Transportation

Kentucky Transportation Center Research Report

University of Kentucky

Annals of the Research Division

Robert C. Deen
Kentucky Department of Highways

This paper is posted at UKnowledge.
https://uknowledge.uky.edu/ktc_researchreports/1399
MEMORANDUM TO:  J. R. Harbison  
State Highway Engineer  
Chairman, Research Committee  

SUBJECT: Research Report 353; "Annals of the Research Division," KYP-64-1; HPR-1(8), Part III

During 1972, the Research Division set goals beyond its normal work capacity. New projects and impromptu assignments were advanced; much nearly finished work was completed; and some work long delayed was finally accomplished. In effect, 1972 became a record year for reporting. The report submitted herewith embellishes the record somewhat.


In this issue, we have included a Bibliography of research reports and the credentials and experience of the present research staff.

Many of the reports shown in the bibliography were not published or distributed outside the Department. Indexing and the preservation of reports in annual bound volumes enables us and perhaps others in the Department to maintain historical continuity -- and certainly avoids duplication of research and the "re-discovery" of previous findings. More importantly perhaps, the historical background enriches the development of the researchable aspects of a problem.

We are striving steadily to improve our hardware and professional service capabilities. We are truly appreciative of the opportunities to be of service in and to perform the research functions of the Department.

Respectfully submitted,

J. H. Havens  
Director of Research

JHH:dw  
Attachment  
cc's: Research Committee
INTRODUCTION

Organization and Objectives

The Division of Research is an engineering branch of the State Highway Engineer’s Office of the Kentucky Department of Highways. The Highway Engineer’s Office is responsible for scheduling and executing all those activities which are necessary to design and construct highway facilities and to maintain them in operational use. More specifically, the Division of Research, headed by a Director, is responsible for:

1. Developing and carrying out a comprehensive research program on all aspects of highway engineering and operations.

2. Maintaining lateral communication and coordination with other segments of the Department regarding development and conduct of research studies and special investigations of various operational and engineering problems.

3. Maintaining relations and cooperating with universities, professional organizations, and other highway departments; evaluating research experiences of these agencies; and utilizing their findings directly or with further research for the benefit of the Kentucky Department of Highways.

4. Maintaining an up-to-date library of research findings on various highway activities throughout the world.
Program

The major portion of the program of the Division of Research is concerned with the development and conduct of a comprehensive research program in cooperation with the U.S. Department of Transportation, Federal Highway Administration. This program is based upon needs and activities of the several Divisions and staff engineers of the Kentucky Department of Highways. Research efforts are developed in cooperation with divisional executives and the Research Committee, which is charged with responsibilities for guidance, review and utilization of research findings within the Department. The Department's Research Committee is composed of the following staff members:

State Highway Engineer, Chairman
All Assistant State Highway Engineers
Assistant Pre-Construction Engineer
Assistant Operations Engineer
Executive Director, Office of Computer Services
Executive Director, Office of Equipment and Properties
Director of Division of Bridges
Director of Division of Construction
Director of Division of Design

Director of Division of Maintenance
Director of Division of Materials
Director of Division of Photogrammetry
Director of Division of Planning
Director of Division of Research
Director of Division of Right of Way
Director of Division of Roadside Development
Director of Division of Rural Roads
Director of Division of Traffic
All District Engineers
Division Engineer, Federal Highway Administration
Chairman, Department of Civil Engineering, University of Kentucky
Associate Dean for Continuing Education, College of Engineering, University of Kentucky

In addition to the formalized research program developed in cooperation with the Federal Highway Administration, the Division of Research also renders other services to the Department as may be required on a non-participating basis in the form of research studies and special investigations of various engineering and operational activities. The Research Division is also involved in development and supervision of research being performed for the Department under contract by various organizations and institutions.
Finances

The Division of Research is partially budgeted through allocations from Highway Planning and Research funds administered through the U.S. Department of Transportation, Federal Highway Administration. These funds, approximately one-quarter of the 1 1/2 percent federal funds for highway purposes coming into the Commonwealth of Kentucky, are merged with state funds in a cooperative, participating program. The total current work program (1972-73) for the Division involves some $900,000 and 45 to 50 research studies. Of this amount $500,000 is supported by federal funds matched by appropriate state funds. The remaining $400,000 represent activities of the Division which are financed entirely by state funds.

### SUMMARY OF RECENT EXPENDITURES

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>KV 1</td>
<td>$500</td>
<td></td>
<td>$140</td>
<td></td>
<td>$85</td>
<td>$725</td>
</tr>
<tr>
<td>KV 2</td>
<td>1,549</td>
<td>82,994</td>
<td></td>
<td></td>
<td>293</td>
<td>6,496</td>
</tr>
<tr>
<td>KV 3</td>
<td>2,429</td>
<td>371</td>
<td>1,074</td>
<td>$363</td>
<td>848</td>
<td>6,964</td>
</tr>
<tr>
<td>KV 5</td>
<td>915</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>515</td>
</tr>
<tr>
<td>KV 6</td>
<td>64</td>
<td></td>
<td>2,648</td>
<td></td>
<td></td>
<td>2,712</td>
</tr>
<tr>
<td>KV 7</td>
<td>64</td>
<td>96</td>
<td></td>
<td></td>
<td></td>
<td>160</td>
</tr>
<tr>
<td>KV 8</td>
<td>156</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2,476</td>
</tr>
<tr>
<td>KV 11</td>
<td>309</td>
<td>76</td>
<td>4,095</td>
<td>4,775</td>
<td></td>
<td>6,165</td>
</tr>
<tr>
<td>KV 13</td>
<td>631</td>
<td>2,479</td>
<td>22</td>
<td></td>
<td></td>
<td>2,533</td>
</tr>
<tr>
<td>KV 14</td>
<td>4,627</td>
<td>20,168</td>
<td>10,245</td>
<td>10,694</td>
<td></td>
<td>31,160</td>
</tr>
<tr>
<td>KV 15</td>
<td>1,024</td>
<td>4,119</td>
<td></td>
<td></td>
<td></td>
<td>5,143</td>
</tr>
<tr>
<td>KV 17</td>
<td>1,646</td>
<td>12,236</td>
<td>5,856</td>
<td>20,802</td>
<td></td>
<td>28,304</td>
</tr>
<tr>
<td>KV 19</td>
<td>22</td>
<td>4,123</td>
<td>1,052</td>
<td>6,246</td>
<td></td>
<td>12,621</td>
</tr>
<tr>
<td>KV 20</td>
<td>700</td>
<td>1,363</td>
<td>630</td>
<td>2,637</td>
<td></td>
<td>6,237</td>
</tr>
<tr>
<td>KV 21</td>
<td>1,370</td>
<td>18,604</td>
<td>673</td>
<td>17,012</td>
<td></td>
<td>35,309</td>
</tr>
<tr>
<td>KV 22</td>
<td>12</td>
<td>52</td>
<td></td>
<td></td>
<td></td>
<td>64</td>
</tr>
<tr>
<td>KV 23</td>
<td>56</td>
<td>76</td>
<td></td>
<td></td>
<td></td>
<td>132</td>
</tr>
<tr>
<td>KV 24</td>
<td>140</td>
<td>180</td>
<td>1,215</td>
<td></td>
<td></td>
<td>1,605</td>
</tr>
<tr>
<td>KV 25</td>
<td>55</td>
<td>51</td>
<td></td>
<td></td>
<td></td>
<td>106</td>
</tr>
<tr>
<td>KV 27</td>
<td>851</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>851</td>
</tr>
<tr>
<td>KV 29</td>
<td>55</td>
<td>76</td>
<td></td>
<td></td>
<td></td>
<td>132</td>
</tr>
<tr>
<td>KV 30</td>
<td>500</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>500</td>
</tr>
<tr>
<td>KV 31</td>
<td>1,547</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,547</td>
</tr>
<tr>
<td>KV 32</td>
<td>1,370</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,370</td>
</tr>
<tr>
<td>KV 33</td>
<td>82</td>
<td>67</td>
<td></td>
<td></td>
<td></td>
<td>149</td>
</tr>
<tr>
<td>KV 34</td>
<td>6,247</td>
<td>2,657</td>
<td>715</td>
<td>2,476</td>
<td></td>
<td>11,456</td>
</tr>
<tr>
<td>KV 35</td>
<td>1,008</td>
<td>3,106</td>
<td>3,382</td>
<td>2,580</td>
<td></td>
<td>11,572</td>
</tr>
<tr>
<td>KV 36</td>
<td>4,697</td>
<td>2,224</td>
<td>205</td>
<td>5,623</td>
<td>19,694</td>
<td>21,222</td>
</tr>
<tr>
<td>KV 37</td>
<td>1,547</td>
<td>1,547</td>
<td>303</td>
<td>7,204</td>
<td></td>
<td>16,287</td>
</tr>
<tr>
<td>KV 38</td>
<td>97</td>
<td>97</td>
<td>503</td>
<td>13,180</td>
<td></td>
<td>14,287</td>
</tr>
<tr>
<td>KV 39</td>
<td>3,106</td>
<td>2,224</td>
<td>205</td>
<td>5,623</td>
<td>19,694</td>
<td>21,222</td>
</tr>
<tr>
<td>KV 40</td>
<td>1,547</td>
<td>1,547</td>
<td>303</td>
<td>7,204</td>
<td></td>
<td>16,287</td>
</tr>
<tr>
<td>TOTALS</td>
<td>36,880</td>
<td>49,566</td>
<td>19,637</td>
<td>39,780</td>
<td>76,944</td>
<td>142,995</td>
</tr>
<tr>
<td>GRAND TOTALS</td>
<td>317,354</td>
<td>266,217</td>
<td>374,539</td>
<td>330,729</td>
<td>487,390</td>
<td>688,195</td>
</tr>
</tbody>
</table>
SUMMARY OF EXPENDITURES FOR PARTICIPATING STUDIES

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>86,701</td>
<td>82,074</td>
<td>82,259</td>
<td>8,290*</td>
<td>1,786</td>
<td>6,119</td>
<td>12,222</td>
<td>45</td>
<td>150</td>
<td>249*</td>
</tr>
<tr>
<td>2</td>
<td>315</td>
<td>1,427</td>
<td>2,031</td>
<td></td>
<td>545</td>
<td>2,365</td>
<td>3,666</td>
<td>582</td>
<td>1,359</td>
<td>3,666*</td>
</tr>
<tr>
<td>3</td>
<td>11,935</td>
<td>18,308</td>
<td>9,477</td>
<td>5,341</td>
<td>5,020</td>
<td>1,700</td>
<td>1,004</td>
<td>114</td>
<td>9</td>
<td>1,427</td>
</tr>
<tr>
<td>4</td>
<td>2,626</td>
<td>2,916</td>
<td>1,235</td>
<td>3,666*</td>
<td>2,626</td>
<td>1,061</td>
<td>3,386</td>
<td>2,036</td>
<td>57</td>
<td>2,036</td>
</tr>
<tr>
<td>5</td>
<td>8,060</td>
<td>7,467</td>
<td>9,490</td>
<td>4,476</td>
<td>7,878</td>
<td>10,533</td>
<td>1,402</td>
<td>53</td>
<td>9</td>
<td>1,402</td>
</tr>
<tr>
<td>6</td>
<td>91</td>
<td>6,339</td>
<td>5,215</td>
<td>12,086</td>
<td>176</td>
<td>23,969</td>
<td>116</td>
<td>54,087</td>
<td>116</td>
<td>54,087</td>
</tr>
<tr>
<td>7</td>
<td>96</td>
<td>30</td>
<td>91</td>
<td>216</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>4,730</td>
<td>11,956</td>
<td>24,752</td>
<td>8,399*</td>
<td>64</td>
<td>16</td>
<td>91</td>
<td>9</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>9</td>
<td>764</td>
<td>93</td>
<td>9</td>
<td>1,424</td>
<td>4,543</td>
<td>7,453</td>
<td>4,741</td>
<td>6,457</td>
<td>7,440</td>
<td>23,369</td>
</tr>
<tr>
<td>10</td>
<td>25,906</td>
<td>18,007</td>
<td>27,631</td>
<td>18,216</td>
<td>3,540</td>
<td>4,962</td>
<td>6,057</td>
<td>446*</td>
<td>1,168</td>
<td>2,052</td>
</tr>
<tr>
<td>11</td>
<td>4,165</td>
<td>27,207</td>
<td>12,366</td>
<td>8,168</td>
<td>19,750</td>
<td>3,561</td>
<td>6,610</td>
<td>4,892</td>
<td>6,992</td>
<td>39,392</td>
</tr>
<tr>
<td>12</td>
<td>7,090</td>
<td>24,182</td>
<td>10,517</td>
<td>13,622</td>
<td>31,144</td>
<td>139,799</td>
<td>49,036</td>
<td>42,631</td>
<td>322,316</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>$13,205</td>
<td>17,716</td>
<td>16,950</td>
<td>14,876</td>
<td>17,080</td>
<td>26,100</td>
<td>26,021</td>
<td>3,725</td>
<td>5,995</td>
<td>57,736</td>
</tr>
<tr>
<td>14</td>
<td>17,050</td>
<td>26,928</td>
<td>37,176</td>
<td>5,172</td>
<td>10,482</td>
<td>10,613</td>
<td>12,372</td>
<td>13,274</td>
<td>102,973</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>20,952</td>
<td>25,709</td>
<td>9,507</td>
<td>5,615</td>
<td>1,952</td>
<td>7,941</td>
<td>1,178</td>
<td>1,087</td>
<td>10,283</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>15,924</td>
<td>16,866</td>
<td>16,558</td>
<td>14,316</td>
<td>17,080</td>
<td>32,100</td>
<td>30,270</td>
<td>1,591</td>
<td>17,789</td>
<td>17,789</td>
</tr>
<tr>
<td>17</td>
<td>4,074</td>
<td>7,255</td>
<td>7,085</td>
<td>23,333</td>
<td>21,093</td>
<td>10,901</td>
<td>5,995</td>
<td>1,952</td>
<td>10,901</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>1,102</td>
<td>1,072</td>
<td>935</td>
<td>6,067</td>
<td>1,702</td>
<td>4,158</td>
<td>3,917</td>
<td>16,375</td>
<td>16,375</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>1,952</td>
<td>3,112</td>
<td>2,514</td>
<td>1,775</td>
<td>2,241</td>
<td>1,555</td>
<td>3,917</td>
<td>16,375</td>
<td>16,375</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>2,570</td>
<td>3,099</td>
<td>7,113</td>
<td>5,030</td>
<td>6,032</td>
<td>6,351</td>
<td>9,225</td>
<td>33,125</td>
<td>33,125</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>11,935</td>
<td>5,935</td>
<td>9,477</td>
<td>5,341</td>
<td>8,060</td>
<td>580</td>
<td>1,100</td>
<td>1,010</td>
<td>1,010</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>825</td>
<td>374</td>
<td>318</td>
<td>452</td>
<td>2,694</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>504</td>
<td>2,538</td>
<td>5,016</td>
<td></td>
<td>64</td>
<td>4,484</td>
<td>12,222</td>
<td>53</td>
<td>1,427</td>
<td>1,427</td>
</tr>
<tr>
<td>24</td>
<td>721</td>
<td>717</td>
<td>109</td>
<td>316</td>
<td>1,178</td>
<td>1,087</td>
<td>1,053</td>
<td>1,010</td>
<td>1,010</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>717</td>
<td>425</td>
<td>2,694</td>
<td>14,943</td>
<td>17,889</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>1,053</td>
<td>1,010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>1,053</td>
<td>1,010</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>17,970</td>
<td>19,142</td>
<td>13,439</td>
<td>19,834</td>
<td>19,834</td>
<td>19,834</td>
<td>19,834</td>
<td>19,834</td>
<td>19,834</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>1,957</td>
<td>2,669</td>
<td>18,496</td>
<td>19,563</td>
<td>19,834</td>
<td>19,834</td>
<td>19,834</td>
<td>19,834</td>
<td>19,834</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>1,983</td>
<td>19,834</td>
<td>19,834</td>
<td>19,834</td>
<td>19,834</td>
<td>19,834</td>
<td>19,834</td>
<td>19,834</td>
<td>19,834</td>
<td></td>
</tr>
</tbody>
</table>

**NOTE:** KYHPR-52 expenditures shown pertain to cost of reporting only for the studies identified with an asterisk.
Facilities

Offices and laboratories of the Division of Research are located at 533 South Limestone Street, Lexington, Kentucky, opposite the main entrance to the University of Kentucky. These facilities were designed and constructed in 1966-67 and were first occupied by the Division of Research in June 1967. The original facilities, located at 132 Graham Avenue on the University campus, were constructed by the Department in 1942 and served as headquarters for research activities until late in fiscal year 1967.

The present facilities are located on a 200 x 200-foot site chosen coordinately with the University’s developmental and land-use plan. The building contains 22,700 square feet of floor area, divided equally between two floors, and covers a little over 25 percent of the total site area -- leaving the remainder for landscaping, walkways, lighting, parking, and a garage. Space is available for parking of approximately 50 vehicles on the landscaped parking lot. Lighting has been provided so that a nighttime appearance which is different but equal in quality to the daytime view is available. Landscaping elements of grass, trees, and shrubbery are used to outline the building and parking areas, to soften the transition between the public sidewalks, parking, and building areas, and to blend all of the physical elements into a unified and visually pleasing design. Bill Qualls, Director of the Lexington-Fayette County Planning Staff, has indicated that "...This development has given our community an extremely pleasing aesthetic blending of good building and landscape architecture that becomes an especially good neighbor to surrounding land uses."

A special effort was made to provide flexibility and versatility in the arrangement of fixtures in the various laboratories. Most of the utilities, hot and cold water, natural gas, compressed air, vacuum, and electrical service (110 volts and 220 volts), are exposed in each of the laboratories. Numerous cut-off valves and switch boxes are provided so that utility connections can be made conveniently when required for new instrumentation or test equipment. All laboratory furnishings are movable, and the arrangement of the various laboratories and work areas can be changed conveniently when the need arises.

The research facilities were further expanded in 1969 on an 82 x 108-foot site adjoining the parking lot. A 2,800 square foot structure contains a garage for housing and servicing special test vehicles and a storage area which serves as a depository for material samples and miscellaneous items and a work area for soil sample
Division of Research Facilities

preparation. The structure is designed for a second level addition or rooftop parking. The remainder of the site is a fenced parking lot for state-owned vehicles.

In addition to the physical plant, the Division of Research has a variety of equipment and instrumentation necessary for routine tests and evaluations of materials and special equipment and instrumentation for research. The list of unusual or significant equipment might include items such as: automatic freeze-thaw box; strain-controlled and stress-controlled triaxial testing machines; consolidation testing equipment; automobile instrumented for ride quality testing; GM type profilometer for measuring pavement profiles and a quarter car simulator and swept spectrum analyzer for evaluating roughness and ride quality of pavements; skid trailer, British Pendulum Tester and Drag Tester for measuring pavement skid resistance; Road Rater used in testing structural characteristics of pavements and substructures; noise level meter and recorder; acoustic emission instrumentation; analog data reduction system; carbon arc lamp weatherometer; a reflex photometer; a colorimeter; a vacuum auger extrusion machine for preparing soil specimens; cone penetrometer; and vane shear apparatus. Accessory equipment such as an infrared thermometer, water baths, digital voltmeters, amplifiers, transducers, voltage and current reference sources, strip-chart and magnetic tape recorders, oscillographs, oscilloscopes, accelerometers, ovens, aggregate processing equipment, testing machines, and desk calculators are available when needed. To fulfill its obligation to prepare and disseminate research findings, the Division of Research is equipped with dark rooms and associated camera and photographic equipment, process camera, and offset multilith printing equipment for reproduction of the various types of reports required.
Support Functions

Instrumentation and Systems Section - Highway technology has advanced to a more sophisticated level in the last decade with the advent of electronics and related sciences. Utilization of electronic instruments and systems in measurements has become routine in research related activities. To assist the Division of Research, the Section a) assists in the selection and recommendation of suitable electronic devices, components, instruments and specialized equipment and systems, including preparation of specifications and inspection and checkout and acceptance of custom fabricated devices; b) maintains, repairs, designs, constructs and calibrates electronic devices, systems and related equipment; c) stocks the instrument shop with spare parts and tools, and stores instruments, devices, systems and miscellaneous equipment; and d) conducts, assists, consults and reports on various laboratory and field studies which require expertise in electronic measurements or monitoring and interpretation of results.

Computers - Electronic data processing is an increasingly valuable tool in many studies undertaken by the Division of Research. Computer facilities are provided by the University of Kentucky Computing Center, and the capabilities and scope of the Division's usage has increased with the growth and expansion of the Center's system.

The first computer available to personnel of the Division was the IBM 650, a popular scientific machine of the late 1950's and early 1960's. Each user operated his own program from the computer console. In 1962, the IBM 650 was replaced by the IBM 1620. Since the late 1960's, user programs have been run on the IBM System 360/65 computer. Since 1964, the Computing Center has been run on a "closed shop" basis, relieving the user of being a machine operator and allowing him to concentrate on application programming.

Many engineers of the Division write their own programs, generally in Fortran IV, as needs arise. In addition to these user-written programs, the Computing Center maintains an extensive program library, which fulfills many analytical and statistical needs of the Division. Often these "canned" routines require only a minimum of programming knowledge. When their unique function is needed, these routines can also be called by user-written programs. In December 1972, an IBM 2770 Data Communications System was installed in the Division of Research. This provided a direct link with the Highway Department's IBM System 370 computer and provided for shorter program turn-around times. The terminal consisted of the IBM 2772 multipurpose control unit, the IBM 2203 printer, and the IBM 2502 card reader. Plans were made to provide for a high-speed printer and for card punch output at the terminal.
## Library Functions and Programs Used by the Division of Research

<table>
<thead>
<tr>
<th>AUTOFLOW</th>
<th>Flowcharts a program</th>
<th>GRAIL</th>
<th>Generalized information retrieval</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMDX85</td>
<td>Nonlinear curve-fitting program</td>
<td>ICES LEASE-1</td>
<td>Slope stability analysis</td>
</tr>
<tr>
<td><strong>CALCOMP Routines:</strong></td>
<td></td>
<td>IEBGENER</td>
<td>Tape utility program</td>
</tr>
<tr>
<td>AXIS</td>
<td>Draws an axis</td>
<td>IEBPTPCH</td>
<td>Prints selected portions of a tape</td>
</tr>
<tr>
<td>BAR</td>
<td>Generates a bar for bar graphs</td>
<td>IEHINITT</td>
<td>Labels tapes</td>
</tr>
<tr>
<td>CRVPLOT</td>
<td>Fits and plots an Nth degree polynomial</td>
<td>MAMULT</td>
<td>Matrix multiplication</td>
</tr>
<tr>
<td>LINE</td>
<td>Draws a line</td>
<td>MATINV</td>
<td>Matrix inversion</td>
</tr>
<tr>
<td>LOGAXS</td>
<td>Draws a logarithmic axis</td>
<td>MULTR</td>
<td>Stepwise multiple regression analysis</td>
</tr>
<tr>
<td>LOGSCA</td>
<td>Generates a log scale along an axis</td>
<td>NLIN</td>
<td>Nonlinear curve fitting program</td>
</tr>
<tr>
<td>NUMBER</td>
<td>Draws a number</td>
<td>NONLIN</td>
<td>Nonlinear curve fitting program</td>
</tr>
<tr>
<td>PLOT</td>
<td>Moves paper and pen to start a new page</td>
<td>OPTDEBE</td>
<td>Prints selected portions of a tape</td>
</tr>
<tr>
<td>SCALE</td>
<td>Generates an arithmetic scale along an axis</td>
<td>PLIDEBE</td>
<td>Prints records from tape</td>
</tr>
<tr>
<td>SMOOTH</td>
<td>Generates a smooth curve through points</td>
<td>RANF</td>
<td>Random number generator</td>
</tr>
<tr>
<td>SYMBOL</td>
<td>Draws text</td>
<td>REREAD</td>
<td>Reading a card under two formats</td>
</tr>
<tr>
<td>CSMP</td>
<td>Simulation of continuous systems</td>
<td>SORTD</td>
<td>Sorting program</td>
</tr>
<tr>
<td>DATA</td>
<td>Assigns alphanumeric values to variables</td>
<td>STNORD</td>
<td>Fortran statement numbering and reordering program for source decks</td>
</tr>
<tr>
<td>DATE</td>
<td>Prints date on computer clock</td>
<td>TTEST</td>
<td>Produces means, standard deviations, corrected sums of squares, variances, coefficients of variation and T-tests</td>
</tr>
<tr>
<td>DEBUG</td>
<td>Debugging aid package</td>
<td>WATFIV COMPILER</td>
<td>Debugging aid</td>
</tr>
<tr>
<td>FCLSQ</td>
<td>Least squares polynomial approximations through a number of constraining points</td>
<td>XBAR</td>
<td>Produces means, standard deviations and variances for up to 200 variables</td>
</tr>
<tr>
<td>FGLEG</td>
<td>Evaluates the integral of a function</td>
<td>XSQ</td>
<td>Produces two-way frequency tables and a contingency Chi square value</td>
</tr>
<tr>
<td>FLSQFY</td>
<td>Least squares polynomial approximation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FORIT</td>
<td>Evaluates the Fourier coefficients for a tabulated periodic function</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FORMAC INTERPRETER</td>
<td>Symbolic manipulation of mathematical expressions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FORTRAN BUILT-IN FUNCTIONS:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ABS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALOG and DLOG</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALOG10 and DLOG10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ATAN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COTAN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXP and DEXP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SIN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SQRT and D SQRT</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Reproduction - Prior to 1957, the photo lab consisted of one enlarger and one mimeograph machine on which all reproduction work was done. Due to increased work load, capability was extended in 1957 to include offset printing of research reports. At that time, a used small offset press was obtained and an 8 x 10-inch view camera was purchased to make line and halftone negatives.

In 1967 when the Division of Research moved to larger facilities, the floor space of the photo lab increased from 350 square feet to 1,500 square feet, including three dark rooms, a light room, an offset press room and an office.

A large offset press and a plate maker have been obtained. Printing, stripping, collating, and binding of all research reports are done in-house. Photographic equipment includes three 35mm cameras, two 4 x 5-inch view cameras, a 20 x 24-inch process camera, a 35mm sequence camera, a 16mm movie camera, ten 16mm surveillance cameras, three instamatic cameras and two enlargers for 35mm and 4 x 5-inch negatives. Facilities are available for processing B/W negatives, color slides, B/W prints, B/W prints from color slides and B/W glossy prints from line drawings. The drafting section does all drafting of figures for research reports and visual aids.

New equipment has also increased the rate of production. Photographic files now contain over 50,000 negatives. An additional 35,000 negatives have been shot for report reproduction, 30 miles of movie film have been taken, 85,000 color slides have been processed and mounted, and 35 tons of paper have been used in printing some 450 research and memorandum reports and other allied material. In addition to these contributions, the Reproduction Section was instrumental in the development of "photo logging" of highway systems that will shortly be implemented by the Department.

The function and field of reproduction is still expanding. Plans have been made for the installation of three color processing for printing and for materials evaluation by infra red and ultra violet photography.
HISTORY

The history of highway research in Kentucky has been continuous with and closely parallels that of the Department. A brief chronology of events which have had significant bearing on the overall development of the present research program follows:

1912 - Organization of Kentucky Department of Highways.
1914 - First Kentucky Highway Conference (a two-week road school).
1914 - Founding of American Association of State Highway Officials.
1914 - Passage of the so-called State Aid Road Law (5-cent property tax) by the Kentucky Legislature. Inter-county Seat Road System plan prepared.
1914 - Establishment of the Road Materials Testing Laboratory at the University of Kentucky; began operation in 1915 under Professor D. V. Terrell. Inspectors required by law to be on all state-aid works.
1916 - Rural Post Road Bill (H. R. 7617).
1917 - Oiled macadam and water-bound macadam roads.
1918 - Inauguration of federal aid.
1919 - Last of first series of highway conferences.
1919 - Ashland-Cannonsburg Road, FA-1 (Brick); Lexington-Winchester Road, FA-2 (Concrete).
1920 - Enactment of 1-cent gasoline and 60-cent horsepower taxes in Kentucky.
1921 - Revision of the federal aid act.
1927 - Experimental concrete paving using sandstone aggregate (Pineville-Harlan Road).
1928 - Establishment of the Materials Testing Laboratory in Frankfort, previously at the University of Kentucky in the basement of Pence Hall; V. P. Ligon, Engineer of Tests; D. V. Terrell, Research Engineer.
1930 - Sandstone used in several reinforced concrete bridges in Eastern Kentucky.
1933 - Beginning of hot-mix bituminous concrete paving. First use of paver in Kentucky for laying Kentucky rock asphalt.
1934 - Authorization by Congress for the use of 1.5 percent of federal aid for Highway Planning Studies.
1937 - First soil-cement base in Kentucky in Daviess County.
1940 - Experimental concrete pavement, US 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. Action envisioned a facility unequaled anywhere in this country, and the original estimate of cost of the facility was $50,000; Professor D. V. Terrell, Director of Research.
1941 - 1946 - World War II. Research facility remained understaffed; Curtis Cantrill, Research Engineer.
1945 - Appointment of L. E. Gregg as Associate Director of Research.
1949 - Renewal of annual highway conferences.
With the beginning of federal-aid highway work in Kentucky, the necessity of specifying the quality of materials for road building and the enforcement of specification requirements through testing became increasingly apparent. Mandatory control of the quality of road material by the then Bureau of Public Roads alarmed some neighboring states, and it appeared for a time that some would subscribe to testing services available at the University of Kentucky under Professor D. V. Terrell. Professor Terrell was appointed to an ad hoc committee in 1918 to establish materials’ requirements and appropriate test methods. Those requirements and test 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, those early efforts inaugurated research in highway materials and perhaps were instrumental in the organization of the Highway Research Board in 1920.

Testing and research were continued jointly under Professor Terrell until 1928; testing services were then transferred to Frankfort where a testing laboratory was provided. 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. Those arrangements continued until about 1939 when it became apparent a more intensified and 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. Because of the onset of World War II, the facility remained understaffed 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. Mr. Robert F. Baker, who later became 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 that 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, former Assistant to the State Highway Engineer; and Carey Burns, deceased. Research was then a branch of the Division of Design. In 1949, it became the Division of Research.

In the subsequent 23 years or so, possibly as many as 1,100 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 dedicated researchers are hard to find and difficult to retain.
From the beginning, it was evident that certain problems associated with design, construction, and maintenance of highway facilities should be studied and investigated apart from regular duties. Such subjects as quality, soundness, and durability of road aggregates, design and control of bituminous mixes, effects of freezing-thawing and wetting-drying and of chemicals and traffic upon concrete and bituminous mixes, many aspects of soils and soil engineering, and construction techniques and methods have been researchable problems and have been under continual surveillance. These general subjects have been the most researched items in the history of highways, and even now a large portion of the research efforts here and elsewhere are 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. Thus, many general topics become subject to perpetual study. Nevertheless, these are the substances of which roads are built and it is toward the proper and efficient utilization of materials that physical research is aimed. Many functions involving design, construction, and maintenance of the highway facility emerge or evolve from the knowledge of materials.

During recent years, there has been a significant trend to expand the highway research program to include the socio-economic and environmental aspects of highway developments. It is anticipated that the research program will continue to expand in these areas with increased efforts in the study of the social, economic and environmental impact of highway facilities, investigation of the legal and administrative techniques and problems associated with the highway system, and the development of more reliable methods and techniques of predicting the demand and(or) need for highway and transportation facilities.

The review of the Kentucky highway research program which follows is to provide a brief compilation of accomplishments and efforts which have contributed and are contributing in various degrees of importance to the main business of the Kentucky Department of Highways - that is, design, construction, and maintenance of roads for the citizens of the state. It would not, of course, be prudent to mention all of the 340 research and memorandum reports prepared by the Division of Research. However, this brief review is an opportunity to present some of the highlights of the overall program.
**Pavement Design**

In 1946, an extensive study of flexible pavements was made to develop design criteria for Kentucky that were based upon the relationship between traffic (as evaluated or measured by EWL's, equivalent wheel loads), thickness of the pavement structure, and strength of the supporting soils (as measured by the California Bearing Ratio, CBR). This was an empirical scheme inaugurated in California in 1941. As a result of that extensive study, the Department adopted a flexible pavement design procedure in 1948. The procedure was re-evaluated and refined as a result of another study made in 1958. Minor changes were made in the design curves at that time. Reappraisal of the design procedure was completed before the AASHO road test was built. However, detailed comparative analyses of Kentucky design charts in relation to findings of the road test have since been made and have been found essentially in agreement.

Pavement deflections of bituminous pavements have been found to be highly dependent upon pavement temperatures. Thus, a method was developed to adjust measured deflections at any temperature to an equivalent deflection at a "standard" temperature. Another study correlating 40 years of flexible pavement design experience and field testing with elastic theory indicated that pavement design and behavior are more closely associated with elastic strains than with deflections. Theoretically derived curves permit design of equivalent pavement structures for varying ratios of thickness of asphaltic concrete to total design thickness. As a verification of full-depth designs, US 60 in Boyd County was constructed utilizing five full-depth design thicknesses of asphaltic concrete and two subgrade types. To evaluate pavement response to static and dynamic loadings, a "Road Rater" was obtained.

An essential part of any pavement design technique is the forecasting of the total accumulation of traffic for the design period. In-stream counting methods have been developed to a rather high degree of perfection and there is a consciousness of the need for total traffic count insomuch as such information is needed to establish the class and geometrics of a roadway. From the standpoint of pavement design, there is also a need to know axle weight distributions as well as the total traffic count. Instrumentation perfected in Texas provides for an in-stream weighing system so that not only traffic counts can be obtained but information concerning the weights of traffic loads and axle spacings can be accumulated. This instrumentation package will be installed on US 60 in Boyd County.

In 1947, a study of "pumping" under concrete pavements was undertaken in Kentucky. Results from this work strongly favored use of a granular insulation course, but more importantly, it provided a method of dealing with composite or mixed traffic for rigid pavements on the same basis as used in the design of bituminous pavements. Through this equality in traffic, the thickness of the two major types of pavements can be compared.

A seven-mile section of continuously, reinforced concrete pavement was placed on I 71 in Carroll, Trimble and Henry Counties in the late 1960's. Construction and performance of that pavement have been monitored closely. A 28-mile length of pavement on I 275 in Northern Kentucky has been designed and partially completed with continuous reinforcement. Performance data from those pavements will provide vital information for use in determining the desirability of that design and construction procedure.

---

**Measurement of Pavement Deflections under Static Loads with a Benkelman Beam**
1958 Flexible Pavement Design Curves

MINIMUM LABORATORY CBR VALUE

<table>
<thead>
<tr>
<th>COMBINED THICKNESS - BASE AND PAVEMENT, INCHES</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>22</td>
</tr>
</tbody>
</table>

Curve Limiting EWL (million)

<table>
<thead>
<tr>
<th>Curve</th>
<th>Limiting EWL (million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IA</td>
<td>0.25</td>
</tr>
<tr>
<td>I</td>
<td>0.5</td>
</tr>
<tr>
<td>II</td>
<td>1</td>
</tr>
<tr>
<td>III</td>
<td>2</td>
</tr>
<tr>
<td>IV</td>
<td>4</td>
</tr>
<tr>
<td>V</td>
<td>8</td>
</tr>
<tr>
<td>VI</td>
<td>16</td>
</tr>
<tr>
<td>VII</td>
<td>32</td>
</tr>
<tr>
<td>VIII</td>
<td>64</td>
</tr>
<tr>
<td>IX</td>
<td>128</td>
</tr>
<tr>
<td>X</td>
<td>256</td>
</tr>
</tbody>
</table>

Measurement of Pavement Deflections under Dynamic Loads with the Road Rater
Materials Characterization

Recently, much emphasis has been placed on the formulation of definitions describing the mechanical behavior of materials. Before this can be done, a thorough understanding of the properties of these materials and their components must be acquired. In recent years, the Division of Research has expended considerable effort in attempting to acquire this knowledge. Asphalts, asphalt-mineral mixes and soils have been and are being studied extensively. Results of these research efforts have shown that mechanical properties of these materials exhibit a large dependency on time, and that over-simplified elastic models are often inadequate in describing this time-dependent behavior.

In the past, attention has been devoted to the development of theoretical design procedures for flexible pavement structures. These procedures rely in part on the computation of certain critical stresses, strains, and deflections within the structure. Computation of the stresses, strains, and deflections in multilayered systems is now possible to the extent that the behavior of the component materials approaches that of ideal elastic solids. Field measurements have shown that the elastic theory may be used as a reasonable approximation of pavement behavior for certain limited conditions such as low ranges of stress, short durations of loading, and limited strains or deflections. Since the elastic theory does not directly take into account the known time-dependent behavior of flexible pavement materials, attention has been directed to the adaptation of the viscoelastic theory to the prediction of pavement response. The viscoelastic theory is applicable to certain materials which exhibit time-dependent, stress-strain behavior. Hence, the theory appears to be promising for use in pavement analysis and has received considerable attention within the past few years. The application of viscoelastic models to pavement response has shown that, at temperatures encountered in the field on warm days, the largest components of deformation are viscoelastic and plastic -- both time-dependent.

Attempts are being made to apply viscoelastic models to observed time-dependent (rheological) behavior of soils. 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 application of rheological theories. Ultimate goals 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. Data obtained thus far have shown that soils do, in fact, exhibit large creep deformations at shearing stresses that are considerably less than the ultimate stress. At present, the major achievement of this research has been the development of a method for obtaining a Mohr’s failure envelope from only one test specimen by application of viscoelastic theory.
Bituminous Paving Materials and Mixes

For some time, the Department of Highways has been aware of certain deficiencies in specifications pertaining to asphaltic concrete construction. Performance characteristics required of bituminous concrete have been observed to change to accommodate changes in the nature and amount of traffic and to accommodate use of materials from various sources. To understand the relationship between the makeup of bituminous mixes and their performance under traffic, one area of research has been directed towards a better understanding of important parameters influencing the behavior of bituminous mixtures. To obtain such information, efforts have been made to evaluate various characteristics of the bituminous materials themselves.

**Bituminous Concretes** - Much of the activity in the area of bituminous paving materials and mixes has been directed towards increased use of local materials, improved construction techniques, evaluation of merits of comparative materials, and evaluation of merits of equipment for paving purposes. Use of coal tars and coal-modified coal-tar binder and bituminous paving materials has received attention by the Research Division. The use of coal and coal-mining waste products as an aggregate in bituminous mixtures has also been studied in the laboratory and field. Because of rapid deterioration under field conditions, those efforts have been abandoned. Evaluations of vibratory rollers for use in compacting bituminous concrete mixes, performance of a machine-laid surmountable bituminous concrete median, and evaluation of lightweight compaction equipment for use by maintenance crews are the types of studies concerning construction techniques that are often undertaken by the Division of Research. Vibratory rollers appear to provide the desired densities in fewer coverages than conventional compaction equipment of comparable weights.

Considerable effort has been directed towards design of bituminous base and surface courses having adequate stability and durability to withstand the action of traffic. Surface course composition requirements have been especially problematic in that void contents of the compacted courses have tended to be high and the stability often low.

**Sand Asphalts** - Bituminous surface courses containing certain types of aggregate (many limestones) tend to become slick after a period of time under traffic. This is attributed to susceptibility of the aggregate to polishing by the action of grit and tires. Kentucky has, and is using, a predominant amount of limestone aggregates and the problem of slick pavements is of great concern. Silica sand-asphalt surfaces are reputed to have high skid resistance, even after considerable wear. Large quantities of quartziferous (silica) aggregates such as sandstones, pit sands, river sands, gravels, and conglomerates are available in the state for use in sand-asphalt mixtures. Considerable effort has been directed towards the development and field testing of thin applications of silica sand asphalt. Angularity of the sand is an essential factor in skid resistance.

**Rock Asphalts** - An ever increasing need is foreseen for a surface-renewal type of treatment for primary roads as well as the more expedient treatments for all classes of roads. Until a few years ago, this need was fulfilled largely by Kentucky rock asphalt, and were it not for its exorbitant cost and performance difficulties, rock asphalt would likely be in wide usage at the present time. Rock asphalt was found to be unreliable and has been studied by the Research Division for many years. A survey of the performance of roads surfaced with the material has shown that the significant variable was the hardness of the natural asphalt. The asphaltic material in those surfaces that were performing well was very hard (penetration as low as 15) whereas the asphalts in new surfaces were very soft (in the range of 300 to 400 penetration). Fresh, uncured materials simply did not have sufficient stability to withstand heavy traffic.

Marshall Stability Test Apparatus
An experimental resurfacing project on US 31W between Kosmosdale and West Point was constructed to illustrate that the material could be precured by drying and heating so it would perform in a reliable way. The point was proven, but the producing company elected to liquidate its assets rather than to venture further development.

Vast quantities of lean-to-rich bituminous sandstones exist as waste and tailings in spoil areas of rock asphalt quarries. Because of a desire to use locally available materials in highway construction and maintenance insofar that they may be practical, economical, and otherwise advantageous, a program was initiated to study the feasibility of using that material as a dust-free, traffic-bound base and surface and as a material for stage construction of bases on rural roads. Additionally, approximately 100 miles of experimental hot-mix, rock-asphalt resurfacing has been undertaken since the mid-1960's. These projects were monitored to evaluate performance of the rock asphalt as a resurfacing material for high-traffic volume roads. Rock asphalts have retained high skid-resistance characteristics even under exposure to traffic.

**Slurry Seals** - Considerable attention was given various types of seal coat applications that might be used on the highway facilities. Use of slurry seals for maintenance applications was tried and studied for approximately three years in the 1960's. Slurry seal maintenance was abandoned because of the unpredictable behavior of the slurries. Apparently, there is a very critical balance between the chemical and(or) electrical charges of the aggregate and the asphaltic binder. The same tank-truck of binder would perform well with aggregate from one source but not that from another.
Concrete and Concrete Structures

Through a wide range of studies involving laboratory and field investigations, considerable effort has been directed towards development of a better understanding of aggregate characteristics; preparation, manipulation and finishing of concrete; and various problems which affect the strength and durability of concrete. Some earlier studies made by the Division of Research involved investigations of air entrainment in portland cement concrete mixes. As a result, air-entraining admixtures are used on a routine basis in most types of concrete now used in construction of modern highway facilities. Associated with the use of air-entraining admixtures are studies of various aspects of the durability of concrete mixes. A basic study concerned detailed investigations of the mechanisms involved in the freeze-thaw phenomena of concrete masses. The effect of various aggregate blends, including the use of expanded shale, upon the durability of concrete has come under more or less continual scrutiny for several years. At various times, studies have been made of the effects and benefits derived from the use of various types of admixtures for purposes of air entrainment, retarding set, accelerating set, etc.

Revibration - Studies made by the Division of Research have shown that revibration after any period of delay will increase the strength of concrete, so long as the mix can be brought to a plastic state. Durability of non-air-entrained concrete is critically decreased while durability of air-entrained concrete is not significantly affected by delayed revibration. Revibration of concrete within a reasonable period does not appear to cause significant segregation and there does not appear to be any critical possibility of over vibrating.

Slip-Form Paving - Conventional methods of placing concrete pavement require use of extensive forming. Slip-form paving has attracted widespread attention in recent years as a construction technique resulting in savings by eliminating need for an elaborate system for forming the pavement. Significant attention has been given to use of slip-form pavers by contractors in Kentucky and results of such construction were closely studied and provided considerable information for further applications of this type of construction; slip-form paving is now used almost exclusively.

Surface Finishes - Studies have been made to determine the most desirable procedure for obtaining a satisfactory surface finish for structural concrete. Attempts were made to evaluate cost versus characteristics of surfaces produced by various methods of forming and(or) finishing structural concrete that may be seen by the motoring public. Criteria or standards whereby concrete surfaces were accepted or rejected were often left to the discretion of individuals involved and were thus subject to wide variation. The requirement for hand rubbing of many concrete surfaces is no longer mandatory, and decorative coatings may be used in lieu of rubbing.

Joint Seals - Adequate sealing of joints in concrete bridge decks is a continuing maintenance problem. Conventional sealants are in many instances only partially effective in preventing seepage of water through joints. Bridge piers become stained and some are scaling as a direct result. Progressive scaling leads to structural deterioration and the staining is unsightly. Often, incompressible matter may become embedded in mastic-type sealants and cause structural damage to the joints during expansion of the deck. Interest in effectively sealing bridge joints is threefold, that is: 1) to prevent spalling, 2) to prevent scaling, and 3) to prevent staining. Preformed neoprene seals have been installed in joints of several bridges. Installation procedures have been monitored and periodic inspections are being made to accumulate data which may be used in evaluating the effectiveness of these seals. At various times, the Division of Research has also been called upon to study the effects of various types of jointing procedures used in portland cement concrete pavements as they are associated with blowups that occur occasionally.
Application of "Epoxy" Protective Coating and Skid-Resistant Sand to a Concrete Bridge Deck which Has Been Repaired by Patching

Field Installation of a Pipe Culvert Showing the Cambered Flow Line
Precast Concrete Bridge Beams - Observations of the manufacture, placement, and performance of prefabricated bridge sections have led to the widespread use of such construction, particularly in Western Kentucky. This type of construction may be handled by maintenance crews or by small contractors and provides a relatively inexpensive and convenient means of constructing bridges on low or moderate class highways.

Bridge Decks - Within the past decade, considerable attention has been focused upon concrete bridge decks which have deteriorated to a point where repairs are needed to maintain adequate surfaces for use by the public. Air-entrained concrete, properly designed and placed, is highly resistant to deterioration, but satisfactory performance of deck concrete is not always assured by present concreting practices. Considerable attention is being given to development and use of more realistic methods and procedures of placing and finishing concrete. In addition, attention must be directed towards evaluation and development of methods whereby concrete decks which are currently in service can be protected from deterioration. There is also a need to provide maintenance procedures and materials for effectively patching deteriorated decks to an acceptable level of smoothness and appearance and to forestall more costly repairs. A comprehensive study is under way to develop voidless concrete, primarily for use in bridge decks. Several emulsifiable liquids are being investigated as a replacement for non-essential water in concrete mixes. In addition, several specially-constructed decks are being monitored to ascertain suitability of altered construction techniques.

Camber in Culverts - 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. Some engineering specifications, handbooks and treatises suggest the desirability of cambering culvert pipe. The literature which had been reviewed did not seem to offer any generally accepted criteria or formula for predicting, even approximately, the magnitude of camber to be used. An investigation, therefore, was undertaken to develop a simplified criterion which would permit the inclusion of camber as a routine design feature in highway culvert installations. A guide for estimating camber for pipe culverts was prepared in nomographic form and has been used in the field for several years.

Structural Design of Box Culverts - With the advent of the interstate system, and the subsequent introduction of new design geometrics, the highway engineer has been faced with design situations wherein technology has been lacking. One such situation is the design of reinforced box culverts under loads imposed by high embankments. Based on findings from studies on pipe culverts, use of the imperfect trench over reinforced concrete box culverts appeared promising. A comprehensive review of design procedures for box culverts revealed that methods for determining actual loads and distribution of loads were inadequate and in many instances suspect. Rather extensive investigations are now under way to develop a procedure for determination of loads to be borne by box culverts. The initial phase of this study is in progress and involves extensive instrumentation of three box culverts under rather high embankments. Imperfect trench construction is being used for those installations. Box culverts to be placed under moderate embankment heights and bedded by conventional procedures will be instrumented also. Data obtained from these installations will be used in development of design parameters for loads on box culverts.
Distress Exhibited by a 54-inch Culvert under a 53-foot Fill

Relationship between Ultimate Load and Total Area of Steel (Internal Reinforcement Plus External Tie Rods)

![Graph showing relationship between Ultimate Load and Total Area of Steel](image)
Aggregate Evaluations

Aggregate evaluations have been undertaken in development of mixes and criteria for the use of bituminous concrete mixes as well as portland cement concrete. Often these studies are not necessarily associated with use of the aggregate in a particular type of mixture, that is, bituminous or portland cement concrete, but are general evaluations of aggregates as they might apply to various uses that may be made of them in construction of highway facilities. One area which has received as much attention as any over a considerable period has been the freeze-thaw and wet-dry behavior of aggregates as it related to the durability of bituminous and portland cement concrete mixes. Many test methods are being used in the laboratory to determine aggregate durability. However, there are many instances on record where there is disagreement between service records and results of those tests. A study to investigate the phenomena of freezing and thawing of aggregates was approached differently in that aggregate particles were studied individually. This necessitated freezing in a media other than the mix. Mercury was selected because of its low freezing point, its high thermal conductivity, and its non-miscibility with water. The procedure permitted a minute examination of each aggregate particle for distress and determination of other physical properties. Correlations were developed which indicated the relationship between the resistance of test specimens to a rapid freeze-thaw and porosity, absorption, and degree of saturation. Investigations of susceptible aggregates in concrete mixes and subsequent development of popouts were made to compare with those produced artificially. Variables associated with popout failures were introduced artificially by varying the size of voids, which represent aggregate particles, and depth of embedment, and measuring resultant pressures required for failure.

At various times throughout the years, studies have been undertaken to develop a background and catalogue of knowledge concerning various chemical and physical characteristics of aggregates throughout the state. Extensive surveys were made of aggregate sources and information concerning the mineralogy of the materials was studied. The effect of aggregates from various sources upon unit weights of paving materials has also been studied in great detail at various times to develop design tables which might be used in determining quantities required for estimating and(or) payment purposes.

Because of a desire to use locally available materials in highway construction and maintenance insofar as they may be practical, economical, and otherwise advantageous, numerous programs have been initiated at different times to study the feasibility of using native aggregates in various types of highway construction. Kentucky, for example, has had a long-standing interest in sandstone as an aggregate because of the extensive areas in the state in which the material is readily available. In 1927, sandstone was used in some 30 miles of concrete pavement between Pineville and Harlan. About 1940, a portion of the Paintsville-Inez road was surfaced with bituminous concrete using sandstone aggregates. The problem has been pursued at various other times throughout the history of research in the Highway Department. Generally, efforts have proved that sandstone can be utilized as paving aggregates when and if the need arises and if other factors are favorable. Other native materials which have received attention at various times include Kentucky rock asphalt, Western Kentucky bank gravel, conglomerate sands, and various pit sands. A material which has come under examination as a possible aggregate for use in lightweight concrete for structural members has been expanded shales, which can be produced from various shale deposits in the state.

In 1963, an investigation of degradation of limestone aggregates due to construction procedures was undertaken. Base construction on 12 projects was sampled and several types of laboratory tests were performed. Variations in gradations from project to project were observed. However, once a gradation was manufactured at a quarry, construction procedures resulted in no significant degradation because Kentucky limestones are typically very resistant.

Recurrent blowups and surface cracking are common symptoms of distress in concrete pavements. Premature appearance of these distress symptoms is alarming because the materials used in the concrete become suspect. Blowups are, as studies have shown, attributable to the expansive forces arising from certain limestone aggregates. A review of the performance of Kentucky limestones has identified certain aggregates (geologically) as suspect materials. The nature of the aggregates is such that its deleterious or expansive character is not normally detected by the more common specification tests and routine safeguards. However, insights beyond specification requirements have been obtained that will eventually provide for an early detection of such deleterious materials.
Aggregate Preparation

Autoclave Specimens Showing Differential and Excessive Expansion Due to Poor-Quality Cement
Intimately associated with design of pavement structures is the development of criteria for various types of base construction. For many years, water-bound macadam bases were used throughout Kentucky. Some disadvantages of this base material pertain to lack of control of grade and smoothness of the finished surface. Another disadvantage results from intrusion of subgrade soil into the base leading to a weakened condition and often resulting in rutting and failure. The material also could not be produced as a feed-discharged product from a plant. As a result of both laboratory and field experimentations with a dense-graded type of base course material, the use of water-bound macadam gradually disappeared. Dense graded aggregate base, a base material capable of plant mixing with water and other additives, such as calcium chloride, is now used almost to the exclusion of other unbound base materials.

Throughout the years, there have been considerable efforts directed towards development of stable and durable bituminous base course mixtures. With respect to other bound materials, numerous studies at various times have been undertaken to evaluate effectiveness of different types of stabilization, such as sodium chloride, calcium chloride, bituminous, portland cement, granular stabilization, and even use of lean concrete for base construction. A bank gravel cement stabilized base was used on the Jackson Purchase Parkway, an extensive high-type highway facility in Western Kentucky. Capable of being used as initial treatments in highway construction of low-type pavements, many stabilization procedures are often suitable for stage construction.
Pavement Surface Characteristics

Roughness - During World War II, there was a severe restriction on speed of vehicles on highways. At the close of the war and after 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 pavements. This sort of thing could develop into safety hazards at high speeds and induce motion sickness and fatigue. It was noted that even when accurate measurements were made and control limits were applied to construction, riding quality might still be only fair to poor. In view of this, efforts were directed towards measurement and evaluation of the effect of pavement surface characteristics upon the comfort of passengers rather than measurement of localized irregularities of the surface itself. A method of monitoring 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.

Since 1957, newly constructed pavements have been measured for roughness and have been periodically retested. These measurements have been evaluated 1) to assess quality of construction, 2) to assess riding quality, and 3) to obtain pavement service-life histories - from which adequacy of a structural design criteria may be deduced. In general, bituminous construction has yielded smoother riding surfaces than concrete construction. The riding quality of concrete pavements, however, is improved on those projects where slip-form paving was used. The rate of deterioration in ride quality was found to be different for each pavement type and varied according to the original or as-constructed roughness of the pavement, structural number, and type of highway facility. Concrete pavements on interstate and parkway roads deteriorated at a considerably lower rate than bituminous pavements on the same type facilities. However, pavements involving high-type construction generally do not exhibit rapid changes in ride quality. The level of service provided by these highways in regard to ride quality, therefore, is foremost related to the as-constructed roughness of the pavement. Bituminous overlaying of older surfaces has eliminated most of the very rough pavements. As a result of these resurfacing efforts, a reasonably valid claim may be made that the ride quality on most primary, two-lane highways in Kentucky has improved since 1957 in spite of the ongoing deterioration of pavements with age and increased traffic and vehicle loads.

The commercial introduction of the Surface Dynamics Road Profilometer, a profile measuring device that operates over a broad wavelength spectrum, has opened new doors to research relative to pavement irregularities and resultant riding quality. The pavement profile contains useful information in analog form when recorded on a strip chart. Visual inspection of the recording quickly pinpoints localized roughness and permits the engineer to 1) locate the pavement area in question, 2) measure the amplitudes and wavelengths of the surface irregularities, and 3) make judgments concerning possible remedial action. The profile analog on magnetic tape lends itself to further evaluation in the laboratory. A Swept Spectrum Analyzer was chosen as a tool to make direct analog analyses of pavement profiles. Spectral information would characterize the pavement for comparison with similar or unlike surfaces and note changes in the profile with time. A special purpose analog computer, known as the Quarter Car Simulator, is an electrical analogy of a vehicle suspension, including the tire, wheel mass, suspension spring, shock absorber, and vehicle mass. Two vehicle simulations are available - the Federal Highway Administration roughometer and a 1969 Chevrolet. Electrical signals representing the pavement profiles taken directly from the profilometer computer, or the magnetic tape recorder, can be processed by the simulator to yield in analog or digital form the displacement between the sprung and unsprung masses; the velocity, acceleration and jerk of the vehicle body; and the tire force on the pavement. Also, the device can be used as a peak signal detector and to simulate any driving speed, regardless of the velocity at which the profile measurement was made. Adaptation of the Surface Dynamics Road Profilometer, Swept Spectrum Analyzer, and Quarter Car Simulator to the measurement and processing of pavement profiles should be regarded as a significant step toward meaningful progress in the field of roughness measurements.

Skid Resistance - Kentucky studies relating to pavement slipperiness extend over a long period of time and have recently received renewed emphasis as a result of attention directed towards highway safety. With an increased desire for skid-resistant pavements, there has accordingly developed an interest in those paving materials which offer high skid resistance. Rock asphalt surfaces have been known to be extremely skid proof, but the material is more expensive and cannot be produced under controlled conditions as bituminous mixes; thus, rock asphalt surfaces have tended to disappear from the scene. Attention has recently been directed to the design of sand-asphalt mixtures to simulate rock asphalt. Angularity of the sand is an essential factor in skid resistance, and recently adopted angularity requirements will hopefully result in
Distribution of Initial Roughness Values for Newly Constructed Bituminous and Concrete Pavements
skid-resistant surfaces. Specifications for bituminous concrete now include requirements that the aggregate contain minimum amounts of highly skid-resistant quartz sand.

Development of improved highway surfaces from the standpoint of slipperiness or skid resistance is greatly dependent upon the ability of the highway engineer to measure and interpret those parameters which accurately portray frictional characteristics of the tire-surface interface. Considerable effort has been devoted to development of better methods of skid-resistance testing and to standardization of testing devices. In 1964, the Kentucky Department of Highways selected an interim method of test using an automobile, which has been an invaluable tool in ascertaining frictional characteristics of pavements in Kentucky. Every type of pavement and sealing and deslicking treatment used in the state has been monitored and assessed as to their frictional properties. New insights were gained and applied towards development and refinements of wearing surfaces.

Development and standardization of a trailer method of test in recent years represents significant progress in measurement techniques. Commercially fabricated trailers have become available and prompted the Division of Research to acquire a General Motors Proving Grounds device, a two-wheeled trailer and towing vehicle. The trailer unit is designed to measure directly frictional forces developed between the test wheels and pavement, as well as vertical loads on the wheels, as it is pulled at constant velocities up to 100 mph. One unique feature of the device is the ability to retard wheel lockup up to 10 seconds, permitting measurement of peak or incipient friction of pavement surfaces. The trailer is equipped with force transducers, velocity transducers, a water-laying system, pneumatic-hydraulic system for brake actuation and accessories, and standard test tires. The towing vehicle accommodates the electronic system, indicating and recording instrumentation, water supply and pumps, pneumatic supply and control system. The skid trailer provides vastly improved reliability and capacity for voluminous testing of pavement skid resistance.

Skid resistance, whether measured with a trailer or an automobile, describes the surface only for the specific conditions of test. Standardization of test methods and procedures insures repeatability of test results only insofar as the testing device is concerned. Seasons, temperature, road surface film, etc., affect skid resistance of pavements and therefore make accurate assessment of friction characteristics of pavements difficult. These influences are being independently evaluated. Measured values could then be normalized with respect to a selected reference point.

Before meaningful improvements in highway safety are to be realized, skid resistance requirements for maintenance and mix design purposes must be established. To this end, considerable effort has been expended to relate skid resistance data to accident statistics for Kentucky highways. Measurements have been completed on rural, interstate, parkway, and primary routes. Relationships between wet-surface accidents and skid resistance were established and indicated that surfaces with skid resistances less than a "critical" value have disproportionately higher wet accident rates.
Wet-Surface Accident Rate versus Skid Number

![Skid Trailer](image-url)
Soils and Foundations

It has been shown that engineering experience and performance histories of earthwork structures and foundations in distinctive physiographic regions provide valuable insight applicable to planning and construction of future projects. Geologic information further categorizes earth materials on the basis of parent material and geologic processes which modify the rock and soil masses. Knowledge of resulting topographic expressions or landforms in reference to geologic and soils information contained in surveys, reports, and maps is particularly useful in early stages of planning and site selection. When sufficient information is available, regional units may be recognized for the purpose of delineating engineering behavior of earth materials. Such regional approaches have been demonstrated to be valid for Kentucky in recognizing areas which are potentially hazardous to landslides and engineering performance of soils.

Mapping - Much effort over the past three decades has been devoted to development of engineering data for pedologically mapped soils in many areas of the country. This type of information has been and will be of benefit to engineers and planners in the preliminary stages of engineering projects. Generally, bedrock in Kentucky is relatively near the surface or actually outcrops and, therefore, is a significant factor in the selection of sites and the resultant designs for many highway and other engineering projects. There is a real and continuing demand, not only from engineers of the Highway Department but also from community planners, geologists and other engineers, for engineering information concerning geologic and soil materials throughout the state.

The Division of Research continues a cooperative program with the Soil Conservation Service, U.S. Department of Agriculture, to provide engineering data for soils series mapped in the state. Additionally, the program has been expanded to determine and assemble engineering data concerning geologic or bedrock conditions.

Landslides - Landslides on Kentucky highways have been quite costly, and as a result, the possibility of reducing their occurrence appeared very attractive. Considerable research was directed towards evaluation and improvement of current methods of exploration, techniques of interpretation of subsurface conditions and methods of analyses, design, and construction whereby embankment failures on highway facilities could be minimized. In-depth investigations of specific embankment failures have provided invaluable insight into the causes of slope instability. Procedures have been developed that appear promising in minimizing slope failures on Kentucky highways.

Extensive use has been made of slope inclinometers, triaxial equipment and computerized slope stability equations in investigations of slope failures to determine failure zones, shear strength and theoretical solutions, respectively. Information obtained has shown that a significant cause of embankment failures is lateral seepage of groundwater into side-hill, cut-and-fill sections (typical design features on roadways in mountainous, hilly, or rolling terrain). With a gradual increase of pore pressures with time, there is a gradual decrease in the shear resistance of the embankment soils until failure occurs. In some cases, it has been observed that failures were induced not only by groundwater conditions but by a reduction of the peak strength of soils located in the failure zone to some residual strength, thereby lowering the safety factor. Hence, an understanding has evolved of why some embankments have stood for a time and then failed. Proper drainage, when used effectively, can in the majority of cases remove the cause of instability. As a result of these studies and the application of modern principles of soil mechanics to stability problems, failures on embankments designed since 1966 have been a rare occurrence.

After a landslide has occurred, it is possible to model the situation through computer programs and to infer or deduce effective strength parameters and thus to analyze possible corrective measures. It is also possible to estimate the stability (safety factor) of earth slopes by judicious use of strength parameters deduced from other known, similar situations.

Settlement - Stability of foundation soils is an important consideration not only with respect to slope stability problems but also in connection with settlement of approaches to many bridges on the highways of Kentucky. Embankments founded partly on valley terraces and partly on side-hill slopes are fraught with treacherous, differential settlements. An estimate of total settlement and rate are extremely pertinent inasmuch as differential subsidence may induce fractures in the embankment, thereby triggering a mass rotation in an otherwise stable condition. Differential settlement occurring between bridges and their approach embankments has become a hazard to high-speed traffic and remedial work is expensive and causes considerable inconvenience to the public. Furthermore, a problem closely allied with settlement of approaches is the unusual movement of bridge abutments, especially where the abutment is located on piles. In a current study, long-term observations of vertical and lateral
Nuclear Moisture-Density Apparatus

Photograph Showing Susceptibility of Wind-Blown Silt to Erosion

Soil Boils
movements of approach embankments are being made at some 14 highway construction sites. To obtain settlement measurements without interfering with construction, a remote-sensing, mercury-filled settlement gage was developed. Evidence gathered to date indicates there are two major causes of faulted bridge approaches: 1) secondary compression (a time-dependent factor) of the embankment foundation and 2) instability of the approach embankment.

**Lateral Creep** - Another study, recently initiated, is addressed specifically to the problem of unusual movements of many bridge abutments perched on piles. Such movements require costly maintenance. By measuring and analyzing lateral and axial forces exerted on abutments and pile foundations, design criteria will be developed. These efforts will involve extensive use of the most modern available field instrumentation such as slope inclinometers, earth pressure cells and strain gages.

**Mineralogy** - Considerable effort over the years has been directed towards study and development of techniques for determining properties and characteristics of soils. Significant advances have been made in development of procedures for fractionating clays so that mineralogical evaluations and analyses may be made on the various fractions of the materials. Studies have been made of the effect of thermal treatment upon the engineering characteristics and properties of soils. The study suggested the possibility of improving and stabilizing certain undesirable soils (clays) so that they might possibly be used for engineering purposes more advantageously.

**Nuclear Testing** - Much attention has been directed toward the application of neutron and gamma ray techniques to soil moisture and density measurements. This application of radiological measurements to highway construction is of great interest to the highway industry since the performance of the total pavement system is highly dependent upon the conditions of the embankment, subgrade, and base components. An important measure of the state of condition of unconsolidated earth materials is their unit weights and moisture contents. The reliability and practicality of nuclear moisture-density apparatuses were studied by the Research Division in the early 1960's. Much new construction is now controlled by moisture-density measurements made by nuclear apparatuses. Nuclear devices have been shown to be consistent and to operate with a great degree of accuracy and repeatability.

**Consolidation Test Apparatus**

**Patch Work Often Required at Bridge Approaches to Maintain Desirable Riding Qualities and Safety**
Illustration of the Importance of Hydrological and Hydraulic Criteria in the Design of Highway Drainage

Drainage

**Hydraulic Design** - About 1950, the Division of Design expressed some dissatisfaction with their practices for sizing culverts. They were concerned about the possibility that criterion used at that time frequently led to overdesign, whereas in some cases new culverts flooded and permitted water to overflow the roadway. Rainfall records were analyzed and intensity-duration curves were developed for various areas of the state. These data provided a statistical basis for determining the runoff and discharge for hydraulic design and sizing of culverts. Later efforts were directed to basic studies of flow characteristics of box and pipe culverts as well as drop-inlet box structures. Basic studies of improved entrances on box culverts led to adoption of criterion for design of hooded entrances for situations where beneficial effects of that design could be realized. Intensity-duration curves have been updated so that greater accuracy will be provided for the computation of runoff from small drainage areas.

**Culvert Corrosion** - In September of 1949, the research staff was requested to investigate premature failures of galvanized corrugated metal entrance pipes on US 60 north of Princess, Kentucky. As a result, an extensive survey of culvert conditions throughout the state was made in the early 1950’s and problem areas were delineated. As an outgrowth of those surveys, the Department adopted certain practices restricting use of some types of culverts in those areas in which corrosive waters were known to exist. Also, in extremely severe situations, special means of protection were recommended. In 1951, a culvert test site was established at Morton’s Gap on US 41 south of Madisonville where a source of highly acidic water was found. Various kinds of concrete pipes and coated and uncoated metal pipes have been installed at different times. The site is under periodic observation and the experiment has demonstrated a need for consideration of life expectancy of culvert materials in all highway construction.

**Legal Liabilities** - It is a foregone fact that the construction of highways involve alterations of the land and drainage patterns. The Department of Highways has power to recover land for these purposes and to justly compensate owners for complete or partial takings as well as for damage to remaining properties. However, this power does not privilege the state to abuse the properties of adjacent owners. Natural drainage cannot be preserved forever; alternations made to enable habitation and cultivation alter primeval conditions. From an engineering design standpoint, the right to alter drainage adjacent to highway facilities should be acquired when the construction of the facility is likely to cause flooding, erosion, or other water damage. Easements, temporary or permanent, may be obtained for channel improvements. Where the attendant damages are likely to be recurrent, either the affected land should be acquired through fee simple purchases or a permanent easement obtained. Consideration should be given to design headwater elevations and appropriate permanent easements obtained as a safeguard against future liabilities. However, to obtain title to all abutting lands likely to be affected by highway construction burdens the state with additional maintenance and deprives private owners of limited but perhaps profitable use of lands. Studies have directed attention to some of these matters associated with the engineering design of drainage facilities and attendant legal responsibilities and liabilities.
Traffic and Safety

**Loads on Pavements** - Since the design life of a pavement is largely dependent upon the reliability of projected traffic information, it is necessary that design engineers be able to predict and project characteristics of future traffic trends to properly evaluate the equivalent wheel loads (EWL's) or axieloads (EAL's) for which they must design. Two research studies recently completed were directly related to this problem of traffic projection. The objective of one study was to re-evaluate traffic parameters presently used for predicting, projecting, and computing EWL's. Efforts were made 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 per vehicle 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 different highway systems.

To develop techniques and factors to use in predicting traffic trends, it is first necessary to study past conditions and relationships between certain socio-economic factors and past traffic trends and patterns. An area in which there is a deficiency of data, both past and current, is that concerning vehicle weights and distribution of axles by weight groups. To collect such data, investigations were conducted to determine the most practical means of measuring and recording dynamic loads produced by moving vehicles. A commercially fabricated weigh-in-motion system will be secured to collect and assemble data necessary for future analyses.

**Crash Cushions** - In the late 1960's and early 1970's, considerable attention was directed towards safety aspects of highway facilities. The presence of fixed objects within the right of way presented many safety hazards to the traveling public. In an attempt to evaluate methods to reduce deceleration when vehicles impel such objects, a number of energy attenuation devices were investigated. Two types of safety barriers evaluated included the Hi-dro cushions (water-filled vinyl cells) and Fitch inertia barriers (sand-filled vessels). Surveillance at experimental installations was aided by a camera-monitoring system which was activated by impelling vehicles shortly before impact. Results of the study indicated that impact attenuation devices can be effective in reducing severity of accidents at high-accident locations. Earth mounds have also been evaluated as a means of redirecting impelling vehicles from bridge piers located along the side of the traveled way. Such studies have provided information from which design criteria were developed.

**Data Inventories** - Records of data pertaining to highway facilities are of utmost importance in planning future construction and maintenance programs, for evaluating the relative merits of various elements of design and construction, and for assessing the adequacy of a section of highway to carry the anticipated traffic both structurally and capacity-wise. In addition, it is necessary that these various engineering considerations be correlated with socio-economic conditions so that the optimum use of the highway dollar will provide a maximum benefit to the people of Kentucky. If such data are to be of value to the management of the Highway Department, they must be made available in a form that retrieval and analysis is rapid. The design of computer-based data files have been considered. A traffic inventory file has been completed and the loading of data against this file has begun. The design of a data file for highway accident data is under study. Ultimately, it is hoped that data files concerning other physical and operational aspects of the highway system can become realities.

**Hazardous Locations** - There is a need to quickly identify hazardous locations on highway facilities so that design or operational improvements can be made to correct the situation. Accident occurrences are used to indicate the existence of a hazardous location. With the challenge of improving hundreds of hazardous highway locations throughout the state, there is a need for an optimum method for identifying such locations. Studies have been undertaken to evaluate the department's current method of identifying high-accident locations (three accidents occurring within the previous 12 months) and to evaluate other possible techniques for more positively identifying such hazardous situations.

**Safety Improvement Evaluations** - Other studies directed to the problem of highway safety have included before-and-after accident studies to determine the effectiveness of various safety improvement projects. Studies have also been made of accident histories of a number of bypasses around small communities. Results from such studies provides information indicating the effectiveness of remedial and design actions which would provide a safer driving environment for the motorists.

**Lane Drops** - A study of lane-drop situations and lane-closure conditions for maintenance purposes on high speed facilities indicate that no single traffic control system is adequate for the various types of situations existing on the highways. It was also noted that the traveling public often is not aware of signing indicating restricted travel flow ahead. It was also observed that motorists were more attentive to such messages when
Accumulation of Traffic Loads (EWL's) on Pavements
they were presented on well maintained and newly painted signs.

Recreational Travel - Investigations have been undertaken to evaluate models of traffic flow from population centers throughout the United States to outdoor recreational areas in Kentucky. Data were obtained by means of license-plate, origin-destination surveys and continuous vehicle counting programs. Attempts to simulate the distributed travel flows concentrated on various single-equation models, a cross-classification model, and gravity and intervening opportunities models. The cross-classification model was found to be an acceptable means for simulating and predicting outdoor recreational travel flow in Kentucky and was decidedly superior to the other models. In this effort, use of the license-plate survey was a unique method of obtaining origin-destination data. A method was also developed whereby incorrect data could be detected and eliminated and "correct" data synthesized to provide a continuous spectrum of traffic flow data for further analyses.

Traffic Noise - Traffic noise has, in the past, been recognized as a nuisance by those subjected to it. However, it has now reached such alarming levels in some urban areas that it is considered a major pollutant of the environment. Current research is concerned with the measurement and monitoring of traffic-generated noise levels and comparing these with predicted levels. It is hoped that predictive techniques can be refined and modified and that effects of various roadway design parameters can be evaluated as to their impact upon highway-generated noise.

Pavement Markings - Prior to World War II, traffic paints consisted largely of linseed oil and natural resins and were usually slow drying. Just before World War II, glass beads were dropped on the paint for nighttime reflectorization. Following the war, premixed paint containing glass beads became available. Some highway departments relied predominantly on formulation-type specifications whereas others merely specified a particular proprietary product or equal. Practically all prewar formulations became obsolete when postwar synthetic resins became available. When the Research Division began to study formulations, it became obvious that a different approach was needed. Various formulations and types of paints as well as proprietary paints were obtained and subjected to comparative road tests. The Department continued to buy paint on the basis of formulations for another few years but also continued the road tests. It became obvious that considerable savings could be realized by purchasing paints on the basis of performance testing. A strong preference was indicated toward paint premixed with beads.

The Department has since been beset by other problems concerning traffic paint. Snow is abrasive and the type of resin being used in the paints is not very resistant to sustained moisture conditions attending melting of snow and ice. Paints do not perform well on new concrete, but part of the trouble arises from the fact that concrete scales. However, it is hoped that experimental applications of primers and special paints will provide considerable insight into this problem. Studies were made to evaluate so-called hot-melt plastic striping materials. Test installations were made at various places throughout the state and the performance characteristics of the plastic lines were observed to evaluate the economical feasibility of those materials.
Signing - Another postwar innovation which has commanded much attention through the years is the reflectorization of highway signs. The Research Division has been evaluating these materials and preparing specifications since 1948. Basic optical functions of spherical lens systems have been studied photographically and diagrammatically. Various optical designs have been analyzed and the efficiencies of these systems were correlated with performance criteria for retrodirective reflectorization. A reflectometer was designed to aid in studies of optical characteristics of various sign materials. Field evaluations were carried out to determine relationships between reflectance, effective sight distance, target size, and performance of reflex-reflective material when illuminated by polarized headlights and viewed through polarizing windshields. Durability determinations of sign materials were made by observing their rates of deterioration upon exposure to natural and accelerated weathering and by subjecting them to chemical agents.

Construction of multilane, median-divided facilities has brought about a significant increase in traffic speed and emphasis on the comfort and safety of the public. Highway sign placement has been affected, and thereby, requirements for sign reflectorization and lane delineation have changed. The automobile continues to undergo evolutionary refinements, thus affecting the driver’s view of highway signs. Retro-reflective materials have improved, providing superior sign optics and serviceability. In recognizing these developments, the Department undertook an investigation of reflex-reflective sign materials and delineators and an updating of specification requirements. The study was primarily concerned with geometric relationships between driver, headlamps and traffic signs; adoption of a modified ESNA Reflex-Photometer and other instrumentation; and an investigation of reflectivity, color and durability of available reflective sign materials and delineators. Evaluations of reflectivity, durability, color and other properties of various retro-reflective materials used on highway signs and roadway delineations from the standpoint of identification, classification, use and specification requirements are being continued.

ESNA Reflex-Photometer
RESEARCH PRIORITIES

Some problems seem insolvable and grow more enigmatic as time goes by; in some cases, the solutions are evident but impractical. In many cases, these challenging problems are defects in the roadway. However, there are some abiding but priority problems.

Night Visibility - Because of increasing traffic, the opportunity to use high-beam headlights is steadily diminishing. In rainy weather, lane and edge lines (beaded paints) lose their reflectivity -- and that is when good visibility is most needed. Urban freeways and many major interchanges are lighted. Continuous lighting as well as imbedded glow-rods, etc. remain impractical under present economic conditions. More effective reflectorization is sought.

Skid Resistance - Pavement slipperiness is an insidious peril. Gritty abrasive pavement surfaces are conceptually skid resistant when new; those which polish under traffic become slippery when wet. An armor coating of sharp grip provides good traction. To allow for attrition of grit, a wearing course composed of somewhat porous, sand asphalt (Special Provision 59-B) is considered ideal. Development is progressing but extensive implementation is anticipated.

Settlement - Highway embankments built on soil foundations slowly compress the underlying soil, and the embankments appear to settle or sag. The subsidence causes dips in the roadway and a "bump at the end of the bridge". The amount of settlement can be predicted fairly accurately from laboratory tests on the soils -- but this is not sufficient to completely eliminate the bump. Approach slabs are being considered as a means of easing the bump. Advance construction of some fills -- to allow for settlement before paving -- has been successful where significant long-term settlement was expected.

Bridge Deck Durability - Historically, concrete in bridge decks has deteriorated more rapidly than concrete in pavements. Some authorities claim that deck concrete is inferior; others say that decks simply freeze and thaw more often. Workmanship and placement methods have improved greatly during recent years. It appears that improved concreting practices, together with judicious use of protective coatings, will provide extended life expectancy.

Rutting and Wear - Wheel-track rutting occurs in bituminous pavements and is due to loading. It is believed to occur during warm weather. It is attributed principally to plastic shear in the foundation soil, but it does not necessarily signify weakening of the structure. Water channeled in the ruts during rainy weather causes excessive spray from vehicle tires and may cause hydroplaning. Additional crown or cross slope compensates somewhat for minor rutting.

Some wear arises from normal abrasives on the pavement or carried by tires. Severe wear is attributed to studded tires. The effects from wheel-track wear are the same as those arising from rutting.

Bleeders
ACID WATER AND CULVERT DURABILITY


121. A Survey Inspection of Plain Corrugated Metal Pipe Arches and Multi-Plate Metal Pipe Arches in Kentucky, West, E. M.; March 1957.


207. Kentucky Highway Research Program, Havens, J. H. and Deen, R. C.; March 1964; also Bulletin No. 73, Engineering Experiment Station, University of Kentucky, September 1964.

228. Obtaining Highway Engineering Services from Professional Engineers in Private Practice, Shaver, R. E. and Hutchinson, J. W.; December 1965.


321. Subject Listing of Research Reports, January 1972.
AGGREGATE EVALUATIONS


44. An Examination of Equipment for Preventing Segregation in Storage of Coarse Aggregates, Collier, S. T.; February 1949.

56. Determination of Unit Weights of Aggregates in the Laboratory and at the Source, Collier, S. T.; February 1950.


224. Freeze-Thaw Characteristics of Aggregates, Laughlin, G. R.; Scott, J. W.; and Havens, J. H.; March 1965; also Bulletin No. 76, Engineering Experiment Station, University of Kentucky, September 1965.


BASE MATERIALS AND CONSTRUCTION PRACTICES

<table>
<thead>
<tr>
<th>No.</th>
<th>Title</th>
<th>Author(s)</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>62</td>
<td>Report No. 1 on an Investigation of Lean Concrete Mixes as Base Courses for Bituminous Surfaces</td>
<td>Collier, S. T.</td>
<td>January 1951</td>
</tr>
<tr>
<td>70</td>
<td>Memorandum Report on Vibratory Compaction of Base Courses</td>
<td></td>
<td>November 1951</td>
</tr>
<tr>
<td>75</td>
<td>Report No. 1 on a Bank Gravel Base Containing Calcium Chloride</td>
<td>Drake, W. B.</td>
<td>February 1952</td>
</tr>
<tr>
<td>82</td>
<td>Report No. 1 on a Limestone-Calcium Chloride Stabilized Base</td>
<td>Drake, W. B.</td>
<td>August 1952</td>
</tr>
<tr>
<td>88</td>
<td>Report No. 2 on a Bank Gravel Base Containing Calcium Chloride</td>
<td>Drake, W. B.</td>
<td>December 1952</td>
</tr>
<tr>
<td>89</td>
<td>Report No. 2 on an Investigation of Lean Concrete Mixes as Base Courses for Bituminous Surfaces</td>
<td>Sawyer, D. H.</td>
<td>December 1952</td>
</tr>
<tr>
<td>92</td>
<td>Report No. 1 on Vibratory Compaction of a Macadam Base</td>
<td>Williams, E. G.</td>
<td>December 1953</td>
</tr>
<tr>
<td>94</td>
<td>Report No. 1 on a Water-Bound, Dense-Graded Aggregate Base for Flexible Pavements</td>
<td>Drake, W. B.</td>
<td>June 1953</td>
</tr>
<tr>
<td>95</td>
<td>Combination Waterbound-Macadam and Dense-Graded Aggregate Base for Flexible Pavements</td>
<td>Drake, W. B.</td>
<td>Proceedings</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Highway Research Board, Vol 32, 1953</td>
</tr>
<tr>
<td>101</td>
<td>Memorandum Report on Inspection of Full Depth Modified Dense-Graded Aggregate Base, Plant Mixed</td>
<td>Drake, W. B.</td>
<td>December 1954</td>
</tr>
<tr>
<td></td>
<td>(Tennessee Project)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>109</td>
<td>Observations of Stabilized Turf Shoulders, Warren County Project No. 1 16(2) and 1 113(5) U. S. 31W and U. S. 68 Bowling Green-Cave City Road</td>
<td>Williams, E. G.</td>
<td>November 1955</td>
</tr>
<tr>
<td>123</td>
<td>Ten Rural Highway Base Stabilization Projects, Havens, J. H. and Drake, W. B.</td>
<td></td>
<td>August 1957</td>
</tr>
<tr>
<td>137</td>
<td>Dense Graded Aggregate Base Development</td>
<td>Drake, W. B.</td>
<td>April 1959; prepared for presentation at the 16th Annual Meeting of Kentucky Crushed Stone Association.</td>
</tr>
<tr>
<td>138</td>
<td>Memorandum Report on Density-Graded Aggregate Base</td>
<td>Drake, W. B.</td>
<td>June 1959</td>
</tr>
<tr>
<td>139</td>
<td>Progress Report on Calcium Chloride Maintained Traffic Bound Roads</td>
<td>Laughlin, G. R.</td>
<td>May 1959</td>
</tr>
<tr>
<td>171</td>
<td>Memorandum Report on Portland Cement Stabilization of Western Kentucky Gravels</td>
<td>Deen, R. C.</td>
<td>November 1961</td>
</tr>
<tr>
<td>176</td>
<td>Evaluation of Calcium-Chloride Maintained, Traffic-Bound Roads</td>
<td>Laughlin, G. R.</td>
<td>February 1962</td>
</tr>
<tr>
<td>187</td>
<td>Base Stabilization Bryantsville-Buena Vista Road, Garrard County, RS 40-326</td>
<td>Deen, R. C.</td>
<td>February 1963</td>
</tr>
<tr>
<td>201</td>
<td>Interim Report on Rural Secondary, Base Stabilization Projects</td>
<td>Deen, R. C. and Shackleford, J. D.</td>
<td>July 1963</td>
</tr>
<tr>
<td>218</td>
<td>Memorandum Report on Inspeciton of Salt-Treated Granular Bases, Multiple Seals</td>
<td>Florence, R. L.</td>
<td>March 1964</td>
</tr>
<tr>
<td>255</td>
<td>Construction and Performance of Trial Sections of Treated Shoulders on the Mountain Parkway Extension</td>
<td>Florence, R. L. and Hopkins, T. C.</td>
<td>June 1968</td>
</tr>
</tbody>
</table>
BITUMINOUS CONSTRUCTION


68. Final Report on Evaluation of Plant Mix Surface Treatments by Road Test Sections, Drake, W. B.; July 1951.

71. Observation on Seal Coats, Tack Coats, Penetration Macadam, and Blade Spread Hot Mix in 1951, Drake, W. B. and Field, H. J., Jr.; December 1951.


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


203. Memorandum Report on Inspection-Performance Report; Plant-Mix, Initial Treatment; Morgantown-Woodbury Road, Butler County, Florence, R. L.; April 1963.


<table>
<thead>
<tr>
<th>No.</th>
<th>Title</th>
<th>Author(s)</th>
<th>Publication Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>143</td>
<td>The Use of Epoxy Resin for Sealing Cracks in a Reinforced Concrete Bridge</td>
<td>Evans, Milton, Jr.;</td>
<td>July 1959.</td>
</tr>
<tr>
<td>200</td>
<td>Concrete Bridge Decks: Deterioration, Coatings and Repairs</td>
<td>Havens, J. H. and Drake, W. B.;</td>
<td>February 1963.</td>
</tr>
<tr>
<td>226</td>
<td>Insulation of Concrete Bridge Decks</td>
<td>Mossbarger, W. A., Jr.;</td>
<td>July 1965.</td>
</tr>
<tr>
<td>301</td>
<td>Evaluation of Cored Specimens from Timber Caisson beneath Pier No. 2 of the US 25 Bridge over the Ohio River between Covington and Cincinnati, F141 (1)</td>
<td>Havens, J. H. and Rahal, R. A.;</td>
<td>December 1970.</td>
</tr>
<tr>
<td>319</td>
<td>Experimental Overlay of Glazon over Two Bridge Decks</td>
<td>Rahal, A. S.;</td>
<td>January 1972.</td>
</tr>
<tr>
<td>323</td>
<td>Stress Histories of Bridge Members from Scratch Gage Records</td>
<td>Hughes, R. D.;</td>
<td>February 1972.</td>
</tr>
<tr>
<td>335</td>
<td>Construction, Protection and Maintenance of Concrete Bridge Decks</td>
<td>Hughes, R. D. and Havens, J. H.;</td>
<td>August 1972.</td>
</tr>
</tbody>
</table>

Non-Destructive Testing of Concrete Specimens
CHARACTERIZATION OF BITUMINOUS MATERIALS AND MIXTURES


CLASS I MIXTURES


85. *A Compendium on Class I, Type C Mixes*, Williams, E. G.; December 1952.


217. *Memorandum Report on Construction of a Class I, Type A Surface Containing Paradise Slag Aggregate (Experimental), Drakesboro-Paradise Road (KY 176); SP 89-43-68*, Florence, R. L.; October 1964.

COAL-TAR MIXTURES

154. Experimental Paving Projects Using Curtiss-Wright's Coal-Modified, Coal-Tar Binder, Hardyman, J. F.; June 1960; also Kentucky's Bituminous Pavement Research on Modified Coal Tar, Drake, W. B.; Bulletin No. 56, Engineering Experiment Station, University of Kentucky, June 1960.

159. Experimental Paving Project Using Curtiss-Wright's Coal-Modified, Coal-Tar Binder (First Year Performance), Hardyman, J. F.; March 1961; also Bulletin No. 60, Engineering Experiment Station, University of Kentucky, June 1961.


A Laboratory Investigation of the Properties of Coal-Bitumed Paving Mixtures, Howard, G. G.; February 1964; also thesis, MSCE, University of Kentucky, 1964; also Bulletin 71, Engineering Experiment Station, University of Kentucky, March 1964.


Tar Concrete Pavement Construction and Performance, Rose, J. G.; December 1972.
CONCRETE MIXTURES


5. Summary Report of Concrete Investigations in Research Projects C-1, C-2, C-3, and C-17, Collier, S. T.; December 1945.


15. Outline of Proposed Study of Sand Used as Concrete Fine Aggregates, March 1946.


19. A Summary of Experiments with Air Entrainment in Cement Concrete, September 1946.


27. Bond Characteristics of Commercial and Prepared Reinforcing Bars, Collier, S. T.; March 1947; also Journal of the American Concrete Institute, Vol 18, No 10, June.


35. Supplementary Report No. 1 on Experiments with Air Entrainment in Cement Concrete, October 1947; also Experiments with Air Entrainment in Cement Concrete, Gregg, L. E.; Bulletin No. 5, Engineering Experiment Station, University of Kentucky, September.


CONCRETE MIXTURES (CONTINUED)


155. A Discussion of the Durability of Expanded Shale Aggregate for Exposed Concrete Structures (Bridges), Havens, J. H.; November 1960.


CONCRETE PAVEMENT


<table>
<thead>
<tr>
<th>No.</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>91.</td>
<td>Applications of Geology to Highway Engineering in Kentucky, Gregg, L. E. and Havens, J. H.; February 1953.</td>
</tr>
<tr>
<td>115.</td>
<td>Kentucky Soils: Their Origin, Distribution and Engineering Properties, Deen, R. C.; March 1956; also Bulletin No. 40, Engineering Experiment Station, University of Kentucky, June.</td>
</tr>
</tbody>
</table>

Slip-Form Pavement Construction
HYDRAULICS AND HYDROLOGY


103. Roughness as a Factor in Culvert Hydraulics, West, E. M.; December 1954.


114. Model Study of Flow through Culverts, West, E. M.; March 1956; also Bulletin No. 40, Engineering Experiment Station, University of Kentucky, June.


Analog Data Reduction System
<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
<th>Authors</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>195</td>
<td>Status Report on Landslide Area on I-75, Covington, Kentucky</td>
<td>Deen, R. C.; May 1963</td>
<td></td>
</tr>
<tr>
<td>196</td>
<td>Status Report on Landslide Area on I-75, Covington, Kentucky</td>
<td>Deen, R. C.; August 1963</td>
<td></td>
</tr>
<tr>
<td>234</td>
<td>Proposed Remedial Design for Unstable Highway Embankment Foundation,</td>
<td>Scott, G. D. and Deen, R.</td>
<td>April 1966</td>
</tr>
<tr>
<td>240</td>
<td>Stability Analysis of Earth Masses, the Case for Slope Instability,</td>
<td>Deen, R. C.; Scott. G. D.;</td>
<td>September 1966</td>
</tr>
<tr>
<td>254</td>
<td>The Crab Orchard and Osgood Formations, the Case for Slope Instability</td>
<td>Deen, R. C.; April 1968</td>
<td></td>
</tr>
<tr>
<td>266</td>
<td>Landslides in Kentucky, Deen, R. C. and Havens, J. H.; September 1968, presented at Landslide Seminar, University of Tennessee, September 18-20, 1968,</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**LANDSLIDES**

<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
<th>Authors</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>267</td>
<td>I 75, Kenton County Slide, Southgate, H. F.; September 1968.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>268</td>
<td>Proposed Experimental Design and Construction Features. Boyd County,</td>
<td>F(10), SP 10-165-231,</td>
<td></td>
</tr>
</tbody>
</table>

**LAW AND ECONOMICS**

<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
<th>Authors</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>244</td>
<td>Impact of I-75 on the Local Economy between Walton and Georgetown</td>
<td>Deen, R. C.; February 1966</td>
<td></td>
</tr>
<tr>
<td>294</td>
<td>Legal Aspects and Guidelines Pertaining to Drainage of Surface Waters</td>
<td>McLellan, D. W., Jr. and Fox, Victor, April 1970.</td>
<td></td>
</tr>
</tbody>
</table>

**MISCELLANEOUS**

<table>
<thead>
<tr>
<th>Page</th>
<th>Title</th>
<th>Authors</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>148</td>
<td>Report on Interim Status of Tire Service Life Study, Drake, W. B.;</td>
<td>Drake, W. B.; February 1960</td>
<td></td>
</tr>
</tbody>
</table>
PAINT


PAVEMENT DEMARCATION


<table>
<thead>
<tr>
<th>No.</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>116.</td>
<td><em>The Application of Kentucky Flexible Pavement Design Method to WASHO Test Road Conditions</em>, Drake, W. B.; March 1956; also <em>Bulletin No. 40</em>, Engineering Experiment Station, University of Kentucky, June.</td>
</tr>
</tbody>
</table>
PAVEMENT DESIGN (CONTINUED)


Field CBR Test
2. Cooperative Investigation of Joint Spacing in Concrete Pavements, Campbell, Louis, 1940.


52. Report No. 2 on a Concrete Pavement without Transverse Joints, Drake, W. B.; December 1949.


64. Report No. 3 on a Concrete Pavement without Transverse Joints, Drake, W. B.; February 1951.


87. Report No. 4 on a Concrete Pavement without Transverse Joints, Drake, W. B.; December 1952.


PAVEMENT ROUGHNESS


PAVEMENT SLIPPERINESS


REFLECTION CRACKING


100. Application of Wire Mesh Reinforcement to Asphaltic Concrete Pavement Overlays, Franklin-Shelby County Project FI 172(12), Williams, E. G.; December 1954.


REINFORCED CULVERT PIPE AND CULVERTS


ROADSIDE TREATMENT


304. Establishment of Wood Plants on Roadsides (Southeastern Kentucky), Whitaker, S. E.; January 1971.

ROCK ASPHALT


SAFETY


348. Elements of Median Design in Relation to Accident Occurrence, Garner, G. R. and Deen, R. C.; December 1972 (prepared for publication by the Highway Research Board).

## SAND ASPHALT


## SETTLEMENT


## SIGN MATERIALS


SLURRY SEALS


SOIL PROPERTIES AND CHARACTERISTICS


TRAFFIC AND OPERATIONS


284. *Weighing Vehicles in Motion*, University of Kentucky Research Foundation; November 1969.


Voids in Concrete Specimens by Linear Traverse Method
APPENDIX

CREDENTIALS

OF

ENGINEERING PERSONNEL
Name: Kenneth Robert Agent
Position: Research Engineer Associate

Education:
BSCE, University of Kentucky, December 1970

Experience:
Divisions of Construction and Traffic (summer employment), Kentucky Department of Highways, 1966 to 1970
Traffic Engineer Assistant, Division of Traffic, Kentucky Department of Highways, January 1971 to August 1971
Research Engineer Assistant, Division of Research, Kentucky Department of Highways, August 1971 to January 1972
Research Engineer Associate, Division of Research, Kentucky Department of Highways, January 1972 to Present
Engineer in Training in State of Kentucky

Professional Societies:
Institute of Traffic Engineers

Name: David Lysle Allen
Position: Research Engineer

Education:
BSCE, University of Kentucky, December 1969

Experience:
Divisions of Design, Construction and Research, Kentucky Department of Highways (part-time and summer employment), June 1963 to December 1969
Division of Research, Kentucky Department of Highways:
Research Engineer Assistant, December 1969 to January 1971
Research Engineer Associate, January 1971 to April 1972
Research Engineer, April 1972 to Present
Name: Rufus Jennings Bruner III
Position: Research Engineer Associate

Education:
BSCE, University of Kentucky, May 1971

Experience:
Divisions of Planning and Research, Districts 11 and 7 (summer and part-time employment), Kentucky Department of Highways, May 1966 to January 1971
Division of Research, Kentucky Department of Highways:
Research Engineer Assistant, January 1972 to August 1972
Research Engineer Associate, September 1972 to Present

Professional Societies:
Kentucky Association of Highway Engineers
Kentucky-Tennessee Water Pollution Control Association

Name: James Lee Burchett, Jr.
Position: Research Engineer Senior

Education:
BSCE, University of Kentucky, December 1965

Experience:
Engineer Aide (part-time and summer employment), Kentucky Department of Highways, 1962 to 1965
Assistant Research Engineer, Kentucky Department of Highways, January 1966 to May 1966
Civil Engineer Assistant, Research, U. S. Army Test and Evaluation Command, U. S. Army Armor and Engineer Board, Fort Knox, Kentucky, May 1966 to May 1968
Division of Research, Kentucky Department of Highways:
Research Engineer Associate, June 1968 to February 1969
Research Engineer, February 1969 to October 1970
Research Engineer Senior, November 1970 to Present
Registered Professional Engineer (Civil) in the State of Kentucky

Publications:
Name: Robert Curba Deen

Position: Assistant Director of Research

Education:
- BSCE (with high distinction), University of Kentucky, June 1951
- Graduate work in Meteorology, University of Chicago, October 1951 to September 1952
- MSCE, University of Kentucky, June 1958
- PhD, Purdue University, May 1964

Experience:
- Divisions of Construction and Research (part-time and summer employment), Kentucky Department of Highways, August 1946 to September 1950
- Instructor (part-time employment), Department of Civil Engineering, University of Kentucky, September 1950 to July 1951
- Research Engineer, Division of Research, Kentucky Department of Highways, May 1955 to September 1958
- Research Engineer, School of Civil Engineering, Purdue University, September 1958 to August 1960
- Division of Research, Kentucky Department of Highways:
  - Research Engineer Senior, August 1960 to March 1963
  - Research Engineer Principal, March 1963
  - Assistant Director, April 1963 to Present
- Lecturer in Civil Engineering (part-time), University of Kentucky, 1960-1965
- Assistant Professor (Adjunct) in Civil Engineering, University of Kentucky, 1965 to 1968
- Registered Professional Civil Engineer in the State of Kentucky
- Registered Land Surveyor in the State of Kentucky

Professional Societies:
- American Society of Civil Engineers -- 1951 to Present
- Corresponding Secretary of Kentucky Section -- 1957
- Secretary-Treasurer of Kentucky Section -- 1963
- Vice President of Kentucky Section -- 1964
- President of Kentucky Section -- 1965
- Contact Member, University of Kentucky Student Chapter -- 1964 to 1969
- District 9 Council -- 1966 to 1970

National Society of Professional Engineers -- 1960 to present
Kentucky Society of Professional Engineers -- 1951 to present
Highway Research Board
- Member, Committee on Exploration and Classification of Earth Materials -- 1962 to 1970
- Chairman, Subcommittee on Classification of Earth Materials -- 1963 to 1967
- Member, Committee on Research Needs, Department of Soils, Geology and Foundations -- 1964 to 1970
- Vice Chairman, Committee on Properties of Soils and Rocks -- 1964 to 1970
- Chairman, Committee on Papers and Programming, Department of Soils, Geology and Foundations -- 1966 to 1970
- Member, Executive Committee, Department of Soils, Geology and Foundations -- 1966 to 1970
- Member, Awards Committee -- 1968
- Chairman, Committee on Chemical Stabilization -- 1970 to Present
- Member, Committee on Compaction -- 1966 to Present
- Member, Committee on Engineering Geology -- 1970 to Present
- Member, Committee on Research Needs, Group 2 Council -- 1971 to Present
- Member, Task Force on Low Volume Roads -- 1972

American Society for Testing and Materials
- Member, Committee on Soil and Rock for Engineering Purposes -- 1971 to Present
- Member, Subcommittee on Identification and
Classification of Soils -- 1971 to Present

Member, Subcommittee on Information Retrieval and Data Automation -- 1972

Publications:

Kentucky Soils: Their Origin, Distribution, and Engineering Properties, Bulletin No. 40, Engineering Experiment Station, University of Kentucky, 1956.


V. S. Lukianov and M. D. Golovko Calculation of the Depth of Freeze in Soils (In Russian), Bulletin No. 23, Union of Transportation Construction, 1957; Translation by A. Kazmarzyk and R. C. Deen, Pult 481, Purdue University, 1960.

M. D. Kaascind, Soil Freezing under an Insulated Surface (In Russian), Doklady, Acad Nauk SSSR, Vol 125, No 4, 1959; Translation by R. C. Deen, Pult 480, Purdue University, 1960.


Developments in Nuclear Moisture-Density Testing, Bulletin No. 64, Engineering Experiment Station, University of Kentucky, June 1962.

Developments in Nuclear Moisture-Density Testing, Bulletin No. 28, Engineering Experiment Station, University of Tennessee, February 1963.

Kentucky Highway Research Program, Bulletin No. 73, Engineering Experiment Station, University of Kentucky, September 1964 (co-authored with J. H. Havens).


And Why Do We Do It This Way?, First Kentucky Soil Mechanics Group Seminar, Kentucky Section, American Society of Civil Engineers, 1970

Transportation Research in Kentucky, Bulletin 94, College of Engineering, University of Kentucky, September 1970.


Name: William B. Drake

Position: Assistant State Highway Engineer
Research and Development

Education:
Transylvania University, 1939 to 1940
BSCE, University of Kentucky, 1948
MSCE, University of Kentucky, 1949

Experience:
B-17 Aircraft Commander, Captain, U.S. Army Air Force, European Theater, 1942 to 1946
Instructor (part time), Department of Civil Engineering, University of Kentucky, 1946 to 1951
Kentucky Department of Highways:
Research Engineer, 1946 to 1954
Design Engineer, 1954 to 1955
Research Engineer Senior, 1955 to 1957
Associate Director of Research, 1957 to 1961
Director of Research, 1961 to 1963
Assistant State Highway Engineer, 1963 to Present

Professional Societies:
American Society of Civil Engineers -- 1948 to Present
Secretary-Treasurer of Kentucky Section -- 1955
Vice President of Kentucky Section -- 1956
President of Kentucky Section -- 1957
Member of Executive Committee, Highway Division
American Association of State Highway Officials
American Society for Testing and Materials
American Public Works Association
Director of Kentucky Chapter -- 1972
Vice President of Kentucky Chapter -- 1973
Kentucky Society of Professional Engineers
Highway Research Board
Chairman of Group 2 Council, Design and Construction of Transportation Facilities
Member, Flexible Pavement Design Committee
Member, Pavement Performance Evaluation Committee

Publications:
Kentucky Flexible Pavement Design Studies, Bulletin No 52, Engineering Experiment Station, University of Kentucky, June 1959.
Kentucky’s Bituminous Pavement Research on Modified Coal Tar, Bulletin No 56, Engineering Experiment Station, University of Kentucky, June 1960.
Full-Depth Asphaltic Concrete Pavement, Proceedings, Kentucky Conference, Bulletin No 99, College of Engineering, University of Kentucky, June 1972.
Name:    Harry Franklin Girdler
Position: Research Engineer Associate

Education:
BSCE, University of Kentucky, December 1970

Experience:
Kentucky Department of Highways:
Divisions of Planning, Construction and Design (summer employment), 1966 to 1970
Research Engineer Associate, Division of Research (part-time and full-time employment), 1970 to Present

CARLSON CELL ARRANGEMENT

Instrumentation of Box Culvert for Measurement of Imposed Soil Pressures
Name: James H. Havens

Position: Director of Research

Education:
Sue Bennett Junior College, London, Ky., 1939-1941
AB, Transylvania University, Lexington, Ky., 1942
Georgia Institute of Technology Graduate School, 1942
University of Kentucky Graduate School, 1946-1948

Experience:
Graduate Instructorship, Georgia Institute of Technology, Department of Chemistry, 1942
Document Identification Specialist, Federal Bureau of Investigation, Washington, D. C., 1942-1943
Aircraft Observer (Flight Engineer, B-29), U. S. Army Air Force, Air offensive against Japanese Empire, 1943-1946
Kentucky Research Foundation, University of Kentucky, 1951 to 1963 (part time).
Division of Research, Kentucky Department of Highways:
Research Chemist, Research Engineer Senior, and Assistant Director of Research, 1946 to 1963
Director of Research, April 1963 to Present

Professional Societies:
Member, American Society of Civil Engineers
Member, Kentucky Society of Professional Engineers
Member, National Society of Professional Engineers
Member, Society of Rheology
Member, Association of Asphalt Paving Technologists
Member, American Society for Testing and Materials:
Committee on Concrete
Committee on Road and Paving Materials
Committee on Soils for Engineering Purposes
Committee on Skid Resistance
Member, American Concrete Institute:
Committee on Research
Highway Research Board:
Committee on Physico-Chemical Phenomena in Soils (Formerly)
Committee on Composite Pavements
Committee on Paint and Highway Marking Materials

Committee on Characteristics of Bituminous Materials and Means of their Evaluation
Committee on Metals in Highway Structures
Committee on Bituminous Bases

Publications:
Field and Laboratory Evaluation of Roadside Sign Surfacing Materials, Bulletin 43, Highway Research Board, 1951 (co-authored with A. C. Peed, Jr.).


Kentucky Flexible Pavement Design Studies, Bulletin No. 52, Engineering Experiment Station, University of Kentucky, June 1959 (co-authored with W. B. Drake).


Thermal Analysis of the Freeze-Thaw Mechanisms in Concrete, Bulletin No. 59, Engineering Experiment Station, University of Kentucky, March 1961.


Kentucky Highway Research Program, Bulletin No. 73, Engineering Experiment Station Bulletin, University of Kentucky, September 1964 (co-authored with R. C. Deen).

Freeze-Thaw Characteristics of Aggregates, Proceedings, 16th Annual Highway Geology Symposium, Bulletin No. 76, Engineering Experiment Station, University of Kentucky, September 1965 (co-authored with G. R. Laughlin and J. W. Scott).


Freeze and Thaw Phenomena of Concrete Aggregate and Blowups and Cracking of PCC Pavements and Structural Paints and Pavement Marking Materials, Bulletin No. 94, College of Engineering, University of Kentucky, September 1970.


The Safety Barrier Dilemma, presented to National Structural Engineering Meeting, American Society of Civil Engineers, April 24-28, 1972 (co-authored with D. Cornette and W. M. Seymour).

Name: Donald Ray Herd
Position: Research Engineer Assistant

Education:
BSCE, University of Kentucky, December 1971

Experience:
Divisions of Planning, Construction and Maintenance (summer employment), Kentucky Department of Highways, June 1967 to August 1971
Research Engineer Assistant, Division of Research, Kentucky Department of Highways, February 1972 to Present
Engineer in Training in State of Kentucky

Professional Societies:
Student member, Institute of Traffic Engineers
Student member, American Society of Civil Engineers
Kentucky Association of Highway Engineers

Name: Tommy Carson Hopkins
Position: Research Engineer Senior

Education:
BSCE, University of Kentucky, 1964
MSCE, University of Kentucky, 1969

Experience:
Division of Construction (summer employment), Kentucky Department of Highways, May 1959 to September 1961
Division of Research, Kentucky Department of Highways:
Scholarship Student, September 1959 to May 1961 and part-time and summer employment September 1961 to May 1964
Research Engineer Assistant (summer and part-time employment) May 1964 to May 1966
Research Engineer Associate, May 1966 to June 1967
Research Engineer, Head of Surveys and Explorations Section, June 1967 to January 1972
Research Engineer Senior, Head of Soils and Foundations Section, January 1972 to Present
Registered Professional Civil Engineer in the State of Kentucky

Professional Societies:
Member, Kentucky Soil Mechanics and Foundation Group

Publications:
Estimated and Observed Settlements of Bridge Approaches, Record 302, Highway Research Board, 1970 (co-authored with G. D. Scott).
The Bump at the End of the Bridge, Record 302, Highway Research Board, 1970 (co-authored with R. C. Deen).
Name: Theodore Hopwood II
Position: Research Engineer Assistant

Education:
BSME, University of Kentucky, May 1969

Experience:
U. S. Steel Corp., Gary, Ind. (summer employment), July 1965 to August 1967
National Southwire Aluminum Co., Hawesville, Ky, Design Engineer, February 1970 to July 1972
Research Engineer Assistant, Division of Research, Kentucky Department of Highways, July 1972 to Present

Professional Societies:
Society of Automotive Engineers -- 1967
National Society of Professional Engineers -- 1968
Emerson Engineer's Club -- 1969
Engineers Club of St. Louis -- 1969
Kentucky Association of Highway Engineers -- 1972

Name: David Ronald Houchin
Position: Research Engineer Associate

Education:
BSCE, University of Kentucky, December 1970

Experience:
Divisions of Planning and Construction, Kentucky Department of Highways (summer employment), June 1966 to September 1969
Watkins & Associates Consulting Engineers (part-time employment), October 1968 to May 1969
Division of Research, Kentucky Department of Highways (part-time and summer employment), September 1969 to January 1971
Division of Research, Kentucky Department of Highways:
Research Engineer Assistant, January 1971 to March 1972
Research Engineer Associate, March 1972 to Present
Name: Ronald Davis Hughes

Position: Research Engineer Chief

Education:
BSCE, University of Kentucky, June 1955
MSCE, University of Kentucky, January 1957

Experience:
Kentucky Department of Highways, Scholarship Student, September 1951 to May 1952
Divisions of Construction, Design and Planning (summer employment), Kentucky Department of Highways, 1951 to 1954
Assistant Party Chief, Location, Kentucky Department of Highways, June 1955 to August 1955
Division of Research, Kentucky Department of Highways:
Assistant Research Engineer (part-time employment), September 1955 to January 1957
Research Engineer, February 1957 to June 1959
Associate Research Engineer, July 1959 to June 1963
Research Engineer, July 1963 to June 1964
Research Engineer Chief, July 1964 to Present
Instructor for Department night classes, September 1959 to Present

Registered Professional Civil Engineer in the State of Kentucky

Professional Societies:
Highway Research Board
Member, Committee on Curing of Concrete
Member, Committee on Adhesives, Bonding Agents and Their Use

Publications:
The Development and Use of Hydraulic Models in a Study of Culvert Performance, Bulletin 41, Engineering Experiment Station, University of Kentucky, 1956.
Name: Willie McCann
Position: Civil Engineer Assistant

Experience:
Division of Materials, Kentucky Department of Highways, March 1963 to December 1968
Division of Research, Kentucky Department of Highways:
  Materials Testing Aide (part-time employment), December 1968 to June 1970
  Civil Engineer Assistant (part-time employment), June 1970 to Present
Registered Professional Highway Engineer in the State of Kentucky

Professional Societies:
  Member, Kentucky Soil Mechanics and Foundation Group
  Member, American Society of Civil Engineers

Name: Thomas Allen Moore
Position: Research Engineer Assistant

Education:
  BSEE, University of Kentucky, 1971

Experience:
  Student Engineer, Kentucky Utilities Co., April 1969 to March 1972
  Research Engineer Assistant, Division of Research, Kentucky Department of Highways, October 1972 to Present
Name: Donald Clyde Newberry, Jr.

Position: Research Engineer

Education:
Centre College, Danville, Ky.
University of Kentucky, Civil Engineering, 1947 to 1950 and 1966 to 1971

Experience:
Division of Research, Kentucky Department of Highways (summer and part-time employment), September 1946 to June 1950
Corp of Engineers, U. S. Army:
Design Officer in District Office, Orleans and Paris, France
Captain -- Staff Engineer, First Arctic Test Center, Ft. Churchill, Manitoba, Canada 1957 to 1960
Company Commander and Battalion Staff Officer, Ft. George G. Meade, Maryland, June 1960 to September 1962
Engineer Staff Officer, U. S. Army Group, Vietnam, Tan Son Nhu Airfield, Saigon, Vietnam, September 1962 to September 1963
Company Commander, A and B Companies, 538th Engineer Construction Battalion, Ft. Knox, Ky., September 1963 to December 1964
Company Commander and Battalion Staff Officer, 1st Engineer Battalion, 1st Infantry Division, Ft. Riley, Kansas,

December 1964 to July 1965
Engineer Staff Officer, 1st Engineer Battalion, 1st Infantry Division, Vietnam, July 1965 to August 1966
Engineer Operations Officer, 16th Armored Group, Ft. Knox, Ky, August 1966 to October 1966
Major, Voluntary Retirement, October 31, 1966
Division of Research, Kentucky Department of Department of Highways:
Research Engineer Assistant, November 1966 to 1968
Research Engineer Associate, 1968 to 1972
Research Engineer Senior, 1972 to Present
Registered Professional Civil Engineer in the State of Kentucky

Professional Societies:
American Society of Civil Engineers

Buffalo Bomag BW 210A Vibratory Roller
Name: Jerry Gordon Pigman
Position: Research Engineer

Education:
BSCE, University of Kentucky, December 1968
MSCE, University of Kentucky, May 1971

Experience:
Divisions of Construction and Research, Kentucky Department of Highways (part-time and summer employment), June 1965 to December 1968
Division of Research, Kentucky Department of Highways:
Research Engineer Assistant, January 1969 to April 1970
Research Engineer Associate, April 1970 to March 1971
Research Engineer, March 1971 to Present

Professional Societies:
Institute of Traffic Engineers, Junior Member
Kentucky Division of the Southern Section of the Institute of Traffic Engineers, Associate Member

Publications:
*Travel to Outdoor Recreation Areas in Kentucky Record 392*, Highway Research Board, 1972 (co-authored with J. A. Deacon and R. C. Deen).

Name: Assaf Sami Rahal
Position: Research Engineer

Education:
BSCE, University of Kentucky, May 1969

Experience:
Geauga County Engineers (summer employment), Geauga County, Ohio, 1964 to 1966
Division of Research, Kentucky Department of Highways:
Part-time and summer employment, 1967 to 1969
Research Engineer, May 1969 to Present

Professional Societies:
Kentucky Association of Highway Engineers

Publications:
Name: Rolands L. Rizenbergs

Position: Research Engineer Chief

Education:
BSEE, University of Kentucky, January 1958.

Experience:
Drafting Aide (summer employment), Division of Design, Kentucky Department of Highways, 1954
Engineering Aide, Geo. T. Stagg Co., 1956
Engineering Aide (part-time and summer employment), Division of Research, Kentucky Department of Highways, 1957
Division of Research, Kentucky Department of Highways:
Research Engineer Assistant, February 1958 to August 1960
Research Engineer Associate, August 1960 to March 1963
Research Engineer, March 1963 to July 1964
Research Engineer Senior, July 1964 to March 1966
Research Engineer Principal, March 1966 to February 1969
Research Engineer Chief, February 1969 to Present
Registered Professional Electrical Engineer in the State of Kentucky
Registered Professional Highway Engineer in the State of Kentucky

Professional Societies:
Member, Institute of Electrical and Electronics Engineers
Member, Kentucky Association of Highway Engineers
American Society for Testing and Materials, Committee on Skid Resistance
Highway Research Board
Committee on Surface Properties-Vehicle Interaction

Publications:
Pavement Friction, Kentucky Engineer, May 1960.


British Pendulum Skid Tester
Name: Jerry D. Ross
Position: Research Engineer

Education:
BSCE, University of Kentucky, December 1967

Experience:
Divisions of Construction and Research (part-time and summer employment), Kentucky Department of Highways, May 1964 to December 1967
Research Engineer Assistant, Division of Research, Kentucky Department of Highways, January 1967 to June 1968
Lieutenant -- Construction Engineer, Corps of Engineers, U.S. Army, Fort Leonard Wood, Mo. and 34th Engineer Group, Republic of Vietnam, June 1968 to April 1971
Research Engineer, Division of Research, Kentucky Department of Highways, May 1971 to Present

Professional Societies:
American Society of Civil Engineers, University of Kentucky Student Chapter, 1964 to 1967
American Society of Military Engineers, 1969 to 1970

Name: Marshall Forrest Smith
Position: Research Engineer Associate

Education:
BSCE, University of Kentucky, December 1968

Experience:
Divisions of Planning, Construction, and Research (part-time and summer employment), Kentucky Department of Highways, June 1964 to September 1969
Construction Inspector, 01D20, U.S. Army, Taegu Air Base, Korea, November 1969 to June 1971
Division of Research, Kentucky Department of Highways:
Research Engineer Assistant, July 1971 to March 1972
Research Engineer Associate, March 1972 to Present
Name: Herbert Fletcher Southgate

Position: Research Engineer Principal

Education:
BSCE, Virginia Military Institute, June 1955
Graduate work in Structural Option of Civil Engineering, University of Illinois, February 1963 to June 1964
MSCE, University of Kentucky, May 1968

Experience:
Coal Mine Surveying Crew (summer employment), U.S. Steel, summers of 1953 and 1954
Warehouseman (summer employment), T. S. Southgate Corp., June 1955 to November 1955
Civil and Chemical Engineer, Nitrogen Division, Allied Chemical Corporation, January 1958 to February 1963
Surveying Party Chief (part-time employment), Goodell Engineering Associates, Champaign, Illinois, February 1964 to July 1964
Division of Research, Kentucky Department of Highways:
Research Engineer Assistant, July 1964 to May 1966
Research Engineer Associate, May 1966 to August 1967
Research Engineer, August 1967 to January 1969
Research Engineer Principal, January 1969 to Present
Registered Professional Engineer in the State of Kentucky

Professional Societies:
National Society of Professional Engineers -- 1968-69
Kentucky Society of Professional Engineers -- 1968-69
Kentucky Association of Highway Engineers -- 1970 to Present

Publications:
"Temperature Distribution within Asphalt Pavements and Its Relationship to Pavement Deflection, Record 291, Highway Research Board, 1969 (co-authored with R. C. Deen)
"Structural Analysis of Bituminous Concrete Pavements, Record 666, Highway Research Board 1972 (co-authored with J.H. Havens and R. C. Deen)."
Name: Larry A. Warren
Position: Assistant Research Engineer

Education:
BSCE, University of Kentucky, May 1972

Experience:
Engineering Aide, Kentucky Department of Highways, 1968
Surveyor and Draftsman, L. E. Gregg, Consulting Engineers, 1970 to 1971
Assistant Civil Engineer, Kentucky Department of Natural Resources, Division of Water, June 1972 to September 1972
Assistant Research Engineer, Division of Research, Kentucky Department of Highways, September 1972 to Present

Name: Charles Victor Zegeer
Position: Research Engineer Assistant

Education:
BSCE, Virginia Polytechnic Institute and State University, June 1972

Experience:
Engineering Technician (summer employment), Safety Branch, D. C. Department of Highways & Traffic, June to September 1971
Traffic Engineer, Safety Branch, D. C. Department of Highways & Traffic, June to August 1972
Research Engineer Assistant, Division of Research, Kentucky Department of Highways, August 1972 to Present

Professional Societies:
American Society of Civil Engineers
Institute of Traffic Engineers
Kentucky Association of Highway Engineers
APPENDIX

LISTING OF RESEARCH STUDIES
DIVISION OF RESEARCH

FHWA PARTICIPATING STUDIES

<table>
<thead>
<tr>
<th>STUDY NUMBER</th>
<th>TITLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>KYHPR 1</td>
<td>Experimental Concrete Pavement Containing Fly-Ash Admixtures</td>
</tr>
<tr>
<td>KYHPR 2</td>
<td>Construction and Finishing Techniques - Concrete Bridge Decks</td>
</tr>
<tr>
<td>KYHPR 3</td>
<td>Protective Coatings for Concrete Bridge Decks</td>
</tr>
<tr>
<td>KYHPR 4</td>
<td>Repair and Maintenance of Concrete Bridge Decks</td>
</tr>
<tr>
<td>KYHPR 5</td>
<td>Slip-Form Paving</td>
</tr>
<tr>
<td>KYHPR 6</td>
<td>Freeze and Thaw Phenomena of Concrete Aggregate</td>
</tr>
<tr>
<td>KYHPR 7</td>
<td>Slurry Seal Maintenance Applications</td>
</tr>
<tr>
<td>KYHPR 8</td>
<td>Experimental Silica Sand-Asphalt Surface</td>
</tr>
<tr>
<td>KYHPR 9</td>
<td>Class I Bituminous Mixtures</td>
</tr>
<tr>
<td>KYHPR 10</td>
<td>Kentucky Rock Asphalt as a Traffic-Bound Base and a Hot-Mix Aggregate</td>
</tr>
<tr>
<td>KYHPR 11</td>
<td>Pavement-Type Selection Basis</td>
</tr>
<tr>
<td>KYHPR 12</td>
<td>Treated Dense-Graded Aggregate Base Investigation</td>
</tr>
<tr>
<td>KYHPR 13</td>
<td>Engineering Properties of Soils</td>
</tr>
<tr>
<td>KYHPR 14</td>
<td>Investigation of Design, Construction and Erosion Control Methods for Use in Wind-Blown Silts</td>
</tr>
<tr>
<td>KYHPR 15</td>
<td>Relationship between Soil Support Value and Kentucky CBR</td>
</tr>
<tr>
<td>KYHPR 16</td>
<td>Development of a Practical Method of Locating and Tracing Seepage Water in Unstable Slopes</td>
</tr>
<tr>
<td>KYHPR 17</td>
<td>Settlement of Bridge Approaches and Embankments</td>
</tr>
<tr>
<td>KYHPR 18</td>
<td>Plastic Stripping Performance Surveys</td>
</tr>
<tr>
<td>KYHPR 19</td>
<td>Durability of Traffic Paint on Portland Cement Concrete Pavements</td>
</tr>
<tr>
<td>KYHPR 20</td>
<td>Flexible Pavement Study Using Viscoelastic Principles</td>
</tr>
<tr>
<td>KYHPR 21</td>
<td>Determination of Traffic Parameters for the Prediction, Projection, and Computation of EWL's</td>
</tr>
<tr>
<td>KYHPR 22</td>
<td>Annual Performance Survey of Reinforced Concrete Pipe</td>
</tr>
<tr>
<td>KYHPR 23</td>
<td>Study of Runoff from Small Drainage Areas</td>
</tr>
<tr>
<td>KYHPR 24</td>
<td>Pavement Slipperiness Studies</td>
</tr>
<tr>
<td>KYHPR 25</td>
<td>Road Roughness and Serviceability Investigation</td>
</tr>
<tr>
<td>KYHPR 26</td>
<td>Research Relating to State Highway Laws, Eminent Domain, or Condemnation Laws</td>
</tr>
<tr>
<td>KYHPR 27</td>
<td>Development of an Electronic Means of Weighing Vehicles in Motion</td>
</tr>
<tr>
<td>KYHPR 28</td>
<td>Right-of-Way Severance Damage Study</td>
</tr>
<tr>
<td>KYHPR 29</td>
<td>Changes in Certain Properties of Aggregate Materials Used in Base Construction Resulting from Construction</td>
</tr>
<tr>
<td>KYHPR 30</td>
<td>Economic Research</td>
</tr>
<tr>
<td>KYHPR 31</td>
<td>Nuclear Moisture Density Research</td>
</tr>
<tr>
<td>KYHPR 32</td>
<td>Compaction Study</td>
</tr>
<tr>
<td>KYHPR 33</td>
<td>Establishment and Maintenance of Roadside Plantings and Turf</td>
</tr>
<tr>
<td>KYHPR 34</td>
<td>Coal Aggregates</td>
</tr>
<tr>
<td>KYHPR 35</td>
<td>Investigation of Use of Preformed, Compressed, Neoprene Seals in Joints of Concrete Bridge Decks</td>
</tr>
<tr>
<td>KYHPR 36</td>
<td>Quality Control Concepts and Their Application to Highway Specifications and Construction</td>
</tr>
<tr>
<td>KYHPR 37</td>
<td>Investigations of Reflective Sign Materials and Delineators</td>
</tr>
<tr>
<td>KYHPR 38</td>
<td>Rheological Study of Cohesive Soils</td>
</tr>
<tr>
<td>KYHPR 39</td>
<td>Curing Concrete</td>
</tr>
<tr>
<td>KYHPR 40</td>
<td>Nuclear Irradiation of Clay Minerals</td>
</tr>
<tr>
<td>KYHPR 41</td>
<td>Tensile Strength of Concrete</td>
</tr>
<tr>
<td>KYHPR 42</td>
<td>Experimental Guardrail Installations and Performance Studies</td>
</tr>
<tr>
<td>KYHPR 43</td>
<td>Engineering Geognosy</td>
</tr>
<tr>
<td>KYHPR 44</td>
<td>Surveillance of Experimental Features of Highway Construction and Planning</td>
</tr>
<tr>
<td>KYHPR 144</td>
<td>Experimental Concrete Pavement Containing Fly-Ash Admixtures</td>
</tr>
<tr>
<td>KYHPR 744</td>
<td>Slurry Seal Maintenance Applications</td>
</tr>
<tr>
<td>KYHPR 944</td>
<td>Class I Bituminous Mixtures</td>
</tr>
<tr>
<td>KYHPR 1044</td>
<td>Kentucky Rock Asphalt as a Traffic-Bound Base and a Hot-Mix Aggregate</td>
</tr>
<tr>
<td>KYHPR 4244</td>
<td>Experimental Guardrail Installations and Performance Studies</td>
</tr>
<tr>
<td>KYHPR 45</td>
<td>Economic Impact of Billboard Control in Highway Beautification Programs</td>
</tr>
<tr>
<td>KYHPR 46</td>
<td>Hot-Mix Coal Tar Pavements</td>
</tr>
<tr>
<td>KYHPR 47</td>
<td>Practicability of Color Aerial Film Used for Photogrammetry</td>
</tr>
<tr>
<td>KYHPR 48</td>
<td>Investigation of Landslides on Highways</td>
</tr>
<tr>
<td>KYHPR 49</td>
<td>Full-Depth Asphaltic Concrete Pavements</td>
</tr>
<tr>
<td>KYHPR 50</td>
<td>General Administration</td>
</tr>
<tr>
<td>KYHPR 51</td>
<td>Highway Research Correlation Service</td>
</tr>
<tr>
<td>KYHPR 52</td>
<td>Preparation of Final Reports</td>
</tr>
<tr>
<td>KYHPR 61</td>
<td>Analysis of Traffic Control on High Speed Facilities during Maintenance</td>
</tr>
<tr>
<td>KYHPR 62</td>
<td>Influence of Recreational Areas on the Functional Service of Highways</td>
</tr>
<tr>
<td>KYHPR 63</td>
<td>Operational Characteristics of Lane Drops</td>
</tr>
<tr>
<td>KYHPR 64</td>
<td>Experimental Installations of Impact Attenuating Devices</td>
</tr>
<tr>
<td>KYHPR 65</td>
<td>Heating Coils in Pavements and Bridge Decks</td>
</tr>
<tr>
<td>KYHPR 66</td>
<td>Correlation of Skid Resistance with Qualities of Sands</td>
</tr>
<tr>
<td>KYHPR 67</td>
<td>Pavement Properties and Performance Study</td>
</tr>
<tr>
<td>KYHPR 68</td>
<td>Loads on Box Culverts under High Embankments</td>
</tr>
<tr>
<td>KYHPR 69</td>
<td>Soil-Bridge Abutment Interaction</td>
</tr>
<tr>
<td>KYHPR 70</td>
<td>Evaluation of the Fatigue Life of Critical Members of Major Bridges</td>
</tr>
<tr>
<td>KYHPR 71</td>
<td>Voidless Concrete Mixture for Bridge Decks</td>
</tr>
<tr>
<td>KYHPR 72</td>
<td>Determination of Flexible Pavement Rutting Behavior</td>
</tr>
<tr>
<td>KYHPR 73</td>
<td>Implementation of Research Findings</td>
</tr>
</tbody>
</table>
## DIVISION OF RESEARCH

### NON-PARTICIPATING STUDIES

<table>
<thead>
<tr>
<th>STUDY NUMBER</th>
<th>TITLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>KYP 1</td>
<td>Annotated Bibliography and History of Highway Research in Kentucky</td>
</tr>
<tr>
<td>KYP 2</td>
<td>Urethane Insulation</td>
</tr>
<tr>
<td>KYP 3</td>
<td>Corrosion Resistance of Culvert Materials</td>
</tr>
<tr>
<td>KYP 4</td>
<td>Structural Design for Torsion and Shear in Reinforced Concrete</td>
</tr>
<tr>
<td>KYP 5</td>
<td>Analysis of Tire Data</td>
</tr>
<tr>
<td>KYP 6</td>
<td>Obtaining Highway Engineering Services from Professional Engineers in Private Practice</td>
</tr>
<tr>
<td>KYP 7</td>
<td>Protection of Exposed Shale Cuts</td>
</tr>
<tr>
<td>KYP 8</td>
<td>Photographic Inventory of Highway Systems</td>
</tr>
<tr>
<td>KYP 9</td>
<td>Median Design and Accident Histories</td>
</tr>
<tr>
<td>KYP 10</td>
<td>Development of a Highway Inventory System</td>
</tr>
<tr>
<td>KYP 11</td>
<td>Loading Histories of Ohio River Bridges</td>
</tr>
<tr>
<td>KYP 12</td>
<td>Research Relating to Legal Liabilities of the State Highway Department</td>
</tr>
<tr>
<td>KYP 13</td>
<td>Engineering Properties of Soils</td>
</tr>
<tr>
<td>KYP 14</td>
<td>Cracking of Bridge Decks</td>
</tr>
<tr>
<td>KYP 15</td>
<td>Hot-Mix Coal-Tar Concrete Pavements</td>
</tr>
<tr>
<td>KYP 16</td>
<td>Operation of Auto-Utility Trailer Combinations on Rural Highways in Kentucky</td>
</tr>
<tr>
<td>KYP 17</td>
<td>Analysis of Pavement Temperature</td>
</tr>
<tr>
<td>KYP 18</td>
<td>Grooving of Pavements</td>
</tr>
<tr>
<td>KYP 19</td>
<td>Energy Absorbing Safety Barriers</td>
</tr>
<tr>
<td>KYP 20</td>
<td>Slope Stability Analysis</td>
</tr>
<tr>
<td>KYP 21</td>
<td>Tartan Surfacing for an Equestrian Overpass</td>
</tr>
<tr>
<td>KYP 22</td>
<td>Galvanized Bridge Structures</td>
</tr>
<tr>
<td>KYP 23</td>
<td>Heating Coils in Pavements</td>
</tr>
<tr>
<td>KYP 24</td>
<td>Noise Abatement</td>
</tr>
<tr>
<td>KYP 25</td>
<td>Bridge Deck Construction</td>
</tr>
<tr>
<td>KYP 26</td>
<td>Modular Expansion Systems</td>
</tr>
<tr>
<td>KYP 27</td>
<td>PCC Shoulders</td>
</tr>
<tr>
<td>KYP 28</td>
<td>Continuously Reinforced Concrete Pavements</td>
</tr>
<tr>
<td>KYP 29</td>
<td>Deterioration of Concrete by Pollutants</td>
</tr>
<tr>
<td>KYP 30</td>
<td>Influence of Recreational Areas on the Functional Service of Highways</td>
</tr>
<tr>
<td>KYP 31</td>
<td>Evaluation of Reflective Sign Materials</td>
</tr>
<tr>
<td>KYP 32</td>
<td>Lane Distribution Study</td>
</tr>
<tr>
<td>KYP 33</td>
<td>Acoustic Emissions</td>
</tr>
<tr>
<td>KYP 34</td>
<td>Accident Potential of Urban-Area Bypasses</td>
</tr>
<tr>
<td>KYP 35</td>
<td>Products Evaluation</td>
</tr>
<tr>
<td>KYP 36</td>
<td>Interchange Studies</td>
</tr>
<tr>
<td>KYP 37</td>
<td>Traffic Inventory</td>
</tr>
<tr>
<td>KYP 38</td>
<td>Landslides</td>
</tr>
<tr>
<td>KYP 39</td>
<td>Voidless Concrete Mixture</td>
</tr>
<tr>
<td>KYP 40</td>
<td>Effects of Safety Improvements on Accidents</td>
</tr>
<tr>
<td>KYP 41</td>
<td>Compaction of Bituminous Mixtures</td>
</tr>
<tr>
<td>KYP 42</td>
<td>Economic Growth Centers</td>
</tr>
<tr>
<td>KYP 43</td>
<td>Consolidation Testing of Soils</td>
</tr>
<tr>
<td>KYP 44</td>
<td>Implementation of Research Findings</td>
</tr>
<tr>
<td>KYP 45</td>
<td>Identification of Hazardous Highway Locations</td>
</tr>
<tr>
<td>KYP 46</td>
<td>Organizational Techniques Used for Accident Surveillance</td>
</tr>
<tr>
<td>KYP 47</td>
<td>Optimal Highway Investment by Dynamic Programming</td>
</tr>
<tr>
<td>KYP 48</td>
<td>Evaluation and Application of Roadway Delineation Techniques</td>
</tr>
<tr>
<td>KYP 49</td>
<td>Ultrasonic Testing</td>
</tr>
<tr>
<td>KYP 50</td>
<td>General Administration</td>
</tr>
<tr>
<td>KYP 51</td>
<td>Freshman Scholarship Program</td>
</tr>
<tr>
<td>KYP 52</td>
<td>Sophomore Scholarship Program</td>
</tr>
<tr>
<td>KYP 53</td>
<td>On-the-Job Training Courses</td>
</tr>
<tr>
<td>KYP 54</td>
<td>Specification Testing</td>
</tr>
<tr>
<td>KYP 55</td>
<td>Impromptu Investigations</td>
</tr>
<tr>
<td>KYP 56</td>
<td>Freshman Scholarship Payroll</td>
</tr>
<tr>
<td>KYP 57</td>
<td>Sophomore Scholarship Payroll</td>
</tr>
</tbody>
</table>