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1946 SUPPLEMENT

SPECIAL PAPERS
ON
THE PUMPING ACTION OF CONCRETE PAVEMENTS

1946

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COMMITTEE
ON
MAINTENANCE OF JOINTS IN CONCRETE PAVEMENTS
AS RELATED TO
THE PUMPING ACTION OF THE SLABS

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1946

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COMMITTEE
ON
MAINTENANCE OF JOINTS IN CONCRETE PAVEMENTS AS RELATED TO THE PUMPING ACTION OF THE SLABS

Special Papers Presented
for
The Twenty-fifth Annual Meeting

Edited by
Fred Burggraf
Associate Director, Highway Research Board

Washington, D. C.
1946

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DEPARTMENT OF MAINTENANCE

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REPORT OF COMMITTEE ON MAINTENANCE OF JOINTS IN CONCRETE PAVEMENTS AS RELATED TO THE PUMPING ACTION OF THE SLABS

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SYNOPSIS

The pumping committee has completed three major projects during 1945: 1. The preparation of recommendations on the design of rigid pavements as requested by the Project Committee on Rigid Pavement Design. 2. A survey of the pumping of concrete pavements in North Carolina; and 3. A survey of the pumping of concrete pavements in Kansas.

The North Carolina and Kansas surveys were made on a cooperative basis by the respective State highway departments and the Portland Cement Association. These reports which supplement the reports issued in 1945/1 are herein published. The conclusions presented in these reports are those of the authors and do not necessarily represent those of the committee.

/1 - "Special Papers on the Pumping Action of Concrete Pavements," Research Reports No. 1-D, Highway Research Board, 1945.

The following recommendations for pavement design as based upon the results of studies made by the Pumping Committee were transmitted to the Committee of the Highway Research Board on Design of Rigid Pavements:

That the road be designed with a high level profile, adequate side ditches and slopes. Such design will aid in snow control, facilitate snow removal, and provide rapid run-off of surface waters.

That adequate subsurface drainage be provided for areas where it is necessary to lower the ground water table or to intercept ground waters.

That soil surveys be made to establish the soil type, its condition and drainage as a basis for determining the need for treatment to prevent pumping on new construction.

Studies by the Committee have shown that under normal conditions of drainage, pumping has not been found on subgrade soils having approximately 55 per cent or more material retained on the No. 270 sieve. Pumping has been found on some fine-grained sandy soils under conditions of very poor drainage where the soils were kept in a saturated state.

The Committee recommends that on primary roads, subbases be constructed on all subgrades composed of fine-grained soils. Such subbases should be constructed to the full roadway width or given adequate drainage if they are constructed of drainable materials. Subbases composed of densely-graded non-draining material built in widths 2 or 3 ft. greater than the width of the pavement are under observation and at the time of the last report were giving satisfactory results.

Experience of the Committee to date on the thickness of subbases is as follows:

Ohio has used classified embankment for depths up to 2 ft. The most widely used depth of subbase has been 12 in..

New Jersey has used bases of bank run sand, gravel or cinders of 8 to 12-in. compacted thickness. A major portion of the installations are of 8-in. compacted thickness.

Illinois experience is with thicknesses ranging from 6 in. to 12 in. A major portion of the subbases are of 6-in. compacted thickness.

Tennessee has used sand admixtures with existing soils. Depths of treatment have ranged from 4 to 8 in.

North Carolina uses selected nonplastic sands and sandy loams of 3 to 6-in. compacted thickness.

Indiana's experience has been largely with 6-in. compacted depth but subbases have ranged from 3 in. to 9 in. in thickness.

Kansas has used subbases of 4-in. to 15-in. compacted thickness.

A major portion of the installations have been of gradings which were not of the free draining type. All thicknesses, including the 3-in. thickness of stabilized stone used in Indiana and the 3-in. nonplastic sands and sandy loams used in North Carolina, have been successful when constructed of suitable materials. Materials found unsuitable for subgrades have likewise been found unsuitable for subbases.

The committee further recommends that shoulders be constructed of low volume change soil or granular materials to a minimum width of 1½ ft. The granular materials should be covered with a nonerodable surface such as bituminous penetration, bituminous mat or hot mix. Where economy permits, the entire width of shoulder may be constructed of low volume change materials which give good support. Shoulders so constructed should be protected against erosion by turf or other suitable covering.

The Committee recommends that a study be made by the Committee on Design of Rigid Pavements to determine the relations between traffic, pavement cross section, the cross section of the subbase, and the nature of the subbase materials.

The Committee has found that pumping has occurred on all thicknesses and cross sections of pavements used generally in highway construction, when soils and traffic conditions were conductive to pumping.

Load transfer devices have not in themselves completely prevented the occurrence of pumping. In New Jersey, pumping has been held to a very small amount by the use of heavy channel type dowels. Therefore, it is suggested that a comprehensive study be made of load transfer devices for both expansion and contraction joints, and that research be undertaken to develop satisfactory load transfer devices.

Joint fillers of the plastic type have failed to exclude water or other materials. Wood shows some promise as a good joint filler. It is suggested that research be continued in an effort to develop a satisfactory material.

The Committee recommends that expansion joints be omitted from concrete pavements or be spaced at the maximum distance necessary for keeping compressive stresses within critical limits.

The Committee has found that pumping has developed at both expansion and contraction joints on pavements built with the expansion provisions commonly used, where soil and traffic conditions are conducive to pumping. Under similar conditions, pavements built with little or no provision for expansion, or that have otherwise been held in restraint, have developed much less or no pumping.

If no expansion joints are used, the spacing of contraction joints should be the maximum, for the materials and proportions used, which is consistent with good crack control and small contraction joint opening. In order to reduce pumping to a minimum, it is the recommendation of this Committee that extensive research be undertaken to determine the best contraction joint spacing, as related to aggregates, cements, proportions, reinforcing and climatic and soil conditions.

It has been observed by this committee that in most instances the crack interval is directly related to the type of aggregates used in pavements built without joints.

The Committee also desires to make the following recommendations pertaining to needed investigations:

1. That research be undertaken to determine the limits of grain sizes which prevent intrusion of fine-grained soils into subbases.

2. That research be undertaken to determine the permeability, drainage, and compaction (rolling) characteristics of various subbase materials as they are related to pumping.

PUMPING OF CONCRETE PAVEMENTS IN NORTH CAROLINA

A Cooperative Study
by
North Carolina State Highway and Public Works Commission
and
Portland Cement Association
With Soil Tests by the
Public Roads Administration

SYNOPSIS

Approximately 300 miles of concrete pavements on main traffic routes connecting principal cities in North Carolina were surveyed to determine the extent and nature of pumping and its relation to traffic pavement design features and subgrade soils.

The survey consisted of (1) Classifying and counting pumping joints and cracks on each project to determine location and extent of pumping and its stage of progress in terms of damage to the pavement. (2) Detail examination of short sections of pumping and non-pumping slavs, and (3) Sampling and testing of soils from under pumping and non-pumping slabs. Traffic data, construction records, and data on pavement design features were assembled for each project and correlated with pumping. The survey included a study of some pavement widening projects.

Pumping occurred at expansion joints, contraction joints and at transverse cracks. The most severe pumping occurred at transverse cracks. Very little difference was found either in the amount or severity of pumping at expansion joints compared to pumping at contraction joints. The older pavements built without expansion joints on subgrade soils conducive to pumping showed less pumping than did the newer pavements built on similar soils and having expansion joints at 90 or 120 ft. intervals and intermediate contraction joints at 30 ft. intervals. Both types of joints were equipped with load transfer devices.

Considerably more pumping occurred on pavement widening built with expansion joints than on the original pavements which were built without expansion joints.

Traffic in terms of number of trucks per day was greatest on the projects on which pumping was found. However, the number of trucks per day was as great as on some of the projects on which the most severe pumping was found.

All soils sampled from under pumping slabs were of a plastic nature and contained less than 50 per cent sand and gravel (retained on the No. 270 sieve) in the total soil. No pumping was found on soils having more than 50 per cent sand and gravel in the total soil.

This report gives the results of a cooperative study made during the spring of 1944 by the North Carolina State Highway and Public Works Commission and the Portland Cement Association to determine the extent and nature of pumping on the principal highways of the Coastal Plains and the Piedmont Region of North Carolina, the types of subgrade soils associated with pumping and the effectiveness of selected soil subbases in preventing pumping. The Public Roads Administration cooperated to the extent of making tests of soil samples taken during the survey.

Prior to the survey, pumping had developed at or near transverse joints and cracks of pavements on the more heavily traveled routes in North Carolina. It is reported that the advent of pumping had coincided with large increases in the number and weight of heavy trucks using the highways.

The field studies described in this report were limited to observations and tests of pavement slabs and subgrades where traffic was causing mud to be ejected at slab ends and edges.

NATURE AND SCOPE OF STUDIES

Before field observations were begun, design and construction data were assembled for a major portion of the concrete pavement projects on the most heavily traveled east-west and some north-south traffic routes. The traffic routes selected for study and the projects on which data were assembled are indicated on the map shown in Fig. 1.

Reconnaissance Survey of Pumping

The reconnaissance survey of pumping was divided into two parts. One observer recorded all expansion joints, contraction joints, cracks, corner breaks and settled and damaged areas. A second observer classified and recorded pumping at expansion joints, contraction joints and cracks. All pumping at the pavement edge and at the longitudinal center joint was credited to the transverse crack or joint near which it was found. All observations made during the reconnaissance survey were made from an auto driven slowly over the project.

Pumping was classified into three classes according to the progressive stages of its development. From the data thus obtained it was possible not only to obtain a description of the amount and severity of pumping, but also to assess the damage which it had caused to the pavement. The three stages of development into which pumping joints and cracks were grouped were as follows:

Class 1. Pumping at joints and cracks without noticeable faulting at slab ends or breaking of slabs as a result of pumping.

Class 2. Pumping accompanied by faulting with no evidence of breaking of slabs as a result of pumping.

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

Detail Examination and Sampling of Selected Sections

During the reconnaissance study of a project, sections which were representative of pumping on a project, or sections on which no pumping had occurred, were noted for further study. The sections noted were later inspected carefully for pumping. Representative samples of subgrade soils, and where used, samples of subbase materials, were taken from under pumping or non-pumping transverse joints or cracks. Some sections were mapped to record the extent and nature of cracking and pumping. Prior to taking samples in the detail study sections, the existing soils were classified pedologically into series and type.

Testing of Soils

Soil samples were sent to the Public Roads Administration in Washington, D. C. for test. The laboratory of the Public Roads Administration conducted Liquid Limit, Plastic Limit, Field Moisture Equivalent, Shrinkage Limit and Mechanical Analysis tests on the samples.

ANALYSIS OF OBSERVATIONS AND DATA

Three major factors which govern the life and behavior of roads were considered in the studies. They are:

(1) the pavement, its design features and maintenance condition;
(2) subgrade soils and their condition;
(3) traffic, including both weight and number of axles.

Data pertaining to each of these factors were obtained during the survey and the relationship of these data to the nature and amount of pumping are presented here in the order indicated above.

Pavement Cross-Section

There was not sufficient variation in pavement thickness without accompanying variations in other pertinent factors such, for example, as spacing of expansion joints, to make it possible to determine the relationship of pavement thickness to pumping for different conditions of traffic. The only comparisons which can be made must necessarily include the older pavements built without expansion joints in one group, compared to the newer pavements built with expansion joints at 90 and 120 foot spacing in another group.

Five pumping projects of 8-7-8x18' cross-section and having an average age of 19 years, a total length of 44 miles and constructed without expansion joints, showed 2.3 per cent of all cracks pumping.

Five pumping projects of 9-7-9x20' cross-section and having an average age of 5½ years, a total length of 49 miles and constructed with expansion joints at 90 or 120 ft intervals showed 7 per cent of all joints and 3.3 per cent of all cracks pumping.

Traffic, based only on the total number of trucks per day, was nearly similar. All ten projects were on soils, a major portion of which were considered to be conducive to pumping.

Here the newer, slightly heavier and wider pavements which had a shorter crack and joint interval pumped more than did the older pavements. This makes it evident that cross-section is of less significance in preventing pumping than are some other factors in pavement design.

Pumping at Expansion Joints, Contraction Joints and Cracks

Pumping occurred at expansion joints, contraction joints and cracks. There was little difference in either the amount or the severity of pumping at expansion joints compared to the pumping at contraction joints. Pumping was more prevalent and more advanced at cracks than at joints on pavements having expansion and contraction joints. However, the number of pumping cracks on any project was in most instances small because of the small number of cracks which had formed. Table 1 shows the relative amounts and nature of pumping at expansion joints, contraction joints and cracks on 10 projects. A few of the cracks indicated in the count were open and were believed associated with restricted movement of the slab at expansion joints due to binding of the dowels.

Effect of Spacing of Expansion Joints

A total of 21 projects built with expansion joints spaced at intervals of 90 and 120 ft. and having a combined length of 118 miles were investigated for pumping during the survey. No pumping was found on nine projects. Two projects showed only small traces of pumping. Ten projects, built on soils considered as being conducive to pumping showed pumping ranging from 0.4 per cent to as much as 20.5 per cent of all joints and cracks pumping. Three of the pumping projects had expansion joint spacings of 120 feet and seven had expansion joints spaced at intervals of 90 feet.

Because of the small range in expansion joint spacing, the difference in age, in traffic, and because of the small number of projects involved, no conclusions can be drawn from the data indicating any difference between the 90 ft. and 120 ft. joint spacing. The data are shown on Table 2.

Pavements which were constructed without expansion joints on subgrade soils conducive to pumping showed much less pumping (only about one-tenth as much) than did pavements built on similar soils and having expansion and contraction joints both with load transfer devices. This is true although the pavement built without expansion joints is much older and carries at least as much traffic. A summary of the data on pumping projects is shown in Table 3.

Evidence was found from observations made during detail examination of sections that transverse cracks in the older pavements having no expansion joints were, in some instances, filled with debris and the slabs appeared to be in compression, but there was no evidence of distress as a result of the compression.

Additional data on the relative amount of pumping on concrete slabs with and without expansion joints are given in later paragraphs on 'Pumping in Pavement Widening."

Pumping in Pavement Widening

Nine projects consisting of old pavements 16 and 18 feet wide and widening ranging from 4 to 10 feet wide, were studied in the reconnaissance survey. A summary of the data obtained is given in Table 4.

TABLE 1

PUMPING AT EXPANSION JOINTS, CONTRACTION JOINTS AND CRACKS

(North Carolina)

(Data for pumping projects only)

Note All projects have expansion joints spaced at 90 or 120 ft. intervals, have load transfer devices at both Expansion Joints and Contraction Joints and are located on Soils of which a major portion are considered to be conducive to pumping.

Project	Age (Yrs.)	Length (Miles)	Total Exp. Joints	Number of Pumping Expansion Joints				Total Contr. Joints	Number of Pumping Contraction Joints				Total Cracks	Number of Pumping Cracks				REMARKS ON SUBGRADE
				Class 1	Class 2	Class 3	Total		Class 1	Class 2	Class 3	Total		Class 1	Class 2	Class 3	Total	
466	6	16.280	981	92	0	10	102	1,961	126	1	12	139	60	21	0	5	26	Cecil & Mecklenberg Gravelly & Normal Soils
4601	3	9.787	424	36	0	0	36	1,271	57	0	0	57	36	4	0	0	4	Davidson, Georgeville & Durham Most pumping on Georgeville
4836	8	11.720	687	36	0	0	36	1,375	20	0	0	20	8	0	0	0	0	Cecil, Durham, Granville, Appling & White Store
5060	2	0.500	21	4	0	0	4	64	8	0	0	8	5	0	0	0	0	Cecil Soils. (Job mudjacked & French drains installed)
5254	5	8.830	507	81	3	14	98	1,038	189	1	14	204	69	19	1	9	29	Cecil, Wilkes, Davidson & Mecklenberg
6151	8	10.748	611	8	0	3	11	1,221	16	0	8	24	29	5	1	3	9	Mostly Cecil Some Iredell, Mecklenberg & Durham
6324	9	6.594	381	43	0	1	44	761	106	0	4	110	18	6	0	0	6	Cecil with heavy B horizon
6582	6	2.540	148	1	0	0	1	296	2	0	0	2	2	2	0	0	2	Cecil with heavy B horizon
7540	8	5.892	345	24	0	2	26	691	19	2	3	24	11	0	0	0	0	Cecil
7541	8	5.945	345	0	0	0	0	691	3	0	1	4	6	0	0	0	0	Cecil C horizon Deep cuts. High Fills Pumping at Settlements
Totals		78.836	4450	325	3	30	358	9369	540	4	42	592	244	57	2	17	76	
Per Cent				7.3	0.1	0.7	8.1		5.8	0.1	0.4	6.3		23.4	0.8	7.0	31.2	
Average	6.3	7.884																

The original pavements on seven projects were built without expansion joints but the more recent widenings were built with expansion joints spaced at intervals of 90 or 120 feet.

The difference in design thickness ranging from 6 to 8 inches and the absence of expansion joints in the old pavement making equitable comparison between the original pavement and the widening on the basis of pavement cross-section. Likewise the difference in width and thickness prevents the determination of any direct relationships between pavements with and without expansion joints. Regardless of the difference in cross-section, it may be said that the trend of more pumping in the newer jointed widening than in the original pavement is in agreement with the relationship found for full width pavements built with and without expansion joints.

Data were not obtained on soil condition (soil water content and density) or on the presence of old macadam surfaces under the old pavement or other items compared to the subgrade conditions under the widening. For that reason there may be additional factors which may have some bearing on the relative amounts of pumping in the widenings compared to that found in the original pavements.

TRAFFIC AND ITS RELATIONSHIP TO PUMPING

Traffic data, especially as regards breakdown into axle weight groups, were not available for the period during which the greatest increase in truck traffic occurred. The most complete data available are for the year 1941 which are given in Table 2 (also in Tables 3, 6, and 7).

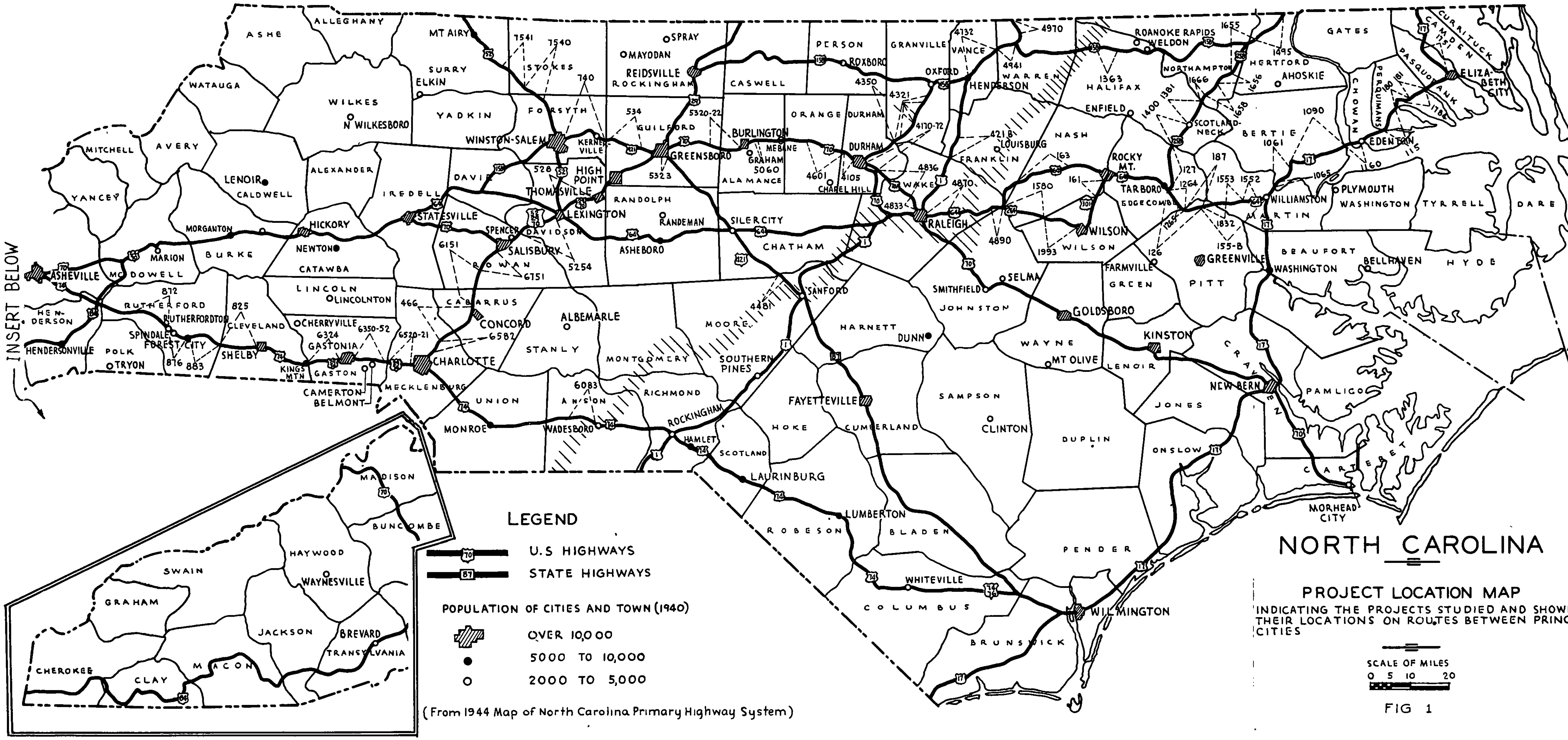
It may be seen from Table 2 that the total number of trucks per 24 hours was nearly the same for the three groups of projects built on soils conducive to pumping, that is, pavements built without expansion joints and pavements having expansion joints at 90 or 120 ft. intervals on soils considered conducive to pumping. It is also of interest to note that the projects which were built largely on soils considered not being conducive to pumping, and on which no pumping or very little pumping occurred had less truck traffic. Average truck traffic for the three groups of "pumpers" was 546 and for the three groups of "non-pumpers" it was 306 trucks per day.

It cannot be said, however, that the pumping of the three groups of projects built on soils conducive to pumping and the lack of pumping in the three groups of projects built on soils considered not conducive to pumping is due to the difference in traffic. There are many cases of projects in the first three groups which carried less traffic than is carried by non-pumping projects in the latter three groups. Traffic is unquestionably a factor but the data here indicate that the type of soil is a more important factor.

SUBGRADE SOILS AND THEIR RELATION TO PUMPING

Soil Series and Horizon

North Carolina is divided into three major physiographic subdivisions. They are the Coastal Plains, the Piedmont and the Mountain Regions. The approximate dividing line between the Coastal Plains region and the Piedmont region is indicated by hachures in Fig. 1. Each of the regions constitutes a different parent material group and form two great soil groups as follows:



(From 1944 Map of North Carolina Primary Highway System)

NORTH CAROLINA

PROJECT LOCATION MAP

INDICATING THE PROJECTS STUDIED AND SHOWING THEIR LOCATIONS ON ROUTES BETWEEN PRINCIPAL CITIES

FIG 1

Table 2

TABLE 2

PUMPING ON PROJECTS BUILT WITH AND WITHOUT EXPANSION JOINTS

Project	Age (Yr.)	Length	Ave. Crack And Joint Interval (Ft.) & Per Mile	Total Exp. Joints	Pumping Expansion Joints								Total Contr. Joints**	Pumping				Contraction Joints				Total No. Cracks	Pumping Cracks								Total Joints And Cracks	Pumping Joints and Cracks								No. Trucks Per Day	REMARKS ON SUBGRADE (Approximate distribution of various soil series on projects)
					Number				Per Cent					Number				Per Cent					Number				Per Cent					Number				Per Cent					
					Class 1	Class 2	Class 3	Total	Class 1	Class 2	Class 3	Total		Class 1	Class 2	Class 3	Total	Class 1	Class 2	Class 3	Total		Class 1	Class 2	Class 3	Total	Class 1	Class 2	Class 3	Total		Class 1	Class 2	Class 3	Total	Class 1	Class 2	Class 3	Total		
PAVEMENTS WITHOUT EXPANSION JOINTS (Built Largely On Soils Conducive To Pumping)																																									
421 B	9	8.230	71.5	-	-	-	-	-	-	-	-	-	88	1	0	0	1	1.1	0	0	1.1	520	6	2	0	8	1.2	0.4	0	1.6	608	7	2	0	9	1.2	0.3	0	1.5	240	Approximately 90% Cecil SL & CL & 10% Appling & Wilkes.
534	9	7.520	97.3	-	-	-	-	-	-	-	-	-	51	1	0	0	1	2.0	0	0	2.0	357	8	4	1	13	2.2	1.1	0.3	3.6	408	9	4	1	14	2.2	1.0	0.2	3.4	537	55% Cecil & Appling, 15% Davidson, 20% Mecklenberg & 10% Wilkes SL & Iredell FSL.
740	8	9.000	109.2	-	-	-	-	-	-	-	-	-	94	0	0	0	0	0	0	0	0	341	1	0	0	1	0.3	0	0	0.3	435	1	0	0	1	0.2	0	0	0.2	430	70% Cecil SL & 30% Durham SL.
825	8	10,195	55.3	-	-	-	-	-	-	-	-	-	96	0	0	0	0	0	0	0	0	862	3	0	0	3	0.3	0	0	0.3	958	3	0	0	3	0.3	0	0	0.3	627	Cecil CL, SL & FSL.
872	17	11,430	27.3	-	-	-	-	-	-	-	-	-	47	0	0	0	0	0	0	0	0	2145	5	0	0	5	0.2	0	0	0.2	2192	5	0	0	5	0.2	0	0	0.2	366	75% Cecil CL & Appling SL. 25% Porters Stony loam.
883	18	9.328	52.3	-	-	-	-	-	-	-	-	-	96	1	0	0	1	1.0	0	0	1.0	838	38	0	3	41	4.5	0	0.4	4.9	934	39	0	3	42	4.2	0	0.3	4.5	462	Cecil CL, SCL & about 5% Cecil SC.
1090	16	15.000	80.5	-	-	-	-	-	-	-	-	-	63	0	0	0	0	0	0	0	0	918	24	6	10	40	2.6	0.7	1.1	4.4	981	24	6	10	40	2.5	0.6	1.0	4.1	315	Approx. 90% Lufkin, Coxville & Dunbar FSL & SiL. 10% Kalmia & Norfolk FSL & FS.
1400	15	7.616	67.5	-	-	-	-	-	-	-	-	-	54	0	0	0	0	0	0	0	0	550	12	6	6	24	2.1	1.1	1.1	4.4	604	12	6	6	24	2.0	1.0	1.0	4.0	150	About 65% Dunbar & 35% Ruston & Norfolk.
4350	18	9.643	70.0	-	-	-	-	-	-	-	-	-	46	0	0	0	0	0	0	0	0	681	17	0	0	17	2.5	0	0	2.5	727	17	0	0	17	2.3	0	0	2.3	433	Largely Iredell, White Store, & Durham.
5320	15	5.650	51.0	-	-	-	-	-	-	-	-	-	47	6	0	0	6	12.8	0	0	12.8	538	2	0	1	3	0.4	0	0.2	0.6	585	8	0	1	9	1.4	0	0.2	1.6	791	Cecil, Mecklenberg, Appling, Wilkes, Davidson, Iredell & Durham.
6500	17	5.294	70.8	-	-	-	-	-	-	-	-	-	62	0	0	0	0	0	0	0	0	333	20	0	13	33	6.0	0	3.9	9.9	395	20	0	13	33	5.1	0	3.3	8.4	1141	Cecil & Iredell Soils.
6350	17	8.713	76.2	-	-	-	-	-	-	-	-	-	100	0	0	0	0	0	0	0	0	504	4	0	2	6	0.7	0.0	0.3	1.0	604	4	0	2	6	0.7	0	0.3	1.0	1160	Cecil C.L. & S.L.
Total	167	107.619	828.9	-	-	-	-	-	-	-	-	-	844	9	0	0	9					8587	140	18	36	194					9431	149	18	36	203						
Average	13.9	8.968	68.7															1.1	0	0	1.1						1.6	0.2	0.4	2.2						1.6	0.2	0.4	2.2	549	
Per Mile													7.8	0.8	0	0	0.8					79.8	1.3	0.2	0.3	1.8					87.6	1.4	0.2	0.3	1.9						
**In the above group, joints listed as Contr. Joints are actually construction joints.																																									
PAVEMENTS WITH ¾" EXPANSION JOINTS AT 120' & CONTRACTION JOINTS AT 30 FT. (LOAD TRANSFER DEVICES AT ALL JOINTS) (Built Largely On Soils Conducive To Pumping)																																									
4601	2	9.787	29.9	424	36	0	0	36	8.5	0	0	8.5	1271	57	0	0	57	8.5	0	0	8.5	36	4	0	0	4	0.3	0	0	0.3	1731	97	0	0	97	5.6	0	0	5.6	601	Davidson, Georgeville & Durham (No pumping on Durham).
5060	1	0.500	28.3	21	4	0	0	4	19.0	0	0	19.0	64	8	0	0	8	12.5	0	0	12.5	5	0	0	0	0	0	0	0	0	90	12	0	0	12	13.3	0	0	13.3	No Data	Cecil soils throughout.
5254	4	8.830	28.9	507	81	3	14	98	16.0	0.6	2.8	19.4	1038	189	1	14	204	18.2	0.1	1.3	19.6	69	19	1	9	29	27.5	1.5	13.0	42.0	1614	289	5	37	331	17.9	0.3	2.3	20.5	601	Cecil, Wilkes, Davidson & Mecklenberg.
Total		19.117	87.1	952	121	3	14	138	12.7	0.3	1.5	14.5	2373	254	1	14	269					110	23	1	9	33					3435	398	5	37	440						
Average	2.3	6.372	29.4															10.7		0.6	11.3						20.9	0.9	8.2	30.0						11.6	0.1	1.1	12.8	601	
Per Mile				49.7	6.3	0.2	0.7	7.2					124.1	13.3	0.1	0.7	14.1					5.8	1.2		0.5	17					179.7	20.8	0.3	1.9	23.0						
PAVEMENTS WITH ¾" EXPANSION JOINTS AT 90' & CONTRACTION JOINTS AT 30 FT. (LOAD TRANSFER DEVICES AT ALL JOINTS) (Built Largely On Soils Conducive To Pumping)																																									
466	5	16.280	28.6	981	92	0	10	102	9.4	0	1.0	10.4	1961	126	1	12	139	6.4	0.1	0.6	7.1	60	21	0	5	26	35.0	0	8.3	43.3	3002	239	1	27	267	8.0	0	0.9	8.9	495	Some Cecil & Mecklenberg Gravelly loam, but mostly plastic B horizon soils. 95% of pumping on latter).
4836	7	11.720	29.9	687	36	0	0	36	5.2	0	0	5.2	1375	20	0	0	20	1.5	0	0	1.5	8	0	0	0	0	0	0	0	0	2070	56	0	0	56	2.8	0	0	2.8	240	Cecil, Durham, Granville, Appling & White Store
6151	7	10.748	30.4	611	8	0	3	11	1.3	0	0.5	1.8	1221	16	0	8	24	1.3	0	0.7	2.0	29	5	1	3	9	17.3	3.4	10.3	31.0	1861	29	2	4	35	1.6	0.1	0.2	1.9	No Data	Largely Cecil Gr.L. Some Iredell, Mecklenberg & Durham.
6324	8	6.594	30.0	381	43	0	1	44	11.3	0	0.3	11.6	762	106	0	4	110	14.1	0	5.3	14.4	18	6	0	0	6	30.0	0	0	30.0	1160	155	0	5	160	13.4	0	0.4	13.8	1059	Cecil Soils throughout.
6582	5	2.560	30.0	148	1	0	0	1	0.7	0	0	0.7	296	2	0	0	2	0.7	0	0	0.7	2	2	0	0	2	100.0	0	0	100.0	446	5	0	0	5	1.1	0	0	1.1	496	Cecil soils.
7540	7	5 892	29.7	345	24	0	2	26	7.0	0	0.6	7.6	691	19	2	3	24	2.8	0.3	0.4	3.5	11	0	0	0	0	0	0	0	0	1047	43	2	5	50	4.1	0.2	0.5	4.8	444	Cecil soils.
7541	7	5.945	29.1	345	0	0	0	0	0	0	0	0	691	3	0	1	4	0.5	0	0.1	0.6	6	0	0	0	0	0	0	0	0	1042	3	0	1	4	0.3	0	0.1	0.4	400	Cecil C horizon. Deep cuts. High fills. Pumping on fills at settled areas.
Total		59.719	207.7	3498	204	0	16	220	5.8	0	0.5	6.3	6996	292	3	28	323					134	34	1	8	43					10628	530	5	42	577						
Average	6.6	8.54	29.6															4.2		0.4	4.6						25.4	0.7	6.0	32.1						5.0	T	0.4	5		
Per Mile				58.6	3.4	-	0.3	3.7					117.1	49	0.1	0.5	5.4					2.2	0.6		0.1	0.7					178.0	8.9	0.1	0.7	9.7						
PAVEMENTS WITHOUT EXPANSION JOINTS (Built Largely On Soils not Conducive To Pumping)																																									
115	20	3.650	79.1	-	-	-	-	-	-	-	-	-	33	0	0	0	0	0	0	0	0	178	0	0	0	0	0	0	0	0	211	0	0	0	0	0	0	0	0	334	Largely A horizon soils. Approximately 85% Portsmouth & 15% Norfolk FSL.
126	19	7.712	73.4	-	-	-	-	-	-	-	-	-	47	0	0	0	0	0	0	0	0	508	0	0	0	0	0	0	0	0	535	0	0	0	0	0	0	0	0	269	Norfolk & Portsmouth.
127	18	11.740	55.0	-	-	-	-	-	-	-	-	-	82	0	0	0	0	0	0	0	0	1045	0	0	0	0	0	0	0	0	1127	0	0	0	0	0	0	0	0	151	Dunbar & Elkston.
155 B	19	18.247	45.8	-	-	-	-	-	-	-	-	-	127	0	0	0	0	0	0	0	0	1997	0	0	0	0	0	0	0	0	2124	0	0	0	0	0	0	0	0	216-300	About 40% Norfolk FSL & LFS. 60% Dunbar, Coxville & Plummer FSL & VFSL.
161	18	6.510	87.2	-	-	-	-	-	-	-	-	-	57	0	0	0	0	0	0	0	0	337	0	0	0	0	0	0	0	0	394	0	0	0	0	0	0	0	0	590	Largely friable sandy soils. 75% Dunbar, Portsmouth & Plummer SL & VFSL. 25% Norfolk SL & FSL.
187	19	4.330	54.4	-	-	-	-	-	-	-	-	-	26	0	0	0	0	0	0	0	0	403	0	0	0	0	0	0	0	0	429	0	0	0	0	0	0	0	0	252	Approx. 60% Norfolk FSL & 40% Portsmouth FSL & SiL.
1993	18	10.177	32.4	-	-	-	-	-	-	-	-	-	35	0	0	0	0	0	0	0	0	1620	0	0	0	0	0	0	0	0	1655	0	0	0	0	0	0	0	0	234	Over 75% Norfolk & Ruston sandy soils.
1751	13	10.463	109.2	-	-	-	-	-	-	-	-	-	28	Slight	Pumping				No	Count		476		Slight	Pumping —	No	Count				504		Slight	Pumping			No Count Made			351	75% Elkston & Norfolk FSL & FS. 25% Portsmouth largely on A horizon.
Total*	144	62.366	427.3	-	-	-	-	-	-	-	-	-	458	0	0	0	0					6330	0	0	0	0					6999	0	0	0	0						
Average	18		73.9	-	-	-	-	-	-	-	-	-						0	0	0	0						0	0	0	0						0	0	0	0	309	
Per Mile													7.3	0	0	0	0					101.5	0	0	0	0					112.2										
*Total & Average values do not include project 1751 which showed slight evidence of pumping.																																									
PAVEMENTS WITH ¾" EXPANSION JOINTS AT 120' & CONTRACTION JOINTS AT 30 FT. (LOAD TRANSFER DEVICES AT ALL JOINTS) (Built Largely On Soils not Conducive To Pumping)																																									
1065	3	2.937	33.4	118	0	0	0	0	0	0	0	0	345	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	464	0	0	0	0	0	0	0	0	305	Norfolk soils throughout. A B & C horizons. Probably mixed.
1658	3	4.180	30.0	182	0	0	0	0	0	0	0	0	540	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	726	0	0	0	0	0	0	0	0	208	Selected subgrade over 90% Lufkin VFSL & 10% Coxville & Lufkin SiL.
1666	3	2.102	33.4	83	0	0	0	0	0	0	0	0	248	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	332	0	0	0	0	0	0	0	0	208	Selected subgrade. Natural soils not classified. Heavy fill.
4105	3	1.077	28.9	77	0	0	0	0	0	0	0	0	112	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	197	0	0	0	0	0	0	0	0	730	White Store, reported. Covered with topsoil from project 4601.
5323	3	1.136	30.0	54	0	0	0	0	0	0	0	0	145	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	200	0	0	0	0	0	0	0	0	No Data	Subgrade reinforcement over Wilkes soils.
Total	15	11.432	155.7	514	0	0	0	0	0	0	0	0	1390	0	0	0	0					15	0	0	0	0					1919	0	0	0	0						
Average	3		31.4															0	0	0	0						0	0	0	0						0	0	0	0	363	
Per Mile				44.9									121.6	0	0	0	0					1.3	0	0	0	0					167.9										
PAVEMENTS WITH ¾" EXPANSION JOINTS AT 90' & CONTRACTION JOINTS AT 30 FT. (LOAD TRANSFER DEVICES AT ALL JOINTS) (Built Largely On Soils not Conducive To Pumping)																																									
1265	4	0.278	27.7	11	0	0	0	0	0	0	0	0	33	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	53	0	0	0	0	0	0	0	0	260	Norfolk SL & FSL throughout.
1381	7	5.355	29.8	314	0	0	0	0	0	0	0	0	629	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	949	0	0	0	0	0	0	0	0	217	Approx. 60% Norfolk, Dunbar & Ruston 25% Roanoake, Coxville & AltaVista. Remainder Wickham & Toxaway).
1495	7	10.0(Approx.)	30.0	589	1	0	2	3	0.2	0	0.3	0.5	1179	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	1774	1	0	2	3	T	0.1	0.1	0.2	385	Norfolk, Coxville, Lufkin, Dunbar & Portsmouth.
1655	6	4.700	30.0	276	0	0	0	0	0	0	0	0	551	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	829	0	0	0	0	0	0	0	0	178	Selected subgrade. Natural soils Norfolk, Coxville & Lufkin.
1656	5	5.148	30.0	306	0	0	0	0	0	0	0	0	602	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	908	0	0	0	0	0	0	0	0	194	Selected subgrade. Natural soils 45% Lufkin VFSL, 35% Coxville SiL & VFSL 20% Dunbar.
4321	6	2.280	29.5	135	0	0	0	0	0	0	0	0	271	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	408	0	0	0	0	0	0	0	0	430	Subgrade reinforcement. Natural soils White Store & Durham.
Total	35	27.761	177.0	1631	1	0	2	3	0.1	0	0.1	0.2	3265	0	0	0	0					25	0	0	0	0					4921	1	0	2	3						
Average	5.8		29.9															0	0	0	0						0	0	0	0						T	0	T	T	278	
Per Mile				58.8				0.1					117.6	0	0	0	0					0.9	0	0	0	0					177.3										

TABLE 3

RELATIVE PUMPING ON PROJECTS BUILT WITH AND WITHOUT EXPANSION JOINTS

(All Projects Have Subgrade Soils Considered Conducive to Pumping)

Number* of Projects	Total Length of Projects (Miles)	Age (Years) Range	Age (Years) Av.	Pumping Joints and Cracks per Mile: Joints	Pumping Joints and Cracks per Mile: Cracks	Pumping Joints and Cracks per Mile: Joints and Cracks	Per Cent of Total Joints and Cracks Pumping: Joints	Per Cent of Total Joints and Cracks Pumping: Cracks	Per Cent of Total Joints and Cracks Pumping: Joints and Cracks	Av. No.** Trucks Per Day	Remarks
Pavements Built with no Expansion Joints											
12	107.619	16-20	17.2	0.1	1.3	1.4	1.1	1.7	1.6	549	Pumping at Joints - all Class 1 Pumping at Cracks (Class 1 = 74% (Class 2 = 13% (Class 3 = 13%
Pavements Built With Expansion Joints at Intervals of 90' & 120' & ¾' Dowels at 12" or 15" Centers											
8	67.588	1-8	5.6	13.4	1.0	14.4	7.6	31.9	8.0	542	Pumping at Joints (Class 1 = 91% (Class 2 = 2% (Class 3 = 7% Pumping at Cracks (Class 1 = 75% (Class 2 = 3% (Class 3 = 22%

* *Number of projects based on those with traffic data available*

** *1941 Traffic Survey*

Table 4

PUMPING ON PAVEMENT WIDENING

Number of Projects	Total Joints and Cracks (Per Mile)	Pumping Joints and Cracks (Per Mile): Class 1	Class 2	Class 3	Total	Pumping Joints and Cracks (Per Cent of Total): Class 1	Class 2	Class 3	Total	Remarks
Pumping on Original 16 and 18 ft. Pavements										
7	69.9	1.3	0.1	0.4	1.8	1.9	0.1	0.6	2.6	Pavements have no expansion joints
Pumping on 4, 6 and 10 ft. Widening (on above projects)										
7	152.1	4.4	0.3	3.0	7.7	2.9	0.2	2.0	5.1	Pavements have expansion joints at 90, 100 or 120 ft. intervals
Pumping on 10 ft. Widening										
2	77.8	2.2	0.1	0.5	2.8	2.8	0.1	0.7	3.6	Pavements have no expansion joints

Physiographic Subdivisions	Parent Material Groups	Great Soil Groups
Coastal Plains	Sands and Clays	Red and Yellow Soils
Piedmont	Crystalline Rocks Sandstones and Shales	
Mountain	Sandstones and Shales	Gray - Brown Podzolic Soils

The topography and parent materials which are characteristic of the various physiographic subdivisions are dominant factors in soil development. Therefore, they are used as a convenient basis for grouping the various soil series units into groups of soils of the Coastal Plain; soils of the Piedmont; and soils of the Mountains. Eight soil series, each with a characteristic variation in texture of the A horizon were encountered on projects located in the Coastal Plain. One soil series, the Norfolk, was identified on 13 of the projects listed in Table 2 as well as on some additional projects not listed. Other series were encountered on from one to six of the projects in Table 2. Twelve series were encountered in the Piedmont region. A few bottom land soils were also encountered. Typical Mountain soils were not encountered in these studies.

A tabulation of the major soil series identified on projects studied, the number of projects on which each occurred, the horizon sampled and a description of the pumping soils were identified, are given in Table 5. The approximate western limit of Coastal Plains materials is indicated on the map in Fig. 1.

Pumping was not encountered on soils of the Norfolk or Ruston series in the Coastal Plain. The two series were identified on a total of 15 projects. Drainage is well established in both the Ruston and Norfolk series.

Pumping did or did not occur on the B and C horizons of the Dunbar series in which drainage is only fairly well established. Pumping occurred on both the Portsmouth and Plummer series having friable B horizons but having poorly established drainage. Likewise pumping occurred on soils of the Lufkin, Elkton and Coxville series also of the Coastal Plain but having plastic B horizons.

Physical Characteristics and Texture of Soils

All soils sampled from under pumping slabs were of a plastic nature. Liquid limits and plasticity indices ranged from a low of 32 and 17 for a clay loam soil having 27 per cent clay with 16 per cent colloids and associated with light pumping to a high of 93 and 64 for a fat clay soil causing severe pumping.

Nine of the 25 samples of soil on which no pumping was found and which are shown in Table 6 were of a non-plastic nature. An additional seven samples were moderately plastic having plasticity indices of 15 or less. Eight soils had plasticity indices in excess of 15, five of these being clay soils with indices of 19, 20, 21, 23 and 30.

No data were obtained which explained why these five clay soils were not pumping. No soil densities nor water contents were obtained during the studies which

Table 5

RELATIONSHIP BETWEEN SOIL SERIES AND PUMPING

(Soil Series, Their Occurrence on Projects Studied, and Samples Taken)

SOILS OF THE COASTAL PLAINS

		Soil Series		Soil Samples Taken		
Major Soil Subdivision	Drainage	Name	Occurrence (No. of Projects Shown in Table 2)	From Under Non-pumping Pavements Sample No. & Horizon	From Under Pumping Pavements Sample No. & Horizon	Descriptions of Pumping (at Location Sampled)
Friable B Horizon	Well Established	Ruston	2	-	-	Not sampled. No pumping encountered.
		Norfolk	13	2-A 3-AB 6-B 13-A-1 13-A-2 13-B 13-C	-	No pumping encountered.
	Fairly Well Established	Dunbar	6	9-A 9-B 10-A 12-A 12-B 12-C	7-C 9-C)	Pumping at transverse crack in old pavement in cut section.
					10-B 10-C)	Trace of pumping in broken slab.
	Poorly Established	Portsmouth	5	16-A	16-B	Class 2 pumping at transverse cracks.
		Plummer	1	-	-	Not sampled. No pumping observed on small area of Plummer soils on Project 155-B.
Plastic B Horizon	Fairly Well Established	Lufkin	4	-	14-B	Class 3 pumping in patched area.
		Elkton	1	17-A	17-B	Class 3 pumping at transverse crack.
	Poorly Established	Coxville*	6	-	15-B	Pumping at transverse crack.

SOILS OF THE PIEDMONT REGION

		Soil Series		Soil Samples Taken		
Major Soil Subdivision	Drainage	Name	Occurrence (No. of Projects Shown in Table 2)	From Under Non-pumping Pavements Sample No. & Horizon	From Under Pumping Pavements Sample No. & Horizon	Descriptions of Pumping (at Location Sampled)
Crystalline Rock Division	Acid Crystalline Group	Durham	6	21-A 21-B 28-C	21-B&C 27-B	Pumping in 4 ft. widening. Class 3 pumping at transverse crack.
		Appling	4	-	5-C	Pumping in 4 ft. widening
		Cecil	17	19-C 29-C 31-C 33-C 34-C	1-C-2	Light pumping on inside of super elevated curve.
					18-C	Class 1 pumping at transverse cracks.
					25-B	Some Class 1 pumping at joints.
					32-B	Class 1 pumping at joints.
	Basic Crystalline Group	Iredell	4	-	-	Not sampled. Pumping encountered on Iredell soils.
		Mecklenberg	4	-	26-B	Pumping in old pavement and widening.
					26-C	Pumping in old pavement and widening.
					30-C	Pumping on super elevated curve.
		Davidson	3	-	22-C	Pumping at transverse crack through asphalt resurfacing.
	Mixed Acid and Basic Group	Helena	-	4-A-1 4-A-2	4-B	Class 2 pumping at transverse crack.
		Wilkes	4	-	-	Not sampled. Some pumping.
Slate Belt (Slates and Fine Grained Volcanic Rocks)		Georgeville	1	-	22-AC	Pumping of mudjacked slab.
Sandstones and Shales		Granville	1	35-C-3	-	No pumping encountered.
		White Store	3	-	20-B 20-C	Pumping at expansion and contraction joints.
		Wadesboro	-	37-C	-	No pumping encountered.

BOTTOM LAND SOILS

Experience with bottom land soils was limited to the Congaree, Toxaway and Wehadkee silt loams which showed traces of light pumping and the Wickham, Alta Vista and Kalmia soils which showed no pumping where encountered.

might have shown adequate reason for the non-pumping condition. It is suggested that a further study of these soils might yield valuable information. Likewise, positive data were not obtained on all projects on the amount of infiltration of soil into pavement cracks and joints which might place the pavement in a state of compression, reducing the entrance of surface water, reducing deflections and preventing the occurrence of pumping.

A study of soil texture by means of plotting fractions of the total soil on a triangular chart (See Fig. 2) gives positive evidence that soils having more than 50 per cent sand and gravel (retained on No. 270 mesh sieve) in the total soil have prevented pumping in North Carolina, in so far as samples taken in this survey are concerned. Seventeen of 25 samples on which no pumping was found, contain sand in excess of 50 per cent. Eight of those are plastic soils having plasticity indices ranging from 8 to 27. No soils having more than 50 per cent sand and gravel were found under pumping slabs.

THE USE OF SUBBASES TO PREVENT PUMPING

Twelve projects constructed with subbases were listed for field study during the survey. Nine of the twelve projects were visited and joint and crack data obtained. No pumping was found. Likewise, no pumping, in which subgrade material was ejected at joints, cracks or pavement edges had been reported by Department Engineers for the other three projects. A summary of project data, pavement design features, soils data and joint and crack data is given in Table 7.

Subbases examined and sampled were built in trench section of pavement width. The average thickness ranged from three to four inches.

Pavements were of 8-6-8 and 9-7-9 and 7 inch uniform thickness and were of 20, 22, 36 and 37 ft. width except one widening project which was 6 ft. wide.

All except one of the projects had either 90 ft. or 120 ft. expansion joint spacing. All had ¾ inch dowels at expansion and contraction joints.

Truck traffic on the various projects ranged from 165 to 730 per 24 hour day, with an average of 324 per day. This compares with a range of 150 to 1,141 (average 546) for the pumping projects, and a range of 151 to 730 (average 306) for the non-pumping projects shown in Table 2. Thus the traffic does not permit of a comparison in pavement behavior under like traffic.

Excepting the 6 ft. widening, which had 18 transverse cracks per mile, the projects which were constructed with subbases showed little transverse cracking.

The materials used for subbase construction on the projects sampled consisted of selected soils of sand, loamy sand and sandy loam texture. The relative percentages of the various sand (and gravel), silt and clay fractions of the total soils used in subbases and also the underlying subgrade soils are listed in Table 7 and shown in the triangular chart in Fig. 3. With one exception all subbase materials had combined sand and gravel contents (retained on No. 270 sieve) of 70 per cent or more. Only three samples had clay contents in excess of 10 per cent.

Grain size curves of three samples which are representative of the range of subbase materials used are shown in Fig. 4. Subbase soils ranged from well graded

Table 6

TABLE 6

SOILS TEST DATA FROM PROJECTS BUILT WITHOUT SUBBASES

SOILS ON WHICH PUMPING WAS FOUND

Project	Sample No.	Soil Series	Hor.	L.L.	P.I.	S.L.	C.M.E.	F.M.E.	P.R.A. Group	Soil Fractions (Per Cent of Total Soil)				Textural Type	24 hr. Truck Traffic (No. Vehicles)	Nature of pumping at location sampled.
										Gravel & Sand	Silt	Clay	Coll.			
115	16-B	Portsmouth SL	B	44	23	15	28	31	A-7	29	25	46	31	Clay	334	Class 2 at transverse crack.
115	17-B	Elkton VFSL	B	38	18	17	24	29	A-7	28	43	29	13	CL	"	Class 3 at transverse crack.
466	30-C	Mecklenberg SL	C	44	23	16	28	29	A-7	49	19	32	18	Clay	488	Severe Class 3 at joints on inside at Superelev curve.
528	27-B	Durham SL	B	43	24	14	27	27	A-7	41	27	32	18	Clay	723	Class 3 at transverse cracks.
534	26-B	Mecklenberg L	B	82	41	21	45	56	A-7	22	15	63	43	Clay	573	Class 1 at Tr. cracks in old pavement and at joints in widening.
534	26-C	" "	C	67	24	24	39	54	A-7	27	29	44	30	Clay	"	
1061	14-B	Lufkin SiL	B	47	20	21	33	39	A-7	30	28	42	23	Clay	305	Class 3 in broken area.
1090	15-B	Coxville SiL	B	54	30	16	31	36	A-7	18	33	49	37	Clay	313	Class 3 at Tr. crack.
1400	7-C	Dunbar SL	C	53	32	17	25	37	A-7	48	7	45	39	Clay	150	Class 1 at Tr. crack.
1400	9-C	" VFSL	C	50	28	15	27	31	A-7	32	23	45	35	Clay	"	" " " " "
1495	10-B	Not Classified	B	33	16	16	23	25	A-4-7	45	22	33	24	Clay	385	Trace of pumping.
1495	10-C	" "	C	32	17	15	21	23	A-4-7	48	25	27	16	CL	"	Pumping at interior corner breaks.
1580	1-C-2	Cecil SiL	C-Z	51	17	37	33	52	A-5	28	65	7	6	SiL	190	Trace of very light Class 1 pumping.
4170	21-BC	Durham SL	Mixed B & C	72	40	14	37	43	A-7	17	33	50	30	Clay	452	Class 2 in widening.
4601	22-C	Davidson SiL	C	59	32	18	32	31	A-7	13	34	53	31	Clay	601	At Tr. crack through resurfacing
	22A-C	Georgeville SiL	C	69	29	25	40	45	A-7	16	25	59	41	Clay	"	Class 2 at mudjacked jt.
4731	S-C	Appling SL	C	78	42	24	39	52	A-7	35	15	50	43	Clay	478	Class 1 at joint.
4833	18-C	Cecil (Hilly Phase)	C	39	16	17	22	32	A-7	44	19	37	25	Clay	367	Class 1 at Tr. crack.
4836	20 B	White Store SL	B	83	50	10	43	50	A-7	15	34	51	42	Clay	240	Class 1 at Exp. joints.
4836	20 C	" " "	C	47	23	14	29	34	A-7	44	28	28	18	CL	"	" " " " "
4970	4 B	Helena SL	B	93	64	12	74	39	A-7	25	17	58	42	Clay	413	Class 2 at Trasv. crack.
5060	25 B	Cecil SL	B	71	38	23	37	44	A-7	23	18	59	40	Clay	601	Class 1 at joint.
6324	32 B	Cecil SL	B	56	30	20	33	36	A-7	28	20	52	34	Clay	698	Class 1 at joint.
														Range	150-698	
														Average	417	

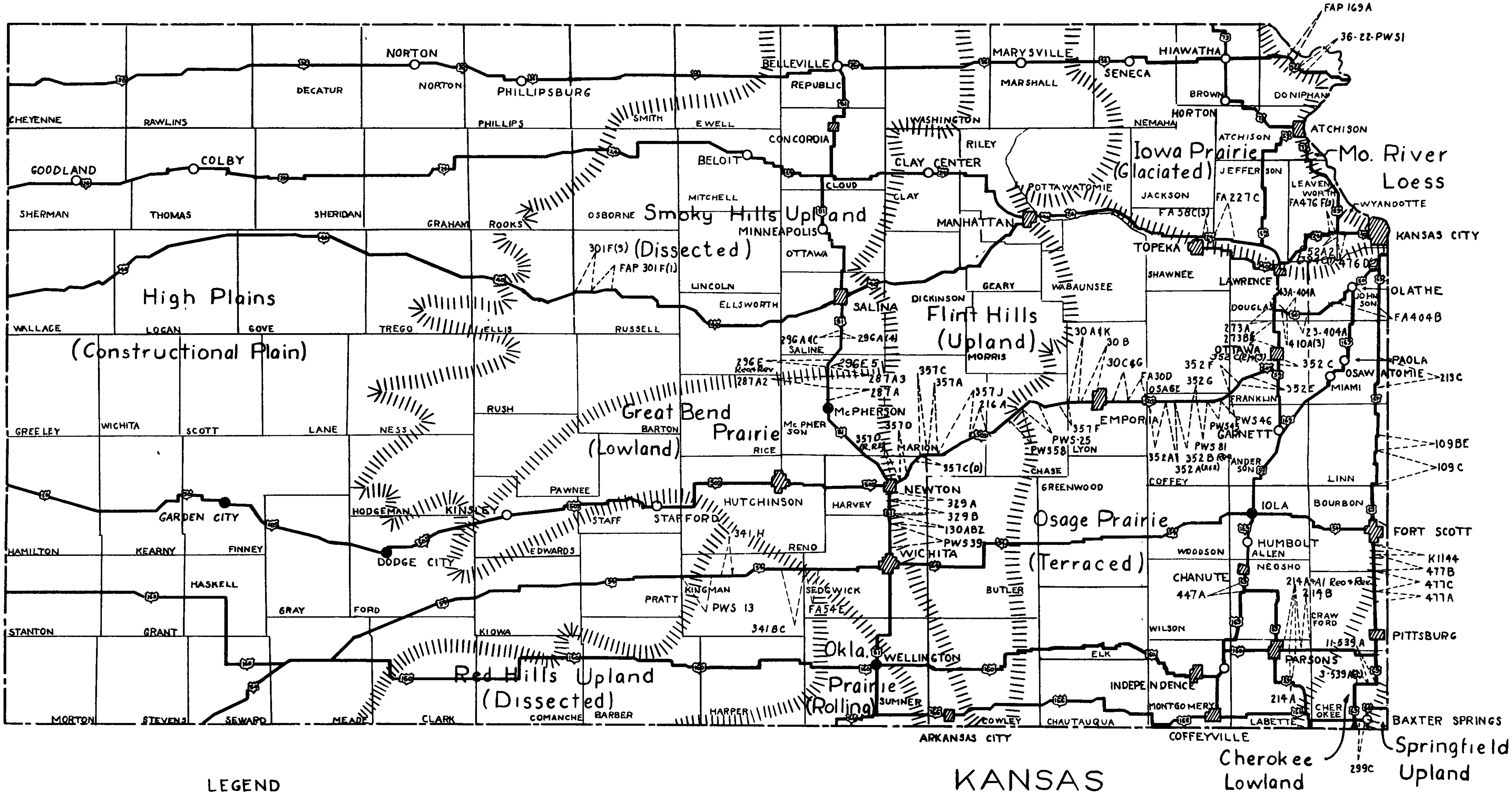
SOILS ON WHICH NO PUMPING WAS FOUND

Project	Sample No.	Soil Series	Hor.	L.L.	P.I.	S.L.	C.M.E.	F.M.E.	P.R.A. Group	Soil Fractions (Per Cent of Total Soil)				Textural Type	24 hr. Truck Traffic (No. Vehicles)
										Gravel & Sand	Silt	Clay	Coll.		
115	16-A	Portsmouth SL	A	32	8	20	23	30	A-4	35	40	25	11	CL	334
115	17-A	Elkton SL	A	21	5	-	12	21	A-4	40	47	13	6	Loam	"
127	6-B	Norfolk FSL	B	24	12	14	16	19	A-2	56	21	23	13	SCL	151
155-B	12-A	Dunbar SL	A	14	NP	-	7	17	A-2	71	21	8	4	SL	250-300
155-B	12-B	" "	B	37	21	14	20	27	A-6	45	21	34	25	Clay	" "
155-B	12-C	" "	C	43	23	11	23	30	A-6	46	17	37	29	Clay	" "
155-B	13-A-1	Norfolk SL	A-1	NP	NP	-	6	22	A-2	81	11	8	5	Sand	" "
155-B	13-A-2	" "	A-2	14	NP	-	7	16	A-2	70	20	10	5	SL	" "
155-B	13-B	" "	B	36	20	16	19	28	A-6	57	10	33	26	SC	" "
155-B	13-C	" "	C	45	27	17	22	31	A-6	66	5	29	25	SCL	" "
528	28-C	Durham SL	C	38	16	20	21	33	A-7-2	60	22	18	13	SL	723
886	33-C	Cecil CL	C	45	20	23	26	35	A-7	42	28	30	19	Clay	241
887	34-C	Cecil CL (Hilly Phase)	C	48	19	24	28	42	A-7	49	13	38	29	Clay	304
1400	9A	Dunbar VFSL	A	16	NP	-	7	20	A-2	70	21	9	6	SL	150
1400	9B	" "	B	30	14	16	17	24	A-4	49	22	29	22	CL	"
1495	10-A	Probably Dunbar VFSL	A	NP	NP	-	9	17	A-2	56	34	10	8	SL	385
1580	2-A	Norfolk SL	A	NP	NP	-	7	17	A-3	87	5	8	6	Sand	190
1993	3AB	Norfolk	Mixed A & B	NP	NP	-	5	17	A-2	86	7	7	5	Sand	234
4170	21-A	Durham SL	A	NP	NP	-	8	16	A-2	83	12	5	-	Sand	452
4170	21-B	Durham SL	B	29	14	13	21	23	A-2	58	16	26	16	SCL	452
4833	19C	Cecil SL	C	38	10	27	19	48	A-2	70	16	14	8	SL	367
4970	4-A-1	Helena SL	A-1	16	NP	14	10	18	A-2	81	11	8	4	LS	413
4970	4-A-2	" "	A-2	20	8	13	13	16	A-1	70	13	17	10	SL	"
6151	29-C	Cecil SL	C	56	14	29	31	52	A-5-2	56	18	26	21	SCL	495
6350-2	31-C	Cecil CL	C	72	30	30	43	52	A-5-7	8	40	52	28	C	1098
														Range	151-1098
														Average	345

TABLE 7

DATA FROM PROJECTS CONSTRUCTED WITH SUBBASES

Project No.	Route & County	Location	Length (Miles)	Age (year) (in 1944)	Pavement Design Features					Soils Data										Source of Sample	Traffic (No. Trucks) hr	Joint & Crack Interval (ft)	Cracks per Mile	Pumping	Remarks
					Cross Section	Joint Spacing Exp.	Joint Spacing Contr.	Load Transfer Exp.	Load Transfer Contr.	Sample No.	L.L.	P.I.	Per Cent Passing #10	Per Cent Passing #40	Per Cent Passing #200	Sand & Gravel	Silt	Clay	Coll						
1363	US - 158 Halifax	Between Littleton & Roanoke Rapids	4.79	3	8-6-6-8x20	120	30	3/4" at 15" cc	3/4" at 15" cc	1 2 4	16 13 16	0 0 0	99 93 90	79 65 69	-- -- --	72 82 76	18 13 19	10 5 5	-- -- --	Subbase Subbase Subbase	165	No Count Made	No Count Made	Reported not Pumping	3" Subgrade Reinforcement. Soils are of Durham, Appling and Cecil Series..
1655	US - 258 Northampton	North of Woodland	4.70	6	8-6-8x20	90	30	3/4"x 15" at 12" cc	3/4"x 12" at 12" cc	--	--	--	--	--	--	--	--	--	--		178	30	0.43	No	No soil test data but selected borrow reported for this project. Only 2 cracks observed on project. Soils are Lufkin, Coxville & Norfolk.
1656	US - 258 Northampton	Rich Square N. to Woodland	5.148	5	8-6-8x20	90	30	3/4"x 15" at 12" cc	3/4"x 12" at 12" cc	11-SR 11-B	30 59	16 30	100 100	78 100	37 80	67 28	15 22	18 50	10 38	Subbase Subgrade	194	30	0.0	No	No cracks observed. No faulting. 3" Subgrade Reinforcement. Subgrade soils are approximately 45% Lufkin V.F.S.L. 35% Coxville Sil & V.F.S.L. & 20% Dunbar
1658	US - 258 Northampton	Rich Square South toward Roanoke River	4.18	3	8-6-8x20	120	30	3/4"x 15" at 15" cc	3/4"x 12" at 15" cc	2 1 3 4 5	46 22 19 24 22	21 0 0 0 0	100 83 97 90 96	99 43 70 73 61	-- -- -- -- --	19 93 86 84 88	36 3 5 4 6	45 3 9 12 6	31 -- -- -- --	Subgrade Subbase Subbase Subbase Subbase	208	29.9	0.95	No	Mixes 94:201 or 193 or 196 Sand: 366 or 368 or 363 Stone 4 cracks in project. No faulting. 3" subgrade Reinforcement. Approximately 90% Lufkin V.F.S.L. & 10% Coxville & Lufkin Sil.
1666	US - 258 Northampton	Roanoke River North to Project 1658	2.10±	3	9-7-9- 7-9 x 20	120	30	3/4" x 15" at 15" cc	3/4" x 12" at 15" cc	--	--	--	--	--	--	--	--	--	--	--	208	29.9	0.48	No	1 Crack on project. No faulting. No soil test data but selected borrow reported for project. Natural soils not classified. Heavy fill.
4105	US - 70 Durham	West City Limits of Durham to Project 4601	1.077	3	9-7-9 x 33'-36'	120	30	3/4" x 15" at 15" cc	3/4" x 12" at 15" cc	--	--	--	--	--	--	--	--	--	--	--	730	29.4	1.2	No	8 cracks (across 12' lane) on project. Top soil from project 4601 reported to have been used on this project. Natural subgrade soil of White Store series.
4172	US - 70 Durham	Durham to Jct. US - 70 Alt.	3.37	5	7" x 6'	120	30	3/4" x 15" at 15" cc	3/4" x 12" at 15" cc	--	--	--	--	--	--	--	--	--	--	--	No Data	27.1	18.7	No	63 cracks in widening. This is a city section. Subgrade Reinforcement over White Store soils.
4321	US - 15 Granville	3 Gaps between Creedmore and Oxford	2.28	6	9-7-9x20	90	30	3/4" x 15" at 15" cc	3/4" x 12" at 15" cc	23-B 24-B 1 11 14 2 5 7 2 8 & 9 10 6 7	66 66 42 51 44 45 39 61 15 16 14 15 16	40 36 21 28 26 11 10 32 0 0 0 0 0	100 100 97 97 95 98 100 96 96 64 91 98 88	93 97 82 79 86 92 98 88 73 37 78 69 55	71 91 -- -- -- -- -- -- -- -- -- -- --	32 15 52 47 39 34 44 33 78 87 73 79 86	21 34 21 22 22 39 40 28 14 8 20 13 9	47 51 27 31 39 27 16 39 8 5 7 8 5	31 26 16 21 22 9 11 18 6 -- -- -- --	Subgrade Subgrade Subgrade Subgrade Subgrade Subgrade Subgrade Subgrade Subbase Subbase Subbase Subbase Subbase	430	29.9	0.88	No	2 cracks in project. No faulting. 3" subgrade reinforcement of Granville-A horizon soil. Natural soils largely White Store series.
4481	US - 421 Lee	South approach to Deep River bridge N. of Sanford	0.848	-	--	--	--	--	--	1 3 4 5	53 38 13 14	20 12 0 0	96 87 100 99	88 88 59 58	-- -- -- --	25 37 71 74	40 43 20 18	35 20 8 8	19 6 -- --	Subgrade Subgrade Subbase Subbase	280	No Count Made	No Count Made	Reported not pumping	3" Subgrade Reinforcement. Not included in survey. Underlying natural soils are Cecil F.S.L. & C.L. & Appling S.L.
4941	US - 1 Warren	Ridgeway to Norlina	4.01	3	9-7-9x22	120	30	3/4" x 15" at 15" cc	3/4" x 12" at 15" cc	7 13 1	17 14 15	0 0 0	96 99 97	64 73 81	-- -- --	83 85 78	12 11 12	5 4 10	-- -- --	Subbase Subbase Subbase	359	No Count Made	No Count Made	No pumping	Subgrade Reinforcement. This project was inspected but no count was made of cracks & joints.
5323	US - 70 Guilford	Reconstruction of East Market St. in Greensboro	1.136	3	7" x 37'	120	30	3/4" x 15" at 15" cc	3/4" x 15" at 15" cc	1 3 8 9 15 17 18	39 38 55 31 60 15 14	23 12 11 5 21 0 0	96 94 98 91 93 93 97	85 84 96 75 81 69 79	-- -- -- -- -- -- --	42 49 19 66 37 75 73	31 33 37 23 28 17 17	27 18 44 11 35 8 10	13 8 30 7 28 -- --	Subgrade Subgrade Subgrade Subgrade Subgrade Subbase Subbase	No Data	29.9	0.88	No pumping	1 crack observed during survey. Subgrade Reinforcement over White Store series soil.
6083	US - 74 Anson	Wadesboro to Polkton	7.837	2	9-7-9x22 & 36'	300	75	3/4" x 15" at 15" cc	3/4" x 12" at 15" cc	35SR 35C-2 35C-3 36B 37C	16 38 34 84 27	4 13 10 52 11	100 100 100 100 100	99 87 94 67 57	-- -- -- -- --	70 33 75 28 73	18 49 17 20 12	12 18 8 52 15	4 3 3 33 9	Subbase Subgrade Subgrade Subgrade Subgrade	491	67.2	8.17	No pumping	64 cracks on project. 3" to 5" Subgrade Reinforcement over Wadesboro - Granville & White Store soils.



LEGEND

US HIGHWAYS

POPULATION OF CITIES AND TOWNS (1940)

▨ OVER 10,000

● 5000 TO 10,000

○ 2000 TO 5000

(From 1942 Map of Kansas State Highway System)

KANSAS

PROJECT LOCATION MAP

INDICATING THE PROJECTS STUDIED AND SHOWING THEIR LOCATIONS ON ROUTES BETWEEN PRINCIPAL CITIES. PHYSIOGRAPHIC REGIONS ARE ALSO SHOWN HACHURES INDICATE DIVIDING LINES BETWEEN THESE REGIONS.

SCALE OF MILES

0 10 20 30

FIGURE 1

TABLE 2 -- SUMMARY OF PUMPING

Joint Arrangement		Pavement Cross-Section	Expansion Joint Filler	Expansion Joint Load Transfer	Type Of Contraction Joint	Contr. Joint Load Transfer	Pavement Rein-forcing	Years Built	Total Length (Miles)	Joint And Crack Interval	Percentage of Pumping Joints and Cracks																				Number of Commercial Axles					Base Of Computations	No. Of Projects
Exp.	Cont.										Expansion Joints				Cont. & Constr. Joints				All Joints				Cracks				Total				Under 10,000-lb.	Over 10,000-lb.	Over 14,000-lb.	Over 18,000-lb.	Total		
											Class-1	Class-2	Class-3	Total	Class-1	Class-2	Class-3	Total	Class-1	Class-2	Class-3	Total	Class-1	Class-2	Class-3	Total	Class-1	Class-2	Class-3	Total							
None	None	6-8-6x18'P	None	None	None	None	None	Prior to 1925	12.047	19.4	Unclassified				Unclassified				7.6	7.8	21.8	37.2	14.5	4.8	11.1	30.4	13.7	5.2	12.3	31.2	1019	175	60	6	1193	All projects	(3)
"	"	"	"	"	"	"	"	'22-'24	10.997	19.5	Unclassified				Unclassified				8.2	8.5	23.8	40.5	16.0	5.4	12.2	33.6	15.1	5.7	13.6	34.4	1083	221	79	8	1303	Pumping projects	(2)
100'-4"	None	9-7-9x20'LC&P(8) 9-7-9x20'LC(1)	Air Core	A	None	—	Mesh	'35-'36	40.353	46.9	13.9	20.1	3.9	37.9	7.0	6.0	2.0	15.0	13.3	18.8	3.8	35.9	0	0	0	0	6.8	9.7	1.9	18.4	707	242	69	9	949	All projects	(9)
		9-7-9x20'LC&P(6) 9-7-9x20'LC(1)	"	A	"	—	"	'35-'36	32.593	42.3	17.0	24.6	4.8	46.4	7.7	6.6	2.2	16.5	16.2	22.8	4.6	43.6	0	0	0	0	7.6	10.8	2.2	20.6	743	282	81	11	1025	Pumping projects	(7)
		9-7-9x20'LC&P(5) 9-7-9x22'LC&P(1)	Ltd. Extr. Rubber	A-1	None	--	Mesh	'36-'37	23.062	57.0	15.4	0.9	0.3	16.6	5.0	0.8	0	5.8	14.5	0.9	0.2	15.6	0	0	0	0	9.0	0.6	0.1	9.7	731	221	47	5	953	All projects	(6)
		9-7-9x20'LC&P(2) 9-7-9x22'LC&P(1)	" " "	A-1	"	—	"	'36-'37	17.342	52.3	20.5	1.2	0.3	22.0	6.6	1.1	0	7.7	19.3	1.2	0.3	20.8	0	0	0	0	10.9	0.7	0.2	11.8	598	190	44	4	787	Pumping projects	(3)
		9-7-9x20'LC&P(13) 9-7-9x20'LC(1) 9-7-9x22'LC&P(1)	Air Core (9) Ltd. Extr. Rub. (6)	A(9)& A1(6)	None	—	Mesh	'35-'37	63.415	50.1	14.5	13.1	2.6	30.2	6.2	4.1	1.2	11.5	13.7	12.3	2.5	28.5	0	0	0	0	7.5	6.8	1.3	15.6	716	235	61	8	951	All projects	(15)
		9-7-9x20'LC&P(8) 9-7-9x20'LC(1) 9-7-9x22'LC&P(1)	Air Core (7) Ltd. Extr. Rub. (3)	A(7)& A1(3)	"	—	"	'35-'37	49.935	45.3	18.2	16.6	3.3	38.1	7.3	4.8	1.5	13.6	17.2	15.5	3.1	35.8	0	0	0	0	8.6	7.7	1.7	18.0	711	261	72	9	972	Pumping projects	(10)
		9-7-9x20'LC&P(7) 9-7-9x20'LC(3)	Ltd. Extr. Rubber	D-1	None	—	Mesh	'36-'39	33.774	61.5	7.9	1.3	0.1	9.3	12.3	4.3	0	16.6	8.3	1.5	0.1	9.9	0	0	0	0	5.8	1.1	0.0	6.9	1026	373	107	15	1399	All projects	(10)
		9-7-9x20'LC&P(6) 9-7-9x20'LC(3)	" " "	D-1	"	—	"	'36-'38	33.327	61.6	8.1	1.3	0.1	9.5	12.6	4.4	0	17.0	8.4	1.6	0.1	10.1	0	0	0	0	5.9	1.1	0.0	7.0	1045	399	115	16	1444	Pumping projects	(9)
		9-7-9x20'LC&P(12) 9-7-9x20'LC(3) 9-7-9x22'LC&P(1)	Ltd. Extr. Rubber	A1(6) D1(10)	None	—	Mesh	'36-'39	56.836	59.7	10.9	1.2	0.1	12.2	9.2	2.8	0	12.0	10.8	1.3	0.1	12.2	0	0	0	0	7.1	0.9	0.1	8.1	928	323	87	11	1251	All projects	(16)
		9-7-9x20'LC&P(8) 9-7-9x22'LC&P(1) 9-7-9x20'LC(3)	" " "	A1(3) D1(9)	None	—	Mesh	'36-'38	50.669	58.1	12.3	1.3	0.1	13.7	10.4	3.2	0	13.6	12.9	1.5	0.1	14.5	0	0	0	0	7.8	0.9	0.1	8.8	964	361	103	14	1325	Pumping projects	(12)
		9-7-9x20'LC&P(20) 9-7-9x20'LC(4) 9-7-9x22'LC&P(1)	Air Core (9) Ltd. Extr. Rub. (16)	A(9) A1(6) D1(10)	None	—	Mesh	'35-'39	97.189	53.6	12.2	8.9	1.7	22.8	8.3	4.1	0.8	13.2	11.8	8.5	1.6	21.9	0	0	0	0	7.0	5.0	1.0	13.0	845	293	80	10	1138	All projects	(25)
		9-7-9x20'LC&P(14) 9-7-9x20'LC(4) 9-7-9x22'LC&P(1)	Air Core (7) Ltd. Extr. Rub. (12)	A(7) A1(3) D1(9)	"	—	"	'35-'38	83.262	50.7	14.1	10.3	2.0	26.4	9.3	4.6	0.9	14.8	13.7	9.9	1.9	25.5	0	0	0	0	7.7	5.6	1.0	14.3	878	330	94	13	1208	Pumping projects	(19)
150'	None	9-6-9x18'P(2)	Poured Bituminous	None	None	—	MB	1927	8.679	47.2	3.3	9.6	3.7	16.6	2.8	0	0	2.8	3.3	8.5	3.2	15.0	3.5	0.9	0.4	4.8	3.4	3.3	1.3	8.0	552	59	15	3	611	All projects	(2)
		9-6-9x18'P(2)	" "	"	"	—	"	1927	8.679	47.2	3.3	9.6	3.7	16.6	2.8	0	0	2.8	3.3	8.5	3.2	15.0	3.5	0.9	0.4	4.8	3.4	3.3	1.3	8.0	552	59	15	3	611	Pumping projects	(2)
353'-9"	25'-3"	9-7-9x20'P	Ltd. Extr. Bit. Fiber	D1	Str. Met. Plate	P-2	Mesh	1940	4.458											No Pumping											745	294	79	18	1039	All projects	(1)
		—	—	—	—	—	—	1940	4.458											No Pumping																Pumping projects	(0)
116'	29'	9-7-9x20'LC&P(1) 9-7-9x20'P(2) 9-6-9x18'P(1)	Poured Bituminous	None	3" dummy groove(3) 2" dummy groove(1)	None	EB(3) MEB(1)	'28-'33	4.692	13.7	0	0	0	0	0.2	0	0	0.2	0.1	0	0	0.1	0	0	0	0	0.1	0	0	0.1	885	306	69	7	1191	All projects	(4)
		9-7-9x20'P(1)	" "	"	3" dummy groove(1)	"	MEB(1)	'28-'33	2.031	12.8	0	0	0	0	0.4	0	0	0.4	0.3	0	0	0.3	0	0	0	0	0.1	0	0	0.1	1054	611	132	15	1665	Pumping projects	(1)
		9-7-9x20'LC&P(3) 9-6-9x18'LC&P(1)	Premoulded Felt	None(3) 10-¾x2'-6" Dowels (1)	3" dummy groove(3) 2" Bit. Felt(1)	None	EB	'30-'31	20.400	20.1	4.0	0.9	0.4	5.3	1.8	0.0	0.5	2.3	2.4	0.2	0.5	3.1	4.3	0.2	0.9	5.4	3.0	0.2	0.6	3.8	697	122	29	2	819	All projects	(4)
		9-7-9x20'LC&P(2) 9-6-9x18'LC&P(1)	" "	None(2) 10-¾x2'-6" Dowels (1)	3" dummy groove(2) 2" Bit. Felt(1)	"	"	'30-'31	16.776	18.9	4.9	1.1	0.5	6.5	2.2	0.0	0.6	2.8	2.9	0.3	0.5	3.7	4.3	0.2	0.9	5.4	3.4	0.3	0.7	4.4	793	151	36	3	944	Pumping projects	(3)
		9-7-9x20'LC&P(4) 9-7-9x20'P(2) 9-6-9x18'P(2)	Poured Bit. (4) Pre. Felt (4)	None(7) 10-¾x2'-6" Dowels (1)	3" dummy groove(6) 2" " " (1) 2" Bit. Felt(1)	None	EB(7) MEB(1)	'28-'31	25.092	18.5	3.3	0.7	0.4	4.4	1.5	0.0	0.4	1.9	2.0	0.2	0.4	2.6	2.7	0.1	0.6	3.4	2.2	0.2	0.4	2.8	816	214	49	5	1030	All projects	(8)
		9-7-9x20'P(1) 9-7-9x20'LC&P(2) 9-6-9x18'LC&P(1)	Poured Bit. (1) Pre. Felt (3)	None(3) 10-¾x2'-6" Dowels (1)	3" dummy groove(3) 2" Bit. Felt(1)	"	EB(3) MEB(1)	'30-'31	18.807	18.0	4.4	0.9	0.5	5.8	2.0	0.0	0.6	2.6	2.6	0.3	0.5	3.4	3.3	0.2	0.7	4.2	2.9	0.2	0.6	3.7	858	266	60	6	1124	Pumping projects	(4)
121'	40'-4"	9-7-9x20'LC&P	Poured Bit. (1) Pre. Felt. (7)	None(7) ?	2" dummy groove	8-⅞x2'-6" Dowels	HEB	'32-'34	22.715	23.9	0.6	1.2	0.5	2.3	0.3	0.3	0.1	0.7	0.4	0.5	0.4	1.3	0.1	0.0	0.0	0.1	0.3	0.3	0.2	0.8	667	215	58	6	882	All projects	(8)
		" " "	Pre. Felt (4)	"	" "	" " "	"	'33-'34	14.330	22.0	1.0	2.0	0.8	3.8	0.5	0.1	0.5	1.1	0.7	0.7	0.6	2.0	0.1	0.0	0.0	0.1	0.4	0.4	0.3	1.1	641	253	75	8	894	Pumping projects	(4)
		9-7-9x20'LC&P	Pre. Felt (8)	None	2" Bit. Felt	8-⅞x2'-6" Dowels	Mesh(1) HEB(7)	'32-'34	28.416	26.2	4.7	4.4	2.1	11.2	5.1	0.9	0.2	6.2	5.0	2.0	0.8	7.8	7.2	2.2	0.3	9.7	5.7	2.1	0.6	8.4	873	174	42	3	1047	All projects	(8)
		" " "	" " (4)	"	" "	" " "	HEB(4)	'32-'34	18.050	23.9	7.4	6.9	3.3	17.6	8.0	1.3	0.3	9.6	7.8	3.2	1.3	12.3	8.8	2.7	0.4	11.9	8.2	3.0	0.9	12.1	805	172	47	4	977	Pumping projects	(4)
		9-7-9x20'LC&P	Poured Bit. (1) Pre. Felt (15)	None	2" dummy groove(8) 2" Bit. Felt(8)	8-⅞x2'-6" Dowels	HEB(15) Mesh(1)	'32-'34	51.131	25.2	2.9	3.0	1.4	7.3	3.0	0.5	0.2	3.7	3.0	1.3	0.6	4.9	3.6	1.1	0.1	4.8	3.2	1.2	0.5	4.9	777	193	50	5	970	All projects	(16)
		" " "	Premoulded Felt (8)	"	2" dummy groove(4) 2" Bit. Felt(4)	" " "	HEB(8)	'32-'34	32.380	23.0	4.6	4.8	2.2	11.6	4.7	0.8	0.4	5.9	4.7	2.0	1.0	7.7	4.5	1.4	0.2	6.1	4.6	1.8	0.6	7.0	723	212	61	6	935	Pumping projects	(8)
100'	50'	9-6-9x18'P	Poured Bit.	None	Def. Metal Plate	None	EB	1928	5.554	34.0	Unclassified				Unclassified				1.3	0.6	3.1	5.0	0.5	0.3	1.4	2.2	0.9	0.5	2.3	3.7	1155	199	53	5	1354	All projects	(1)
"	"	" " "	" "	"	" " "	"	"	1928	5.554	34.0	Unclassified				Unclassified				1.3	0.6	3.1	5.0	0.5	0.3	1.4	2.2	0.9	0.5	2.3	3.7	1155	199	53	5	1354	Pumping projects	(1)
100'-8"(2) 100'-4"(1)	50'-4"(2) 50'-2"(1)	9-7-9x20'LC(2) 9-7-9x20'LC&P(1)	Ltd. Extr. Bit. Fiber	A-1	Str. Met. Plate	P2 (2) P1 (1)	Mesh	'40-'41	6.727	49.3	11.7	0	0	11.7	11.9	0	0	11.9	11.8	0	0	11.8	0	0	0	0	11.6	0	0	11.6	1151	303	79	5	1454	All projects	(3)
		9-7-9x20'LC(2) 9-7-9x20'LC&P(1)	" " "	A-1	" " "	P2 (2) P1 (1)	"	'40-'41	6.727	49.3	11.7	0	0	11.7	11.9	0	0	11.9	11.8	0	0	11.8	0	0	0	0	11.6	0	0	11.6	1151	303	79	5	1454	Pumping projects	(3)
100'-8"	50'-4"	9-7-9x20'P(1) 9-7-9x22'P(5) 9-7-9x22'LC&P(1)	Ltd. Extr. Bit. Fiber	A-2	Str. Met. Plate(6) 2" dummy groove(1)	P2 (7)	Mesh(5) HM(2)	'40-'42	12.365	47.1	2.9	0.5	0	3.4	5.5	8.7	0.1	14.3	4.3	4.8	0.1	9.2	0	0	0	0	4.2	4.8	0.1	9.1	934	487	118	14	1421	All projects	(7)
"	"	9-7-9x20'P(1) 9-7-9x22'P(4)	" " "	A-2	Str. Met. Plate(4) 2" dummy groove(1)	" (5)	Mesh(4) HM(1)	'40-'42	12.275	47.1	3.0	0.5	0	3.5	5.5	8.8	0.1	14.4	4.3	4.8	0.1	9.2	0	0	0	0	4.2	4.8	0.1	9.1	876	490	124	15	1366	Pumping projects	(5)
100'-4"(1) 100'-8"(1)	50'-2"(1) 50'-4"(1)	9-7-9x20'P(1) 9-7-9x20'LC&P(1)	Ltd. Extr. Bit. Fiber	D-1	Str. Met. Plate	P2 (1) D1 (1)	Mesh(2)	1940	1.937	46.5										No Pumping											739	275	72	10	1014	All projects	(2)
--	—	—	—	—	—	—	—	--	—																											Pumping projects	(0)
100'-4"(2) 100'-8"(10)	50'-2"(2) 50'-4"(10)	9-7-9x20'LC(2) 9-7-9x20'LC&P(2) 9-7-9x20'P(2) 9-7-9x22'P(5) 9-7-9x22'LC&P(1)	Ltd. Extr. Bit. Fiber	A1(3) A2(7) D1(2)	Str. Met. Plate(11) 2" dummy groove(1)	P2 (10) P1 (2) D1 (1)	Mesh(10) HM(2)	'40-'42	21.029	47.7	5.5	0.3	0	5.8	6.9	5.2	0.1	12.2	6.2	2.9	0.0	9.1	0	0	0	0	6.1	2.9	0.0	9.0	938	415	103	12	1353	All projects	(12)
100'-4"(7) 100'-8"(1)	50'-2"(7) 50'-4"(1)	9-7-9x20'LC(2) 9-7-9x20'LC&P(1) 9-7-9x20'P(1) 9-7-9x22'P(4)	" " "	A1(3) A2(5)	Str. Met. Plate(7) 2" dummy groove(1)	P2(7) P1(1)	Mesh(7) HM(1)	'40-'42	19.002	47.8	6.1	0.3	0	6.4	7.7	5.8	0.1	13.6	6.9	3.2	0.0	10.1	0	0	0	0	6.8	3.2	0.0	10.0	955	436	111	12	1391	Pumping projects	(8)

Notes:

Construction joints listed under Contraction joints.
Numbers in parentheses refer to number of projects investigated.
LC = Lip curb
P = Plain
EB = Bars at edges and joints.
MEB = Mesh and bars at edges and joints.
HEB = Hairpin bars at expansion joints and bars at edges and joints.
HM = Hairpin bars at expansion joints and mesh.

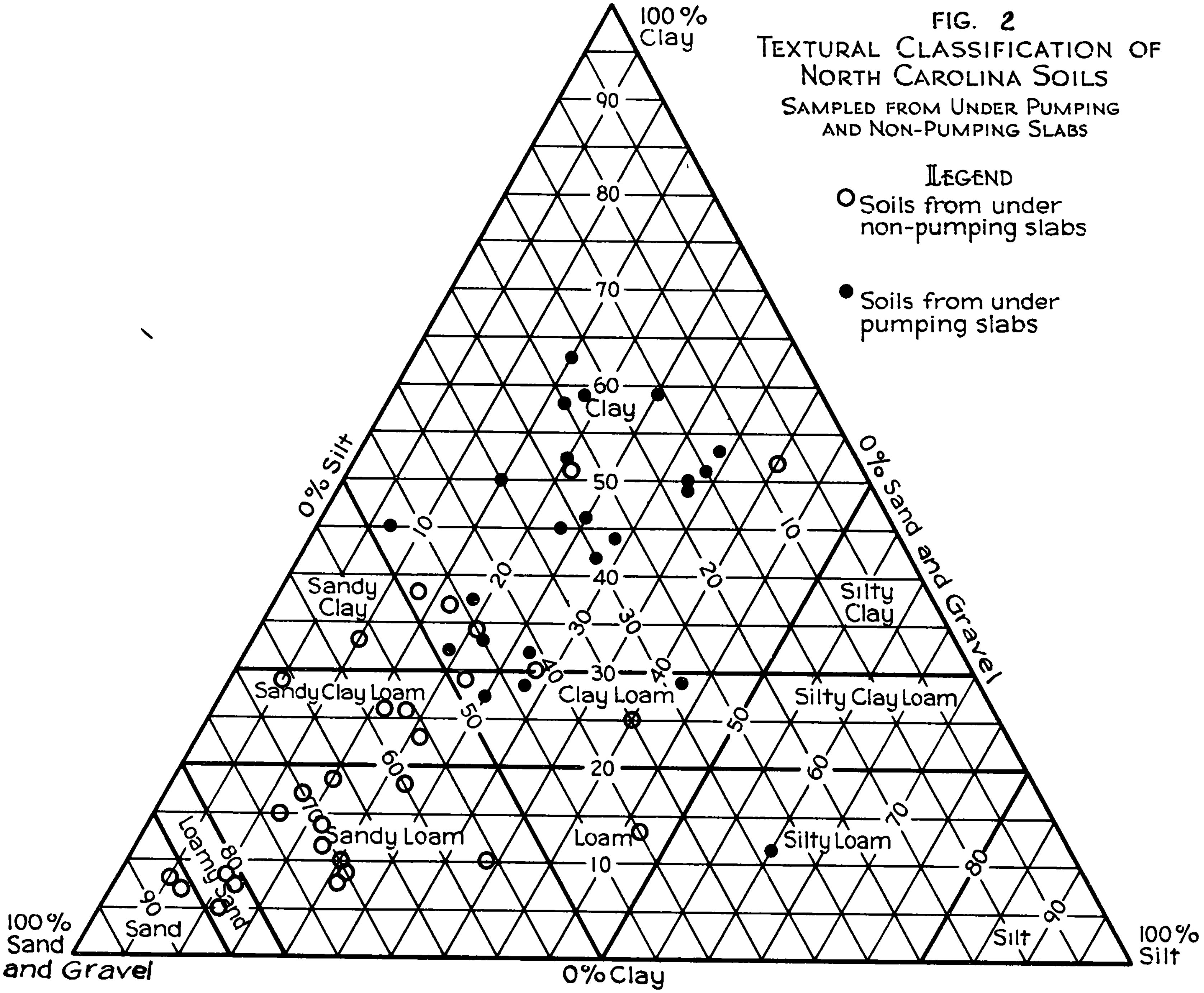
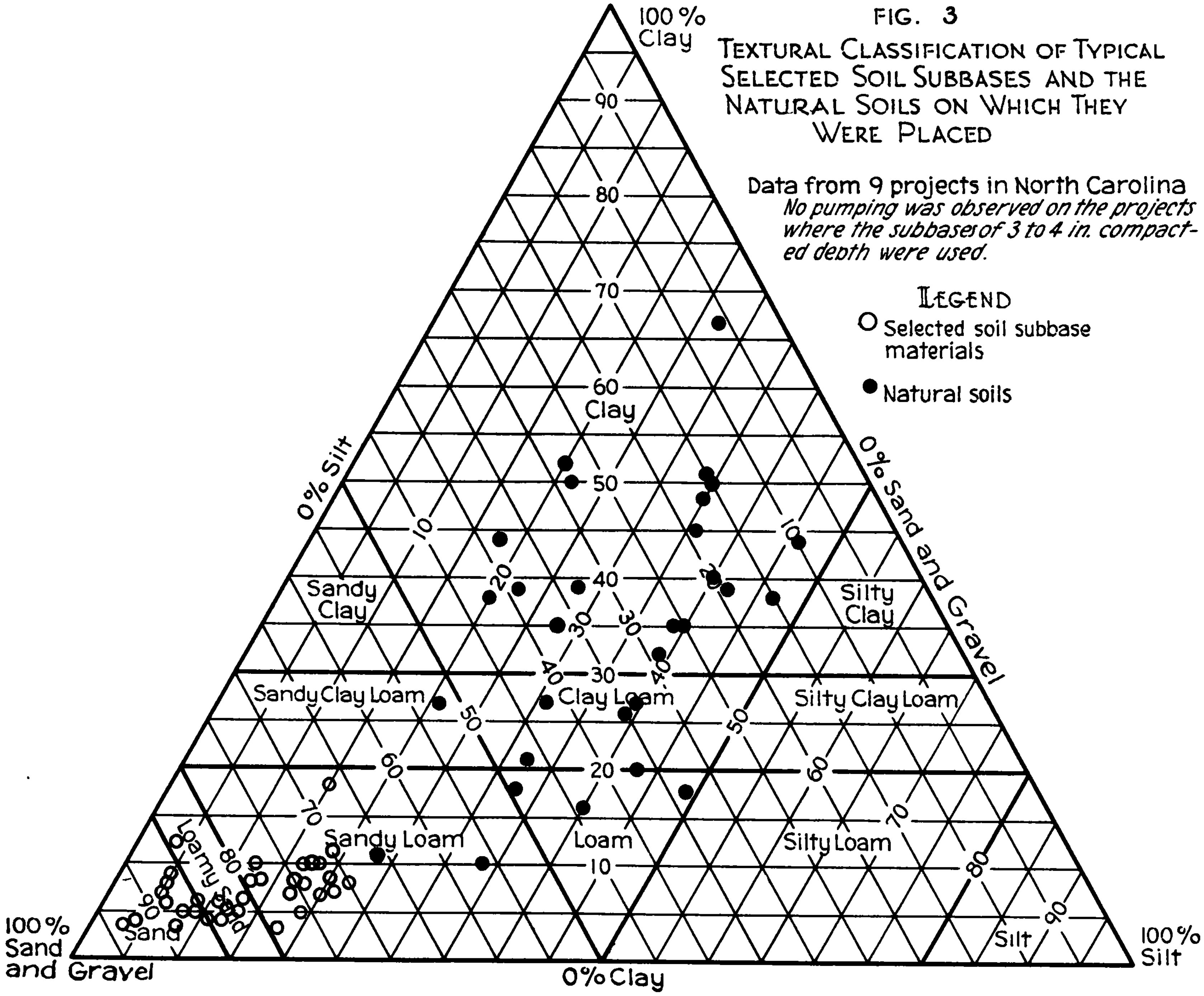


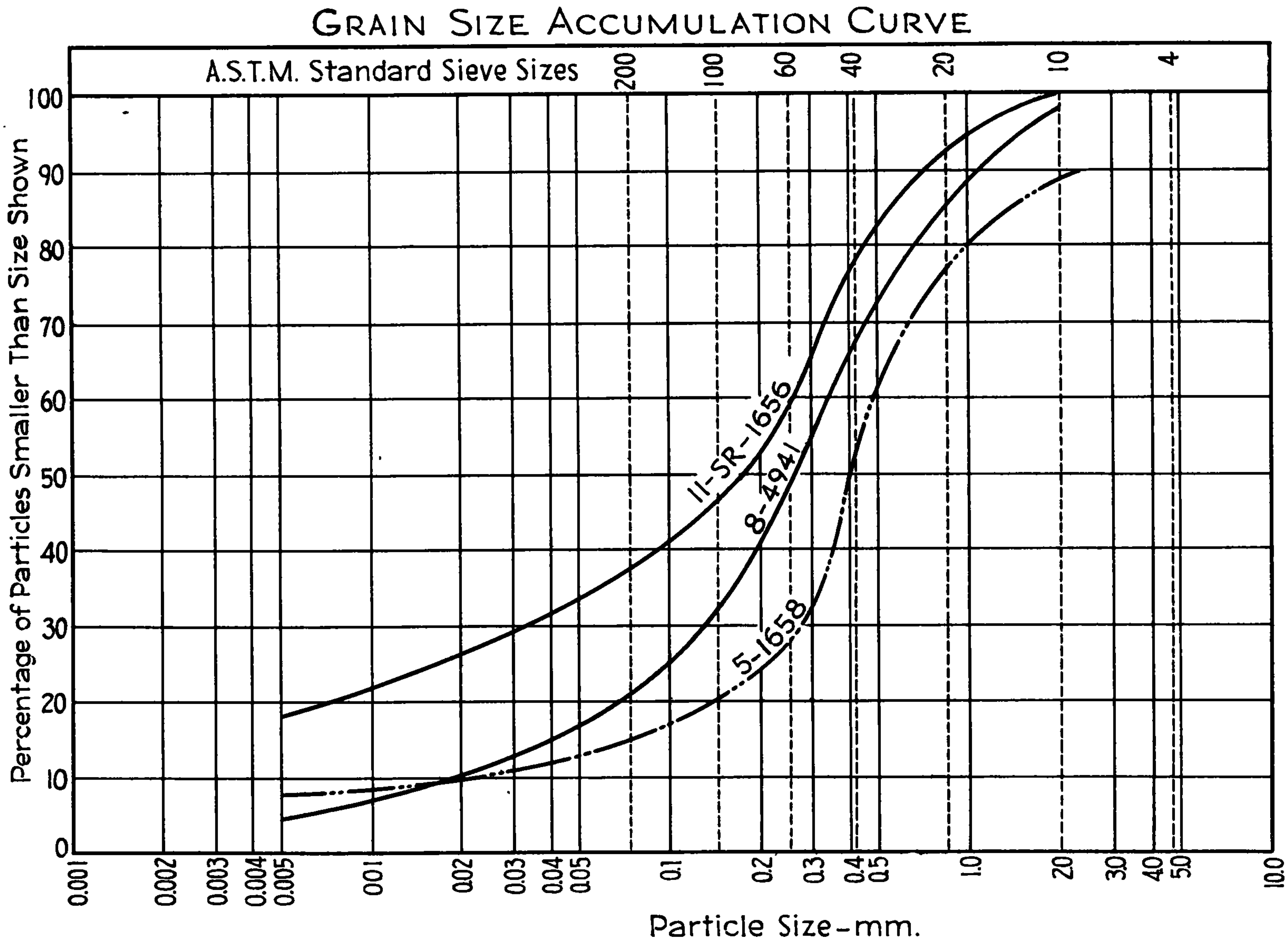
FIG. 2
TEXTURAL CLASSIFICATION OF NORTH CAROLINA SOILS
SAMPLED FROM UNDER PUMPING AND NON-PUMPING SLABS

FIG. 3

TEXTURAL CLASSIFICATION OF TYPICAL SELECTED SOIL SUBBASES AND THE NATURAL SOILS ON WHICH THEY WERE PLACED

Data from 9 projects in North Carolina
No pumping was observed on the projects where the subbases of 3 to 4 in. compacted depth were used.





TOTAL CLAY-less than 0.005	SILT	SAND		GRAVEL	
		FINE	COARSE	FINE	COARSE
COLLOIDS-less than 0.001	0.005 - 0.05	0.05-0.25	0.25 - 2.0	2.0-4.76	4.76+

GRAIN SIZE CURVES INDICATING RANGE OF GRADINGS WHICH WERE USED IN SUBBASES

FIG. 4

materials to gradings having as much as 50 per cent of the total material between the No. 20 and 60 sieves. All had little or no volume change and all were densely graded to the degree that they restricted the downward movement of surface water and thus served to protect the underlying plastic subgrade soil.

The Use of Selected Top Soil in Shoulder Construction

Some projects constructed with subbase, also included shoulders of a dark gray dense sandy loam top soil. No samples were taken of the soil nor were data obtained pertaining to the volume change or permeability of the soil. The soil supported the growth of grass -- and yet appeared to have very little volume change.

Observations showed that even when dry the material maintained close contact with the edge of the slab. The close contact did not permit water to have free access to the subgrade in the manner commonly found in shoulders constructed of high volume change clays which shrink away from the edge of the pavement. While no specific data were obtained from which its efficiency could be measured, observations were that it resulted in shoulders which had higher supporting value when wet and which gave better protection to the subgrade near the pavement edges.

SUMMARY

The most severe pumping occurred on the newer pavements built with expansion joints at 90 or 120 ft. intervals and intermediate contraction joints at 30 ft. intervals. Considerable pumping was also found on some of the older pavements built without expansion joints. However, in no instance did the percentage of pumping slabs on any of the older projects equal the heaviest pumping found on the newer jointed pavements. Average values for 20 projects showed that the per cent of pumping joints and cracks on jointed pavements was 5 times as great as that for pavements without joints. As there are more joints and cracks on the jointed pavement, the actual number of pumping joints and cracks per mile of pavement is 10 times as great as on the unjointed pavement. This is even more outstanding because of the greater age of the unjointed slab.

Many miles of pavement in good condition and with little or no pumping were examined during the survey. The non-pumping group included both pavements built with expansion joints and those built without joints. These pavements were either constructed on granular subbases or on natural soils, the major portion of which are not conducive to pumping.

The variation in pavement design thickness did not show a significant relationship to pumping.

There was but little difference, either in the amount or severity of pumping at expansion joints compared to contraction joints. Pumping was more prevalent and more severe at transverse cracks than at transverse joints on pavements built with expansion and contraction joints, although the total number of transverse cracks was smaller on the newer jointed pavements. There was little difference in either the amount of severity of pumping at cracks and contraction joints in pavement built with out expansion joints.

Considerably more pumping occurred on the newer jointed pavement widening than on the original pavements built without expansion joints.

Traffic, in terms of number of trucks per day was greatest on the projects on which pumping was found. However, the number of trucks per day was as great on some non-pumping projects as on some of the projects on which the most severe pumping was observed.

Pumping was found only on plastic soils having more than 50 per cent silt and clay combined in the total soil. Pumping was not found on natural soils or on subbases having more than 50 per cent sand and gravel (retained on No. 270 sieve) in the total soil.

Subbases of 3 to 5 inches compacted depth of densely graded non-plastic sands, loamy sands and sandy loams and generally having 70 per cent or more retained on the No. 270 sieve were successful in preventing pumping in North Carolina.

PUMPING OF CONCRETE PAVEMENTS IN KANSAS

A Cooperative Study
by
State Highway Commission of Kansas
and
Portland Cement Association

SYNOPSIS

The study was divided into three phases; reconnaissance, detailed surveys of sections of pumping and non-pumping pavements, and load deflection studies at various locations selected during the detailed surveys. The reconnaissance was made during one of the wettest spring seasons in Kansas.

The reconnaissance survey covered 237.6 miles of concrete pavement on the heaviest traveled routes in Kansas and was made to assess the degree and extent of pumping on the principal traffic routes during the spring wet weather season. After the reconnaissance survey, a detail study was made on 54 selected sections from 36 projects. Selection was based largely on uniformity of subgrade soil throughout a length sufficient for observing absence or presence of pumping, faulting, joint opening, and related items. The purpose of the detail study was to examine closely all the variables which may affect pumping. Samples of the subgrade from each section were taken at two locations. Those for determination of water content, density, and for routine tests were taken through core holes drilled through the pavement. Those for determining moisture-density relations in the compaction tests were taken under the edge of the slab. Upon completion of the detail studies, load deflection tests were made at the same transverse joints where soil samples had been taken.

Traffic data, construction records, and data on pavement design features were assembled for each project and correlated with pumping.

No significant difference was found in the amount of pumping on comparable pavements with or without lip curb. With about the same expansion joint spacing, pavements shorter slab lengths pumped less than those with longer slabs. Construction of relatively short slabs by the use of intermediate contraction joints between expansion joints at relatively long intervals resulted in reduction of pumping. Distributed reinforcing which held intermediate cracks together tightly prevented pumping at such cracks. The number of pumping projects having poor seals or no seals at expansion joints was almost three times as great as the number having food or fair seals. This ratio increases to four to one at contraction joints.

In general, total commercial traffic was about the same on pumping and non-pumping pavements, but the number of axle loads of over 10,000, 14,000, and 18,000 lb. was substantially greater on the pumping projects.

The most significant single relationship between any feature or combination of features of pavement design, subgrade soil type, traffic or other factor which may affect pumping lies in the textural classification of the subgrade soil immediately beneath the pavement. In no instance was pumping found to occur on subgrade soils having one or more of the following textural characteristics: 1. Less than 15 percent clay, 2. More than 50 per cent sand and gravel (larger than 0.05mm), or 3. More than 40 per cent retained on the No. 200 sieve.

Pumping of concrete pavements in the vicinity of transverse joints and cracks was first observed in Kansas in the spring of 1935. Pumping of consequence was then limited to about two miles of highway on US Route 40 between Wamego and St. George in Pottawatomie County where the pavement had been constructed on a plastic clay derived from a rapidly weathering soft clay shale. During the period since 1935, pumping has become more widespread and has been found on residual clay soils in the eastern half of the State on US Routes 24, 40, 50 and 50-S, 69, 73, 81 and 166. The most severe pumping has occurred in localities where the traffic includes concentrations of heavy industrial trucks, hauling products from oil refineries, coal mines and lead and zinc mines.

This report gives the results of a cooperative study made by the State Highway Commission of Kansas and the Portland Cement Association during the spring and summer of 1945 to determine the extent of pumping, its causes, and means of preventing its occurrence on new construction.

PUMPING DEFINED

Pumping of concrete pavements may be defined as the ejection of a soupy mixture of subgrade soil and water from the joints and cracks in the pavement when the slab ends are repeatedly depressed by heavy wheel loads.

Pumping may be observed in any one of several stages, from the earliest stage of the beginning of ejection of mud to its final stage of the breaking of the slab. Therefore, in order to make an accurate assessment of the condition of the pavement, it was necessary to devise a means of classifying pumping according to its stage of progress. Accordingly, pumping was classified into three classes as follows:

Class 1. Pumping at 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 of the slab as a result of loss of subgrade support due to pumping.

NATURE AND SCOPE OF STUDIES

The studies were divided into three phases. The first phase consisted of a reconnaissance study to assess the degree and extent of pumping on the principal traffic routes during the spring wet weather season when pumping is most widespread, most severe and easiest to detect. Concrete pavement projects representing various designs, various subgrade construction methods and age groups on 11 of the principal traffic routes were selected for study. The routes on which pumping was studied were as follows:

1. US-24 west of Kansas City and east of Topeka
2. US-36 northwest of Troy in Doniphan County
3. US-40 west of Russell in Russell County
4. US-50 and 50-S from Olathe to Newton
5. US-54 west of Wichita in Sedgwick and Kingman Counties
6. US-59 south of Chanute
7. US-69 south of Kansas City to US-66
8. US-73 in Leavenworth County
9. US-81 between Saline and McPherson
10. US-160 east and west of Parsons
11. US-166 in Cherokee County

The second phase consisted of detail surveys of sections of non-pumping and pumping pavements at locations selected during the reconnaissance survey. The third phase consisted of load deflection studies at locations investigated during the detail survey. The locations of the various projects with respect to traffic routes and principal cities is shown in the map of Kansas illustrated in Figure 1.

Reconnaissance Survey of Pumping

Prior to beginning the reconnaissance survey, design and construction data were gathered on the following items for each of the many projects to be investigated for pumping:

1. County, State route and Federal route number and project identification

2. Length of project

3. Date constructed

4. Contractor and Resident Engineer

5. Concrete mix, cement factor and water-cement ratio

6. Source of coarse aggregate, fine aggregate and cement

7. Pavement cross-section

8. Longitudinal joint and tie bar design

9. Transverse expansion joint spacing, width and type of filler.

10. Transverse contraction joint spacing, type and depth

11. Load transfer devices at contraction and expansion joints

12. Reinforcing

13. Thickness and width of subbase

14. Miscellaneous data on construction, such as method of curing, subgrade paper, and other items

Data on the above items were recorded on the "Office Data" side of the reconnaissance survey data sheet. An example of the data sheet is shown in Figure 2.

The reconnaissance survey was conducted by a four-man party consisting of a driver, two observers and a recorder. All observations were made by two observers seated on the front fenders of an auto driven at a very slow rate of speed. One observer counted all expansion joints, contraction joints, transverse cracks, interior and exterior corner breaks, blow-ups, lineal feet of longitudinal cracks, broken, patched and replaced areas. The second observer counted and classified all pumping expansion joints, contraction joints and cracks, and recorded the number of joints and cracks which had faulted but were not pumping at the time of the survey.

In addition to assessing the extent and degree of pumping, several stops were made on each project to observe pavement condition, surface drainage and other factors which might yield data of value in the analysis of data on pumping. Observations were made and recorded on the following items:

Average and maximum faulting at joints and cracks

Width of opening of joints and cracks

Condition of seal at joints and cracks

Drainage condition of shoulders

Road section -- cut or fill

Soil series and horizon

Condition of the concrete

Figure 2

SURVEY OF CONCRETE PAVEMENTS
IN KANSAS

Sheet ___ of ___

OFFICE DATA

County ______________ State Route ______________

Federal Route ______________ Project Ident. ______________

Location, from ______________ to ______________

Length, Miles ________ Feet ________ Date Built, Begin ________ End ________

Contractor ______________ Res. Engr. ______________

CONCRETE DETAILS	Mix ________ Cement Factor ________ W/C ________	
	Cement	
	Fine Agg.	
	Coarse Agg.	

Cross Section ______________ Width ________

Longit. Jt. Details ______________

Tie Bars ______________

Trans. Exp. Jt. Spacing ________ Width ________ Type of Filler ________

Cont. Jt. Spacing ________ Type ______________ Depth ________

Load Transfer Devices, Exp. ______________

Load Transfer Devices, Cont. ______________

Reinforcing ______________

24 Hour Traffic		
Year		
Total Vehicles		
Trucks		
Truck Axles		
Axles 8 - KIPS		
Axles 8-10 KIPS		
Axles 10-12 KIPS		
Axles 12-14 KIPS		
Axles 14-16 KIPS		
Axles 16-18 KIPS		
Axles 18-22 KIPS		
Axles 22+ KIPS		

Description of Project and Remarks

SURVEY OF CONCRETE PAVEMENTS
FIELD DATA

Sheet ____ of ____

Project ______________________ Date ________

Line No.	ODOMETER READING OR STATION			JOINT AND CRACK DATA						LOAD CORNER BREAKS		PUMPING DATA											
				JOINTS			CRACKS	JOINTS & CRACKS				Expansion Joints				Contraction Joints				Cracks			
												Number				Number				Number			
	From	To	Length (Miles or Ft.)	Exp. (No)	Con. (No)	Int. (Ft)	(No.)	No.	Int. (ft)	I (No)	E (No)	Cl. 1	Cl.2	Cl.3	Total	Cl. 1	Cl.2	Cl.3	Total	Cl.1	Cl.2	Cl.3	Total
1																							
2																							
3																							
4																							
5																							
6																							
7																							
8																							
9																							
10																							

Line No.	JOINT AND CRACK DATA						CONCRETE CONDITION	ROAD SECTION		SOILS DATA
	Joint & Crack Opening			Joint & Crack Seal				Cut	Fill	Series - Horison - Texture - Remarks
	Exp.	Contr.	Cracks	Exp.	Contr.	Cracks				
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										

Line	REMARKS

An effort was made in the reconnaissance survey to obtain data on pumping from which the relative influence of lip curb, cut or fill section and soil series could be evaluated. For example, several projects having relatively uniform subgrade soils and light cut and light fill sections were broken into sections of lip curb and no lip curb during the survey of pumping.

Sections of each project which appeared to be typical of pumping or of non-pumping portions were noted for further observations during the detail study. Close attention was given to selecting sections which were in the same soil horizon and which had relatively uniform soils throughout.

The reconnaissance survey included 68 projects totaling 237.6 miles of concrete pavement on the heaviest traveled principal traffic routes. The mileage studied represents approximately 18 per cent of the total mileage of concrete pavements in Kansas. Excepting three projects of 6-8-6 cross-section constructed prior to 1925, all pavements were of thickened edge design; 13.2 per cent of the mileage was of 18-ft. width; 77.3 per cent of 20-ft. width, and 9.5 per cent of 22-ft. width. The reconnaisance survey was made in one of the wettest spring seasons on record in Kansas.

No effort was spared in obtaining an accurate appraisal of the amount and the stage of progress of pumping in the reconnaisance survey. Some projects where pumping was in the early stages and others which were constructed with subbases were inspected by walking over portions of projects or, in some instances, the entire project. Occasional measurements were made to determine faulting and joint opening. A pickax was used frequently to facilitate examination of slab edges at joints where the surface evidence of pumping was not positive.

In so far as possible, the information obtained was recorded as numerical data. However, data on items like shoulder drainage, condition of joint seal, etc., were recorded by word description. Where possible to classify conditions, the limits of each group were defined to facilitate gathering and recording data. For example, the following classes and their definitions were adopted for use in describing the condition of the joint seal:

Condition good - Filled. Seal appears relatively watertight.

Condition fair - Filled but effectiveness appears doubtful.

Condition poor - Seal partly gone or appears ineffective.

No seal - Seal completely missing.

Pumping was found to vary in amount and degree with traffic and subgrade soil type. Heavy clays showed light pumping in the early stages but invariably were associated with severe pumping in the more advanced stages. The lighter textured clay loams, etc., were usually found associated with light pumping even though it was evident that pumping had been in progress for some time. These items are discussed later in this report. The data obtained were recorded on the "Field Data" side of the reconnaissance survey data sheet (see Figure 2)

Detail Survey and Sampling of Selected Sections

After completion of the reconnaissance survey, a detail study was made of selected sections. A total of 54 sections on 36 projects were given special study. Selection was based largely on uniformity of subgrade soil throughout a length sufficient for observation of absence or presence of pumping, faulting, joint opening and related items.

The purpose of the detail survey was to permit a closer examination, on a short section of a project, of all the variables which may affect pumping. The following observations and measurements were made and recorded:

A. The pavement and shoulders

1. Location of all joints and cracks
2. Presence or absence of lip curb
3. Faulting at joints and cracks
4. Location and stage of progress of pumping
5. Extent and nature of spalling along longitudinal center joint and transverse joints and cracks
6. Joint and crack openings
7. Roadbed section, cut, grade or fill
8. Condition of joint filler and joint and crack seal
9. Condition of maintenance and surface drainage of shoulders
10. Drilling cores to determine pavement thickness and, in some instances, the thickness and condition of joint fillers, apparent restraint of slabs and other pertinent data.

Considerable time and effort were given in the detail study to examine joints for pumping. Joint fillers were removed and excavation made at the edges of the slab to insure that pumping was observed even though it was in its earliest stages.

B. The subgrade

1. Samples for determination of water content, density, and for routine tests were taken through core holes drilled through the pavement.

2. Samples for determining moisture-density relations in the compaction test were taken under the edge of the slab.

Subgrade soils were taken to various depths below the bottom of the pavement depending upon the soil types encountered and the thickness of the subbase. Where there was no subbase, the sample included all soil to an average depth of 8 in. Where a subbase existed, separate samples were taken to represent the subbase and the underlying subgrade soil.

Testing of Soils

Samples of subgrade removed through core holes at or near pumping and non-pumping joints were weighed in the field, sacked in new sacks and, together with large samples taken for standard moisture-density tests, were submitted to the Central Soils Laboratory of the Kansas Highway Commission for test. The volume of the test holes to determine the "in-place" density and moisture content of subgrades was measured by using a dry sand of known weight per cu. ft. The subgrade samples were dried to constant weight at 100° C. and weighed for use in computing field water content and field density. The following tests were conducted on the samples after drying:

1. Liquid limit
2. Plastic limit
3. Mechanical analysis
4. Specific gravity

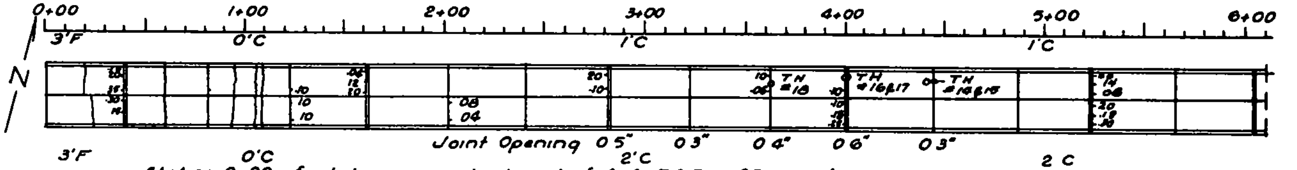
Standard compaction and optimum water content determinations were made on the large samples taken from under the edge of the pavement.

Observations and measurements made on each project during the study of detail sections, the test data on subgrade samples, and information obtained during the reconnaissance survey were assembled and recorded on data sheets for study. Figure 3 illustrates a typical data sheet for a project or portion of a project.

Load Deflection Studies

Upon completion of the detail studies, load deflection tests were made at the identical transverse joints where soil samples had been taken and field density and water content tests of the subgrade had been made. A four-wheel drive Oshkosh truck shown in Figure 4, was loaded to produce a front axle weight of 8,000 lb. and a rear axle weight of 16,000 lb. Dimensions of tires, wheel base, and other data pertaining to the truck are given in Figure 5.

Ames dials were used for measuring pavement deflection under load. They were mounted on a special "T" bracket which in turn was supported by a 1-in. round steel pin 3 ft. long driven into the subgrade.



Station 0+00 - first transverse joint west of 4x4 RCB 1.95 miles from east end of project. No pumping and no spalling on this section. Joint seal in place but pulled away from concrete.

Scale
Long equals ft
Transv equals ft

Date of Mapping 6-15-45
8-7-45

Weather Conditions Clear 80°F (8-7) Rain (8-5)

PROJECT LOCATION AND DESIGN DATA

COUNTY Franklin US ROUTE 50S FROM 7.113 Mi. N.E. Williamsburg TO Williamsburg LENGTH (MI) 7.113 (FT) 37,557 DATE BUILT, BEGIN 6-32 END 7-32
Mix 1:1.55:4.63 C.F W/C Cement Atlas, Monarch, Dewey, Victor F.Agg. Topeka C.Agg. Ottawa
Cross Section 9-7-9x20', lip curb & plain Long C Jt Deformed metal plate Tie Bars ½"x4'-0" at 5'-0" cc. Ex Jt. Spacing 121' Width 1" Filler Felt
Contr Jt. Spacing 40'-4" Type Ribbon Depth Groove 2" Load Transfer - Exp. Jt. None Contr. Jt. 8-¾"x2'-6" dowels
Reinforcing ⅜" rd. sm. bars at edges and expansion joints. 8-5/8"x1'-0" hairpin bars at exp. joints
Remarks subgrade paper. Asphalt seal.

PROJECT RECONNAISSANCE FIELD SURVEY DATA *Date of Survey 5-11-45*

Line No F. to E.	Length (Mi)	Joint & Crack Data				Load Corner Breaks						Pumping at Expansion Joints, Contraction Joints and Cracks																												
		Joints		Cracks	Jts & Cracks	Interior			Exterior			Expansion Joints					Contraction Joints					Exp. & Contr. Joints					Cracks					Joint & Cracks					Joints & Cracks Per Mile			
		Exp (No.)	Contr (No.)	(No)	(No.)	No	Max Poss	Per Cent	No.	Max Poss	Per Cent	Total No	Total %	% of Total Cl.1	Cl.2	Cl.3	Total No.	Total %	% of Total Cl 1	Cl.2	Cl.3	Total NO.	Total %	% of Total Cl.1	Cl.2	Cl 3	Total No.	Total %	% of Total Cl 1	Cl.2	Cl.3	Total No.	Total %	% of Total Cl.1	Cl.2	Cl.3	Cl.1	Cl.2	Cl.3	Total
1	2.129	91	193	62	346	1	1384	0.1	1	1384	0.1										No Pumping																			
2	4.984	212	457	106	775	0	3100	0	3	3100	0.1	2	1.0	50	0	50	3	0.6	33	34	33	5	0.7	40	20	40	1	0.9	0	0	100	6	0.8	33	17	50	0.4	0.2	0.6	1.2
Proj.	7.113	303	650	168	1121	1	4484	0.1	4	4484	0.1	2	0.6	50	0	50	3	0.5	33	34	33	5	0.5	40	40	40	1	0.6	0	0	100	6	0.6	33	17	50	0.3	0.1	0.4	0.8

Size of Joint and Crack Opening, and Condition of Seal

Joint and Crack Opening			Joint and Crack Seal			Condition of Shoulders and Ditches
Expansion Joints	Contraction Joints	Cracks	Expansion Joints	Contraction Joints	Cracks	
Normal to partly closed	Tight to partly open	Tight	Poor to fair	Fair to poor	None	Shoulders 0.1' to 0.2' higher than slab where lip curb is absent.

FIELD AND LABORATORY SOILS DATA FROM DETAIL STUDY SECTIONS

Field Data								Joint Nearest Sample					Laboratory Data														
Date	Subbase Th (in)	Subbase Width (ft)	Soil Series and Horizon	Sample No.	Depth (in.)	Water Content (%)	Density (p.c.f)	Type	Op. (in.)	Condition	Pumping	Th Pvt. (in.)	Mechanical Analysis (Per Cent) % Retained #4	#10	#40	#200	Gravel & Sand	Silt	Clay	Coll	Texture Group	Specific Gravity (-#10)	L.L	P.I.	Optimum W.C. %	Max. Density (P.C.F)	P.R.A. Group No.
6-15-45			Crawford and Summit	14	0-7	30.4	85.4	(8-7) Contr	0.3 0.4	Good	No	7.15	0	0	1	3	15	54	31	16	SiC	2.51	37	15	22.9	99.0	A7
				15	7-9	31.2							0	0	1	4	16	43	41	25	C	2.50	43	20			A7
				16	0-7	29.3	85.0	Exp.	0.6	Some faulting	No	-	0	0	2	7	20	54	26	14	SiCL	2.50	37	14			A4-7
				17	7-10½	33.1		(8-7)	0.4				0	0	0	3	14	43	43	28	C	2.46	64	40			A7
				18	0-7	30.9	88.4	Cont.	0.3	Good	No	7.10	0	0	1	5	17	46	37	20	C	2.48	46	23			A7

LOAD DEFLECTION DATA

Date and Hour	Weather Temp.	Weather Sunshine	Weather Wind	Location No.	Speed (m.p.h)	Load Deflections - (in thousandths of an inch) Pos. 1	Pos 2	Pos. 3	Pos. 4	Residual Deformations (in thousandths of an in. after one minute) Pos 1	Pos. 2	Pos 3	Pos. 4	Date and Hour	Temp. (°F)	Loc. No.	Speed (mph)	Load Deflections - (in thousandths of an inch) Pos. 1	Pos 2	Pos 3	Pos 4	Residual Deformations (in thousandths of an in. after one minute) Pos. 1	Pos 2	Pos. 3	Pos. 4
7-27-45 3 PM	90	Clear		14 & 15	18	7	8	3	2	1	1	1	0	7-27 3 PM	90	16 & 17	18	10	10	2	2	2	2	0	1
					10	8	10	3	3	1	1	1	1				9	11	11	3	3	3	2	1	1
					5	8	8	3	3	2	2	2	1				5	10	10	4	4	3	2	1	1
					Static A	13	10	4	3								A	12	12	3	4				
					" B	14	14	4	4								B	13	13	3	5				
					" C	13	15	5	4	4	4	2	2				C	13	14	4	5	4	4	1	1

Rt. rear tire against lip curb during static readings.

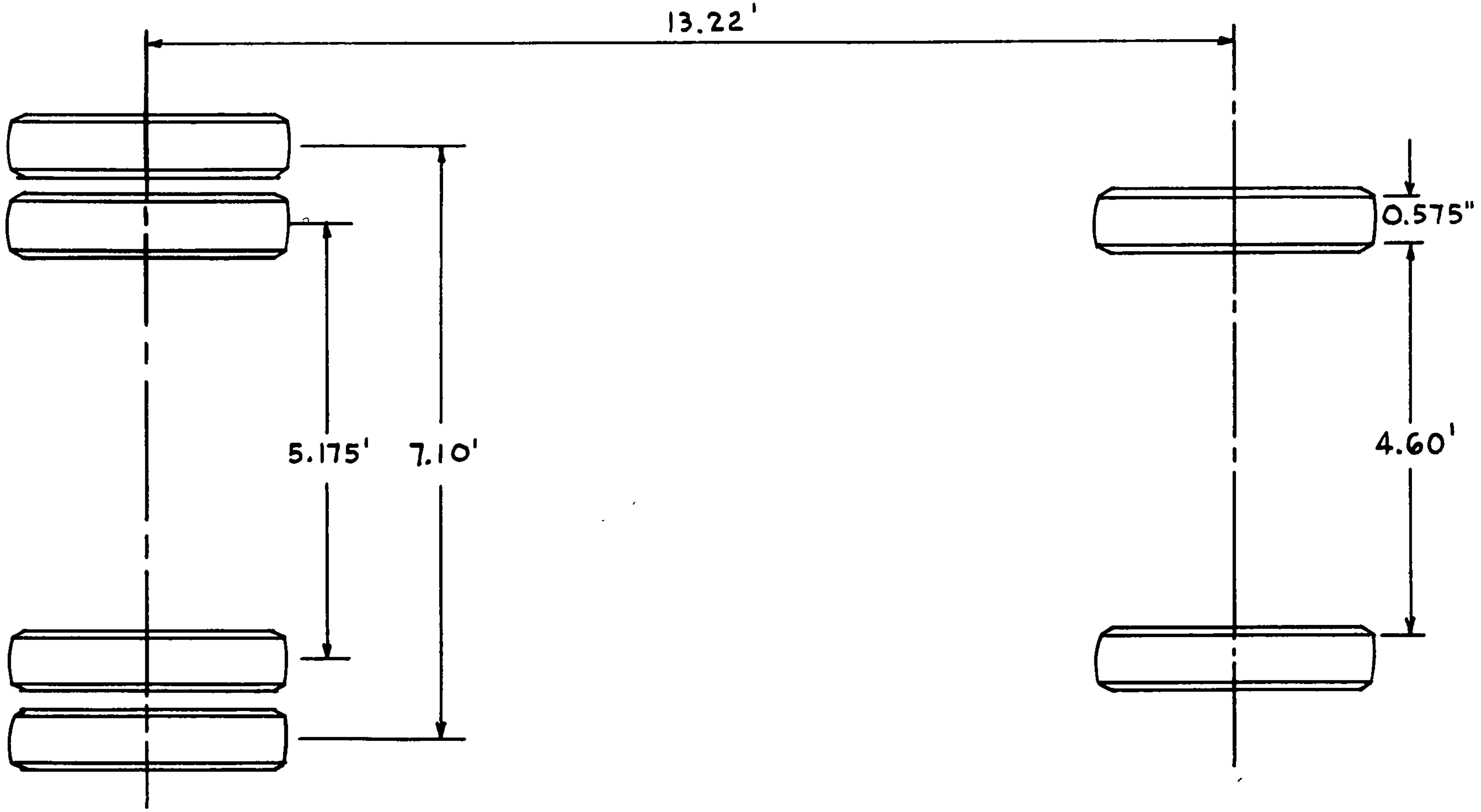
TRAFFIC DATA

No. Truck axles per day shown cumulatively for weight groups				
Under 10,000	Over 10,000	Over 14,000	Over 18,000	Total
694	293	63	2	937

Remarks Line 2-50 lineal feet of breakage. 61 faulted expansion joints, 3 faulted cont. & constr. joints. Faulting order of 1/8".

Sheet 1 of 1
50-S-33-1- FAP 352 E

1'1



TIRE DATA

Tire Size 9.75" x 20"
Tread Width 6.9" = 0.575'
Air pressure 80 p.s.i.
All tires had been recapped and treads were in good condition.

WHEEL LOADS
(For loaded truck)

Wheel	Weight (Lb.)
Lt. Front	4000
Rt. "	4000
Lt. Rear	8000
Rt. "	8000

FIGURE 5
DIMENSIONS AND WEIGHTS OF LOADED TRUCK USED IN DEFLECTION STUDIES

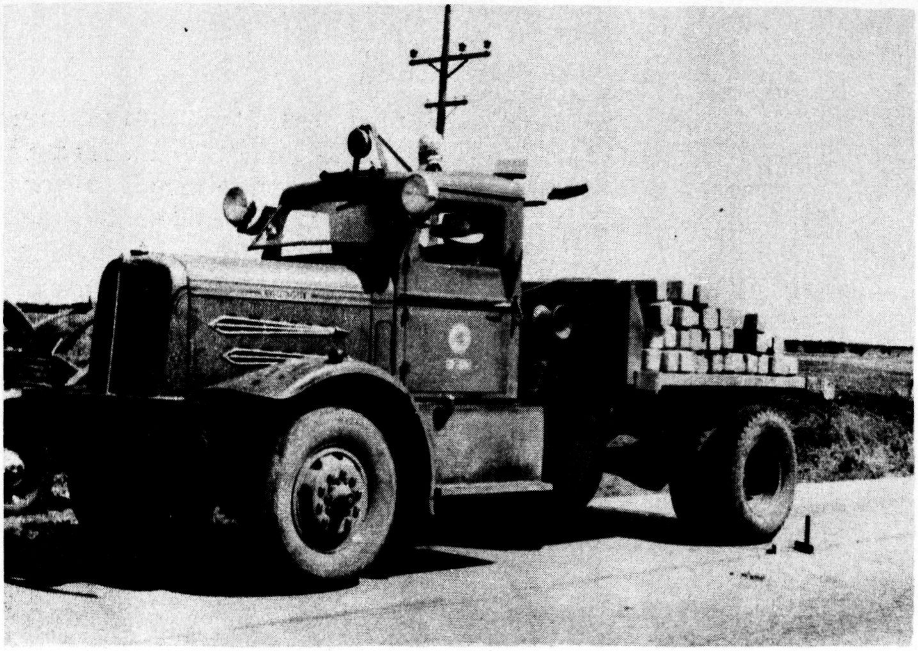


Fig. 4 Truck as Used in Load-Deflection Studies

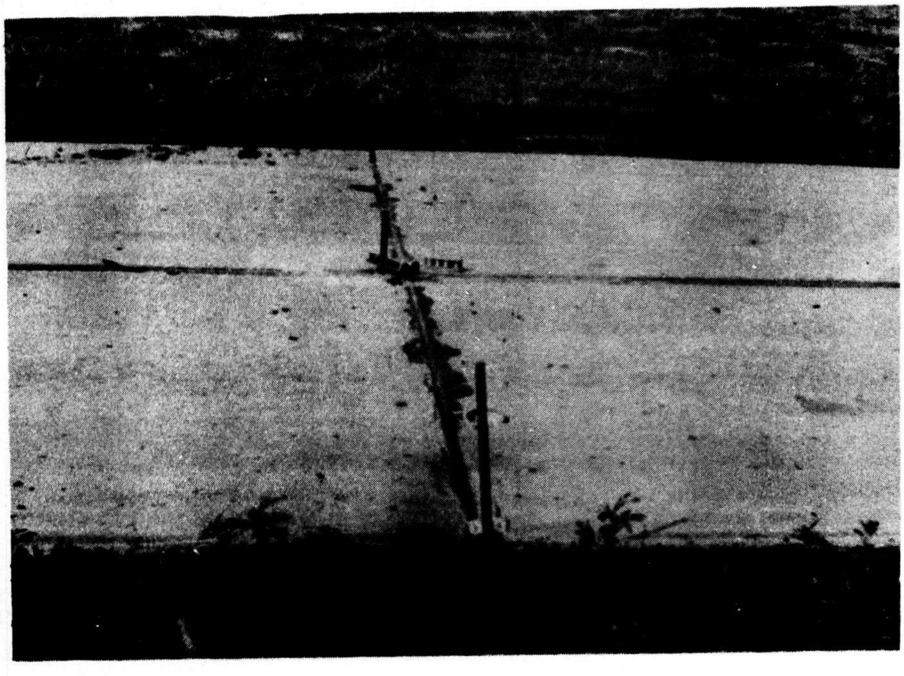


Fig. 6 Mounting of Ames Dials for Deflection Measurements in Load-Deflection Studies

The supporting pin near the intersection of the longitudinal center joint and transverse joint was driven through a 2½-in. hole drilled in the slab. Similar pins at the edge of the pavement were driven just clear of the slab. Each "T" bracket supported two Ames dials so that at each setup one dial was bearing on each of the four slab corners of one traffic lane at a transverse joint. See Figure 6.

One observer was assigned to each of the four dials. Maximum deflections were observed at each of the four dial positions at truck speeds of 20, 10 and 5 mph. The 20 mph speed was the maximum at which reliable readings could be obtained by this method of observation.

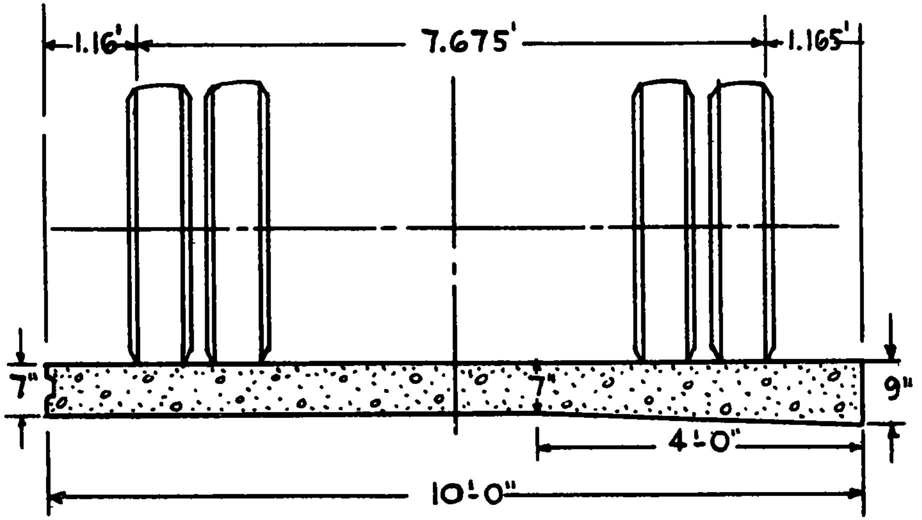
At each setup, readings were first taken under moving loads. Later readings were taken under static loads at each of the four dial positions with the rear wheels immediately back of the joint; with the wheels centered over the joint; and, with the wheels immediately ahead of the joint as indicated in Figure 7. Following the removal of the load from wheel position C, a period of one minute was allowed prior to observing residual deflection. All deflection tests were made with the truck centered in the lane and moving in the direction of traffic for the lane being tested. An example of the data obtained in the load deflection tests is shown on the data sheet of Figure 3.

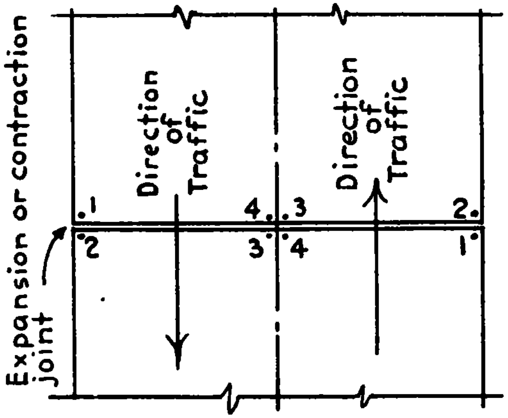
Two series of static load deflection tests were made to determine the effect of off-center loading. In Series 1, the inside rear wheel was kept two inches from the dials along the center line (dial positions 3 and 4). In Series 2, the outside rear wheel was kept a distance of three inches from the outside dials (dial positions 1 and 2). These static load deflection tests were taken in order to determine the possible effect of off-center loadings in the moving-load-deflection observations. The data obtained in the two series of tests are shown in Table 1 below.

TABLE 1

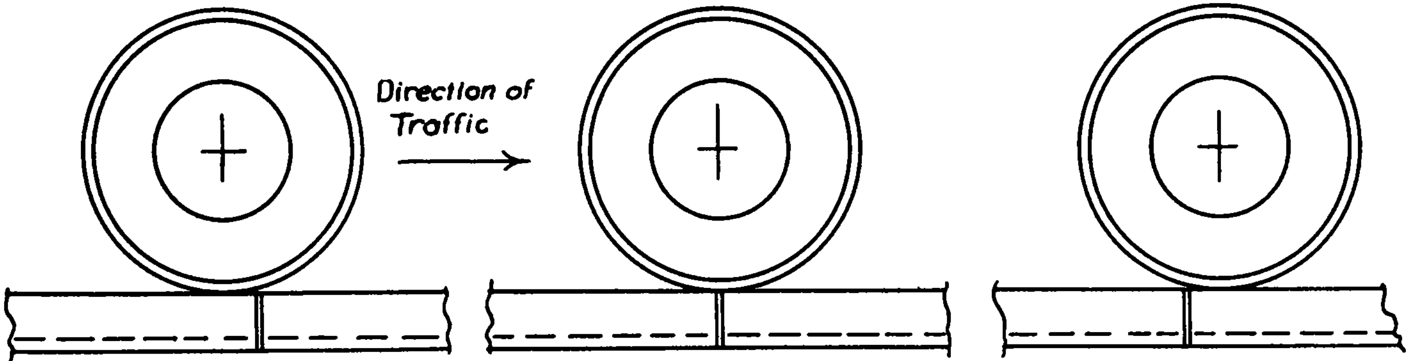
		Load deflection Inches 10^{-3}				Residual Deflection Inches 10^{-3}			
		Dial Positions				Dial Positions			
Series No.	Wheel Position	1	2	3	4	1	2	3	4
1	A	27	21	19	37				
1	B	29	25	19	28				
1	C	20	36	30	10	4	5	9	6
2 2	A	34	25	13	34				
2	B	34	31	23	25				
2	C	23	45	29	11	5	6	11	8

A study of these data shows that for the most extreme positions of the wheels in a lane, the dials along the edge of the slab varied only about .005 in., and the dials along the center joint varied





Location of instruments for measuring deflections under static and moving loads.



Position - A Position - B Position - C

Wheel Positions In Static Loadings

FIGURE 7
POSITION OF TRUCK WHEELS FOR LOAD - DEFLECTION STUDIES

Traffic Studies

The latest comprehensive loadometer survey in Kansas was made in 1936, while the most recent statewide traffic count was made in 1941. For the purpose of the pumping studies, the 1941 axle loads were estimated by comparing the 1941 traffic count with the results of the 1936 loadometer survey. The per day volume of commercial traffic only was considered for this study and this was divided into the following four axle weight groups: under 10,000 lb., over 10,000 lb., over 14,000 lb., and over 18,000 lb. The load estimates for 1941 were made separately for each group and at each station whose count affected the project under consideration. Single unit and combination vehicles were considered separately. The calculated weight will not be an accurate representation of the actual truck traffic because the 1936 weighted sample was predominately of loaded vehicles and the 1941 traffic count includes both loaded and empty trucks. The traffic data were recorded on the data sheets, an example of which is shown in Figure 3.

Additional traffic data of a detailed and comprehensive nature on axle weights and number of and speed of units in each weight group for each traffic lane were obtained for one location included in this study. These data are described in more detail later in this report.

ANALYSIS OF DATA AND OBSERVATIONS

The reconnaissance survey was made during May and June, the detail survey during June and July, and the load-deflection measurements during July and August, 1945.

A summary of the reconnaissance data shows that 68 projects totaling 237.6 miles in length were included in the survey. Of this total, 24 projects, 58.9 miles in length and equal to 24.8 per cent of the total mileage surveyed, showed no pumping. The 44 projects on which pumping was found had a total of 11.6 per cent of all joints and cracks pumping. If all joints and cracks found to be pumping during the survey occurred consecutively and were spaced at the average joint and crack interval of the pumping projects, a total of 20.7 miles of the 237.6 miles surveyed would be involved.

The data from the reconnaissance and detail surveys show the status of pumping on each project for the traffic, the subgrade conditions and the climatic conditions which prevailed prior to and during the survey. It was found that pumping occurred on all except one of the various slab designs used, but not on all subgrade soils. This one slab design was used on only one project of recent construction and also involved the use of joint drains at expansion joints spaced at 353-ft. intervals. There were differences of considerable magnitude in the amount and degree of pumping on various pavement designs, subgrade soils and subgrade conditions, and for different concentrations of various axle weights. The relationships between pumping and the various factors of pavement design, subgrade soil and traffic found from the data are given in the paragraphs which follow:

RELATION BETWEEN PAVEMENT DESIGNS AND PUMPING

Pavement Cross-Section - Thickness and Width

Nearly all projects surveyed were built with a 9" - 7" - 9" cross-section, the transition from the 9" to 7" thickness being obtained in 4 ft. A large proportion were of 20-ft. width. The number of projects having a 9"-6"-9" and 6"-8"-6" cross-section was insufficient to obtain a significant comparison of pumping on different cross-sections. That is also true for pavements built with 18 and 22-ft. widths as compared with pavements of 20-ft. width.

Lip Curb Design

Seven projects having lip curb on hill sections and no lip curb on the flatter grades were studied to determine the influence of lip curb on pumping. They were all located on fine grained residual soils derived from limestones and shales and which are considered "potentially pumping soils". The lip curb was 3 in. high at the pavement edge and sloping inward for a distance of 12 in. The 7 projects totaled 21.885 miles in length. The relative amount of pumping on pavement having lip curb as compared with pavement having no lip curb is shown in Table 3. There is little difference in the total per cent of pumping joints and cracks on the two designs. There is a slightly higher percentage of pumping joints and cracks on the lip curb section, but the degree of pumping is less severe than on the section without lip curb. This is indicated by the ratio of Class 2 to Class 1 pumpers. The number of Class 1 and Class 2 pumpers was about equal on the lip curb section, while on the pavement without lip curb there were nearly twice as many Class 2 pumpers as Class 1 pumpers. No edge pumping occurred on lip curb sections, but it should be kept in mind that lip curb sections were all on hill sections which afforded better surface drainage than on the flatter grades where the sections without lip curb were located.

Faulting and deflections under load on sections with lip curb and sections without lip curb are discussed later in the report.

Jointing Arrangement and Pumping

Sixty-five projects having 8 different jointing arrangements and 3 projects built with only construction joints were covered in the reconnaissance survey. Expansion joint spacings, with two exceptions, were very nearly the same, ranging from 100'-4" to 121'-0". However, the spacing of contraction joints resulted in original slab lengths ranging from 25'-3" to 100'-4".

Of three projects built prior to 1925 having joints at construction stops only, two projects showed pumping.

TABLE 3

RELATION BETWEEN LIP CURB AND PUMPING

Length (mi.)	Year Built	Jointing Arrangement		Expansion Joints			Contraction Joints			Number			Joint & Crack Interval (ft.)	Percent of Pumping Joints and Cracks																			
														Exp. Joints				Cont. & Constr. Jts.				All Joints				Cracks				Total			
		Exp. Jt. Spacing (ft.)	Cont. Jt. Spacing (ft.)	Width (in.)	Type of Filler	Load Transfer	Type	Depth (in.)	Load Transfer	Exp. Jts.	Cont. & Constr. Jts.	Cracks		Cl.1	Cl.2	Cl.3	Total	Cl.1	Cl.2	Cl.3	Total	Cl.1	Cl.2	Cl.3	Total	Cl.1	Cl.2	Cl.3	Total	Cl.1	Cl.2	Cl.3	Total
PARTS OF PROJECTS WITH LIP CURB																																	
0.508	1933	121'	40'-4"	1	Premoulded Felt	None	Dummy Groove	2"	Dowels ¾"x2'6"	21	45	10	35.3	4.8	9.5	0	14.3	4.4	0	0	4.4	4.6	3.0	0	7.6	0	10.0	0	10.0	4.0	3.9	0	7.9
3.698	1935 1936	100'-4"	—	1	Air Core	A	—	—	—	196	21	126	56.9	23.5	63.8	1.5	88.8	33.3	19.1	0	52.4	24.4	59.5	1.4	85.3	0	0	0	0	15.5	37.6	0.9	54.0
8.235	1938	100'-4"	—	1	Lim. Extr. Rubber	D1	—	—	—	440	37	175	66.7	18.2	0.2	0	18.4	21.6	8.1	0	29.7	18.4	0.9	0	19.3	0	0	0	0	13.5	0.6	0	14.1
12.441	(Totals for Parts of Projects with Lip Curb)									657	103	311	61.3	19.3	19.5	0.5	39.3	16.5	6.8	0	23.3	18.9	17.8	0.4	37.1	0	0.3	0	0.3	13.4	12.7	0.3	26.4
PARTS OF PROJECTS WITHOUT LIP CURB																																	
0.546	1933	121'	40'-4"	1	Premoulded Felt	None	Dummy Groove	2"	¾"x2'6" Dowels	24	50	9	34.7	4.2	8.3	0	12.5	0	0	0	0	1.4	2.7	0	4.1	0	0	0	0	1.2	2.4	0	3.6
3.890	1935 1936	100'-4"	—	1	Air Core	A	—	—	—	202	11	77	70.7	12.9	48.5	1.5	62.9	9.1	27.3	0	36.4	12.7	47.4	1.4	61.5	0	0	0	0	9.3	34.8	1.0	45.1
5.008	1938	100'-4"	—	1	Lim. Extr. Rubber	D1	—	—	—	260	22	92	70.7	11.2	0	0	11.2	18.2	4.6	0	22.8	11.7	0.4	0	12.1	0	0	0	0	8.8	0.3	0	9.1
9.444	(Totals for Parts of Projects without Lip Curb)									486	83	178	66.8	11.5	20.6	0.6	32.7	6.0	4.8	0	10.8	10.7	18.3	0.5	29.5	0	0	0	0	8.2	13.9	0.4	22.5

Subgrade and traffic conditions are similar for the above projects upon which the relation between lip curb and pumping was investigated. The project with contraction joints is a non-mesh project. The remainder contain mesh reinforcement.

TABLE 4

PUMPING AS AFFECTED BY JOINTING ARRANGEMENT-MAJOR DESIGN GROUPS

Total Number Projects Surveyed	Number Pumping Projects	Age Group (years built)	Jointing Arrangement (Spacing in ft. & in.)		Reinforcing	Total Pumping Joints (percent of Totals Occurring on Pumping Projects)				Total Pumping Joints Per Mile of Pumping Projects	Average Number of Commerical Axles Per Day on Pumping Projects			
			Exp. Jt.	Contr. Jt.		Class 1	Class 2	Class 3	Total		Under 10,000 lbs.	Over 10,000 lbs.	Over 14,000 lbs	Over 18,000 lbs
8	4	1930-1931	116-0	29-0	Marginal Bars	2.6	0.3	0.5	3.4	6.2	858	266	60	6
16	8	1932-1934	121-0	40-4	" "	4.7	2.0	1.0	7.7	10.1	723	213	61	6
12	8	1940-1942	(100-4 (100-8	50-2) 50-4)	56 lb. mesh	6.9	3.2	0.0	10.1	11.0	(a)955	436	111	12
25	19	1935-1938	100-4	None	" " "	13.7	9.9	1.9	25.5	15.0	(b)878	330	94	13

(a) Based on 7 pumping projects
(b) Based on 18 pumping projects

Of two projects built in 1927 having expansion joints at 150' and no intermediate contraction joints, both projects showed pumping.

One project built in 1940 having expansion joints at 353'-9" and intermediate contraction joints at 25'-3" showed no pumping.

One project built in 1928 having expansion joints at 100' and contraction joints at 50' showed pumping. This project differed in iesign from a group of several projects having 100'-4" and 100'-8" expansion joints and intermediate contraction joints in that it did not have mesh reinforcing.

A tabulated summary of the pumping on the above mentioned projects and three other groups, all having about the same expansion joint spacing and each containing a number of projects (61 for the four groups) is given in Table 4. Because the use of distributed mesh reinforcing appeared to influence pumping considerably, the groups with and without mesh will be considered separately in discussing the effect of jointing arrangement. An inspection of Table 4 will show that for the two groups with mesh and for the two groups without mesh, expansion joint spacings being held about the same in both instances, the pavement having the shorter original slab lengths developed considerably less pumping. It will be seen that this is true when the amount of pumping is expressed as a percentage of joints pumping or as the number of pumping joints per unit length.

Comparison of Pumping at Contraction Joints and Expansion Joints

Pumping data for the 20 projects in the major design groups having both expansion and contraction joints are shown in Table 5. Each of the first two groups (built without mesh reinforcement) shows about twice as much pumping at expansion joints as at contraction joints on the basis of the percentage of total number of each type of joint. This may be due to a greater difficulty of keeping expansion joints effectively sealed. This relationship on the third group of projects, which contained mesh, is reversed; the pumping at contraction joints being about twice that at the expansion joints. This may be the result of the mesh holding cracks tightly together and causing the 50-ft. slabs (the longest original slab length of the three groups) to act as units. The resulting large contraction joint openings make it more difficult to maintain an effective seal and, in turn, allow the entrance of more water through the joint into the subgrade. (See "Pumping on Pavements with Reinforcing" in a later paragraph.)

Pumping on Different Expansion Joint Fillers

Only one type of expansion joint filler appears to have a major effect on pumping, the air-core "copper seal" type. This type was used on 9 projects, 7 of which were pumping. Pumping was from 3 to 5 times more severe on the 7 pumping projects having air-core joints at

100'-4" and no intermediate contraction joints than on 12 pumping projects with limited extrusion rubber joints and similar jointing arrangement (See Table 6). Difference between other fillers are less marked and because jointing arrangement appears to have a major influence, further direct and pertinent comparison of types of filler cannot be drawn from the data.

Load Transfer Devices and Pumping

Pumping occurred at joints having all types of load transfer devices used at both expansion and contraction joints. Data from the reconnaissance survey show (see Teble 7) that in only one instance did the type of load transfer device have any influence on the amount of pumping or the severity of pumping. The various types of load transfer devices used are described on page 59.

The data in Table 7 indicate that the expansion joints having types A and A-1 devices (Translode) and spaced at 100'-4" without intermediate contraction joints developed unusually heavy pumping. However, that jointing group includes the use of the copper seal (air-core) filler which has previously been shown to be an inferior joint filler and seal.

Expansion joints with the A-2 type of load transfer device appear to have developed only a small amount of pumping, but it should be noted that 6 of the 7 projects on which they were used were built on selected soil subbases. The one project which did not have selected soil subbase showed severe pumping (14% of expansion joints, also 50% of contraction joints having type P-2 load transfer device pumped).

Several of the older pavements have no load transfer devices but soil was found to be tightly packed in joint space. Inspection by cutting out the tightly packed soil and by means of core holes drilled directly through the joints gave evidence that the slabs were in restraint. It seems apparent that this restraint provided some load transference without the presence of load transfer devices.

A direct comparison can be made in the 100'-4" expansion joint spacing group (with no intermediate contraction joints) between the projects using dowels and those using type A-1 load transfer devices. Both groups used limited extrusion rubber fillers. Reference to Table 8, page 41, will show that the total percentage of pumping expansion joints having A-1 load transfer devices was about twice as great as for expansion joints having dowels (D-1 load transfer device).

Pumping on Pavements with Reinforcing

The use of distributed mesh reinforcement was found to confine pumping to slab ends at joints only (no pumping of intermediate cracks) but it did not reduce the total number of joints or cracks pumping per unit length (see Table 9). It will be seen from the table that

TABLE 5

A COMPARISON BETWEEN PUMPING AT EXPANSION JOINTS AND CONTRACTION JOINTS

Total Number Projects Studied	Number of Pumping Projects	Age Group (yr. built)	Jointing Arrangement		Pumping (Percent of Totals Occurring on Pumping Projects)											
					Expansion Joints				Contraction Joints				All Joints			
					Class				Class				Class			
			Exp.	Contr.	1	2	3	Total	1	2	3	Total	1	2	3	Total
8	4	1930-1931	116'-0"	29'-0"	4.4	0.9	0.5	5.8	2.0	0.0	0.6	2.6	2.6	0.3	0.5	3.4
16	8	1932-1934	121'-0"	40'-4"	4.6	4.8	2.2	11.6	4.7	0.8	0.4	5.9	4.7	2.0	1.0	7.7
12	8	1940-1942	(100'-4" (100'-8"	50'-2" 50'-4"	6.1	0.3	0.0	6.4	7.7	5.8	0.1	13.6	6.9	3.2	0.0	10.1

TABLE 6

PUMPING ON DIFFERENT EXPANSION JOINT FILLERS

Total No. Projects Studied	No. of Pumping Projects	Age Group (Year Built)	Jointing Arrangement		Type of Exp. Jt. Filler	Pumping at Exp.Jts. (% of Exp.Jts. Pumping on Pumping Projects)				Number of Commercial Axles Per Day on Pumping Projects			
			Expansion	Contraction		Class				Under 10,000 lbs.	Over 10,000 lbs	Over 14,000 lbs	Over 18,000 lbs.
						1	2	3	Total				
4	1	1930-1931	116-0	29-0	Poured bituminous	Pumping at contraction joints only.				1054	611	132	15
4	3	1930-1931	116-0	29-0	Premolded felt	4.9	1.1	0.5	6.5	793	151	36	3
15	8	1932-1934	121-0	40-4	Premolded felt	4.6	4.8	2.2	11.6	723	212	61	6
12	8	1940-1942	(100-4 (100-8	50-2) 50-4)	Limited extrusion) Bituminous fiber)	6.1	0.3	0.0	6.4	(a)955	436	111	12
9	7	1935-1936	100-4	None	Air Core	17.0	24.6	4.8	46.4	743	282	81	11
16	12	1935-1936	100-4	None	Limited extrusion rubber	12.3	1.3	0.1	13.7	(b)964	361	103	14

(a) Based on 7 pumping projects
(b) Based on 11 pumping projects

TABLE 7

RELATION BETWEEN LOAD TRANSFER DEVICES AND PUMPING

No. of Projects Studied	No. of Pumping Projects	Age Group (yr. built)	Jointing Arrangement		Expansion Joint Filler	Load Transfer Device	Pumping at Exp. Jts. (% of Exp. Jts. Pumping on Pumping Projects)				Type of Contraction Joint	Load Transfer Device	Pumping at Contr. & Constr. Jts. (% of Contr. & Constr. Jts. Pumping on Pumping Projects)					Number of Commercial Axles Per Day on Pumping Projects		
			Exp. Jt.	Contr. Jt.			Class 1	2	3	Total			Class 1	2	3	Total	Under 10,000 lbs	Over 10,000 lbs.	Over 14,000 lbs.	Over 18,000 lbs.
8	4	1928-1933	116'-0"	29'-0"	Poured & Pre-molded Bituminous	None (1)	4.4	0.9	0.5	5.8	Dummy Groove & Ribbon	None	2.0	0	0.6	2.6	858	266	60	6
16	8	1932-1934	121'-0"	40'-4"	Poured & Pre-molded Bituminous	None	4.6	4.8	2.2	11.6	Dummy Groove & Ribbon	8¾"x2'-6"	4.7	0.8	0.4	5.9	723	212	61	6
3	3	1940-1941	100'-4" 100'-8"	50'-2" 50'-4"	Limited Extrusion Fiber	A 1	11.7	0	0	11.7	Straight Plate Full Depth	(1-P-1 (2-P-2	11.9	0	0	11.9	(a)1151	303	79	5
15	10	1935-1937	100'-4"	None	Air Core & Lim. Extr. Rubber	A & A 1	18.2	16.6	3.3	38.1	None (Constr. Jts. Only)	None	7.3	4.8	1.5	13.6 (2)	(b) 711	261	72	9
7	5	1940-1942	100'-8"	50'-4"	Lim. Extr. Fibre	A 2	3.0	0.5	0	3.5	6 Projects Straight Plate Full Depth, 1 Dummy Groove	P-2	5.5	8.8	0.1	14.4 (3)	876	490	124	15
2	0	1940	100'-4" 100'-8"	50'-2" 50'-4"	Lim. Extr. Fiber	D 1	No Pumping				Straight Plate Full Depth	P-2 D-1	No Pumping					No Pumping		
10	9	1936-1939	100'-4"	None	Lim. Extr. Rubber	D 1	8.1	1.3	0.1	9.5	None (Constr Jts. Only)	None	12.6	4.4	0	17.0 (4)	1045	399	115	16

(1) One of 4 projects had 10-¾"x2'-6" round dowels

(2) & (4) No contraction joints. Pumping shown is at construction joints.

(3) Pumping at dummy groove contraction joints as well as at straight plate contraction joints.

(a) Based on 2 pumping projects
(b) Based on 9 pumping projects

TABLE 8

COMPARISON OF PUMPING AT EXPANSION JOINTS

HAVING D-1 AND A-1 LOAD TRANSFER DEVICES

Number of Projects Studied	Number of Projects Pumping	Age Group (Year Built)	Exp. Jt. Load Transfer Device	Pumping at Exp. Jts. (% of Exp. Jts. Pumping on Pumping Projects) Class				Number of Commercial Axles Per Day on Pumping Projects			
				1	2	3	Total	Under 10,000 lbs.	Over 10,000 lbs.	Over 14,000 lbs.	Over 18,000 lbs
6	3	1936 - 1937	A-1	20.5	1.2	0.3	22.0	(a) 598	190	44	4
10	9	1936 - 1938	D-1	8.1	1.3	0.1	9.5	1045	399	115	16

(a) Based on 2 pumping projects

TABLE 9

THE EFFECT OF REINFORCING ON PUMPING

No. of Projects Studied	No. of Pumping Projects	Age Group (Yr. Built)	Jointing Arrangement		Reinforcing	Amount of Pumping on Pumping Projects: Per Cent of Pumping Joints and Cracks* Class				Number of Pumping Joints & Cracks* Per Mile Class				Number of Commercial Axles Per Day on Pumping Projects			
			Exp.	Cont.		1	2	3	Total	1	2	3	Total	Under 10,000 lbs.	Over 10,000 lbs.	Over 14,000 lbs.	Over 18,000 lbs.
-37	27	1935-1942	100'4" 100'8") 100'4")	None 50'-4") 50'-2")	56 lb.Mesh	7.5	5.1	0.9	13.5	7.9	5.4	0.9	14.2	768	231	61	6
24	12	1928-1934	116' 121'	29' 40'-4"	Marginal Bars	3.9	1.1	0.6	5.6	9.8	2.8	1.6	14.2	900	360	99	13

* No pumping at cracks on projects with distributed mesh reinforcing.

TABLE 10

RELATION BETWEEN SIZE OF JOINT OPENING AND PUMPING

No. of Projects Studied	No. of Projects Pumping	Jointing Arrangement (Spacing of Joints in ft. & in.)		Av. Joint Opening (In inches for all projects)		PUMPING AT JOINTS (Per cent of totals occurring on pumping projects): Exp. Joints Class				Contr. & Constr. Jts. Class			
		Exp. Jt.	Contr. Jt.	Exp.	Contr.	1	2	3	Total	1	2	3	Total
1	None	353-9	25-3	0.41	Tight	No pumping							
8	4	116-0	29-0	0.64	0.02	4.4	0.9	0.5	5.8	2.0	0	0.6	2.6
16	8	121-0	40-4	0.41	0.20	4.6	4.8	2.2	11.6	4.7	0.8	0.4	5.9
12	8	100-4 100-8	50-2 50-4	0.56	0.24	6.1	0.3	0	6.4	7.7	5.8	0.1	13.6
25	19	100-4	None	0.78	-	14.1	10.3	2.0	26.4	9.3	4.6	0.9	14.8

while the number of pumping joints or cracks per mile was the same on mesh and non-mesh projects, the percentage of pumping was higher on the mesh projects. This difference becomes even higher if the percentages are expressed on the basis of joints alone. This higher percentage appears to be due to greater opening at the joints on the longer original slabs with mesh reinforcing which held all intermediate cracks tightly closed. This is discussed further in the following paragraph "Joint Opening and Pumping".

Size of Joint Opening and Pumping

It has been shown in Table 4 that more pronounced pumping occurs as the constructed slab length is increased. It may be seen from Table 10 that greater original slab lengths and the use of mesh reinforcing increased joint openings. It may also be seen that the amount and severity of pumping increased as the size of joint openings increased. This appears to confirm reasons for pumping increasing; (a) with increased original slab lengths (Table 4) and (b) on long slabs with mesh reinforcing (Table 9).

Relation Between Age of Pavement and Pumping

Each of the four major pavement design groups represented a certain age. Because of the many variables of design that existed between the different groups, the effects, if there were any, of pavement age on pumping could not be determined with the exception that an increase in Class 3 pumping was noted as the pavement age increased (see Table 4). This may be the result of pumping being present on many of the older pavements over a longer period of time, for it is known that the severity of pumping increases as pumping continues.

Relation Between Joint Seal and Pumping

As was mentioned earlier in the report, seals were classified as "Good" if they appeared to be effective in preventing water from entering the subgrade, as "Fair" if their effectiveness appeared doubtful, and as "Poor" or "Missing" if they appeared to be ineffective or were gone completely. Table 10-A shows the results of the study of joint seal condition made during the reconnaissance survey.

Table 10-A

SEAL CONDITION AND PUMPING

	Seal Condition					
	Expansion Joints			Contraction Joints		
Type	Good	Fair	Poor or No Seal	Good	Fair	Poor or No Seal
No. of Pumping Projects	1	7	23	2	2	16
No. of Non-Pumping Projects	8	6	14(1)	1	4	9(2)

(1) At least 7 of these are non-pumping soils
(2) At least 3 of these are non-pumping soils

Reference to Table 10-A shows that the number of pumping projects having poor seals or no seals at expansion joints is almost three times as great as the number having good or fair seals. This ratio increased to four to one at contraction joints. In contrast to this, for non-pumping projects, the number having no seals or poor seals at expansion joints is shown to be about the same as the number having good or fair seals, while the ratio is about two to one at contraction joints. Taking into consideration also the fact that many of the non-pumping projects having poor seals or no seals have subgrades not conducive to pumping, it becomes even more apparent that sealing of joints is an important factor in controlling pumping.

Relation Between Pavement Tightness and Pumping

No statistical data were gathered on pavement tightness, but general observations were made when drilling cores at joints. It was found that several of the older pavements had soil packed tightly enough in the joints to place the slabs in restraint. These pavements had good records in regard to pumping and it appears evident that the pavement restraint and load transference gained through the action of the tightly packed soil, together with the sealing quality of the packed soil itself, were factors in preventing or reducing pumping on these pavements.

Joint Drains and Their Effectiveness

Drains have been used under expansion joints in Kansas at various times, the earliest installations being made in 1934. Three types have been used. They are (1) Precast concrete drains in which the upper portion is cast of porous concrete; (2) Pipe drains consisting of a four or six inch clay tile or perforated corrugated metal pipe covered with either crushed stone or gravel, a layer of sand being in immediate contact with the slab; and (3) French drains consisting of a trench back-filled with crushed stone or gravel. Nearly all installations were placed only under expansion joints. All drains extended through the shoulder and, with few exceptions, under the joint for the full width of the slab.

All three types were encountered in this survey. Four projects were surveyed which had installations of joint drains. They were as follows:

	Project	County	Type of Installation
50-S-32-NRH	30 A&K	Lyon	Porous concrete
50-S-31-NRH	357 F	Chase	Porous concrete
40-84-FAP	301 F (1)	Russell	Corrugated metal pipe with crushed stone backfill
50-S-27-NRH	216 A	Marion	French drains through shoulders only

No pumping was found on Project 301 F (1) in Russell County. The drains on that project were functioning well in that the outlets were relatively clean and there had been no intrusion of subgrade material. This project was built with the 353'-9" expansion joint spacings and the expansion joints had closed from an original opening of 1-3/4" to 0.4" at the time of the survey. Contraction joints were tight. No faulting occurred at the expansion but at a major portion of these joints the abutting slab ends were depressed and cracks had developed in many instances. These probably were caused by consolidation of the trench backfill.

There was evidence that a small amount of pumping (0.2%) had occurred in Project 216 A east of Florence in Marion County. This project has a selected soil subbase throughout all but a small part of its length.

Some severe pumping was found at expansion joints on Projects 30 A & K and 357 F in Lyon and Chase Counties on the heavy alluvial soil in the Cottonwood River flood plain. Two cores were drilled through expansion joints where pumping was encountered. In the construction of the joint drains, a depth of approximately 5 in. of concrete sand was placed over the porous concrete drain. The top 2 to 2-1/2 in. of this sand was found to be saturated with asphaltic materials. It was evident that hot asphaltic materials used in pouring the joints had penetrated the sand, making an impervious mat directly under the joint and making the drain totally ineffective. Outlets on most of the drains were clean and open. Tests made after the sand-asphalt material was removed showed the two drains so tested functioned perfectly. The soils on these two projects are high volume change clays which shrink away from the pavement edges during dry seasons permitting water to reach the subgrade. A major portion of the pumping at expansion joints was at pavement edges.

In summary, the value of the joint drains cannot be determined from these data: On Project 301 F (1) the jointing arrangement (long intervals between expansion joints, 353'-9", and the 25'-3" contraction joint spacing) may be the major factor as indicated by other studies; the selected soil subbase on Project 216 A is essentially a non-pumping soil; and the joint drains on 30 A & K and 357 F had been made totally ineffective. Experience on 301 F (1), depression of abutting slabs at drains under expansion joints, indicates the necessity of close attention to consolidation of the granular material used in drain trenches.

The Subgrade and Its Relation to Pumping

Reconnaissance and detail surveys were made in eight major physiographic regions in Kansas. Two projects investigated on U. S. Route 36 in Doniphan County have subgrades composed of well drained friable silty soils of the Missouri loess region. No pumping was found on these loess soils. Projects on U. S. Routes 24 and 73 in Leavenworth and Wyandotte Counties on glacial till and residual soils covered with selected loam and clay loam soils derived from sandstones showed light pumping. No pumping occurred on selected sandy loam soils derived from identical sources.

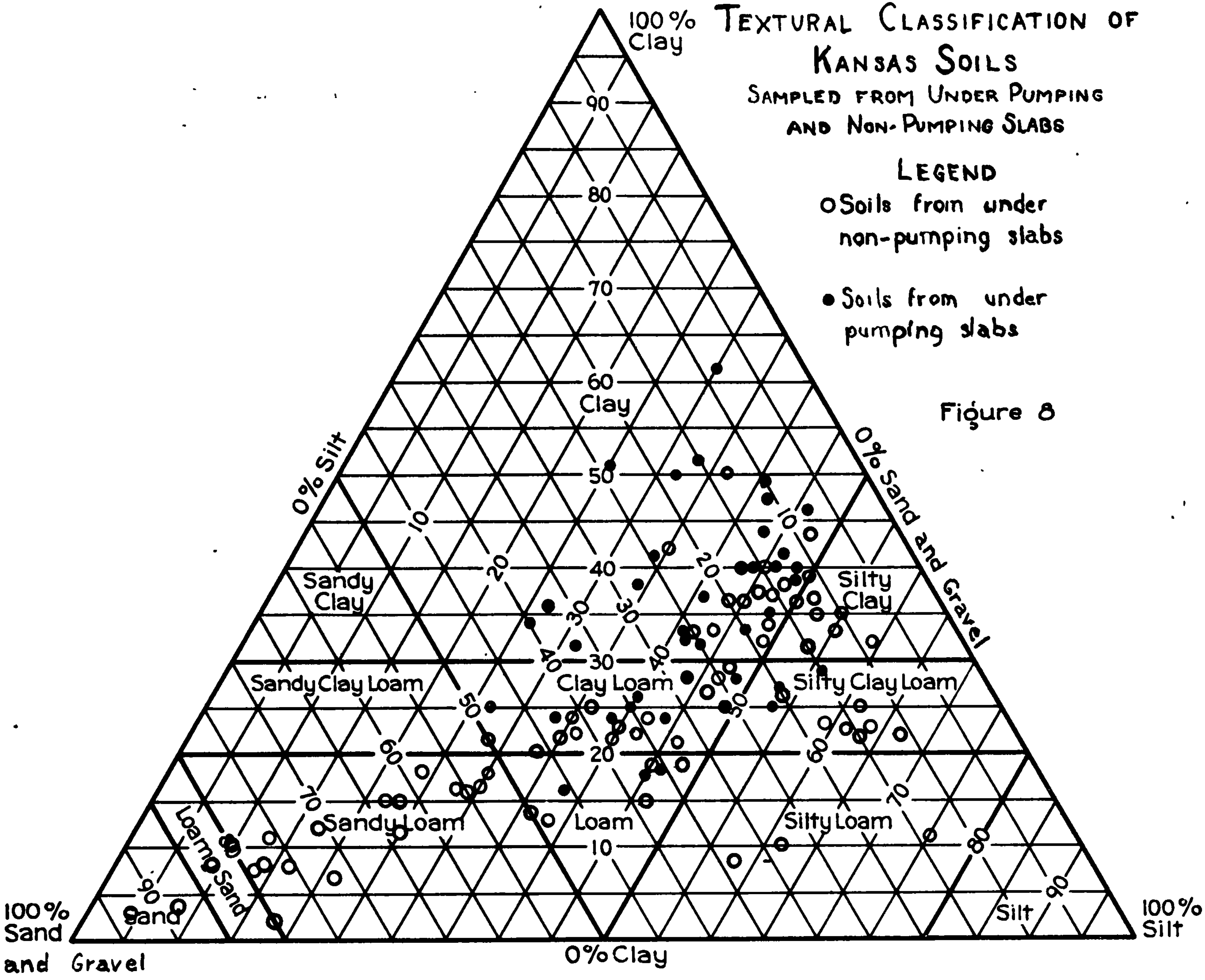
Moderate to extremely heavy pumping was encountered on U. S. Routes 50 and 50-S from Olathe southwest to Elmdale and on U. S. Route 69 from Louisburg south through Bourbon County across the Osage Prairie region and on U. S. 69 in the Cherokee Lowlands. The soils in these regions are derived from limestones and silt and clay shales, except for a minor group derived from a comparatively narrow belt of medium grained sandstones. Pumping on U. S. Route 50-S across the Flint Hills Upland and in the Cottonwood River flood plain was heavy.

Moderate to light pumping occurred between Salina and Wichita in the Smoky Hills Upland, on materials derived from Rocky Mountain outwash and on alluvial and terrace deposits in the Great Bend Prairie. U. S. Route 81 across this area carries heavy industrial trucking emanating from refineries, oil fields and manufacturing sources in the Salina, McPherson and Wichita areas.

Little or no pumping occurred on the more sandy soils of the Red Hills Upland or on the outwash materials west of Wichita and Kingman. Observations made during the reconnaissance survey showed that well drained soil profiles consisting of soils having a large silt fraction and soils having large sand fractions were the best performers and were not found to be associated with pumping.

PRA Soil Groups and Pumping

Pumping was found to occur and not occur on plastic soils of the A-4, A-6 and A-7 PRA soil groups. In no instance was pumping found on soils of the A-1, A-2 and A-3 groups nor on the more sandy soils of the A-4 group having low plasticity indices.



TEXTURAL CLASSIFICATION OF KANSAS SOILS

SAMPLED FROM UNDER PUMPING AND NON-PUMPING SLABS

LEGEND

○ Soils from under non-pumping slabs

● Soils from under pumping slabs

Figure 8

Soil Texture and Its Relation to Pumping

The most significant single relationship between any feature or combination of features of pavement design, subgrade soil type, traffic or other factors which may affect pumping lies in the texture of the subgrade soil immediately below the pavement. Pumping was found to occur and not to occur on soils having less than 50 per cent of material retained on the No. 270 sieve. However, in no instance was pumping found to occur on soils having more than 50 per cent of material retained on the No. 270 sieve in the soils encountered in this survey. The relationship between soil texture and pumping is illustrated in the triangular chart in Figure 8. Soils on which no pumping was found include the sand, loamy sand and sandy loam textural groups.

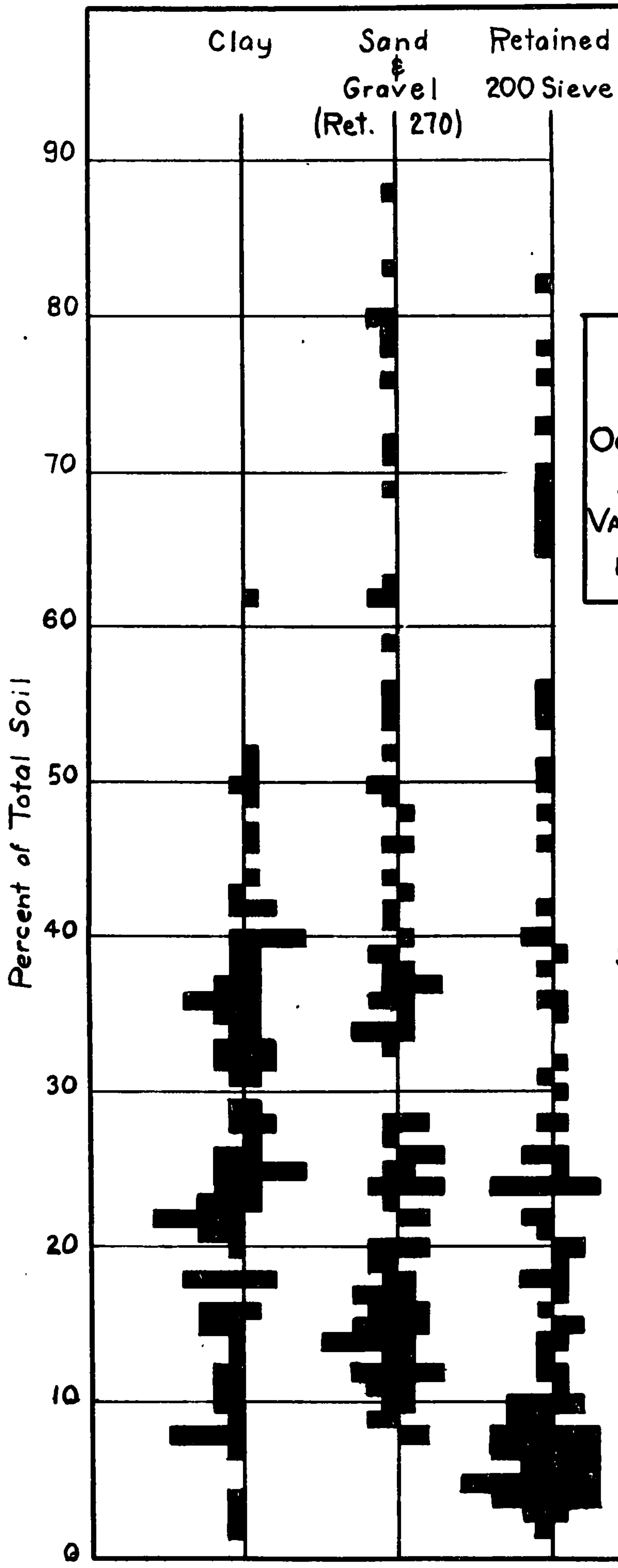
Figure 9 shows the relation between the relative frequency of occurrence of pumping and the per cent of clay (smaller than 0.005 mm. diameter); the per cent sand and gravel (retained on the No. 270 sieve); and the portions of the total soil retained on the No. 200 sieve. These data show the limiting values of clay, sand and gravel and the No. 200 sieve fractions in all soil samples taken from the detail study sections. The fractions shown for sand and gravel, retained on the No. 270 sieve and for material retained on the No. 200 sieve are per cents of the total samples and include all plus No. 10 sieve material. The clay fraction represents the per cent clay in the total sample. A study of Figure 9 shows that pumping was not found in Kansas on soils having one or more of the following textural characteristics:

1. Less than 15 per cent clay.
2. More than 50 per cent sand and gravel (material retained on the No. 270 sieve or having grain diameters larger than 0.05 millimeters).
3. More than 40 per cent retained on the No. 200 sieve.

Soil Water Content and Density and Their Relation to Pumping

Inasmuch as pumping was not encountered on soils having 50 per cent or more sand and gravel, and pumping was found to occur and not to occur on soils having less than 50 per cent sand and gravel, all soils were placed into three groups to aid in further analysis. The three groups are as follows:

1. Soils found under pumping slabs (all had less than 50 per cent send and gravel).
2. Soils having less than 50 per cent sand and gravel, from under non-pumping slabs.



RELATION BETWEEN FREQUENCY OF OCCURRENCE OF PUMPING AND PER CENT OF VARIOUS SOIL FRACTIONS IN THE TOTAL SOIL

— Legend —

Soils indicated to left of line were found under slabs which were not pumping.

Blocks to right of line indicate soils found under pumping slabs.

Figure 9

3. Soils with 50 per cent or more sand and gravel.

Water content determinations made at each sampling of soil showed that where pumping occurred the soil water contents were below the plastic limits at only four locations. One of the four soils was a lean clay of the A-4-7 group having combined sand and silt fractions of 67 per cent. The other three soils were loams of the A-4 group having between 15 and 20 per cent clay. All were light pumpers. The remaining 35 samples from under pumping pavements had water contents in excess of the plastic limit. They had an average water content of 25 per cent compared to an average value of the plastic limit fo 20 for the corresponding soil samples.

The average soil water content, plastic limit and their ratio are shown in Table 11, for the three groups of soils. It will be seen that the values shown are highest for pumping soils, intermediate for potentially pumping soils and lowest for non-pumping soils. This data indicates some relationship between these values and pumping. The data, however, are not sufficient to permit their use in predicting or designing against pumping.

Table 11

Ratio Between Average Field Water Content and Plastic Limit and Its Relation to Pumping

Description of Soil Group	Average Soil Water Content for Group	Average Plastic Limit for Group	Ratio of Water Content to Plastic Limit
Soils found under pumping slabs. All contained less than 50 per cent sand and gravel.	24.8	19.4	1.2833
Soils having less than 50 per cent sand and gravel and found under non-pumping slabs.	22.8	19.2	1.198
Soils containing more than 50 per cent sand and gravel, none of which pumped.	13.6	14.1	0.979

No effort was made during the detail survey to study the moisture gradient in the soil under the slab to determine whether the concentration of soil water was greatest in the soil immediately below the slab or at some depth below the pavement. All determinations of water content were made for the full depth of the sample taken for determination of field density and physical characteristics. The samples were taken to represent the subgrade from 0 to 8" below the pavement except where subbases were used, in which instances separate samples were taken of the subbase and the natural subgrade soil.

Pumping occurred on soils having relatively low compacted densities, low standard densities and low relative compaction. Soils having (in the average) high densities showed less or no pumping.

The average field density, average standard density and the relative compaction for the three soil groups are given in Table 12. These data indicate some relation between compacted density and pumping. The data obtained, however, are not significant enough to make any predictions as to minimum densities and corresponding water contents for various soil types that would prevent pumping.

Table 12

Description of Soil Group	Average Field Density for Group (p.c.f.)	Average St'd. Density for Group (p.c.f.)	Relative Compaction (% of St'd.)
Soils found under pumping slabs (all had less than 50% sand and gravel)	98.9	104.3	94.8
Soils having less than 50% sand and gravel from under non-pumping slabs	99.8	106.8	93.5
Soils having 50% or more sand and gravel	115.5	117.6	98.3

Subbases and Their Effectiveness in Preventing Pumping

Subbases were first constructed in Kansas in 1933. They were then built to control differential volume change of highly expansive clay soils to maintain smooth riding surfaces. The more recently constructed subbases were built to serve the combined purposes of controlling soil shrinkage and swell, providing increased subgrade support and preventing the occurrence of pumping.

The reconnaissance survey indicated that only 1½ per cent of all joints and cracks in pavements constructed on subbases were pumping. This investigation included approximately 38 miles of pavement placed on subbase. It should be noted here that this survey did not include all pavements on subbase now in service in Kansas.

The pumping which did occur was largely of a light nature, there being only a small amount of moderate pumping and no severe pumping. Even where light to moderate pumping did occur, the subbases can be said to have reduced pumping because they were used on heavy clay subgrades which are known to be associated with severe pumping.

Pumping of pavements built on subbase occurred only on such subbases having less than 50 per cent of sand and gravel in the total material. This is shown in textural classification chart of Figure 10. Figure 10A shows typical grain size distributions of soils used successfully in subbases. Sample No. 19 is from a subbase of crushed stone screenings.

Subbases ranged from 4 in. to 18 in. in design thickness. Widths were from 22 ft. (for 20-ft. pavement) to full roadway width. The major portion was built two feet wider than the pavement.

No relation was found between thickness of subbase and pumping. At one location (Sample 21, FA Project 352 F Franklin County, U.S. Route 50-S) where the subbase consisted of moderately open textured limestone screenings 2½ in. in thickness (plan thickness 4 in.), the underlying clay soil subgrade had become muddy at the interface with the subbase and mud had intruded into the screenings. No pumping was found at the time of sampling and there was no evidence that pumping had occurred. However, the fact that intrusion had taken place indicates that pumping may take place under continued wet weather and heavy traffic.

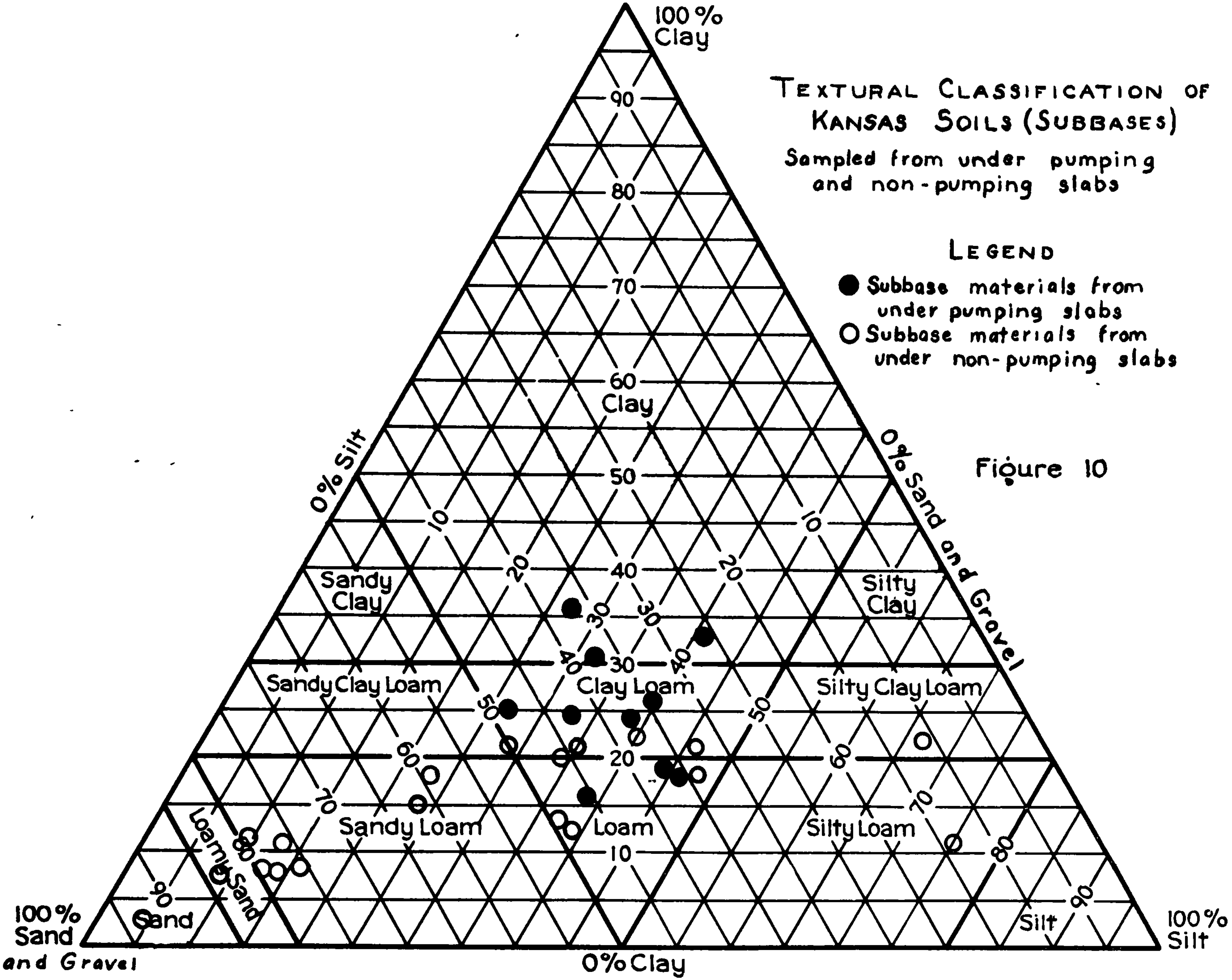
Neither was pumping found on subbase thicknesses ranging from 4 in. up to 18 in. where the subbase material had 50 per cent or more material coarser than the No. 270 sieve (0.05 mm. diameter). Pumping occurred irrespective of thickness on subbases having less than 50 per cent of material coarser than the No. 270 sieve.

Faulting, Pumping and Load Transference

Table 13 shows the percentage of faulted expansion and contraction joints for the various types of load transfer devices of the four major pavement design groups as determined from the reconnaissance survey.

An inspection of the data will show that no general comparison can be made between the amounts of faulting on pumping and on non-pumping pavements. The data do show, however, considerably less faulting occurred at expansion joints of pavements with load transfer devices than at expansion joints without these devices. Also, that the D1 (dowel) has, on the average, a better record than the other load transfer devices in reducing the amount of faulting. One project with A-2 load transfer devices showing a large amount of faulting was too short (0.1 mile) for comparative purposes.

The amount of faulting at contraction joints is seen to be far greater on the projects constructed during and after 1940. Very little faulting developed on pavements constructed during the years from 1928



TEXTURAL CLASSIFICATION OF KANSAS SOILS (SUBBASES)

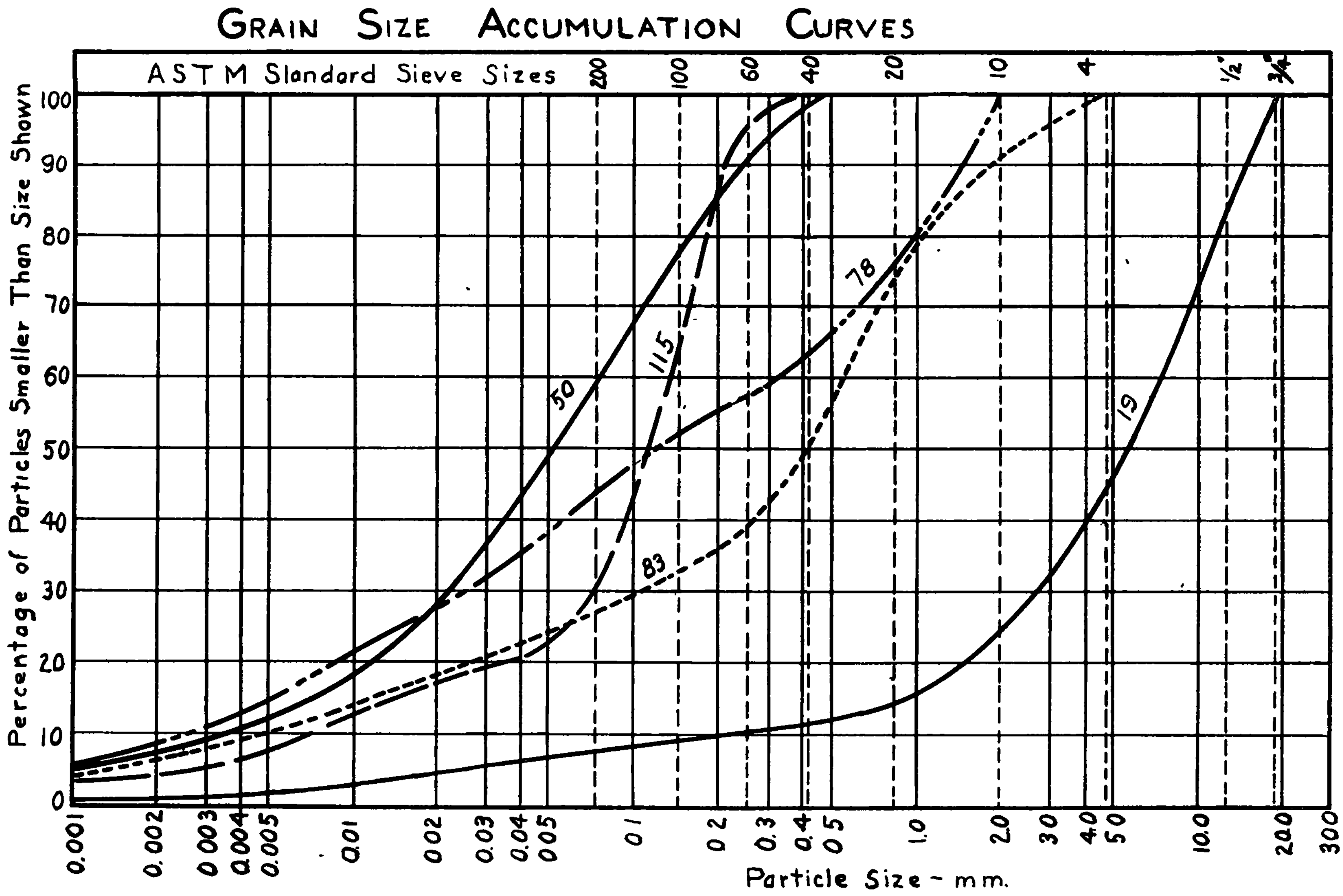
Sampled from under pumping and non-pumping slabs

LEGEND

● Subbase materials from under pumping slabs

○ Subbase materials from under non-pumping slabs

Figure 10



TOTAL CLAY - less than 0.005	SILT	SAND		GRAVEL	
COLLOIDS - less than 0.001	0.005 - 0.05	FINE 0.05 - 0.25	COARSE 0.25 - 2.0	FINE 0.25-4	COARSE 4.76+

GRAIN SIZE CURVES INDICATING RANGE OF GRADINGS OF NON-PUMPING SUBBASE MATERIALS Figure 10A

TABLE 13
Amount of Faulting
(From Reconnaissance Survey)

Number of Projects							Percentage of Faults			
			Jointing Arrangement		Load Transfer		Exp. Joints		Cont. Joints	
Pump-ing	Non-Pump.	Age Group (Yr. Built)	Exp.	Cont.	Exp.	Cont.	Pumping Projects	Non-P. Projects	Pumping Projects	Non-P. Projects
7	1	1935-1939	100'-4"	None	A	-	15.7	3.1	-	-
3	2				A1	-	5.2	8.4	-	-
9	1				D1	-	6.8	0	-	-
19	4				A,A1,D1	-	9.9	4.9	-	-
4	3	1928-1933	116'	29'	None	None	17.5	25.5	1.1	1.9
8	8	1932-1934	121'	40'-4"	None	8 dowels $\frac{3}{4}$"x2'-6"	24.4	20.1	1.0	1.0
3	0	1940-1942	100'-8" 100'-4"	50'-4" 50'-2"	A1	P-2 (2)* P1 (1)	0	-	0.8	-
5	1				A-2	P-2	3.0	25.0	29.1	16.7
	1				D1	D1	-	0	-	22.1
8	2				A1,A-2,D1	P1,P-2,D1	1.9	0.9	19.0	19.2

* Numbers in parentheses refer to number of projects investigated.

TABLE 14
Depth of Faulting
(From Detail Survey)

					Average Fault (in.)			
	Jointing Arrangement		Load Transfer		Exp. Joints		Cont. Joints	
Age Group (Yr. Built)	Exp.	Cont.	Exp.	Cont.	Pumping Projects	Non-P. Projects	Pumping Projects	Non-P. Projects
1935-1939	100'-4"	None	A,A1	-	.24	.18	-	-
			D1	-	.09	.11	-	-
	Group		A,A1,D1		.22	.17	-	-
1928-1933	116'	29'	None	None	-	.23	-	.09
1932-1934	121'	40'-4"	None	8 dowels $\frac{3}{4}$"x2'-6"	.25	.22	.18	.08
1940-1942	100'8" 100'4"	50'-4" 50'-2"	A1,A-2	P1,P-2,D1	.06	.10	.13	.10

to 1934 with dummy groove and weakened plane contraction joints either with or without load transfer devices. The greater amount of faulting on the newer pavements appears to be due to certain design features common to them alone. The newer pavements had full depth metal plates separating adjacent slabs and complete dependency was placed on devices for load transfer and the prevention of faulting. It is apparent that the added load transference through aggregate interlock at the dummy groove type joints was of value in preventing faulting.

Table 14 shows a summary of faulting measurements made on the detail study sections. Reference to the table shows that for the four major design groups the average depth of faults is slightly greater at pumping joints than at non-pumping joints and is, in general, somewhat greater at expansion joints than at contraction joints. A further study of the table shows that the depth of faulting, as well as the amount, is generally less for expansion joints having load transfer devices. The exception to this is the group having the A and A-1 devices and which undoubtedly shows the influence of the A (air core) filler, a definitely inferior filler as has been discussed previously. No great difference is seen in the depth of faulting at contraction joints.

For the locations at which soil samples were taken the average depth of fault was found to be slightlygreater at joints at which pumping was taking place, as compared to joints on potentially pumping soils but at which no pumping was taking place and as compared to joints on non-pumping soils. The smallest average depth of fault was found at joints under which there were non-pumping soils.

Study of Pavement Deflections and Pumping

Data obtained in pavement deflection studies showed that under both moving and static loads, vertical movements of the slab ends at both expansion and contraction joints were greater at pumping joints than at non-pumping joints. Slightly greater total deflections were observed under static loads than under loads moving at speeds up to 20 m.p.h. The difference is not great enough, however, to permit the development of trends in the relationships between deflection and pumping, deflection and subgrade soil type; or in the tendency toward differential deflections with the various load transfer devices, as affected by static and moving loads. For this reason, the deflection values for static loadings have been used in analyzing the data.

The same grouping of soils -- soils on which pumping was found; soils having less than 50 per cent of sand and gravel but taken from under non-pumping slabs; and soils having more than 50 per cent of sand and gravel on which no pumping was found during the survey -- are used in analyzing the deflection data.

There are summarized in Table 15 the range and average maximum measured deflections at each of the four slab corners for the joints at which deflections were measured. Maximum deflections occurred under

TABLE 15

SUMMARY OF MAXIMUM DEFLECTIONS
(in thousandths of an inch)

Dial Position	Static Wheel Position	Expansion Joints						Contraction Joints					
		Pumping Joints		Potential Pumping Soil		Non-Pumping Soils and Joints		Pumping Joints		Potential Pumping Soil		Non-Pumping Soils and Joints	
		Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range
1	A	30 (14)	9-66	14 (18)	5-28	8 (3)	3-16	21 (15)	7-54	11 (10)	4-21	9 (10)	2-17
2	C	38 (14)	11-78	15 (18)	6-30	8 (3)	3-16	27 (15)	9-72	12 (10)	3-26	10 (10)	2-18
4	A	20 (13)	5-36	7 (18)	4-13	3 (3)	1-8	15 (15)	4-33	6 (10)	2-13	5 (10)	1-15
3	C	24 (13)	7-45	10 (18)	4-24	4 (3)	1-9	18 (15)	4-50	6 (10)	2-13	5 (10)	1-15

Numbers in parentheses refer to number of joints involved.

TABLE 16

SUMMARY OF MAXIMUM EDGE DEFLECTIONS ON LIP CURB AND PLAIN SECTIONS
(in thousandths of an inch)

	Dial Position	Wheel Position	Expansion Joints						Contraction Joints					
			Pumping Joints		Potential Pumping Soils		Non-Pumping Soils and Joints		Pumping Joints		Potential Pumping Soils		Non-Pumping Soils and Joints	
			Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range
Lip Curb	1	A	15 (5)	9-21	17 (9)	8-28	4 (2)	3-4	16 (3)	10-26	9 (6)	4-18	12 (1)	12
Plain	1	A	37 (9)	20-66	13 (11)	5-26	16 (1)	16	22 (12)	7-54	14 (4)	8-21	9 (9)	2-17
Lip Curb	2	C	17 (5)	11-21	19 (9)	9-39	4 (2)	3-4	18 (3)	13-27	10 (6)	3-26	13 (1)	13
Plain	2	C	49 (9)	26-78	15 (11)	6-26	16(1)	16	29 (12)	9-72	15 (4)	8-22	9 (9)	2-18

Numbers in parentheses refer to number of joints involved.

the loaded slab in every instance, i.e., maximum deflections were observed on dials 1 and 4 when the wheels were in position A, and on dials 2 and 3 when the wheels were in position C. See Figure 7 for positions of dials and wheels during the load deflection studies. Reference to the table will show that the average maximum deflection at each dial is at least twice as great for pumping slabs as it is for non-pumping slabs. It will also be seen that the far side of the slab in the direction of traffic deflects as much as or more than the near side (comparing deflections at dial positions 1 and 2; 4 and 3), and that the edge deflections are greater than the center deflections (comparing deflections at dial positions 1 and 4; 2 and 3).

Pavement Deflections and Lip Curb

Lip curb was found to reduce edge deflections considerably in most instances. This is shown by the general comparisons in Table 16.

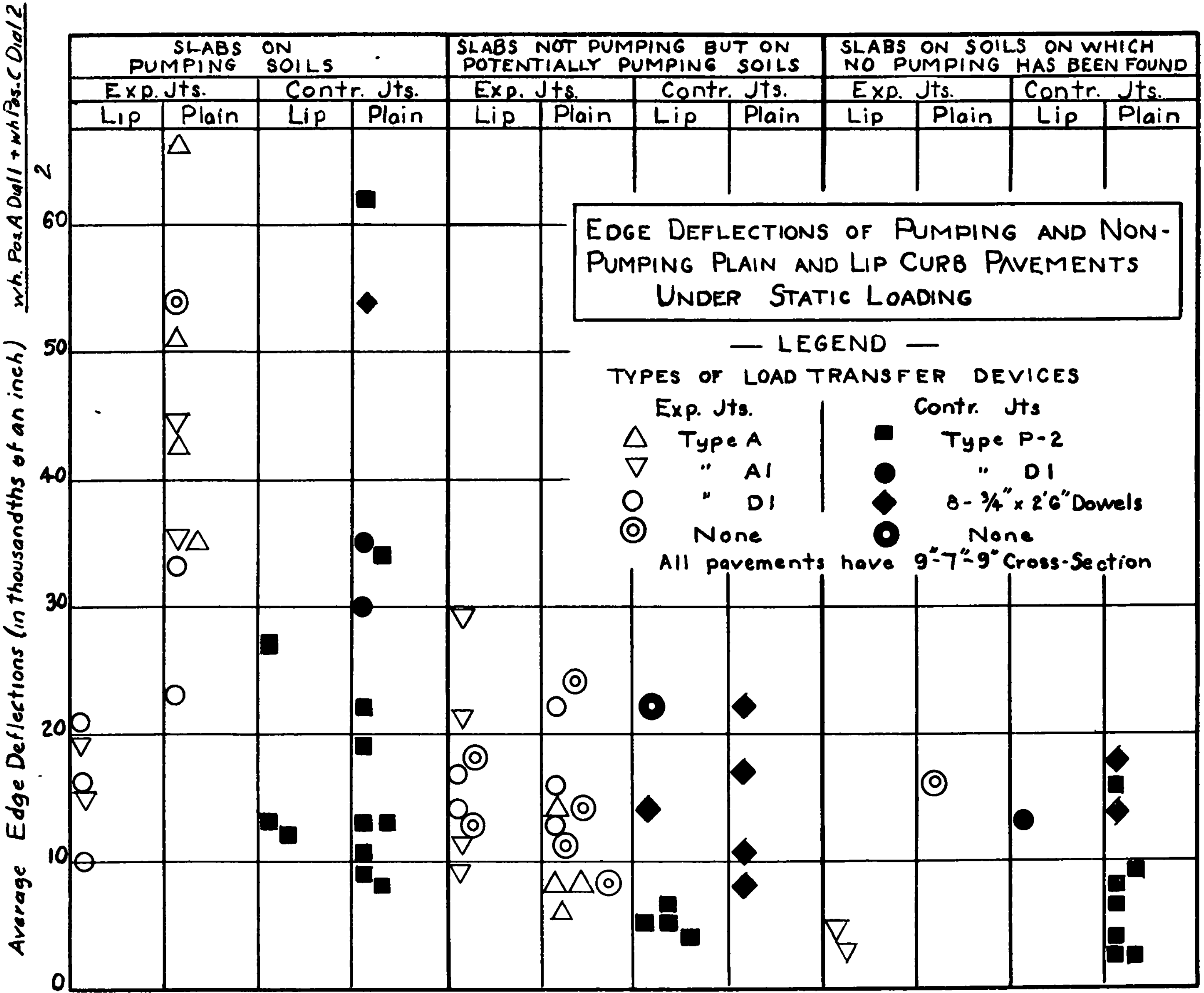
In Figure 11 are shown graphically the average maximum deflections at exterior corners for pavements with and without lip curb built on the three major soil groups and with various load transfer devices. Reference to Figure 11 shows that the vertical movements of slab ends at the exterior corners of expansion joints for pavements built on pumping soils are much greater on cross-sections without lip curb than they are on cross-sections having lip curb. This is true regardless of the type of load transfer device used.

Further reference to Figure 11 shows that the effect of lip curb on edge deflections is also apparent but not as pronounced at contraction joints of pavements placed on pumping soils. However, it should be noted that these pavements were placed on selected subbase soils containing less than 50 per cent sand and gravel and were for the most part associated with only very light pumping.

Because of the influence of lip curb on edge deflections at pumping joints, further studies to correlate observed deflections on all pavements with pumping and with the effectiveness of load transfer devices in preventing differential movement at joints will be confined to deflections at interior corners. This procedure materially increases the number of projects and mileage of pavement that can be considered in the study.

Deflection measurements were made at expansion joints employing two of the three types of load transfer devices used and also at expansion joints where no load transfer devices were used. Two types were used at contraction joints, with a variation in spacing of the units of one type.

The following brief descriptions of the various types of load transfer devices will aid in interpreting the data obtained in the deflection measurements:



EDGE DEFLECTIONS OF PUMPING AND NON-PUMPING PLAIN AND LIP CURB PAVEMENTS UNDER STATIC LOADING

Figure 11

Types A and A-1 which are similar and which are commonly known as the "Translode" type, consist of pieces of structural angles, each piece approximately 1 ft. long. The vertical leg of the angle is cut and sections bent out to provide embedment in the concrete. The horizontal leg extends under and beyond the joint filler and serves as a support for the slab end opposite to the side to which the vertical angle is anchored. Contiguous units facing in opposite directions are assembled in a metal base of a length equal to the width of the slab. Types A and A-1 were used at expansion joints only.

Type A-2 load transfer device for expansion joints consists of a number of structural angles with 2½ in. legs and 2½ in. long. A bent bar is welded to the top of the vertical leg for embedment in the concrete. The horizontal leg extends under and beyond the filler to give support for the slab end opposite the slab which provides embedment. They are placed in pairs, facing opposite directions, approximately 20 in. apart. A metal base sleeve serves to hold the units in alignment during placement. Type P-2 represents the same units when used at contraction joints. A 20 gauge full depth vertical plate separates the concrete when used at contraction joints.

Type P-1 device commonly known as the "Crosslode" type was used at contraction joints only. It consists of two strips of 12 gauge metal laid flatwise to form the "Crossload " members and each welded to 19 gauge strips of metal placed vertically to provide full depth separation of the concrete. The combined unit is provided with a shoe which holds the assembly in place on the subgrade.

Type D-1 consists of 7/8" x 24" smooth round dowels placed at 12" centers at expansion joints and of 3/4" by 12" smooth round dowels placed at 14 inch centers at contraction joints. 8-3/4" x 2'-6" round smooth dowels were used at contraction joints in one design having expansion joints spaced at 121 ft. and contraction joints spaced at 40'-4" intervals. No load transfer devices were used at the expansion joints in this design.

Deflections, Load Transfer and Pumping

The average difference in center deflections which indicates the differential movements of slab ends for pavements placed on different classes of subgrade soil and using different types of load transfer devices are shown in Figure 12. It will be noted that in most instances slabs on pumping soils showed the greatest differential

RELATIONSHIP BETWEEN DIFFERENCE IN MAXIMUM MOVEMENT OF SLAB ENDS AT INTERIOR CORNERS AND PUMPING FOR VARIOUS LOAD TRANSFER DEVICES UNDER STATIC LOADING

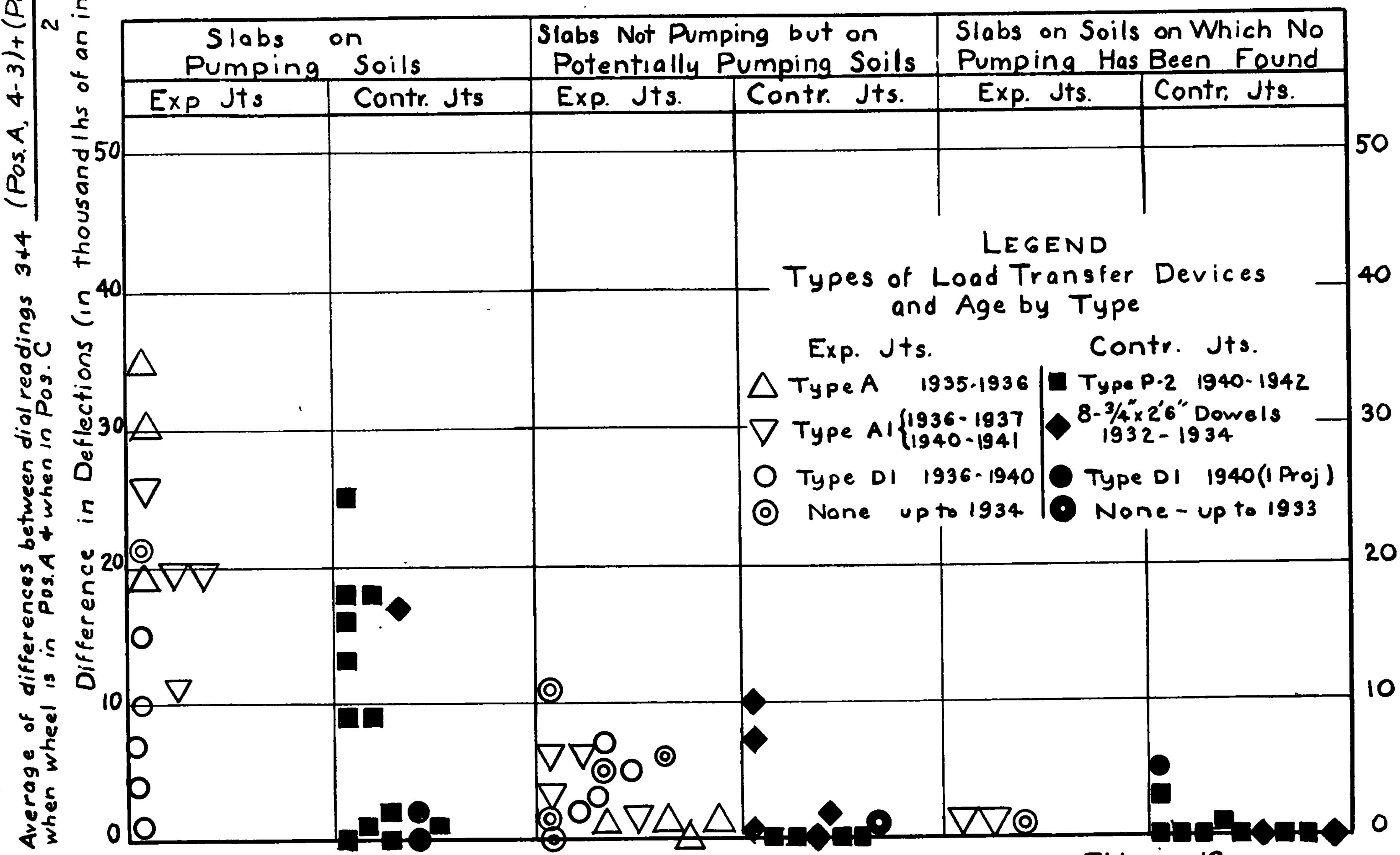


Figure 12

movements. It will also be seen that at pumping expansion joints differential movements were greatest where A and A-1 load transfer devices were used and least where the D-1 (dowel) was used. Differential deflections are also shown to be low at pumping contraction joints employing dowels, but these joints, together with a group of five projects with P-2 devices showing about the same differential deflection, were placed on subbases and were associated only with very light pumping. Non-pumping projects built on soils having less than 50 per cent sand and gravel but considered to be potentially pumping soils, showed relatively small differential movements at slab ends for all types of load transfer devices. Pavements on non-pumping soils had low deflections and showed practically no differential movements.

Figure 13 shows both the differential movements and the total deflections at interior corners for the various types of load transfer devices and the three groups of subgrade soils. Perfect load transfer expressed in terms of absence of any differential movement occurred largely under non-pumping conditions. However four pumping joints showed no differential movement and small total deflection. All of these four were on subbases and associated with only light pumping.

Traffic as Related to Pumping

Studies of pumping made to date indicate that traffic, as well as the type of soil and presence of free water on the subgrade, is definitely related to pumping. These studies show that pumping occurs on pavements having relatively heavy truck traffic, but to date insufficient detailed data have been available for all variables concerned to definitely establish the volume and weight of critical axle loads.

As previously stated, the latest comprehensive loadometer survey in Kansas was made in 1936 and the most recent state-wide traffic count was made in 1941. For the pumping studies, 1941 axle loads were estimated on the basis of the 1936 loadometer survey. These data were considered sufficiently accurate to use as a control in comparing other variables in the pumping studies but, since complete traffic data were not available at the date of the survey or at any previous date for which there were accurate data on pumping, a definite relationship between pumping and traffic cannot be established for the state as a whole.

The data in Table 17 show the general relation that existed between the estimated commercial traffic on the projects surveyed for which traffic data are available.

Table 17

TRAFFIC AND PUMPING

	No. of Proj.	Average No. of Commercial Axles Per Day			
		Under 10,000 lb.	Over 10,000 lb.	Over 14,000 lb.	Over 18,000 lb.
Pumping Projects	(42)	860	298	82	10
Non-Pumping Proj.	(23)	814	209	48	6

Reference to Table 17 shows that the average total commercial traffic on projects on which pumping has developed is of no significant difference from the average total commercial traffic on projects on which pumping was not found. There is a marked difference in the average number of commercial axles over 14,000 lb., being 71 per cent greater on the pumping projects than on the non-pumping projects. Similarly, the commercial axle loads per day over 18,000 lb. were 67 per cent greater on the pumping projects. The number of axle loads over 10,000 lb. was only 43 per cent greater on the pumping projects than on the non-pumping projects and the total traffic was only 13 per cent greater. These data would seem to indicate that a relatively small amount of the heavier axle loads may have been the cause for pumping on some projects. Also, there is some indication that the critical axle loads may be on the order of 14,000 lb.

A more recent loadometer study, made on U.S. Route 81 south of Salina, when compared with the pumping found on three projects whose traffic is indicated by this loadometer study, gives somewhat more direct information on the influence of axle loads on pumping. It is possible from this traffic study to separate commercial axle loads of several weight groups traveling in each direction. These data are shown in Table 18.

Table 18

COMMERCIAL AXLE LOADS PER DAY

Direction of Traffic	Number of Commercial Axles Per Day			
	Under 10,000 lb.	Over 10,000 lb.	Over 14,000 lb.	Over 18,000 lb.
Northbound	349	275	155	10
Southbound	506	38	17	3

Loadometer study made in 1943.

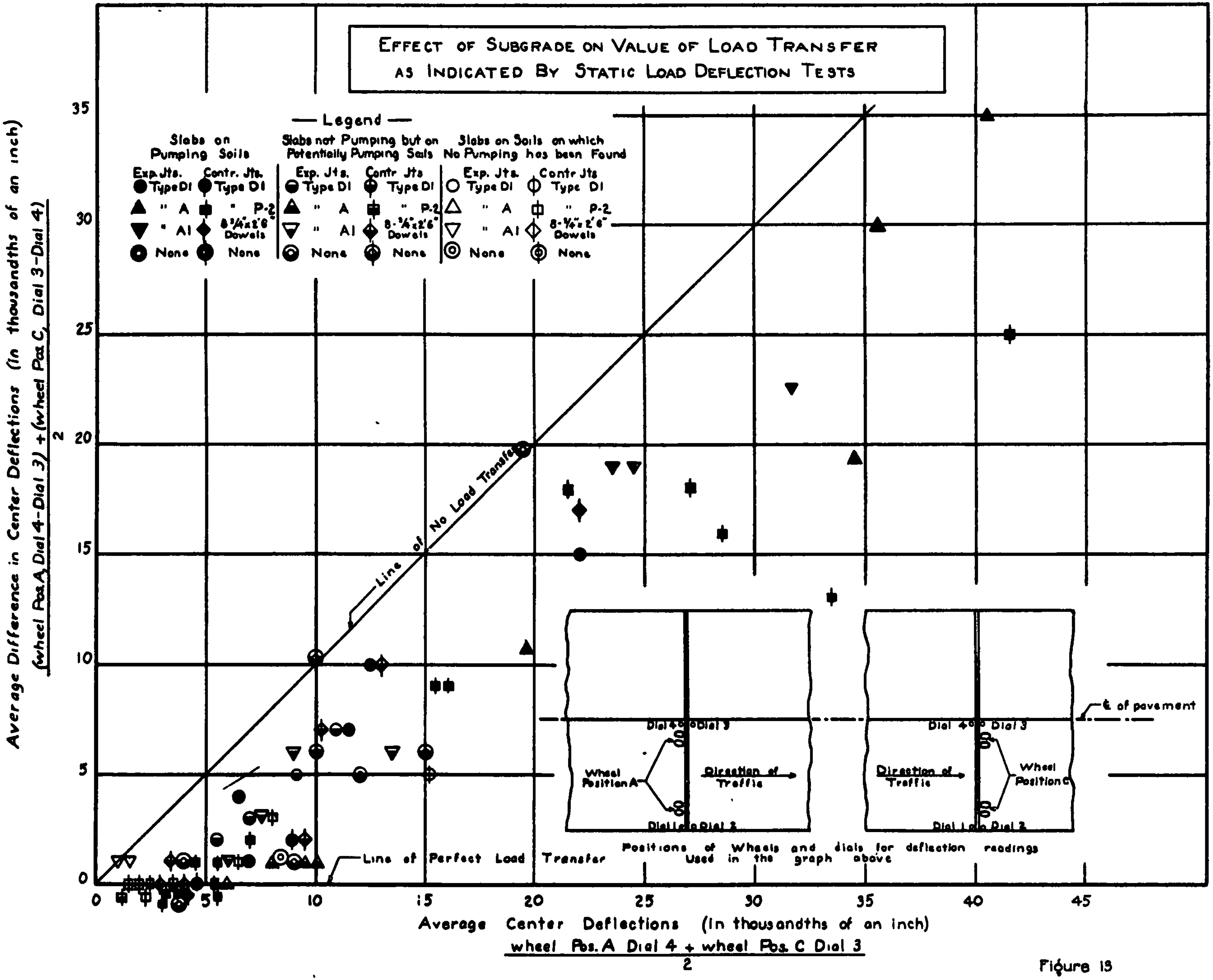

EFFECT OF SUBGRADE ON VALUE OF LOAD TRANSFER
AS INDICATED BY STATIC LOAD DEFLECTION TESTS
— Legend —
Slabs on Pumping Soils
Exp. Jts.
Type DI
" A
" AI
None
Contr. Jts.
Type DI
" P-2
8-3/4"x2'6" Dowels
None
Slabs not Pumping but on Potentially Pumping Soils
Exp. Jts.
Type DI
" A
" AI
None
Contr. Jts
Type DI
" P-2
8-3/4"x2'6" Dowels
None
Slabs on Soils on which No Pumping has been Found
Exp. Jts.
Type DI
" A
" AI
None
Contr. Jts
Type DI
" P-2
8-3/4"x2'6" Dowels
None
Line of No Load Transfer
Line of Perfect Load Transfer
Average Difference in Center Deflections (in thousandths of an inch)
(wheel Pos. A Dial 4 - Dial 3) + (wheel Pos. C Dial 3 - Dial 4) / 2
Average Center Deflections (in thousandths of an inch)
wheel Pos. A Dial 4 + wheel Pos. C Dial 3 / 2
0
5
10
15
20
25
30
35
40
45
Dial 4
Dial 3
Dial 1
Dial 2
Wheel Position A
Wheel Position C
Direction of Traffic
℄ of pavement
Positions of Wheels and dials for deflection readings Used in the graph above

Figure 13

The data collected on the reconnaissance pumping survey showed that 4.3 per cent of the joints and cracks on these three projects were pumping; also that practically all of the pumping was in the northbound lanes. The detailed survey of selected sections on these projects confirms the above data. Faulting was also found to be twice as pronounced in the more heavily traveled northbound lane. Reference to Table 18 will show there is not a great deal of difference in the total number of all commercial axles on the northbound or southbound lanes, but that there is an outstanding difference in the number of axle loads of over 10,000, 14,000 and 18,000 lb. These respectively are about 7, 9 and 3 times greater on the northbound than on the southbound lanes. These data are considered to be significant in showing the relationship between traffic loads and pumping as the subgrade soil and subgrade conditions in each of the lanes could vary but little.

Climate as Related to Pumping. According to the Atlas of American Agriculture and rainfall records kept over a 20-year period from between 1895 and 1914, the average precipitation in Kansas ranges from 20 in. per year in extreme western Kansas to about 30 in. in the vicinity of Wichita and to 40 in. per year in the southeast corner of the state. Between 60 and 80 per cent of this rainfall occurs during the months from April to September, inclusive.

Very little pumping was found or is known to exist to the west of Wichita or that part of the state to the west of U.S. 81 running north and south through about the east central part of the state. This would indicate that difference in the annual precipitation may have some influence on the pumping of projects included in the survey but is not considered to be a major variable (such as soil and traffic) at the time the survey was made. It should be remembered that traffic and soils play an important part in accounting for a lack of pumping in the western part of the state. Pumping has been reported to be more severe during the late spring and early summer months at which time the rainfall is usually heaviest.

SUMMARY AND CONCLUSIONS

The following paragraphs give the conclusions reached during the study of the survey data, together with the principal facts leading to the findings.

Subgrades. No pumping took place on soils containing more than 50 per cent sand and gravel (material retained on the No. 270 sieve) regardless of any of the other variables.

Pumping was and was not found on soils of the A-4, A-6 and A-7 PRA groups. No pumping was found associated with A-1, A-2 and A-3 soils, and with soils of the A-4 group having low plasticity indices.

Pumping may best be prevented through a control of the soil supporting the pavement slab. The texture (grain size) of a soil is the best measurement of its ability to resist pumping.

Subbases. Subbases varied in width from shoulder-to-shoulder construction to one foot wider on each side of the slab. They ranged from 4 in. to 18 in. in depth.

Regardless of width or depth, subbases having more than 50 per cent sand and gravel were effective in preventing pumping.

Slab Lengths. With about the same expansion joint spacing (100 ft., 4 in. to 121 ft.), pavements with shorter slab lengths pumped less than those with longer slabs. Pavements with original slab lengths of 29 ft. pumped less than those of 40 ft. 4 in., while pavements with original slabs 50 ft. 2 in. and 50 ft. 4 in. pumped less than slabs 100 ft. 4 in. long.

Construction of relatively short slabs through the use of intermediate contraction joints between expansion joints at relatively long intervals is of aid in the reduction of pumping.

Greater joint opening caused by longer constructed slab lengths or by distributed reinforcing which held intermediate cracks tightly together, thus causing longer slabs to act as units, resulted in increased pumping at these joints.

Distributed reinforcing which held intermediate cracks tightly together prevented pumping at such cracks.

Expansion Joints. The performance of older pavements having expansion joints packed tightly enough with soil to cause slab restraint indicates the desirability of reducing expansion provisions or spacing expansion joints at long intervals.

Of the various load transfer devices used, none were found which prevent pumping. Dowels show a better service record than other types.

Faulting of joints on the average was greater at pumping joints than at non-pumping joints. Some load transfer devices reduced its amount and severity.

No expansion joint filler was found to play a major role in reducing or preventing pumping. The air core type was shown to be definitely inferior to the other types.

Poorly sealed joints in pavements placed on pumping soils pumped more than did well sealed joints.

The value of joint drains in reducing or preventing pumping cannot be determined definitely from their service record because of the major influence of other variables included in the pavements surveyed.

In summary, joint spacing, types, fillers and load transfer devices influence pumping but may not in themselves prevent pumping when the pavement is placed on potentially pumping soils. Good joint seals prevent or reduce pumping. Some load transfer devices reduced the amount and severity of pumping.

Contraction Joints. No type of contraction joint was found to appreciably influence pumping. Faulting was greater at contraction joints with full depth metal plate joints than at dummy groove joints. It is apparent that the added load transference through aggregate interlock at the dummy joint was of value in minimizing faulting.

Pavement Cross-Section. The variation in thickness and width of the pavements surveyed was not sufficient to obtain significant comparisons of pumping.

No significant difference was found in the amount of pumping on comparable pavements built with or without lip curb, the amount being somewhat greater but of less severity on pavement with lip curb. Edge pumping did not occur and edge deflections were less on pavements with lip curb but such sections of pavement were all on grades which afforded better surface drainage than parts of the same projects without lip curb.

Load Deflection Studies. Measurement of slab end deflections at joints, under moving and static loadings, showed greater vertical movement on pumping pavements than on non-pumping pavements, and that all factors permitting increased vertical movements of slab ends contribute to an increase in pumping.

Differential movements were small at joints on potentially pumping soils and rarely measurable at joints on non-pumping soils. Differential movements were, on the average, less at contraction joints than at expansion joints.

The deflection measurements were of particular value in showing the relative efficiency of the various load transfer devices in reducing the differential slab movements found to be generally associated with pumping.

Traffic. Truck traffic at selected locations, to give results fairly indicative for Kansas, had increased considerably in 1944 over 1936. The percentage of axles weighing over 14,000 lb. increased about three times in the years between 1936 and 1944, while axle weights of

18,000 lb. or more increased about fivefold in the same period. These increases in the heavier axle loads undoubtedly are the cause for the more widespread pumping since 1935, at which time it was limited to two miles of pavements.

Traffic data were not available in sufficient detail to definitely determine the weight and volume of critical axle loads. In general, total commercial traffic was about the same on pumping and non-pumping pavements but the number of axle loads of over 10,000, 14,000 and 18,000 lb. was substantially greater on the pumping projects.

Recent and detailed commercial traffic data on U.S. 81 south of Salina, Kansas, show a significant influence of the weight and volume of axle loads on the pumping which has developed on the north and southbound traffic lanes on three projects. Faulting was twice as pronounced and pumping was practically confined to the joints on the northbound lanes where axle loads of over 10,000, 14,000 and 18,000 lb. were respectively seven, nine and three times greater than for the southbound lanes.

Irrespective of the weight and volume of commercial traffic, pavements placed on natural subgrade soils or on subbases containing more than 50 per cent sand and gravel (material retained on No. 270 sieve) will not pump.