MAPCRACKING IN CONCRETE PAVEMENTS AS INFLUENCED BY SOIL TEXTURES

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SYNOPSIS

Performance surveys of 3,300 miles of rigid pavements in Indiana revealed an outstanding correlation between the coarse aggregate used in the concrete and the mapcracking and blowup performance of the pavement. These data were reported at the Twenty-Fifth Annual Meeting of the Highway Research Board (*20*). It was also noted in the performance surveys, which were of a reconnaissance nature, that some degree of relationship existed between the severity of deterioration of pavements constructed with inferior aggregates, the texture of the subgrade soil, and the freedom of the subgrade to drain. Accordingly, more detailed surveys were made of many of the pavements showing distress with particular emphasis on these features. The studies were made to obtain pertinent leads to the reason for the aggregate performance to be used as guides in developing a large-scale laboratory research program, and to develop design and construction methods which could be used as stop-gap procedures in those instances where questionable aggregates must be used because of economies, or because of inadequate test methods for identification of inferior aggregates.

It was found that those pavements with uniformly poor performance were located on either silty-clay soils or on semi-granular soils with a high water table. Those projects which showed a range of performance from extremely bad to reasonably good were located on a wide range of soil types. Detailed examination of four of these projects, comprising 41 miles of pavements constructed between 1928 and 1941 with four different coarse aggregates, indicated that:

(1) A striking correlation existed between pavement mapcracking and soil texture and drainage position; (2) The mapcracking associated in Indiana with the use of inferior coarse aggregates in concrete can be minimized by the use of methods to facilitate drainage, and that; (3) In a laboratory study of physical and chemical characteristics of inferior coarse aggregate, the moisture variable is a primary factor.

During the past several years, increased attention has been given to field studies of the performance of portland cement concrete pavements. Methods for making performance surveys have been developed and have been used extensively in Indiana, in which approximately 3,300 miles of concrete pavements were studied in the field. The results of a number of important findings have been published (*18*, *19*, and *20*).[1]

In the report on blowups in rigid pavements (*20*) it was shown that the source of coarse aggregate was the major contributing variable in the performance of the pavements. For example, 1,188 blowups occurred in 284 miles of concrete pavements made from only five sources of coarse aggregates. In contrast, 1,715 miles of pavement constructed from 82 other sources of coarse aggregate contained only 203 blowups. The correlation between the coarse aggregate component and pavement durability was also observed in Kentucky (*3*) and in Missouri (*1*). The Indiana data show that blowups can be used as an index of performance since mapcracking and short life were generally associated with this type of failure. It was also indicated in this report that excessive blowups occurred in certain pavements regardless of the variables of traffic, time of year of construction, other materials used, and subgrade soils. However, it was emphasized that the condition of mapcracking was much worse in poorly-drained situations or on impermeable soils such as clays than on well-drained granular-textured soils.

It is the purpose of this paper to record the data obtained on certain specific projects in which a wide range of soil textures were present as subgrades, and to show the correlation which exists in the field between mapcracking

[1] Italicized numbers in parentheses refer to list of references at the end of the paper.

and the subgrade drainage as indicated by soil textures. As an incidental development, techniques for evaluating performance of this type are described, including the use of low-altitude aerial strip photographs (*6*) and soil maps developed from high-altitude aerial photographs (*4*).

In contrast to other current subgrade studies (*5* and *23*) the failures described in this paper do not indicate lack of subgrade support as a primary causal factor. A typical failure is shown in Figure 1. The appearance of the mapcracking corresponds closely to the description of "deterioration due to accelerated weathering" given by Jackson (*7*). He describes the "D lines" as cracks "ordinarily close to and parallel to the edge and (are) usually filled with a dark-colored deposit, probably calcium carbonate.... In the case of pavements, cracks of this type almost invariably form first along transverse joints and cracks where water can enter, later along longitudinal joints and free edges."

The importance of the position of the highway in relation to the drainage situation, as well as to the drainage characteristics of soil textures of the underlying subgrade materials was indicated by Walker (*14*). He states that "any chert gravel concrete road showing a high proportion of disintegration also shows numerous sections in entirely satisfactory conditions. Generally, disintegrated sections are on terrain where opportunities for natural drainage are not good—in cuts, on side hills where ground water from above collects on and under the slab, on low flat sections with inadequate side drainage, on soil that retains water. On the other hand, the good sections of a doubtful gravel are generally on terrain where drainage is reasonably good."

In the same review, Walker shows the effect of degree of saturation on concrete resistance to freezing and thawing. One of the early references to this importance of porosity is Blatchely (*2*), who states, in part, that "a rock with 3 percent of fine pore space is more dangerous than that having 10 or even 15 percent of the coarser space, as it is readily seen that the water is ejected more quickly from the latter. It has been found that pores not more than nine-tenths full of water are not injurious to the stone." In regard to this latter point Kreuger (*8*) indicates that materials not greatly weakened by becoming saturated and which ordinarily do not absorb a volume of water greater than 85 percent of the total pore space usually have a high resistance to frost action. Additional study of the degree of saturation, with reference to brick and building stone has been reported by other investigators, including McBurney (*9*), Thomas (*13*) and Richmond (*10*). Application of these principles to concrete and concrete aggregate was pointed out by Wray and Lichtefeld (*21*) who showed that stream-wet gravel is the least resistant to freezing and thawing, and that these aggregates, after oven-drying became only 70 percent saturated by 24-hr immersion in water. They further showed that aggregate with this degree of saturation (24-hr soaking) was highly resistant

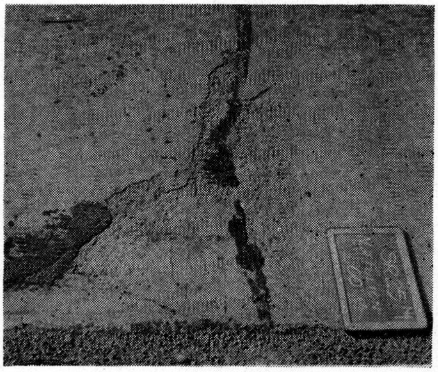

Figure 1. Typical Mapcracking at a Crack

to freezing and thawing. The importance of the degree of saturation in cherts in relationship to their performance under freezing and thawing tests was reported by Sweet (*11*). Wuerpel (*22*) showed the correlation between resistance to freezing and thawing and absorption. However, Walker (*15*) pointed out that "at least one chert gravel of very high absorption . . . has a good service record."

FIELD SURVEYS

The Indiana performance surveys (*20*) showed several hundred miles of pavements which are in varying degrees of distress as a result of the use of inferior aggregates. On some of these roads the performance is more or less uniformly poor, while on others performance is spotty, ranging from extremely bad to reasonably good. Detailed analysis of

several dozen of these projects has revealed that the uniformly bad pavements are located either on silty-clay soils or on semi-granular soils with a high water table. In contrast, those projects which show a large range in performance conditions were found to occur on a wide range of subgrade soil types. Three such projects are reported in this paper. The purpose of this limited field study was two-fold: to obtain pertinent leads concerning the reason for the aggregate performance which could be used in developing a large-scale laboratory research program and in evaluating the type of tests to be used; and to develop design and construction methods which could be used as stop-gap procedures in those instances where questionable aggregates must be used because of economics, or because of the inadequacy of available test methods used for evaluating aggregates.

TABLE 1
CONSTRUCTION AND DESIGN DATA ON ROAD SECTIONS SURVEYED

Road No.	S.R. 25	U.S. 31	U.S. 31	S.R. 37
Project	152B	722A1	87AB	258
Length (miles)	6.0	7.9	14.6	12.7
Date of Construction	1928–29	1941–42	1937–38	1932–33
Width (ft)	18	22	22	18
Thickness (in.)	9–7–9	9–7–9	9–7–9	9–7–9
Expansion Joints	None	D@120′	D@120′	None
Contraction Joints	None	D@40′	D@40′	None
Cement Content (bbl. per cu yd.)	1.70	1.50	1.50	1.70
Cement Source[a]	11	3	11	8
Fine Aggregate[a]	52-2	3-3	3-7	62-1
Coarse Aggregate[a]	9-1S	3-1S	3-1S & 40-3S	62-1G
Soil Types	Sand; Wisconsin drift.	Wind-blown sand; Wisconsin drift, Granular terrace	Wind-blown sand; Wisconsin drift; Granular terrace Illinoian drift; Terrace depression	Residual soil on sandstone and shale.
Average Crack Interval				16.8
No. of Blowups per Mile	3.5	0	0	5.2

[a] Code number used in the Joint Highway Research Project to designate material producers

Four road contracts on three different roads covering a total of 41 miles of pavement were chosen. Table 1 shows the pertinent data in regard to the construction of these four sections of pavement. Three limestone coarse aggregates and one gravel were incorporated in these sections. Contraction and expansion joints were employed in only two of the four projects. Likewise, two of the four contracts are older than 13 years, while the other two contracts are of more recent construction. Of the three roads, one is located in north-central Indiana, one in southeastern Indiana, and the third is in the extreme southern portion of the state. The roads were chosen so as to represent wide extremes of traffic and soil conditions and some variation of climate.

Soils. State Road No. 25, the road located in north-central Indiana, is situated in a soil area commonly described as shallow sand on till. It is constructed near the border of a glacial lake sand region, the sands having been deposited on top of glacial drift of Wisconsin age. Such a situation is ideal for a study of this nature in that well-drained sands are available in some sections while in others the pavement is placed directly on relatively impervious, silty-clay soil. Typical soil profiles for these materials are shown in Figure 3, profile A being typical of Wisconsin drift and profile B representing Wisconsin drift covered with sand.

U. S. No. 31 extending from just north of Columbus, Indiana to the intersection with U. S. No. 50 is so situated that an extremely wide range in soil types and soil textures is available for performance study. These are shown in the soil map, Figure 2, which was developed from high-altitude aerial photographs. One large section of the road is located on a semi-granular terrace with an overlying developed soil profile (Fig 3E). Glacial drifts of Wisconsin and Illinoian age are also present (Fig 3A and 3C). Further variations in soils occur because of the presence of deep wind-blown sands which have been deposited as an intermittent border on the east side of the east fork of White River (Fig 3B and 3D). Fortunately for this study, the grade and alignment are such that the pavement is located in the different horizons of all of these various soil materials.

In the case of S.R. No. 37, which is located in the extreme southern part of Indiana, the soils are of residual development, derived primarily from sandstones and shales; however, the embankments are composed frequently of soil-rock mixtures (Fig 3G). This general area of the state is well dissected, necessitating the use of deep cuts and high fills. More

detailed descriptions of the soil types shown in Figure 3 are given in Reference *24, p. 154.*

Procedures. Many different methods of obtaining performance survey data were employed. The most efficient method developed consisted of the following steps: (1) general soil texture information was obtained from soil strip maps developed from contact aerial photographs flown at a high altitude; (2) general performance information from low altitude aerial strip photographs of the highway was later used; and (3) the general information obtained in the laboratory was checked in the field at the time detailed performance surveys were made.

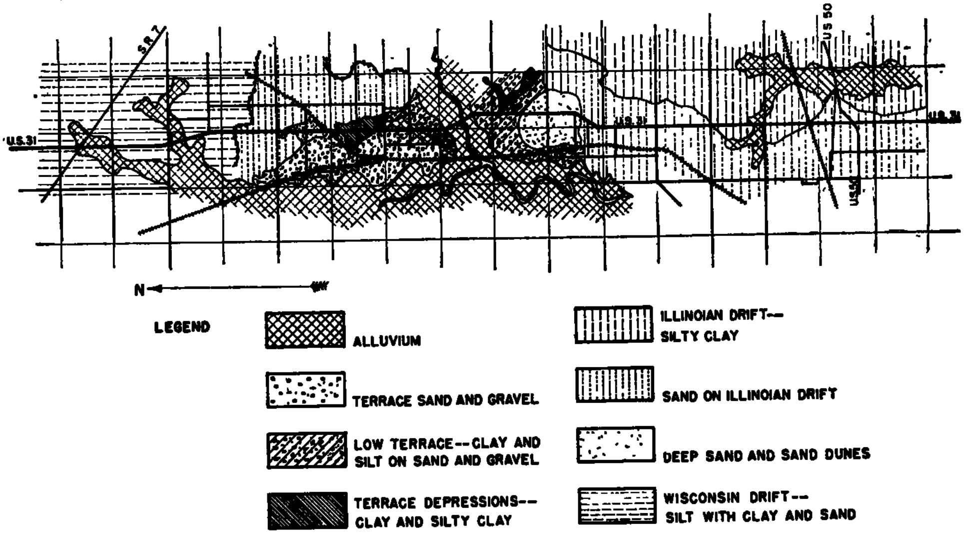

Figure 2. Strip Map of Engineering Soils for Field Survey of Highway Performance U.S. 31 Between S.R. 7 & U.S. 50

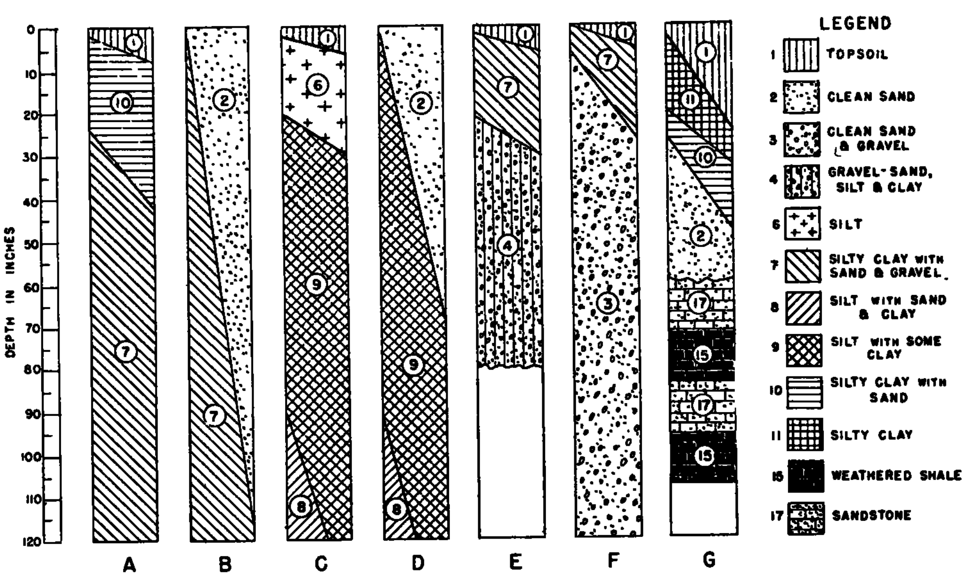

Figure 3. Typical Soil Profiles Encountered on S.R. 25, U.S. 31, S.R. 37

Field inspections were concentrated on two

primary ideas: that of evaluating the mapcracking of the various sections of the pavements in relationship to the soil areas previously bounded and of checking the soil information obtained from the aerial photographs. However, because of the construction procedures employed for the selection and placement of soils, in some instances silty clays were found as subgrade materials in sand areas. In the case of shallow sands on

Figure 4. Mapcracking Typical of Performance in Cuts on S.R. 37

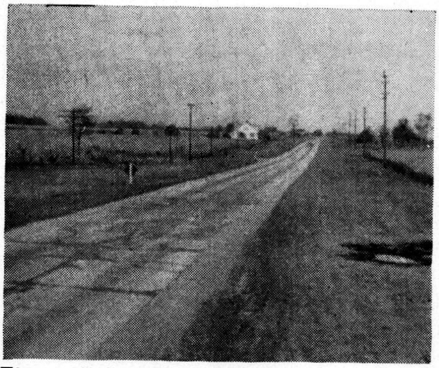

Figure 5. Severe deterioration in cut on S. R. 25. See also Figure 7 which is a low-altitude strip photograph which shows this same general condition

till, the grade was frequently such as to cut through the sands; in these instances the pavements were located on the impervious underlying till.

In evaluating the amount of mapcracking present in a given section, it was observed early in the performance survey work that mapcracking was associated with joints and cracks. Thus it was feasible to obtain a relative rating of different sections by counting the number of joints and cracks in a section which were affected. The severity of mapcracking varied in the different soil areas and was noted. Figures 4, 5 and 6 show the range in mapcracking conditions on these three road projects. This procedure was followed on each of the three projects described.

RESULTS

The data obtained on the number of mapcracked joints and cracks are shown in Tables 2, 4, 5, and 7. These tables show the maximum depth of cut or fill, the length of the cut, fill, or grade, the prevailing soil texture in each, and the number of joints or cracks with mapcracking in the pavement section. To reduce the data on mapcracking to a com-

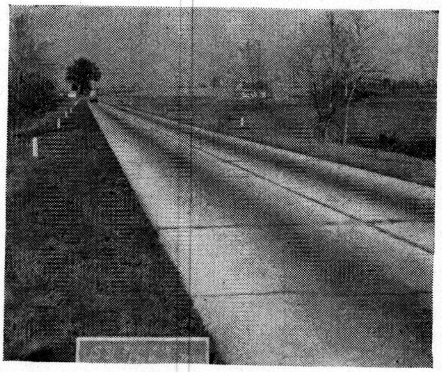

Figure 6. Wisconsin Drift Fill on U.S. 31 Showing Slight Deterioration

parable basis, the number of mapcracked joints (or cracks) per 1,000 ft of pavement was calculated for each section. For convenience in the following discussion, this will be referred to as the performance index.

The data are summarized in Tables 3, 6, and 8. For each road, the average number of mapcracked joints or cracks per 1,000 ft (performance index) is presented with the variables of soil texture and grade, cut, or fill isolated. As will be noted, striking differences in performance are shown between cut and fill sections and between sections of different soil texture.

The differences between the aggregates used and the ages of the roads are reflected in the grand average performances index for

each road. The index for the oldest, S. R. No. 25, averaged 38.9 and ranged from 18.3 to 102.0. The youngest of the three roads, U. S. No. 31, averaged 16.0 with a range of proximately 27 percent of the cracks are mapcracked. In the cuts in clay soils, on the other hand, approximately 81 percent of the cracks show distress.

TABLE 2
PERFORMANCE OF S.R. 25, PROJECT 152B
Coarse Aggregate· 9-1S Constructed in 1928, 29.

Location	Max. Depth of cut or fill (ft)	Length (ft)	Cracks Mapcracked		Subgrade Soil
			No.	No. per 1,000 ft	
Sta 0–32	0	3,200	118	36.8	Sandy Wisconsin drift
	4C	500	18	36 0	" " "
	3F	400	14	35 0	" " "
	0	800	23	28 7	" " "
	3C	400	17	42.5	" " "
	2F	300	9	30 0	" " "
	2C	300	16	53 3	" " "
	0	1,700	57	33 5	" " "
	3C	600	20	33 3	" " "
	0	3,100	85	27.4	" " "
	2F	1,000	27	27 0	" " "
Sta 123–149	0	2,600	56	21 5	Sand
	4C	500	18	36 0	Wisconsin drift
Sta 154–164	0	1,000	28	28.0	" "
Sta 164–170	3C	600	42	70.0	" "
Sta 170–174	2C	400	8	20 0	Sand
City of Fulton					
Sta 207–216	0	900	39	43.3	Sandy Wisconsin drift[a]
Sta 216–229	8C	1,300	75	57.7	" " "
Sta 229–235	2F	600	17	28.3	" " "
Sta 235–240	8C	500	51	102.0	" " "
Sta 240–246	2F	600	11	18.3	Sand
Sta 246–249	4C	300	13	43.3	Sandy Wisconsin drift[a]
Sta 249–263	0	1,400	70	50 0	" " "
	4F	200	10	50.0	" " "
Sta 265–274	5C	900	82	91 1	" " "
	0	500	18	36 0	" " "
	2C	400	13	32 5	" " "
	0	700	23	32 8	" " "
Sta 290–295	3C	500	29	58.0	" " "
	5F	500	16	32.0	" " "
	2C	600	30	50.0	" " "
	2F	300	14	46 6	" " "
	2C	600	45	75 0	" " "
Sta 315–325	2F	1,000	35	35.0	" " "
Sta 325–337	5C	1,200	47	39 2	" " "
Sta 337–344	2F	700	19	27.1	" " "
Sta 344–348	1C	400	11	27 5	" " "
		31,500			

[a] Muck settlements have occurred under portions of these sections, the performance index represents that portion of the sections not so affected.

5.0 and 36.0. State Road No. 37, constructed in 1932–33 had an average index of 21.6 ranging from less than 2.5 to 80.0.

Discussion of S. R. No. 25 Performance. The contrast between the performance of the pavement on granular soils in fill sections and impermeable soils in poorly-drained locations is marked for all three roads. The performance index for a sand fill on S. R. 25 was 18.3. In contrast, the performance index for clay soils in cut sections ranged from 27.5 to 102.0, averaging 54.9. Since the average crack interval on this road was approximately 14.8 ft, the index for the sand fill indicates that ap-

TABLE 3
SUMMARY OF S.R 25 PERFORMANCE

Subgrade Soil Texture	No. of Joints or Cracks Mapcracked per 1,000 ft			Total Length
	Grade	Cut	Fill	
				ft
Sand				
Average	21.5	20.0	18.3	3,6C0
Range	21.5–21.5	20.0–20.0	18.3–18 3	
Wisconsin Drift				
Average	34.7	54.9	32.2	27,900
Range	27.4–50.0	27.5–102.0	27.0–50.0	
Average for all soils	32.5	53.5	30.7	

Grand Average: 38.9 mapcracked cracks per 1,000 ft.
Total length 31,500 ft.

TABLE 4

PERFORMANCE OF U.S. 31, PROJECT 722A1

Coarse Aggregate: 3-1S. Constructed in 1941, 42

Location	Max. Depth of cut or fill	Length	Joints or Cracks Mapcracked		Subgrade Soil
			No.	No. per 1,000 ft	
	ft	ft			
Jct 31 & 31A	3F	5,700	92	16.1	Granular Terrace
	10F	4,400	38	8.6	" "
	10F	2,400	16	6.7	" "
	0	2,600	40	15.4	" "
	2F	9,400	128	13.6	" "
	10C	1,600	12	7.5	" " (cut into clean gravel)
	10F	3,000	45	15.0	" "
Sta 283–291	10F	800	10	12.5	" "
Sta 291–296	10C	500	12	24.0	Wisconsin drift
	10C	700	4	5.7	Wind-blown sand
Sta 303–312	5F	900	8	8.8	" " "
	2C	900	13	14.4	Wisconsin drift
Sta 321–327	10F	600	8	13.3	" "
	10C	600	3	5.0	Wind-blown sand
Sta 333–347	4F	1,400	10	7.1	" " "
	4F	2,300	24	10.4	Wisconsin drift (with sand patches)
	4C	600	11	18.3	" "
	2F	2,100	54	25.7	" "
	10C	500	14	28.0	" "
	2F	2,000	55	27.5	" "
	5C	1,500	42	28.0	" "
Jct 31 & 7	10F	2,700	55	20.4	" "

TABLE 5

PERFORMANCE OF U S. 31, PROJECT 87A AND B

Coarse Aggregate. 3-1S and 40-3S. Constructed in 1938

Location	Max. Depth or cut or fill	Length	Joints or Cracks Mapcracked		Subgrade Soil
			No.	No. per 1,000 ft	
	ft	ft			
Jct 31+7	10F	2,600	57	21.9	Wisconsin drift
	5F	1,000	22	22.0	" "
	4C	600	21	35.0	" "
	4F	500	9	18.0	" "
	0	800	22	27.5	" "
	5C	3,100	82	26.5	" "
	10F	1,100	20	18.2	" "
	10F	1,700	28	16.5	" "
Sta 578–580	6C	200	4	20.0	" "
	0	2,400	14	5.8	Wind-blown sand
	5C	1,400	18	12.9	" " "
	2F	3,700	27	7.3	" " "
	0	1,800	17	9.4	" " "
	10C	3,000	24	8.0	" " "
Sta 703–707	3F	400	5	8.0	" " "
	3F	800	15	18.8	Terrace depressions (clay)
	0	1,900	42	22.1	" "
	3F	2,100	40	19.1	" "
Sta 755–761	0	600	4	6.7	Granular Terrace
	0	2,600	16	6.2	" "
	10F	500	4	8.0	" "
Sta 792–840	10F	4,800	65	13.5	" "
Sta 843–869	10F	2,600	59	22.7	Alluvium Fill (clay)
	10F	1,700	39	22.9	" "
	10F	1,200	28	23.3	" "
Sta 898–942	5C	4,400	58	13.2	Wind-blown sand
	0	2,800	35	12.5	" " "
Sta 970–1014	0	4,400	116	26.4	Illinoian drift
	5C	300	8	26.7	" "
Sta 1017–1031	5C	1,400	5	3.6	Wind-blown sand
	5F	800	10	12.5	" " "
	5C	1,500	15	10.0	" " "
	5F	500	7	14.0	" " "
Sta 1059–1064	10C	500	18	36.0	Illinoian drift
	0	900	11	12.2	Wind-blown sand
	5C	500	7	14.0	" " "
Sta 1078–1084	5F	600	15	25.0	Illinoian drift
	5C	400	7	17.5	" "
	5F	800	19	23.8	" "
	10C	3,000	67	22.3	" "
	8F	900	24	26.7	" "
	10C	800	16	20.0	" "
Sta 1143–1178	0	3,500	30	8.6	Silt horizon Illinoian drift
Sta 1178–1189	10C	1,100	30	27.3	Illinoian drift
Jct 50+31	0	3,500	73	20.8	Illinoian drift

It may be noted from Table 3 that, regardless of soil texture, the performance was much better in fills than in cuts. The consequent drainage situation is probably the major contributing factor to this observed performance; however, construction practices and natural soil profile development, combined with the peculiar soil conditions in this region, undoubtedly have had some influence. A thin sheet of sand has been deposited on top of the silty-clay Wisconsin drift. In constructing the road with balanced earthwork the rises in topography have been cut into and utilized for embankment material. The topography in this region is gently undulating and both cuts and fills are shallow. The result has been that the surface sheet of sand has been removed in cut sections and has been incorporated in the fills. Indeed, most cuts go through or nearly through the sand; the fills have varying combinations of sand and drift material and have been separated in the tabulation so that only fills of relatively clean sand are so classified. Thus, it is probable that the better performance in fills classified as Wisconsin Drift was due to the more granular texture of the material as well as to the better drainage position. A portion of a low-altitude strip photograph of this road is shown in Figure 7. The contrast in performance on cuts and fills is marked.

Discussion of U. S. No. 31 Performance. As previously noted, this road is located in a region of widely varying soil types. The performance on each type is summarized in Table 6. The performance index for pavement on wind-blown sands in fill sections is 8.7 mapcracked joints and cracks per 1,000 ft. The average for cuts in soils of clay mixture (alluvium, Wisconsin and Illinoian drift, and terrace depressions) was 24.6. Based on the joint spacing of 40 ft, these figures indicate that 35 percent of the joints in fills of sand are affected while approximately 100 percent of those in cuts through clay are mapcracked. Since some intermediate cracks have occurred and show mapcracking, the percentage figures noted above are only approximations.

Of particular interest is the good performance indicated in the section of pavement on top of the silt horizon of the Illinoian drift. A 3,500-ft section of pavement placed on the top of this horizon in a location above the surrounding country showed an index of 8.6, approximately the same as that for wind-blown sand.

The influence of the weathered profile (Fig 3) on the pavement performance on fills constructed with granular terrace material is

TABLE 6
SUMMARY OF U.S. 31 PERFORMANCE

Subgrade Soil	No. of Joints or Cracks Mapcracked per 1,000 ft			Total Length
	Grade	Cut	Fill	
				ft
Wind-blown sand				
Average	9.7	9.9	8.7	29,100
Range	5.8–12.5	5.0–14.0	7.1–14.0	
Granular Terrace				
Average	10.3	7.5	13.4	37,400
Range	6.2–15.4	7.5–7.5	8.0–16.1	
Silt Horizon-Illinoian drift				
Average	8.6			3,500
Range	8.6–8.6			
Alluvium				
Average			22.9	5,500
Range			22.7–23.3	
Wisconsin Drift				
Average	27.5	25.2	19.8	25,500
Range	27.5–27.5	14.4–35.0	10.0–27.5	
Illinoian Drift				
Average	23.9	23.9	25.2	15,300
Range	20.8–26.4	17.5–36.0	23.8–26.7	
Terrace Depression				
Average	22.1		19.0	4,800
Range	22.1		18.8–19.1	
Summary				
Clean Sand: (Wind-blown sand)				
Average	9.7	9.9	8.7	29,100
Range	5.8–12.5	5.0–14.0	7.1–14.0	
Semi-granular (Granular terrace and Ill. drift silt horizon)				
Average	9.7	7.5	13.4	40,900
Range	6.2–15.4	7.5–7.5	8.0–16.1	
Clay: (alluvium Wisc. and Ill. drift, Terrace depressions)				
Average	23.9	24.6	20.9	52,100
Range	20.8–27.5	14.4–36.0	10.0–27.5	
Average for all soils	15.1	16.9	16.0	

Grand Average: 16.0 mapcracked joints or cracks per 1,000 ft

indicated by the index of 13.4 shown. A cut through the weathered profile into clean gravel showed much better performance with an index of 7.5.

In none of the soil regions on this road was there much difference in the performance index of cuts and fills. However, the severity

TABLE 7
PERFORMANCE OF S R 37, PROJECT 258
Coarse Aggregate· 62-1G Constructed in 1932, 33

Location	Max. Depth of cut or fill	Length	Cracks Mapcracked		Subgrade Soil
			No.	No. per 1,000 ft	
	ft	ft			
2 mi. SW of Leopold	5F	100	0	10.0	Sandy
	5C	200	0	5.0	"
	10F	200	0	5 0	"
Sta 5-8	8C	300	3	10 0	"
Sta 14-16	5F	200	0	5 0	"
Sta 16-20	15C	400	26	65 0	Shale
	15F	600	12	20.0	"
	20C	500	17	34.0	"
	10F	300	4	13.3	"
	12C	500	21	42.0	"
	20F	200	6	30 0	"
	5C	300	7	23 3	"
	10F	200	3	15 0	"
Sta 46 49	2C	300	14	46 7	Shale
	10F	500	10	20 0	"
	10C	400	12	30.0	"
	10F	200	4	20 0	"
	10C	600	24	40 0	"
	10F	100	1	10.0	Shale
	8C	300	24	80 0	"
Sta 70-73	0	300	3	10 0	Sandy
Sta 73-77	10C	400	23	57 5	Shale
Sta 77-79	30F	200	2	10 0	Sandy
Sta 79-83	20C	400	19	47.5	Shale
	30F	100	3	30.0	"
	5C	700	31	44.3	"
	40F	400	12	30 0	"
	10C	700	34	48.6	"
	20F	300	8	26.7	"
Sta 105-116	15C	1,100	49	44 5	"
Sta 116-119	40F	300	6	20 0	Shale
	10C	500	18	36 0	"
	30F	200	0	5 0	Sandy
	15C	500	8	16 0	"
	30F	400	3	7 5	"
	5C	600	20	33.3	"
Sta 141-143	0	200	1	5.0	"
	5C	200	5	25 0	"
	10F	300	0	3 3	"
Sta 148-151	10C	300	8	26.7	Shale
Sta 151-154	30F	300	1	3.3	Sandy
	10C	400	6	15.0	"
	20F	200	0	5.0	"
	5C	300	4	13.3	"
	0	400	3	7.5	"
	10C	900	26	28.9	"
	30F	200	0	5 0	"
	10C	400	7	17 5	"
	20F	400	0	2 5	"
	10C	400	11	27.5	"
	20F	1,200	11	9.2	"
	10C	600	18	30.0	"
	20F	400	4	10.0	"
	5C	300	18	60.0	"
	0	400	4	10.0	"
	5C	200	7	35 0	"
	C	300	2	6.7	"
	5C	500	18	36 0	"
	20F	200	0	5 0	"
	4C	200	4	20.0	"
	10F	200	0	5.0	"
Sta 235-239	5C	400	8	20 0	"
Sta 239-241	30F	200	2	10 0	"
	10C	400	6	15 0	"
	10F	300	1	3 3	"
	5C	300	3	10 0	"
	40F	600	9	15.0	"
	15C	400	7	17 5	"
	40F	500	5	10.0	"
	5C	500	8	16.0	"
	20F	300	0	3.3	"
	4C	400	5	12.5	"
	0	1,300	6	4.6	"
	5C	400	13	32.5	"
Sta 295-299	30F	400	1	2.5	Sandy
	5C	300	6	20.0	"
	20F	400	0	2.5	"
	5C	800	27	33.7	"
	0	400	1	2.5	"
Sta 318-324	5C	600	24	40.0	Shale
	10F	200	2	10.0	"
	5C	400	18	45.0	"
	20F	400	7	17.5	"
Sta 334-337	5C	300	4	13.3	Sandy
	10F	300	2	6.7	"
	10C	800	14	17.5	"
Sta 348-353	10F	500	8	16.0	Shale
Sta 359-363	10C	400	24	60.0	"
	20F	400	10	25 0	"
	15C	1,000	48	48 0	"
	0	500	14	28.0	"
	5C	600	28	46.7	"
Sta 388-389	10F	100	3	30.0	"
	10C	300	10	33.3	"
	10F	200	4	20.0	"
	12C	600	12	20.0	"
Sta 400-404	15F	400	4	10.0	"
	10C	200	13	65.0	"
	20F	400	3	7.5	"
	10C	200	12	60.0	"
	20F	300	3	10.0	"
	10C	300	16	53.3	"
	20F	300	5	16.7	"
	10C	500	25	50.0	"
	10C	200	5	25.0	"
	10F	400	6	15.0	"
Sta 432-435	15C	300	13	43.3	"
Sta 435-437	10F	200	3	15.0	"
	5C	300	16	53.3	"
	10F	400	3	7.5	"
	5C	200	11	55.0	"
	30F	300	14	46.7	"
	10C	500	32	64.0	"
	20F	200	3	15.0	"
	5C	300	4	13.3	"
	0	400	8	20.0	"
	5C	1,200	36	30.0	"
	30F	300	4	13.3	"
Sta 478-482	15C	400	13	32.5	Sandy
	40F	300	3	10.0	"
	10C	200	3	15.0	"
	20F	200	2	10.0	"
	20C	400	6	15.0	"
Sta 493-496	20F	300	0	3.3	"
	15C	300	4	13.3	"
	20F	200	1	5.0	"
	5C	400	10	25.0	"
	20F	400	4	10.0	"
	10C	500	11	22.0	"
	10F	600	5	8.3	"
	5C	700	16	22.8	"
	5C	300	2	6.7	"
	15F	200	0	5.0	"
Sta 532-539	10C	700	11	15.7	"
	15F	500	3	6.0	"
	10C	1,300	36	27.7	"
	10F	200	3	15.0	"
	10C	400	14	35.0	"
	10F	300	1	3.3	"
	10C	600	22	36.6	"
Sta 572-576	10F	400	3	7.5	"
Sta 584-587	10F	300	4	13.3	"
	20C	500	3	6.0	"
	0	1,700	10	5.9	"
	10C	1,100	13	11.8	"
	5F	800	1	1.3	"
	15C	600	7	11.7	"
	5F	900	4	4.4	"
City Lmit-Tell City	8C	400	2	5.0	"
Sta 647-651	8C	400	3	7.5	"

of deterioration, not covered by the performance index, was more pronounced in cuts (Fig 8), than in fills or at grade (Fig 9).

Limestone coarse aggregates from two sources were used in constructing the southern portion of the U. S. 31, Project 87A and B. During construction these two materials were rather thoroughly mixed so that the influence of each cannot be separated. The available data indicate that some strata from both sources are to be regarded with suspicion.

Discussion of S. R. No. 37 Performance. A much different situation is represented in S. R. 37 which is in an unglaciated rock region of alternating sandstones and shales. Topographically the region is deeply dissected. Deep cuts and high fills are the rule in contrast to those on the more level topography of the other two roads. The subgrade materials are classified as "sandy" and "shale" in Table 7 to indicate the texture as well as the parent material. Fills on sandy material showed an index of 5.6, compared to 43.4 for cuts in shales. The wide difference in performance in cut or fill for either material appears to indicate the importance, here, of drainage position as accentuated by the extremes of cut and fill noted.

TABLE 8
SUMMARY OF S.R. 37 PERFORMANCE

Subgrade Soil	No. of Cracks Mapcracked per 1,000 ft			Total Length
	Grade	Cut	Fill	
				ft
Sandy				
Average	6.0	21.0	5.6	38,900
Range	2.5–10.0	5.0–60.0	2.5–15.0	
Shale				
Average	24.4	43.4	19.3	24,200
Range	20.0–28.0	13.3–80.0	7.5–46.7	
Average for all soils	8.8	30.4	9.1	

Grand Average: 21.6 mapcracked cracks per 1,000 ft.
Total Length, 63,100.

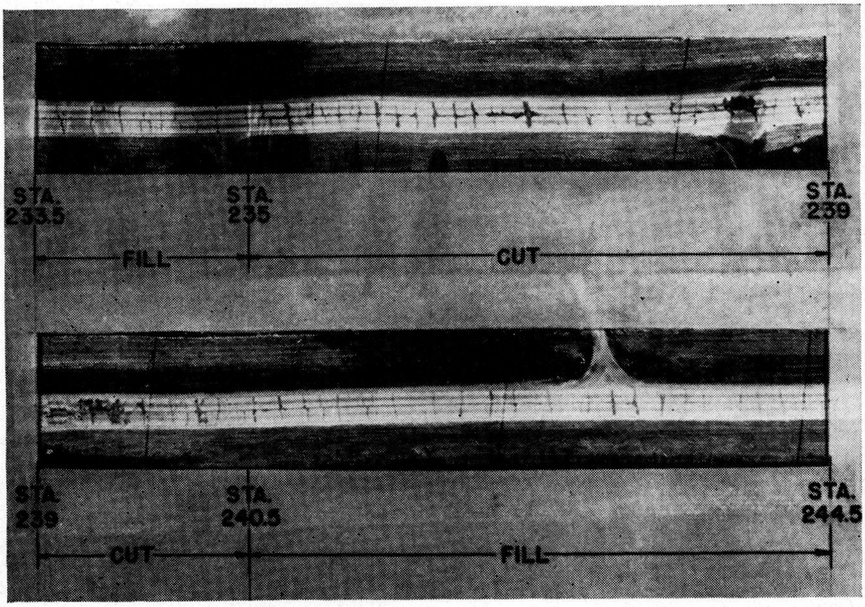

Figure 7. Strip Photograph of Section of S. R. 25

General Discussion. The data for all three roads indicate, with a high degree of consistency, the importance of adequate drainage of the subgrade in minimizing the mapcracking associated with the use of inferior aggregates as coarse aggregate for concrete. The relative excellence of performance on wind-blown sands, which because of their uniform size, are very permeable materials, emphasizes the desirability of using as subgrade, material with a minimum of fines (or maximum of permeability). The importance of the effect of moisture on the durability of the concrete pavements indicated

by the field data gives an important lead for further investigations in laboratory and field, of the causes of the performance noted. It may be speculated that the lack of durability of the aggregates in concrete might be caused by wetting and drying, freezing and thawing, chemical attack, or some other weathering action affected by the presence of water. It has been well established that degree of saturation is a dominant factor in the rate of

Figure 8. Performance in Slight Cut in Wisconsin Drift

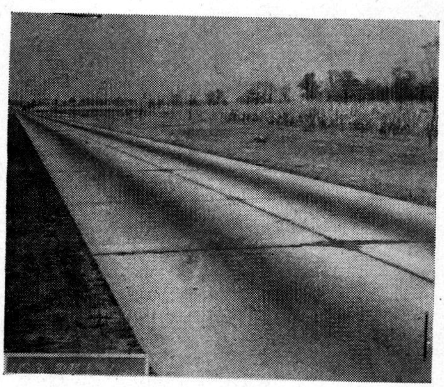

Figure 9. Typical Performance in grade or Fill in Wisconsin Drift, U.S. 31

deterioration in freezing and thawing. Laboratory freezing and thawing tests of concrete beams containing the same coarse aggregates as the road sections described in this report have further emphasized the importance of degree of saturation. Beams containing aggregate 9-1S, the material used in S. R. No. 25, decreased 50 percent in dynamic modulus in 13 cycles of freezing and thawing when the coarse aggregate was vacuum-saturated before being incorporated in concrete. (The aggregate was evacuated for one hour at a pressure of 2 cm of mercury and immersed in water while still under the vacuum.) When the degree of saturation of the aggregate was that obtained by 24-hr immersion (78 percent of the vacuum-saturated absorption) no appreciable change in dynamic modulus occurred up to 100 cycles of freezing and thawing. It is of interest to note that the beams containing material vacuum-saturated increased in length

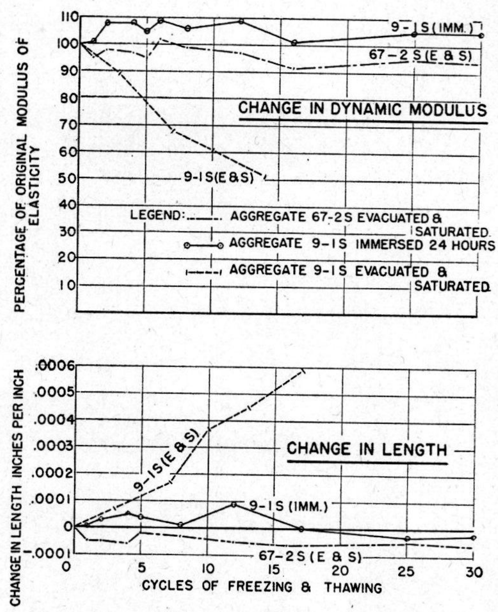

Figure 10. Effect of Coarse Aggregate and Degree of Saturation on Dynamic Modulus and Length of Concrete Beams

0.0005 in. per inch during the 13 cycles of freezing and thawing, while no change in length occurred on the beams with immersed aggregate. This length change would correspond to 0.6 in. expansion in a 100-ft pavement slab and furnishes a possible explanation of the correlation already described between mapcracking and the occurrence of blowups. These data are shown graphically in Figure 10 and are compared with the test results on a material with a good performance record, 67-2S. Similar results have been obtained in tests of the other coarse aggregates used in the pavements studied.

The available data indicate that for maximum resistance of concrete pavement to freezing and thawing a number of precautions may be taken to prevent the concrete or its constituent aggregate from becoming highly saturated. Some of these are enumerated as follows:

1. Allow adequate drainage by stockpiling before use materials which have a high degree of saturation in their natural state. In this category are river gravels as shown by Walker (*21*), Wray and Lichtefeld (*15*) and Sweet and Woods (*22*). Recent tests in the Purdue Joint Highway Research laboratories have shown that freshly quarried limestone from quarries being pumped constantly may also have a high degree of saturation.
2. It seems logical that more impervious concrete would be of benefit in preventing the reabsorption of moisture. Walker's studies (*23*) showed a trend in this direction in the comparison of the effect of rich and lean mixes on freezing and thawing resistance of dried aggregate.
3. Provide adequate subgrade drainage to prevent saturation of the concrete by capillary action or water vapor travel. The data contained in this report indicate that a pervious base course contributes greatly to increased durability.

These procedures are of importance under conditions where the use of questionable aggregates is contemplated because of lack of adequate test procedures for detection of unsatisfactory material or because economics indicate the desirability of the use of questionable aggregates in combination with precautionary procedures rather than the expense of importing sound material.

CONCLUSIONS

Detailed performance surveys of concrete pavements showing mapcracking and deterioration because of the use of inferior aggregates showed many sections of road with consistently bad performance and other sections with performance ranging from very bad to reasonably good. It was found that those sections with uniformly poor performance were located on either silty-clay soils or on semi-granular soils with a high water table. Examination of four construction projects showing variable performance indicated the following conclusions:

1. In widely separated areas of Indiana with extremes of soil types, different ages of pavement and different concrete constituent materials, a striking correlation existed between pavement mapcracking and soil texture and drainage position.
2. The mapcracking associated in Indiana with the use of inferior aggregate in concrete pavements can be minimized by the use of a high-level grade line to facilitate drainage in combination with freely-draining subgrade material, as typified by the wind-blown sands encountered in these surveys.
3. In developing a laboratory research program to study physical and chemical characteristics of inferior coarse aggregate, the variable of moisture should be given primary consideration.

Acknowledgements

The writers wish to thank Messrs. D. W. Lewis and R. E. Frost of Purdue University, and Mr. P. D Miesenhelder, Engineer of Tests, State Highway Commission of Indiana for their assistance in compiling this report. Mr. Lewis aided in the performance surveys, Mr. Frost developed the map of soils encountered on U. S. 31, and Mr. Miesenhelder furnished valuable information on construction details of the projects surveyed.

REFERENCES

1. Axon, E. O., Willis, T. F., and Reagel, F. V., "Effect of Air-entrapping Portland Cement on the Resistance to Freezing and Thawing of Concrete Containing Inferior Coarse Aggregate," *Proceedings*, American Society for Testing Materials, 1943.
2. Blatchley, W. S., "Indiana Department of Geology and Natural Resources," 32nd Annual Report, Wm. B. Burford, Indianapolis, Indiana, 1907.
3. Cantrill, Curtis, and Campbell, Louis, "Selection of Aggregates for Concrete Pavement Based on Service Records," *Proceedings*, American Society for Testing Materials, Vol. 39, p. 23, 1939.
4. Frost, R. E., "The Use of Aerial Maps in Soil Studies and Location of Borrow Pits." Presented at Kansas Highway Engineering Conferences at Kansas State College, March 1, 1946.
5. Henderson, E. A., and Spencer, Walter T., "Effect of Experimental Subgrade Treatments on Pavement Faulting and Pumping," *Proceedings*, Highway Research Board, Vol. 26 (this vol.), p. 319.

6. Hittle, J. E., "Application of Aerial-Strip Photography to Highway and Airport Engineering," *Proceedings*, Highway Research Board, Vol. 26 (this vol.), p. 226.
7. Jackson, F. H., "The Durability of Concrete in Service," *Journal*, American Concrete Institute, Vol. 18, No. 2, October, 1946.
8. Krueger, H., "Investigations of Climatic Action on the Exteriors of Buildings," *Transactions*, Royal Swedish Institute for Scientific Industrial Research, No. 24, 1923. Abstracted by Douglas E. Parsons in *Proceedings*, American Society for Testing Materials, Vol. 31, 1931. Part II.
9. McBurney, J. W., "The Water Absorption and Penetrability of Brick," *Proceedings*, American Society for Testing Materials, Vol. 29, 1929.
10. Richmond, J. C., and McBurney, John W., "Effect of Freezing Temperature in Freezing and Thawing Tests of Brick," *Proceedings*, American Society for Testing Materials, Vol. 41, 1941.
11. Sweet, Harold S., "Chert As A Deleterious Constituent in Indiana Aggregates," *Proceedings*, Highway Research Board, Vol. 20, 1940.
12. Sweet, H. S., and Woods, K. B., "A Study of Chert as a Deleterious Constituent in Aggregates," Engineering Bulletin of Purdue University, Sept., 1942.
13. Thomas, W. N., "Experiments on the Freezing of Certain Building Materials," Technical Paper No. 17, Building Research Board, Department of Scientific and Industrial Research, 1938.
14. Walker, Stanton, "Discussion of Freezing and Thawing of Concrete," *Proceedings*, American Society for Testing Materials, Vol. 43, 1943.
15. Walker, Stanton, "Discussion on the Soundness of Chert," *Proceedings*, American Society for Testing Materials, Vol. 40, 1940.
16. Walker, Stanton, "Technical Information Letter No. 24," National Sand and Gravel Association, June 16, 1941.
17. Walker, Stanton, "Technical Information Letter No. 25," National Sand and Gravel Association, August 12, 1941.
18. Woods, K. B., and Shelburne, T. E., "Pumping of Rigid Pavements in Indiana," *Proceedings*, Highway Research Board, Vol. 23, 1943.
19. Woods, K. B., and Gregg, L. E., "Pavement Performance Related to Soil Texture and Compaction," *Proceedings*, Highway Research Board, Vol. 24, 1944.
20. Woods, K. B., Sweet, H. S., and Shelburne, T. E., "Rigid Pavement Blowups Correlated with Source of Coarse Aggregates," *Proceedings*, Highway Research Board, Vol. 25, 1945.
21. Wray, R. N., and Lichtefeld, H. J., "The Influence of Test Methods on Moisture Absorption and Resistance of Course Aggregate to Freezing and Thawing," *Proceedings*, American Society for Testing Materials, Vol. 40, 1940.
22. Wuerpel, Charles E., and Rexford, E. P., "The Soundness of Chert Measured by Bulk Specific Gravity and Absorption," *Proceedings*, American Society for Testing Materials, Vol. 40, 1940.
23. Yoder, Eldon J., and Woods, K. B., "Compaction and Strength Characteristics of Soil-Aggregate Mixture," *Proceedings*, Highway Research Board, Vol. 26 (this vol.), p. 511.
24. Belcher, D. J., Gregg, L. E , Woods, K. B., "The Formation, Distribution, and Engineering Characteristics of Soils," Engineering Bulletin of Purdue University, No 87, Vol. 27, Jan., 1943.

DISCUSSION

MR. W. R. WOOLLEY, *Public Roads Administration:* The correlation of durability of concrete pavement with soil texture and drainage conditions gives valuable clews which may be used to prolong the life of concrete. It seems the authors are justified in suggesting that the performance of concrete containing certain types of coarse aggregate may be greatly improved by keeping the moisture content of the concrete relatively low. Their data show definitely better performance of the concrete laid on sand fills, than on silty clay cuts. It is stated, however, that, "uniformly bad pavements are located either on silty-clay soils or on semi-granular soils with a high water table." Presumably this uniformly bad condition of the concrete existed on both cuts and fills in silty-clay soils. A high grade line, in itself, would not be expected to result in improved concrete durability if the subgrade soils were more or less impervious, because, surface water is trapped under the concrete and thus is likely to maintain a high moisture content in the concrete.

The question which needs to be answered is what design practices are most effective in reducing the moisture content of concrete pavement laid on impervious soils?

Very likely placing granular material from shoulder to shoulder under the pavement is a considerable help, and yet in one instance the writer found free water in such an installation of open graded material. Apparently the open graded material had been rendered impervious by dirt filling the voids at the point where the granular material intersected the fill slope.

A variation of the practice of placing porous granular material all the way across the grade is to place it only under the pavement and to drain it by means of tile drains. This may or may not be an effective method of drainage. On one such project the writer has never been able to discover any water coming out of the outlet of the drains.

Still a third design for granular bases calls for relatively dense graded material in a trench section under the pavement. This design has been criticized by many engineers on the theory that it traps water under the pavement.

The writer has dug numerous holes in such dense graded undrained sub-bases and has not been able to find free water in them at any time. It is known, however, that all observers have been able to find small amounts of free water in undrained sub-bases. The presence of more free water in dense graded undrained sub-bases than in open graded material with drains has not been established. The cost of constructing the open graded type with drains is much more than the cost of the other design.

Mr. Sweet and Mr. Woods have shown that the type of subgrade has a marked effect on the durability of concrete made with certain aggregates. It seems, however, that not enough is known as to how to obtain low moisture contents in granular sub-bases over impervious soils. More data showing moisture contents in sub-bases of various designs, and if possible, moisture contents in the overlying concrete, is needed in order to intelligently design granular sub-bases that will keep the concrete pavement relatively dry.

MR. T. E. SHELBURNE, *Virginia Department of Highways:* The authors have presented in a most interesting manner additional performance survey data which emphasize this method as a means of evaluating the factors affecting pavement behavior. One of the outstanding features of the report is the use of aerial photographs in conjunction with such surveys. While such procedures are relatively new, they will undoubtedly become more general in use and be of increasing value. It seems that one of the best methods of recording actual performance conditions of any experimental pavement project would be by the use of low altitude flight strip photos taken at definite periodic intervals.

During the past year a reconnaissance survey was made of the existing concrete pavements in Virginia. First of all, information was collected regarding the location, design features, sources of materials and other factors. Surveys were then made to determine the absence or presence of such conditions as pumping, scaling, mapcracking, blowups, pitting and popouts, fill settlements, et cetera. The purpose of this survey was to determine the types and extents of failures, if any, and to evaluate, if possible, the factors affecting performance such as material sources and design features. The results of this survey have not been analyzed completely; however, certain projects are of interest which permit comparisons of coarse aggregate performance.

It is unfortunate, from a performance viewpoint, that most of the older concrete pavements have been resurfaced. There is available on Route 29 south of Lynchburg, Campbell County, sections of concrete pavement built in 1927 and 1928. The pavement which is of 8–6–6–8-in. cross section, 18 ft wide, was constructed without longitudinal or transverse joints. This pavement is located in the Piedmont Province and the soils are fine grained and rather plastic, having been derived from the weathering of granitic and metamorphic rocks. The soils in this area are classified in the Cecil-Appling group by the pedologists. The topography is undulating to gently rolling. This particular road carried a total traffic count of approximately 1,500 vehicles per day, of which about 25 percent are trucks.

The condition of this pavement may best be seen by examining the following pictures. Figure A illustrates differences in pavement performance attributed to the use of two

different coarse aggregate sources. The man in the photograph is standing at the change in coarse aggregates. In the background aggregate "A" was used and has resulted in a pavement requiring a minimum of maintenance. The average transverse crack in-

Figure A. The junction of two sources of coarse aggregate are marked by the man in the picture. In the background, the use of aggregate "A" has resulted in a pavement requiring a minimum of maintenance. In contrast, the use of aggregate "B" has resulted in extensive ravelling and spalling along the cracks, and mapcracking.

Figure B. This picture of the pavement built with coarse aggregate "A" illustrates excellent performance.

terval is 53 ft and there is very little evidence of mapcracking.

In the foreground aggregate "B" was employed and has resulted in a pavement which has required a considerable amount of patching. Ravelling along the cracks is pronounced and mapcracking is extensive, particularly in those areas of poor drainage. The average transverse crack interval on this portion is 20 ft.

The general good performance of the section of concrete pavement containing aggregate

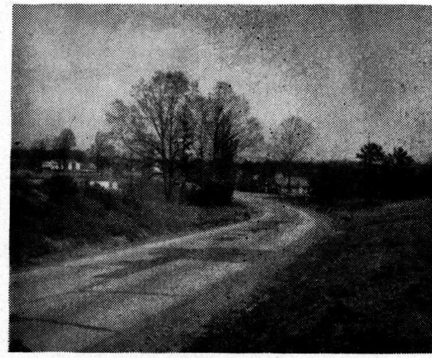

Figure C. A portion of the pavement with coarse aggregate "B" showing ravelling and spalling at cracks and extensive mapcracking. Note particularly the extensive amount of patching.

Figure D. A close-up view of a portion of the pavement in Figure C. Note particularly the extensive mapcracking.

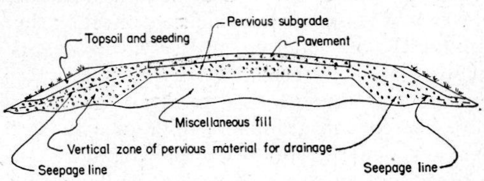

Figure E

"A" is further illustrated by Figure B. It should be mentioned, however, that most of the pavement in this picture is located on a fill where natural drainage conditions are normally good.

In contrast, Figure C illustrates the condition of the pavement containing aggregate "B". Extensive ravelling or spalling at cracks, mapcracking and general disintegration are in evidence. These failures have necessitated a considerable amount of patching. A close-up of this pavement showing the extensive amount of mapcracking is further illustrated in Figure D.

Results of the Virginia survey will show what types of failures are prevalent and will indicate the type of problems on which detailed research studies are desired. While some of the newer pavements do not indicate such decided differences in performance as those older pavements illustrated by the Figures in this discussion, records of design features, source of materials, etc. will be available for evaluation at later dates.

In conclusion, pavement performance surveys constitute one of the best means for evaluating material sources and design features, and in establishing the problems on which research is most urgently needed.

MR. GORDON R. WILLIAMS, *Knoppen Engineering Company, New York:* In the control of moisture in sub-grades and highway fills it appears that the highway engineer might benefit from the experience of the hydraulic and soils engineers in the design of earth dams and levees. In hydraulic structures water enters the fill because of the relatively high hydrostatic pressures which are exerted on the upstream side. In highway fills water enters the fill through pervious subgrades. The amount of water may be considerable because of large impervious surfaces draining towards the shoulders which may not always have special drainage facilities. As seepage works down through the fill, considerable hydrostatic head may be built up.

The control of the seepage line in either the hydraulic structure or the highway fill can best be made by a vertical zone or zones of pervious material as shown in Figure E. The pervious zone forces the seepage line or hydraulic gradient downward and outward towards the toe of the fill. In hydraulic structures it is essential that the seepage lines intersect the downstream slope at the toe in order to prevent the effluent from causing boils and erosion. In highway fills the quantity of sub-surface drainage will be relatively less and the control of the frost line is more important than the control of the outflow.

Under former methods of making highway fills by vertical dumping, the introduction of a zone of controlled materials would be more difficult and costly. However, with the advent of rolled fills as in dam and levee construction, the introduction of vertical zones of controlled materials presents no problem and would add little to the costs.