PUMPING OF CONCRETE PAVEMENTS IN TENNESSEE

Cooperative Study
By
Tennessee Department of Highways
and
Portland Cement Association

SYNOPSIS

A cooperative study was made during March and April, 1944 to determine the nature, extent, cause and remedy of pumping in Tennessee. Approximately 290 miles of pavement on the main traffic routes connecting the principal cities were studied in the survey. The projects studied were representative of the range of traffic, loadings, pavement designs and subgrade soils encountered over the State.

Reconnaissance surveys were made to obtain a quantitative measure of pumping of pavements under different traffic loads on various soil types. Three stages or classes of pumping were recognized; slab ends where pumping occurred without accompanying faulting; pumping accompanied by faulting; and pumping and faulting accompanied by a broken slab end.

The reconnaissance surveys were followed by detail studies of traffic, pavement design and soils on individual projects. Sections of individual projects were mapped and sampled. Mapping included sketches showing pavement jointing, cracking, pumping, typical soil section, location of sampling, with notes on soil condition and pertinent construction data. Undisturbed as well as disturbed soil samples and water content samples were taken from under both pumping and non-pumping pavement joints and cracks. Density tests, routine soil-constant tests, mechanical analysis, compaction tests, consolidation tests and triaxial compression tests were made to determine the relationships between soil types, soil condition and pumping.

Some of the concrete pavements on the more heavily traveled main highways in Tennessee began to pump at transverse joints and cracks under the heavy axle loads which the roads carried immediately prior to and since the beginning of the war.

This report gives the results of a cooperative study made by the Tennessee Department of Highways, and the Portland Cement Association to determine the causes of pumping and its extent in Tennessee. The laboratory tests of soils was conducted by the Public Roads Administration.

The investigation was limited to the study of factors related to the pumping action under repeated heavy loads causing mud to be ejected at cracks and joints and resulting in eventual loss of subgrade support and breaking of the pavement slab. The ejection of water, where not detrimental, or the faulting of slab ends due to permanent compression of coarse grained soils and not accompanied by removal of soil were not included in the studies.

NATURE AND SCOPE OF STUDIES

The survey was planned to study pumping under the ranges of traffic loadings and soil types which exist on the principal traffic routes. A major portion of the concrete pavement projects on the seven most heavily traveled routes representing the major soil groups and carrying the largest number of heavy trucks were selected for study. Selected projects on two routes carrying medium to light truck traffic also were included in the survey. The heavy traffic routes were as follows:

1. Memphis north on U. S. Route 51.
2. Memphis northeast to Nashville on U. S. Route 70 with some added projects on State Routes 1 and 76 in the vicinity of Milan and Humboldt.
3. Nashville northwest to Clarksville on U. S. Route 41W.
4. Nashville southeast to Chattanooga on U. S. Route 41.
5. Chattanooga northeast to Knoxville on U. S. Routes 27 and 70.
6. Chattanooga northeast toward Knoxville on U. S. Route 11.
7. Knoxville east on U. S. Routes 70 and 11E.

Projects on State Route 76 near Paris and U.S. Route 70N between Cookeville and Crossville which routes carried less traffic than the seven mentioned above were included in the survey.

Reconnaissance Survey of Pumping

A method of classifying pumping slab ends in terms of the progressive stages of development was developed prior to the beginning of the reconnaissance survey. The use of this classification made it possible, by counting the number of pumping slab ends of the various classes, to express the stage of development of pumping, and assess the extent of damage to the pavements on various subgrade soils and under different conditions of traffic.

Pumping was grouped into three classes as follows:

Class 1. Pumping of slab ends at joints and cracks with no evidence of faulting at slab ends or breaking of slabs due to pumping.

Class 2. Pumping accompanied by faulting with no evidence of breaking of slabs due to pumping.

Class 3. Pumping accompanied by faulting and breaking as a result of loss of subgrade support due to pumping.

The reconnaissance survey included a count of the number of expansion joints, contraction joints and cracks for quantitative analysis of pumping. All pumping cracks and joints were classified and counted to determine the number and percentage of pumping slab ends of each of the three classes. Counting was done from an auto driven very slowly over the road. One observer recorded the number of pavement joints, cracks, corner breaks and related pavement items. A second recorder classified and recorded pumping. Where practical, each project was separated into sections according to soil series and horizon, and on some projects between cut and fill and the pumping tabulated for each section. Sections of each project on which pumping and no pumping had developed were noted during the reconnaissance survey for later detailed study.

Detail Survey and Sampling of Selected Sections

Upon completion of the reconnaissance surveys of a number of contiguous projects, the sections noted for detail study were re-examined. Those having the most nearly uniform soil type and soil conditions throughout their length were selected for further study and sampling to determine the reason for the absence or presence of pumping.

The detail survey of selected sections consisted of the following:

1. Mapping the location of all joints and cracks.
2. Describing and classifying pumping and mapping all locations which were pumping.
3. Making soil borings and sketching the soil section represented in the soil profile.
4. Determining the pedological soil series classification.
5. Taking undisturbed soil samples, disturbed soil samples and samples for water content determination.
6. Observing surface drainage condition of shoulders.

An example of the data obtained in the mapping of the detail study sections is shown in Figure 1.

Samples for water content determination were taken at depth of 0 to 1, 2 to 4 and 5 to 8 in. below the pavement. Exceptions were made where pumping had left a cavity, and mud existed in the cavity. There the first sample was taken from the uppermost firm soil beneath the liquid mud. Samples were taken at distances of from two to three ft. in from the edge of the slab. Samples were placed in 6 or 8 ounce metal containers and sealed to prevent loss of moisture.

Undisturbed samples were taken by excavating in from the edge of the slab a distance of two to three feet and removing an undisturbed column of soil as shown in Figure 2. Upon removal the column was trimmed to a cylindrical shape 6 in. in diameter and 8 to 10 in. in height, coated with alternate layers of paraffin and cloth, and packed in sawdust for shipment. Disturbed samples consisted of 50 to 75 lb. soil set aside during removal and trimming of the undisturbed soil cylinder.

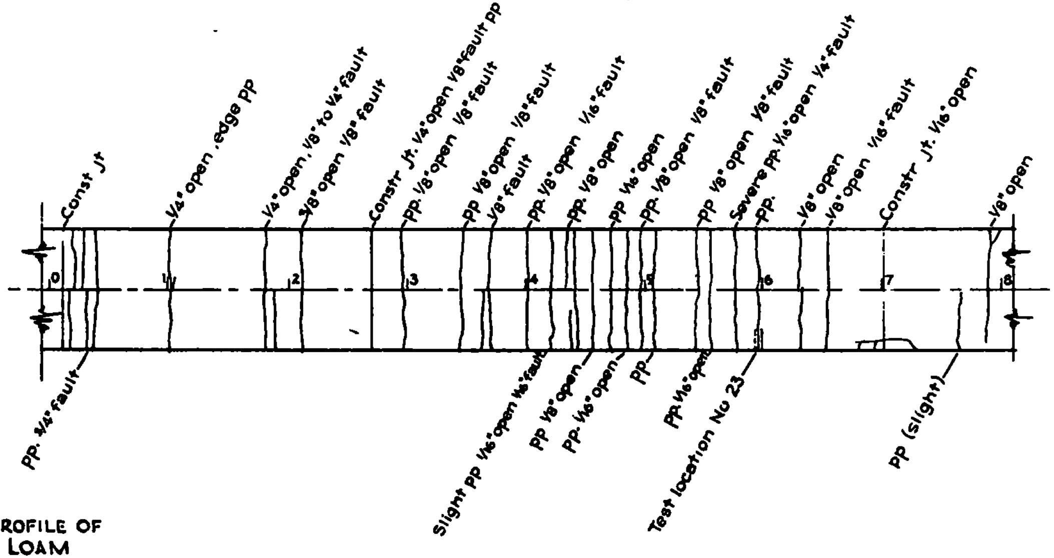
Testing of Soils

Samples for water content determination were tested in the central soils laboratory of the Department of Highways at Nashville. Large undisturbed and disturbed samples were shipped by the Tennessee Department of Highways to the Public Roads Administration for test. The following tests were conducted by the Public Roads Administration Laboratory.

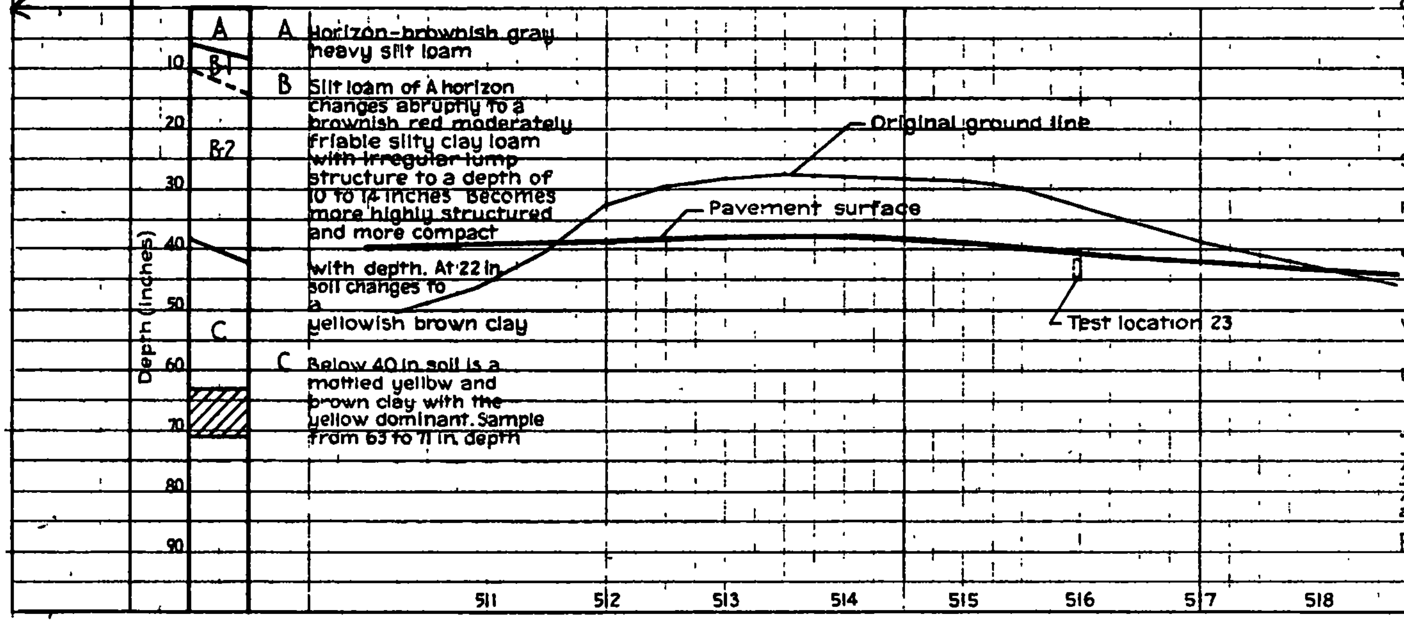
1. Liquid limit, plastic limit, field moisture equivalent, centrifuge moisture equivalent, and shrinkage limit.
2. Mechanical analysis.
3. Standard compaction.
4. Consolidation.
5. Triaxial compression.
6. Water content and density on specimens prepared from undisturbed samples for the consolidation and triaxial compression tests.

Traffic Studies

The earliest comprehensive traffic data available were obtained during the 1937 traffic surveys. Additional traffic data were available from the 1942 and 1943 surveys. In some instances the 1942 count and weighing of vehicles showed a greater number of heavy axle loads than did the 1943 survey. However, since the 1943 survey represented the count most nearly applicable to traffic conditions existing at



TYPICAL SOIL PROFILE OF DEWEY SILT LOAM
(From vicinity of station 515+93)



A Horizon–brownish gray heavy silt loam

B Silt loam of A horizon changes abruptly to a brownish red moderately friable silty clay loam with irregular lump structure to a depth of 10 to 14 inches Becomes more highly structured and more compact with depth. At 22 in soil changes to a yellowish brown clay

C Below 40 in soil is a mottled yellow and brown clay with the yellow dominant. Sample from 63 to 71 in. depth

CONSTRUCTION DATA

LOCATION

STATE	*Tennessee*	COUNTY	*McMinn*
US ROUTE	*11*	PROJECT	*FAP 60 AS*
LOCATION NO.	*23*	STATION	*510+10 518+10 (515+93)*
LENGTH (MI)	*7 020*	YEAR BUILT	*1926*

MATERIALS

C A	*Gravel – Tennessee River – Lenoir City*	F A	*Sand – Tennessee River – Lenoir City*
CEMENT	*Signal Mt*	CF	*1 2·3½*

PAVEMENT DESIGN DETAILS

CROSS SECTION *9-6-9 x 18 & 9-6-9-6-9 x 18* LONG JT *Metal plate except at thickened center where butt joint was used*

TIE BARS *½" x 4' @ 5' c.c., except none at thickened center sections.*

EXP. JT SPACING *None* WIDTH – FILLER –

CONTR. JT SPACING *None* TYPE – DEPTH GROOVE –

LOAD TRANSFER *None*

SOIL TYPE

SOIL SERIES & HOR. *Dewey C Horizon*

P.R.A. GROUP *A-7* TYPE *Clay* PI *45*

% S & GR. *18* % SILT *11* % CLAY *71*

SOIL CONDITION

WATER CONTENT – 0-1" *41* 2"-4" *39* 5"-8" *40* AT

DENSITY *(PCF)* *No test made*

REMARKS

Severe edge pumping and several class-3 broken slabs as a result of pumping. Cavity under pavement 1/8" to 1/4" deep and [illegible] long at station 515+93. Shoulders were high from material recently graded from side ditch and left in a windrow on shoulder. Side ditch was shallow.

FIG I DETAIL STUDY LOCATION No. 23

the time of the study of pumping it was decided to use the 1943 count. Very little pumping was observed in Tennessee prior to 1937. For these reasons, the data on traffic were compiled for each project for both 1937 and 1943 to show the change in traffic loadings which occurred during the incidence of pumping.

ANALYSIS OF OBSERVATIONS AND DATA

In some instances it was found difficult to obtain a true appraisal of pumping during the reconnaissance survey. It has been mentioned that the progress of pumping from incidence to loss of subgrade support and the breaking of the slab was divided into three stages and classification of pumping made on that basis. During the detail survey when each joint and crack was examined closely it was found that in some locations pumping had begun but had not yet become visible on the surface of the pavement. In the earliest stage, a thin film of mud was found under the slab end on the far side of the joint in the direction of traffic. As the action continued, the mud gradually worked up along the edge of the slab and into the joint or crack opening until it reached the surface. Therefore, the reconnaissance data include only pumping which was visible at the surface while the detail study sections include pumping in its earlier stages where there was unquestioned evidence that a mud had formed and that the mud was progressing toward the surface.

Pumping was found to be a progressive action and its occurrence depended upon so many factors that close correlation between traffic and any other single factor of pavement design feature or subgrade soil type with definite amounts and degrees of pumping was not found. In some instances the maintenance of joints and crack openings in the pavement had been timely and good and had prevented or greatly reduced pumping. In other instances on similar soils and traffic but with less effective maintenance, pumping had become severe and considerable damage done to the pavement.

The correlation between pumping and the various factors which may affect pumping differed with the various factors of subgrade soil, pavement design and traffic. The relationships brought out by the data are given in the paragraphs which follow.

Relation Between Traffic and Pumping

No pumping of serious consequence was reported in Tennessee prior to 1937 when the first comprehensive traffic survey was made. Although no survey of pumping had been made at that time it is safe to assume that the number of truck axle loads at that time did not cause pumping except at locations of poor drainage or as a secondary effect where pavements had become damaged. Traffic counts and weighings were made again during 1942 and 1943. Since the 1943 count was made only a few months before this survey of pumping, the 1943 traffic data have been used. Table 1 shows the comparative 1937 and 1943 traffic count and axle weights for four projects included in the pumping survey. The projects were located near weighing stations used in the traffic survey.

In 1937 traffic carried only a small number of axle loads in excess of 14,000 lb. with few to none in excess of 16,000 lb. The 1943 count showed a large increase in axle weights in excess of 14,000 lb. a large proportion of which exceeded 16,000 lb. in weight. The pavements for which the data are shown are 8 in. by 6 in. by 8 in. parabolic cross section as are many of the pavements examined in this survey.

TABLE I

1937 AND 1943 TRAFFIC COUNTS AND AXLE WEIGHTS ON FOUR PROJECTS
(Located Near 1937 and 1943 Weighing Stations)

Project	Year Built	Location	Year of Traffic Survey	24 Hour Total Traffic (Number Vehicles)	24 Hour Truck Traffic (Number of trucks)	24 Hour Truck Axle Loads in Kips (Cumulative) Under 8	Over 8	Over 10	Over 12	Over 14	Over 16	Over 18	Over 22	Total Number Axles	Remarks
FAP R-8A(4) (Reop. & Ext.)	1936	3 miles north of Memphis on US Route 51	1937	1580	356	586	148	56	33	19	9	-	-	734	
			1943	5740	1383	2479	522	372	189	102	48	9	-	3001	No pumping (Loess Soils)
FAP 36DS	1929	2 miles east of Memphis on US Route 70	1937	3200	547	845	304	182	60	11	-	-	-	1149	
			1943	3740	748	1302	575	517	367	196	130	40	8	1877	30% of joints and cracks pumping (Loess Soils)
FAP 231AS	1930	10 miles north of Chattanooga on US Rt. 27	1937	2560	351	477	224	183	131	23	-	-	-	702	Clay soils derived from dolomitic and cherty limestones.
			1943	3780	692	1124	530	457	359	262	131	25	-	1654	17% of joints and cracks pumping.
NRH 269B	1934	17 miles east of Chattanooga on US Routes 41 & 64	1937	1180	313	517	150	95	60	9	4	-	-	667	Clay soils derived from cherty limestones.
			1943	2975	690	1054	574	481	398	282	116	23	-	1628	26% of joints and cracks pumping.

It appears from the data shown in the table that pumping developed from the increase in number of axle loads of the 14,000 lb. to 18,000 lb. range. The axle loads necessary to start pumping undoubtedly depended on the type and condition of the subgrade soil.

A correlation between traffic and pumping was found for the uniform loess soils in western Tennessee. Table 2 shows the soil analyses, axle loads and pumping found on 11 projects built on loess soils. It is evident that the loess soils on the various scattered projects are very nearly similar in characteristics. Under average maintenance conditions the pavement built on loess soils of average water content and density did not pump until the number of 14,000 lb. wheel loads exceeded 50 per day on an 8 in. by 6 in. by 8 in. pavement. A study of the projects on which slight to moderate pumping occurred showed that such pumping was associated largely with open cracks or poor surface drainage of the pavements. On project 36DS (7.97 miles in length) 122 of the 135 pumping slab ends were at cracks. The higher water content of the soil on that project is indicated in Table 2.

An over-all study of pavements built on all soil types failed to show any direct relation between the amount of pumping and the number of axle weights in the 12,000 to 18,000 lb. range.

No quantitative data were obtained on the relation between speed of traffic and pumping. It was observed, however that many of the long mountain grades in eastern and southeastern Tennessee showed a marked difference in surface condition and pumping on the uphill traffic lanes compared to the downhill traffic lanes. The very marked difference in the density of the oil streak (indicative of slow speed and tractive effort) found on many long grades is shown in Figure 3. A second example is shown in Figure 4. Here severe pumping occurred on the uphill lane while the downhill lane showed little pumping.

The influence of traffic on pumping also was evident on 4 lane roads where nearly all pumping occurred in the outside lane which carries nearly all truck loads. Almost no pumping occurred in the inner passing lane of 4 lane divided or undivided highways.

Relation Between Roadbed Design and Pumping

A tabulation of pumping slabs on multi-lane divided and undivided highways showed the undivided highway had a tendency to pump somewhat less than the divided type.

No effort was made to determine the relative effect of lip curb on pumping during the reconnaissance survey. General observations were that its use did not increase or decrease pumping to an extent which was significant.

On four lane divided and undivided highways both traffic lanes drained toward the shoulder. There was no evidence that such drainage resulted in more pumping than occurred on many two lane roads.

Relation Between Pavement Cross Section and Pumping

Of 36 projects on which pumping was studied during the survey, 26 were of 8 in. by 6 in. by 8 in. cross section. Ten of the 36 projects were 18 ft. wide, 18 were 20 ft. wide and 3 were 22 ft. wide. Two projects were of 7 in. uniform thickness and 4 were of 9 in. by 7 in. by 9 in. by 20 ft. cross section.

TABLE 2

SUBGRADE SOILS DATA, AXLE LOADS AND PUMPING ON LOESS SOILS

County	Project	Sample Location No.	L.L.	P.L.	P.I.	F.M.E.	C.M.E.	S.L.	P.R.A. Soil Group	Mechanical Analysis				Textural Soil Type	Soil Water Content (Per Cent)			Soil Density (p.c.f.)	24 Hr. Truck Axle Loads in Kips (Cumulative)				Remarks on Pumping
										Gravel & Sand	Silt	Clay	Colloids		0-1"	2"-4"	5"-8"		Over 12	Over 14	Over 16	Over 18	
Dyer	39AS	13C	40	22	18	32	25	20	A-7	10	61	29	16	SiCL	-	-	-	-	54	29	14	3	None
Henry	280F	37	37	19	18	26	22	18	A-7	18	52	30	14	SiC	18	18	18	-	54	29	19	6	None
Shelby	31CS	12b	32	21	11	27	19	22	A-4	25	61	14	7	SiL	-	-	-	-	57	31	15	3	None
Gibson	147CS-DS	14C	35	18	17	24	22	18	A-7-4	19	61	20	8	SiCL	-	-	-	-	92	49	23	4	None
Madison	51CS	11	39	19	20	28	24	17	A-7-6	22	53	25	10	SiCL	21	24	22	101-108	93	50	33	10	None
Shelby	R-8-A IV Reop. Ext.	10C	36	21	15	28	25	22	A-4	10	67	23	10	SiCL	-	-	-	-	189	102	48	9	None
Fayette	36AS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	227	121	80	24	None
Shelby	36DS	9	45	23	22	32	29	19	A-7	11	61	28	12	SiCL	23	26	27	93-96	367	196	130	40	None (for detail Study Section) only
Gibson	147CS-DS	15b	42	18	24	33	26	20	A-7	10	56	34	19	SiC	-	-	-	-	92	49	23	4	Slight Pumping (No Count Made)
Shelby	R-8-A III	11C	40	21	19	29	27	20	A-7	11	65	24	10	SiCL	-	-	-	-	140	76	36	7	Moderate Pumping (No Count Made)
Shelby	36BS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	174	93	62	19	Moderate Pumping (3% of Joints and Cracks Pumping)
Shelby	36CS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	199	106	70	21	Moderate Pumping (3% of Joints and Cracks Pumping)
Shelby	36DS	10	46	23	23	35	30	20	A-7	9	60	31	6	SiC	25	26	26	96	367	196	130	40	Severe Pumping (30% of Joints and Cracks Pumping)
Shelby	36GS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	475	253	168	51	Slight Pumping (0.5% of Joints and Cracks Pumping)

Samples 13C, 14C, 9, 15b, 11C and 10 were classified as Loring Series; Samples 12b, 11, and 10C as Memphis Series and Sample 37 as Lexington Series. All samples not followed by the letter "C" were from the B Horizon.

FIGURE 2. UNDISTURBED COLUMN OF SOIL REMOVED FROM UNDER A PUMPING EXPANSION JOINT. NOTE THAT A SOFT MUD HAD FORMED ONLY UNDER THE FAR SIDE OF THE JOINT IN THE DIRECTION OF TRAFFIC.

FIGURE 3. NOTE THE DIFFERENCE IN THE OIL STREAKS RESULTING FROM DIFFERENCE IN UPHILL AND DOWNHILL SPEEDS AND TRACTIVE RESISTANCE OF VEHICLES ON A LONG GRADE. FAP 486 A (2) STA. 380 COFFEE COUNTY (4-6-44)

FIGURE 4. ANOTHER EXAMPLE SHOWING THE DIFFERENCE IN THE OIL STREAKS IN THE UPHILL AND DOWNHILL LANES DUE TO SPEED OF TRAFFIC ON A LONG 6% GRADE. NOTE THE PUMPING AND DAMAGE TO PAVEMENT IN THE UPHILL TRAFFIC LAND. FAP 269 B MARION COUNTY (3-22-44)

Pumping occurred on all pavement cross sections where other conditions conducive to pumping were present. The 9 in. by 7 in. by 9 in. thickness showed an average of approximately 1/3 as much pumping as did the 8 in. by 6 in. by 8 in. pavements, but the former carried about two thirds as many heavy axle loads as did the 8 in. by 6 in. by 8 in. pavements.

Relation Between Pumping and Joint Type and Spacing

The counting of the total number of joints and cracks made it possible to determine the joint and crack interval for various expansion joint spacings and combinations of expansion joint and contraction joint spacing. Pavement with longer expansion joint spacings had longer joint and crack intervals. A trend in reduction of pumping is indicated for pavements with expansion joints at 300 ft. intervals. For pavements with the 500 ft. expansion joint spacing there was a considerable reduction in the amount of pumping.

Pumping was classified and recorded separately at joints and cracks on 33 of 41 projects studied. The 33 projects represent a total of 229 miles of pavement and cover the range of soils encountered in Tennessee. A summary of observations on 41 projects is given in Table 3. In the average, the amount of pumping at joints differed but little from the pumping at transverse cracks. However, very few individual projects showed the same amount of pumping at joints and cracks, the amount being influenced by the occurrence of cracks, the spacing of expansion joints and resulting width of crack opening, the relative maintenance condition of the sealing material at joints as compared to cracks, and apparently, whether the dowels at joints permitted free movement of the slab ends. The following examples illustrate the wide difference in pumping at joints as related to pumping at cracks on individual projects: On one 4-lane divided highway, having no transverse cracks, 6 per cent of the joints pumped. On another project pumping occurred on 1 per cent of the joints compared to pumping at 21 per cent of the transverse cracks. The expansion joints were uniformly of the width constructed but cracks had opened from 1/8 to 3/8 in. indicating definitely that the dowels were restricting normal slab movements on that project.

Table 3 shows that in the average the amount of pumping of transverse joints (expansion and contraction joints) was about the same as at transverse cracks, (18 and 21 per cent of the joints and cracks respectively).

It was difficult to differentiate between expansion joints and contraction joints in the reconnaissance survey on many of the projects investigated. Therefore, observations on the relative pumping at expansion and contraction joints were limited to six projects having a combined length of approximately 62 miles. It may be seen from the average values in Table 4 that pumping occurred in almost equal amounts at expansion joints, contraction joints and cracks.

Considerable pumping occurred along the longitudinal center joint near transverse joints and cracks. A deformed metal plate was used to form the center longitudinal joint on most projects. Likewise, pumping occurred along the outside edge of the pavement. All pumping at the edge and at the center joints was credited to the nearest transverse crack or joint. In only one instance was pumping found along the edge of uncracked slabs of 20 to 30 ft. in length and that was on the inside of a superelevated curve in a deep cut near the top of a long steep grade.

Table 3

SUMMARY OF OBSERVATIONS OF PUMPING ON 41 PROJECTS IN TENNESSEE

(Located on Principal Traffic Routes)

Location				Pavement Design				Joint and Crack Count			Pumping Joints (Per Cent)				Pumping Cracks (Per Cent)				Pumping Joints & Cracks (Per Cent)				Miles of 2 lane Width of Pumping Pavement
Project	Length (Miles)	County	Route	Pavement Cross-Section	Joint Spacing Exp.Jt.	Joint Spacing Contr.Jt.	Load Transfer	Total No. Joints	Total No. Cracks	Joints and Cracks	Class 1	Class 2	Class 3	Total	Class 1	Class 2	Class 3	Total	Class 1	Class 2	Class 3	Total	
35	7.650	Hamilton	SR 29	6-7½-6x16'	—	—	—	921	353	1274	1.3	0.7	2.9	4.9	6.8	2.5	4.8	14.2	2.8	1.2	3.5	7.5	0.49
36 AS	7.882	Fayette	US 70	8-6-8x18'	35	—	None	1252	785	2037	—	—	—	—	—	—	—	—	—	—	—	—	—
36 BS	2.138	Shelby	US 70	8-6-8x18'	500	—	None	20	472	492	—	—	—	—	1.9	0.4	0.4	2.8	1.8	0.4	0.4	2.6	0.06
36 CS	8.624	Shelby	US 70	8-6-8x18'	500	—	None	1090	1912	3002	0.6	—	—	0.6	2.4	1.0	0.4	3.8	1.8	0.6	0.3	2.7	0.23
36 DS	7.970	Shelby	US 70	8-6-8x18' 8-6-8-6-8x36'	500	—	None	52	396	448	11.5	5.8	7.7	25.0	22.2	7.8	0.8	30.8	21.0	7.6	1.6	30.1	2.40
36 GS	1.820*	Shelby	US 70	8-6-8-6-8x36'	500	—	None	34	565	599	—	—	—	—	0.5	—	—	0.5	0.5	—	—	0.5	0.02
41AB(4)(5)	2.264*	Knox	US 70	7" unif.x22'	90	30	(Special (Base Plate	786		786	6.4	—	—	6.4	—	—	—	—	6.4	—	—	6.4	0.58
41AB(Reop.)	7.291*	(Knox- (Loudon	US 70	7" unif.x22'	90	30	(Univ. or (Nat'l.	2549	11	2560	38.0	0.2	—	38.2	27.3	—	—	27.3	38.0	0.2	—	38.2	5.57
51AS(& Ext)	10.697	Carroll	US 70	8-6-8x18'	40	—	¾"x4' at 3'c.c.	1401	1033	2434	—	—	—	—	—	—	—	—	—	—	—	—	—
55AS	9.689	Anderson	US 25W	8-6-8x18'	40	—	¾"x4' at 3'c.c.	1279	248	1527	—	—	—	—	—	—	—	—	—	—	—	—	—
56A(2)(3)	5.231*	Davidson	US 41	(8-6-8-6-8x22' (& 7"unif.x22'	90	30	¾"x2' at 12"c.c.	1027	192	1219	26.9	1.2	—	28.2	12.0	11.55	0.5	24.0	24.5	2.8	0.1	27.4	2.88
58AS	10.646	Bradley	US 11	8-6-8x18'	40	—	None	1391	105	1496	3.5	3.5	0.4	7.3	4.8	—	—	4.8	3.5	3.3	0.3	7.2	0.72
60AS	7.020	McMinn	US 11	(9-6-9x18' & (9-6-9-6-9x18'	—	—	—	75	678	753	9.3	8.0	2.7	20.0	9.6	6.0	1.8	17.4	9.6	6.2	1.9	17.6	1.76
78 AS	9.263	Bradley	US 11	? x18'	35	—	None	1365	357	1722	2.9	1.3	0.9	5.1	3.1	—	—	3.1	3.0	1.0	0.7	4.7	0.47
78 BS	7.110	Hamilton	US 11	8-6-8x20'	40	—	¾"x4' at 3'c.c.	935	424	1359	1.8	0.3	—	2.1	4.0	1.2	—	5.2	2.5	0.6	—	3.1	0.31
208 G	8.901	Rutherford	US 41	8-6-8x20'	90	30	¾"x2' at 12"c.c.	1573	630	2203	44.0	9.8	2.2	55.9	39.3	49.3	9.5	98.1	42.6	21.1	4.3	68.0	6.19
208 H	3.181	Coffee	US 41	8-6-8x20'	90	30	¾"x2' at 12"c.c.	552	169	721	15.4	2.4	0.4	18.1	19.5	37.3	10.0	66.8	16.3	10.5	2.6	29.5	0.94
208 I (2) 486 A (2)	5.963	Coffee	US 41	8-6-8-6-8x22'	90	30	¾"x2' at 12"c.c.	1022	415	1437	1.2	0.1	—	1.3	9.2	10.8	1.0	21.0	3.5	3.1	0.4	7.0	0.42
208 J	7.316	Rutherford	US 41	8-6-8x22'	90	30	¾"x2' at 12"c.c.	1320	1369	2689	6.0	0.2	—	6.1	0.4	0.3	—	0.7	3.2	0.2	—	3.4	0.34
228 B	7.211	Knox	US 70	9-7-9x20'	300	50	None	708	1144	1852	19.4	4.9	0.6	25.0	20.5	8.1	1.2	29.8	20.0	6.9	1.0	28.0	2.01
231 A	4.046	Hamilton	US 27	8-6-8x20'	500	—	None	71	344	415	50.7	7.0	—	57.7	8.7	—	—	8.7	15.9	1.2	—	17.1	0.69
231 B	4.355	Roane	US 27	8-6-8x20'	300	50	None	464	62	526	3.9	1.7	—	5.6	1.6	1.6	—	3.2	3.6	1.7	—	5.3	0.23
231 D	3.587	Hamilton	US 27	9-7-9x20'	300	—	None	64	150	214	—	1.6	1.6	3.1	2.0	—	—	—	1.4	0.5	0.5	2.3	0.08
35 A (3) 231 D (2)	1.353	Hamilton	US 27	8-6-8-6-8x22'	90	30	¾"x2' at 12"c.c.	234	20	254	—	—	—	—	—	—	—	—	—	—	—	—	—
231 E	8.792	(Hamilton- (Rhea	US 27	8-6-8x20'	500	—	None	146	649	795	3.4	1.3	—	4.8	10.0	1.8	—	11.9	8.8	1.8	—	10.6	0.93
231 GFC	25.215	Rhea	US 27	9-7-9x20'	300	50	None	2651	772	3423	2.5	0.2	0.1	2.8	2.1	0.4	—	2.5	2.4	0.2	—	2.7	0.68
239 A	6.574	(Cheatham- (Robertson	US 41-W	8-6-8x20'	90	30	¾"x2' at 12"c.c.	1144	69	1213				**				**	20.0	13.4	—	33.4	2.20
239 B	12.887	Montgomery	US 41-WJ	8-6-8x20'	90	30	¾"x2' at 12"c.c.	2302	385	2687				**				**	5.6	1.5	0.2	7.3	0.94
239 C	7.942	Cheatham	US 41-W	8-6-8x20'	90	30	¾"x2' at 12"c.c.	1402	28	1430				**				**	16.6	6.9	—	23.5	1.87
240 A	10.493	Marion	SR-2	8-6-8x20'	500	—	None	143	1180	1323	9.8	5.6	5.6	21.0	4.1	1.3	6.4	11.8	4.7	1.7	6.3	12.7	1.28
267 A	8.361	Davidson	SR 24	9-7-9x20'	320	40	None	1104	426	1530	—	—	—	—	0.2	—	—	0.2	0.1	—	—	0.1	0.05
269 B	5.627	Marion	US 41	8-6-8x20'	320	40	None	735	314	1049	5.9	12.2	5.7	23.8	18.5	11.8	1.3	31.5	9.6	12.1	4.4	26.1	1.47
269 C	5.238	Marion	US 41	8-6-8x20'	90	30	¾"x2' at 12"c.c.	857	254	1111	8.3	1.3	4.3	13.9	21.7	15.0	2.4	39.0	11.3	4.4	3.9	19.6	1.03
269 D	5.586	(Marion- (Hamilton	SR-2	8-6-8x20'	320	40	None	709	144	853	24.5	18.1	3.7	46.3	36.8	11.1	3.5	51.4	26.6	16.9	3.6	47.1	2.63
269 H	3.851	Marion	US 41	8-6-8x20'	90	30	¾"x2' at 12"cc.	633	215	848	17.2	1.9	1.7	20.9	13.0	23.3	2.8	39.1	16.2	7.3	2.0	25.5	0.98
280 F	5.145	Henry	SR-76	8-6-8x20'	90	30	J-bars at 20"c.c.	893	415	1308	—	—	—	—	—	—	—	—	—	—	—	—	—
313 AS	4.105	Louden	SR-1	8-6-8x18'	40	—	None	546	142	688	27.5	18.5	9.0	54.9	26.1	9.9	5.6	41.6	27.2	16.7	8.3	52.2	2.14
322 BS	2.943	McMinn	US 11	8-6-8x18'	500	—	None	55	191	246	3.6	12.7	12.7	29.1	3.1	8.4	12.6	24.1	3.3	9.3	12.6	25.2	0.74
339 CS	6.498	Hamilton	US 11	8-6-8x18'	40	—	¾"x4' at 3'cc.	808	619	1427	5.2	1.2	0.4	6.8	8.1	3.4	1.0	12.5	6.4	2.2	0.6	9.2	0.60
379 AS	3.110	Knox	US-25&70	8-6-8x18'	500	—	None	53	385	438	30.2	7.5	1.9	39.6	21.6	9.9	3.4	34.8	22.6	9.6	3.2	35.4	1.10
379 BS	3.003	Sevier	US-25&70	8-6-8x18'	500	—	None	51	449	500	5.9	—	—	5.9	15.6	3.6	0.2	19.4	14.6	3.2	0.2	18.0	0.54
							Average (Pumping Projects)				12	4	2	18	12	7	2	21	12	5	2	19	
Total	291.4																						42.8

** Pumping Joints and Cracks not recorded separately in reconnaissance survey.

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It should be noted here that distributed reinforcing was used on only a part of one of the projects studied. Also that the data available did not permit a study on the influence of expansion joint fillers. Construction records showed that nearly all projects were built with premolded or poured bituminous fillers.

Load Transfer Devices and Their Relation to Pumping

Twelve projects on which load transfer devices were used and 30 projects without load transfer devices at joints were investigated in the reconnaissance survey. Four of the projects on which no load transfer devices were used were located on soils of loess origin. Inasmuch as the other projects were on clay and cherty clay soils having generally similar characteristics, the four projects on loess soils were left out in assembling the average values shown in Table 5. Inclusion of pumping data from the four projects on loess soils would result in only very small changes in some of the values for pumping shown in the table.

The total per cent of pumping joints was only slightly greater for the projects without load transfer devices. However, the truck traffic on the projects involving the use of load transfer devices was much heavier than on the older pavements built without load transfer devices. The load transfer devices did appear to reduce to marked degree the per cent of classes 2 and 3 pumping joints which involve faulting and breakage. However, it should be noted that more severe pumping of classes 1 and 2 was found at intermediate transverse cracks where the pavements were built with load transfer devices at joints.

Close inspection of transverse joints on two of the projects on which load transfer devices were used showed that the dowels did not allow free movement of the slabs when the slab expanded or contracted on those projects. The total effect of restricted movement due to frozen dowels could not be determined for all projects, but it may account for the more severe pumping generally indicated at transverse cracks in pavements having doweled joints.

The Effect of Shoulder Drainage on Pumping

Pumping occurred under conditions of good surface drainage as well as poor surface drainage. Severe pumping was observed on grades and on heavy clay soils at many locations where shoulders were lower than the pavement edge, had slopes in excess of one inch per foot and where runoff was not impeded by vegetation. Contrariwise, pumping occurred on some projects having loess subgrade soils only where poor surface drainage existed.

The Subgrade and Its Relation to Pumping, Soil Parent Material and Soil Series

The reconnaissance and detail study surveys were planned for the principal traffic routes traversing the major representative soil groups of Tennessee. Beginning at Memphis and proceeding eastward the survey covered the following soil areas in the order given:

1. The yellow silty clay loams and silty clay soils of western Tennessee which originate from deep loess to the soils derived from shallow loess underlain by coastal plains materials.

TABLE 4
COMPARISON OF PUMPING AT EXPANSION JOINTS, CONTRACTION JOINTS AND CRACKS
(Six Projects totaling 62 Miles in Length)

Projects	Pumping Exp. Joints (Per Cent)				Pumping Contr. Joints (Per Cent)				Pumping Cracks (Per Cent)				Pumping Joints & Cracks (Per Cent)				Remarks
	Class				Class				Class				Class				
	1	2	3	Total	1	2	3	Total	1	2	3	Total	1	2	3	Total	
41AB (4)(5)	18.7	-	-	18.7	9.7	-	-	9.7	-	-	-	-	12.7	-	-	12.7	2-22 ft. lanes - 8 ft. grass dividing strip. 7" unif. 30-90 ft. Jt. spacing. Edge curb along dividing strip. Univ. or Nat'l Load Transfer. Heavy clay soil.
41AB (Reop.)	40.4	0.2	0.1	40.7	36.8	0.1	-	36.9	27.3	-	-	27.3	38.0	0.2	-	38.2	2-22 ft. lanes - 4 ft. concrete dividing strip. 7" unif. 30-90 ft. Joint spacing. Spec. base plate under Exp. Jts. Heavy clay soil with 2" loose sand mixed to depth of 6".
208I(2) 486A(2)	3.0	-	0.3	3.3	0.3	-	-	0.3	9.2	10.8	1.0	21.0	3.5	3.1	0.4	7.0	8-6-8-6-8x22' 30-90 ft. Joint spacing. $\frac{3}{4}$"x24" dowels at Exp. & Contr.Jts. at 12" c.c. A-4 clay soil with 2" to 3" loose sand mixed to depth of 6" to 8".
228BS	15.7	7.4	0.9	24.0	20.2	4.5	0.5	25.2	20.5	8.1	1.2	29.8	20.0	6.9	1.0	27.9	9-7-9x20' 50-300 ft. joint spacing. No load transfer. A-6-7 cherty clay soils.
231BS	-	-	-	-	4.7	2.1	-	6.8	1.6	1.6	-	3.2	3.6	1.7	-	5.3	8-6-8x20' 50-300 ft. joint spacing. No load transfer. A-6-7 cherty clay soils.
231GFC	2.0	0.2	0.2	2.4	2.6	0.2	-	2.8	2.1	0.4	-	2.5	2.4	0.2	0.1	2.7	9-7-9x20' 50-300 ft. joint spacing. No load transfer. Cherty clay soils.
Average	13.3	1.3	0.3	14.9	12.4	1.2	0.1	13.7	10.1	3.5	0.4	14.0	13.4	2.0	0.3	15.7	

Note: No cracks were observed on Project 41AB (4)(5)

TABLE 5

RELATION BETWEEN LOAD TRANSFER DEVICES, PUMPING AND TRAFFIC
(33 Projects Having Clay, Clay Loam and Cherty Clay Subgrades)

Number of Projects	Load Transfer	Pumping Joints (Per Cent)				Pumping Intermediate Cracks (Per Cent)				Pumping Joints & Cracks (Per Cent)			
		Class				Class				Class			
		1	2	3	Total	1	2	3	Total	1	2	3	Total
21	None	13	6	3	22	12	5	3	20	11	6	3	20
12	3/4"x24" at 12"cc*	18	2	1	21	17	17	3	37	17	6	1	24

Number of Projects	Load Transfer	24 Hour Traffic						
		Total Vehicles	Total Trucks	Truck Axle Loads in Kips (Cumulative)				
				Over 10	Over 12	Over 14	Over 16	Over 18
21	None	2,186	419	256	200	142	65	12
12	3/4"x24" at 12"cc*	3,144	690	441	362	258	109	21

*One project used a special type of load transfer device and a second project used 3/4 in. x 48 in. dowels spaced on 36 in. centers.

2. Sandy soils derived from coastal plains materials.

3. Cherty clay soils in west central Tennessee derived from cherty limestones.

4. Clay soils derived from limestones and shales and massive limestones, including phosphatic limestones.

5. Sandy and silty soils derived from sandstones and shales.

6. Gravelly clay soils derived from cherty limestones and limestones in east central and east Tennessee.

Soils which originate from the deeper loess formations were investigated on U.S. Route 51 north of Memphis in Shelby, Lauderdale and Dyer counties; on U.S. Route 70 in Shelby, Fayette, Madison and Carroll counties and on State Route 76 in Gibson county. Thin loess underlain by coastal plains deposits was investigated in Henry county on State Route 76.

The deep loess is classified pedoligically into three soils series as follows:

1. The Memphis series occupies the narrow highland ridges and forms on rolling to hilly land. It has a slightly to moderately plastic B horizon of yellowish brown to faintly reddish brown silty clay loam. Relatively good surface and subsurface drainage are characteristic of the Memphis series.

2. The Loring series occupies the nearly level to rolling uplands. It develops a more plastic and more compact B horizon which is characterized by slower drainage than that of the Memphis series. The brownish silty clay loam and clay B horizon is splotched with gray, rust-brown and yellow characteristic of less perfect drainage.

3. The Granada series consists of loess overlying coastal plains material at depths of 4 to 15 ft. It develops a semi-clay-pan B horizon which restricts drainage and occupies undulating to gently rolling topography ranging in slope from about 2 to 7 per cent.

A fourth series, the Lexington, consists of a few inches to about 2 ft. of loess over ferruginous sands and sandy clays of the coastal plains deposit. Roads on the Lexington soils lie mostly in the sandy materials although one location investigated in Henry county was in the B horizon of a soil classified as Lexington.

No pumping was found during this survey on loess soils of the Memphis group, all pumping being found on the B horizon of the Loring series which is a compact, imperfectly drained soil. Although no pumping was found on the more lightly traveled roads built on loess soils of the Granada series, it is believed that its compact and imperfectly drained B horizon needs attention to avoid pumping under a large volume of heavy axle loads.

A summary of soils test data, axle weights and pumping is given in Table 2 for all loess soils tested. Neither the soils constants nor the mechanical analysis indicate a wide difference in the physical characteristics of these soils.

It is evident from the test data that there is a very small difference between the loess soils where pumping has or has not developed. The difference is mainly one of compactness and movement of water in the soil profile.

No pumping occurred on the sandy soils of the coastal plains materials which are classified in the Ruston series and which form the C horizon of the Lexington series.

Pumping prevailed on pavements built on all cherty clay soils in west central Tennessee which were derived from cherty limestones. These soils were classified in the Baxter, Dickson and Bodine series. Pumping occurred in both the B and C horizons of all 3 series except where the sand and gravel content prevented its occurrence. The relation between sand and gravel content of a subgrade soil and pumping is discussed later in the report.

Pumping occurred throughout the Hagerstown, Maury and Mercer groups derived from limestones and also from gravelly clay soils derived from cherty and dolomitic limestones except for subgrades having high gravel content which will be discussed later. These gravelly clay soils are represented by the Clarksville, Fullerton and Dewey series.

No pumping occurred on the more sandy soils of the Muskingum and Hartsells series which were formed from sandstones and shales. However, the occurrence of strata of fine plastic clay in some areas of sandy soils created localized areas of poor drainage which resulted in severe pumping of the clay soils even under relatively light traffic.

PRA Soil Groups

Pumping was found on the A-7, A-6 , A-5-7 and A-4 soil groups. It was also found in the A-2-4 and A-2-6 borderline groups having near the minimum sand content in the soil mortar for those soils.

No pumping was encountered in soils of the A-2 and A-3 groups nor on many of the borderline A-2-4 and A-2-6 and A-2-7 groups containing near maximum sand and gravel content for those groups.

In many instances soil samples taken from under pumping and non-pumping slabs showed generally similar soil constants. This is true for some of the clay, silty clay and silty clay loam soils. It is difficult, for that reason, to make a positive statement regarding the limiting values of soil constants for pumping or non-pumping soils. It is of interest to note in Table 6, which shows soil constants of all soil samples taken from detail study sections that both the range of values and the average values of all soil constants are considerably lower for the soils of the clay, silty clay, silty clay loam and clay loam soils where no pumping occurred than for soils of similar textural types found under pumping slabs.

Consolidation and Triaxial Compression Characteristics

Tests were made to determine the relative consolidation characteristics of soil types and soil conditions associated with pumping as well as those found where no pumping occurred. Undisturbed samples were taken immediately under or adjacent to transverse joints and cracks. A portion of each sample was tested in the condition in which it was received at the laboratory. A test was made on another portion of the sample in an inundated condition.

Nine soils from under pumping slabs and five soils from under non-pumping slabs were tested for consolidation. The average values of per cent reduction in height for various loads and average per cent consolidation between load increases at various time periods for both pumping and non-pumping soils are given in Table 7.

The data, although representing relatively few samples, do indicate a trend of greater total and residual compression for pumping soils than for non-pumping soils. Soils from under pumping slabs resulted in greater consolidation under all loads in both the "existing" and "inundated" conditions and consolidated in a shorter time than did the samples from under non-pumping slabs. The data therefore indicate a trend of greater total and residual compression for the pumping than for the non-pumping soils.

A tabulation of per cent reduction in height and maximum difference between vertical and normal pressures obtained in the triaxial compression test for both pumping and non-pumping soils is given in Table 8. The values for per cent reduction in height follow a trend similar to that observed in the consolidation tests. The values for shearing stress computed from the maximum differences between vertical and lateral pressures shown in Table 8 are erratic and do not show a well defined trend.

Permeability tests were made on nine pumping soils and six non-pumping soils. All were fine grained silty clay loam to clay soils except one sand. No significant trends are evident from the data obtained.

TABLE 7
SUMMARY OF DATA FROM CONSOLIDATION TESTS

Method of Conducting Consolidation Tests	Per Cent Reduction in Height at Load of (Kips /.s.f.)								Remarks
	0.02	0.10	0.35	1	2	4	8	0.10	
Tested as Received	0.0	0.31	0.52	0.89	1.36	2.38	3.94	2.69	Pumping Slabs
Tested as Received	0.0	0.14	0.28	0.52	0.94	1.48	2.54	1.75	Non-Pumping Slabs
Inundated	0.0	0.11	0.01	0.40	1.10	2.13	3.87	2.18	Pumping Slabs
Inundated	0.0	0.0	0.10	0.36	0.78	1.56	2.72	1.43	Non-Pumping Slabs

Method of Conducting Consolidation Tests	Average Per Cent Consolidation at Time of (Minutes)								Remarks
	0.09	0.25	0.49	1	4	9	25	64	
Tested as Received	37	42	47	51	60	66	74	79	Pumping Slabs
Tested as Received	48	54	60	66	73	78	82	86	Non-Pumping Slabs
Inundated	44	52	56	62	71	78	83	88	Pumping Slabs
Inundated	51	57	62	68	77	81	86	90	Non-Pumping Slabs

Sample 38, a non-plastic sand, not included in above tabulation.

Soil Texture

Data obtained from sieve and hydrometer analysis on all samples of soil from detail study sections are shown in Table 6. The data obtained on soils from under pumping and non-pumping slabs show a definite relation between textural soil type and pumping, when the grading of the total subgrade soil is considered. The percentages shown in Table 6 as sand and gravel, comprise all sand and gravel in the total soil sample, i.e., all materials coarser than 0.05 mm. diameter (retained on No. 270 sieve). The relation between pumping and soil texture is illustrated in the triangular chart in Figure 5.

No pumping was encountered in Tennessee on soils having more than 55 per cent sand and gravel (coarser than 0.05 mm. diameter) in the total soil. It may be seen that pumping did and did not occur on some soils having a combined sand and gravel fraction of less than 55 per cent. Many of these non-pumping soils having less than 55 per cent sand and gravel, had relatively high silt content and low clay content. These soils permit more rapid movement of water away from leaky joints and

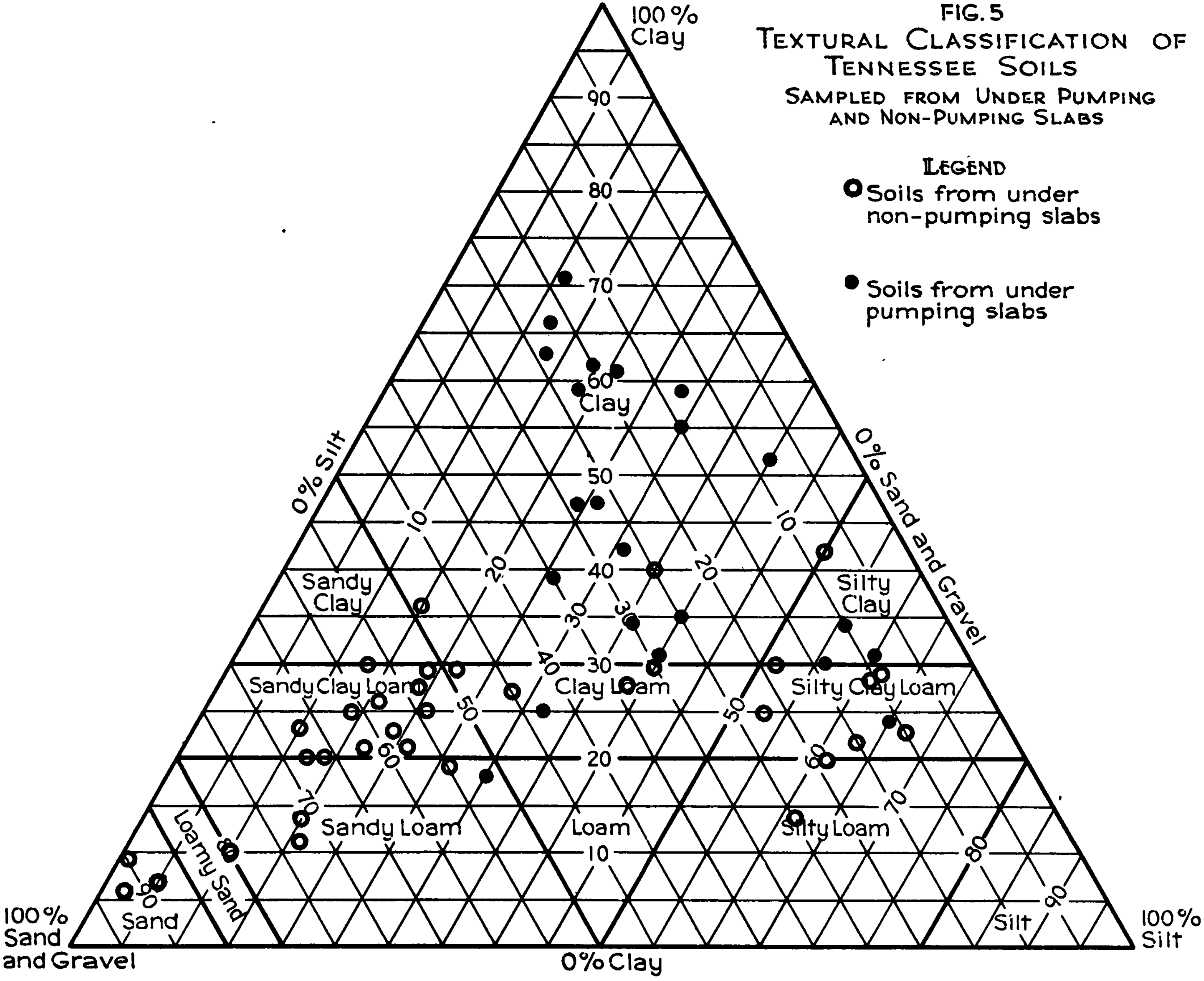

FIG. 5

TEXTURAL CLASSIFICATION OF TENNESSEE SOILS SAMPLED FROM UNDER PUMPING AND NON-PUMPING SLABS

TABLE 8

Triaxial Compression Test Results

Loc. No.	Pumping: Max. P_v-P_h (Kips /.s.f.) $P_h=0$	$P_h=2$	Red. in height (Per Cent) $P_h=0$	$P_h=2$	ø (deg.)	Non-Pumping: Max. P_v-P_h (Kips /.s.f.) $P_h=0$	$P_h=2$	Red. in height (Per Cent) $P_h=0$	$P_h=2$	ø (deg.)
1	3.9	5.0	2.4	1.6	12					
5	4.4	4.4	6.0	4.8	0					
7						3.0	3.8	2.3	2.5	9
8						2.3	2.6	0.8	1.1	5
9						1.3	2.6	1.5	2.0	14
10	2.1	3.0	5.0	1.5	10.5					
11						4.0	4.0	0.5	0.6	0
12						8.8	-	1.0	-	-
14	1.0	-	0.9	-	-					
26	3.0	2.9	1.2	1.7	0					
27	1.0	1.0	3.0	4.0	0					
29	5.2	3.0	1.5	2.5	0					
30	2.0	3.3	4.5	4.5	14.5					
31	0.8	3.2	0.9	12.5	21.5					

cracks in the pavement and thus either prevent pumping or limit its occurrence to prolonged periods of wet weather. Such soils have been observed to be wet weather pumpers and do not pump during periods of infrequent rains as do the more plastic and more impervious clay soils.

Soil Water Content and Density

Soil water content determinations were made at 14 locations where pumping occurred and 15 where no pumping occurred. The results of soil water content determinations are shown in Table 6. Water contents of less than the plastic limit were found in only two of the 14 locations where pumping occurred. The major portion of the pumping locations had water contents of 3 to 5 percentage points greater than their corresponding plastic limits. The overall average water content exceeded the average plastic limit by 3.

Five of the eleven tests of plastic soil from under non-pumping slabs had water contents below their plastic limits and six had water contents 1 to 4 percentage points greater than their plastic limits. Average water content for plastic non-pumping soils immediately under the pavement was 19.4 per cent compared to an average plastic limit of 18.9 per cent.

Density and water content tests showed that in nearly every instance the soil was at or near saturation. Thus, the higher densities shown in Table 6 for non-pumping plastic soils limited the water holding capacity of the soils and prevented the absorption of sufficient water to soften the soil, reduce its bearing capacity, permit greater slab deflections and start pumping.

The variation in soil structure and compactness of different horizons in the soil profile had little or no influence on pumping in some soils and much in others. Pumping was often equally severe in the B and C horizons of soils derived from limestones and cherty limestones. However, in soils formed from loess, the more compact and less perfectly drained B horizon of the Loring series accounted for a major portion of the pumping found on those soils. The soils of the Muskingum and Hartsells series formed from sandstones and shales sometimes had compact clay strata underlying more pervious sandy soil. The less pervious compact clay strata restricted drainage, and caused the clay soils to become saturated and pump badly where the clay strata intersected the grade.

The Effect of Subgrade Treatments

Subgrade treatments consisting of 2 to 4 in. of loose sand mixed with the existing clay subgrades to 4 to 8 in. compacted depths were employed on three projects included in the survey. Detail study sections were included on 2 of the 3 projects. The natural subgrade soils on all three projects consisted of heavy clay soils derived from cherty limestones and are representative of the worst pumping soils in the State.

Some pumping occurred on all three projects. However, the soil samples taken during the detail study showed that where the sand and gravel content (portion having particles larger than 0.05 mm. diameter) in the treated subgrade soil was greater than 55 per cent, pumping did not occur. Two of these projects carry a moderate number of heavy axle loads. The third carried the greatest number of heavy axle loads encountered in the State.

There was evidence on some projects that the use of applications of sand-gravel to provide temporary surfacing for local traffic during the period between grading and paving had been effective in materially reducing pumping.

The Effect of Pavement and Shoulder Maintenance

Inasmuch as very little mudjacking as a maintenance operation to fill cavities under pumping slab ends had been done in Tennessee at the time of this survey observations could not be made regarding its effectiveness.

It has been mentioned previously that pumping on heavy clay soils occurred where shoulders were well sloped and permitted rapid runoff of surface water. However, it was observed that often the most severe pumping occurred in cuts and at the bottom of hills at low points in the grade where surface drainage was poor. Likewise, on borderline soils, that is, soils which pump only during prolonged periods of wet weather, pumping occurred only when associated with poor surface drainage due to high shoulders or to ruts in shoulders at the edge of the slab.

In summary, the observations showed that good maintenance of joints, cracks and surface drainage either prevented pumping of materially reduced the progress of pumping.

Summary and Correlation of Data

The data and observations indicate that methods and designs for preventing pumping on new construction can be grouped into two categories. First, a group of minor factors which tend to reduce or minimize pumping and second, a group of major factors to prevent the occurrence of pumping.

The first group includes the following factors:

1. The design of pavement and shoulders to obtain rapid runoff of surface water.
2. The use of minimum provisions for expansion or a maximum spacing of expansion joints of a given width. This tends to keep the pavement in restraint and reduces the amount of opening of intermediate contraction joints or cracks.
3. The use of a pavement thickness adequate for prevailing wheel loads.
4. The provision for load transferance at transverse joints to prevent faulting.
5. The control of water content and density of the subgrade during construction to obtain the greatest supporting value which the soil can be expected to maintain under service conditions.
6. Close attention to surface maintenance of the pavement and shoulders to reduce the entrance of water to the subgrade.

The data and observations pertaining to this first group are not conclusive but they do give positive evidence that all of the above factors will tend to reduce pumping. The observations on loess soils showed that pumping was often associated with poor surface drainage and that no pumping occurred on contiguous slabs on similar soils where the surface drainage was good.

The longest spacing of expansion joints was associated with less pumping. Pavements having load transferance at joints and carrying a substantially greater volume of heavy axle loads than did pavements with no load transfer devices showed approximately the same percentage of pumping joints as was found on pavements without provisions for load transfer. It is significant however, that the amount of Class 2 and Class 3 pumping at tranverse joints was less where load transferance was provided. Where "frozen" dowels restricted normal slab movements, transverse cracks showed greater pumping than found on pavements where the dowels functioned properly or on pavements built without dowels.

The results of observations on the beneficial effects of timely and good surface maintenance have been mentioned previously.

The close correlation between soil water content and pumping indicated that compaction with control of water content is of considerable value in reducing pumping. It is known that heavy clay soils having high volume change, although compacted to high densities, may swell and eventually absorb water in excess of their plastic limits. For such soils compaction with water content control may be of temporary value. However, for some soils having moderate volume change which will not swell and absorb water in excess of their plastic limits, the data indicate that compaction prevented the occurrence of pumping on those soils.

The second group includes the following two major factors which prevent the occurrence of pumping:

1. The use of a natural subgrade soil, an admixture of sand with natural soil or subbases of granular material which will not erode readily under normal expected movements of the slab.
2. The compaction of the better graded friable soils which do not erode readily to provide the maximum supporting value for the slab, which the soils can be expected to maintain.

Soils having more than 55 per cent retained on the No. 270 sieve have prevented pumping under the conditions found in Tennessee at the time of the survey. The above statement is based on normal conditions of drainage found on the projects studied and does not pertain to locations where drainage conditions permit abnormal accumulation of water. The statement likewise pertains to the combinations of pavement thickness and traffic loads which prevailed.

It should be noted from the mechanical analysis of the soils that most of the sandy soils encountered were fairly well graded. It is possible that very poorly graded sandy soils having a large fine sand fraction might pump under heavy traffic and abnormal drainage conditions.

The data regarding thickness of subbases and subgrade treatments over pumping soils are not extensive. However, the thicknesses of treatment used, which consisted of mixing sand with the natural soils subgrades to form compacted depths of four to six in. (in one instance 8 in.) were effective in preventing pumping where the total soil mixture contained more than 55 per cent of material retained on the No. 270 sieve.

The data and observations indicated that adequate compaction was a major factor in preventing pumping on the better graded friable soils having relatively low volume change, by limiting the water holding capacity of those soils. Such soils were found to maintain good support at water contents near saturation.