Effect of Coarse Aggregate on Concrete Pavement Performance in Indiana

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Previous surveys of concrete pavements in Indiana have established a definite correlation of the coarse aggregate source with the concrete durability. A color motion picture was made recently to illustrate the effects of aggregate on concrete pavement performance. This paper reports the results of performance surveys of the projects included in the movie.

Data are reported on 12 projects, in which 15 sources of coarse aggregate were used. In several instances, more than one coarse aggregate was used in a single project with all other factors remaining constant. These form excellent illustrations of the change in performance with change in coarse aggregate.

The results of the surveys substantiate the conclusion that the coarse aggregate is a major factor in the performance of concrete pavements in this area. Differences in the prevalence of blowups and D-line cracking and in the transverse crack interval are attributed to the coarse aggregate used in the concrete.

INTRODUCTION

The effect of coarse aggregates on the durability of concrete pavements in Indiana has been recognized for a number of years and has been the subject of a large amount of research and investigation, both in the laboratory and in the field.

The problem was first pointed out by Woods, Sweet and Shelburne (14) in 1945, when they reported the results of very extensive field performance surveys. All of the concrete pavements built before 1935, totaling more than 2600 miles, were included in the survey. Statistical analyses of the data collected showed a positive correla-
tion between the source of coarse aggregate and the frequency of pavement blowups. It was noted that the pavements that were the most susceptible to blow-ups also showed deterioration by D-line cracking. No correlation could be established between the fine aggregates or the cements and the pavement performance. Although only about 10 per cent of the pavement mileage surveyed was found to have significantly bad performance, the problem is one of considerable economic importance. A later paper by Sweet and Woods (11) showed the correlation of soil textures with the severity of D-line cracking and blowups. The subgrade soil texture is a major factor in determining the moisture conditions to which the pavement is subjected.

An extensive laboratory research program has been underway for several years to develop information and data about the role of aggregates in concrete pavement durability. Sweet (10) reported the correlation of laboratory weathering tests and aggregate characteristics with field performance. The effect of air entrainment on the durability of concrete made with various Indiana aggregates has been reported by Bugg (2) and Blackburn (1). Other studies have included work on the effect of restraint of expansion on the durability of concrete, determination of the pore size of the aggregates, and an investigation of the influence of fine aggregates on durability by Pendley (7), Fears (3), and Higgs (4), respectively.

All of the reports cited above have been summarized in published papers by Lewis (5), Lewis and Woods (6) and Woods (13). These papers also point out the possible applications of the laboratory studies to acceptance testing of concrete aggregates.

Since the majority of the laboratory tests were conducted on crushed stone aggregates, the correlations of the test results with field performance are chiefly applicable to those materials. Either good or bad field performance may be found with gravels as well as with crushed stones. Current laboratory work is being directed primarily toward gravels.

The results of all the field and laboratory studies reported in the papers cited above are very briefly summarized below:

1. The standard acceptance tests for aggregates are not adequate to differentiate between the materials with good performance records and those with poor records.

2. Freezing and thawing of some coarse aggregates, when saturated, is the major factor in lack of durability of the concrete in which they are used. The pore or void characteristics of these materials determine their water absorption and retention characteristics.
and, therefore, their susceptibility to damage by freezing and thawing. The topographic position of the pavement and the nature of the subgrade soil would influence the durability through their effect on the amount of moisture available.

3. The fine aggregates and cements have had little effect on the durability of the concrete in field use.

4. The field performance records have been correlated with: (a) laboratory freezing and thawing tests of concrete in which the aggregates are used, (b) the absorption and degree of saturation of the aggregates under vacuum, and (c) the percentage of voids less than 0.005 mm. in diameter in the aggregates.

5. The durability of concrete made with inferior aggregates apparently may be improved by: (a) the use of air entrainment, (b) drying the aggregate before use, (c) use of construction practices that will aid in keeping the concrete dry and (d) restraint of expansion of the concrete slabs.

For years some of the concrete pavements in Indiana have provided outstanding illustrations of the effect of coarse aggregates on performance. An extensive resurfacing program is resulting in the covering of many of the pavements constructed with inferior materials. During the summer of 1950, a color motion picture was made to record the appearance of pavements with widely varying performance characteristics. This paper presents the results of recent field performance surveys of the projects which were included in the movie.

**PERFORMANCE SURVEY DATA**

The performance surveys were conducted by driving over the projects at slow speeds with frequent stops for closer inspection of the pavement. The crack intervals were determined with a foot-odometer mounted in the car, with several counts made in random sections 1000 feet or more in length. Counts of the percentage of transverse cracks affected by D-lines were made in a similar manner. The prevalence of blowups was determined by counting all those that occurred in the entire project.

Severity of the D-line deterioration was rated as follows:

- **Slight**—Areas affected by D-lines only a few inches in diameter at the intersections of cracks or joints.
- **Moderate**—Areas affected range up to one foot in diameter, edges of pavement affected at transverse cracks.
Severe—Larger areas affected, D-lines spreading back into the slabs along the joints or major cracks.

The data obtained in the performance surveys are shown in Table 1. The road sections listed were selected to show performance of pavements constructed with aggregates having outstandingly good or bad records. Where the performance of aggregates used in different projects is contrasted, the projects have similar subgrade soils and comparable traffic. Unless otherwise noted, the pavements have a 9-7-9-inch cross-section, marginal bar reinforcement, and no transverse joints.

### Table 1

**Performance of Pavements Built With Coarse Aggregates With Very Good or Bad Performance Records**

<table>
<thead>
<tr>
<th>Road and Section</th>
<th>Date Built</th>
<th>Project Number</th>
<th>Coarse Aggregate Code No.</th>
<th>Crack Interval Ft.</th>
<th>Blowups Per Mile</th>
<th>D-Line Cracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>40-D</td>
<td>1922</td>
<td>FA6D&lt;sup&gt;(a)&lt;/sup&gt;</td>
<td>67-1S</td>
<td>26.2</td>
<td>---</td>
<td>Slight 5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>84-2G</td>
<td>12.6</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>43-M, N</td>
<td>1930</td>
<td>S169A</td>
<td>79-1G</td>
<td>18.3</td>
<td>2.1</td>
<td>Moderate 50</td>
</tr>
<tr>
<td>54-B</td>
<td>1930</td>
<td>S184B</td>
<td>9-1S</td>
<td>12.5</td>
<td>7.2</td>
<td>Slight 5</td>
</tr>
<tr>
<td>54-C, D</td>
<td>1930</td>
<td>S175A</td>
<td>60-1S</td>
<td>19.7</td>
<td>0.1</td>
<td>Severe 80</td>
</tr>
<tr>
<td>3-E, F</td>
<td>1937</td>
<td>S328A&lt;sup&gt;(b)&lt;/sup&gt;, B&lt;sup&gt;(b)&lt;/sup&gt;</td>
<td>3-1S</td>
<td>1 crack/0 slab</td>
<td>0</td>
<td>Moderate 40</td>
</tr>
<tr>
<td>7-A, B</td>
<td>1930</td>
<td>S164A, B</td>
<td>40-5S</td>
<td>81.0</td>
<td>0</td>
<td>Severe 90</td>
</tr>
<tr>
<td>62-H</td>
<td>1930</td>
<td>S198</td>
<td>3-2G</td>
<td>16.0</td>
<td>0.4</td>
<td>None</td>
</tr>
<tr>
<td>37-M, L</td>
<td>1924</td>
<td>FA63B&lt;sup&gt;(c)&lt;/sup&gt;</td>
<td>55-2G</td>
<td>13.2</td>
<td>0.2</td>
<td>Moderate 50</td>
</tr>
<tr>
<td>37-Y</td>
<td>Unknown</td>
<td></td>
<td>35-2S&lt;sup&gt;(d)&lt;/sup&gt;</td>
<td>15.2</td>
<td>20.7</td>
<td>None</td>
</tr>
<tr>
<td>3-B, C</td>
<td>1935</td>
<td>S260A</td>
<td>40-1S</td>
<td>103.5</td>
<td>0</td>
<td>Severe 80</td>
</tr>
<tr>
<td>25-F, G</td>
<td>1929</td>
<td>FA152B</td>
<td>10-8G</td>
<td>18.2</td>
<td>0.4</td>
<td>None</td>
</tr>
<tr>
<td>53-A, B</td>
<td>1930</td>
<td>FA137A, B</td>
<td>9-1S</td>
<td>11.8</td>
<td>8.2</td>
<td>Slight 10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Moderate&lt;sup&gt;(e)&lt;/sup&gt; 50</td>
</tr>
</tbody>
</table>

<sup>(a)</sup> 7-8-7-in. cross-section. Patching of both blowups and structural failures with concrete made a blowup count impossible.

<sup>(b)</sup> Wire mesh reinforcement, 40-ft. joint interval.

<sup>(c)</sup> 7-in. uniform cross-section.

<sup>(d)</sup> County road jobs, now in state system.

<sup>(e)</sup> Deterioration very severe in shallow cuts.
Figure 1. Effect of Aggregates on Pavement Performance. The two photographs were taken in opposite directions from the construction joint at which the coarse aggregate source was changed from 9-1S to 79-1G. All materials other than the coarse aggregate are the same for both sections of pavement.
DISCUSSION OF RESULTS

The first two road sections listed in the table of performance data each have two different coarse aggregates used in a single project. The factors of cement, fine aggregate, subgrade soil and traffic are identical for the different coarse aggregate sections of each.

The project on U. S. 40, Section D, is one of the oldest pavements in Indiana in which the effect of coarse aggregate is shown. With all other conditions identical, coarse aggregates 67-1S and 84-2G were used in contiguous sections. The section in which 67-1S, a good-performing aggregate, was used has a crack interval of more than 26 feet and very slight D-line cracking which effects less than five per cent of the transverse cracks. Aggregate 84-2G, a poor performing material, was used in an immediately adjacent section which has a crack interval of less than 13 feet and 50 per cent of the cracks are affected by moderate D-line deterioration.

The project on S. R. 43, Sections M and N, in which aggregates 79-1G and 9-1S were used, provides an even more striking contrast in the relative amounts of D-line cracking. The section with aggregate 79-1G has slight D-lining at about five per cent of the transverse cracks, while 80 per cent of the cracks in the 9-1S section are severely D-lined. Figure 1 shows the appearance of this pave-

Figure 2. Severe Deterioration on S. R. 3, Section E. The pavement, constructed with poor-performing coarse aggregate 3-1S, is only 13 years old.
ment on both sides of a construction joint at which the coarse aggregate source was changed. The fact that all materials, other than the coarse aggregates, are identical in both sections of pavement shown should be kept in mind.

The performance survey of the two projects on S. R. 54 illustrates a less pronounced, but frequently encountered, difference in pavement performance attributable to the coarse aggregate used. The number of blowups varies from 0.1 per mile with aggregate 60-1S to 3.9 with aggregate 28-1G, with corresponding differences in D-line cracking.

The pavement on S. R. 3, Sections E, F, provides an example of the very rapid deterioration sometimes found. Constructed with aggregate 3-1S, a crushed stone, 90 per cent of the transverse cracks and joints were severely affected by D-line cracking after 13 years (See Figure 2). No blowups were found, probably due to the use of expansion joints at an 80-foot spacing in the project. In contrast with this project is the pavement built with aggregate 40-5S on S. R. 7, Sections A, B. Although seven years older, the 40-5S pavement shows no deterioration of any kind (Figure 3).

The influence of coarse aggregate on the transverse crack interval is shown by the data on S. R. 7, Sections A, B and S. R. 3, Sec-

Figure 3. S. R. 7, Section B. This pavement, built with coarse aggregate 40-5S, shows no deterioration after 20 years.
tions B, C. In each of these projects, two different coarse aggregates were used, with the other materials remaining the same throughout the job. On S. R. 7 the change in coarse aggregate produced a change in crack interval from 81 to 16 feet for aggregates 40-5S and 3-2G, respectively. Crack intervals on S. R. 3 were over 100 feet for the 40-1S section as compared to 18.2 feet where aggregate 10-8G was used.

The projects on S. R. 62, Section H and S. R. 37, Sections M, L, illustrate the range of performance to be found with gravel coarse aggregates. The pavement built with aggregate 73-1G has one-half the cracks D-lined and more than five blowups per mile after 20 years; while that built with aggregate 55-2G shows no D-lines and only 0.2 blowups per mile after 26 years in service.

Figure 4 illustrates the D-line cracking on a pavement built with a cherty limestone coarse aggregate on S. R. 37, Section Y. This was a county road job of unknown age and its performance is as poor as that of any road in the state, with very severe D-line cracking and 20.7 blowups per mile. The pavements discussed above in which aggregates 40-5S and 40-1S were used on S. R. 7 and

Figure 4. Severe D-line Cracking. In addition to the very extensive D-line cracking on this project, in which a cherty limestone coarse aggregate was used, 20.7 blowups per mile were found.
S. R. 3, respectively, show the opposite extreme of performance for crushed stones, with no deterioration to be found.

The projects in which bad performing coarse aggregate 9-1S was used on S. R. 25, Sections F, G and S. R. 53, Sections A, B, were included in the movie to illustrate the effect of subgrade moisture on performance. In the case of S. R. 25, there is much more severe deterioration in the cut sections than in fill, although D-line cracking is to be found throughout the project. In Figure 5 the appearance of the edge of the pavement on S. R. 53 is shown. The deterioration is the most severe at transverse cracks and along the bottom of the pavement where the most water would be present.

SUMMARY

The projects described in this report were selected to illustrate the extremes of pavement performance as affected by the coarse aggregate. D-line cracking ranges from none to severe at 90 per cent of the transverse cracks, blowups from none to more than 20 per mile, and the transverse crack interval from 11.8 to more than 100 feet where various coarse aggregates have been used.
When the comparisons are restricted to single projects in which all factors except coarse aggregate are identical, the performance ranges are from slight D-line cracking at five per cent of the transverse cracks to severe D-lining at 80 per cent, from 2.1 to 7.2 blowups per mile and from a transverse crack interval of 18.2 feet to 103.5 feet. In these cases, the coarse aggregate is the only possible cause of the variations in performance since a difference in source of the aggregate is the only variation between the sections compared.

The performance data presented supplements that previously reported and substantiates the conclusion that the coarse aggregate is a major factor in the performance of concrete pavements. Wide variations in the prevalence of D-line cracking and blowups and in the transverse crack interval are shown to be caused by the use of different coarse aggregates.

**BIBLIOGRAPHY**


3. Fears, F. K., "Determination of Pore Size of Four Indiana Limestones," *Thesis*, submitted to Purdue University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, February, 1950.


8. Slate, F. O., “Physico-Chemical Disintegration of Concrete,” Proceedings, 35th Annual Road School, Extension Series No. 69, Purdue University, p. 93, 1949.


