Performance of Concrete Pavements on Granular Subbase

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● 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

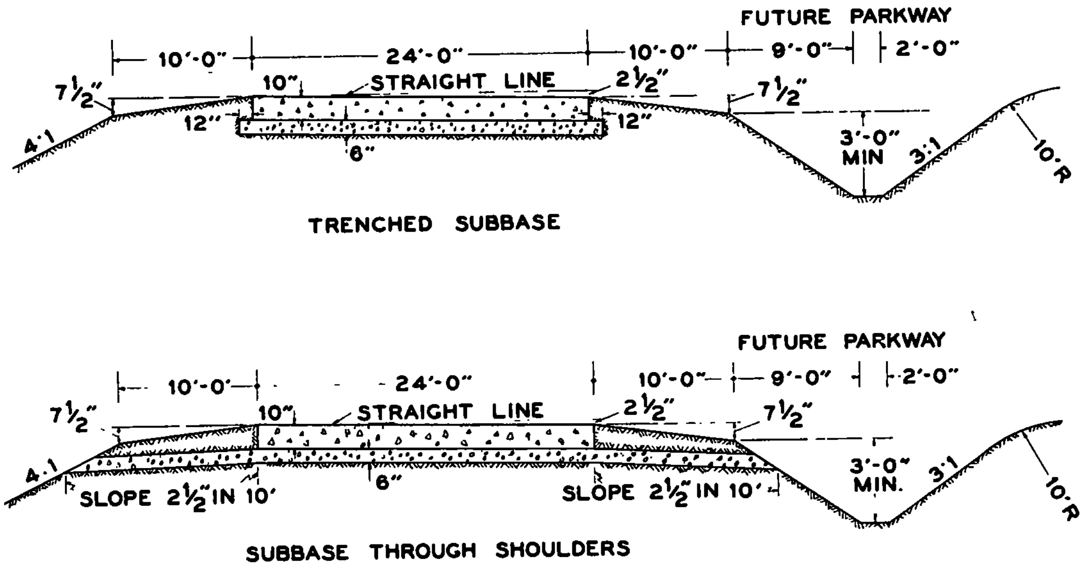

Figure 1. Cross sections showing design of granular subbases in general use on Route US 66 in Illinois.

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-

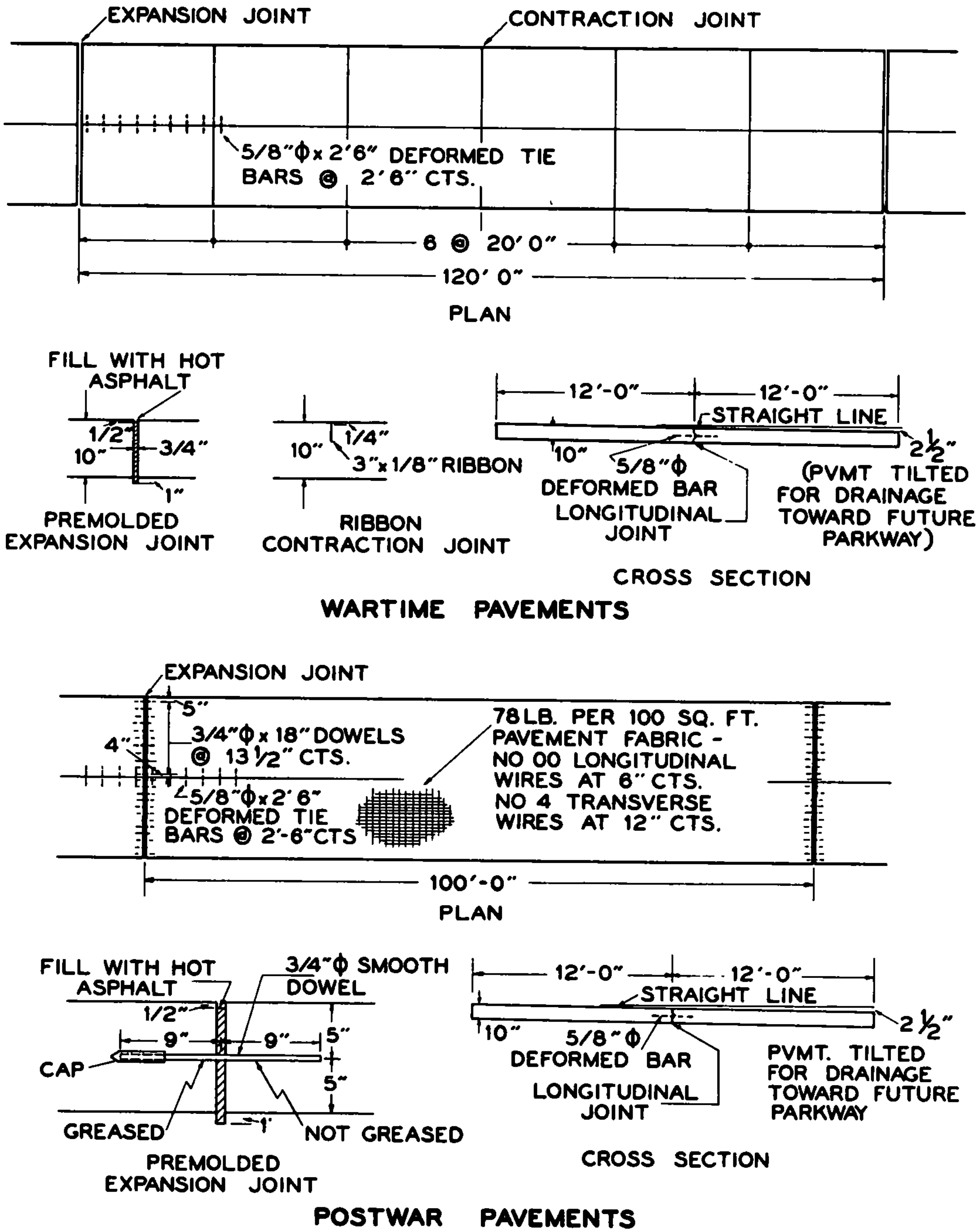

Figure 2. Design of pavements on granular subbases on route US 66 in Illinois.

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								
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.