summarize the soils data in the files of the Research Division in a way that could be readily available and usable.

For the past three years the Division of Research has been actively engaged in a cooperative program to provide additional soils data for Kentucky. Personnel of the Soil Conservation Service, US Department of Agriculture, go into the field and identify soils and prepare maps showing areal distribution of these soils. The SCS men also obtain samples and submit them to the Highway Research Laboratory for testing in order to determine the various engineering characteristics of the different types of soils. Mapping and testing for several counties -- Fulton, Boone, Campbell, Kenton, McCreary, and Grayson Counties -- have been completed or will be completed in the near future. A report containing engineering data and characteristics of Bath County soils has been published recently by the Department of Agriculture. The engineer and planner have found a scarcity of information about Kentucky soils to use in

* Deen, R. C. "Kentucky Soils: Their Origin, Distribution and Engineering Properties," Bulletin No. 40, Engineering Experiment Station, University of Kentucky, June, 1956.

** Deen, R. C. "An Engineering Soil Survey of Fayette County, Kentucky," Bulletin No. 213, Highway Research Board, 1959.

their deliberations but work such as that now in progress will provide data which can be of great value. By having this information available, time and money usually required for preliminary surveys can be used for a more rapid development of the project.

Structural Adequacy of Concrete Pipe Culvert

A group of 113 reinforced concrete pipe culvert installations on interstate routes I-64 and I-75 in Jefferson, Shelby, Franklin, Clark, Montgomery, Scott, Grant, and Kenton Counties, were selected early in 1960 for observation. Complete design and installation data were obtained for each installation. Records are made of the condition of every section of pipe for each culvert at the time of inspection. All signs of distress are indicated on diagrams of each culvert in order that the overall condition of the culvert may be noted. To date, four performance surveys have been made on this group of pipes and have been summarized in departmental reports.

During the first field survey several culverts were found to be in serious distress. Figure 24 is a photograph of a pipe culvert beneath a 53-foot fill indicating major distress. The bottom of the pipe shows that the concrete has sheared and pulled away from the reinforcing steel. The same tendencies are seen in the top of the pipe. A compressive failure of the concrete wall is seen at the spring line. The pipe also exhibited numerous small and hairline cracks.

It is significant to note that the more serious signs of distress developed within the first year after installation. Progressive distress was observed to be less and less with time suggesting that the pipe were approaching equilibrium with its surroundings. A study of all information concerning the pipe installations under observation points out the importance of tending to the details of construction. The bedding conditions, i.e. the absence or presence of unyielding foundation material and the degree of compaction of the material beneath the hunches of the pipe to distribute the load, as well as the compaction of material on either side and above the pipe are extremely important factors influencing the performance of the culvert.

Observations of in-place pipe, which were damaged structurally to an extent that the welded joints in the steel cage were exposed, revealed that some welds had broken. This caused some concern about the effects of pipe manufacturing procedures and their influence upon the load carrying capacity of the pipe. A study* was under-

* Deen, R. C. and Havens, J. H. "Some Effects of Fabrication Practices on the Strength Characteristics of Reinforced Concrete Culvert Pipe," Presented to Annual Meeting of Highway Research Board, January, 1964 (Accepted for Publication).

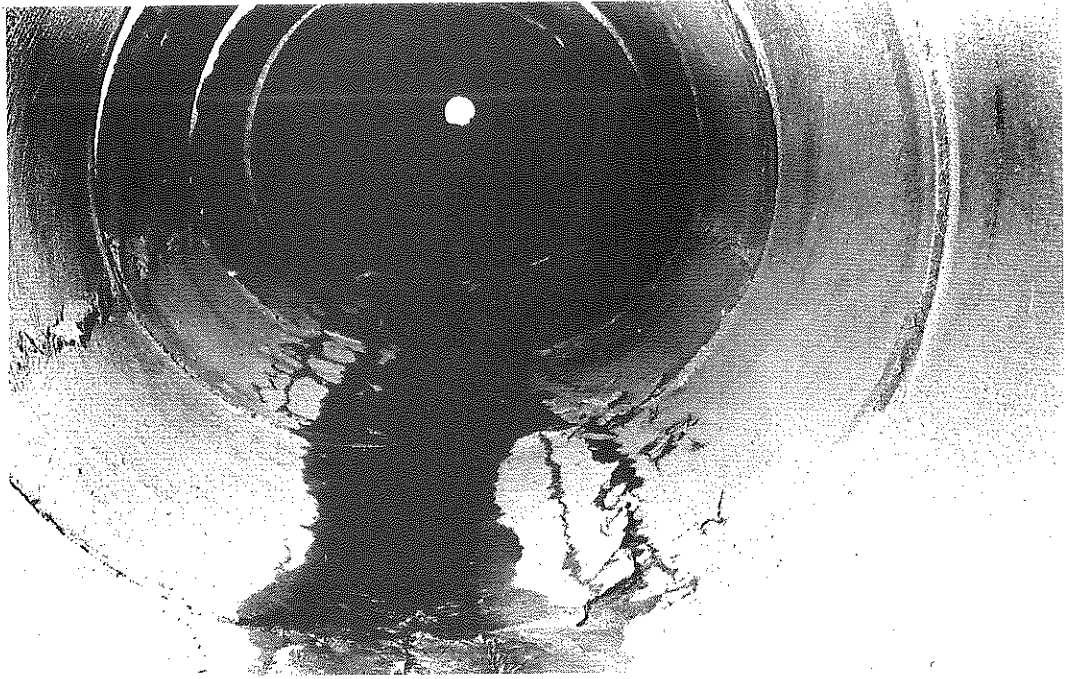


Figure 24. Distress Exhibited by a 54-inch Culvert under a 53-foot Fill.

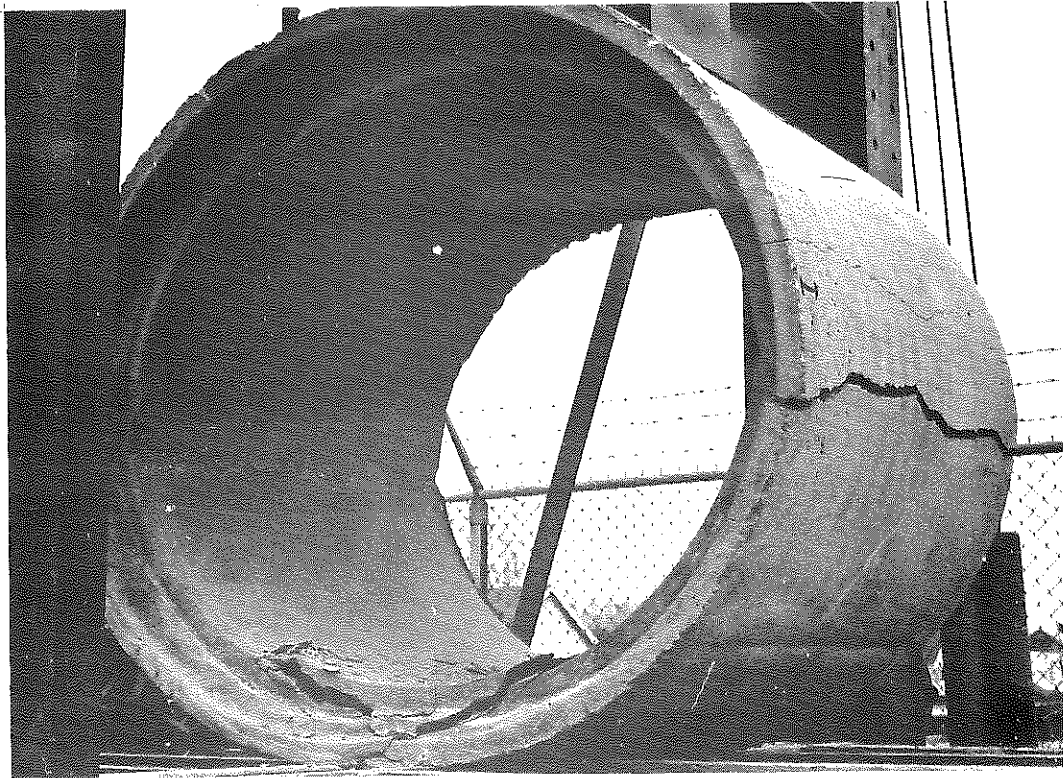


Figure 25. Distress Exhibited by a 54-inch Culvert Pipe in the Three-Edge Bearing Test.

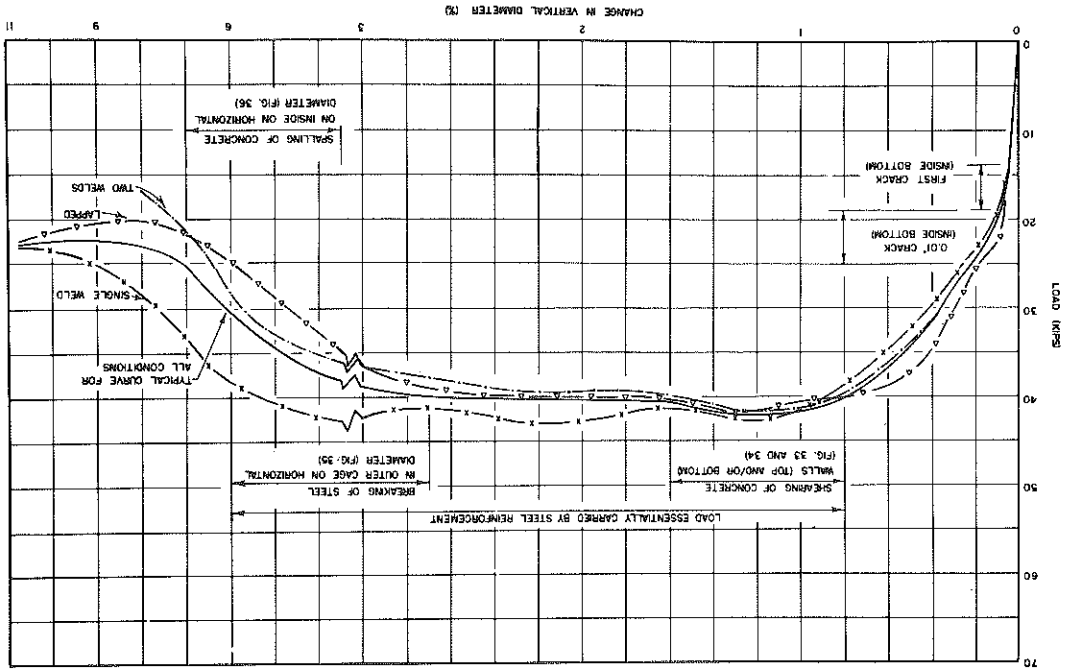
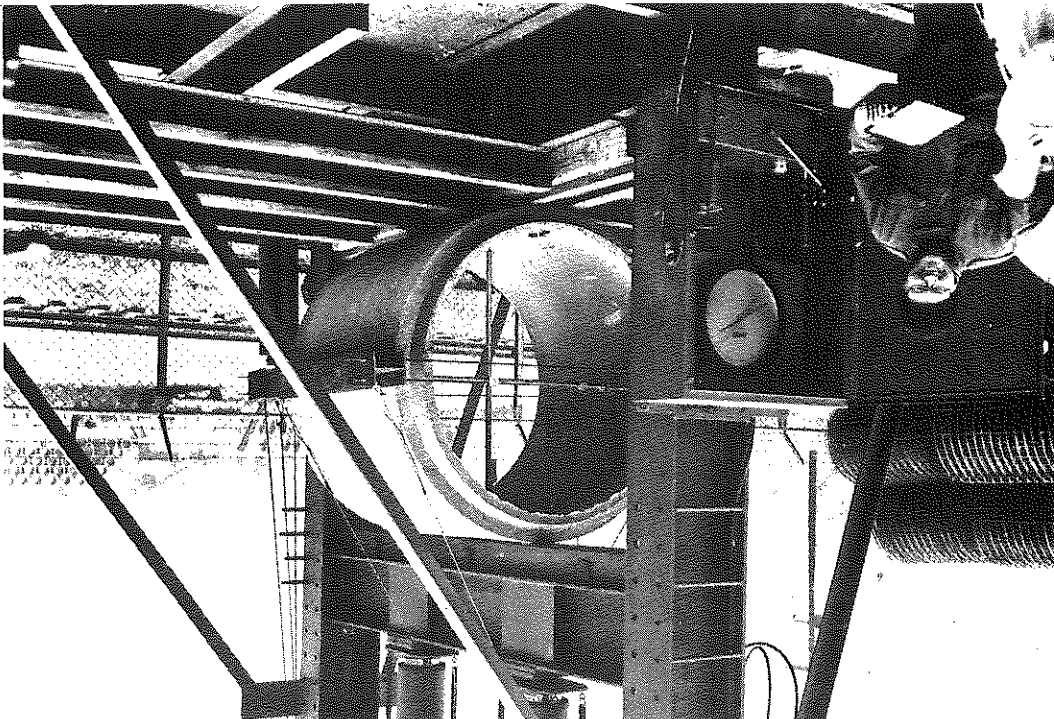


Figure 26. Yoke Assembly for Providing Lateral Restraint.



One pipe installation on I-75 in Scott County has been selected for special study of the two bedding conditions permitted by the Department of Highways. Both the Standard or B bedding condition and the High Fill or B₁ bedding condition were used at this site. The High Fill bedding makes use of the imperfect trench proposed by Mars-ton and Spangler to reduce the load acting on the pipe. A depart-mental report on this investigation indicates that the imperfect trench is effective in reducing the embankment load acting on the pipe thereby making it possible for a pipe of given strength to safely withstand the loads of a higher fill.

Camber Design

Experience has shown that culverts which settle excessively below their original straight grade frequently become clogged with silt and debris, become disjointed and faulted, leak, become undermined, and endanger the stability of the embankment. These and other dam-ages attendant to settlement restrict the flow of water, prevent adequate inspection of the structure, and may eventually require extensive maintenance or complete replacement of the structure. Some of this damage may be avoided by placing the culverts on cambered grades, that is, by installing the culvert with its flow line some-what above its normal or desired elevation along the central portion of its length, as illustrated in Figure 29. This idea anticipates that settlement under the load of the embankment will, in time, lower the culvert approximately to the desired straight grade.

Some engineering specifications, handbooks and treatises suggest the desirability of cambering culvert pipe, but the literature which has been reviewed does not seem to offer any generally accepted cri-terion or formula for predicting even approximately the magnitude of the camber to be used. While it is well recognized among soils en-gineers that extensive consolidation data and foundation settlement analyses are necessary in the design of large and costly structures, it would not be practical to require these analyses for each culvert installation on a highway. To avoid such an expensive and time- con-suming procedure, a short, fairly accurate, simple method is desired, whether it be rational or empirical.

An investigation,* therefore, was undertaken to develop a simpli-fied criterion which would permit the inclusion of camber as a routine design feature in highway culvert installations. A guide for estimat-ing camber for pipe culverts was prepared in nomographic form and has been used in the field for several years. Fairly close agreement has

* May, A. D. and Deen, R. C. "Camber Design Study for Concrete Pipe Culverts," July, 1963 (Submitted to American Society of Civil Engineers for Publication)

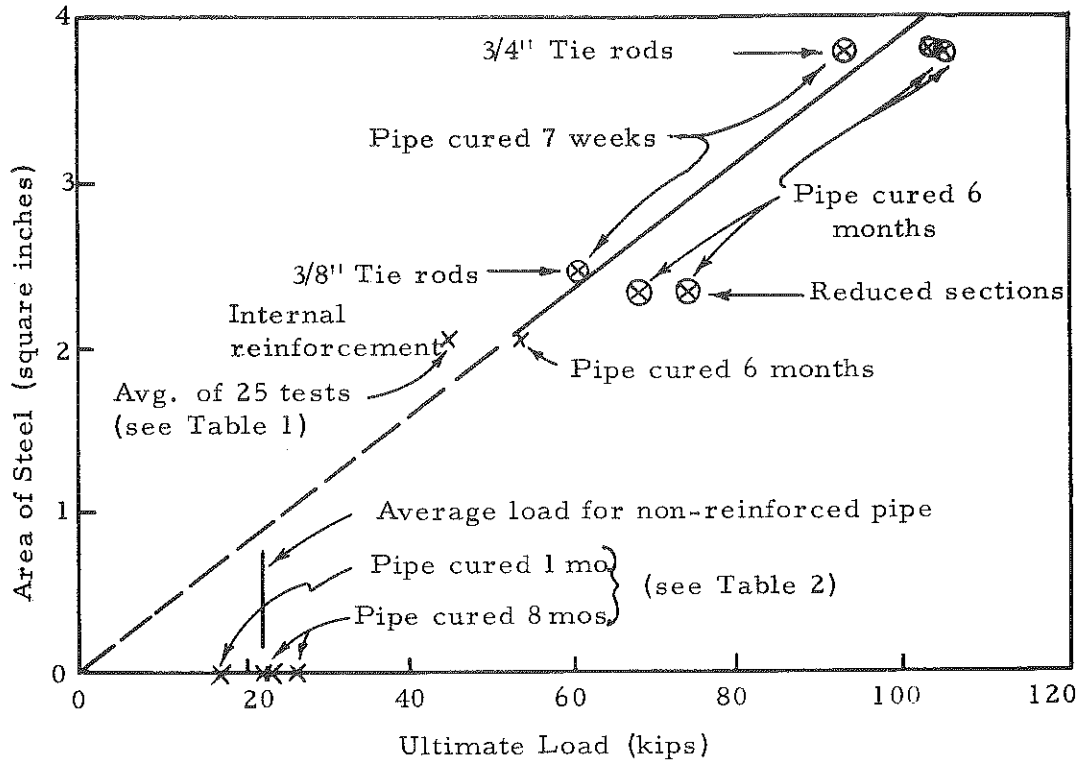


Figure 28. Relationship Between Ultimate Load and Total Area of Steel (Internal Reinforcement Plus External Tie Rods).



Figure 29. Field Installation of a Pipe Culvert Showing the Cambered Flow Line.

been noted between predicted and observed settlements for culvert installations under study. Insofar as the soils involved in the study might be considered to be typical of many Kentucky areas, it may be inferred that the camber guide that has been prepared would provide a reasonable approximation of the settlement expected in many pipe culvert installations.

Traffic Parameters

Since the design life of a pavement is largely dependent upon the reliability of projected EWL's, it is necessary that the design engineer be able to predict and project the characteristics of future traffic trends in order to properly evaluate the EWL's or axle loads for which he must design. Two research projects in the current work program are directly related to this problem concerning traffic projection and determination of EWL's.

The objective of one of these projects is to re-evaluate the traffic parameters presently used for predicting, projecting, and computing EWL's. Appropriate traffic data from the files of the Highway Department are to be analyzed to determine growth factors for total traffic counts, the ratio of truck traffic to total traffic, and information concerning the truck traffic such as number of axles and the distribution of axles by weight. These various factors must be determined for roads carrying different traffic volumes, rural and urban roads, and the various highway systems. This project is expected to provide more insight into methods for fitting the various traffic parameters to local conditions.

In order to develop techniques and factors to use in projecting and predicting traffic trends, it is first necessary to study past conditions and discover the relationship between certain socio-economic factors and past traffic trends and patterns. An area in which the state has a great deficiency of data, both past and current, is that concerning vehicle weights and distribution of axles by weight groups. To collect and evolve such data, a research project has been initiated to develop techniques of weighing vehicles in motion.

The loads that the pavement systems of our highways must withstand are often dynamic in that they are applied by moving vehicles. These loads oftentimes are different from the static loads of the same vehicles, and it would be very desirable if these dynamic loads of various types of vehicles were known at the time the pavement is designed. With regard to law enforcement, it is now necessary to require vehicles to come to a stop in order to check weights. A more desirable situation is to be able to check vehicle weights without requiring them to stop.

Basic investigations have been conducted to determine the most practical means of measuring and recording dynamic loads produced by vehicles in motion. Equipment to measure these type loads has been developed and installed on the approach to the loadometer station on Interstate 64 in Shelby County, Kentucky. It is hoped that such weighing devices can soon be installed at many sites over the state so that

information which is needed for highway planning and design can be collected.

Rheological Studies

In the past the majority of flexible pavement design criteria has been based upon empiricism. In recent years, however, emphasis has shifted to studies more fundamental in nature. The most fundamental studies have utilized elastic concepts which appear to suffice as an approximation, particularly for low ranges of stress, short durations of loading, and limited strains or deflections. The practical application to flexible pavement design is questionable since the theory fails to provide any means whereby the element of time may be included. Since the constituent materials which comprise a flexible pavement system are known to exhibit time-dependent stress-strain characteristics, this appears to be a major restriction limiting the use of the elastic theory. Consequently a resurgence of research activity among highway agencies has been devoted to the adaptation of the theory of viscoelasticity. The Highway Research Laboratory is actively engaged in a research study to determine fundamental mechanical properties of bitumens and bituminous mixes when subjected to static and dynamic stress conditions at different temperature levels and to apply these results to the establishment of stress-strain-time-temperature relationships which may be adapted to flexible pavement design.

Viscoelastic theory is concerned with materials which exhibit time-dependent stress-strain behavior. However, the theory is relatively new and there are many problems inherent to its use. These problems may be grouped into three major divisions: 1) development of methods for measuring material properties and improvement of standard methods already in use, 2) investigation of the most convenient mathematical representation of viscoelastic behavior as applied to a specific material and establishment of relationship to other mathematical representations, and 3) application to specific stress analysis problems.

An extensive library "search" has been conducted and summary index file completed. Early efforts have been devoted primarily to the study of asphalts and other bitumens which differ in penetration grade, source, and manufacturing process. Development of equipment needed for testing also has been undertaken. A study of bituminous mixes with various bitumen contents and aggregate gradations is anticipated. The development of equipment needed for testing is to be continued. Application of results to flexible pavement design and analysis will be undertaken.

It is felt that the approach to be taken in this study - utilizing viscoelastic theory - is superior to others because the theory is concerned with idealized material behavior which more nearly approaches that exhibited by the constituent materials in the flexible pavement system. Therefore, it is anticipated that the results and conclusions gained will be significant and beneficial contributions to the understanding of flexible pavement behavior.

Settlement of Bridge Approaches

Figures 30 and 31 illustrate a situation which often develops on bridge approaches throughout this state as well as others. The differential settlement occurring between bridges and their approach embankments is a serious problem in highway maintenance (Figure 32). On modern roads, this defect has become a hazard to high-speed traffic, and remedial work is expensive and causes considerable inconvenience to road users.

A project in the Research Division's current work program is aimed at determining the causes of settlement at bridge approaches and developing methods of design and construction whereby settlement can be prevented.

As a preliminary investigation, an attempt will be made to relate settlement to the geological, topographic, and subsoil conditions at the bridge site, the type of pier or abutment, and the type of embankment. To accomplish this, case studies will be made of several existing bridges throughout the state.

It is proposed, too, that specific studies will be made to determine if the settlements are occurring within the foundation soil or within the embankment material. Pore pressure measuring devices, settlement platforms, and possibly radioactive tracers will be used to detect these settlements. Close supervision during construction will provide definite information regarding condition of the materials and the construction methods employed.

Landslides

A condition which is receiving much attention is illustrated in Figures 33, 34, and 35. The occurrence of landslides has been a problem for maintenance personnel for years. The slide area shown in Figure 33, for example, has existed for several years on US 25 in Rockcastle County. The difficulties and expense involved in maintaining a passable roadway of satisfactory riding quality in these circumstances can appear, at times, almost overwhelming. Sometimes slides occur on our highway facilities soon after, or even before, they are opened to traffic (Figure 34). Occasionally slips will develop in areas where such is not expected (Figure 35) and the cause for such a slide often can be difficult to ascertain.

The recurrence of earth movements in many of these slide areas during or soon after a wet season is indicative of troublesome underground seepage. In order to evaluate such a situation and to methodically undertake corrective action, it is essential that the source of the seepage water be located and cut off. A systematic investigation of each slide would eliminate trial-and-error methods of correction which are often expensive and disheartening.

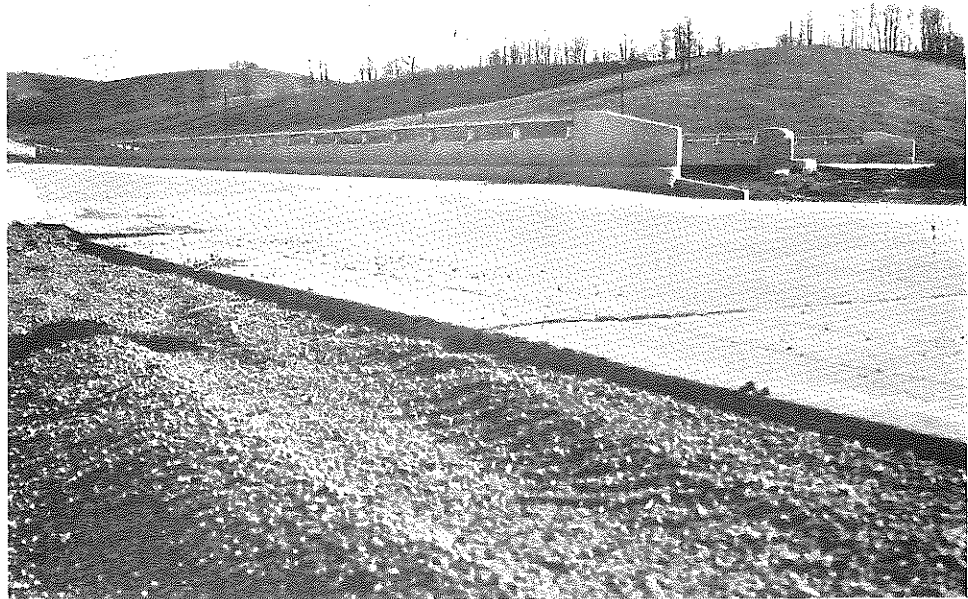


Figure 30. Settlement of Bridge Approach Slab.



Figure 31. Development of a Void at Bridge Abutment that often Attends Settlement of Bridge Approach Slab.



Figure 32. Patching Work often Required at Bridge Approaches to Maintain Desirable Riding Qualities and Safety.

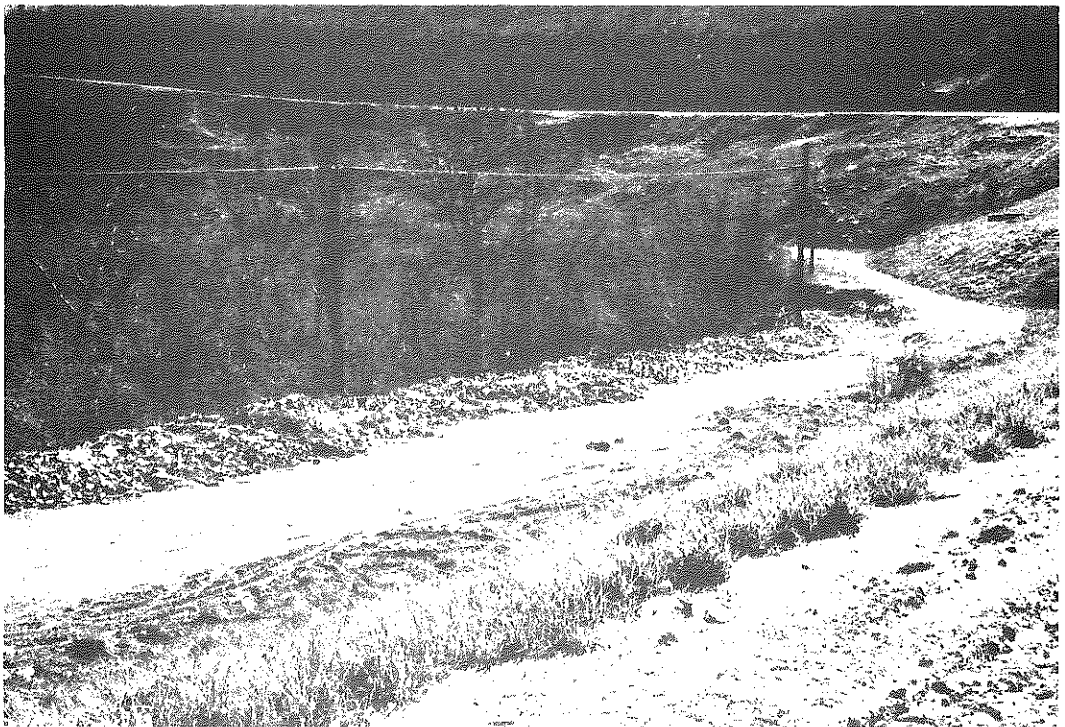


Figure 33. Landslide Area on US 25, Rockcastle County.

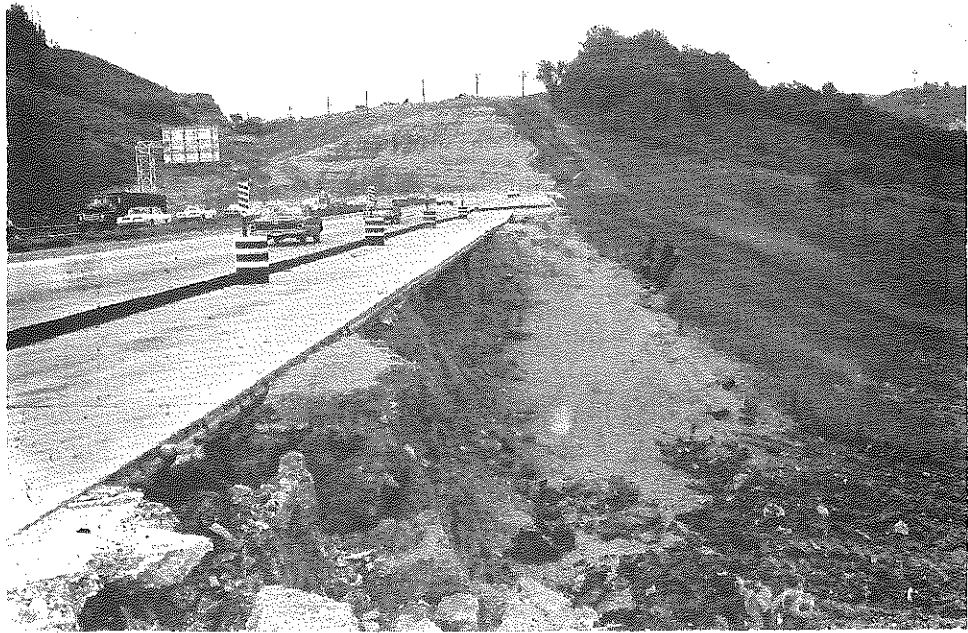


Figure 34. Landslide Area on I-75, Kenton County.



Figure 35. Landslide Area on the Mountain Parkway.

A reliable, rapid method is needed to make the necessary subsurface exploration in landslide zones. The Research Division is actively engaged in an attempt to develop a practical method or methods of locating and tracing seepage water in unstable slopes. Selected existing slides are being surveyed and attempts will be made to determine the extent and classification of the slide. Methods of exploration to locate and trace seepage water that are being investigated will make use of fluorescent dyes, radioactive tracers, and earth resistivity methods.

A LOOK AHEAD

After a glimpse of the highlights of early highway research in Kentucky and a review of some of the work in progress at the present, it is well to pause and take a look at some of the areas that will receive attention in the future. No doubt many of the research projects which have received and are receiving attention will continue to be of concern to us here in Kentucky. As more is learned about certain aspects of these projects, efforts can be shifted and directed to phases and portions of the problem not yet surveyed. In addition, many facets of highway engineering and administration will come under the scrutiny of the researcher, and it is some of these areas that will receive attention in the near future that will be discussed at this time.

Wind-Blown Silts

A preliminary investigation has been made of a construction project (grade and drain, and portland cement pavement) near Henderson, Kentucky. The soil encountered there was a wind-blown silt, and numerous problems were recognized in excavating cuts, compacting embankments and subgrade, and in controlling erosion (see Figures 36 and 37). The project was beset with numerous delays, repairs, and damages to abutting property.

The objectives of a research project to be initiated soon are to evaluate designs, construction techniques, and erosion control methods used in wind-blown silts and to discern methods which will assure future successful construction in such deposits in Kentucky.

Certain types of silty soils often require special techniques of design and construction. Such soils, predominately wind-blown silts, cover extensive areas along the Ohio River in Western Kentucky and in the Jackson Purchase region. Ordinary construction practices frequently induce a "quick" condition in silty earth or otherwise induce widespread instability and erosion problems. Certain precautionary practices should be invoked in these areas, and the areas should be defined sufficiently to alert all unwary parties.

Design and construction records will be reviewed to discover the techniques and methods which have been the most successfully used in Kentucky, and elsewhere, in silt deposits. The performance of various embankments and cut-sections will be analyzed and an attempt will be made to associate satisfactory performance with design and construction methods. It is planned to develop criteria which will provide helpful guidance in future construction in critical areas and which will serve to forewarn design and construc-



Figure 36. Photograph Showing Area of Wind-Blown Silt where Erosion Control and Stability Problems were Encountered during Construction.



Figure 37. Photograph Showing Susceptibility of Wind-Blown Silt to Erosion.

tion engineers of certain dangers that are likely to be encountered.

Roadside Turf and Plantings

The suitability and choice of different plant materials for roadside planting will be governed primarily by cost of establishment and maintenance, by the effectiveness in stabilizing soil, and by the safety and beauty achieved. It must be recognized that conditions encountered in roadside plantings are different from normal conditions found in fields and yards. Soils often consist of unclassified material and are not agricultural soils in the usual sense. This material usually contains very little if any organic material and little plant food and often is highly susceptible to erosion. Under these conditions the establishment and maintenance of plants and turf present major problems.

The present area of roadside turf in Kentucky has been estimated at approximately 125,000 acres. One mile of interstate highway, for example, includes about thirty acres of roadside turf. Along our roadways, extensive plantings of turf, vines, trees, and shrubs have been made. These will require continual care by trained personnel if the plantings are to survive and reach maturity. Few plants may be expected to survive and still fewer to thrive under the unnatural conditions along our roadways.

A research program is soon to be initiated for the testing of chemicals used in weed and brush control, for the testing of fertilizers, and for the development of new grasses for ground cover and mulches for grass seed and shrub beds. Testing is needed for a long list of vines and woody plants that might possibly be adapted and suitable for roadside plantings. Methods of establishment on different exposures, slopes, and soils are to be studied. Erosion control techniques as well as equipment and methods of roadside maintenance will also be under investigation.

Pavement-Type Selection

Generically pavements are classified as being "flexible" or "rigid", these terms alluding to bituminous concrete and to portland cement concrete, respectively. Assuming that design criteria are sufficiently reliable and assuming that equivalent load-carrying capacities are sought in each of the two pavement types, the selection of the type becomes wholly a matter of comparative costs rather than an arbitrary preference. This does not mean that preferences and opinions are altogether invalid, rather such preferences should be substantiated in terms of economic benefits, safety, and overall service.

The objective of a future research project will be to study those design factors which alter the pavement cross-section (i.e., total thickness of pavement and the thickness of individual courses within the pavement) and the manner in which these factors affect

pavement construction costs. The long term objective is to develop a working plan for selection of pavement type (flexible or rigid) based upon the best engineering judgement and experience available. A realistic plan for selection of pavement type is contingent upon a thorough understanding of the factors which affect first costs (construction costs). This study will attempt to isolate those factors.

Basically there are two methods of determining pavement types:

1. Alternative Bidding - Engineers design comparable pavements and advertise for bids on each; the lowest bid determines the type.
2. Engineer's Cost Estimate - Engineers estimate the cost of equivalent pavements and advertise for bids on the type for which their estimate was the more favorable.

Contractors' bids provide the more realistic cost information; however it is limited solely to "first costs" or cost of construction and does not take into account any of the maintenance costs. The engineer's cost estimate may also be limited, by choice, to "first cost," but it is not necessarily so limited. In other words, the engineer's cost estimate could include both construction and maintenance costs, particularly so if maintenance costs could be estimated reliably.

Construction cost or "first cost" is the primary criterion and often, as the result of financial limitations, the only criterion used in selection of pavement type; hence, a thorough understanding of the manner in which various factors affect first cost is of considerable significance. Although the nature of the proposed study is exploratory, it will aid in clarifying the manner in which those factors influence first costs. The study will also aid in establishing a firm background upon which future studies of a more engrossing nature can be based. It is recognized that a complete pavement-type selection study must take into account such factors as maintenance cost, effective pavement life, and salvage value. A study which includes these factors must be relegated to some future date when sufficient factual information becomes available.

Joints in Concrete Bridge Decks

Adequate sealing of joints in concrete bridge decks is a continuing maintenance problem. Conventional sealants used with copper water-stops are in many instances only partially successful in preventing the flow of water through the joints. Foreign matter often becomes embedded in the sealant and spalling may become serious with the expansion of the deck. Numerous bridge piers have become stained and are scaling as a direct result of leakage through the joints onto the piers. Progressive scaling precedes structural deterioration and increased staining is unsightly. A research project soon to be proposed will provide for the observation and evaluation of performance of various sealers used in the joints in concrete bridge decks.

Rheology of Soils

In recent years there have been considerable advances made in the rheological theory and its application to various materials. There has not, however, been much work done toward the application of rheology to soil mechanics. Before this concept can be used, the characteristics of the viscoelastic behavior of soils must be determined and test methods which can be used to evaluate design parameters must be developed.

Soon it will be proposed that a study be made of the rheological characteristics of cohesive soils subjected to dynamic loading and to correlate these properties with the response of these soils to long-time creep loads in order to obtain the general rheological response for a wide range of rates of loading. Since shallow foundations and subgrades may be subjected to dynamic loadings and since deep foundations and slopes may exhibit large creep deformations, it is anticipated that significant contributions toward a better understanding of soil behavior can be made through the application of rheology. The ultimate goals of this study are to propose deformation and failure criteria that will include time effects and to develop suitable test procedures and practical methods of computation for rational design purposes.

Quality Control

Because of the rapid expansion of the highway construction program, increased costs of construction, and the necessity of building highways that will have minimum expenses of maintenance, many current specifications have come under study and may need to be revised or improved. Specifications are needed to define all items in a contract explicitly, and they serve to insure a minimum level of quality, to provide a uniform basis for bidding, and to establish standard methods and procedures. Requirements usually include limiting numerical values for measurable identifying or quality characteristics.

Each limiting value and its associated acceptance sampling plan should be based on the importance of the measured property as it affects safety, performance, or durability. A major requirement of good engineering is to find the proper compromise between cost and the various risks. Over design or costly over control is not the best answer. It is the designer's responsibility to specify what is needed and the desired level; but, in general, he must accept unavoidable variability due to the nature of the material or process. Failure to recognize this basic concept could materially affect the overall balance between specifying risk and cost.

It should be clearly understood that specification requirements do not control the natural variability of materials or processes. Variation, however, does govern the establishment of realistic specification limits. It is just this fact that has suggested a need for

research to provide information regarding correlation between specification requirements and performance for all critical and important factors. It is anticipated that a future research project will attempt to provide factual answers to such questions as "What should be specified?" and "What level is required?". Also of very great importance are the answers to the questions "What is the optimum degree of uniformity?" and "What is the relative cost of various degrees of deviation or failure when the specified tolerances for both level and uniformity are not met?". No doubt such a research study will make use of the statistical methods of quality control that have been used by industry for years.

The look at the future also indicates that more research efforts will be directed toward the socio-economic aspects of highway development. A better understanding of the complex relationships and interactions between the social and economic development of various types of transportation facilities is needed.

The near future also may see the construction of a short test road to evaluate the use of coal products as an aggregate for bituminous surfacing. Preliminary laboratory investigations suggest that this type of construction might have application for roads carrying low volumes of traffic in areas in which the coal is readily available and other aggregate are uneconomical.

As previously stated, much of the time and effort of a researcher is devoted to the documentation of data, observations, evaluations, and resulting recommendations. But the work cannot stop here. It becomes the responsibility of all Department engineers and administrators, as well as the researcher, to see that findings are put into use where it is practical. The responsibility is even broader than this. Every person concerned with the highway and transportation industry should keep himself informed of the latest research developments and make use of these where they will serve the public more efficiently and economically.