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Performance of Concrete Pavement on Granular Subbase

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Performance of Concrete Pavement on Granular Subbase

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Effectiveness of Granular Bases for Preventing Pumping of Rigid Pavements

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SYNOPSIS

THIS STUDY, covers a condition survey in Indiana of 328.5 mi. of rigid pavements constructed with granular bases.

Indiana has constructed a large mileage of rigid pavements. Most of these have performed satisfactorily, but some have shown distress. Pumping has been one of the major problems in these pavements, and much study has been given to pumping by many agencies, including a special project committee of the Highway Research Board, the Joint Highway Research Project of Purdue University, and many state highway departments.

Data were gathered on six types of distress related to pumping: (1) active pumping at joints or cracks; (2) active pumping along pavement edges; (3) inactive pumping at joints or cracks; (4) inactive pumping along pavement edges; (5) pumping out of base-course materials resulting in second-stage blows; and (6) pumping out of water from base course or on top of base resulting in first-stage blows. The terms *second-stage blows* and *first-stage blows* have been coined for this report and the terms cover types of distress that are comparatively new.

Analysis of the data is divided into two sections: (1) General performance of the bases and pavements studied; specifications for 13 performance groupings were formulated, ranging from Group 1, covering projects with no pumping defects, through Group 13, covering projects with the poorest performance of those studied; specifications for the various groups are expressed in the number of defects per mile for each class of defect; a summary is included to show the number of miles falling into each specification group. (2) Extent or degree to which the various defects exist on each project; defects on each project were classified as "slight," "moderate," or "large;" a summary is included which shows mileage falling into each of these categories for the six types of pumping defects studied; another summary is included, which shows the miles and percentages falling into the extreme lower limits of the "slight" category.

The data and analyses show that granular bases have been effective in preventing pumping of rigid pavements in Indiana up to the time the study was made.

FOR MANY YEARS, rigid pavements have carried, in general, the traffic imposed upon them in a satisfactory manner. However, since the advent of large trucks with heavy axle loads, a serious problem has been created in Indiana as well as in other states (1,2,3). The movement of these heavy loads on rigid pavements constructedon fine-grained soils in the presence of excess moisture has caused pumping in many instances. Pumping is that action consisting of the deflection of a slab under moving wheel loads which results in the ejection of water from under the slab carrying particles of soil in suspension (2,3,4,5,7). If this action continues, cavities develop under the pumping slab and finally subgrade support is diminished to the point where the pavement breaks or cracks and, under like conditions, a new cycle is started at the newly formed cracks (2,3,5,7). The ultimate is complete destruction of the pavement.

PREVIOUS WORK

Intensive study continues in an effort to solve the pumping problem. The Joint Highway Research Project, Purdue University has been conducting extensive condition surveys of both rigid and flexible pavements since 1940 (3). Some preliminary surveys were made in 1941. One of these showed that there was no appreciable pumping on Indiana Route 67, extending from the Illinois to the Ohio lines. In both 1943 and 1947, the location, amount, and severity of pumping of rigid pavements in Indiana were determined by surveys. Both showed that pumping occurred generally on the heavily traveled roads, regardless of pavement design. The latter survey also revealed that, although corrections were made on sections of pumping pavements during the period 1943 to 1947, there was a net increase in the total amount of pumping (3). These surveys also revealed that in 1940 pumping was practically nonexistant in Indiana, that in 1943 approximately 6.0 percent of the miles of rigid pavement in the state were affected, and that in 1947 it had increased to 12.0 percent.

The Highway Research Board early recognized the seriousness of pumping and organized a project committee to study the problem (2,4,6,8). Surveys have been made and reports have been issued from time to time.

The engineering staff of the State Highway Commission of Indiana has been aware of the seriousness of this problem from its inception and has cooperated with the Joint Highway Research Project in their studies. The writer conducted a survey during 1949. A map of the state, showing pumping existing at that time, is included in this study. Other states have also conducted surveys (7).

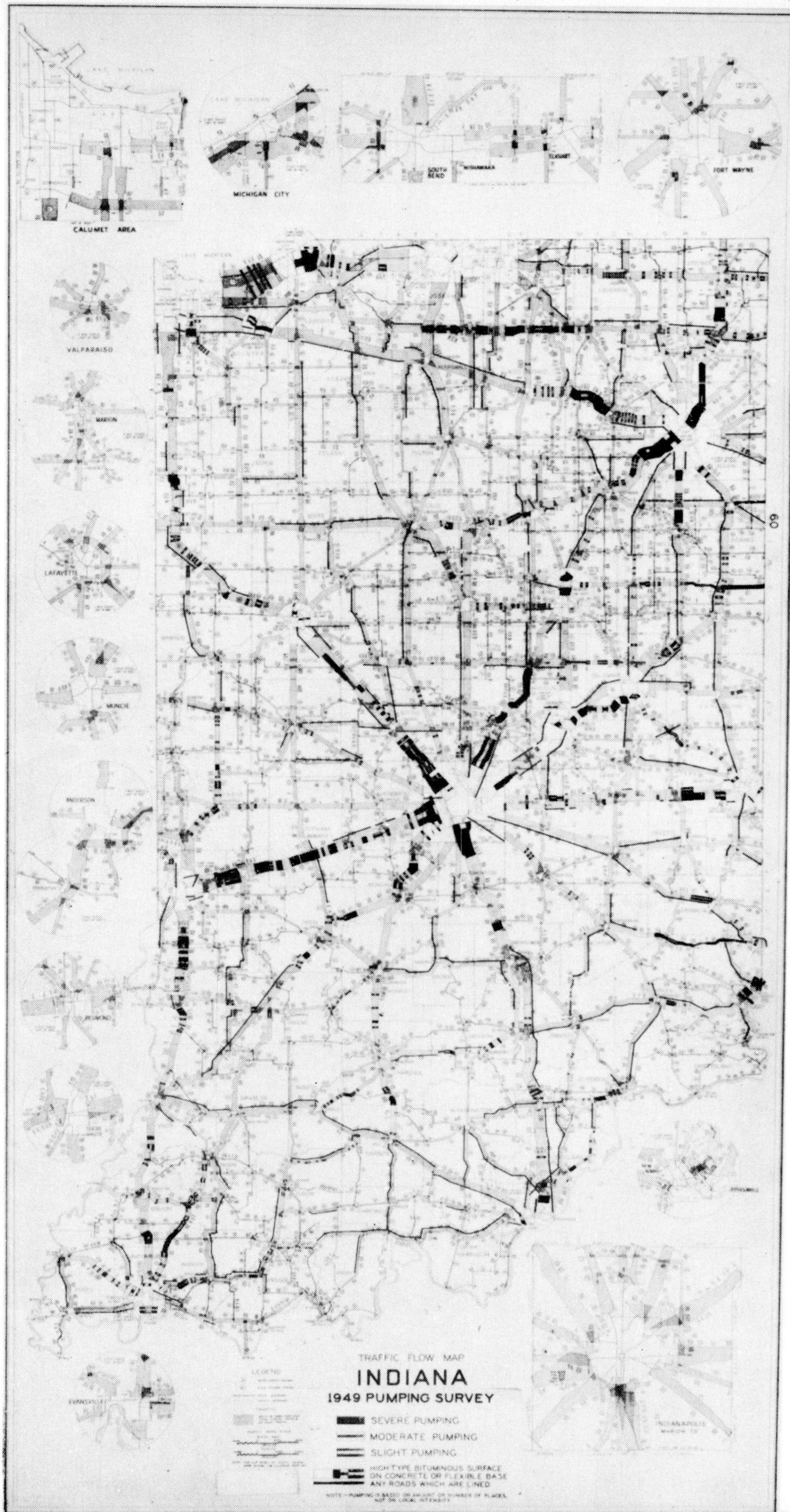
Various measures have been taken to prevent or correct pumping including the use of subsurface drainage. Tile installations along the pavement edges on a number of pumping pavements were constructed in Indiana in 1943-4 (10). These checked or retarded pumping for a short period of time, but later became ineffective in a number of locations due to the silting of the granular backfill in the trenches.

The use of mudjack materials and hot asphalt under the pavement has been used with varying degrees of success by many states from time to time (2). Undersealing pumping pavements with cement slurries or asphalt has been used more recently as a corrective measure. Ohio, Texas, and Missouri have used asphalt as an underseal extensively, and Indiana undersealed a considerable mileage with asphalt in 1950, after having had reasonably good success on several projects in 1949.

Another corrective measure consists of the use of granular subgrade treatments or bases. This method has been used by a number of states in recent years (1,2,5,6,7). The earliest treatments placed in Indiana were not constructed for the purpose of preventing pumping; but, since they are in place and are on roads where pumping occurs, the results obtained are included. Some of the early treatments were of material which would not pass present specifications, both as to material employed and depth placed. The first used was in 1935 and 1936 on a project 10.586 miles long and was placed to a depth of 3 inches. It was used to secure a better subgrade than existed on a heavily traveled road. The next was placed on US 30 east of Schererville in 1937 as part of an experiment for controlling pavement curling. Two of the seven sections placed employed the use of granular material. During the last war the Pullman Company, located in Hammond, used a section of US 30 for test runs of 28-ton tanks manufactured for the British Government. Those sections of the road located on plastic soils soon developed pumping, one of the first serious developments on our state highway system. The problem became so serious by 1943 that subsurface drains were constructed along the edge of the pavement with the exception of the two sections of the experimental portion mentioned above. This arrested the pumping for some time, but during 1949, due to the advanced stage of deterioration, the pavement was undersealed and resurfaced, with the exception of the same two test sections; these were in sufficiently satisfactory condition so that it was not necessary to resurface or treat them.

In 1938, when pumping had not become a serious problem, granular subgrade treatments were incorporated in the construction of two projects to correct poor soil conditions. The treated portions amounted to 3.6 mi. In 1939, 3.54 mi. were constructed; in 1940, 0.626 mi., and in 1941, 5.708 mi. During the latter part of 1941, six contracts were let which included granular subgrade treatment in the design. These were constructed in 1942 and totaled 18.59 miles. By this time, pumping was being recognized as a formidable problem.

The only concrete pavements constructed during the last world war, after the awarding of the contracts for the projects just mentioned, were those approved by the War Department and declared necessary for the war effort. There are not many in this group. However, pumping developed considerably during the war years, and when construction went forward again at the conclusion of hostilities, there was a full realization of the problem. All subsequent contracts for concrete pavements on roads carrying considerable traffic, or even on lighter traveled roads on exceedingly poor


CALUMET AREA
MICHIGAN CITY
SOUTH BEND
MISHAWAKA
ELKHART
FORT WAYNE
VALPARAISO
MARION
LAFAYETTE
MUNCIE
ANDERSON
RICHMOND
EVANSVILLE
INDIANAPOLIS
MARION CO.
TRAFFIC FLOW MAP
INDIANA
1949 PUMPING SURVEY
SEVERE PUMPING
MODERATE PUMPING
SLIGHT PUMPING
HIGH TYPE BITUMINOUS SURFACE
ON CONCRETE OR FLEXIBLE BASE
ANY ROADS WHICH ARE LINED

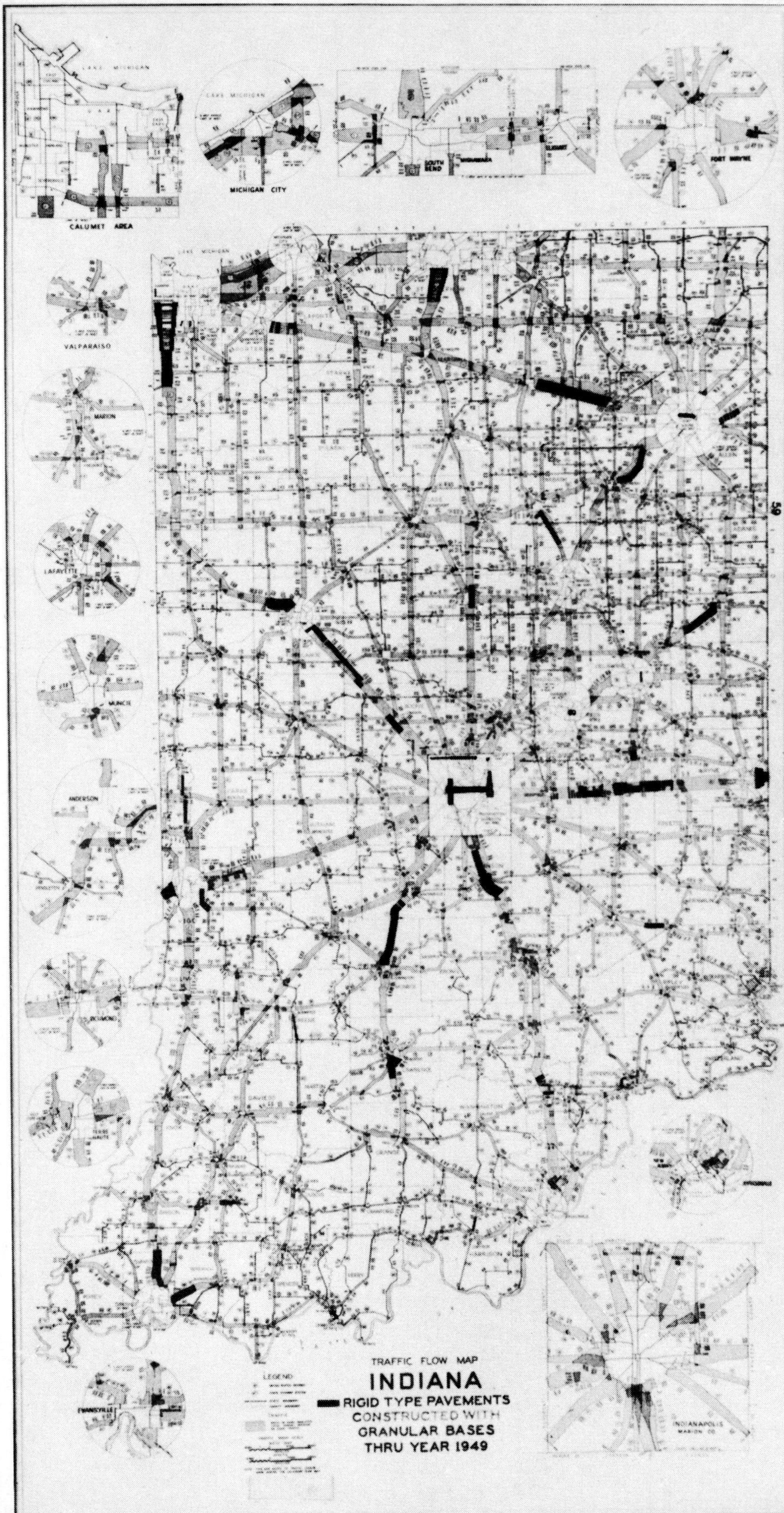

LAKE MICHIGAN
CALUMET AREA
MICHIGAN CITY
SOUTH BEND
FORT WAYNE
VALPARAISO
MARION
LAFAYETTE
MUNCIE
ANDERSON
RICHMOND
EVANSVILLE
INDIANAPOLIS
MARION CO.
LEGEND
TRAFFIC FLOW MAP
INDIANA
RIGID TYPE PAVEMENTS
CONSTRUCTED WITH
GRANULAR BASES
THRU YEAR 1949

TABLE 1

REQUIREMENTS FOR SUBGRADE-TREATMENT MATERIALS TYPE I

Sieve sizes through which substantially all material passes approx. top size	Total percents retained on sieves having square openings									
	2½-in	2-in.	1½-in.	1-in.	3/4-in.	1/2-in.	No. 4	No. 8	No. 30	No. 200
2-in.	0	0-5	2-25	10-40	15-50	20-80	40-75	55-85	75-95	95-100[a]
1½-in.		0	0-5	2-25	10-40	15-55	33-75	50-85	75-95	95-100[a]
1-in.			0	0-10	2-25	10-40	30-70	45-80	70-95	95-100[a]
1/2-in.			0			0-10	10-50	30-70	60-90	95-100
No. 4			0				0-10	5-55	40-90	95-100
No. 8			0					0-10	25-85	95-100
No. 30			0						0-10	95-100

[a] In addition to the above requirements, the amount passing the No. 30 sieve shall not be less than two times the amount passing the No. 200 sieve.

soils, called for granular treatments or bases. Since the early part of 1948, all concrete pavements constructed have had such bases. Through 1949, a total of 82 projects located in 39 counties in practically all sections of the state have been so constructed. This study covers 280.628 mi., some of which are dual lanes. Converted to equivalent two-lane roads, the total is 328.548 mi. The exact information on location and mileages, as well as the width of pavements involved and depths of treatment is included in Table 2.

Indiana specifications for subgrade treatment cover two types of material, namely: Type I (open-graded,) see Table 1 - and Type II (dense-graded).

TYPE II

Retained on the 2-in. square sieve..0-5 percent

Retained on the No. 4 square sieve..0-65 percent

It shall contain sufficient binding material to compact satisfactorily.

The fraction passing the No. 200 sieve shall not be greater than one half the fraction passing the No. 30 sieve, nor greater than one fourth the fraction retained on the No. 30 sieve, except that no material will be rejected on account of the amount passing the No. 200 sieve provided such amount does not exceed 10 percent.

Practically all treatments placed, with the exception of a very few, have been Type II.

STATEMENT OF PURPOSE

The purpose of this study is to determine through a condition survey and analysis, the effectiveness to date of one type of preventative measure; namely, granular subgrade treatment. With 328.548 mi. in place in various sections of the state, a great many of which are on high-traffic-count roads carrying heavy loads, some idea can be secured through such a study as to whether or not this type of preventative measure is giving satisfactory performance.

SCOPE AND PROCEDURE

This study is limited to one type of preventative measure. Detailed observations were made of all rigid pavements constructed through 1949 in which granular base courses were employed. The field work consisted of making close inspections, including the driving of each project at very low speeds coupled with numerous stops, as well as on-foot inspections in order that pavement-edge as well as pavement-surface conditions could be observed. Data have been collected covering six types of distress or defects: (1) active pumping at joints or cracks; (2) active pumping along pavement edges; (3) inactive pumping at joints or cracks; (4) inactive pumping

TABLE 2 DATA TABULATION AND

SECTION 1

1 State Road No.	2 Project No.	3 LOCATION	4 Year Constructed	5 Pavement Width	6 Treatment Width	7 Treatment Depth	8 Treated Length Miles	9 Equivalent 2 lane Tr. Length	10 Class 1 Active Joint Pumping		11 Class 2 Active Edge Pumping		12 Class 3 Inactive Joint Pumping		13 Class 4 Inactive Edge Pumping		14 Class 5 2nd Stage Blow Holes		15 Class 6 1st. Stage Blow Holes		16 Restraint Cracks	
									Total	No.PerMi.	Total	No.PerMi.	Total	No.PerMi.	Total	No.PerMi.	Total	No.PerMi.	Total	No.PerMi.	Total	No.PerMi.
		LA PORTE DISTRICT																				
41	NRHM 69 K	Cook to St. John	1935-6	Widened 18' Pavement to 40' and 40'	Shoulder to Shoulder	3"	6.046	6.528													•	
41	N R H M 69H&K	North of St. John	1935-6	Widened 18' Pavement to 40' and 40'	Shoulder to Shoulder	3"	4.540	5.470							2	0.36			1	0.18	•	
30	FA 17A Part H	Schererville east (2 Experimental Sections)	1937	22'	W+2'	6"&3"	1.140	1.140							2	1.75			16	14.03	•	
30	577A&B	Valparaiso - Wanatah	1942	1&2 at 22'	Shoulder to Shoulder	0.6' Uniform	3.970	6.140													•	
41	SNFA 69 (17)	SR2 to Cook (N.B. Lane South Section)	1946	24'	W+2'	9"-8"-9"	4.469	4.469													•	
41	SNFA 69 (18)	SR2 to Cook (N.B. Lane North Section)	1946	1&2 at 24'	W+2'	9"-8"-9"	4.426	4.944							1	0.20			3	0.61	•	
31	F-10 (10)	Lakeville-South Bend (South Section)	1947	2 at 22'	W+2'	7"to 8"	3.684	4.934													•	
31	F-10 (11)	Lakeville-South Bend (North Section)	1947	2 at 22'	W+2'	7"to 8"	3.039	4.584													•	
4 20	UI-265(6)	Jackson St. to Delmar St. in Hammond	1948	2 at 24'	W+2'	6"-5"-6"	1.302	2.604													•	
41	FI-69 (19)	SR2 to Cook (S.B. Lane South Section)	1949	24'	W+2'	9"-8"-9"	3.683	3.683											29	7.87	-	
41	FI-69 (20)	SR2 to Cook (S.B. Lane North Section)	1949	24'	W+2'	Experimental Various Depths	4.107	4.107							4	0.97			187	45.53	-	
		TOTALS					40.406	48.603														
		FT. WAYNE DISTRICT																				
6	FA209 C(2) 210C(2)A(2)	In Nappanee	1944	22'&36'	W	6"-5"-6"	1.244	1.244													•	
24	SN-A-FA 477 B(1)	New Haven Northeast	1945-6	22'	W+2'	Approx. 4"	3.060	3.060							1	0.32			95	31.04	1	0.32
24	FI 98 (24)	Huntington-Mahon (EBL)	1946	22'	W+2'	6"-5"-6"	5.970	5.970											1	0.16	•	
24	FA 98 A(7) B (9)	Mahon-Roanoke (EBL)	1946	22'	W+2'	6"-5"-6"	5.191	5.191											2	0.38	•	
13	S-2 (3)	North Manchester By-Pass	1947	22'	W+2'	6"	0.320	0.320													•	
3 24	F-724 (1)	Ft. Wayne Circumurban	1947-8	24'	W+2'	6"-5"-6"	3.920	3.920											1	0.25	•	
15	S-253 (1)	LaFountaine - Treaty	1949	22'	W+2'	3"	4.853	4.853							10	2.06			115	23.70	25	5.15
15	S-253 (3)	Treaty - Wabash	1949	22'	W+2'	3"	5.778	5.778											11	1.9	3	0.51
13	S-572 (3)	South edge of Wabash	1949	22'	W+2'	3"	0.685	0.685											4	5.83	-	
30	F-792 (5)	Warsaw - Pierceton	1949	22'	W+2'	6"-5"-6"	6.089	6.089			1	0.16			4	0.66	100	16.42	1218	200.03	92	15.10
30	F-792 (6)	Pierceton - Larwill	1949	22'	W+2'	6"-5"-6"	4.989	4.989							2	0.40	211	42.29	1005	217.47	56	11.2
30	F-792 (7) Part B	Larwill - Columbia City	1949	22'	W+2'	6"-5"-6"	6.571	6.571							18	2.74	1291	196.47	3582	545.12	124	18.87
		TOTALS					48.670	48.670														
		CRAWFORDSVILLE DISTRICT																				
46	705-A	Riley - Terre Haute	1942	22'&36'	W+2'	12"&6"	4.780	4.780													•	
52	SN-FA74&12D5	Monroe - Lafayette	1942	1&2 at 22'	W+2'	6"	4.720	5.080													•	
5 52	DA-NI 12A(1)	Lafayette By-Pass	1943	22'	W+2'	8"	1.063	1.063													•	
63	DA-WI8B(1)	US 36 North (North Section)	1943	22'	W+2'	6"-5"-6" & Variations	3.200	3.200													•	
63	DA-WI8A(1)	US 36 North (South Section)	1943-4	22'	W+2'	8" and Variations	1.549	1.549													•	
52	PW-FA 74C (7)D(8)	North of Monroe to Nickle Plate RR (NBL)	1946	24'	W+2'	6"-5"-6"	4.836	4.836			3	0.62			5	1.03	2	0.41	27	5.58	7	1.44
52	FA74C(8)B(7)	Nickle Plate RR to Thorntown Rd. (NBL)	1946	1&2 at 24'	W+2'	6"-5"-6"	4.442	** 4.689									9	1.91	16	3.41	25	5.33
52	FI770 (3)	Lebanon By-pass (South Section)	1948	24'	W+2'	6"-5"-6" & Variations	2.410	3.073													•	
52	FI 74 (39) FI 770(1)	Lebanan Bypass (North Section)	1948-9	24'	W+2'	6"-5"-6" & Variations	2.103	2.573													•	
40	FI 14 (2)	Illinois State Line to W.Terre Haute	1948-9	2 at 24'	W+2'	6"-5"-6"&Va.	4.420	8.840							4	0.45	11	1.24	169	19.12	191	21.61
52	FI 75 (6) Part A	W. Lafayette - Klondyke	1949	2 at 24'	W+2'	3"to9"	3.428	6.648					2	0.30	5	0.75			170	25.57	47	7.06
52	FI 75 (6) Part B	Klondyke - Montinorenci	1949	2 at 24'	W+2'	6"-5"-6" & Variations	3.034	6.068			1	0.16	1	0.16	2	0.33	3	0.49	87	14.33	7	1.15
63	F 305 (4)	Clinton - Hillsdale	1949	22'	W+2'	6"-5"-6"	5.394	5.394													•	
		TOTALS					45.379	57.793														
		GREENFIELD DISTRICT																				
40	FA 13C(4)	Knightstown - Dunrieth	1939	2 at 22'	Shoulder to Shoulder	8"Uniform	1.770	3.540														
100	AW-FA 246A (2)	Nora - Castleton	1942	22'	W+2'	6"Uniform	0.960	0.960			9	9.38					4	4.17				
40	SN-FA 13 B (2)	Greenfield - Cleveland	1942-3	22'	W+2'	6"Uniform	1.080	1.080									1	0.92	31	28.70		
40	SN-FA 13 B (3)	Cleveland - Knightstown	1943-4	1&2 at 22'	W+2'	6"Uniform	5.971	7.628									6	0.78	75	9.83		
40	SN-FA 13 C (6)	Dunrieth - Lewisville	1945	22'	W+2'	6"-5"-6"	4.123	5.573			1	0.18			1	0.18	129	23.1	40	7.17	53	9.51
40	13 D (2)	Lewisville - Straughn	1945	22'	W+2'	6"-5"-6"	2.627	5.169									148	28.63	30	5.80	79	15.28
40	13 D(3)5D	Straughn - Dublin	1945-6	22'	W+2'	6"-5"-6"	3.882	5.507									39	7.08	34	6.17	37	6.71
100	F 246 (8)	SR. 29 to Nora	1946-7	24'	W+2'	6"-5"-6"	4.642	4.642									9	1.93	24	5.17	32	6.89
31	FI 9 (4)	Greenwood - Franklin	1946-7	1&2 at 24'	W+2'	6"-5"-6"	7.606	8.974											25	2.78	6	0.66
40	FI 112 (3)	Richmond-Ohio State Line	1947	2 at 24'	W+2'	6"-5"-6" & Variations	1.804	3.608											16	4.43		
100	F 246 (11)	US 40 to 56th. St. Indianapolis	1947	24'	W+2'	6"-5"-6"	5.115	5.115									4	0.78	284	55.52	14	2.73
32	U 391 (2)	E. Jackson St. in Muncie	1947	30' to 36'	W+2'	6"Min.	0.623	0.623													•	
3	U 176 (1)	New Castle By-pass	1947	22'	W+2'	6"-5"-6"	1.714	1.714													•	
34	U 107 (7) Part B	West 16th St. Indianapolis	1947	62'	W+3'2"	Variable 5"to 8"	1.035	2.070														
31	F 222 (1)	N.Meridian St. Indianapolis	1947	54'	W	Variable4"	1.001	2.002														
67	F 130 (7)	Red Key - Como	1947	22'	W+2'	6"-5"-6"	5.005	5.005			2	0.40	10	1.99	3	0.60	4	0.80	302	60.33	91	18.18
67	F 130 (8)	Como - Portland	1947	22'	W+2'	6"-5"-6"	4.496	4.496			17	3.78			4	0.88	33	7.36	550	122.33	99	22.01
100	F 246 (6)	US 52 to SR 29	1948	24'	W+2'	6"-5"-& Variations	4.668	4.668											28	5.99	3	0.64
109	S 56 (6)	Columbus Ave - Anderson	1948	38'	Center 22' Par. + 2'	3" Uniform	1.011	1.011													•	
32	S 166 (1)	West of Noblesville	1949	22'	W+2'	6"-5"-6" & Variations	1.642	1.642													•	
31	U 771 (1)	Kokomo - By-pass	1949	22'	W+2'	6"-5"-6" & Variations	3.544	3.544													•	
31	U 771 (3)	Kokomo - By-pass	1949	22'	W+2'	6"-5"-6" & Variations	3.627	3.627													•	
		TOTALS					67.946	82.198														
		VINCENNES DISTRICT																				
57	291 C	Near Daylight	1942	22'	W+2'	6"Uniform	0.550	0.550			4	7.27									•	
41	F 36 (5)	Evansville - Inglefield	1947	1&2 at 22'	W+2'	6"-5"-6"	4.506	6.341											1	0.16	1	0.16
41	28 (4) F 28 (5)	Inglefield - Stacer	1947	2 at 22'	W+2'	6"-5"-6"	4.387	8.774					1	0.11					49	5.58	64	7.29
157	F 739 (1)	Scotland-Bloomfield (S.Section)	1947	22'	W+2'	6"-5"-6" & 12"-11"-12"	4.202	4.202													•	
157	F 739 (4)	Scotland-Bloomfield (N.Section)	1948	22'	W+2'	6"-5"-6"	2.867	2.867													•	
50&37	U 16 (19)	Bedford-White River	1948	22'&60'	W+2'	3" to 9"	2.906	3.631											4	1.10		
50&37	F 16 (20)	White River-Mitchell	1949	22'	W+2'	6"-5"-6"	4.000	4.000													•	
66	S 167 (1)	Tell City - Cannelton	1949	22'&36'	W+2'	3"-2¼"-3"	3.565	3.565													•	
64	S 88 (6)	West of Arthur to Augusta	1949	22'	W+2'	6"-5"-6"	5.243	5.243														
62	F 793 (1)	Smythe - Caney Creek	1949	22'	W+2'	6"-5"-6"	5.646	5.646							1	0.17			10	1.77	33	5.84
662	S 179 (1)	Evansville East	1949	22'	W+2'	3"-2¼"-3"	5.518	5.518													•	
		TOTALS					43.390	50.337														
		SEYMOUR DISTRICT																				
37	FA 428 B	Martinsville South	1938	22'	Shoulder to Shoulder	9"-8"-9"	1.030	1.030														
107	FA 565 A	Madison By-pass	1938	20'	Shoulder to Shoulder	6" Uniform	2.570	2.570											2	0.78		
31	FA 21 E(5)	North of Scotsburg	1940-1	22'	Shoulder to Shoulder	9" Uniform	0.626	0.626					5	7.99	6	9.58						
31	FA 21 E (7)	North of Austin	1941	22'	Shoulder to Shoulder	9" Uniform	0.525	0.525														
46	FA 728C(1)	New Point - Batesville	1941-2	22'	W+2'	2¼" Uniform	5.183	5.183			6	1.15	2	0.38	5	0.96			73	14.08	1	0.19
31	FA 762A(1)	Franklin-Amity (South Section)	1946-7	2 at 24'	W+2'	6"-10½"-6" & 9"-8"-9"	2.819	5.638											9	1.59	5	0.88
31	FA 762B(1)	Franklin-Amity (North Section)	1946-7	2 at 24'	W+2'	5"-5"-4" & 6"-5"-4"	3.001	6.002													•	
135	S 124 (1)	Corydon-North	1948	22'	W+2'	3"-2½"-3"	3.380	3.380														
37	U 134 (3)	College Ave. in Bloomington	1949	44'±	W	4" to 7"	0.290	0.580														
37	F 428 (11)	Bloomington-Bean Blossom Creek	1949	22'	W+2'	6"-5"-6" & Variations	3.748	3.748											46	12.27	15	4.00
37	F 428 (12)	Bean BlossomCreektoNE. of Modesto	1949	22'	W+2'	6"-5"-6" & Variations	4.213	4.213											95	22.54	14	3.32
37	F 428 (13)	NE. of Modesto to Morgan Co. Line	1949	22'	W+2'	6"-5"-6" & Variations	3.250	3.250							5	1.53			141	43.38	29	8.92
37	F 428 (14)	Morgan Co. Line to Old SR.37	1949	22'	W+2'	6"-5"-6" & Variations	4.202	4.202							12	2.86			233	55.45	45	10.70
		TOTALS					34.837	40.947														

NOTE: W = Pavement Width

NOTE: • Projects Not Checked for Restraint Cracks

** 4.689 Miles of Equivalent 2 Lane Treated Length Were Included Out of an Actual 7.713 Miles of Equivalent 2 lane Treated Length.

DEFECT ANALYSIS RESULTS

SECTION 2

17 REMARKS	18 Group Desig-nation	19 Class 1 Active Joint Pumping			20 Class 2 Active Edge Pumping			21 Class 3 Inactive Joint Pumping			22 Class 4 Inactive Edge Pumping			23 Class 5 2nd. Stage Blow Holes			24 Class 6 1st. Stage Blow Holes			25 Restraint Cracks			State Road No,
		Slight	Moderate	Large	Slight	Moderate	Large	Slight	Moderate	Large	Slight	Moderate	Large	Slight	Moderate	Large	Slight	Moderate	Large	Slight	Moderate	Large	
This stretch has been resurfaced	1																						41
This stretch has been resurfaced	4										5.470						5.470						41
	5										1.140						1.140						30
Faulting at joints No dowel bars used	1																						30
	1																						41
	4										4.944						4.944						41
	1																						31
	1																						31
Has not been opened to thru traffic	1																						420
No expansion Joints	3																3.683						41
No Expansion Joints	8										4.107							4.107					41
											15.661						15.237	4.107					
	1																						6
No Expansion Joints	8										3.060							3.060		3.060			24
	2																5.970						24
	2																5.191						24
	1																						13
	2																3.920						324
No Expansion Joints	7										4.853						4.853			4.853			15
No Expansion Joints	2																5.778			5.778			15
No Expansion Joints	3																0.685						13
No Expansion Joints	11				6.089						6.089			6.089					6.089	6.089			30
No Expansion Joints	12										4.989				4.989				4.989	4.989			30
No Expansion Joints	13										6.571					6.571			6.571	'6.571			30
					6.089						25.562			6.089	4.989	6.571	26.397	3.060	17.649	31.340			
	1																						46
This stretch has been resurfaced	1																						52
Some faulting. No dowel bars	1																						552
	1																						63
	1																						63
No Expansion Joints	5				4.836						4.836			4.836			4.836			4.836			52
No Expansion Joints	5													4.689			4.689			4.689			52
Has not been opened to thrutraffic to date	1																						52
Has not been opened to thru traffic to date	1																						52
No Expansion Joints	5										8.840			8.840			8.840			8.840			40
No Expansion Joints	6							6.648			6.648						6.648			6.648			52
No Expansion Joints	5				6.068			6.068			6.068			6.068			6.068			6.068			52
	1																						63
					10.904			12.716			26.392			24.433			31.081			31.081			
Expansion Joints Used	1																						40
Expansion Joints Used	7				0.960									0.960									100
20'ContractionJointsWithoutDowel bars and ExpansionJointsWithDowel BarsUsed. ConsiderableFaulting.	6													1.080			1.080						40
	5													7.628			7.628						40
No Expansion Joints	9				5.573						5.573			5.573			5.573			5.573			40
No Expansion Joints	9													5.169			5.169			5.169			40
No Expansion Joints	7													5.507			5.507			5.507			40
No Expansion Joints	5													4.642			4.642			4.642			100
No Expansion Joints	3																8.974			8.974			31
No Expansion Joints	3																3.608						40
No Expansion Joints	8													5.115				5.115		5.115			100
	1																						32
	1																						3
No Expansion Joints	1																						34
No Expansion Joints	1																						31
No Expansion Joints	8				5.005			5.005			5.005			5.005				5.005		5.005			67
No Expansion Joints	11				4.496						4.496			4.496					4.496	4.496			67
No Expansion Joints	3																4.668			4.668			100
	1																						109
	1																						32
Road not opened to thru traffic	1																						31
Road not opened to thru traffic	1																						31
					16.034			5.005			15.074			45.175			46.849	10.120	4.496	49.149			
	7				0.550																		57
No Expansion Joints	2																6.341			6.341			41
No Expansion Joints	5							8.774									8.774			8.774			41
	1																						157
	1																						157
No Expansion Joints	2																3.631						50&37
No Expansion Joints	1																						50&37
	1																						66
	1																						64
No Expansion Joints	4										5.646						5.646			5.646			62
	1																						662
					0.550			8.774			5.646						24.392			20.761			
This Project has Exp. Joints	1																						37
This Project has Exp. Joints	2																2.570						107
This Project has Exp. Joints	7							0.626			0.626												31
This Project has Exp. Joints	1																						31
Has been resurfaced This Project has Exp. Joints	5				5.183			5.183			5.183						5.183			5.183			46
No Expansion Joints	2																5.638			5.638			31
No Expansion Joints	1																						31
	1																						135
No Expansion Joints	1																						37
No Expansion Joints	3																3.748			3.748			37
No Expansion Joints	6																4.213			4.213			37
No Expansion Joints	8										3.250							3.250		3.250			37
No Expansion Joints	8										4.202							4.202		4.202			37
					5.183			5.809			13.261						21.352	7.452		26.234			

along pavement edges; (5) second-stage blows; and (6) first-stage blows.

The defects are listed above in the order of their seriousness, active pumping at joints being regarded as the most serious and first-stage blows as the least serious. It should be noted that inactive pumping at joints and inactive pumping along pavement edges, in general, represent a lesser degree of pumping than do Items 1 and 2; also, that second-stage blows and first-stage blows are two types of distress that are comparatively new. The latter two cannot, under the accepted definition of pumping, be considered as pumping defects, yet it is possible that in time they might develop into a problem comparable with pumping. During the early inspections, attention was directed only to Defects 1 through 4, but after the two types of blows were discovered and studied, it was decided that the cause of these defects was related to the occurrence of heavy loads in the presence of free water, in that they consist of the pumping out of water from on top of base and the pumping out of base course materials. Data were then obtained wherever these types of distress were found. Later on another defect appeared, restraint cracks (see Figs. 1 and 11). A numerical check was made on all projects subsequently inspected; but since this problem is not related to pumping, the data collected are included only to show the extent to which the problem exists.

This report does not deal with all the causes of the defects involved, as there are variables present upon which the necessary data are not available, such as the number, type, and weight of the various axle loads traveling over each project.

DEFECTS INVESTIGATED

Listed below are the definitions and descriptions of the seven types of defects investigated and studied in this report:

No. 1 - Active Pumping at Joints and Cracks - Any joint or crack, where pumping was taking place at the time of the inspection or where the intensity was such that it was evident that pumping had existed for some time, was listed under this category.

No. 2 - Active-Edge Pumping - Any spot along the edge of a pavement, where edge pumping was taking place at the time of the inspection or where the intensity was such that it was evident that edge pumping had existed for some time, was listed under this category.

No. 3 - Inactive Pumping at Joints and Cracks - Any joint or crack, where a slight degree of pumping had occurred prior to the time of inspection, as evidenced by mud stains on the pavement, was listed under this category. Pumping in this category was of a lesser degree than that described in No. 1.

No. 4 - Inactive-Edge Pumping - Any spot along the edge of a pavement, where there was evidence that there had been a slight degree of edge pumping prior to the time of inspection, was listed under this category. This type was difficult to determine, in some cases, because vertical movement of the slab at the edge of a pavement in the presence of moisture might produce a stain by rubbing the soil next to the pavement edge. Pumping in this grouping was of a lesser degree than that defined in No. 2 above.

No. 5 and No. 6 - Second-Stage Blows and First-Stage Blows - As previously mentioned, second- and first-stage blows are two types of defects which, to the author's knowledge, are comparatively new. The terminology, has been coined by the writer. Blows consist of vertical openings at the edge of the pavement slab. In the first stage, these might be as small as the tip of a pencil, or larger. After a study of numerous blows on a number of projects, it is thought that they are caused by the ejection of a minute amount of free water from between the bottom of the slab and the surface of the subgrade as a result of the passing of a heavy load. The soil against the edge of the slab is eroded by the water flowing from the point of load application and the resultant hydrostatic pressure exerted at some point along the edge of the pavement (see Figs. 8 and 10). Blows occur in the vicinity of transverse joints or cracks, generally just ahead of them, but they also occur at midslab locations. Repeated load applications enlarge the blows and often there is a tendency to elongate the channel longitudinally. Observation has shown that when a blow is filled with water, there is a vertical and longitudinal surging action resulting from the passing of a heavy load, which causes the soil particles around its perimeter to be ejected through the surface hole, thus enlarging the hole. Blows of this nature are classified as first stage and are placed in Category 6. Figures 1 and 2 show advanced first stage blows.

In the early stages, blows are often, although not always, found as single holes. They are also found in series, as shown in Figure 3. Generally when the blows occur in this manner, they are associated with a low shoulder-edge along the pavement, which was caused by a vehicle or vehicles running off the surface in wet weather and leaving the vertical face of the pavement exposed for a depth of 1 to 3 or more in. for some distance.

With increased quantities of water, followed by the subsequent moistening of the granular base and the slab deflections caused by the passing of heavy loads, some of the granular material from the base is forced up into the first-stage-blow cavities. Some also might be ejected through the surface hole. When this degree of distress has been reached, the blow is classed as

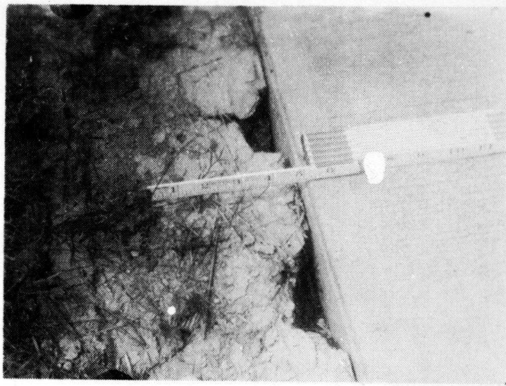


Figure 2. Edge-blows (first-stage, midpanel) on Indiana 67, at Station 1025+60 of Project F-130 (7), east of Red Key.

Figure 1. Edge-blows (first-stage) and restraint cracks on Indiana 67 at Station 858+75 of project F-130(7), east of Red Key. Water seepage in this area is from plugged underdrain constructed along the edge of the old pavement. Excavation of blow at joint shows bottom edge spall.

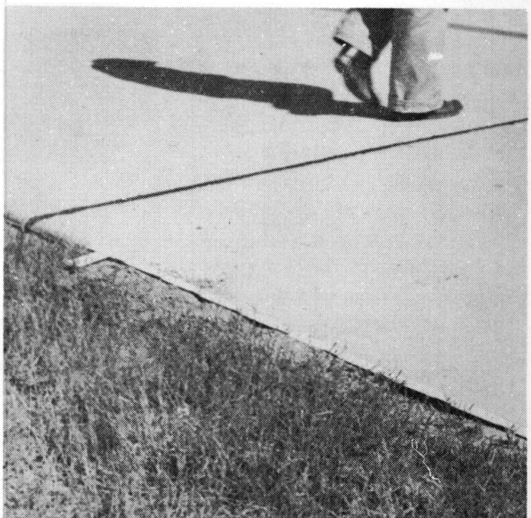


Figure 3. Series of edge-blows 5½ ft. long ahead of joint (in direction of traffic) on US 30 at Station 641+28 of Project F-792(7) Part B, west of Columbia City.

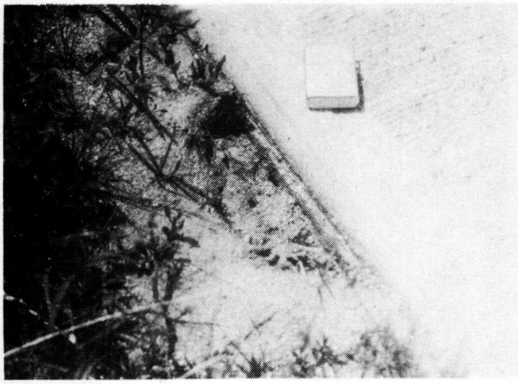


Figure 4. Closeup showing granular material in edge-blow (second-stage) along south edge of eastbound lane of US 40 at Station 270+00 of Project 13 D2, east of Lewisville. Note the typical elliptical or half-moon shape.

second stage. Figure 4 shows a second-stage blow, while Figure 5 shows the material which has been ejected from a blow.

Numerous excavations made where this condition exists substantiate the above statements (see Fig. 6, 7, and 8).

Figure 9 shows a cross section of a second-stage blow about 5 in. below the surface, while Figure 10 shows the condition of the bottom of the blow. These illustrations are typical of many investigated. It should be noted that the cavity is approximately 2½ in. wide at the widest point and is about 10 in. long. The longitudinal dimension on some is as high as 15 in. or more. Figure 10 shows the channel eroded on the surface of the treatment at the pavement edge. The vertical marks on the edge at the top show where the blow opening was located.

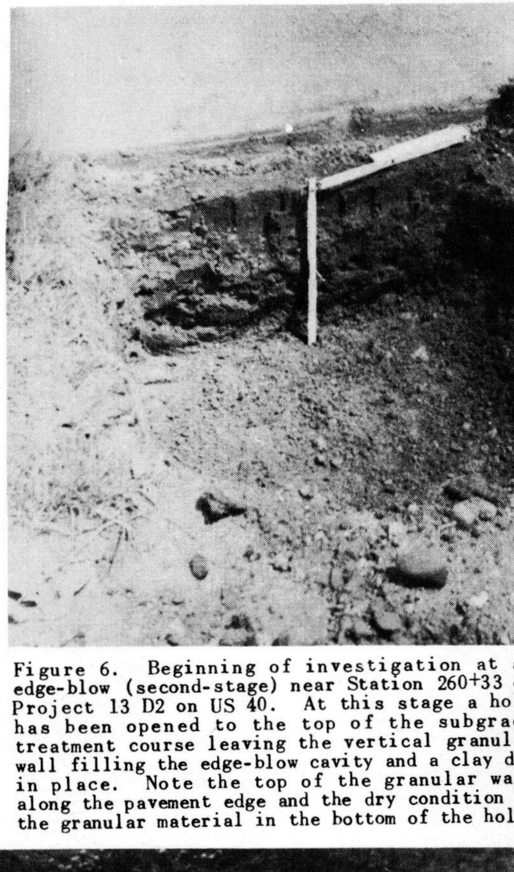


Figure 6. Beginning of investigation at an edge-blow (second-stage) near Station 260+33 of Project 13 D2 on US 40. At this stage a hole has been opened to the top of the subgrade treatment course leaving the vertical granular wall filling the edge-blow cavity and a clay dam in place. Note the top of the granular wall along the pavement edge and the dry condition of the granular material in the bottom of the hole.

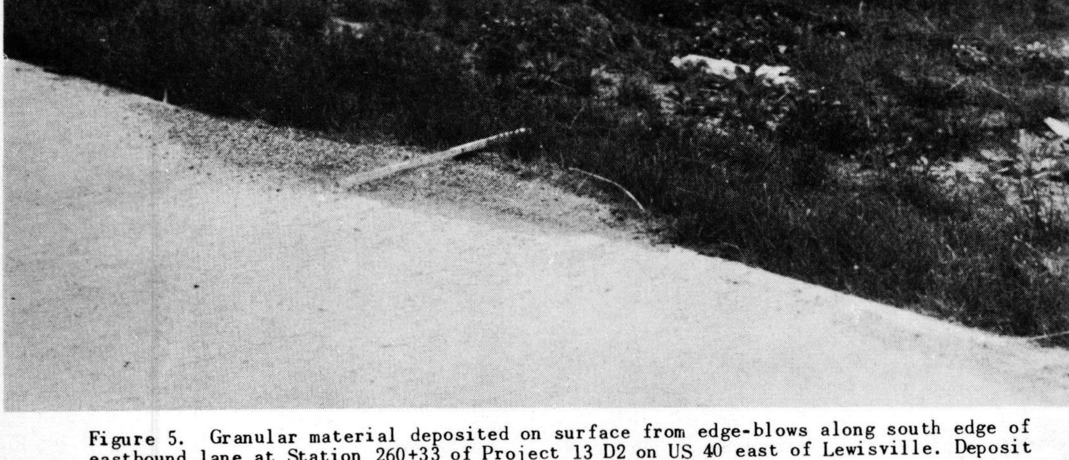


Figure 5. Granular material deposited on surface from edge-blows along south edge of eastbound lane at Station 260+33 of Project 13 D2 on US 40 east of Lewisville. Deposit covered an area approximately 3 by 1½ ft. and weighed 14.3 lbs.

Figure 7. A continuation of the investigation at Station 260+33. At this stage part of the clay dam and granular wall filling the cavity has been removed allowing the water to drain from under the pavement. Note opening under pavement edge where water flowing from beneath the pavement has broken the wall of granular material.

Figure 8. Final stage of the investigation at Station 260+33. Note the cavities under the pavement edge and the continuation of the granular material along the edge of pavement beyond the limits of the excavation.

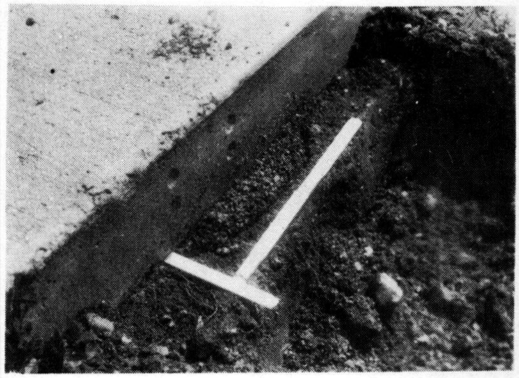


Figure 9. Station 1221+37 of Project F-130(8) on Indiana 67. Granular material in edge-blow at a depth of 5 in. below the surface of the pavement.

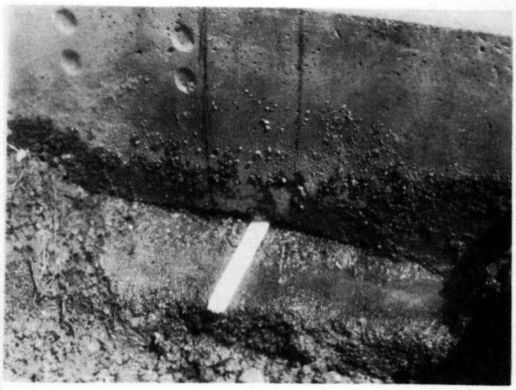


Figure 10. Station 1221+37 of Project F-130(8). Rule placed in opening beneath pavement at location of edge-blow. Note free water flowing from under pavement.

Figure 11. Restraint cracking and edge-blows along south edge of eastbound lane of US 40, east of Lewisville at Station 265+00 of Project 13 D2.

As previously stated, restraint cracks are not included as a primary part of this report. However, since they exist on a number of projects, data were obtained to show the extent of the problem. Restraint cracks are defined as longitudinal cracks occurring at joints, approximately 6 in. to 2½ ft. from the edge of the pavement. They are caused by the infiltration of material into the crack at the edge or under the pavement near the edge during the contraction period of contraction and expansion cycles. The cracks appear or are lengthened when expansion takes place in order to relieve the induced stresses. Figure 11 shows typical restraint cracking.

CONDITION SURVEY

Detailed data were taken on each of the 82 projects included in this study. Actual counts were made of each type of defect so that when the inspections were completed, the exact condition of every project could be determined through subsequent study of the field data. Supplementing data on the pumping related defects were data concerning the occurrence of restraint cracks on a number of projects.

TABULATION OF DATA

Upon the completion of the field work, the data collected together with other information, were tabulated as shown in the first 17 columns of Table 2. The following information is included: state road number, project number, location, year constructed, pavement width, treatment width, treatment depth, treated length, equivalent two-lane treated length, Class 1, Class 2, Class 3, Class 4, Class 5, Class 6, restraint cracks, and remarks. In the columns labeled Class 1 through Class 6 and restraint cracks, the total of each defect on each project is recorded. The tabulation is by individual projects by date of construction in each state highway district.

DISCUSSION OF RESULTS

The analysis of the data is divided into two sections. This was done in order to get a comparison of each project by defects, thus enabling a relative grouping of all projects and also to secure a quantitative analysis.

In Section 1, the total number of each type of defect on each project is broken down into the number per mile, thus giving a value for each type on each project which can be compared with the same type on any other or all projects. As can be observed, there are values of from as low as 0.11 defects per mile in one class to as many as 545.12 in another. Of course there are a considerable number of projects with no defects. With this information on all projects, an attempt has been made to rate them relatively from best to poorest insofar

TABLE 3

SPECIFICATIONS FOR GROUPS 1 THROUGH 13

Group	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
1	0	0	0	0	0	0
2	0	0	0	0	0	less than 2
3	0	0	0	0	0	2 to 20
4	less than 2 in 2 or more classes					
5	less than 2 in 1 or more classes					2 to 20
6	less than 2 in 1 or more classes					20 to 30
7	between 2 and 10 in 1 or more classes					less than 30
8	less than 10 in 1 or more classes					30 to 80
9	between 10 and 30 in 1 or more classes					less than 30
10	between 30 and 80 in 1 or more classes					less than 80
11	less than 30 in all classes except one, one class over 80					
12	between 30 and 80 in 1 or more classes and over 80 in 1					
13	over 80 in 2 or more classes					

NOTE: Specifications for groups are based on number of defects per mile.

TABLE 4

SUMMARY OF MILEAGE IN GROUPS 1 THROUGH 13

GROUP		LAPORTE	FT. WAYNE	CRAWFORDSVILLE	GREENFIELD	VINCENNES	SEYMOUR	TOTALS	ACCUMULATIVE TOTALS	ACCUMULATIVE PERCENTAGE
1	Total Miles	29.259	1.564	26.712	19.773	25.395	11.517	114.220	114.220	
	Percentage	60.200	3.214	46.220	24.055	50.450	28.127	34.765		34.765
2	Total Miles		20.859			9.972	8.208	39.039	153.259	
	Percentage		42.858			19.810	20.045	11.882		46.647
3	Total Miles	3.683	0.685		17.250		3.748	25.366	178.625	
	Percentage	7.578	1.407		20.986		9.153	7.721		54.368
4	Total Miles	10.414				5.646		16.060	194.685	
	Percentage	21.427				11.216		4.888		59.256
5	Total Miles	1.140		24.433	12.270	8.774	5.183	51.800	246.485	
	Percentage	2.345		42.277	14.927	17.431	12.658	15.766		75.022
6	Total Miles			6.648	1.080		4.213	11.941	258.426	
	Percentage			11.503	1.314		10.289	3.634		78.656
7	Total Miles		4.853		6.467	0.550	0.626	12.496	270.922	
	Percentage		9.971		7.868	1.093	1.529	3.803		82.459
8	Total Miles	4.107	3.060		10.120		7.452	24.739	295.661	
	Percentage	8.450	6.287		12.312		18.199	7.530		89.989
9	Total Miles				10.742			10.742	306.403	
	Percentage				13.068			3.270		93.259
10	Total Miles								306.403	
	Percentage									93.259
11	Total Miles		6.089		4.496			10.585	316.988	
	Percentage		12.511		5.470			3.222		96.481
12	Total Miles		4.989					4.989	321.977	
	Percentage		10.251					1.519		98.000
13	Total Miles		6.571					6.571	328.548	
	Percentage		13.501					2.000		100.000
Total Miles Treated		48.603	48.670	57.793	82.198	50.337	40.947	328.548		
Percentage of Treated Total in State		14.793	14.814	17.590	25.019	15.321	12.463	100.000		

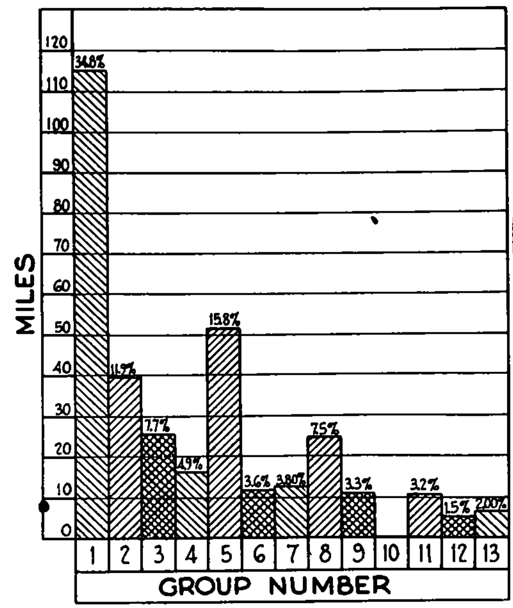


Figure 12. Mileage and percent of total mileage in each of groups No. 1 thru group 13 as shown in table No. 4

as the defects studied are concerned to determine the relative effectiveness of the granular subgrade treatments or bases.

Specifications for this grouping are shown in Table 3. Should further work be done along this line, it is possible that a particular requirement for some groups might have to be modified in order that a project can be placed in its correct position relative to other projects.

As shown in Table 3, Group 1 includes those projects where there are no defects in any class. Group 2 contains those with no defects in the first five classes and with less than two per mi. in Class 6, the least serious. Group 3 was established with the same requirements as those of Group 2, with the exception that there are an allowable 2 to 20 first-stage blows per mi. Group 4 contains projects in slightly more serious conditions containing up to two defects per mi. in two or more classes. Groups 5 and 6 have the same requirements for the first five classes, but differ in the number of allowable first-stage blows. It should be noted that projects in Group 5 are only slightly worse than those in Group 3, in that there is an allowable number of defects up to two in one or more of the first five classes, and this together with Class-6 requirements also make Group 5 projects slightly more serious than Group 4 projects. In other words, the difference between any two successive groups are very slight. The same reasoning has been used in determining requirements for the remaining groups, thereby securing groupings in which each successive one includes projects with slightly inferior performance as compared to those included in the preceding group.

Column 18 of Table 2 shows the relative group number in which each project falls after making this type of analysis.

Table 4 summarizes the grouping shown in Column 18 by districts. The summary shows the total miles of equivalent two-lane pavement constructed, the number of miles of Group 1 pavements, together with the percentage of that amount of the total in the district, the number of miles in Group 2, along with its percentage of the total, and so on through all groups. Another column shows the total miles treated in the state, the total of each group for the state as well as each group's percentage

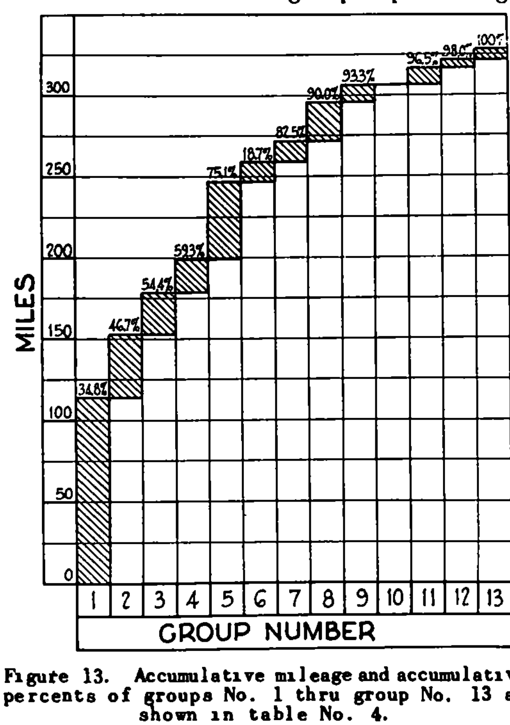


Figure 13. Accumulative mileage and accumulative percents of groups No. 1 thru group No. 13 as shown in table No. 4.

of the total. The last two columns show the accumulated totals progressively by groups and the accumulated percentages. In other words, by a single glance, one can see the total number of miles of pavement that is better than or meets the requirements of any particular group. Figures 12 and 13 show the totals in each group and the accumulated totals, graphically.

From this one will observe that of the 328.548 mi. treated, 114.220 mi., or 34.765 percent, have no defects and to date have given perfect performance, thereby meeting the requirements of Group 1; that Group 2 includes 39.039 mi., or 11.882 percent, which are perfect with the exception of having less than two first-stage blows per mi., and this mileage together with that in Group 1 amounts to 153.259 mi., of 46.647 percent of the total; that Group 3 includes 25.366 mi., or 7.721 percent, which are perfect with the exception or having from 2 to 20 first-stage blows per mi., and this together with the mileage in previous groups total 178.625 mi., or 54.368 percent of the total that are at least this good; that Group 4 includes 16.060 mi., or 4.888 percent, which have less than two defects per mi. in two or more classes, thus producing a total, when added to mileage of the previous groups, of 194.685 mi. or 59.256 percent, that Group 5 includes 51.800 mi. or 15.766 percent which have less than two defects per mile in one or more of the first five classes and from 2 to 20 in Class 6, and this together with the mileage in the first four groups give a total of 246.485 mi. or 75.022 percent having this performance or better; that Group 6 includes 11.941 mi., or 3.634 percent, which have less than two defects per mile in one or more of the first five classes, and between 20 and 30 in Class 6, thus producing a total of 258.426 mi., or 78.656 percent when the mileage of the first five groups are added; that Group 7 includes 12.496 mi., or 3.803 percent, which have between 2 and 10 defects per mi. in one or more of the first five classes and less than 30 in Class 6, and this together with the mileage in Groups 1 through 6 produce a total of 270.922 mi. or 82.459 percent that are of this caliber or better.

Group 8 includes 24.739 mi., or 7.530 which have less than 10 defects per mi. in one or more of the first five classes and between 30 and 80 in Class 6, thus producing a total, when added to those of the previous groups, of 295.661 mi. or 89.989 percent that have this performance or better; that Group 9 includes 10.742 mi., or 3.270 percent, which have between 10 and 30 defects per mi. in one or more of the first five classes and less than 30 in Class 6, and this together with the mileage in the first eight groups amount to 306.403 mi., or 93.259 percent, having this performance. The same accumulated total and accumulated percentage applies to Group 10, as no projects upon analysis fall into this group.

Figures for the remaining three groups show that Group 11 includes 10.585 mi., or 3.222 percent, which have less than 30 defects per mi. in all classes except one, while the exception has over 80 per mi., and this together with the mileage in the previous 10 groups amount to 316.988 mi., or 96.481 percent, having this performance or better; that Group 12 includes 4.989 mi., or 1.519 percent, which have between 30 and 80 defects per mile in one or more classes and over 80 in one other, and when added to the previous groups, amount to 321.977 mi., or 98.000 percent. The poorest performance group contains 6.571 mi., or 2.000 percent, which has over 80 defects per mi. in two or more classes.

From Table 2 it will be observed that one project falls into this group, US 30 between Larwill and Columbia City. This project has a total of 3,582 first-stage blows averaging 545.12 per mi., and 1,291 second-stage blows averaging 196.47 per mi. along with 18 inactive-edge pumping spots. Field notes show that of the 3,582 blows, 2,210 are on the eastbound lane and 1,372 on the westbound lane; that of the 1,291 second-stage blows, 938 occur on the eastbound lane and 353 on the westbound lane; that of the 18 inactive-edge pumping spots, 17 are on the eastbound lane and one on the westbound lane.

Only one project is included in Group 12. This is US 30 between Pierceton and Larwill, the next section west of the one just mentioned. Of the 1,085 first-stage blows, averaging 217.47 per mi., 655 are on the eastbound lane and 430 on the westbound. There are 211 second-stage blows averaging 42.29 per mi., of which 115 are on the eastbound lane and 96 on the westbound. US 30 between Warsaw and Pierceton is one of two projects falling in Group 11. This project has a total of 1,218 first-stage blows averaging 200.03 per mi., of which 579 are on the eastbound lane and 639 on the westbound. Of 100 second-stage blows averaging 16.42 per mi., 38 are on the eastbound lane and 62 on the westbound.

It is difficult to understand the difference in performance of these three projects, as it is believed that traffic conditions are practically the same. Likewise, it is not known why the worst conditions are found on the eastbound lane on the two east projects; while on the third, the opposite is true. No doubt further attention should be directed to a study of traffic conditions and also to a study of the characteristics of the treatment used under the pavement.

Table 2 also shows that on Indiana 67 between Como and Portland, there are totals of 550 first-stage blows averaging 122.33 per mi., 33 second-stage blows averaging 7.36 per mi., and 17 active-edge pumping spots averaging 3.78 per mi. Field notes show that 225 first-stage blows, 5 second-stage blows, and 9 active-edge pumping spots are on the eastbound lane, while 325 first-stage, 28 second-stage, and 8 edge-pumping spots are on the westbound lane. This is the other project falling in Class 11.

The next section west on Indiana 67 between Red Key and Como, constructed by a different contractor at the same time (which is included in Class 8), has a total of 302 first-stage blows averaging 60.33 per mi., 4 second-stage blows averaging 0.80 per mi., 10 inactive pumping joints averaging 1.99 per mi., and 2 active-edge-pumping spots averaging 0.39 per mi., of which 101 first-stage blows, 2 second-stage blows, and 6 inactive pumping joints are on the eastbound lane, while there are 201 first-stage blows, 2 second-stage blows, 4 inactive pumping joints and 2 active-edge pumping spots on the westbound lane. There is no doubt but that traffic conditions are the same on both of these projects. The above data indicate that heavier loads occur on the westbound lane. However, there is considerable difference in the overall performance of the two sections.

Group 9 includes two projects on US 40, one between Dunreith and Lewisville, and the other between Lewisville and Straughn. These are the only two projects, with the exception of the three projects on US 30 between Warsaw and Columbia City, where there are a considerable number of second-stage blows, the first mentioned having 129 averaging 23.1 per mi., and the second 148 averaging 28.63 per mi. Strangely enough, both of these projects have a relatively small number of first-stage blows. The reverse is generally true, with the first-stage damage preceding the second-stage in development.

There are six projects included in Class 8, the only other class where there is an appreciable number of first-stage blows per mi. Shadeland Avenue, a part of the Indianapolis circumurban route, has 284 first-stage blows which average 55.52 per mi., but has only 4 second-stage blows. The experimental subgrade-treatment section on US 41 south of Cook has 187 first-stage blows averaging 45.53 per mi., 4 inactive-edge pumping spots, but no second-stage blows. It is interesting to note that the section to the south, with the same traffic conditions and employing standard subgrade treatment, has only 29 first-stage blows averaging 7.87 per mi. with no other defects, which places it in Class 3. The two sections in the northbound lanes opposite these two sections, contain standard subgrade treatment and are in Classes 1 and 4. This indicates that some of the experimental-type treatments are not giving as good performance as the standard-type now in use. It should also be noted that this particular stretch is a heavily-traveled road and carries considerable heavy trucking.

The third and fourth sections on Indiana 37 north of Bloomington have 141 first-stage blows averaging 43.38 per mi. with 5 inactive-edge-pumping spots and 233 first-stage blows averaging 35.45 per mi. with 12 inactive-edge-pumping spots respectively. Both of these sections fall in Class 8.

The two south sections fall in Class 3 and Class 6 and have 46 first-stage blows averaging 12.27 per mi. and 95 first-stage blows averaging 22.54 per mi. respectively. Yet the traffic conditions are the same on all four sections. The only known variable is the type of subgrade treatment, the two north sections consisting of gravel and the other two of crushed stone.

The other project falling in Class 8 is US 24 northeast of New Haven. It has 95 first-stage blows averaging 31.04 per mi. with 1 inactive-edge-pumping spot. There are seven intermittant stretches on this project employing subgrade treatment. There is no treatment on the intervening gaps and it is interesting to note that considerable pumping exists in these areas. This is definite proof that granular subgrade treatment is of great value.

Several additional projects which fall into better classifications, should be mentioned. Indiana 15 between LaFontaine and Treaty has 115 first-stage blows averaging 23.69 per mi.; whereas, the section just north has only 11 first-stage blows averaging 1.9 per mi. The traffic conditions are practically the same. The first section falls into Class 7, while the latter is in Class 2. It should be mentioned that both of these have only a 3-inch treatment as against the standard 6-5-6-in. treatment used on most projects. US 52 between Klondyke and the west end of the Lafayette By-pass has 170 first-stage blows averaging 25.57 per mi. and is in Class 6; whereas, the section to the west with the same traffic conditions has 87 first-stage blows averaging 19.11 per mi., placing it in Class 5. US 40, between the Illinois State-line and west Terre Haute, has 169 first-stage blows averaging 19.11 per mi. and falls into Class 5. US 40, between Cleveland and Knightstown, has 75 first-stage blows averaging 9.83 per mi. and 8 second-stage blows averaging 0.78 per mi., placing it in Class 5. Both US 52 and US 40 are heavily traveled and although the projects on them just mentioned are grouped in good-performance classes to date, with the number of first-stage blows that have developed, it is possible that they might fall to poorer classifications in the future. Indiana 46 between New Point and Batesville has 73 first-stage blows averaging 14.08 per mi. and is in Class 5. This project has a 2½-in. treatment and was constructed in 1941. Although traffic is not so heavy as compared with those just mentioned, the road does receive a considerable number of heavy loads. The performance of this project also indicates the value of granular subgrade treatments. This road stretching to the east, with practically the same traffic and loads, has been pumping badly for several years throughout almost the entire length to its intersection with US 52.

Of the remaining roads falling into better classifications, a number including US 31 from Lakeville to South Bend, US 40 to Knightstown to Dunreith, US 41 north of Evansville, and Franklin to Amity on US 31 (all of which carry heavy traffic), have given excellent performance to date. All city-street projects, wherever constructed, are in very good condition as well as a number of projects on roads having moderately heavy traffic.

As can be observed in Table 2, several projects have not had a fair test, since they have not been opened to through traffic. A few projects, showing good performance, have been resurfaced since the date of original construction. It is not known whether any of those resurfaced were afflicted with the defects studied or not, but it is known that resurfacing was placed on certain stretches for other reasons.

The analysis in Section 1 gives a comprehensive perspective as to the general performance of the granular subgrade-treated pavements studied, through the mileage falling into the various groups. Section 2 is presented to elaborate on the picture by showing the extent or degree to which the various defects exist on each project. To accomplish this end-point, the following specifications, with respect to damage, were set up:

Slight - 0 to 30 defects per mi.
Moderate - 31 to 80 defects per mi.
Large - Over 80 defects per mi.

The specifications are entirely arbitrary as were those established for Section 1. This classification is justified on the basis that there are approximately 132 joints per mi. on concrete pavements which, together with intermittant cracks that often appear, increase the potential spots considerably for developing pumping. Therefore, any number of defects up to 30 per mi. would be less than 20 percent of the potential for pumping at joints or cracks and considerably less for edge-pumping or blow holes. Likewise, 31 to 80 defects per mi. would give from approximately 20 percent to as high as 50 to 55 percent for pumping at joints or cracks. As noted before, the percentage in this category for edge pumping or blow holes would be less. All in all the mileage falling into these categories could be considered on the conservative side.

From Section 1 of Table 2, it is to be noted that on SNFA Project 69(18), the northbound lane on the north section just south of Cook on US 41 there are two types of defects; namely, one defect of Class 4 (inactive-edge pumping) and three defects of Class 6 (first-stage blows) averaging 0.20 and 0.61 per mi. respectively. Since these averages are less than 30 per mi., the total mileage of the project is included under "slight" for Class 4 and Class 6, as shown in Columns 22 and 24.

Likewise, for Project F-792(5) on US 30 from Warsaw to Pierceton, there are one active-edge pumping defects (average 0.16 per mi., four inactive-edge pumping (average 0.66 per mi.), 100 second-stage blows (average 16.42 per mi.), and 1,218 first-stage blows (average 200.03 per mi.), which places 6.089 mi. (the length of the project) under "slight" in Class 2, Class 4, and Class 5; while the same mileage falls under "large" in Class 6.

In making the analysis, each defect is classified as "slight", "moderate", or "large" on each project as to amount, and the mileage of the project is shown under the proper category.

Table 5 is a summary of the mileage of the classified amounts by districts for each defect; also shown is the percentage of the total treated in each district for the classified amount of each defect, as well as the totals of each defect for the state and its percentage of the total treated in the state.

It can be seen that there is no mileage of active-joint pumping (the most serious defect) in any district in any of the three categories, "slight", "moderate", or "large". So far as active-edge pumping in the "slight" classification is concerned, no mileage is affected in the LaPorte District of 48.670 treated mi. in the Fort Wayne district, 6.089 mi. or 12.511 percent are affected; of 57.793 mi. treated in the Crawfordsville District, 10.904 mi. or 18.867 percent are affected; of 82.198 mi. in the Greenfield District, there are 16.034 mi. or 19.507 percent affected; of 50.337 mi. treated in the Vincennes District, 0.550 mi. or 1.093 percent are affected; of 40.947 mi. treated in the Seymour District, 5.183 mi. or 12.658 percent are affected, and of 328.548 treated-miles in the state, a total of 38.760 mi. or 11.797 percent have slight active-edge pumping. There is no active-edge pumping falling into the "moderate" or "large" categories. In other words, in the most serious defect class, "active-joint pumping", there is no affected mileage; and in the second most serious defect class, the only affected mileage is in the "slight" category and totals 11.797 percent of total mileage treated in the state.

In Class 3, "inactive-joint pumping", there is no mileage in the "moderate" or "large" categories of any district. In the "slight" category, there are 12.716 mi. or 22.003 percent of the total treated in the Crawfordsville District, which are affected, 5.005 mi. or 6.089 percent affected in the Fort Wayne District; 8.774 mi. or 17.431 percent in the Vincennes District, 5.809 mi, or 14.187 percent in the Seymour District; and a total of 32.304 mi. or 9.832 percent of the treated mileage for the entire state.

In Class 4, "inactive-edge pumping", there is no mileage in the "moderate" or "large" categories of any district. In the "slight" category, there are 15.661 mi. or 32.222 percent of the total treated in the LaPorte District which are affected; 25.562 mi. or 52.521 percent in the Fort Wayne District; 26.392 mi. or 45.666 percent in the Crawfordsville District; 15.074 mi. or 18.339 percent in the Greenfield District; 5.646 mi. or 11.216 percent in the Vincennes District; 13.261 mi. or 32.386 per-

TABLE 5

SUMMARY OF MILEAGE IN SLIGHT, MODERATE OR LARGE CATEGORIES FOR EACH OF SIX CLASSES OF DEFECTS

DEFECT	AMOUNT	LAPORTE Miles	LAPORTE Percentage	FT WAYNE Miles	FT WAYNE Percentage	CRAWFORDSVILLE Miles	CRAWFORDSVILLE Percentage	GREENFIELD Miles	GREENFIELD Percentage	VINCENNES Miles	VINCENNES Percentage	SEYMOUR Miles	SEYMOUR Percentage	TOTALS Miles	TOTALS Percentage
Active Joint Pumping	Slight														
	Moderate														
	Large														
Active Edge Pumping	Slight			6 089	12.511	10.904	18.867	16 034	19.507	0 550	1.093	5 183	12 658	38 760	11 797
	Moderate														
	Large														
Inactive Joint Pumping	Slight					12 716	22.003	5 005	6 089	8 774	17 431	5 809	14.187	32.304	9.832
	Moderate														
	Large														
Inactive Edge Pumping	Slight	15 661	32.222	25.562	52.521	26.392	45.666	15.074	18.339	5 646	11.216	13 261	32 386	101 596	30.923
	Moderate														
	Large														
Second Stage Blow Holes	Slight			6.089	12 511	24.433	42 277	45 175	54.959					75.697	23 040
	Moderate			4.989	10 251									4 989	1 518
	Large			6.571	13 501									6.571	2.000
First Stage Blow Holes	Slight	15.237	31.350	26.397	54.237	31 081	53.780	46.849	56.995	24 392	48 457	21 352	52.145	165.308	50.315
	Moderate	4.107	8.450	3.060	6.287			10.120	12 312			7.452	18 199	24 739	7 530
	Large			17 649	36.263			4 496	5 470					22.145	6.740
Restraint Cracks	Slight			31.340		31.081		49 149		20 761		26 234		158.565	
	Moderate														
	Large														
Miles Treated		48 603		48.670		57 793		82.198		50.337		40.947		328.548	

TABLE 6

SUMMARY OF MILEAGE WHERE NUMBER OF DEFECTS PER MILE ARE LESS THAN TWO FOR EACH OF SIX CLASSES OF DEFECTS

	LAPORTE Miles	LAPORTE Percentage	FT. WAYNE Miles	FT. WAYNE Percentage	CRAWFORDSVILLE Miles	CRAWFORDSVILLE Percentage	GREENFIELD Miles	GREENFIELD Percentage	VINCENNES Miles	VINCENNES Percentage	SEYMOUR Miles	SEYMOUR Percentage	TOTALS Miles	TOTALS Percentage
Active Joint Pumping														
Active Edge Pumping			6 089	12 511	10 904	18 867	10.578	12 869			5 183	12 658	32 754	9 969
Inactive Joint Pumping					12.716	22.003	5.005	6 089	8 774	17.431	5 183	12 658	31.678	9 642
Inactive Edge Pumping	15 661	32.222	14 138	29 049	26.392	45 666	15.074	18 339	5 646	11 216	8 433	20 595	85 344	25 976
Second Stage Blow Holes					24 433	42.277	23.470	28 553					47 903	14 580
First Stage Blow Holes	10.414	21.427	20 859	42 858					15.618	31 027	8 208	20 045	55 099	16 770
Restraint Cracks			8 838		10.904		13.642		6 341		10 821		50 546	
Miles Treated	48 603		48 670		57.793		82 198		50.337		40 947		328 548	

cent in the Seymour District; and a total of 101.596 mi. or 30.923 percent of the treated mileage for the entire state.

In Class 5, "second-stage blows", in the "slight" category there are 6.089 mi. or 12.511 percent affected in the Fort Wayne District; 24.433 mi. or 42.277 percent in the Crawfordsville District; 45.175 mi. or 54.959 percent in the Greenfield District; none in the remaining districts, and a total of 75.697 mi. or 23.040 percent for the entire state. In the "moderate" category, there are 4.989 mi. or 10.251 percent in the Fort Wayne District, and a total of 4.989 mi. or 1.518 percent for the entire state. In the "large" category, there are 6.571 mi. or 13.501 percent in the Fort Wayne District and a total of 6.571 mi. or 2.000 percent for the entire state.

In Class 6, "first-stage blows", in the "slight" category, there are 15.237 mi. or 31.350 percent in the LaPorte District; 26.397 mi. or 54.237 percent in the Fort Wayne District; 31.081 mi. or 53.780 percent in the Crawfordsville District; 46.849 mi. or 56.995 percent in the Greenfield District; 24.392 mi. or 48.457 percent in the Vincennes District; 21.352 mi. or 52.145 percent in the Seymour District, a total of 165.308 mi. or 50.315 percent of the treated mileage for the entire state. In the "moderate" category, there are 4.107 mi. or 8.450 percent in the LaPorte District; 3.060 mi. or 6.287 percent in the Fort Wayne District; 10.120 mi. or 12.312 percent in the Greenfield District; 7.452 mi. or 18.199 percent in the Seymour District, and a total of 24.739 mi. or 7.530 percent for the entire state. In the "large" category, there are 17.649 mi. or 36.263 percent in the Fort Wayne District; 4.496 mi. or 5.470 percent in the Greenfield District, and a total of 22.145 mi. or 6.740 percent of the treated mileage for the entire state. Figure 14 shows the mileage and its percent of the total treated in the "slight," "moderate," and "large" categories for each of the six classes of defects graphically.

On the basis of the data presented in the column labeled "totals" in Table 5, it can be observed that under the four most serious defects, active-joint pumping, active-edge pumping, inactive-joint pumping, and inactive-edge pumping, the defects that are present are all in the "slight" category and the percentages of miles affected vary from 0 percent to 30.923 percent. Of the two least serious defects, there are 23.040 percent and 50.315 percent of the total mileage treated in the "slight" category, 1.518 percent and 7.530 percent in the "moderate" category, while 2.000 percent and 6.740 percent of the total are in the "large" category. In other words, where the most serious defects are involved, the amounts involved are slight; while in the least serious defects, the amounts increase.

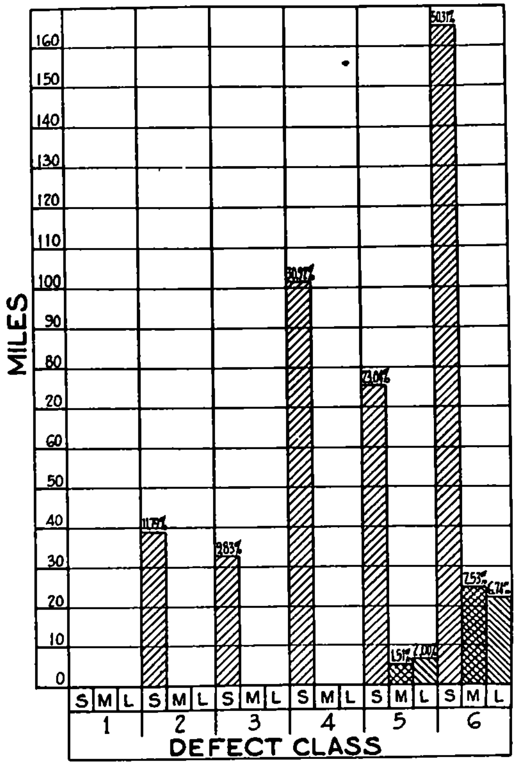


Figure 14. Summary of mileage and percents of total mileage in slight, moderate, or large categories for each of six classes of defects as shown in table No. 5.

Table 6 is included to show the degree of slightness of values shown under "slight" in Table 5. As stated before, the mileage of a project is included in the "slight" category for each defect or class, if the number of that particular defect amounts to 30 or less per mi. Table 6 shows the mileage for each defect or class, when the num-

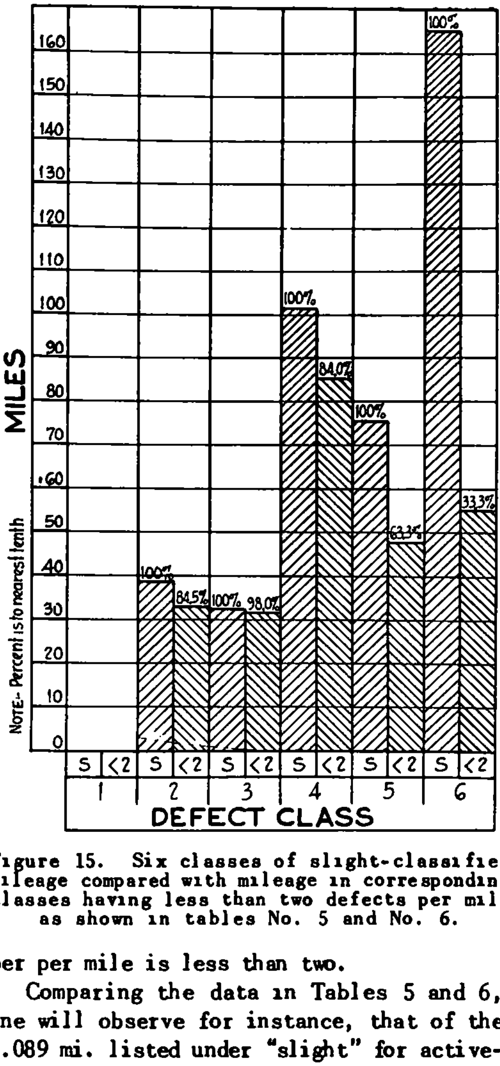


Figure 15. Six classes of slight-classified mileage compared with mileage in corresponding classes having less than two defects per mile as shown in tables No. 5 and No. 6.

ber per mile is less than two.

Comparing the data in Tables 5 and 6, one will observe for instance, that of the 6.089 mi. listed under "slight" for active-edge pumping in Table 5 in the Fort Wayne District, 6.089 mi., the entire amount, have less than two defects per mi., as shown in Table 6; of 16.034 mi. listed under "slight" for active-edge pumping in the Greenfield District, 10.578 mi. have less than 2 defects per mi. The same comparison can be made for each "slight" classification figure for each defect in every district. Likewise, totals for the state of each defect, can be compared. Such a comparison shows that of 38.760 mi. of the "slight" classified active-edge pumping, a total of 32.754 mi. have less than 2 defects per mi., which is 84.5 percent of the total for this classification, while 15.5 percent or 6.006 mi. have between 2 and 30 defects per mi.; of 32.304 mi. of "slight" classified inactive-joint pumping, a total of 31.678 mi. have less than 2 defects per mi., which is 98.06 percent of the total for this classification; of 101.596 mi. of "slight" classified Inactive-Edge Pumping, a total of 85.344 mi. have less than 2 defects per mi., which is 84.0 percent of the total for this classification; of 75.697 mi. of "slight" classified second-stage blows, a total of 47.903 mi. have less than 2 defects per mi., which is 63.28 percent of the total for this classification; and of 165.308 mi. of "slight" classified first-stage blows, a total of 55.099 mi. have less than 2 defects per mi., which is 33.33 percent of the total for this classification. Figure 15 shows these comparisons graphically.

On the basis of the data presented in Tables 5 and 6, one can observe that for the four most serious classes of defects, the entire mileage of treated pavement falls in the "slight" category, and that the percentage of this mileage having less than 2 defects per mi. of the various classifications varies from 84.0 percent to 98.06 percent. In other words, the percentage of mileage of treated pavement falling outside the extreme lower limits (less than 2 defects per mi.) of the "slight" category for each of the four most serious defects is so small, it is apparent that the amount of resultant damage may be considered negligible. One can observe that for the two least serious classes of defects (Classes 5 and 6), the percentage of the mileage having less than 2 defects per mi. is somewhat less, 63.28 percent and 33.33 percent respectively. Although this shows that there are a greater number of defects in these two classes, the resultant damage to the pavement structure can be considered as infinitesimal, since the nature of the defects themselves appear to have had little affect on pavement performance at the time of the investigation.

As mentioned previously in this report, supplemental information or data were taken on another type of defect, "restraint cracks", which appeared during the course of the field inspections. From Columns 16 and 9 of Table 2, it can be observed that of the 82 projects covered in this study, 46 totaling 206.367 mi. in length were examined for this particular defect. Of the remaining 36 projects, four totaling 17.603 mi. have been resurfaced so that it is impossible to determine whether or not this condition is present, leaving 32 projects totaling 104.578 mi. of nonresurfaced pavement upon which there is no data included herein regarding "restraint cracks". From Tables 2 and 5, one can observe that of the 46 projects inspected, 29 totaling 158.565 mi. are afflicted with this defect and the average number per mile varies from 0.16 to 22.01, which places the entire mileage in the "slight" category when the same qualifications for such rating of other defects is applied. Table 6 shows that 50.546 mi. of the total have less than 2 "restraint cracks" per mi. Perhaps the most signifipoint regarding these data is that 183.750 mi. of the 206.367 observed were constructed with no expansion joints, yet all of the "restraint cracks" observed with the exception of one, totaling 1198, occur on the projects where there are no expansion joints. Only one "restraint crack" was observed on the 22.617 mi. in which expansion joints were incorporated.

CONCLUSIONS

It is the prevailing opinion among the engineering staff of the State Highway Commission of Indiana that granular bases have been an aid in preventing pumping and increasing the performance and life of rigid pavements; but, due to the fact that no detailed observations or surveys have previously been made, it has been impossible to know just how effective such treatments have been.

From the data included herein and the analysis of the same, it is the author's opinion that the succeeding statements and conclusions are in order:

1. Granular base courses have been very effective in preventing pumping of rigid pavements for the following reasons:

(a) Analysis of data shows that 295.661 mi. or 89.989 percent of treated mileage falls into groups which are considered to be showing very good performance.

(b) There are no active-pumping joints or cracks on the 328.548 mi. of treated pavements.

(c) There are but 44 active-edge pumping spots, 21 inactive-pumping joints or cracks, and 107 inactive-edge pumping spots on the 328.548 mi. of treated pavements.

(d) Of the 21 inactive-pumping joints or cracks, 10 are located on granular bases, which according to sieve-analysis are on the high side of the specification for material passing the No. 200 sieve. Most of these are construction joints which are not sealed.

(e) Where the four most serious defects exist, 100 percent are in the "slight" category (0 to 30 defects per mi.) and of the mileage affected, a very large percent have less than 2 defects per mi.

(f) 114.220 mi. have no defects of any class.

(g) Pavements constructed on granular bases on such heavy duty roads as U. S. Routes 30, 41, 24, 52, 40, 31, and Indiana Routes 57, 46, and 100 falling in good-performance groups, have a total of but 22 active-edge-pumping spots, four inactive-pumping joints or cracks, and 13 inactive-edge-pumping spots, while pavements constructed without granular bases either parallel to or adjoining are or were pumping seriously. Some of these have been resurfaced lately. It should also be noted that for each of the subgrade-treated projects on these roads, the traffic conditions are practically the same on the parallel or adjoining sections, where there are large amounts of pumping.

2. First- and second-stage blows are newly developed defects which bear watching, but up to the present do not appear to have affected pavement performance. An effort should be made to remedy the cause. It is believed that a less-dense-granular base, subgrade-treatment drainage or stabilized shoulders of some description might aid. It should be noted that no blows existed at any point within the limits of bituminous or granular road approaches.

3. Blows are more prevalent in the vicinity of transverse joints. This indicates that there is more deflection of the pavement at these points during the passing of heavy-wheel loads and that there is a

need for increasing the capacity of the load-transfer devices.

4. Construction joints should be installed in a manner conducive to being sealed.

5. Further study should be made in an effort to correlate the number and weight of heavy loads with defects that exist. Data should be secured on the number of single and tandem axles. These data should also be correlated with the analysis of material used in the bases.

6. Checks should be made at certain periods or intervals of time in order to determine whether conditions found on projects during this study are progressing or possibly being arrested.

7. Supplemental data on restraint cracks show that such defects occur when expansion joints are eliminated. Further checks should be made in order to determine their progress and seriousness. If proved to be a serious defect, steps should be taken to eliminate the cause.

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DISCUSSION

M. P. BROKAW, *Regional Highway Engineer, Portland Cement Association* - It was this writer's fortune to observe many of the projects studied in Indiana and be present during some of the field investigations. In addition, the Portland Cement Association has conducted several independent surveys both in Illinois and Indiana.

Since granular subbases are employed primarily to prevent pumping, the results of the Indiana survey are particularly significant. Vogelgesang has not found evidence of active joint or crack pumping in any of the 328.548 mi. surveyed. However, 21 inactive pumping cracks or joints were observed without evidence of damage resulting from the action. It is important to note that 10 of the 21 locations were on project F 130(7), where new construction was placed on old pavement which was pumping severely. In this project the old slab was broken into small fragments before the 5-in. subbase was laid. It is possible that poor drainage existing in the original soil subgrade reduced the stability and effectiveness of the subbase.

In addition, the survey also shows the presence of 151 active and inactive edge-pumping locations. There seems to be a reasonable doubt as to their identity, since first-stage blows, in which shoulder soil is removed by water action, present an appearance of mud-pumping. It would be valuable to know if excavations were made in the shoulder to determine the origin of the mud stains which were considered evidence of pumping.

Edge blows observed by Vogelgesang were first identified and studied in the Illinois pumping survey conducted in 1946. At that time 67.9 mi. of pavement constructed on granular subbase were examined. The following is quoted from the Illinois report:

> Some instances of eroded holes were found at the edges of pavements near joints and cracks. These holes had the same appearance as those usually identified with pumping, although no evidence was found of subbase material being ejected from underneath the pavement. Rather, several excavations in the shoulders showed shoulder material washed between pavement and subbase.... It is quite likely that consolidation of subbase or subgrade under traffic has been largely responsible for both the faulting and the holes, and that both can be substantially reduced by compaction of subbase and subgrade to a density capable of supporting the loads imposed without detrimental consolidation.
>
> Free water was found in subbases in some instances, usually immediately after heavy rains. Although neither faulting nor shoulder holes could be definitely traced to free water in the subbase, it is more than likely that free water would hasten the consolidation of an insufficiently compacted subbase and cause their occurrence.

In 1950, the Portland Cement Association resurveyed 10 of these projects and found a reduction in the number of shoulder holes or edge blows in 5, and increase in 2 and no change in 3 of the projects. Five of the projects were free of shoulder holes and none showed evidence of pumping.

Previous findings of the pumping committee show that 55 percent of sand and gravel in a native soil or artificial subbase are sufficient to prevent pumping in the presence of water. Considering current practices in subbase design, it is probable that water will be retained on the surface of subbases containing appreciable quantities of silt and clay. To remove this water would require subbases containing a very small amount of fines so that the permeability would be sufficient to provide immediate and rapid drainage. In addition, pipe drains or extensions of the subbase

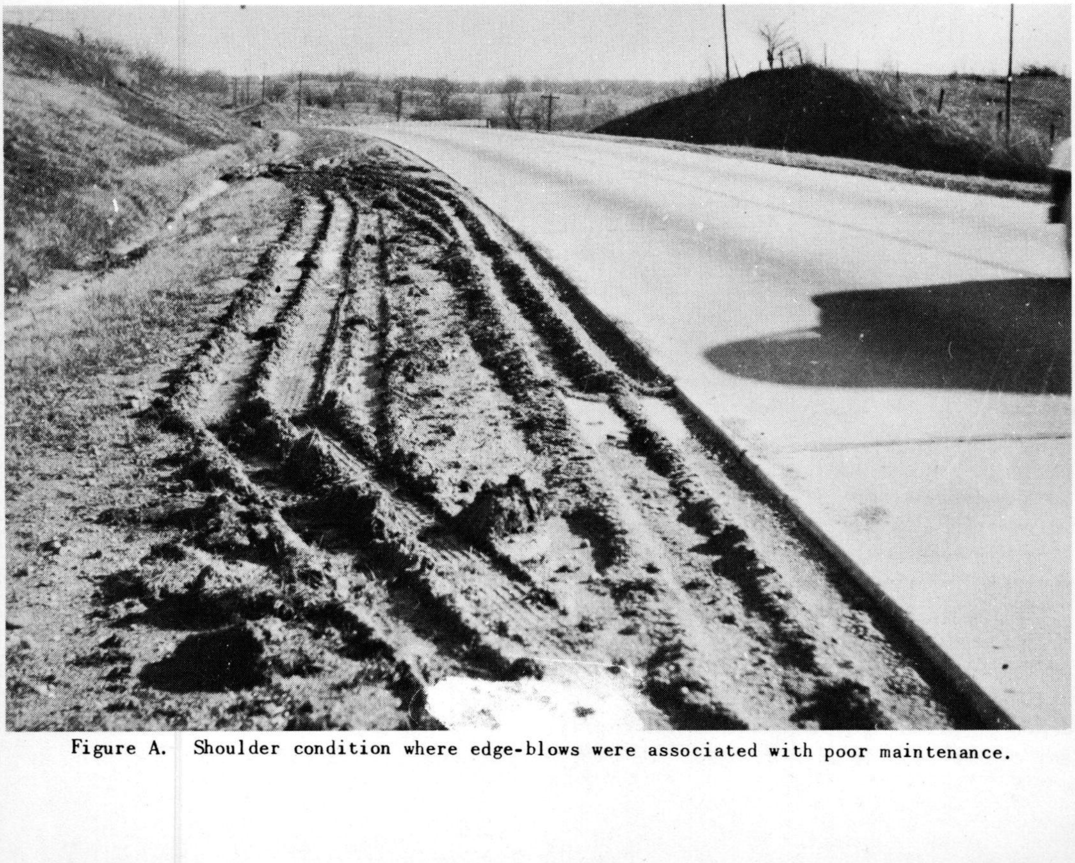

Figure A. Shoulder condition where edge-blows were associated with poor maintenance.

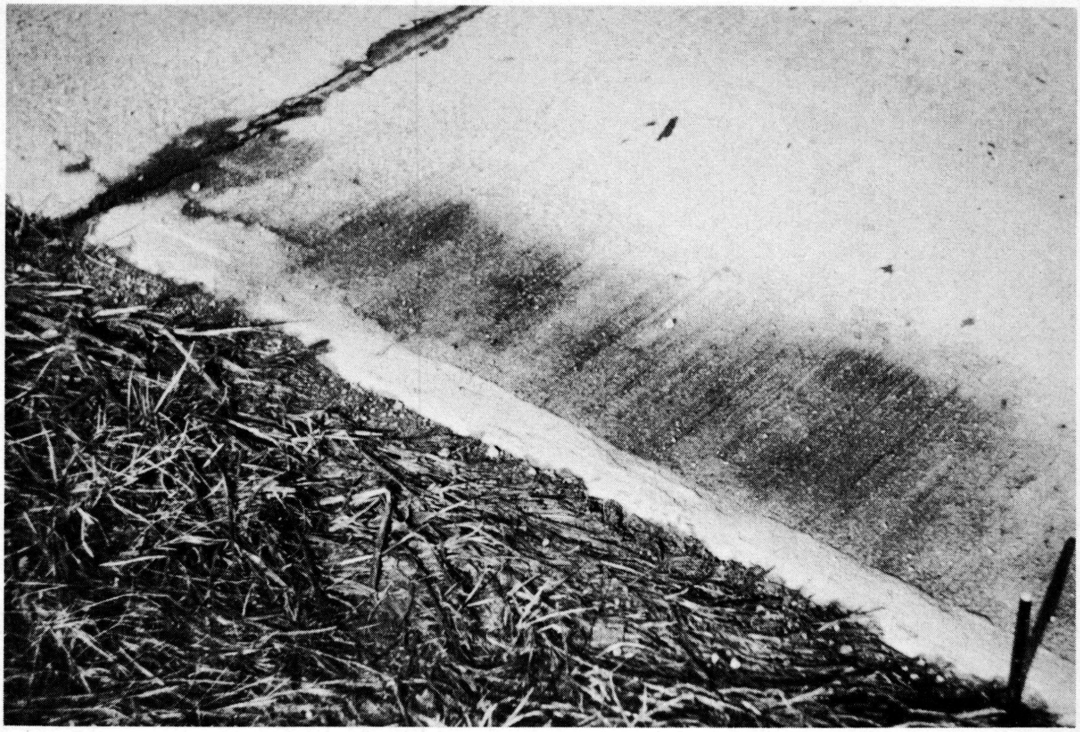

Figure B. Edge condition near Station 260+33 on Project 13 D2 18 months after an edge-blow was excavated and backfilled. Replacement and compaction of shoulder material have removed conditions causing the edge-blow illustrated in Figures 6, 7 and 8.

through the shoulders would be necessary to prevent water-logging. These additions are quite costly in most instances and are not always effective. Therefore, it is attractive to consider means by which the performance of impermeable subbases can be improved.

Investigations show that edge-blows do not occur where flat gutters have been attached to the pavement to provide berm and ditch protection on superelevated curves, steep grades or in cuts where the berm and ditch width is reduced. This indicates that the water responsible for edge-blows originates on the surface of the pavement and penetrates to the subbase through shoulder shrinkage cracks at the pavement edge. Examination of many miles of pavement verifies that edge-blows may be observed where shoulders have high-shrink characteristics or are low, rutted and improperly maintained. Figure A shows a shoulder condition where edge-blows were associated with poor maintenance on project F 792(7) Part B. Likewise longitudinal sodded strips at the edge of the pavement have been noted to shrink away and allow entry of surface water during periods of rainfall.

On the other hand, observations show an absence of edge-blows where the shoulders are dense, well-compacted and given good maintenance. In those localities where shoulder maintenance consists of dragging and addition of granular material to prevent edge-rutting and preserve transverse drainage, edge-blows have not been found.

It is also significant that the water responsible for edge-blows is not present continuously at the edge or under the pavement in affected areas. Excavations in active edge-blows have shown the presence of water, while similar excavations made within one foot of the active location have been free of water both at the edge and under the pavement. This feature indicates that the precise location of an edge-blow may be fixed by voids, pockets or volumes of loose material which provide a reservoir for impounding water in the shoulder embankment.

Construction practices followed on most of the Indiana projects contribute to shoulder defects of this type. Final grade of the subbase is obtained by operation of mechanical subgraders which deposit excess granular material at form-side. This material, conbined with accumulations of waste concrete and shoulder debris, are commonly bladed against the exposed edges of the pavement for a curing agent. The resulting lack of uniformity in shoulder composition and compaction at slab-edge provide conditions favorable for edge-blow occurrence.

Further verification of this theory was undertaken in observations made on Indiana project 13D2 of which Vogelgesang shows Figures 6, 7, and 8, illustrating the excavation of a second-stage blow. The excavation was made during the spring of 1950. Upon completion of the work, the hole was filled and tamped. Eighteen months later the location was again visited to determine if the edge-blow had resumed activity. Figure B shows the edge condition at that time. There are no indications of either first- or second-stage blows and the turf has been completely regrown. There seems little doubt that replacement and compaction of existing shoulder material were instrumental in removing conditions conducive to forming an edge-blow.

Vogelgesang reports restraint cracks in several projects and suggests that elimination of expansion joints may have contributed to their presence. Restraint cracks may be caused by infiltration of dirt, sand, or other fine debris into unprotected joints or cracks. When this occurs, subsequent high temperatures cause unequal distribution of compressive stresses across the obstructed joint which results in the typical crow-foot crack observed on the Indiana projects or in surface spalls or edge spalls, depending upon the location of the intruding material.

Restraint cracking may be prevented or minimized in pavements without expansion joints by spacing contraction joints at close intervals. Joints so spaced will open only slightly and have small annual movement which adds to the longevity and effectiveness of the sealing material. Where expansion joints have been eliminated, this is an important consideration since the available expansion space is supplied in each contraction joint by setting and drying shrinkage of the concrete. Loss of this space by infiltration results in establishing a condition favorable for early restraint cracking. Even where expansion joints are used, lack of adequate joint and crack maintenance may result in restraint cracking although it will be delayed for some time.

Advantages arising from omission of expansion joints outweigh the risk of restraint cracking, and observations over a long period show little, if any, distress resulting from the cracks.

It has been observed on most of the Indiana projects that contraction joints, spaced at 40 ft., have been well sealed at the surface. Since the restraint cracks are near the edge, it is more than likely that joint obstructions have been caused by soil washed in from the shoulder during edge-blow activity. Protection from this infiltration could be provided by closer spacing of joints.

Vogelgesang has indicated the need for additional study of some of the features brought out by his survey. Much could be accomplished with data accruing from an intensive field and office investigation. Without information on the gradation and in-place densities of subbase materials, the composition and soil classification of shoulder embankments, the location of edge-blows correlated with alignment and gradient, and other pertinent data from the construction records, it is difficult to explain some of the inconsistencies in performance where pavements have been designed and constructed under apparently identical specifications and conditions.

The illustrations and discussion in the paper apply to edge-blow locations which were most spectacular. Since these do not represent a general condition, their presence need not detract from the excellent service rendered. The fact that 90 percent of the mileage is showing "very good performance" and that the balance falls slightly outside of this category because of edge-blows, seems adequate justification for retaining the economy of impermeable, trenched-in subbases.

Present knowledge indicates that several steps should be taken to prevent edge-blows and improve subbase performance.

(1) Subbases should be constructed with a measured density not less than 95 percent of standard (AASHO T99-49).

(2) Shoulder enbankment should be constructed with a density not less than 95 percent of standard (AASHO T99-49).

(3) Where possible, shoulder material should be selected for nonshrink characteristics.

(4) Efforts should be made to obtain adequate shoulder maintenance.

CARL E. VOGELGESANG[1] *Closure* - There is need for further study of granular bases. Although, in general, performance in Indiana has been satisfactory, it is difficult to predict future performance with the upward trend in weight and size of vehicles that is prevalent.

Brokaw's remarks are timely and, in general, verify opinions held by the writer. It is interesting to note that Illinois identified edge blows in 1946 as "eroded holes," and that "no evidence was found of subbase material being ejected from underneath the pavement. Rather, several excavations in the shoulders showed shoulder material washed between pavement and subbase." Insofar as we know, this conditiin does not exist in Indiana. All our evidence points to the eroding of the surface of the subbase in the process of developing first-stage blows (open), and with progressive action, the eventual ejection of granular material, thus the creation of second-stage blows. This is contrary to previously reported information to the effect that a material composed of 55 percent of sand and gravel in a native soil or artificial subbase is sufficient to prevent pumping in the presence of water.

The discussion mentions the desirability of considering means by which the performance of impermeable subbases can be improved for economic reasons. Certainly this is a worthy goal. However, it is questionable how much an impermeable granular base for a pavement subjected to a large volume of heavy axle loads can be improved. Indiana has recently (June 1952) done some experimental work on existing projects in an effort to find means of improving the performance of densely graded granular bases. This consisted of the removing of relatively high-volume-change soil along the pavement edge and replacement with a dense, well-compacted mixture containing a high percent of granular material. This treatment was applied at widely separated locations on several projects that have shown a high percentage of edge blows. Although it is too early to predict the results, first-stage blows have since developed at several installations. It is possible that at these particular locations, pavement bearing or support has decreased or been lessened by previous action to the point that pavement deflections under heavy loads are great enough that edge blows will continue to develop.

Although the writer is not familiar with the details of construction of concrete pavements in other states, it is believed that the practices in Indiana are not much different from those of other highway departments, in regard to possibilities cited in the discussion as contributing factors to the creation of edge blows in this state. Insofar as excess granular material, along with other debris, being deposited at pavement edges by mechanical subgraders, which could be bladed against exposed edges, thus forming pockets for potential blows, it does not appear that this is a major factor in developing blows, in that so far as is known, all mechanical subgraders in use in this state deposit the granular material trimmed from the finished subgrade on one side of the pavement only. Yet edge blows occur on both sides; also that to date, excavation of blows have not revealed any "nest or pocket" of waste concrete or debris at pavement edges, nor very little lack of uniformity in shoulder compaction and composition.

Figure B shows the edge condition 18 months after the investigation illustrated by Figures 6, 7, and 8. Although there is not much evidence of granular material at the pavement edge shown in Figure B, a recent check at this location revealed that the original investigation extended from approximately Station 260+32.5 to Station

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260+34.5; that a second-stage blow now exists between Station 260+31.5 and Station 260+32, and another from Station 260+34 to Station 260+41.4, while a first-stage blow exists at the joint. From this it seems possible that previously existing pressures, which were relieved by the original blow, were possibly recreated when the original excavation was filled, and have subsequently been relieved by new blows on each side of the original.

Under Indiana specifications, it is possible to use a granular mixture with a relatively high percentage of material passing the No. 200 sieve. Some of our poorest performing bases are those where sieve analyses show from as high as 15 to 18 percent minus 200-mesh material. However, blows are occurring on bases having 9 percent passing the 200-mesh sieve. There is no doubt that poor shoulder maintenance contributes to the development of blows; on the other hand, there are many blows on well-maintained shoulders.

The writer, during the year of 1951, rechecked 150 mi. of the heaviest truck routes. Spot checks have been made during 1952 and data compared with that of 1950. Some blows have disappeared during that time, some are still present and others have developed. It cannot be predicted just what future checks will show.

From data available, it is evident that restraint cracks occur only on projects where there are no expansion joints with one exception. Elimination of restraint cracks by changing contraction-joint spacing cannot be predicted. There is no doubt that restraint cracks are caused by the infiltration of foreign material at the pavement edge. It is our belief that they are also caused by fine particles of soil or granular material being forced upward from the subgrade into the open joint when water is present and at the time of the passing of heavy loads.

Although edge-blow conditions in general, discussed in the report, were those which were cited by Brokaw as the most spectacular, their prevalence on several projects and their magnitude indicate that they could become harmful to pavement life.

At present, the exact period of life added to pavements through the use of these granular bases is not known, but we feel certain that it is appreciable. It is believed, with further study and subsequent improvement in construction methods and materials used, additional life can be attained over that already secured.

Performance of Concrete Pavements on Granular Subbase

W. E. CHASTAIN, SR., *Engineer of Physical Research, and* JOHN E. BURKE, *Assistant Engineer of Physical Research, Bureau of Research and Planning, Illinois Division of Highways*

● DURING and since World War II, Illinois has been placing all new concrete pavement on granular subbase where the natural soil is fine-grained and heavy truck traffic is expected. Both trenched and shoulder-to-shoulder subbases have been used. The trenched subbases, however, have been used much more frequently than have those which have been extended through the shoulders. They have usually been built with fairly well-graded and potentially high-density materials in which void space can be reduced to a minimum. Drainage has not been provided with the trenched subbases except under unusual conditions or at infrequent intervals. Drainage has usually been provided where soil surveys show important concentrations of ground water. Most of the subbases have been built 6 in. in compacted thickness, although 4-in. subbases and subbases greater than 6 in. thick have also been used. Several miles of 4-in. subbase placed under a concrete pavement carrying very heavy truck traffic have been in service for seven years without evidence of pumping. This pavement is being kept under close observation. Subbases thicker than the generally specified 6 in. have usually been used where soil studies indicate the likelihood of detrimental frost action or very low load carrying capacity of the existing soil.

The much lower cost of constructing the trenched, undrained subbase has been a deciding factor in the preference which has been thus far shown for this type of subbase. Fairly well-graded materials which do not respond well to drainage are generally much more readily available in Illinois than are open-graded, easily drained materials. Also, the substantial economy to be gained by omitting drainage facilities has made it very desirable that the undrained subbase be tested thoroughly before adopting a more expensive design requiring drainage. The trenched subbases appear to be performing satisfactorily, but observations of their performance are continuing.

A specification governing a gradation for subbase materials was first included in the Illinois standard specifications in 1942. It was at that time that it became apparent that concrete pavements required protection against contact with fine-grained soils where they were expected to carry concentrations of heavy commercial traffic. The standard specifications which were issued in 1942 prescribed the following gradation limits for granular subbase materials:

Passing 3-in. sieve - 100 percent
Passing No. 4 sieve- Not less than 35 nor more than 65 percent
Passing No. 50 sieve -Not more than 20 percent
Total clay and silt not to exceed 10 percent.

These specifications were adjusted in many instances to fit locally available materials. The local materials were usually somewhat finer than permitted under the standard specifications but appeared to have granular contents sufficient to prevent pumping, or at least to hold it within a negligible limit. The standard specifications were changed in 1947 to increase the likelihood of obtaining relatively impervious materials. The new specifications, in which separate requirements were prescribed for gravels and crushed stones, were as follows:

Passing	Gravel Percent	Crushed Stone Percent
3-in. sieve	100	100
No. 4 sieve	45 to 90	20 to 60

No. 50 sieve	5 to 25	5 to 25
No. 200 sieve	3 to 10	3 to 15

The lower limit for the No. 200 sieve was raised from 3 to 5 percent in 1951.

A compaction to at least 90 percent of the maximum wet density, as determined by standard AASHO testing procedure, is required for embankment construction in Illinois. In addition, no material may be placed when the moisture content exceeds 120 percent of wet optimum.

GENERAL PERFORMANCE

Pumping - The granular subbases which have been placed in Illinois appear to be aiding materially in the control of pumping. Although pumping has not been completely eliminated, its control is not a major maintenance problem where subbases have been used. Only isolated ejections of granular material have been noted, and so far as is known, such ejections have been mostly confined to US 66, the main highway between Chicago and St. Louis, carrying some of the heaviest truck traffic in the state.

Shoulder Holes - Holes in the shoulders at the pavement edges and in the vicinity of transverse joints and cracks, similar to those found in connection with pumping but with no sign of ejected material, have been found on numerous occasions where the pavements in Illinois lie on granular subbases and carry heavy traffic. These holes have also been found in some instances where granular subbases have not been used. In this report such holes will be referred to as "shoulder holes" where no ejected material, either granular or fine-grained, is found in connection with them. Where either granular or fine-grained material is found to have been ejected, the term "pumping" is applied.

Shoulder holes were probably first observed in Illinois on US 66 soon after some pavement placed between Pontiac and Dwight during the war was opened to traffic. This pavement is 10 in. thick and 24 ft. wide, and placed on a 6-in. trenched and undrained subbase built 2 ft. wider than the pavement. Bituminous fiber expansion joints were placed at 120-ft. intervals in the pavement and intermediate weakened-plane contraction joints at 20-ft. intervals. No load-transfer devices were used. In addition to the shoulder holes and a few isolated spots of pumping, this pavement has developed slight faulting at most of the joints.

The shoulder holes which have been seen in Illinois are usually found within a few feet of a transverse joint or crack and generally ahead of the joint or crack in the direction of traffic. They vary in size from perhaps the diameter of a pencil to an eroded hole 1 to 1½ in. long and 3 or 4 in. wide. The holes in most instances appear to extend to the bottom of the pavement. Holes of the larger size mentioned are not common.

The performance of the pavement between Pontiac and Dwight, and of other pavements of the same and of differing designs, was studied in Illinois in 1946 during a survey of pumping made in cooperation with the Portland Cement Association. The study showed the shoulder holes to be not uncommon in connection with pavements placed on granular subbases and carrying heavy traffic. However, no pumping was found at that time in connection with granular subbases.

Several subbase density tests made through core holes in the pavements during the Portland Cement Association study indicated that the subbases generally had densities somewhat less than the maximum dry density as determined by standard AASHO methods. An average dry density of about 94 percent was indicated.

The subbase materials which have usually been used in this state, and in connection with which shoulder holes have usually been found, are generally fairly well graded and have from perhaps 4 to 17 percent passing the No. 200 sieve.

ROUTE 66 STUDY

The Illinois Division of Highways is at the present time engaged in making a comprehensive study of the performance of the entire length of US 66 between Springfield and Chicago. Although the performance of the granular subbases is being observed in detail, the study is not limited to subbases but includes detailed observations of over-all road performance. The study was initiated in 1949 and the preliminary condition survey and sketching of the pavement completed in 1951. About 180 mi. of pavement, both with and without subbase, have been included in the study. The present plan is to continue the study from year to year, noting the effects on performance of such items as design, materials, traffic, and climate. The initial field work has consisted of noting and mapping all failures and unusual conditions, including cracks, pumping at joints and cracks, shoulder holes, faulting, spalling, corner breaks, scaling, D-cracking, and raveling. Subgrade soils and subbase materials, and the conditions of subgrades and subbases, including their densities, permeabilities, and moisture contents are to be studied in detail, but no work has yet been done on these features.

The pavement included in the study carries one of the highest volumes of traffic of any rural pavement in the state, averaging about 5,000 vehicles per day during 1950. Vehicle counts made near Dwight, which is immediately north of most of the subbase sections, indicated an annual daily average of 1,530 commercial vehicles, including 1,150 semi-trailers and full trailers. Counts made near Sherman, which is immediately south of the subbase sections, showed an annual daily average of 1,640 commercial vehicles, including 1,050 semi-trailers and full trailers. The legal axle-load limit in Illinois is 18,000 lb. for single axles, and 16,000 lb. for each tandem axle. Until a concerted effort was recently made to enforce these restrictions, violations were numerous.

A total of 84.8 mi. of concrete pavement placed on granular subbase has been examined during the course of the condition survey. The subbases include the trenched type and some which have been extended through the shoulders (see Fig. 1). Drainage was provided with the trenched type at only isolated locations. All pumping and shoulder hole locations visible at the time of the survey were noted.

A limited amount of pumping and numerous shoulder holes were observed in connection with the granular subbases during the survey. Not much difference was noted between the performance of trenched and shoulder-to-shoulder subbases where the pavement designs were the same. However, no effort is being made to compare the performance of the trenched subbases and of those which have been brought through the shoulders until additional information is available concerning their densities, permeabilities, and material characteristics.

The pavements on granular subbase included in the survey are of two general designs (see Fig. 2), but all have the same thickness and width: 10 in. by 24 ft. Those built during the war years contain no reinforcing, have bituminous-fiber expansion joints at 120-ft. intervals and intermediate weakened-plane contraction joints at 20-ft. intervals. No load-transfer devices have been provided. The postwar pavements included in the study contain mesh reinforcement weighing 78 lb. per 100 sq ft., and have bituminous fiber expansion joints at 100-ft. intervals. Round dowels ¾-in. by 18-in., are placed at 13½-in. centers for load transfer at the expansion joints. There are no intermediate contraction joints.

Pumping - A limited amount of pumping was found to be taking place on granular subbase in connection with both pavement designs (see Table 1). For the wartime design, the likely effectiveness of the subbase in controlling pumping may be measured by comparing the pumping found on granular subbase with that found for the same design of pavement placed on the natural fine-grained subgrade. A total of 20.2 mi. of this type of pavement placed on granular subbase showed 2.4 pumping locations per mile, while 18.1 mi. of similar pavement placed on a fine-grained subgrade showed 79.4 such locations per mile at the time of the survey. All of this pavement replaced a severely damaged existing concrete slab of thinner section which showed excessive pumping on fine-grained subgrades. Pumping of the new (built 1943) pavement on the natural soil had become sufficiently advanced by 1951 that the entire length was undersealed with bituminous material.

A similar comparison cannot be made for the postwar pavements, since the entire

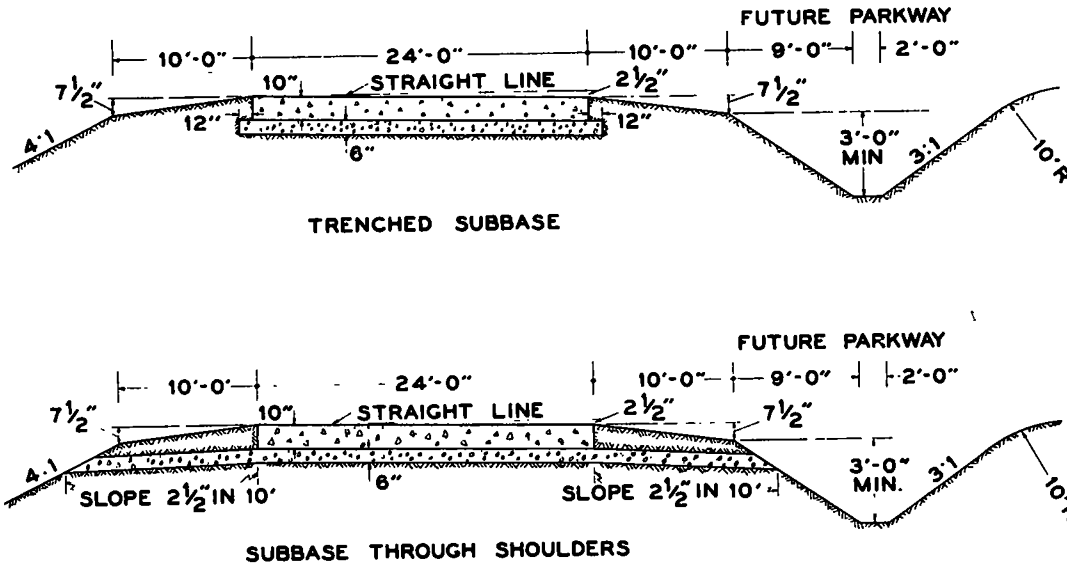

Figure 1. Cross sections showing design of granular subbases in general use on Route US 66 in Illinois.

mileage examined during the survey was placed on granular subbase. However, the pavement of this design, which also replaced badly damaged pavement showing excessive pumping on fine-grained subgrades, showed only 1.2 pumping locations per mile for the 64.6 mi. included in the survey.

A few excavations were made where evidence of pumped granular material was found on the surface. In each case a small tunnel was found in the shoulder at the pavement edge near the bottom of the slab. The tunnel was connected with the surface by one or more holes through which granular material had been ejected, and was found to be partially filled with loose, granular material washed clean of fines. Excavations some distance away from the joints near which the pumping was found showed the tunnels to be limited in extent. An investigation of the subbase at the pavement edge at the affected locations revealed that it was not in full contact with the bottom of the slab. A layer of loose, granular material washed of fines and about ¼-in. thick was found underneath the slab. A screwdriver with a shank about ¼-in. in diameter could be easily inserted between pavement and subbase for the entire length of the 6-in. shank. Immediately below was a ¼ to ¾-in. zone in which the subbase appeared to be discolored with shoulder material. This, and the undisturbed subbase below, appeared to be quite dense and contained no free water. In a few instances the space between the bottom of the slab and the subbase was found to contain a small amount of free water at the time the excavations were made.

Where granular material was found ejected to the surface, the largest-sized particles ranged up to somewhat over 1/8 in. in size, grading down to minus No. 200 material visible only as a stain on the pavement.

Shoulder Holes - Shoulder holes were found with both pavement designs, but were seen to occur much more frequently with the wartime design. The 20.2 mi. of wartime-design pavement showed an average of 209.4 shoulder holes per mile while the 64.6 mi. of postwar pavement showed an average of only 14.8 per mile. The number of shoulder holes for the individual construction sections are tabulated in Table 1.

Excavations at a number of locations where shoulder holes were found showed that the holes extended to the bottom of the pavement. In many instances the pavement did not appear to be in good contact with the subgrade in the vicinity of the holes, and sometimes the discoloration and charac-

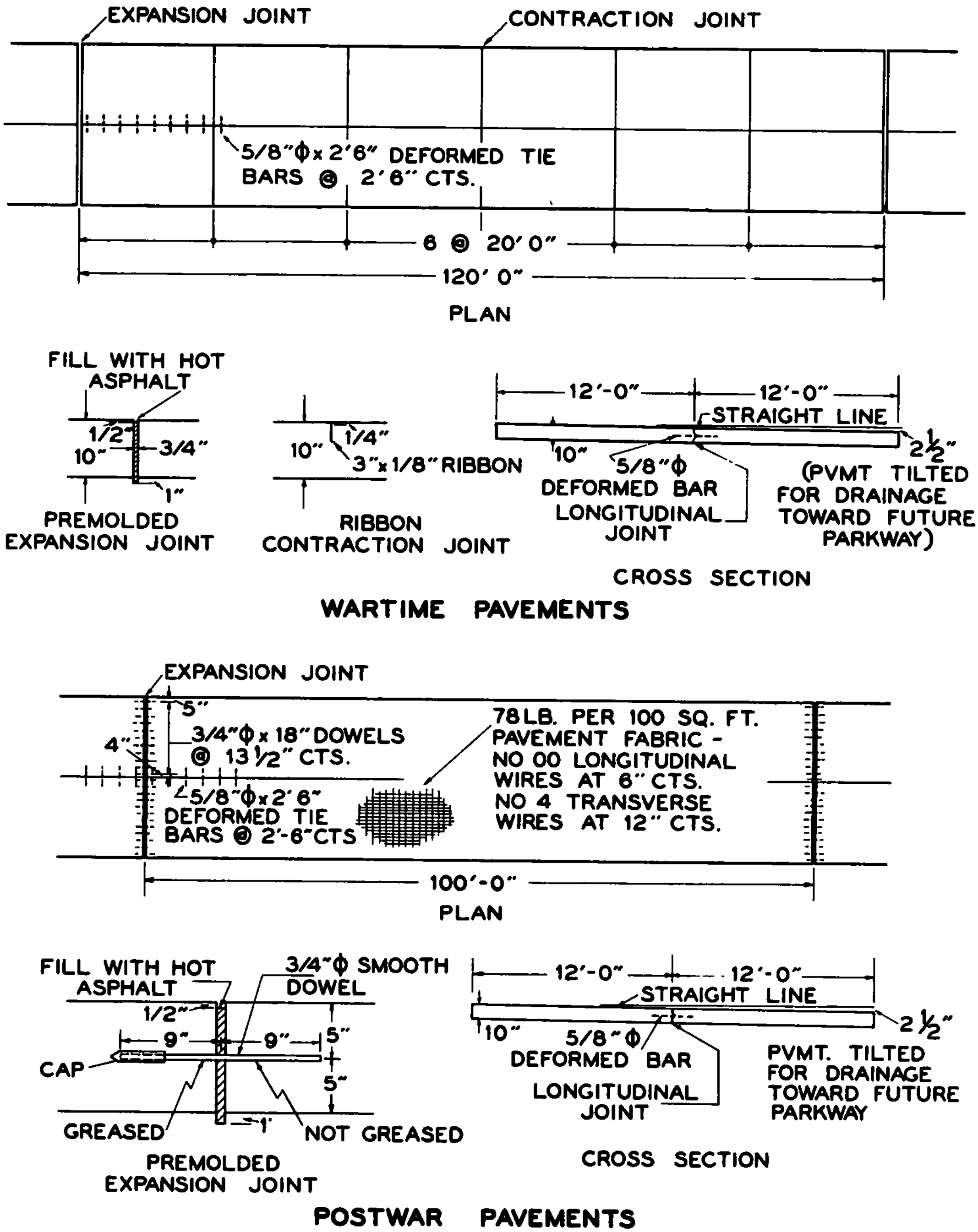

Figure 2. Design of pavements on granular subbases on route US 66 in Illinois.

TABLE 1

PUMPING AND SHOULDER HOLE DATA FOR THE PAVEMENTS OF US ROUTE 66 PLACED ON GRANULAR SUBBASE BETWEEN CHICAGO AND SPRINGFIELD, ILLINOIS

Section	Year Built	Year Examined	Length Miles	Pavement Design 1	Subbase Design 2	Gradation Range of Subbase Materials as Indicated by Material Reports Per Cent Passing 3"	1"	1/2"	No 4	No 50	No 200	Pumping Number of Joints and Cracks Affected (Lane Width)	Shoulder Holes Number of Joints and Cracks Affected (Lane Width)	Remarks
6R-7R	1942-43	1950	5 52	(a)	(b)	99-100			43-63	12-16	6-9	0	1095	
8R	1943-44	1950	3 53	(a)	(a)	100			43-63	14-18	6-10	33	1344	Twelve inches of subbase in a few cuts
9R	1943-44	1950	5 77	(a)	(b)	100	95-65		35-65		13-23	12	1029	Twelve inches of subbase in a few cuts
10R	1943-44	1950	5 35	(a)	(b)	100	99		51-59		17-21	4	756	Twelve inches of subbase in a few cuts

Pavement Design (a)

Total length, miles 20 2
Joints and cracks per mile showing pumping 2 4
Joints and cracks per mile showing shoulder holes 209 4

Section	Year Built	Year Examined	Length Miles	Pavement Design 1	Subbase Design 2	3"	1"	1/2"	No 4	No 50	No 200	Pumping	Shoulder Holes	Remarks
29R	1945	1949	1 48	(b)	(a)	100	62-100	45-79	40-47	7	5	0	143	
114R	1944	1949	0 78	(b)	(c)	85-100	63-92	47-78	40-61	9-21	8-11	0	9	Portions of subbase drained with pipe
7X-2	1946	1950	4.24	(b)	(a)			100	81	18	9	18	19	
11X-1	1945	1950	3 81	(b)	(a)	100			61-69	7-9	6-10	0	64	
12R-2	1947	1951	0 67	(b)	(b)	Crushed pavement with agricultural limestone						0	0	Includes 200 feet of pipe underdrain
12R-1	1944-45	1951	5 55	(b)	(a)	100	95-100	87-93		8-13	5-9	0	45	Includes about 200 feet of twelve-inch subbase
13R	1945	1951	7.99	(b)	(c)	100			74-86	12-28	9-19	13	251	Includes a small amount of pipe underdrainage
14R	1945	1951	7 71	(b)	(c)	100	93-100	82-95	57-84	4-19	2-7	0	102	Includes a small amount of pipe underdrainage
15R	1945	1951	5 24	(b)	(c)		100		80-88		4-5	1	37	Includes a small amount of pipe underdrainage
16R	1945	1951	6.40	(b)	(c)	100	85-96	72-84	51-68	4-15	1-8	5	8	
17R-1	1946	1951	1 23	(b)	(a)	100	96-100	82-91	60-74		2-4	19	7	
17R	1945	1951	3 90	(b)	(c)	100	96-100	82-91	60-74		2-4	2	13	Includes a small amount of pipe underdrainage
18R	1946	1951	5 16	(b)	(a)	100			78	28	17	16	120	
20R	1946	1951	3 37	(b)	(a)	100			58	11	6	5	67	Includes a few hundred feet of twelve-inch subbase
21R	1946	1951	7 10	(b)	(a)	100			80	13	4	0	70	Includes a few hundred feet of twelve-inch subbase

Pavement Design (b)

Total length, miles 64 6
Joints and cracks per mile showing pumping 1 2
Joints and cracks per mile showing shoulder holes 14 8

1 Pavement Design

Design (a) - Wartime Pavements

P C Concrete 10-inch uniform x 24 feet
Expansion joints spaced at 120 feet
Contraction joints spaced at 20 feet
No load transfer devices
No reinforcement

Design (b) - Post-war Pavements

P C Concrete 10-inch uniform x 24 feet
Expansion joints spaced at 100 feet
No contraction joints
3/4-inch x 18-inch dowels at 13½-inch ctrs
Mesh reinforcement 78 pounds per 100 sq ft

2 Subbase Design

Design (a)

6 inches x 26 feet
No drainage

Design (b)

6 inches x 26 feet
Scattered drainage

Design (c)

6 inches thick
Extended through shoulders

ter of the material immediately underneath the slab suggested that shoulder material had actually washed in between the pavement and subbase.

SUMMARY

The results of the studies made in Illinois indicate that granular subbases have been effective in the control of pumping. Although some pumping has occurred on granular subbase materials, the problem has not become one of importance. Shoulder holes were found to be fairly common, though no pavement failures could be attributed to their presence and no direct connection between them and pumping has been definitely established. It appears, however, that filling the shoulder holes and shaping the shoulders to lines and grades that prevent the entrapment of water adjacent to the pavement edges will be a profitably expended maintenance effort.

DISCUSSION

M. P. BROKAW, *Regional Highway Engineer, Portland Cement Association* - In addition to the surveys made by the Illinois Division of Highways on Route 66, the Portland Cement Association in 1950 resurveyed 10 of the projects originally covered in the 1946 Illinois Pumping Survey. Table A is a summary of the data on shoulder holes collected in 1946 and 1950.

As noted by Chastain, the original pumping survey disclosed presence of shoulder holes without evidence of pumping, as defined. The PCA resurvey in 1950 indicated little change of significance during the four-year interim. It should be emphasized, however, that the presence and appearance of shoulder holes will vary with the amount of rainfall, the period of time elapsing between the observation and last precipitation, and the amount of shoulder maintenance performed.

As a result of the PCA resurvey, which was made in some detail to detect influences of shoulder construction, alignment and gradient, and a study of the data obtained in the original pumping survey, some tentative conclusions and observations can be made in regard to subbase performance:

1. Shoulder holes were observed where truck semitrailer counts exceeded about 400 per day.
2. Shoulder holes ejected only water.
3. Shoulder holes were observed mostly

TABLE A

SUMMARY OF FIELD OBSERVATIONS COMPARING 1950 SURVEY WITH 1946 ILLINOIS PUMPING REPORT

ROUTE	SECTION	COUNTY	LENGTH Mi.	1946 SURVEY SHOULDER HOLES	1946 SURVEY PUMPING LOCATIONS	1950 SURVEY SHOULDER HOLES	1950 SURVEY PUMPING LOCATIONS
US 14	29R	McHenry	5.14	175	0	110	0
Ill. 131	UR	Lake	1.39	0	0	0	0
US 30	116R-1	DeKalb	2.67	178	0	31	0
Ill. 55	57-59-60	Dupage Kane	11.04	0	0	0	0
US 66	29R	Will	1.60	2	0	97	0
US 66	114-R1	Will	0.78	8	0	47	0
Ill. 4A	DR-CR	Will	3.82	261	0	0	0
US 66A	2R	Will	4.52	0	0	0	0
US 30	13R	Will	0.54	11	0	8	0
US 30	12R-1	Will	1.10	1	0	0	0

on steep grades and on the low side of superelevated curves, or where shoulders were low, rutted and poorly maintained.

4. Stabilized or granular shoulders were practically unaffected by shoulder holes, while sodded or high-shrink shoulders were particularly vulnerable.

5. Shoulder holes were never observed where concrete side gutters were attached to the pavement. This was found to be true even in projects where shoulder holes were otherwise numerous and the traffic was the heaviest.

6. Subbases under pavements carrying light traffic and which were without shoulder holes had an average relative density of 87 percent as compared to 94 percent for subbase with shoulder holes. This would indicate that heavy loads, which always accompanied the presence of shoulder holes, had caused consolidation of those subbases which were placed at densities substantially less than about 94 percent of maximum.

7. There was no pavement distress which could be attributed to shoulder holes.

Our findings and conclusions are in close agreement with those of Chastain and Burke. There seems to be little reason to abandon the use of impermeable, trenched-in subbases where they are substantially economical. Likewise there appears to be little doubt that performance could be improved by adopting standards requiring at least 95 percent of maximum density (AASHO T99-49) for both subbase and shoulder construction. Where possible, shoulder embankment should be selected for low-shrink characteristics.

Greater emphasis should be placed on shoulder maintenance. In those locations where pavement run-off tends to create unsatisfactory and dangerous shoulder conditions, the use of attached gutters may be justified for maintenance relief.

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