Progress Report No. 1
on
Research Project S-2

A STUDY OF THE RELATIONSHIP BETWEEN
SUBGRADE CALIFORNIA BEARING RATIOS AND
PUMPING OF RIGID PAVEMENTS

by

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Concrete Pavement as Related to Pumping Action of Slabs)

Cooperative Research with
Public Roads Administration
Project No. SWHP 1(9)

Highway Materials Research Laboratory
Lexington, Kentucky

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I. PURPOSE
The purpose of this investigation was to determine the relationship between the pumping of rigid pavements and the modified California Bearing Ratio of the subgrade soil, beneath the pavement. The ultimate objective is a design criteria for eliminating or minimizing in the most economical way, pumping of rigid pavements in Kentucky.

II. SCOPE
The study consisted of sampling and testing 215 locations that included both pumping and non-pumping situations. The locations were selected so as to give first, the widest possible range of soil types; and second, soils over which traffic had been relatively heavy. In all, 475 miles of concrete pavement were studied. The soils have been analyzed, with the emphasis on grain size and the C.B.R. value. Future work will embody other characteristics in more detail.

III. METHODS
A. Selection of Roads to be Studied
The selection of roads to be studied was made on the basis of the 1945 truck-traffic count. Initially, all roads that had in excess of 500 trucks per day were selected. In addition to these, roads with less traffic but different soils were selected on the basis of a study of the geologic maps available. All roads are shown prominently in Fig. 1. As can be seen, they represent a wide cross-section of the State.
B. **Traffic Analysis**

In conjunction with the study, an extensive traffic analysis was initiated through cooperation of our Division of Planning. This analysis will result in valuable information as to the number and weight of the axles passing over the various roads selected. Loadometer measurements were taken at all of their regularly scheduled locations of which 8 were used in the preliminary analysis of traffic for this study. In addition, temporary stations were employed for more accurate determinations on the roads that appeared to have different traffic conditions than those that existed at the regular stations. Fig. 1 shows the location of all of the stations used, with an indication as to which are permanent and which are temporary.

The type of equipment used for the loadometer measurements is shown in Fig. 2. Details such as overall truck width, length, and height; distance between axles, etc., were also obtained.

Calculations have been based on the 1946 traffic counts, with the number and weights of axles estimated from the single eight-hour measurement conducted at each location for this study.

C. **Performance Surveys**

Pavement performance was determined in two ways. First, through information from the District Offices of the State Highway Department; and second, by direct observation.

Early in May of this year, questionnaires were sent to each District with a request that they discuss the performance of each of the roads selected for study that lay in their District. At a later date, and after the sampling was completed,
Fig. 2. A Section of Good Pavement (U.S. 42, East of Louisville).
the District offices were again contacted and the individual roads discussed in the light of the exact locations selected. From these contacts the type of information listed in Table I was obtained.

TABLE I
QUESTIONS ON PROJECT PERFORMANCE
DISCUSSED WITH DISTRICT ENGINEERS

A. PAST PERFORMANCE

1. When did pumping start (if pumping)
2. No. of corner breaks repaired (due to pumping)
3. Square yards of pavement replaced (due to pumping)
4. Square yards of resurfacing (due to pumping)
5. Unusual influences on traffic during past few years.

B. PRESENT PERFORMANCE

1. Location by station, of pumping sections
2. Location, by station, of bad failure caused by pumping
3. Maintenance methods used to correct pumping.

Prior to the actual sampling the pavements were studied in detail. This consisted of at least two and not more than four trips over each project or road in question. In general, projects were considered individually, and then collectively, so as to minimize the sampling.

In the majority of the cases, the type of information listed in the first part of Table II was obtained some time after the sampling. This data was considered essential, but secondary to the actual sampling itself.

As to classing a sample location as pumping or non-pumping, considerable care was taken. First, to be classed as non-pumping, there had to be no evidences of pumping such as faulting, jacking, gaping joints or cracks that might be pumping.
Second, to be classed as pumping, there actually had to be mud spots on the pavement; or evidences of jacking. In the latter case, local maintenance personnel were questioned as to the reason for jacking. Pumping at bridge and culvert approaches were not considered as fair evidence of what the soil should do, so none of these locations were sampled. All of the field observations for pumping or non-pumping classification were considered in light of the questionnaires sent to the District Engineers.

### TABLE II
**OUTLINE OF RECONNAISSANCE SURVEY**

A. **TYPE OF FAILURES CONSIDERED IN PERFORMANCE SURVEYS**

1. No. of cracks per mile per project
2. Estimate of percent of joints and cracks pumping
3. No. of interior and exterior corner breaks
4. No. of jacked slabs per mile per project
5. Estimate of degree of pumping

B. **FACTORS INFLUENCING CHOICE OF SAMPLE LOCATIONS**

1. Project
2. Performance
3. Soil Area
4. Design
5. Direction of Traffic
6. Safety

D. **Selection of Sample Locations**

In the latter part of Table II are listed all the factors considered before a location was chosen for sampling. As to the intensity of the sampling a section of good pavement is shown in Fig. 2. If this was typical of the road, samples were selected where the soil was likely to vary. If the soil in cuts did not appear to vary, and if the geologic maps did not show a change, sampling was cut to a minimum.
However, if sections such as those in Fig. 3 occurred more or less sporadically, more samples were required.

**E. Field Sampling and Testing**

After deciding to sample at a given site, excavation was begun along the edge of the pavement. Fig. 4 illustrates the extent of this excavation. It represented about ten cubic feet per location, or roughly seventy cubic yards for the entire study.

Wherever possible, a density determination was made on the subgrade for a depth not exceeding 12" beneath the pavement. Fig. 5 shows how the sample was taken from beneath the pavement. The undisturbed portion was removed and cut with knives into the two largest cubes or prisms possible, and the average length, width, and height determined by measuring. The weight and two moisture content samples completed this phase of the sampling. In calculations, the average of the two densities was considered to be the density of the subgrade. Also of interest, sampling was executed at joints or cracks, since there was some possibility of variation at any other spot.

After the density determination was completed, a 50 to 75 pound sample was taken, and the hole backfilled.

Where the subgrade was extremely granular, no density determinations were made, although moisture contents samples were taken. In approximately 90% of the locations, a photograph was taken of the road, as well as the excavation.

Where the material immediately beneath the pavement differed radically from the remainder of the subgrade, a small 2-pound sample was obtained. This material was nearly always
Fig. 3. A Section of Pumping Pavement
(U.S. 42, East of Warsaw).
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Fig. 4. Typical Excavation to Obtain Sample.

Fig. 5. Typical Preparation for Obtaining Field Density Sample.
2-pound sample was obtained. This material was nearly always granular, and the main purpose was to determine the grain size analysis and limits.

Originally it had been hoped that density and type of material in the subgrade could be checked by coring through the concrete in at least one-third of the locations. However, nearly one-half hour was required to core the pavement, and the difficulties in getting an accurate density check at the bottom of the small 4" round hole ruled out this procedure.

F. Laboratory Testing

Laboratory testing was started in June with a skeleton laboratory staff. Only sample preparation, Proctors and C.B.R's, were conducted up until October. At that time, hydrometers, and the specific gravities using volumetric flasks were begun. A.S.T.M. standards were followed throughout except for the C.B.R. procedures.

Our set-up for the C.B.R. is shown in Fig. 6. Fundamentally, the procedure was the same as outlined in the A.S.T.M. Procedures for Testing Soils. The basic difference lies in the duration of soaking. The A.S.T.M. procedure called for a 4-day soaking period. In our testing, the soil was allowed to soak until it swelled less than .003" in 24 hours. This period varied from 4 days to three weeks. The additional soaking period was allowed in order to be able to correlate results with our Testing Laboratory.
Fig. 6. Laboratory Set-up for C.B.R. Test.
In order to determine if the C.R.R. values could be duplicated using the prescribed method, three 60 pound samples were taken at ten locations. One sample of each was sent to our Highway Testing Laboratory in Frankfort and to the Public Roads Administration in Washington.

G. Study of Construction and Design Features

The evaluation of construction and design features will be accomplished from data such as pavement thickness, type and spacing of joints, year graded and paved, etc., obtained from the State Highway Department files. This data will be analyzed in the light of the other variables.

IV. SUMMARY OF WORK COMPLETED

In Table III there is a summary of the work completed to date. It represents the data upon which the results included in this report are based.

TABLE III
SUMMARY OF WORK COMPLETED

A. FIELD WORK

1. Miles of pavement surveyed ....................... 475  
2. No. of projects surveyed .......................... 91  
3. No. of loadometer stations ......................... 22  
4. No. of samples .................................... 215  
5. Average no. of miles per sample ................... 2.22  
6. No. of samples with field density determinations 107  
7. No. of samples with field content determinations 215  

B. LABORATORY WORK

1. California Bearing Ratio ............................ 265  
2. Moisture Density Relation .......................... 213  
3. Mechanical Analysis ................................ 213  
4. Specific Gravity ................................... 213  
5. Atterburg Limits ................................... 17
V. RESULTS

Before discussing the results obtained it is well to keep in mind that little time has been available for analysis. Efforts have been concentrated toward completion of the laboratory work by December 1.

A. Traffic Vs. Pumping

In order to arrive at some basis for estimating the traffic required to start pumping, the five roads upon which pumping occurred, and which carried at least 7-ton axles daily, have been listed in Table IV.

<table>
<thead>
<tr>
<th>Road</th>
<th>Daily No. of Axle Loads (Both Directions)</th>
<th>Over 5 T.</th>
<th>Over 6 T.</th>
<th>Over 7 T.</th>
<th>Over 3 T.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Louisville-Bedford</td>
<td></td>
<td>84</td>
<td>64</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>U.S. 42</td>
<td></td>
<td>79</td>
<td>60</td>
<td>42</td>
<td>21</td>
</tr>
<tr>
<td>Carrollton-Warsaw</td>
<td></td>
<td>75</td>
<td>57</td>
<td>27</td>
<td>13</td>
</tr>
<tr>
<td>U.S. 42</td>
<td></td>
<td>96</td>
<td>58</td>
<td>24</td>
<td>3</td>
</tr>
<tr>
<td>Bedford-Carrollton</td>
<td></td>
<td>155</td>
<td>40</td>
<td>17</td>
<td>10</td>
</tr>
<tr>
<td>U.S. 60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lexington-Winchester</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.S. 23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pnintsville-Prestonsburg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U.S. 23</td>
<td></td>
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</tbody>
</table>

A study of this table indicates that the average of the number of various axle weights is consistent except for the 7-ton weights. In the latter class, two roads have less than the average and yet pump. For the purpose of this preliminary analysis,
the average values have been considered as the number of axle loads required to start pumping.

A total of 42 roads were selected for study; of these 42, ten had no pumping, and of these ten, six had less traffic than the average required to produce pumping.

B. C.B.R. Vs. Pumping

The criteria advanced by our Testing Laboratory states that soils with C.B.R. above 15 will not pump, and those with C.B.R. under 8 should pump. Those with C.B.R. between 8 and 15 will depend on the Plasticity Index and the clay content. In Table V there is a summary of the C.B.R. values versus pumping.

In sections C and D of Table V, a total of 15 non-pumping samples from the roads carrying less than the traffic required to produce pumping, have been excluded.

Since only 17 limits tests have been conducted, it was impossible to analyze the values between 8 and 15.

Up to the present time, no attempts have been made to use other C.B.R. values than 8 and 15 as the limiting values.
TABLE V
C.B.R. VALUE VS. PUMPING

A. NO. OF C.B.R. TESTS COMPLETED ............ 206

B. SUMMARY OF RESULTS ON PUMPING SAMPLES
1. No. of C.B.R. Values over 15 ............ 19
2. No. of C.B.R. Values under 8 ............ 67
  Per Cent Accuracy ............ 77.9

C. SUMMARY OF RESULTS ON NON-PUMPING SAMPLES
1. No. of C.B.R. Values over 15 ............ 49
2. No. of C.B.R. Values under 8 ............ 21
  Per Cent Accuracy ............ 70.1

D. SUMMARY OF SAMPLES WITH C.B.R. BETWEEN 8 and 15
1. No. of samples .......................... 35
2. No. of pumping samples ................... 17
  3. Per Cent Pumping .................... 48.6

C. Texture Classification

On the triangular classification chart, all 213 samples completed have been plotted. In calculating the percent accuracy, however, the same 15 samples eliminated from consideration in the C.B.R., have been excluded.

As can be seen, there were 98 samples from under pumping slabs that had less than 55% coarser than 0.5 mm. (#270 sieve), however, there were 10 samples that had more than 55% sand and gravel size and yet were taken from under pumping slabs.

Of equal interest is the fact that of the 68 samples from under non-pumping slabs, only 21 had as much as 55% sand and gravel size.
Fig. 7. Textural Classification Vs. Pumping.
D. Summary

As a brief summary, Table VI illustrates the accuracy of the C.B.R. and the Texture Classification for predicting pumping under present conditions in Kentucky.

<table>
<thead>
<tr>
<th>PERCENT ACCURACY (Non-pumping Soils)</th>
<th>C.B.R.</th>
<th>Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>70.1</td>
<td>30.9</td>
<td></td>
</tr>
<tr>
<td>PERCENT ACCURACY (Pumping Soils)</td>
<td>77.9</td>
<td>90.8</td>
</tr>
<tr>
<td>OVERALL PERCENT ACCURACY</td>
<td>74.1</td>
<td>67.6</td>
</tr>
</tbody>
</table>

The analysis is at present only about 10% complete. There are several important variables that have not been considered in evaluating either the C.B.R. or Texture Methods of predicting soil performance as regards pumping. Factors yet to be analyzed include: Soil areas; traffic variations during past few years; and effects of age and design features. The final recommendation will, of course, consider the economic and practical aspects to this problem of eliminating or minimizing pumping.