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KENTUCKY PAVEMENT (BITUMINOUS) PERFORMANCE EVALUATIONS AND DESIGN STUDIES

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Prior to 1942: Presumably pavements were designed by experience -- or possibly by the Massachusetts rule.

1942 - 1948: Kentucky adopted California's CBR method -- including design curves.

cf. Grumm, F. J.; "Designing Foundation Courses for Highway Pavements and Surfaces", California Highways and Public Works, November 1941 and March 1942.

1948 - 1958: In 1947, Kentucky began an extensive field and laboratory study for the purpose of developing design curves applicable to its own region. The study included 435 miles of road; test pits were excavated at 185 sites. The resulting design chart is shown in Fig. 1.

Baker, R. F., and Drake, W. B.; "Investigation of Field and Laboratory Methods for Evaluating Subgrade Support in the Design of Highway Flexible Pavements", Bulletin No. 13, Engineering Experiment Station, University of Kentucky, September 1949; also Proceedings, Highway Research Board, Vol 28, 1948.

The WASHO Road Test was built in 1952; the ensuing developments there were compared with the 1948, Kentucky design charts; no changes were considered necessary. However, the Benkelman beam method of measuring deflections of a pavement under a loaded wheel, which evolved there, was regarded with much interest.

Some other significant developments during this period were:

1. Development of dense-graded aggregate base courses.

Drake, W. B.; "Combination Waterbound-Macadam and Dense-Graded Aggregate Base for Flexible Pavements; Proceedings, Highway Research Board, Vol 32, 1953.

Drake, W. B.; "Dense Graded Aggregate Base Development," Reports of the HMRL, Vol XIV, April 1959; prepared for presentation at the 16th Annual Meeting of Kentucky Crushed Stone Association.

2. Discovery of subgrade soil intrusions into waterbound bases.

Drake, W. B.; "Pavement Investigation, Middletown-Eastwood Portion of U. S. 60, Louisville-Shelbyville Road," June 1954.

3. Development of a method of evaluating pavement roughness -- i. e. serviceability.

Gregg, L. E., and Foy, W. S.; "Triaxial Acceleration Analysis Applied to the Evaluation of Pavement Riding Qualities," Proceedings, Highway Research Board, Vol 34, 1955.

4. Skid tests (1954) with Tennessee trailer disclosed slipperiness of bituminous surfaces containing limestones.
5. Development of method of skid-testing with an automobile.
6. Pavement design considerations for the Kentucky Turnpike (1954).

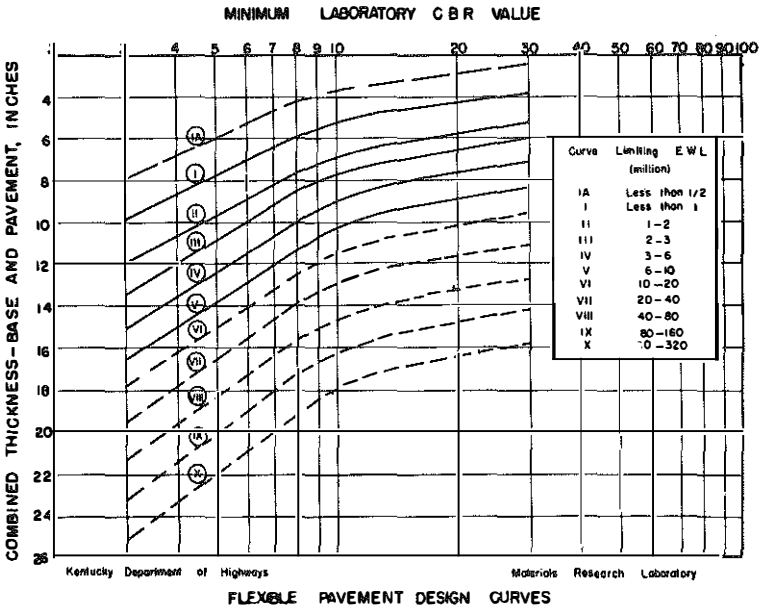

Fig. 1: Kentucky Flexible Pavement Design Curves. Curves I through V proposed in 1948; IA and VI through X added by extrapolation, 1954.

7. Preliminary design considerations for pavements on interstate system. Curve X (extrapolated into 1948 design chart, 256 million EWL's, adopted).

1958-1968: In order to further substantiate the extrapolations of the 1948 charts into higher traffic domains and in recognition of pending interstate design needs, a re-evaluation of the design charts was begun in 1957. Approximately 75 construction projects which had been designed since 1948 were evaluated in terms of roughness, patching, Benkelman beam deflections, selected test-pit sites, and traffic histories (EWL's). The design chart shown in Fig. 2 evolved.

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

This re-evaluation predated the AASHO Test Road (final report, 1962). Then too, much attention was given to the AASHO Interim Guides which evolved therefrom. Fortunately, with the 1958 revision, Kentucky began to design on the basis of 20-year EWL (formerly 10-year EWL). Formulas were developed to transform equivalent 5-kip wheel loads (EWL's) into 9-kip wheel loads or 18-kip axleloads. By using respective structural coefficients, SN values for Kentucky pavements could be computed; and direct comparisons could be made between the two design criteria. Even so, no revisions appeared to be needed. The Department elected to continue to use the 1958 design chart.

Some intuitivism was involved in shaping the 1958 design curves. As before, most of the control data was within the range of CBR's from 5 to 10. It was reasoned then that the curves should tail downward severely as the CBR decreased below 3. At the high end of the CBR scale, it seemed on the one hand that the scale should terminate at 100 (by definition) and that the design curves should merge upward to the point where a great thickness of 100 - CBR foundation material would require only minimum bituminous concrete surfacing to sustain immense EWL's. On the other hand, an alternative considered but abandoned was that the CBR could exceed 100 and equal upper layers (Boussinesq solid) -- in which case the curves would have continued somewhat diagonally rightward rather than merely warped upward. The control data also indicated that Curve X should have passed through 23 inches at CBR 7.1. Conservativism was somewhat overpowering, and the curve was drawn through 21 inches (Note: This fault was corrected in a succeeding evaluation.) The 1958 design chart was based largely upon analysis of spring deflections -- without regard to pavement temperatures. Perchance the pavements were cool. Some afterthoughts relating to the significance of deflections were expressed in 1962, as follows:

> *"...the empirical significance of deflections in relationship to pavement performance is inherently that of establishing critical magnitudes, whereas the theoretical significance is that of relating deflections to critical stresses (sic, and strains)."**

*Havens, J. H.; "Observations on the Significance of Pavement Deflections," Proceedings, Association of Asphalt Paving Technologists, Vol 32, 1961.

At that time, it was difficult to calculate stresses and strains (and deflections) in layered pavement structures. It was not until the Chevron computer program was developed (1963) that these computations could be done routinely. Nevertheless, deflection continued to be the most measureable property of a pavement structure. Even so, there were definite trends among theorists toward mechanistic approaches to pavement design.

Satellite studies envisioned by others following the AASHO Test Road did not materialize. The state of the art during this period is reflected in the Proceedings of the First (1962) and Second (1967) International Conferences on the Structural Design of Asphalt Pavements, University of Michigan.

All bituminous sections of interstate, toll roads, and other state roads designed and built in Kentucky

since 1958 were designed according to the chart shown in Fig. 2. Indeed, methods of monitoring performance of these pavements -- from the standpoint of serviceability (roughness and slipperiness) -- were needed. Fortunately, developmental studies were already well advanced. Selected bibliographical citations follow:

Pavement Roughness, Riding Quality, Serviceability

Gregg, L. E. and Foy, W. S.; "Triaxial Acceleration Analysis Applied to the Evaluation of Pavement Riding Qualities," Reports of the HMRL, Vol X, Part I, 1955; also Proceedings, Highway Research Board, Vol 34, 1955.

Foy, W. S.; "Analysis of Pavement Riding Quality, a Triaxial Evaluation of Pavement Roughness," Reports of the HMRL, Vol XI, Part III, November 1956.

Rizenbergs, R. L.; "Analysis of Pavement Roughness," Reports of the HMRL, Vol XVI, Part II, March 1961.

Rizenbergs, R. L.; "Pavement Roughness Studies (A Progress Report)," Reports of the HMRL, Vol XVII, Part I, March 1962.

Havens, J. H.; "Pavement Roughness Studies," Proceedings, SASHO, 1962.

Rizenbergs, R. L.; "Accelerometer Method of Ride-Quality Testing," Reports of the HMRL, Vol XX, Part I, February 1965.

Rizenbergs, R. L.; "Road Roughness," Proceedings, Kentucky Highway Conference, College of Engineering, University of Kentucky, November 1969.

Rizenbergs, R. L.; Burchett, J. L.; and Davis, L. E.; "Pavement Roughness: Measurement and Evaluation"; KYHPR-64-25, HPR-1(7), Part II; December 1971.

Skid Resistance

Stutzenberger, W. J. and Havens, J. H.; "A Study of the Polishing Characteristics of Limestone and Sandstone Aggregates in Regard to Pavement Slipperiness," Reports of the HMRL, Vol XIII, Part I, January 1958; also Bulletin 186, Highway Research Board, 1958; also thesis, MS in CE, Stutzenberger, W. J.; University of Kentucky.

Havens, J. H.; "Skid Prevention Studies in Kentucky," Reports of the HMRL, Vol XIII, Part III, 1958; also Proceedings, First International Skid Prevention Conference, Part II, August 1959.

Rizenbergs, R. L.; "Pavement Friction," Kentucky Engineer, Vol 22, No. 4, May 1960.

Havens, J. H. and Rizenbergs, R. L.; "Pavement Slipperiness Studies (A Progress Report)," Reports of the HMRL, Vol XVII, Part I, February 1962.

Rizenbergs, R. L. and Ward, H. A.; "Skid Testing with an Automobile," Record No. 189, Highway Research Board, 1967. Discussion by Jas. H. Havens.

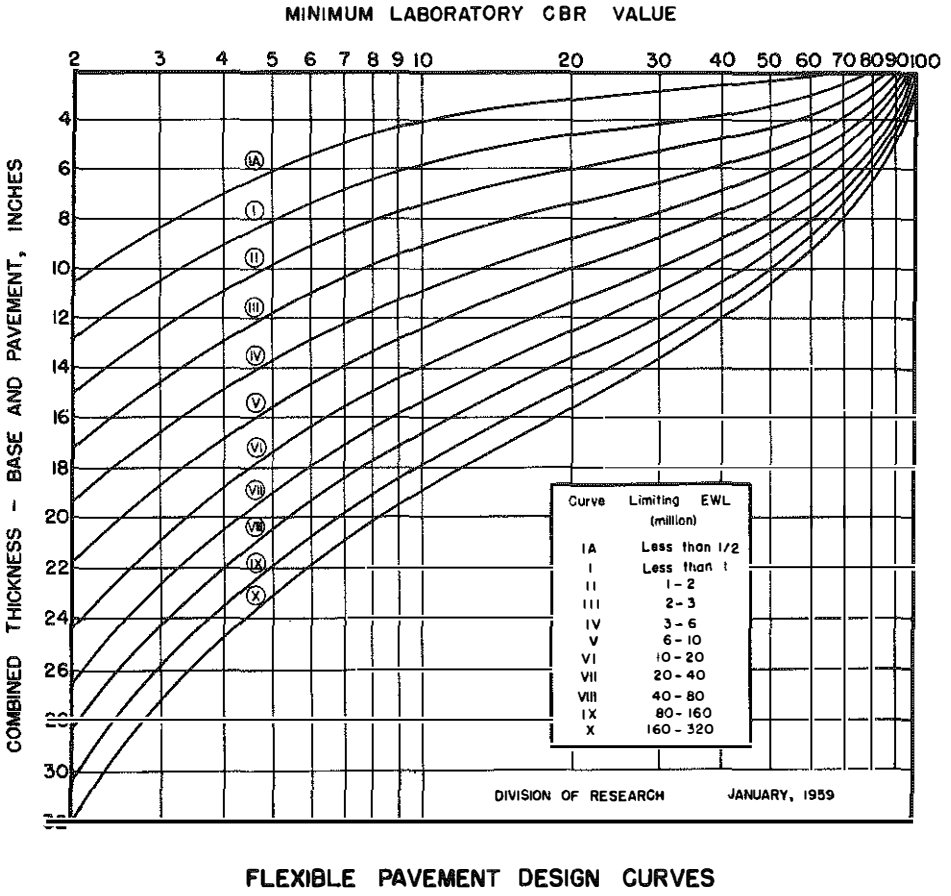

Fig. 2: Revised Flexible Pavement Design Curves.

Rizenbergs, R. L.; "Florida Skid Correlation Study of 1967 - Skid Testing with Automobiles," STP-456, Highway Skid Resistance, American Society for Testing and Materials, 1969.

Rizenbergs, R. L.; "Skid Resistance;" Proceedings, Kentucky Highway Conference; College of Engineering, University of Kentucky, November 1969.

Burchett, J. L. and Rizenbergs, R. L.; "Pavement Slipperiness Studies," KYHPR-64-24, HPR-1(7), Part II; March 1970.

Pavement Slipperiness Studies; Progress Report; KYHPR-64-24, HPR-1(7), Part II; Pending.

Skid Resistant Surfaces

Sandstone

"Report I on Research Project B-9, Bituminous Construction with Sandstone Aggregate, Johnson County Project S. P. 58-37-1," Reports of the HMRL, Vol I, Part II, January 14, 1943.

Williams, E. G.; "Report No. 2 on a Test Road for the Evaluation of Sandstone as an Aggregate in Plant-Mix Bituminous Pavements," Reports of the HMRL, Vol VIII, Part I, April 1953.

Williams, E. G.; "Report No. 1 on a Test Road for the Evaluation of Sandstone as an Aggregate in Plant-Mix Bituminous Pavements," Reports of the HMRL, Vol VII, Part II, April 1952; also Williams, E. G. and Gregg, L. E.; "Evaluation of Sandstone as an Aggregate in Plant-Mix Bituminous Pavements," Proceedings, Association of Asphalt Paving Technologists, Vol 22, January 1953.

Havens, J. H.; "Memorandum Report on Sandstone Specifications," Reports of the HMRL, Vol XII, Part I, February 19, 1957.

Kentucky Rock Asphalt

Havens, J. H. and Williams, E. G.; Memorandum Report on "Performance of Kentucky (Natural Sandstone) Rock Asphalt," Reports of the HMRL, Vol X, Part I, April 12, 1955.

Havens, J. H. and Williams, E. G.; "Report No. 2 on a Study of the Properties and Performance of Kentucky (Natural Sandstone) Rock Asphalt," Reports of the HMRL, Vol XI, Part I, February 1956.

Havens, J. H.; Memorandum Report on "Use of Kentucky Rock Asphalt for De-slicking Purposes," Reports of the HMRL, Vol XIX, Part II, November 16, 1964.

Florence, R. L.; "Kentucky Rock Asphalt Bases and Hot-Mix Surfaces; Experimental Construction," April 1966.

Sand-Asphalts

Strunk, L. H.; "Bridge Resurfacing with Silica Sand-Asphalt Mixture," Reports of the HMRL, Vol

XIII, Part III, December 1958.

Florence, R. L.; "The Design of Thin, Silica Sand-Asphalt, Wearing Surfaces for Highways and Bridges," Reports of the HMRL, Vol XIV, July 1959; also thesis, MS in CE, Florence, R. L.; University of Kentucky.

Florence, R. L.; "Performance Report on Bridge Resurfacings with Silica Sand-Asphalt Mixture," Reports of the HMRL, Vol XVI, Part I, March 1961.

Havens, J. H.; Memorandum Report on "Proposed Specification for Sand-Asphalt, Skid-Resistant, Wearing Course," Reports of the HMRL, Vol XVI, Part III, March 27, 1961.

Florence, R. L.; "Construction and Interim Performance of Silica Sand-Asphalt Surfacing," Reports of the HMRL, Vol XX, Part I, February 1965.

Florence, R. L. and Southgate, H. F.; "Experimental Sand-Asphalt Surface;" KYHPR-64-48, HPR-1(6), Part II; October 1970.

Rose, J. G. and Havens, J. H.; "Aggregate Shape and Skid Resistance;" KYHPR-71-66, HPR-1-(7), Part II; September 1971; also Proceedings, Conference on Skid Resistant Surface Courses, FHWA, Region 15, Chicago Heights, Ill., September 14-16, 1971.

Traffic Studies

Faulkner, P. A.; "Determination of Flexible Pavement Cost Indices for Use in the Analysis of Highway-User Tax Responsibilities by the Incremental Method," 1956 (Developed increase factors incorporated into 1958 criteria for EWL's).

Deacon, J. A. and Lynch, R. L.; "Determination of Traffic Parameters for the Prediction, Projection and Computations of EWL's," KYHPR-64-21, HPR-1(4), Part II; August 1968.

Lynch, R. L. and Hamby, G. N.; "Lateral Distribution of Traffic on a Four-lane and Six-lane Section of I-75, South of Covington;" KYP-56, June 1969.

Siria, B. S.; "Operational Effects of Auto-Utility Trailer Combinations on Rural Highways in Kentucky;" KYP-16, January 1971.

Carr, B. W. and Rizenbergs, R. L.; "Development of an Electronic Means of Weighing Vehicles in Motion;" KYHPR-61-27, HPR-1(6), Part II; April 1971.

Pigman, J. G.; "Influence of Recreational Areas on the Functional Service of Highways;" HPR-1(6), Part I, Vol 4, Chapter 9; August 1971.

Bituminous Concrete

Williams, E. G.; "A Compendium on Class I, Type C Mixes," Reports of the HMRL, Vol VII, Part IV, December 1952.

Strunk, L. H.; "Comparative Laboratory Evaluation and Field Observations of a Modified Class I Base," Reports of the HMRL, Vol XIII, Part I, February 1958.

Florence, R. L.; "Class I Bituminous Mixtures," September 1966.

Pavement Design

Baker, R. F. and Drake, W. B.; "Investigation of Field and Laboratory Methods for Evaluating Subgrade Support in the Design of Highway Flexible Pavements," Reports of the HMRL, Vol IV, Part I, August 1949; also Bulletin No. 13, Engineering Experiment Station, University of Kentucky, September 1949; also Proceedings, Highway Research Board, 1948, Vol 28; also Drake, W. B.; "Evaluation of Subgrade Support for Flexible Pavements by Field CBR and North Dakota Cone Test," thesis, MS in CE, University of Kentucky.

"Report No. 1 on Test Sections, BPR Project on Correlation of Truck Traffic and Pavement Conditions," Reports of the HMRL, Vol V, Part I, September 4, 1950.

Drake, W. B.; "The Application of Kentucky Flexible Pavement Design Method to WASHO Test Road Conditions," Reports of the HMRL, Vol XI, Part II, March 1956; also Bulletin No. 40, Engineering Experiment Station, University of Kentucky, June 1956.

Drake, W. B. and Havens, J. H.; "Re-evaluation of the Kentucky Flexible Pavement Design Criterion," Reports of the HMRL, Vol XIV, January 1959; also Bulletin 233, Highway Research Board, 1959.

Drake, W. B.; Memorandum Report on "Pavement Design for Interstate Highways," Reports of the HMRL, Vol XV, June 7, 1960.

Havens, J. H. and Hutcheson, D. F.; "Dynamics of Sprung Loads on Pavements," Reports of the HMRL, Vol XVII, Part I, January 1962; also Hutcheson, D. F.; thesis, MS in CE, University of Kentucky.

Havens, J. H. and Hughes, R. D.; "Comments on: AASHO Interim Guide for the Design of Rigid Pavement Structures (AASHO Committee on Design, February 1962)," Reports of the HMRL, Vol XVII, Part II, May 1, 1962.

Havens, J. H.; "Proposed Research Relating to Composite Pavements," Record 37, Highway Research Board, 1963.

Southgate, H. F.; "An Evaluation of Temperature Distribution within Asphaltic Pavements and Its Relationship to Pavement Deflection;" KYHPR-64-20, HPR-1(3), Part II; April 1968.

Hopkins, T. C.; "Relationship between Soil Support Value and Kentucky CBR," KYHPR-64-15, HPR-1(6), Part II; December 1970.

In 1966, it seemed timely again (on the basis of a 10-year cycle) to begin a new evaluation of the design criterion (1958) -- giving due attention to thicker structures built in the interim. Again, principal reliance was given to Benkelman beam deflection measurements. Many deflection measurements were made; but, unfortunately, they were made in the late spring and summer -- without regard to pavement temperatures. The data could not be analyzed. This information was shelved while a method of estimating pavement temperatures and

deflection-adjustment factors were developed (Southgate, 1968). Further attempts to analyze deflections involved computations of stresses and strains as well (Chevron, elastic theory, computer program). These explorations became so challenging that an all-out effort was made to associate fatigue theory (load repetitions) with elastic theory (states of stresses and strains) and to compare them to the 1958 design curves (representing equations of failure). Fortunately, the pavements designed by the 1958 criterion consisted of approximately one-third asphaltic concrete and two-thirds unbound base. The coupling of logic proved rewarding. A report (cited below) was issued in 1968.

Southgate, H. F.; Deen, R. C.; and Havens, J. H.; "Rational Analysis of Kentucky Flexible Pavement Design Criterion;" KYHPR-64-20, HPR-1(4), Part II; November 1968.

The report was reviewed critically and subjectively; implementation of the proposed design criterion was deferred. Confirming analyses and purification of some weak points of logic were desired. Re-analyses were undertaken and a sequel report emerged in May 1971.

Deen, R. C.; Southgate, H. F.; and Havens, J. H.; "Sturctural Analysis of Bituminous Concrete Pavements;" KYP-56, HPR-1(6), Part III; May 1971.

The above report is presently undergoing review, and implementation remains pending.

Current Research:

KYP-69-8: Roadway Design Review and Performance Analysis by Photographic Methods (Photologging)

Related to but not solely for the purpose of recording pavement performances (being implemented by the Division of Photogrammetry).

KYP-60-10: Development of a Highway Inventory System

Deen, R. C.; "Highway Information Management System," April 1970.

Study has a phase relationship with KYHPR-64-11. Note: Pilot study of Hardin County reported by TRW -- Highway Inventory, 1971.

KYHPR-64-11: Pavement-Type Selection Basis
Involves initial costs plus maintenance costs -- long-term basis.

KYP-69-17: Analysis of Pavement Temperature Distributions
Sequel to phase of study in KYHPR-64-20 (reported by Southgate, April 1968).

KYP-70-30: Influence of Recreational Areas on the Functional Service of Highways
A continuation involving analysis of additional data (reported by Pigman, August 1971).

KYP-71-32: Lane Distribution of Traffic
A continuation of study reported by Lynch and Hamby, June 1969. ATR loops installed in inner and outer lanes at five stations (Pending).

KYP-56: Analysis of Surface Cracking; I 64, Fayette-Clark County Line to Ewington.

(Report Pending).

KYHPR-64-24: Pavement Slipperiness Studies

In addition to fundamental study of factors affecting friction, high accident sites are being surveyed for remedial treatments. All types of surfaces are being monitored (periodic testing) to establish trends with respect to time and traffic. Accident data and rates are being analyzed with respect to prevailing skid numbers. Warrants pertaining to degree of skid resistance needed are expected to be forthcoming. Also, it appears likely that warrants regarding types of surfaces will evolve. Several reports issuing from this study have been cited (progress report pending).

KYHPR-64-25: Road Roughness and Serviceability Investigation

In addition to the basic study, extensive survey data has been accumulated -- in some instances dating from 1957. Several progress reports have been cited. A more analytical report relative to pavement performance ("Pavement Roughness: Measurement and Evaluation") is scheduled for issuance during January 1972.

KYHPR-64-20: Flexible Pavement Study Using Viscoelastic Principles

Report pending on Phase I on viscoelastic properties of asphaltic binders. This phase involves eventual estimates of creep characteristics and absolute value of the complex modulus of elasticity of bituminous concrete (not final in this phase).

KYHPR-71-66: Aggregate Shape and Skid Resistance

Interim reports previously cited. Awaiting field trials and evaluation of in-service performance.

KYHPR-72-67: Pavement Properties and Performance Study

FHWA, R and D, direct research contract with Corp of Engineers (Vicksburg) involved Kentucky participation in opening test pits on Newtown Road and KY 4 (to be reported by others).

Experimental Pavements (Current):

KYP-68-15: Hot-mix Coal-tar Concrete Pavement

Six-mile section of KY 15; Junction KY 7 to Sassafras; APD 102(64) and APD 102(65). Construction and interim performance report by D. C. Newberry and J. G. Rose issued June 1971.

KYHPR-70-69: Full-Depth Asphaltic Concrete Pavements

F 1(10); Ashland-Cannonsburg Road, US 60. Construction completed November 1971.

Research Features:

1. Road Rater and deflection measurements.
2. Pavement temperature monitoring.
3. Roughness and slipperiness measurements.
4. Traffic and loading surveys.

I 65, Upton Interchange (Deep-strength section).

US 62, Princeton to Eddyville (Deep-strength section).

Needed Research:

Rutting: Surveys of rut depths were made in connection with the 1958 and the 1968 re-evaluations of pavement performance. A quick method of rut measurement is needed to enable accumulation of historical data concurrently with roughness surveys. A study proposal relative to rutting mechanism is currently in draft form.

Adapting Traffic Statistics: In connection with Deacon and Lynch's study of 1968, all available classification traffic and loadmeter data were stored on magnetic tape. Annual updating would enable more frequent adjustments of estimating factors and retrieval of service histories. Tapes might be expanded to include ADT's and origin-destination information.

Road Rater Surveys: In addition to monitoring the Ashland-Cannonsburg Road project, various interstate, toll, and other system roads should be tested seasonally and at other intervals to establish ecological variability and irreversible damage trends.