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A SURVEY OF PUMPING
IN
ILLINOIS

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

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A SURVEY OF PUMPING IN ILLINOIS

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PUMPING OF CONCRETE PAVEMENTS IN ILLINOIS

A Cooperative Study
by
Illinois Division of Highways and Portland Cement Association
With Soil Tests by the Public Roads Administration

SYNOPSIS

During the spring and summer of 1946 approximately 300 miles of the principal highways located in 14 northeastern Illinois counties were the subject of an intensive pavement pumping study to determine the cause and extent of pumping and possible means of preventing its occurrence on future projects.

The area surrounding Chicago was selected for this work because the great concentration of highways and traffic therein permitted the study of an appreciable mileage of various major design groups built on a wide, though not complexing, variety of subgrade soils and subjected to varying conditions of traffic.

The study involved the collection of design and construction data for 78 projects, a reconnaissance survey of the various projects, detailed studies of representative portions of each project, the sampling and testing of subgrade soils, in-place density measurements of subgrades and subbases, traffic surveys, and the analysis of data and observations.

The analysis confirmed the fact that free water must be present, axle loads must be heavy and frequent, and the subgrade soil must be capable of going into suspension, to produce pavement pumping.

Design features such as pavement width and thickness,pavement reinforcement, expansion and contraction joints, joint spacing and fillers, and load transfer devices were found to have, in most cases, some influence on pumping. However, no single feature or group of features were found capable of preventing pumping under all conditions of moisture, traffic and soil.

The texture of the subgrade determined its susceptibility to pumping. Increased compaction generally reduced pumping. Soil containing more than 55 percent sand and gravel (material retained on the No. 270 sieve) was found to prevent pumping. Furthermore, granular subbases will prevent pumping.

Prompt and continued pavement and road maintenance was also found to be effective in controlling and reducing pumping. Repeated subsealing effectively controlled pumping.

INTRODUCTION

Pumping has been described as the forceful ejection of water-suspended subgrade soil from underneath concrete pavements during the passage of heavy axle loads. It occurs exclusively at or near joints and cracks, and may be recognized from soil stains on the pavement or slurries of soil and water at the pavement edges. Three fundamental conditions must be satisfied to produce pumping: (1) free water must be present, (2) axle loads must be heavy and frequent, and (3) the subgrade soil must be capble of going into suspension. Pumping will not occur if any one of these three elements is absent. Continued, uncontrolled pumping leads to fauling and breaking of pavements.

This report gives the results of a cooperative study of pumping made during the spring and summer of 1946 by the State of Illinois, Division of Highways, and the Portland Cement Association. Soil tests were made by the Public Roads Administration.

PUMPING IN ILLINOIS

It has been reported that pavement failures, now known to have resulted from pumping, were first noted in Illinois on U. S. 66 between Pontiac and Odell in 1928. However, it was not until 1930 that the true nature of these failures was recognized. Special methods of maintenance were begun immediately. The following years saw a growth in the extent of pumping, a growth coincident with the rapid rise in the number and weight of commercial vehicles using the highways.

This increase in pumping directed attention towards its prevention on new construction. Accordingly, after the successful usage of granular subbases in the prevention of pumping at a few selected locations constructed during 1935 and 1936, there was constructed in 1937 the first full length section of concrete pavement placed on granular subbase used expressly for the prevention of pumping. This project (Ill. 131-Sec.UR), replacing an older pavement, is today in excellent condition with no signs of pumping. The use of granular subbases has continued since that time, but it was not until 1942 that, given impetus by the effects of the heavy loadings of wartime transport on those pavements placed on fine grained soils, their usage was extended to all projects in fine grained soil areas which were expected to carry concentrations of commercial traffic.

Pumping in Illinois is not confined to any one area of the State but takes place wherever there exists unfavorable combinations of subgrade soil type, free water, and heavy axle loadings. However, it is confined to those sections of the heavier arteries of interstate and intrastate travel which have been placed on fine grained subgrades. A few other pavements on fine grained soils, carrying unusual concentrations of heavy commercial loadings peculiar to the area they serve, are also involved.

Pavements placed on granular soils, pavements carrying only moderately heavy commercial traffic, and those carrying mostly passenger traffic, even though the passenger traffic be of considerable volume, have not developed pumping. Figures 1 and 2 show two pavements of comparable age, design and traffic conditions. The pavement in Figure 1 is placed on a granular subgrade and is today giving excellent service after 16 years of use. The pavement in Figure 2, placed on a fine grained subgrade, showed pumping at most of the joints and cracks.

Since much of the population of Illinois and a large proportion of its industry are centered within the Chicago area, an area replete with fine grained soils, it is to be expected that much of the pumping within the State may be found on the highways leading to and located within this area.

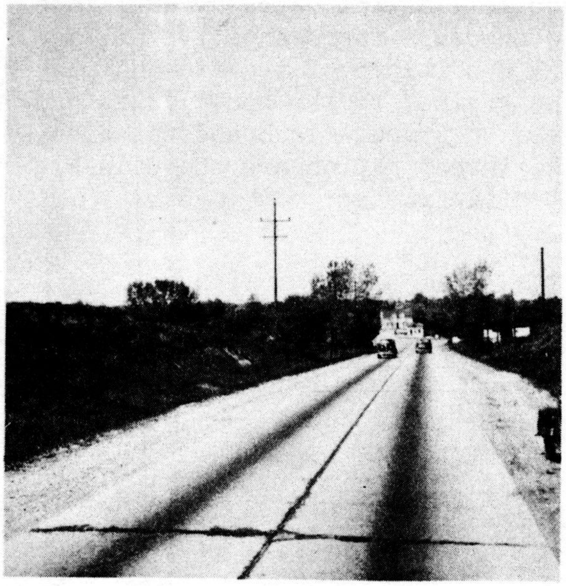


Figure 1. This pavement (U.S. 12, Sec. 106) was built in 1930 on a granular subgrade. Traffic is similar to that carried by the pavement in Fig. 2. There is no pumping, and the pavement is in excellent condition.

Figure 2. This pavement (Ill. 59A, Sec. 118) was built in 1933 on a fine grained subgrade. Traffic is comparable to that carried by the pavement in Fig. 1. Pumping is taking place at joints and cracks.

METHODS AND SCOPE OF STUDY

The pumping survey was made in an effort to gain a better understanding of the primary causes of pumping and the interrelationships existing between them, and to evaluate the influence on pumping of such other factors, which by reason of their position and function, affect the amount and severity of pumping in varying degree. Among these modifying factors are joint type, joint spacing, method of load transfer, and shoulder and pavement maintenance. The final objective of the survey is to contribute knowledge useful in determining the most practical, effective and economical means of preventing pumping of future concrete pavements.

The nature and purpose of the survey, as outlined in the preceding paragraph, dictated the selection of a relatively small percent of the total mileage of concrete pavement in Illinois for field study. It was decided to limit studies to principal highways in the area surrounding Chicago. These pavements were all within 14 counties of Districts 1 and 3 of the Illinois Division of Highways. Though the area of study was small when compared with the entire state, the great concentration of roads and traffic therein permitted the study of an adequate mileage of all the major pavement design groups subjected to varying conditions of traffic and having a wide, though not complexing, variety of subgrade soils.

Projects were selected for study on the basis of the commercial traffic they carried, their design characteristics, and subgrade soil as indicated by soil maps and previous experience. Every effort was made to choose a representative mileage of each pavement design group, subjected to varying conditions of traffic and placed on subgrades ranging from the very plastic and fine grained to the non-plastic and granular. A considerable mileage of pavement placed on granular subbase was also included for study. Projects included in the field investigation are shown in Figure 3 and are located on the following principal traffic routes:

Ill. 4A
U.S. 12
U.S. 14
U.S. 20
U.S. 24
U.S. 30
U.S. 41
U.S. 45
U.S. 52
U.S. 54
*Ill. 55
Ill. 59A
Ill. 64
U.S. 66
Alt.U.S. 66
Ill. 83
Ill. 116
Ill. 131

*Incomplete. Local traffic only.

Preliminary Work

Prior to beginning the field survey, data on the following items of design and construction were assembled from district office files and tabulated for individual projects considered for study:

1. Project identification
2. Stationing and length
3. Date of construction
4. Contractor and resident engineer
5. Cement and aggregate source, mix and average beam strength
6. Pavement width and cross-section
7. Longitudinal joint details, tie bars and tie bar spacing
8. Transverse joint details, and jointing arrangement
9. Load transfer details
10. Reinforcing details
11. Subbase design, material specifications and average gradation of material used
12. Miscellaneous data on such items as relative density of embankments as indicated by field tests during construction. Yardage of concrete patches, where such information was available.

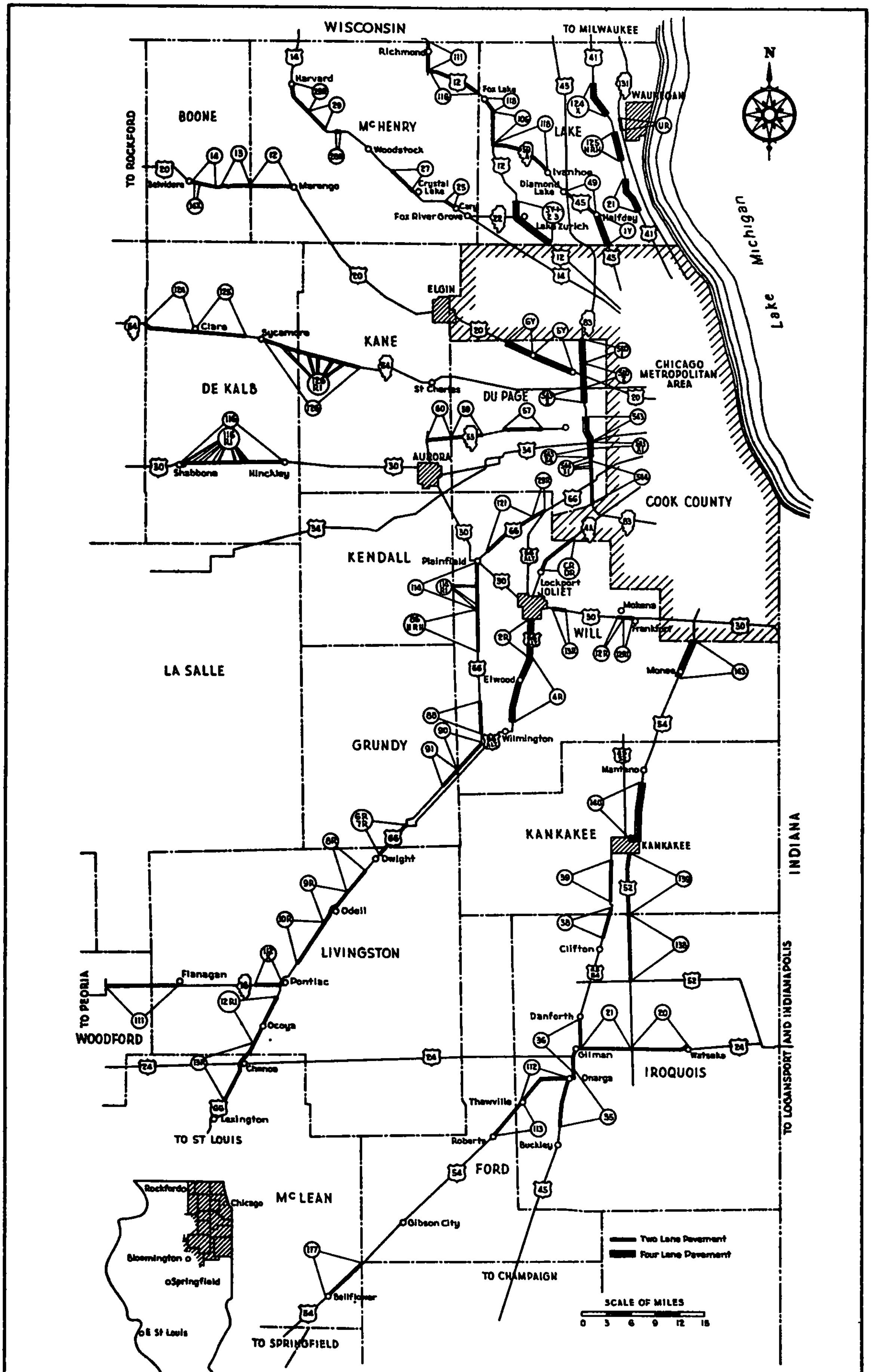


FIGURE 3
MAP SHOWING LOCATION OF
PROJECTS INCLUDED IN
ILLINOIS PUMPING SURVEY

Reconnaissance Survey

Each project selected for field study was covered, usually on foot, (except for 3 or 4 which were observed by riding fenders) by two or more observers who tabulated the amount and severity of pumping. Soil stains on the pavement at joints and cracks, mixtures of soil and water ejected from underneath the pavement at joints and cracks and onto the adjacent shoulder, and dried soil which had obviously been ejected in a slurry from underneath the pavement were accepted as evidences of pumping. To accurately evaluate its severity pumping was divided into the following three classifications:

Class 1.	Pumping, with no evidence of faulting or cracking of the pavement through loss of subgrade support due to pumping.
Class 2.	Pumping combined with faulting, but no evidence of additional cracking resulting from loss of subgrade support due to pumping.
Class 3.	Pumping, and cracking of the pavement due to loss of subgrade support through pumping.

Items indicative of pavement performance, items thought to influence pumping, and soil information of a general nature were also noted during the reconnaissance survey. Sections of projects were separated according to cut, fill and grade, and subgrade soil type, where such separations were possible. Following is a list of items upon which observations were made and noted:

1. Weather conditions, including last date of rainfall
2. Number of expansion joints, contraction joints and cracks
3. Number of joints and cracks at which pumping was taking place, and class of pumping
4. Number of faulted joints and cracks
5. Interior and exterior load corner breaks
6. Joint and crack openings
7. Joint and crack seal condition
8. Extent of concrete patching
9. Shoulder condition and drainage
10. General soil information
11. Miscellaneous information, such as notations on sub-sealing if such was used

Detail Survey

Studies of a detailed nature were made of representative portions of each project immediately after completion of the reconnaissance survey of that project. Sections of pavement uniform in performance and subgrade soils and 800 ft. or more in length were chosen for these studies. On those projects exhibiting sharp changes in performance or soil type, sections representative of each condition were selected for detailed investigation. During the detail survey, observations and measurements were made on the following:

1. Location of all joints and cracks
2. Road section (cut, fill or grade)
3. Extent and class of pumping
4. Joint and crack openings
5. Depth of faulting at joints and cracks (measurements were made in each wheel track)
6. Spalling
7. Interior and exterior corner breaks
8. Shoulder and drainage conditions
9. Condition of joint and crack seal
10. Approximate textural type of soil
11. The location and index number of soil test holes and samples
12. Subbase condition, on subbase projects
13. Miscellaneous items, such as patches, etc.

A device (see Figure 4) consisting essentially of a length of $\frac{1}{2}$-in. pipe mounted on a 2x4 and containing a movable 5/16-in. rod permitting the reading on a scale at eye level of the depth of faulting at joints and cracks was used on detail sections during the survey. Results of all observations and measurements on each detail section were recorded on sheets as shown in Figure 5.

Soil Sampling and Testing

In-place measurements of the density of subgrades and subbases were made, and samples taken for the determination of moisture content, through core holes drilled in the pavements with a core drill. Cores and soil samples were taken, and tests made, at selected joints or cracks on each of the detail sections. Non-pumping, as well as pumping locations were included in the study. Holes were usually drilled in the center of a traffic lane and a few feet on the far side of the joint or crack in the direction of traffic.

Density determinations were made by removing the subgrade soil, usually with a 2½ in. auger, to a depth of 8 in., (to the thickness of subbase where subbases were used) and the volume of the hole determined by the sand-hole method. A simple device was developed during the survey for supporting the sand-density apparatus in the core hole during the density test. Picture "A" in Figure 6 shows the apparatus and the supporting device separately. A fish line spool with strings attached was used for opening and closing the sand valve down in the core hole. Picture "B" in Figure 6 shows the apparatus and support in operating position. Adjustable screws are provided to support the device on the pavement so that the bottom will remain at subgrade level throughout the test. A representative portion of each subgrade and subbase sample taken through the core hole was weighed and sent to the district laboratories for the determination of moisture content. In addition, though no density determinations were made of subgrades underlying subbases, samples were taken therefrom following completion of the density tests of the subbase for the determination of moisture contents.

Samples of subgrade and subbase material similar to those taken from underneath the pavement at the core holes were taken from beneath the shoulder at the edge of the pavement opposite the core hole, sacked, and shipped to the Public Roads Administration laboratories in Washington for testing.

The following physical tests were made on subgrade and subbase samples by the Public Roads Administration:

1. Combined sieve and hydrometer analysis
2. Liquid limit
3. Plastic limit
4. Shrinkage test
5. Field moisture equivalent
6. Centrifuge moisture equivalent
7. A.A.S.H.O. compaction test

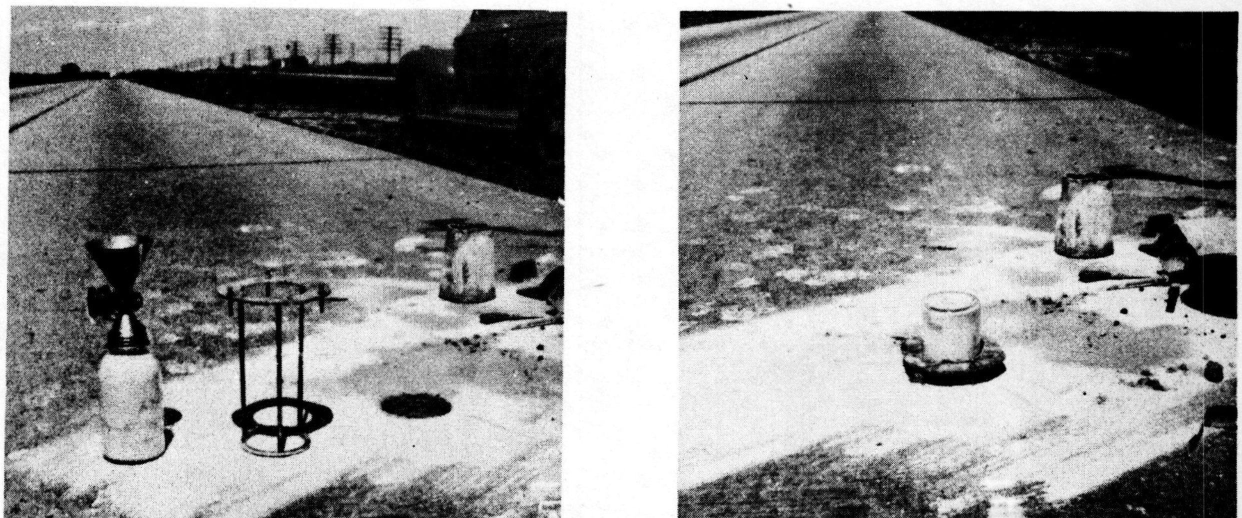
In addition, the coefficient of permeability was determined for a considerable number of subbase samples.

Traffic Data

The earliest comprehensive commercial traffic volume and axle load survey in Illinois was made in 1936. The most recent of several surveys during intervening years was made in 1943. Results of this last comprehensive survey were used in analyzing the pumping data. More recent spot surveys indicate some changes in commercial traffic volume and a tendency toward heavier axle loadings since 1943, but the more complete data for 1943 appear to be sufficiently accurate for the use made in the pumping study.

Commercial axles were grouped according to weight as follows: under 10,000 lb., over 10,000 lb., over 14,000 lb., and over 18,000 lb. The average number of commercial axles traveling each project per day was calculated by applying appropriate factors to the vehicle count made at the station affecting that project. Single unit and combination vehicles were counted separately and the counts expanded separately to axle loadings. Distribution into the axle weight groups was made

Figure 4. Measurement of depth of fault being made with device which permits readings at eye level.



(A)

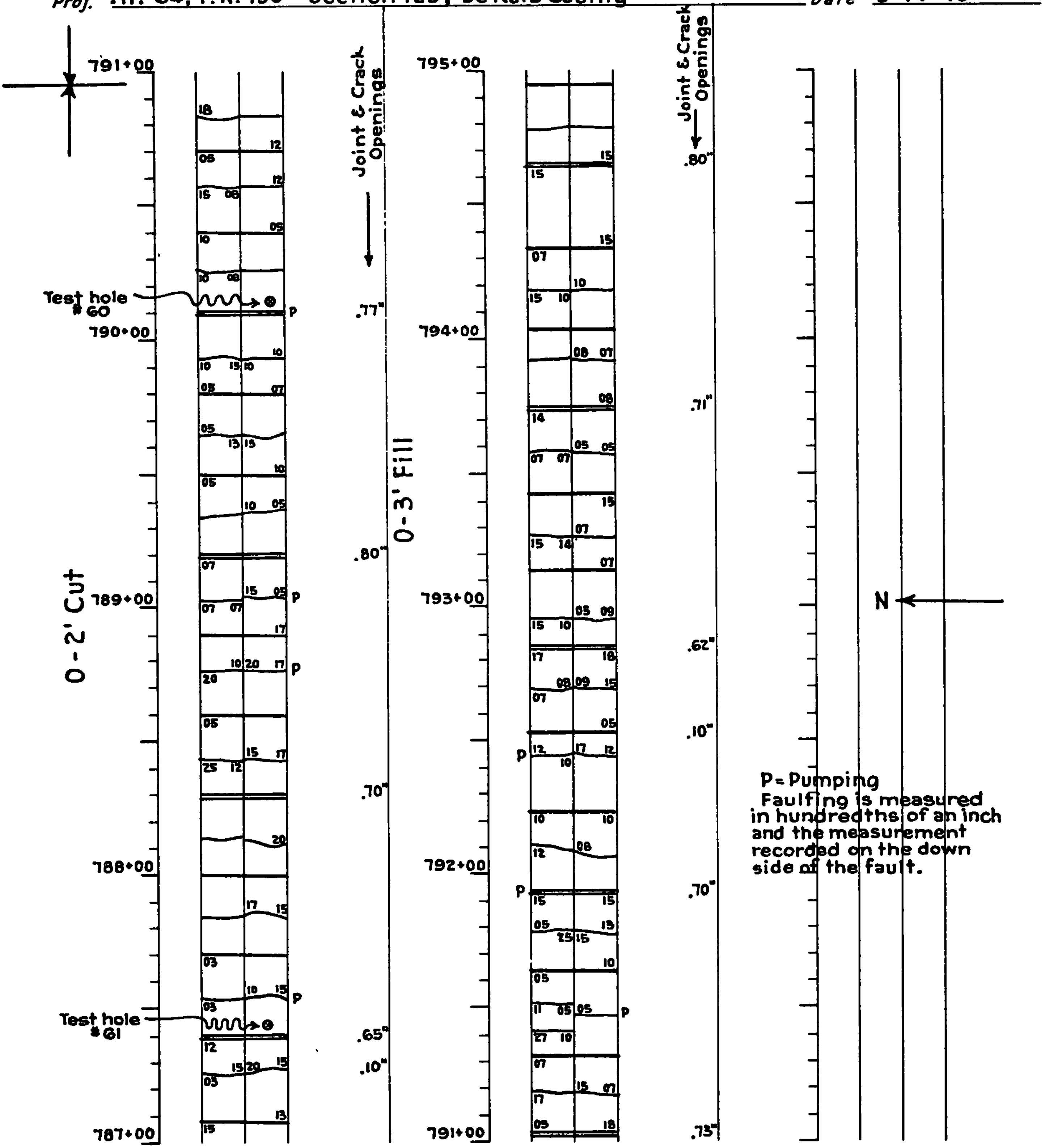
(B)

Figure 6. The view at the left (A) shows sand-density apparatus used for determining densities and the device used for supporting the apparatus in the core hole. View (B) shows the device and apparatus in position for operation.

PORTLAND CEMENT ASSOCIATION CONCRETE ROAD SURVEY
FIELD SKETCH SHEET

Page ____
J.E.B.
G.K.R.

Proj. Ill. 64, F.A. 136 Section 125, De Kalb County *Date* 5-14-46



P= Pumping
Faulting is measured in hundredths of an inch and the measurement recorded on the down side of the fault.

Remarks:

Partly cloudy, 70° - Last rain 5-10-46
New Seal
Cracks open 0.05" to 0.10", Contraction joints tight
No spall at joints. Small amount at cracks
Shoulders flush and flat
Very light pumping
Si C Lm. subgrade

FIGURE 5

on the basis of a distribution percentage worked out for the state as a whole. Axle loadings for loaded and empty single unit and combination vehicles were each considered separately in this distribution.

A special traffic count, in which the number and type of vehicles traveling in each direction were tabulated separately, was made at one location. The application of the results of this count to the study of pumping on projects affected by it will be discussed in detail later in the report.

ANALYSIS OF DATA AND OBSERVATIONS

The field reconnaissance and detail surveys were made during the spring and early summer of 1946 and all analyses of data are based on observations of conditions as they existed at the time. Soil stains on the pavement, mixtures of soil and water ejected onto the shoulder, and dried soil which had obviously been ejected by pumping action at joints and cracks were accepted as evidences of pumping. Those joints and cracks at which pumping had been halted by recent surface maintenance or by subsealing were not included in the pumping count.

Precipitation immediately prior to and during the survey was only slightly less than average (18.33 in. for the first seven months of 1946, as compared with a normal of 19.94 in. for the same period), although the month of April was unusually dry with a deficiency of 2.07 inches.

A total of 300.9 miles of pavement was covered during the reconnaissance survey. Of this total mileage of pavement, 186.2 miles were on predominantly fine grained subgrades, 45.9 miles on predominantly granular subgrades, and 68.8 miles on granular subbase. A total of 78 separate projects, varying widely in design, subgrade soils, and frequency and weights of axle loadings were included in the survey. Pumping was found to be absent entirely, or to vary widely in extent and severity with the different combinations of these factors.

The principal factors affecting pumping and the relation they bear to it will be considered in the following order:

1. Pavement design, including cross-section, reinforcing, joint types, load transfer, joint spacing and joint opening
2. Pavement maintenance
3. Rainfall
4. Traffic, including number and weights of axle loading
5. Subgrade soil, including its physical characteristics and in-place condition
6. Subbases

Pumping and faulting will also be discussed.

Pavement Design

To successfully compare the relative effects of the various features of pavement design on pumping it is necessary to limit comparisons to those pavements placed on comparable subgrade soils and subjected to similar conditions of traffic. Otherwise, substantial variations in either of these two factors would tend to obscure the effects of the differing features of design. Therefore, to reduce the variations in these two elements to a minimum and yet provide for study an adequate mileage of pavement containing varying features of design, the following analysis was limited to those pavements (1) placed on subgrades predominating in fine grained soils, as indicated by observations made during the reconnaissance survey, and known to be capable of producing pumping, and (2) subjected to axle loadings known to cause pumping under adverse soil and water conditions.

The pavements surveyed could be placed in a number of distinct design groups, each representing a definite period of design practice, and each characterized and dominated by a joint spacing and arrangement individual to that period. A description of the design features of the four principal groups, together with percentage figures and bars indicating the amounts of pumping found at joints and cracks of each group during the reconnaissance survey, are shown in Figure 7. The average age of each group, as well as the mileage surveyed (on fine grained subgrades) is also shown. No evidence was found to indicate that pavement age, in itself, had an important influence on pumping.

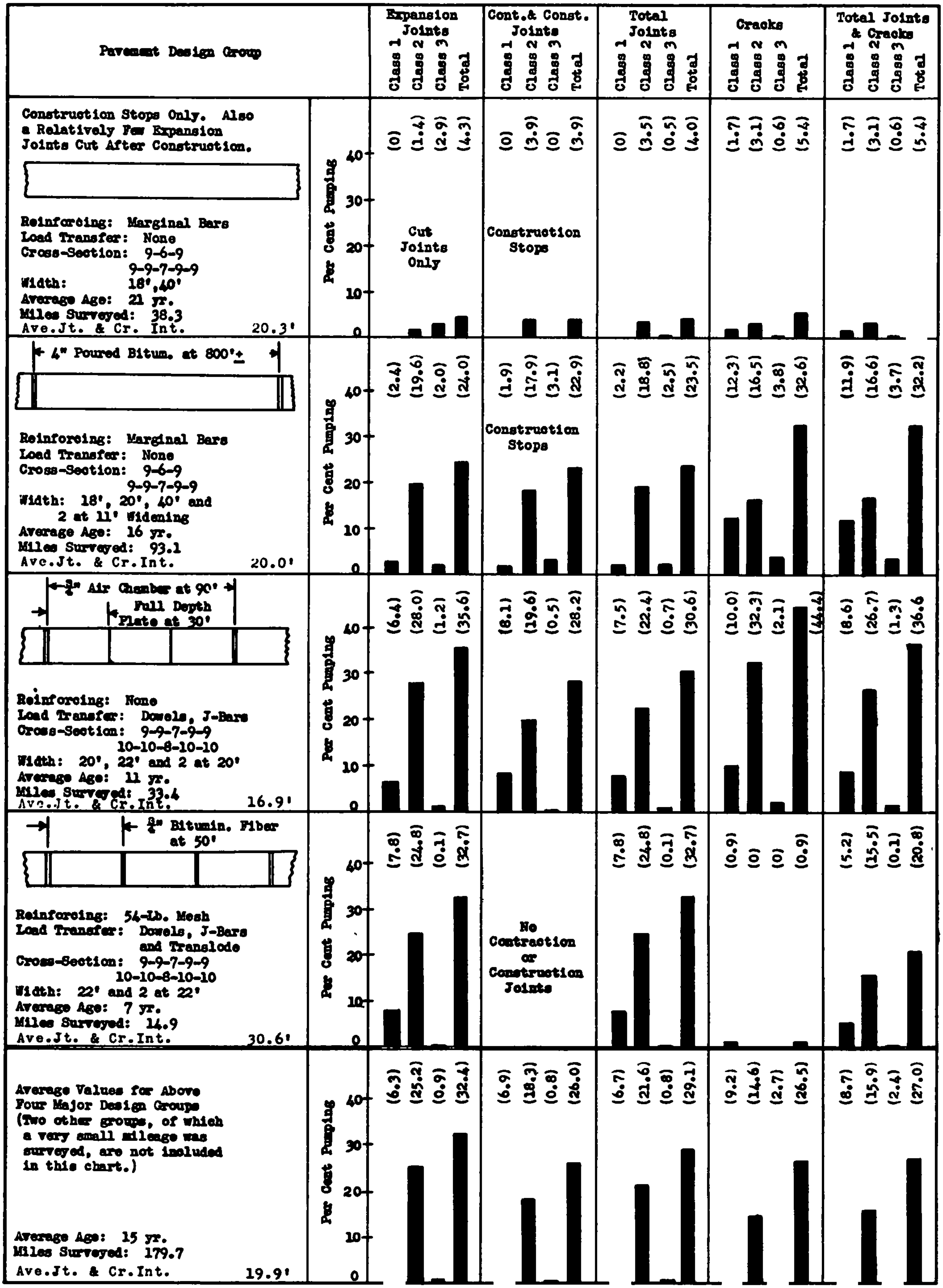
Two additional design groups, each represented by a single project in which the pavement was placed on a fine grained subgrade, were included in the survey. One of the projects, constructed in 1933 and only 0.33 miles in length, has doweled 3/4-in. bituminous fiber filled expansion joints spaced at 30 ft. intervals. There are no contraction joints. The pavement is 40 ft. in width and consists of two adjacent 9-9-7-9-9-in. by 20 ft. slabs. A total of 23.3 percent of the joints and cracks were found to be pumping. The other project, completed in 1943, was a divided highway consisting of two 10 in. uniform by 24 ft. lanes separated by a depressed parkway. The pavements carrying the traffic in opposite directions were of unequal length, but averaged 6.19 miles. Expansion joints with 3/4 in. bituminous fiber fillers were spaced at 120 ft. intervals and ribbon contraction joints at 20 ft. intervals. No load transfer devices were used. A total of 5.0 percent of the joints on this project were pumping.

Differences in the average number of commercial axle loadings in the various weight groups were not extreme between the four major design groups, with one exception as may be seen from an inspection of the traffic data appearing in Table 3, on page 19. It will be noted that the design group carrying the least number of axles in each of the four weight classes, and showing the most extreme variation from the average for all design groups in each of the weight classes, is that group featuring mesh reinforcing. This may be reflected in the performance figures for this group. The differences in axle loadings between the remaining three design groups were not great, with those of the group having the 90 ft. expansion joint spacing being somewhat greater than the other two.

The relationships of the various features of design to pumping, as indicated by the features of the major design groups, are considered in detail in the paragraphs that follow:

FIGURE 7

A COMPARISON OF THE AMOUNT AND SEVERITY OF PUMPING EXISTING ON PAVEMENTS GROUPED ACCORDING TO JOINTING ARRANGEMENT
(For Pavements on Subgrades of Predominantly Fine Grained Soils)



Pavement Width, Geometric Design and Pumping

Pavements of 18-, 20-, 22-, 24-, and 40-ft. widths, and 11-ft. widenings placed on each side of original 18-ft. pavements were included in the survey. Also included were divided highways with 20-, 22-, and 24-ft. pavements separated by either raised median strips, or raised or depressed parkways. Because of the small mileage of pavement representing some of the widths and layouts of pavements, and because of the pronounced influence on pumping of some of the other features of design, it was not possible to develop any relation between width of pavement, or geometric design, and pumping. Although it might be expected that the wider, newer pavements would pump less than older, narrower pavements, the data did not show this to be true, indicating that other variables have a more pertinent effect on pumping.

Pumping on multi-lane and widened pavement was confined almost exclusively to the outer lanes used by the heavier, slower moving commercial traffic.

Pavement Thickness and Pumping

Pavements of the following thicknesses were examined during the survey: 7-in. uniform, 9-6-9-in., 9-9-7-9-9-in., 10-10-8-10-10-in. and 10-in. uniform. No evidence was found to indicate, within the range of thicknesses studied in this survey, that thicker pavements pump less than thinner ones. In fact, the data of Table 1 indicate that for pavement of the same jointing arrangement more pumping developed on the thicker pavements. However these pavements carried much heavier traffic which will be shown to exert a considerable influence on pumping (see Traffic and Pumping). Undoubtedly this additional traffic was responsible for the greater amount of pumping on the thicker pavements. Even though the amount of pumping was greater on the thicker pavements with the heavier traffic it will be noted that the percent of Class 3 pumpers was less for the thicker pavements for each jointing arrangement. This indicates the greater resistance of thicker pavements to failure through loss of subgrade support. It should be pointed out, however, that there is no evidence that additional thickness of pavement alone will reduce pumping.

Reinforcing and Pumping

Pavements without reinforcing, pavements with marginal bars and pavements with mesh reinforcing, all on fine grained subgrades, were included in the survey (see Figure 7).

Pavements with marginal bar reinforcing were built either without expansion joints or with 4-in. poured bituminous expansion joints spaced at 800 ft. intervals. No other joints were included in either group except at construction stops. On the pavements built without expansion joints, very much less pumping was found (see Figure 7) in comparison to that found on the pavements built with expansion joints at 800 ft. intervals. Since marginal bars were used in both groups it is apparent that the difference in the amount of pumping must be attributed to other causes. Traffic, both in volume and axle loads was substantially the same for both designs (see Table 3).

TABLE 1
THE EFFECT OF PAVEMENT THICKNESS ON CLASS 3 PUMPING
For Pavements on Predominantly Fine Grained Subgrades

Jointing Arrangement Exp.	Jointing Arrangement Cont.	Cross-Section	Miles of Pavement	Class 3 Pumping	Total Pumping	24-Hr. Commercial Axle Count in 1943 Under 10,000 Lb.	Over 10,000 Lb.	Over 14,000 Lb.	Over 18,000 Lb.
ft.	ft.	in.		%	%				
800	None	9-9-7-9-9	52.5	3.4	38.6	773	540	289	46
		9-6-9	40.5	4.2	24.7	598	497	272	41
90	30	10-10-8-10-10	11.0	1.1	51.5	1477	1241	683	111
		9-9-7-9-9	22.4	1.4	30.4	564	401	216	35

TABLE 2
EFFECT OF LOAD TRANSFER DEVICES ON PUMPING
(MAJOR DESIGN GROUPS)
For Pavements on Predominantly Fine Grained Subgrades

Kind of Joint	Load Transfer	Type of Joint	Jointing Arrangement Exp. Jts.	Jointing Arrangement Cont. Jts.	Miles Surveyed	Percent Pumping Class 1	Class 2	Class 3	Total	Ratio of Class 2 and 3 Pumping To Total Pumping
			ft.	ft.						
Exp.	None	4 in. Open	800	Const. Stops Only	93.06	2.4	19.6	2.0	24.0	.90
Exp.	J-Bar Dowel Translode	Air Chamber Bit. Fiber	90 50	30 None	48.35	3.9	18.4	0.9	23.2	.83
Cont.	None	Construction Stops	800 None	Const. Stops Only	131.37	1.1	12.5	1.9	15.5	.93
Cont.	J-Bar Dowel	Full Depth Plate	90	30	33.42	8.1	19.6	0.5	28.2	.71

The marginal bars were used to provide a continuous dowel for load transference at any cracks which may later form. Therefore, this type of reinforcing is essentially only comparable with load transfer devices installed at joints. Such devices, as will be shown later, did not reduce the amount of pumping but did lessen its severity somewhat by retarding faulting and the development of Class 3 pumpers.

Pavements built with distributed mesh reinforcement had 3/4-in. bituminous fiber joints at 50 ft. intervals. They were carrying considerably less commercial traffic (both in volume and axle loads) than the other design groups of Figure 7 (see Table 3 for traffic). It is quite apparent from the data that the distributed mesh reinforcement which held intermediate cracks tightly together had a distinct influence on pumping at these cracks. Very little pumping has developed at these intermediate cracks. However, as will be seen from Figure 7, the group containing mesh showed only a little less pumping at expansion joints in comparison to the group with the 90 ft. expansion joint interval, an interval sufficiently close to the 50 ft. interval of the mesh reinforced pavements, for comparative purposes, even though the mesh pavements carried considerably less traffic. Since, as will be shown later, the weight and volume of traffic has a considerable effect on pumping, the expansion joints of the mesh pavements would probably have shown more pumping than did the expansion joints of the comparable group of non-mesh pavements under more equable traffic conditions. This is substantiated by a comparison of pumping on individual projects of the two groups subjected to similar traffic loadings.

In the above comparison it should be pointed out that air chamber joints were used in the non-mesh pavements while bituminous fiber filled expansion joints were used in the pavements with mesh reinforcement. However, examination in the field indicates that neither the air chamber nor the fiber filler appeared to have much effect in preventing water from reaching the subgrade (see following discussion).

Expansion Joint Fillers and Pumping

Metal air chamber expansion joints, joints with a bituminous fiber filler and joints with a poured bituminous filler were included in the survey. No type was found to have a definite influence on pumping.

Expansion joints with a poured bituminous filler showed (see Figure 7) the best service record in regard to pumping. These joints were constructed originally with a four inch opening, but at the time of the survey most of them were found to be either tightly closed or only partly open and the filler packed tightly with debris. This tightness, resulting from their relatively longer spacing (800 ft.), is probably responsible for their better performance. Pavement built with the other two fillers showed very little difference in their pumping performance.

Contraction Joint Type and Pumping

Except for construction stops which act as contraction joints, the only type of contraction joint used to any extent on the projects covered during the survey was the full depth metal plate. These were used in combination with air chamber expansion joints spaced at 90 ft. intervals. The only comparison for their performance which can be made is with that of construction joints in the other two design groups (see Figure 7). It will be noted that the percent of pumping is greater for the metal plate contraction joints, being 28.2 percent as compared with 22.9 percent for construction joints on projects constructed with expansion joints at 800 ft. intervals, and 3.9 percent for construction joints on projects constructed without expansion joints. It is not believed that the metal plate contraction joint was in itself responsible for this greater amount of pumping, but that the greater opening of these joints, caused by the close spacing of the expansion joints, permitted a more free entrance of surface water into the subgrade, thereby encouraging pumping.

A contraction joint formed by a 3-in. ribbon placed $\frac{1}{4}$-in. below the pavement surface was used on one project having a fine grained subgrade. This project was of recent construction and was carrying fairly light traffic at the time of the survey. About 5 percent of these joints were pumping.

Load Transfer Devices and Pumping

Wide differences in axle loadings prevented an equitable comparison of the relative influence on pumping of the three types of load transfer device examined; the dowel, the J-bar and the Translode angle. However, the data did permit the examination of the effect on pumping of the general usage of load transfer devices.

Load transfer devices, as will be seen from Table 2, apparently had no effect in reducing total pumping. Total pumping at expansion joints was about the same whether or not load transfer devices were used. At contraction joints, pumping was considerably greater in amount where load transfer devices were used, being 28.2 percent for joints with them and 15.5 percent for those without, but the greater amount of pumping may have been due to the general openness of the joints containing load transfer devices, resulting from a close spacing of expansion joints where the load transfer devices were used. However, as will be further seen from Table 2, load transfer devices did tend to reduce the severity of pumping, as is indicated by the ratio of Class 2 and 3 pumping to total pumping for joints with and without load transfer devices. The table shows that, for expansion joints, this ratio is 0.83 for joints with devices and 0.90 for those without. For contraction joints, the ratio is shown to be 0.71 for those with load transfer devices and 0.93 for those without. It appears, from this, that load transfer devices, through their ability to reduce faulting and distribute loads more evenly, reduced somewhat the severity of pumping at joints where they were used, although they did not reduce total pumping.

Pumping at Contraction Joints Compared with Pumping at Cracks

Since the use of contraction joints spaced at relatively short intervals has been advocated for the purpose of controlling cracking, it seems desirable to compare the relative amounts of pumping occurring at contraction joints and cracks.

It will be noted from an inspection of the percents of pumping and the bar diagrams of Figure 7 that for each design group employing contraction joints (construction joints being considered as contraction joints) pumping at contraction joints was considerably less than at cracks in most instances. It is possible that the greater ease with which contraction joints may be sealed and the seal maintained is responsible for the better performance of contraction joints over cracks as far as pumping is concerned.

Joint Spacing and Pumping

No single feature of design, as has been indicated in much of the foregoing discussion of the effects of the various features of pavement design on pumping, was found to exert an influence equal to that of joint spacing. It was definitely established that the provision of a minimum of expansion space in pavements is of considerable aid in controlling pumping.

Figure 7 and Table 3 show the effect of joint spacing on pumping for the major design groups. It will be noted that, for the three design groups built without mesh reinforcing, decreasing the interval between expansion joints resulted in a definite increase in the percent of expansion joints, contraction joints and cracks which were pumping. These pavements were built on predominantly fine grain soils and carry similar traffic. In Table 3 it will be seen also that the total number of pumping joints and cracks per mile increases as the expansion joint interval is decreased. It is not believed that the considerably better performance of the first group is due entirely to the wide spacing of expansion joints, but that other factors, such as a generally better grade of subgrade material, even though fine grained, contributed to the better performance of this group. However, the effect of expansion joint spacing is believed to have been substantial.

The pavement design group having the shortest interval between expansion joints (50 ft.), and differing from the other groups in that the pavements of this group were built with mesh reinforcing, carried commercial traffic substantially below those of the other design groups in all weight classes (see Table 3). This prevents an equitable comparison of pumping on all four of the major design groups. It will be noted that even though commercial traffic is much lighter on the mesh pavements, pumping at expansion joints is greater than on pavements built with 800 ft. expansion and with no expansion joints and only slightly less than on pavements built with 90 ft. expansion joints.

That there should be less pumping on pavements provided with a minimum of expansion space is reasonable when the effects of limiting the expansion space are considered. If expansion space is sufficiently limited, the pavement will be in compressive restraint much of the time. This is desirable because, by holding the pavement in compression, tensile stresses are held low and the structural capacity of the slab increased. Better load transfer is also effected, minimizing deflections of the pavement which lead to pumping at joints and cracks. Furthermore, tight joints and cracks maintain their seal more easily, and prevent or retard entrance of surface water to the subgrade, thereby eliminating or effectively controlling one of the three primary causes of pumping.

Joint and Crack Opening and Pumping

An effort was made during the detail survey to measure joint and crack openings to determine the effect of openings on pumping. Expansion joint openings could be measured quite accurately, but results of measurements of contraction joint and crack openings were found to be very erratic because of the difficulty of obtaining these measurements and the relatively small measurements involved. Construction features of contraction joints made it almost impossible to measure

TABLE 3

SUMMARY TABLE SHOWING, ON BOTH A PERCENTAGE AND PER MILE BASIS, THE AMOUNT OF TOTAL PUMPING OCCURRING AT JOINTS AND CRACKS OF PAVEMENTS IN THE MAJOR JOINTING GROUPS

(For Pavements on Subgrades of Predominantly Fine Grained Soils)

Jointing Arrangement		Miles in Survey	Pumping at Joints and Cracks Expressed as a Per Cent of the total Number of Joints and Cracks					Number of Pumping Joints and Cracks Per Mile					Twenty-four Hour Commercial Axle Count in 1943			
Exp.	Cont.		Exp. Joints	Cont. Joints	Total Joints	Cracks	Total Jts.& Cracks	Exp. Joints	Cont. Jts.	Tot. Jts.	Cracks	Tot. Jts.& Crks.	Under 10,000 lbs.	Over 10,000 lbs.	Over 14,000 lbs.	Over 18,000 lbs.
(1) None	(2) None	38.31	4.3	3.9	4.0	5.4	5.4	0.1	0.3	0.4	13.6	14.0	864	521	271	43
800'	(2) None	93.06	24.0	22.9	23.5	32.6	32.2	1.4	1.2	2.6	83.1	85.7	697	521	281	44
90'	30'	33.42	35.6	28.2	30.6	44.4	36.6	21.0	33.2	54.3	60.4	114.7	862	678	370	60
(3) 50'	None	14.93	32.7	-	32.7	0.9	20.8	35.3	-	35.3	0.6	35.9	456	289	150	18
TOTAL		179.72	32.4	26.0	29.1	26.5	27.0	7.6	6.9	14.5	57.2	71.7	743	531	285	45

(1) A few expansion joints were cut after construction and these have been included in the tabulations.
(2) Construction stops have been treated as contraction joints.
(3) Mesh Pavement.

their openings while spalling at cracks was chiefly responsible for making difficult accurate measurements of their openings. Therefore, though it was noted that pumping was greatest in both amount and severity at contraction joints and cracks of those projects having the greatest contraction joint and crack openings, statistical data are available only for openings at expansion joints.

Table 4 compares the average openings of pumping and non-pumping expansion joints for each of three design groups in which expansion joints were sufficiently well represented on the detail study sections for comparative purposes. It will be noted that pumping expansion joints in each design group had an average opening greater than the opening of non-pumping expansion joints. Only the joints on those detail study sections on which pumping was found were considered in this analysis. It will be noted in the table that the difference of opening between pumping and non-pumping expansion joints ranges from 0.05 in. for the 120 ft - 20 ft. jointing arrangement to 0.12 in. for the 90 ft. - 30 ft. arrangement.

Pavement and Roadway Maintenance

Although no statistical data were assembled during the reconnaissance and detail surveys on the part played by pavement and roadway maintenance in the prevention and control of pumping, general observations indicated that prompt and continued maintenance can be effective in its prevention and control. Observations made during the period that maintenance forces were engaged in the annual spring sealing of joints and cracks showed that a considerably greater amount of subgrade material was being ejected at those joints and cracks not yet sealed. It was also noted during the survey that sub-sealing of joints and cracks added much to the control of pumping, although it was obvious from a study of several projects which had been sub-sealed some years ago and the process not repeated, that this type of maintenance offers only a temporary cure.

TABLE 4

RELATION BETWEEN EXPANSION JOINT OPENINGS AND PUMPING

(From Detail Study Sections on Which Pumping Occurred)

Jointing Arrangement		No. of Detail Sections	Reinforcement	Joint Filler	Expansion Joint Openings (Inches)				
						Pumping		Non-Pumping	
Exp.	Cont.				Constructed	Range	Ave.	Range	Ave.
120	20	2	None	Bitum. Fiber	3/4	.52-.58	.55	.43-.65	.50
90	30	15	None	Air Chamber	3/4	.30-.90	.61	.10-.80	.49
50	None	10	Mesh	Bitum. Fiber	3/4	.56-1.12	.81	.58-1.10	.76

Careful attention to shoulder and ditch drainage was also seen to be a factor in the control of pumping. Ruts similar to that shown at the pavement edge in Figure 8 should be filled as soon as they form.

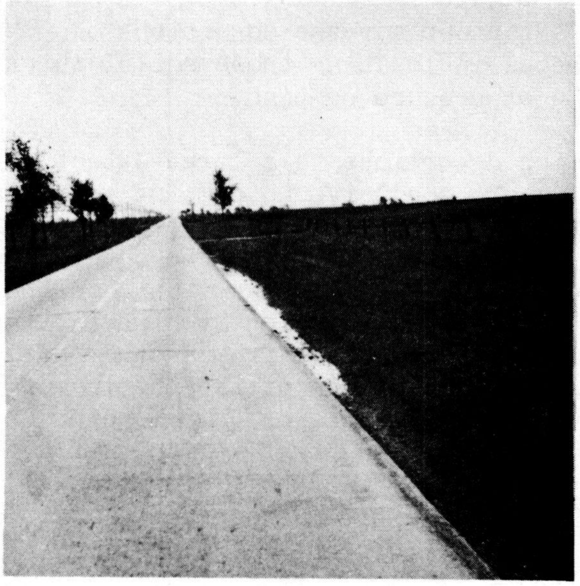


Figure 8. Water trapped at the pavement edge fosters pumping. The joints and cracks opposite the water in the picture are pumping.

Rainfall

The amount and distribution of rainfall is much the same in Illinois as it is throughout the Middle West and other large areas of the country. The annual yearly average in the area of the survey is about 33 inches. Yearly departures from the average are not great. Somewhat over half of the annual rainfall usually occurs during the spring and summer months, being divided about equally between them. The least precipitation occurs during the winter months, and usually comes in the form of snow. Pumping is most widespread in the spring and fall, during periods of long steady rainfall. The short heavy rains which make up much of the summer's precipitation are not as conducive to pumping as the longer, steadier rains.

The precipitation for the first seven months of 1946, the months immediately prior to and during which the pumping survey was made, totaled 18.33 in. for the northern portion of Illinois, which includes most of the area surveyed. Though the month of April was the driest on record since 1932, with a deficiency in rainfall of 2.07 in., the total deficiency for the seven month period was but 1.61 inches. These rainfall data are presented to show that, for the most part, average conditions of precipitation prevailed throughout most of the survey.

Traffic

It is well known that a frequent repetition of heavy axle loadings is a major feature causing pumping of pavements. Beyond this, not much is known. The probable frequency and weight of loading necessary to produce pumping with any given soil and pavement design cannot yet be predicted. Lack of traffic data of the comprehensive and detailed nature necessary for the establishment of accurate relationships between traffic, soil and pumping is largely responsible for this paucity of information.

Before beginning the field survey in Illinois it was established that the traffic information presently available would not permit the determination of any critical frequency and weight of axle loading above which pumping would occur for any one pavement, group of pavements or soil type. The method of establishing axle loadings for the separate projects is given under that part of "Methods and Scope of Study" (see pages 8 and 11). Therefore, in order to gain a maximum of information on the relation of soil and pavement design to pumping, it was decided to limit studies to those pavements believed to be carrying traffic of a density and weight known to produce pumping, at least under adverse conditions of soil and moisture. This was particularly advantageous in locating those soils, which, even under abnormally heavy traffic loadings, will not produce pumping.

That the weight and frequency of axle loading determines to a large extent the amount and severity of pumping, if the other factors conducive to pumping are present, was verified during the Illinois pumping survey in several ways. Observations of multi-lane highways showed pumping to be confined almost exclusively to the outer lanes used by the slow moving, heavy trucks. Practically no pumping was found in the inner lanes used only for passing by light passenger traffic traveling at higher rates of speed. Further verifications of the part played by traffic came from a study of the concurrent histories of traffic and pumping, from a comparison of the pumping of those pavements placed on fine grained soils, grouped on the basis of axle loading frequency, and from a comprehensive study of pumping in opposing traffic lanes of a pavement carrying widely different loadings in opposite directions, all of which will be discussed in detail in the paragraphs which follow.

Traffic Trends and Pumping

As has been true throughout the country, commercial traffic in Illinois has shown a notable increase in both frequency and weight through the years. Though the increase in number has been considerable, the trend toward a higher frequency of axles in the heavier weight groups has been most marked, as evidenced by the data presented in Table 5. This table shows the relative increase in the number and weight of commercial axle loadings on Illinois highways which occurred between 1936 and the years 1941, 1943 and 1945. It will be seen from the table that while total axle loadings increased about 1½ times between the years 1936 and 1945, axle loadings over 10,000 lb. increased 3 times, those over 14,000 lb. increased nearly 7 times, and for every axle load of over 18,000 lb. in 1936 there were 33 such loads in 1945. Coincident with this rapid rise in the number and weight of axles traveling Illinois highways was the ascendance of pumping (see page 2) further verifying the substantial influence of heavy axle loads on pumping. Proportionate increases took place in the number of axle loadings in the heavier axle weight groups for pavements included in the pumping survey, as will be noted from an inspection of Table 6. Attendant increases in pumping also took place. Traffic data for the years 1941 and 1943 were available for all pavements included in the survey while partial data believed to be fairly representative were available for 1936 and 1945. It should be noted that Table 6 shows the actual number of loadings per day rather than comparative loadings based on 1,000 axles per day in 1936, as is shown in Table 5.

TABLE 5

A COMPARISON OF THE NUMBER AND WEIGHT OF COMMERCIAL AXLES TRAVELING THE ILLINOIS PRIMARY HIGHWAY SYSTEM DURING THE YEARS 1936, 1941, 1943 and 1945

(Based on 1,000 Axles in 1936)

Axle Load Groups of Commercial Vehicles	Number of Axles in:			
	1936	1941	1943	1945
All axle loads	1000	1683	1395	1471
Axle loads under 10,000 lb.	877	1365	1094	1115
Axle loads over 10,000 lb.	123	318	301	356
Axle loads over 14,000 lb.	31	146	150	202
Axle loads over 18,000 lb.	1	13	25	33

It is of interest to note, through a comparison of the data presented in Tables 5 and 6, that the pavements of the survey, besides having a frequency of commercial loading far greater than that for the average pavement of the state, which a glance at a commercial traffic flow map of the state will show, carried a greater number of heavy loadings in proportion to the total loadings. It will be noted from the tables that the proportions of axles in the heavier weight groups (axles 10,000 lb. and over), for the pavements of the survey, are normally about twice those for the average pavement of the state. This is true for all the years for which data are presented. Since not only the volume but the weight of commercial loading is greater on the pavements of the survey, it becomes even clearer why the incidence of pumping on these pavements is far above the average for the state.

TABLE 6

AXLE LOADINGS ON PAVEMENTS INCLUDED IN THE ILLINOIS PUMPING SURVEY FOR THE YEARS 1936, 1941, 1943 AND 1945

Axle Load Groups of Commercial Vehicles	24 Hour Commercial Axle Count in: 1936 (216.4 miles)	1941 (289.8 miles)	1943 (289.8 miles)	1945 (44.7 miles)
All axle loads	1187	1589	1304	1188
Axle loads under 10,000 lb.	883	977	780	712
Axle loads over 10,000 lb.	304	612	524	476
Axle loads over 14,000 lb.	71	301	278	251
Axle loads over 18,000 lb.	1	22	44	42

Frequency of Heavy Traffic and Pumping

During analysis of the relation of traffic to pumping it was found that the pavements placed on soils conducive to pumping could be divided, on the basis of traffic, into two groups, each containing a sufficient number of miles of pavement for comparative purposes. This division was made on the basis of an axle loading frequency above or below 300 axles in the 14,000 lb. weight class. This particular weight class was chosen because it was thought to best represent axle loadings contributing to pumping.

The influence of axle loadings on the amount of pumping on pavements of the survey placed on fine grained subgrades is shown in Table 7 and Figure 9. It will be noted in the table and figure that pumping of joints and cracks on those pavements carrying more than 300 axles per day weighing 14,000 lb. and over is almost twice as great as it is for pavements carrying less than 300, 14,000 lb. axle loads per day. It will be further noted that comparable ratios exist for expansion joints, contraction joints and cracks when considered separately.

Similarly, as indicated in Table 8 and Figure 10, Class 2 and Class 3 pumpers were found to be substantially greater on those projects having a higher frequency of axle loading in the 14,000 lb. weight group. The table and figure show a comparison of the ratios of the percent of Class 2 and 3 pumping (Class 2 includes faulting and Class 3, breaking) to the percent of total pumping for the two previously mentioned axle load groups. It will be noted that this ratio is consistently greater for the

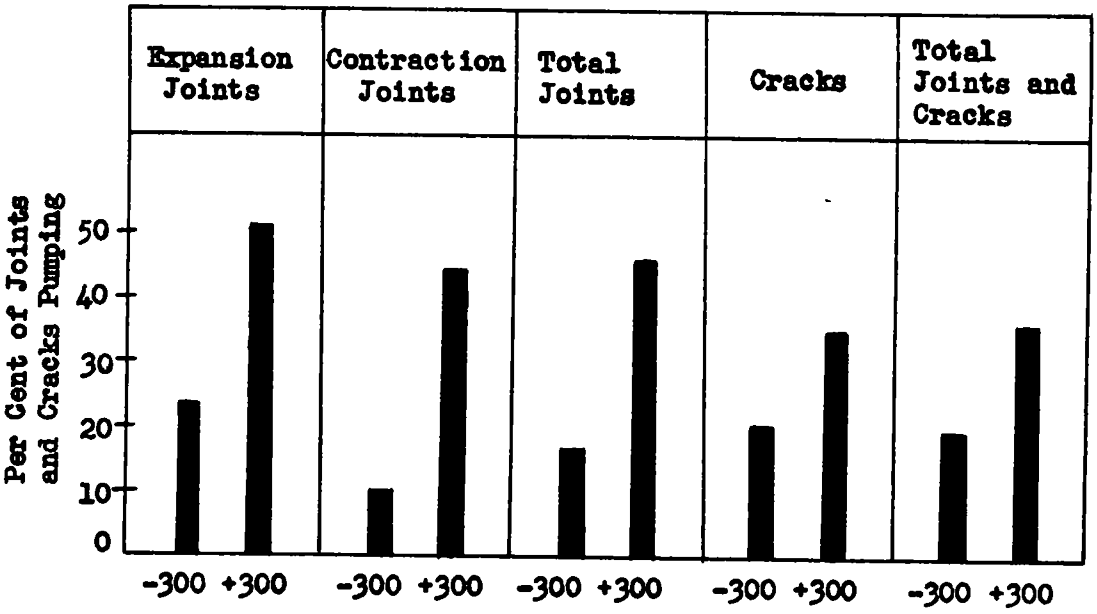
TABLE 7

THE EFFECT OF TRAFFIC ON THE AMOUNT OF PUMPING
(For Pavements on Predominantly Fine Grained Subgrades)

Group	Miles Involved	Per Cent of Joints & Cracks Pumping Exp. Joints	Cont. Joints	Total Joints	Cracks	Total Jts. & Cracks
Less than 300 Axles Per Day of Over 14,000 Lb.	114.8	23.1	10.1	16.0	20.5	19.5
More than 300 Axles Per Day of Over 14,000 Lb.	71.4	50.5	43.2	45.9	34.3	36.2
Total	186.2	30.6	21.4	25.4	24.5	26.2

FIGURE 9

THE EFFECT OF TRAFFIC ON THE AMOUNT OF PUMPING
(For Pavements on Predominantly Fine Grained Subgrades)



Number of Axles Per Day of Over 14,000 Lb.
Above or Below 300

(Graphical Presentation of Values of Table 7)

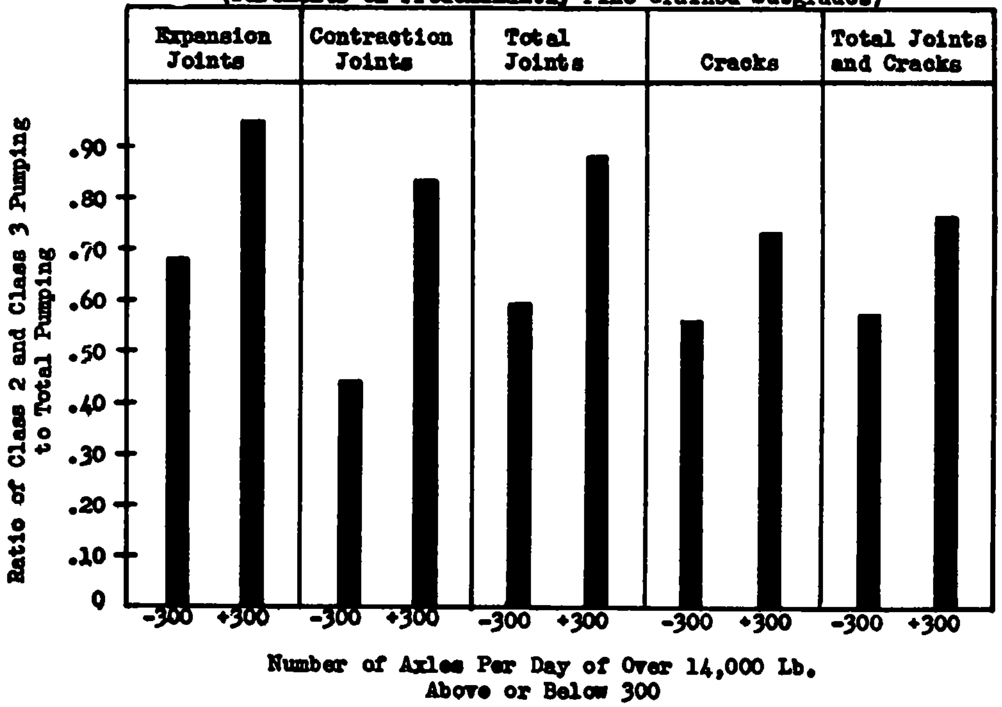
TABLE 8

EFFECT OF TRAFFIC ON THE SEVERITY OF PUMPING
(Pavements on Predominantly Fine Grained Subgrades)

Group	Miles Involved	Per Cent of Pumping														
		Expansion Joints			Cont. Joints			Total Joints			Cracks			Total Jts.& Cracks		
		Class 2 and 3	Total	Ratio	Class 2 and 3	Total	Ratio	Class 2 and 3	Total	Ratio	Class 2 and 3	Total	Ratio	Class 2 and 3	Total	Ratio
Less than 300 Axles Per Day of Over 14,000 Lb.	114.8	15.7	23.1	.680	4.4	10.1	.436	9.5	16.0	.594	11.4	20.5	.556	11.0	19.5	.564
More than 300 Axles Per Day of Over 14,000 Lb.	71.4	47.9	50.5	.949	35.9	43.2	.831	40.4	45.9	.880	25.1	34.3	.732	27.6	36.2	.762
Total	186.2	24.5	30.6	.801	15.2	21.4	.710	19.2	25.4	.756	16.0	24.5	.653	17.7	26.2	.676

FIGURE 10

EFFECT OF TRAFFIC ON THE SEVERITY OF PUMPING
(Pavements on Predominantly Fine Grained Subgrades)



(Graphical Presentation of Values of Table 8) more heavily traveled pavements. For joints and cracks considered together, the ratio is 1½ times greater for pavements having more than 300 axle loadings per day in the 14,000 lb. weight class. This difference in the amount and severity of pumping under conditions comparable except for traffic is additional evidence of the important part traffic plays in pumping.

Detail Study of Pumping on Illinois Route 83

Extreme difference in the volume and weight of axles carried by opposing traffic lanes exists on a part of Illinois Route 83. Commercial traffic traveling in a northbound direction is made up largely of loaded oil trucks emanating from a refinery, while the southbound traffic is composed largely of empty trucks returning to the refinery. There is a considerable difference in the amount and severity of pumping occurring in the two lanes. During the reconnaissance survey of projects on this route, pumping in the opposing traffic lanes was considered separately. A special survey of traffic, in which vehicles traveling in opposite direction were noted separately, was made a few weeks after the reconnaissance and detail surveys. During the traffic survey, besides separating passenger and commercial traffic, commercial traffic was grouped as to type; i.e., as single unit trucks, tractor-truck semi-trailers, and trailer combinations. All oil trucks were noted. The commercial vehicle count was expanded into axle loadings and these loadings divided into weight groups as previously explained (see pages 8 and 11) except that all northbound oil trucks were considered to be loaded and southbound oil trucks to be empty.

Table 9 shows the relation between the amount of pumping in the north and southbound lanes and the computed axle loadings traveling in each direction. It will be seen that the number of axles in the heavier weight groups and the percent of pumping joints and cracks are considerably greater for the northbound lane. It will be noted that there is over twice as much pumping in this heavier traffic lane.

Table 10 shows the relative severity of pumping in the opposing traffic lanes. Severity is shown as the ratio of Class 2 and 3 pumping to total pumping. It will be noted that for joints and cracks combined, this severity ratio for the northbound lane is 1½ times greater than for the lane of lesser traffic. No explanation is offered for the slightly greater severity of pumping indicated at contraction joints of the southbound lane. Referring again to Table 10 and comparing the actual percents of Class 2 and 3 pumping in opposing traffic lanes it will be noted that there is over three times as much Class 2 and 3 pumping in the lane of heavier traffic. This further demonstrates the effect of traffic on pumping.

Subgrade Soils

A major factor necessary to the production of pumping is a subgrade soil which will go into suspension when agitated in the presence of free water by repetitive movements of the pavement under traffic. A summary of previous discussion shows that modifying factors of pavement design and pavement and roadway maintenance foster or allay pumping, but do not prevent it.

Following a brief description of the physiographic and pedological features of the area surveyed, there will be presented the results of studies of the effects on pumping of glacial features, road section (cut, fill and grade), and the physical condition of the subgrade. The relation between the standard physical

TABLE 9

TRAFFIC AND AMOUNT OF PUMPING - ILL. RT. 83

Lane	Miles of Pvt.	Per Cent of Joints and Cracks Pumping, April 9-15, 1946					24-Hour Commercial Axle Count June 3, 1946			
		Exp. Joints	Cont. Joints	Total Joints	Cracks	Jts. & Cracks	Under 10,000 lb.	Over 10,000 lb.	Over 14,000 lb.	Over 18,000 lb.
Northbound	15.9	56.8	49.0	55.0	46.5	49.1	390	309	223	57
Southbound	15.9	16.7	25.6	19.0	25.2	23.0	488	42	23	4

TABLE 10

TRAFFIC AND SEVERITY OF PUMPING--ILL. RT. 83

Lane	Miles of Pvt.	Per Cent of Pumping April 9-15, 1946															24-Hour Commercial Axle Count June 3, 1946			
		Expansion Joints			Contraction Joints			Total Joints			Cracks			Joints & Cracks						
		Class 2 and 3	Total	Ratio	Class 2 and 3	Total	Ratio	Class 2 and 3	Total	Ratio	Class 2 and 3	Total	Ratio	Class 2 and 3	Total	Ratio	Under 10,000 lbs.	Over 10,000#	Over 14,000#	Over 18,000#
Northbound	15.9	44.8	56.8	.789	21.8	49.0	.445	39.1	55.0	.711	22.4	46.5	.482	27.4	49.1	.558	390	309	223	57
Southbound	15.9	12.2	16.7	.731	14.0	25.6	.547	12.6	19.0	.663	6.7	25.2	.266	8.7	23.0	.378	488	42	23	4

test constants and pumping, and pumping within the Public Roads Administration soil groups will also be discussed. Of all the relationships developed, that between grain size and pumping has been found to offer the best means of identifying soils which will or will not pump.

Traffic conditions for pavements on fine grained subgrades, granular subgrades, and granular subbases(subbases will be discussed as a separate topic), were quite similar, thus permitting an equitable comparison between the performance of pavements grouped accordingly. This will be seen from an inspection of Table 11 which shows traffic in the various weight classes for the two types of subgrade and for subbases. Variations from the average are of little consequence.

TABLE 11

AVERAGE AXLE LOADINGS ON PAVEMENTS INCLUDED IN ILLINOIS PUMPING SURVEY

(1943 Traffic)

	Miles of Pavement	24 Hour Commercial Axle Count			
		Under 10,000 lb.	Over 10,000 lb.	Over 14,000 lb.	Over 18,000 lb.
Predominantly fine-grained subgrades	186.2	771	525	279	44
Predominantly granular subgrades	45.9	750	500	264	42
Granular subbases	57.7	836	544	287	46
Total	289.8	780	524	278	44

Physiography and Soils of Survey Area

Physiographically, the survey area, as well as all of Illinois except the extreme southern tip, lies within what is known as the Central Lowland province. It is generally flat to rolling in character with occasional low broad ridges (moraines) rising above the surrounding plains, and is typical of much of Illinois, Indiana and Ohio. Undrained depressions and lakes are to be found in the more youthful terrain of the northeast section of the area.

The surface cover of the survey area consists almost wholly of material transported thereto during the Wisconsin period of glaciation. Topographically, the area is much the same as it was at the time of the retreat of the final Wisconsin glacier. The glacial depositions within the area, including the moraines, representing lines of farthest advance of the numerous glaciers, and the major glacial lakes (long since drained) formed by melt water from the retreating ice fronts, are shown in Figure 11. The projects surveyed are also shown. The morainal ridges have greater local relief than the plains below them, a factor which, as will be explained later, has had some influence on pumping. The least relief usually occurs in areas once covered by the glacial lakes.

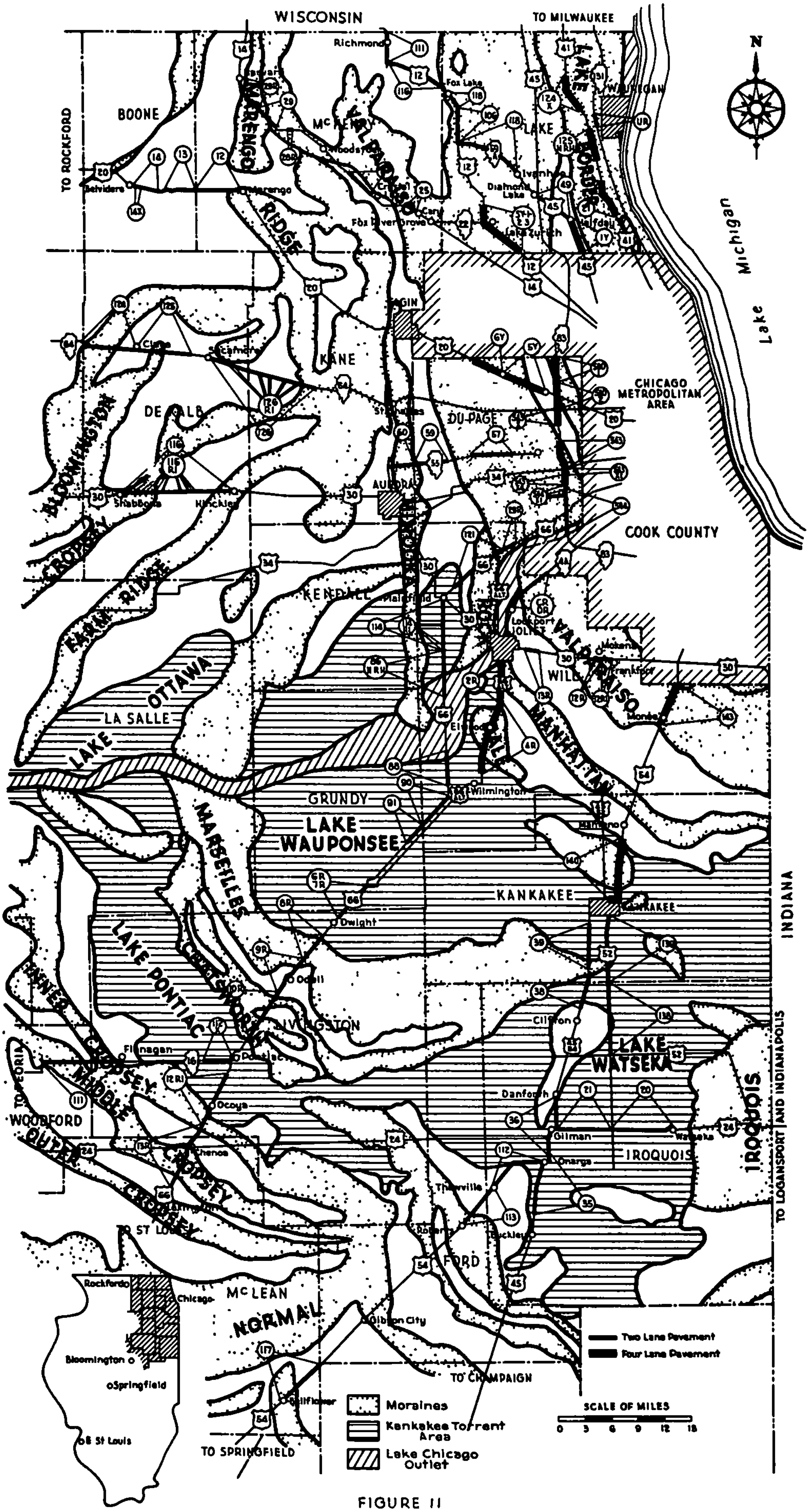


FIGURE 11
MAP SHOWING GLACIAL FEATURES OF REGION
COVERED IN ILLINOIS PUMPING SURVEY,
TOGETHER WITH THE LOCATION OF PROJECTS SURVEYED

Geological data taken (with permission) from a map compiled by George E. Ekblaw, Illinois State Geological Survey

The glacial drift, which includes both materials dropped in situ by the retreating glaciers and materials dropped by their melt water, varies from clay to accumulations of gravel and boulders. The till, which includes only the material dropped from the glaciers themselves, is mostly calcareous, usually quite high in silt and clay content, and generally contains some sand and a small percent of gravel. In certain localities the till is exceptionally high in clay content and contains little granular material. The incidence of pumping at joints and cracks is highest on pavements placed on subgrades composed of this fine grained, impermeable material.

The average soil of the survey region is formed from either the glacial drift or from loess which attains a maximum thickness of about 50 in. in the area. Little loess is to be found on drift deposited by those glaciers following the Marseilles (see Figure 11). Soils derived from the loessial material are usually silty and do not contain much granular material. Soils derived from the drift vary from granular to highly impervious clay depending upon the characteristics of the parent material.

Almost all of the soils of the area, with the exception of some in Boone and McHenry counties, were developed under grass vegetation and belong to the Prairie group of soils. The exceptions in the two previously mentioned counties are Gray-Brown Podzolic soils. Soil profiles are generally immature because of their comparative youthfulness and are not well defined.

No pumping was found on the sandy materials predominating in parts of the glacial lake areas and outwash plains. A moderate amount of pumping, mostly of a light nature, was found on subgrades of silty loessial soils, while the most pumping, and the severest, was found on pavements having subgrades composed of highly impermeable calcareous glacial clays. Table 12 shows the physical test constants for representative soils of the area.

Glacial Features and Pumping

Results of the survey indicate that pumping was usually greater in morainal areas. Nineteen projects containing a total of 47.5 miles of fine grained subgrade are indicated by the map of Figure 11 to lie wholly within the limits of moraines. Nineteen other projects, totaling 61.6 miles of fine grained subgrade, are indicated to be wholly outside morainal limits. A total of 36.1 percent of joints and cracks of the former group were found to be pumping while only 19.1 percent of those of the latter group were pumping. This indicates that there was almost twice as much pumping within the area of the moraines. Field observations and soil test results indicated that the incidence of pumping was higher in morainal areas because the rougher character of their terrain made necessary greater depth of cut and fill for the establishment of a satisfactory grade line, thereby making necessary the use of greater amounts of the more plastic "B" and "C" horizon soils in the subgrade, with an attendant increase in pumping. In the flatter intermorainal areas and on the glacial lake beds, where the pavements (particularly the older pavements) followed closely the original ground line, the subgrades were composed largely of surface soils which were somewhat coarser and less plastic as a result of leaching or of being formed from silty loess, and were less prone to pump. The present day trend toward higher grades in relatively flat areas entails the frequent use of "B" and "C" horizon materials in the construction of

TABLE 12

TYPICAL SOILS OF ILLINOIS PUMPING SURVEY AREA

a. General Description

Sample No.	Route	Section	County	Textural Class	PRA Group	Remarks
104	U.S. 41	125NRH	Lake	CLm	A-7	Topsoil containing little or no loess Fairly conducive to pumping
110	U.S. 41	124X	Lake	C	A-7	Subsoil of glacial till high in clay content A major pumper
54	U.S. 30	116	DeKalb	SiCLm	A-7	Topsoil containing loess Will pump under very adverse conditions
116	Alt. 66	4R	Will	C	A-7	Subsoil of the more friable glacial till Will pump under adverse conditions
162	U.S. 45	35	Iroquois	Sdy Lm	A-2	Topsoil from glacial lake area No pumping found on this soil
125	U.S. 66	90	Will	Sd	A-2-3	Subsoil from glacial lake area No pumping found on this soil

b. Test Results

Sample No.	AASHO Maximum Density (P.C.F.)	Optimum Moisture (%)	Sieve Analysis % Passing Sieve No.				Texture (Percent)							
			4	10	40	200	Sand & Gravel	Silt	Clay	Coll.	LLL	LPL	PI	SL
104	113	15	99	99	96	70	36	39	25	11	48	31	17	20
110	102	21	99	97	95	89	16	30	54	23	42	20	22	15
54	106	17	98	94	90	86	24	52	24	8	44	22	22	15
116	117	15	91	90	85	78	31	38	31	14	35	19	16	17
162	121	11	100	100	99	35	69	21	10	3	18	15	3	15
125	109	13	100	100	100	14	89	8	3	2	NP	-	NP	-

fill and subgrade and largely nullifys the advantage usually gained in earlier day construction. It should be noted that the use of fine grained surface soils in the subgrade caused pumping to be less extensive only, and did not prevent it.

Road Section (Cut, Fill, Grade, and Pumping)

Pumping of consequence was found on pavements in cut, on fill and at grade, as will be seen from an inspection of Table 13. This indicates that, to be successful under conditions similar to those obtaining within the area of the survey, measures used to prevent pumping must extend throughout the length of a section of pavement in a fine grained soil area and cannot be confined to single areas chosen with respect to the original ground line.

It will be seen in Table 13 that there is little difference between the amount of pumping in cut and on fill. The fact that only about half as much pumping occurred on pavements at grade probably reflects the better quality of the surface soils which predominate in subgrades constructed at grade. The severity of pumping varies little between the road sections.

TABLE 13

RELATIVE AMOUNT AND SEVERITY OF PUMPING IN CUT ON FILL AND AT GRADE/1

		Amount	Severity			
			Percent of Total			Total
Road Section	Miles of Pvt. (2)	Percent of Joints and Cracks Pumping	Class 1	Class 2	Class 3	Percent
Cut	67.5	24.7	34.6	57.8	7.6	100
Fill	163.4	21.7	32.3	60.3	7.4	100
Grade	54.3	11.7	29.9	60.7	9.4	100

/1 - Figures are all natural subgrades.
(2)- Pumping, when considered separately for opposing traffic lanes during field survey, is here considered separately.

PRA Soil Groups and Pumping

The most severe pumping was found on soils of the A6 and A7 groups. Light to moderate pumping was found to be taking place on soils of the A2-4, A4 and A7 groups. No pumping was found to occur on soils of the A1, A2 and A3 groups.

Soil Texture and Pumping

Of all relationships developed from the survey data, that between soil grain size and pumping appears to be the most significant. A study of performance data and accompanying tests of subgrade soils discloses that pavements built on subgrades or subbases containing more than 55 percent sand and gravel (material retained on the 270 sieve) have developed no pumping. A total of 61 such samples were taken from beneath non-pumping pavements.

In contrast to this, all of the 54 samples taken at pumping locations were found to contain less than 55 percent sand and gravel (material retained on the 270 sieve). Matching samples were taken at non-pumping locations wherever possible to evaluate the influence of such factors as subgrade density, water content and joint maintenance in the prevention of pumping on soils apparently similar physically to the soils taken at pumping locations. A total of 56 such samples were taken. The textures of all subgrade and subbase samples taken during the survey (exclusive of samples taken from under subbases) are shown on the trilineal chart of Figure 12. Grain size curves typical of subbase materials are shown in Figure 13 on page 37.

Field Condition of Subgrade and Pumping

Table 14 summarizes the results of the tests made to determine subgrade moisture contents and in-place densities. Also summarized are results of laboratory compaction and Atterberg limit tests on samples taken in connection with the field tests. The results shown in Table 14 are for subgrades immediately under pavements and do not include the results of tests on subbases, and subgrades under subbases. The results of tests on the latter two will be treated later. Test holes were dug to a depth of 8 inches below the pavements (except in the case of subbases and their subgrades) and the moisture contents and densities represent subgrade conditions throughout this depth.

Since the average values of the laboratory test results (see Table 14) indicate a close similarity between the fine grained soils (less than 55 percent sand and gravel) at pumping and non-pumping locations it appears that their average field water contents and relative densities can be compared to determine what effects subgrade moisture and relative compaction have on pumping. Little difference will be noted between the average field water contents, and a comparison of these with the average plastic limits will show that high subgrade water contents extending to a considerable distance below subgrade are not normally the cause of pumping. General observations showed that only a relatively thin layer of subgrade was affected by pumping action. Field water contents were in all cases within a few percent of the plastic limits for the individual fine grained soil samples. For the granular soils, it will be noted that their average field water content was less than half that for the fine grained soils, both pumping and non-pumping. It is also well below the corresponding average plastic limit for the granular soils.

A further consideration of Table 14 will show that the fine grained subgrades were somewhat more dense at non-pumping locations than they were at pumping locations. The average relative density was 92.4 percent as against 90.9 percent. It is possible that better compaction of the subgrades at the non-pumping locations had some influence in preventing pumping. The somewhat higher relative density of the granular samples (94.1 percent) may reflect the greater ease with which granular materials may be compacted.

No direct relationships were found to exist between either maximum densities and optimum moistures as determined in the standard compaction test or Atterberg limit test constants and pumping.

Subbases

Early observations of the absence of pumping on pavements placed on granular soils, even though subjected to traffic of considerable intensity, pointed to

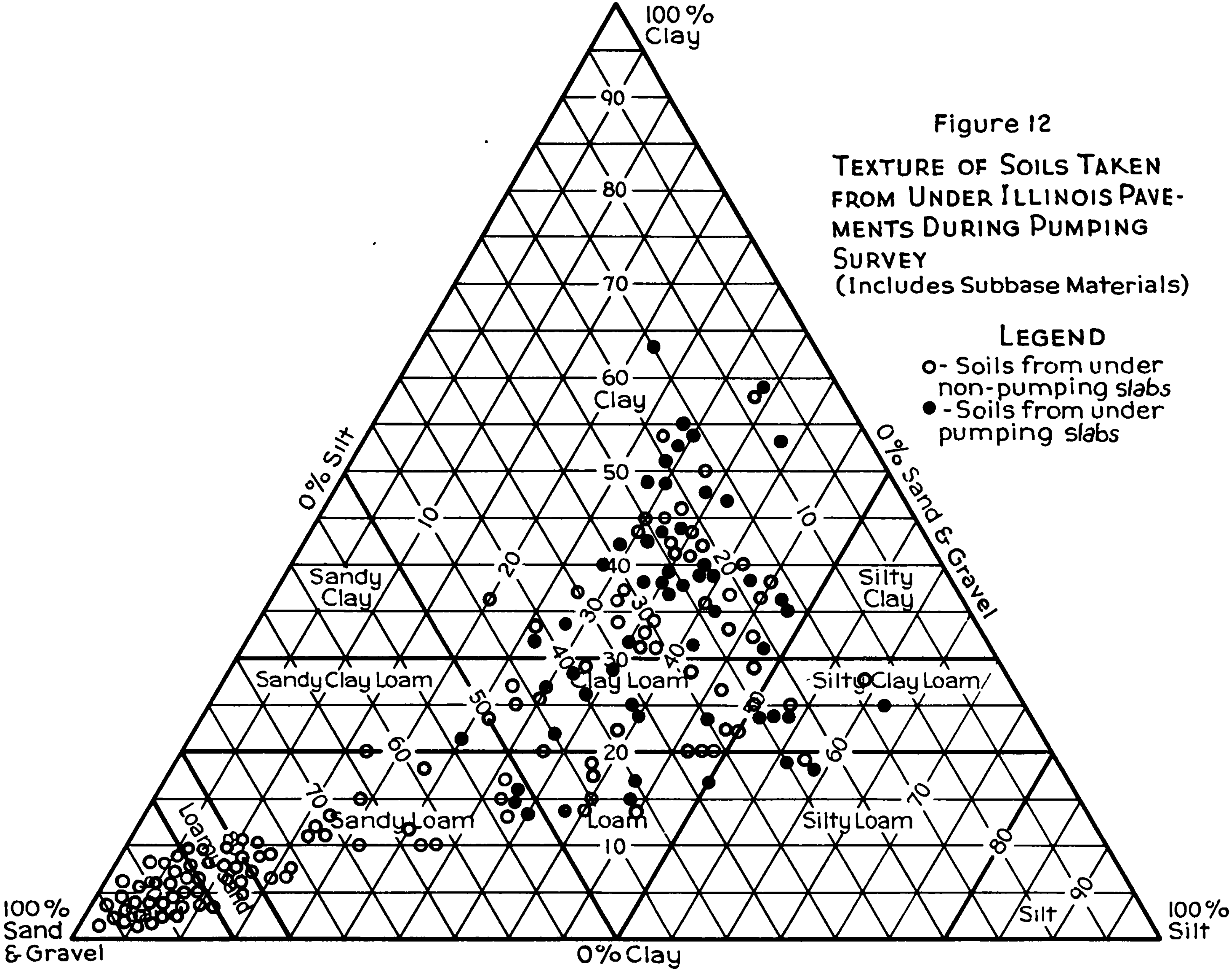


Figure 12

TEXTURE OF SOILS TAKEN FROM UNDER ILLINOIS PAVEMENTS DURING PUMPING SURVEY
(Includes Subbase Materials)

LEGEND
○ - Soils from under non-pumping slabs
● - Soils from under pumping slabs

TABLE 14

SUMMARY OF SUBGRADE SOIL CHARACTERISTICS--ILLINOIS PUMPING SURVEY

(Does not include subbase samples or
samples from subgrades under subbases)

	Total No. of Samples	(1) Ave. Field Water Content	(1) Ave. Field Density p.c.f.	Ave. Optimum Moisture Content %	Ave. Standard Density p.c.f.	Relative Density %	L.L.L.		L.P.L.		P.I.	
							Ave.	Range	Ave.	Range	Ave.	Range
Pumping soils (all contain less than 55% sand & gravel)	54	21.7	98.9	17.2	110.5	90.9	38.9	21-54	20.5	14-31	18.4	7-29
Soils not pumping but containing less than 55% sand and gravel	56	21.9	100.8	17.7	109.0	92.4	39.9	19-57	21.4	14-32	18.6	5-29
Non-pumping soils containing more than 55% sand and gravel	27	9.6	121.6	10.7	129.2	94.1	21.2 N.P.	NP-36	14.3 N.P.	NP-25	7.7 N.P.	NP-16

(1) 0-8" below subgrade

the use of granular subbases for the prevention of pumping on new construction. As mentioned previously, Illinois constructed in 1937 its first full length section of pavement on granular subbase used expressly for the prevention of pumping. Many additional miles of pavement have been placed on subbase since that time. A total of 56.9 miles of such pavement (plus an additional 11.0 miles not yet subject to heavy traffic) was included in the present survey. The observed performance of these pavements justified the earlier conclusion that they would not pump. No pumping was noted, even though the average intensity of traffic for these pavements was substantially the same as that for the pumping pavements placed on fine grained soils, (see Table 11 on page 28).

The subbases studied were generally of trench construction, six inches in compacted thickness and built two ft. wider than the pavements. No subbases had design thicknesses of less than six inches, except in a few instances where the granular subbase was used as a blanket course between a new and an old pavement and reached at times a minimum thickness of three inches. Subbases were extended to as much as 48 in. in thickness in areas of anticipated differential frost heave, and to replace soils offering poor support under prevailing moisture conditions.

Designs did not provide for subbase drainage except on three projects where the use of fairly open graded materials in the subbases was anticipated, and in connection with subbases used to correct for frost heave or low subgrade support in which an excess of moisture was expected to be present in the soil surrounding the subbase. Instead, materials of a gradation thought to give a relatively impervious subbase under normal compaction were specified.

Grain size curves of materials representative of all those used in the subbases of the survey are shown in Figure 13. It is evident that all granular subbases were of material which was fairly well graded. This includes those for which drainage was provided. All were very high in sand and gravel content (material retained on the No. 270 sieve).

No soil stains or ejected subbase material were found to indicate that pumping was taking place on any pavement placed on granular subbase, even though observations were made on many of these pavements under weather conditions most conducive to pumping.

Although no pavement with subbase was found pumping, and the major portion was performing in a satisfactory manner, light faulting was found at joints on some projects (see Table 16 on page 42). The pavement on these projects was of the 120 ft.-20 ft.jointing arrangement with no dowels at the contraction joints. Some had dowelled expansion joints.

In addition to the faulting, though not always in connection with it, some instances of eroded holes were found at the edges of pavements near joints and cracks. These holes had the same appearance as those usually identified with pumping, although no evidence was found of subbase material being ejected from underneath the pavement. Rather, several excavations in the shoulders showed shoulder material washed between pavement and subbase. Holes of this nature were found on projects having mesh pavements and expansion joints spaced at 100 ft. intervals (no contraction joints), as well as on projects having the 120 ft.-20 ft. jointing

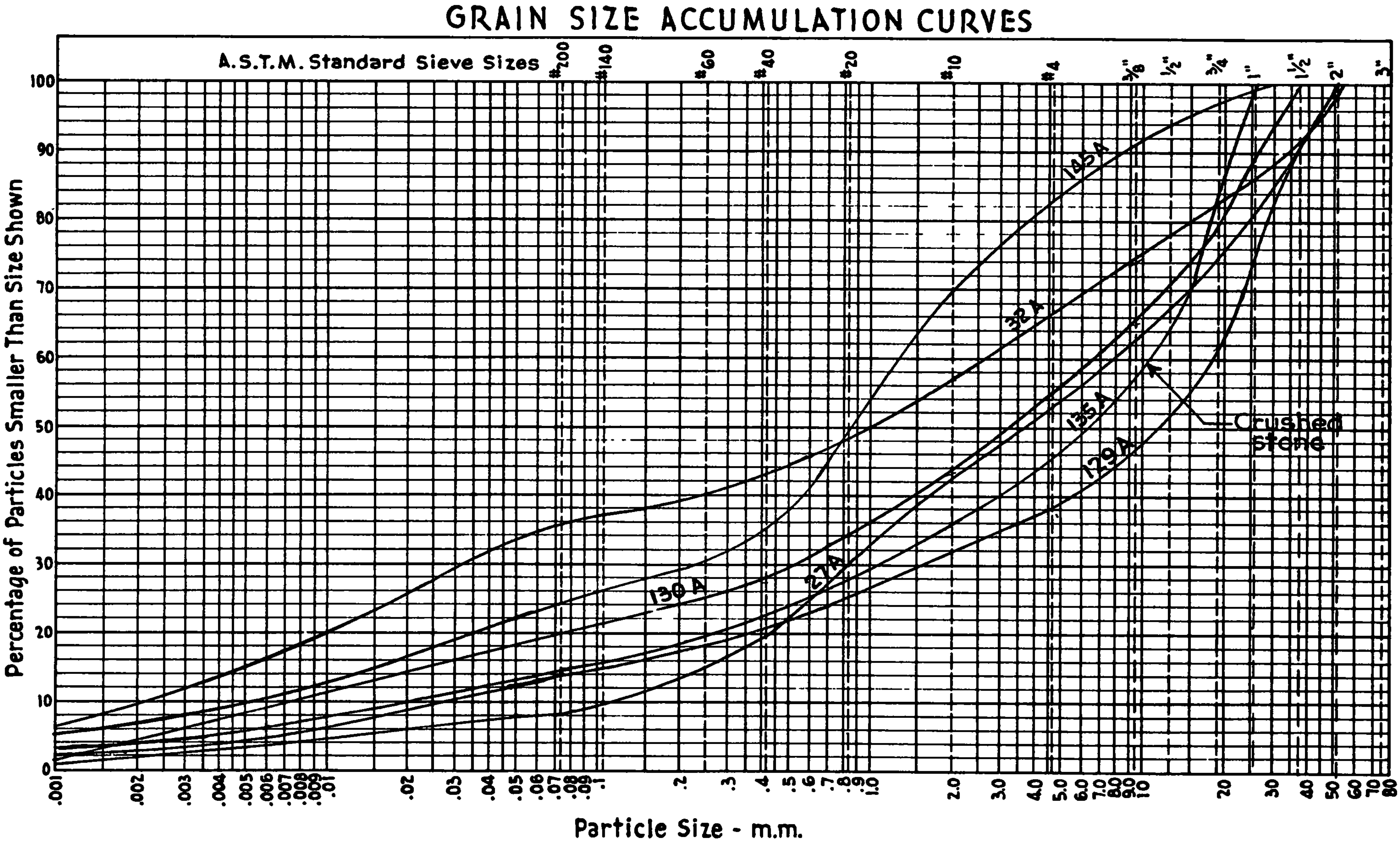


Figure 13

GRAIN SIZE CURVES OF TYPICAL SUBBASE MATERIALS
ILLINOIS PUMPING SURVEY

arrangement. It is quite likely that consolidation of subbase or subgrade under traffic has been largely responsible for both the faulting and the holes and that both can be substantially reduced by compaction of subbase and subgrade to a density capable of supporting the loads imposed without detrimental consolidation.

Free water was found in subbases in some instances, usually immediately after heavy rains. Although neither faulting nor "shoulder holes" could be definitely traced to free water in the subbase, it is more than likely that free water would hasten the consolidation of an insufficiently compacted subbase and cause their occurrence.

Free water was found on projects with and without drains. Both french and pipe drains had been used. On some projects these had been placed at infrequent intervals following construction. On two projects they were placed at 300 ft. intervals during construction. A single project having both lateral and transverse drains showed no free water but was visited during a dry period which made it impossible to determine whether or not this subbase would hold water for a considerable period of time following a heavy rainfall.

Water in the subbases did not appreciably affect the moisture contents of the underlying subgrades. This will be discussed later.

Not a single instance of intrusion of subgrade material into subbase was observed during the survey.

The many miles of granular subbase found to be giving completely satisfactory service indicate that pavement faulting and extreme saturation of subbase are not inherent to dense graded granular subbase construction, and can be prevented. Both appear to have been due largely to insufficient consolidation. Permeability tests disclosed that most of the subbase materials became relatively impervious when compacted to maximum density at optimum moisture content. The results of these tests, and others, will be treated in detail in the following paragraphs.

Permeability of Subbases

Permeability tests were made on a total of 23 of the subbase samples. These tests were made on the fractions of the samples passing the No. 4 sieve and compacted to maximum density at optimum moisture content. Samples were compacted in standard test cylinders and the coefficients of permeability determined by the "falling head" method. The range of permeability coefficients determined in the tests and the gradations of the materials tested (100 percent passing a No. 4 sieve) are shown in Figure 14.

The coefficients of permeability, as determined in the permeability tests and under the conditions noted, ranged between 0.000045 and 0.28 ft. per day. Since all of the total samples (inclusive of material retained on the No. 4 sieve) were fairly well graded, it appears that, under similar conditions of compaction and moisture content, the total samples would be even less pervious than their minus No. 4 sieve fractions. Therefore, the coefficients of permeability noted would seem to indicate that, with the possible exception of those materials having coefficients in excess of perhaps 0.1 ft. per day, the subbase materials studied

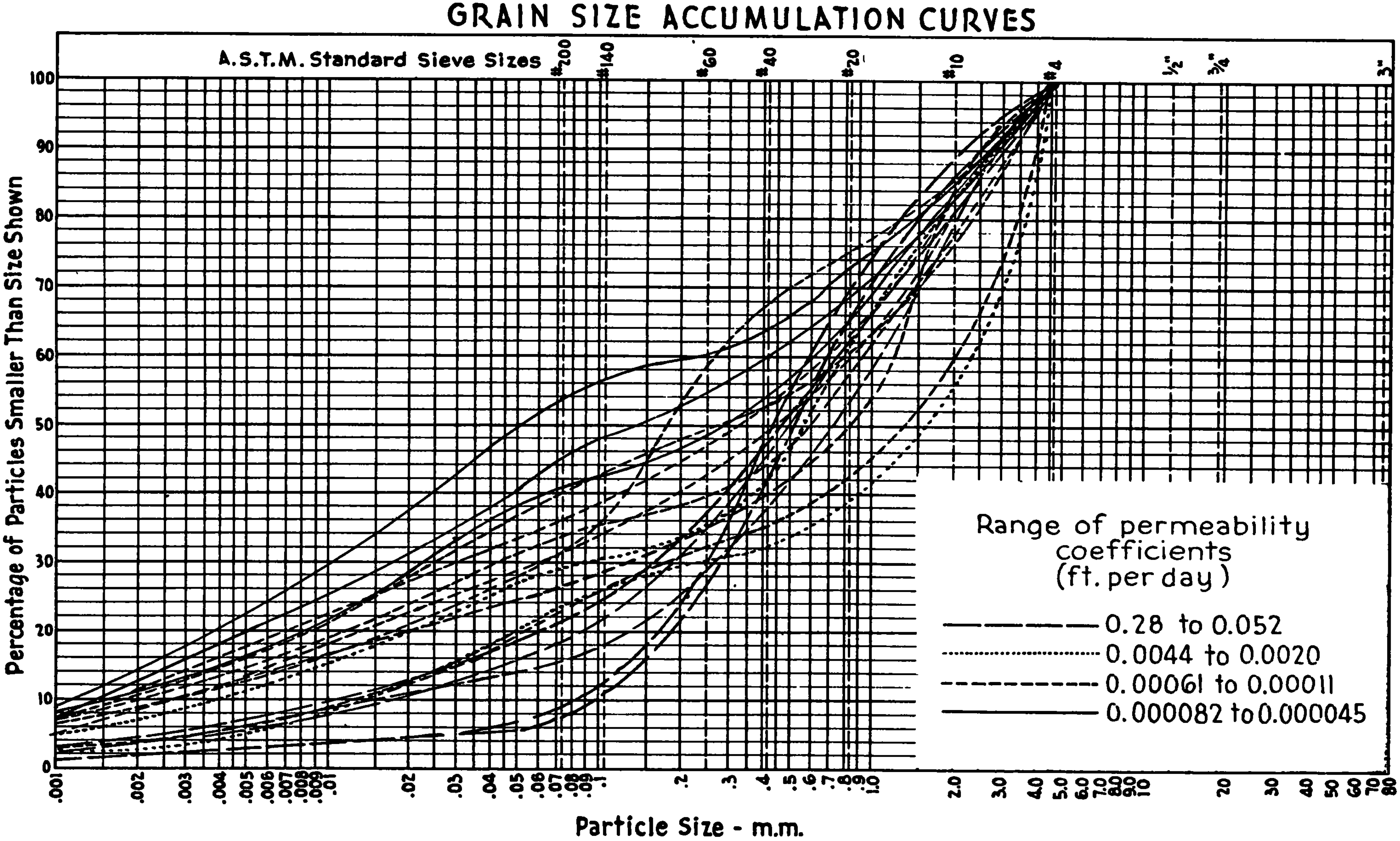


Figure 14

RELATION BETWEEN GRAIN SIZE AND COEFFICIENT
OF PERMEABILITY
(Samples compacted to maximum density at optimum moisture)
ILLINOIS PUMPING SURVEY

would, if compacted to maximum density at relative moisture content, prevent undesirable accumulations of water under the pavement. Furthermore, experience indicates that such compaction would prevent additional consolidation of the subbases under traffic.

An inspection of Figure 14 will show that, for the samples tested, there appears to be a relationship between the amount of clay and silt (material passing the No. 270 sieve) in the minus No. 4 sieve fraction and the coefficients of permeability. It will be noted that, in general those materials having the higher percentages of clay and silt had the lower coefficients of permeability. The same relationship will be seen to hold when the minus No. 200 sieve fraction content is considered instead of the clay and silt content (material passing the No. 270 sieve). All total samples (inclusive of material retained on the No. 4 sieve) had a clay and silt content well below the 55 percent figure, which, when exceeded, is indicative of a material capable of producing pumping.

No precise relationship could be established between the coefficient of permeability and the plasticity of the soil fines in the subbase materials. Plasticity indices ranged from N.P. to a high of 13, averaging 7.0 for the materials exhibiting plasticity. In general, those materials having the higher plasticity indices had the lower coefficients of permeability.

Relative Density of Subbases

Field density tests indicated that in most instances subbases were not compacted to maximum density as was done in the case of the permeability test samples. Average relative compaction based on the standard compaction test was indicated to be 94 percent. It is quite likely that many of the subbases in service were much more pervious than indicated by the coefficients of permeability as determined in the permeability tests. Unfortunately, it was not possible to determine densities at locations where water was found in the subbases because of the washing of material into the test holes.

Water Content of Subgrades Under Subbases

The average field water content of samples taken from subgrades underlying subbases (0-8 in. depth) was 22.5 percent, as compared with an average plastic limit of 21.3 percent. Variances of water content from plastic limit for the individual samples were not great, even though in some instances water was found in the subbase immediately over the point sampled. These values of field water content and plastic limit and the relation between them compares favorably with those shown for the fine grained subgrade soils of Table 14, indicating that the densely graded granular subbases did not cause an appreciable rise in the water content of the fine grained soils immediately below them.

Faulting

The amount and severity of faulting at joints and cracks determine to a considerable extent the riding quality of concrete pavements. Extensive faulting adds appreciably to maintenance costs if a satisfactory riding surface is to be maintained. Since much faulting results from loss of subgrade support caused by pumping, faulting was studied in detail during the present survey. The results, however, indicate that, though pumping is the leading cause of faulting, faulting of consequence occurs where there is no pumping. Unequal pavement settlement through additional consolidation or shifting of the subgrade plays an important part, as is attested by the fact that considerable faulting was found at joints and cracks of pavements supported by granular, non-pumping subgrades and granular subbases. This serves to emphasize the absolute necessity of carefully controlled compaction of fill, subgrade and subbase during construction.

As would be expected, load transfer was found to influence faulting. As will be seen from Table 15 faulting was less in amount and severity at those joints provided with load transfer devices. This applies to both expansion and contraction joints. It will be noted in the table that a considerable amount of light faulting occurred at contraction joints which depend on aggregate interlock for load transfer. Their failure to perform as anticipated is undoubtedly due to the close spacing (120 ft.) of expansion joints used in connection with them. This close spacing permitted the contraction joints to open an amount sufficient to destroy effective aggregate interlock. The most striking effect of load transfer will be seen from a comparison of the doweled and undoweled expansion joints of the 120 ft.-20 ft. jointing arrangement. It will be seen that the doweled joints, similar to the others except for the load transfer provision, show faulting considerably less in amount and severity than the undoweled joints. Load transfer devices, as previously noted, did not reduce the amount of pumping, but did lessen its severity.

The effect of the type of subgrade (fine grained and granular) on the amount and severity of faulting is shown in Table 16. Data showing the amount and severity of faulting on granular subbases are also included in the table. Results from the reconnaissance survey indicate the amount of faulting, while results from the detail survey indicate its severity. It will be noted that the amount and severity of faulting were greater for those pavements having fine grained subgrades, when compared with pavements on granular subgrades, although differences are not marked. The comparatively short period of service (ave. 2½ yrs.) of pavements on subbase prevents an equitable comparison of their faulting with that of the older pavements. As stated previously, the results of the survey indicate that much faulting is not the result of pumping but stems from weaknesses of support which can be largely eliminated through proper care in the densification of embankment, subgrade and subbase.

Table 17 compares the amount and severity of faulting at pumping and non-pumping joints and cracks of pavements placed on similar subgrades (predominantly fine grained). Data from the reconnaissance survey show the percent of pumping joints and cracks which are faulted to be three times that for non-pumping joints and cracks. The severity of faulting at pumping joints and cracks, as determined from measurements made during the detail survey, will also be seen to be greater. It will be noted in the table that the percent of pumping joints and cracks having faults of ¼-in. to ½-in. is three times that for non-pumping joints. It will also be noted that while 1.7 percent of the pumping joints and cracks showed faults of over ½-in., only 0.2 percent of the non-pumping joints and cracks showed such faults. These data indicate that pumping increased considerably the extent and severity of faulting.

TABLE 15

EFFECT OF LOAD TRANSFER ON FAULTING

Jointing Arrangement		Expansion Joints					Contraction Joints					Average Age of Pvt.
Exp.	Cont.	Load Trans.	Per Cent Faulted (Recon. Survey)	No. Meas. (Detail Survey)	Per Cent Faulted: >1/8"	Per Cent Faulted: >1/4"	Load Trans.	Per Cent Faulted (Recon. Survey)	No. Meas. (Detail Survey)	Per Cent Faulted: >1/8"	Per Cent Faulted: >1/4"	
(1) None	(2) None	None	76.9	12	66.7	58.3	None	80.4	48	60.4	43.8	21
800'	(2) None	None	84.5	38	60.5	29.0	None	80.3	47	51.0	23.4	16
90'	30'	Dowels J-Bars	41.0	247	40.9	11.7	Dowels J-Bars	24.5	508	22.5	5.3	11
50'	None	Dowels J-Bars Translode	39.6	332	39.8	7.5						7
120'	20'	Dowels	3.5	42	23.8	0	Aggre. Interlock Only	43.4	925	15.3	1.4	3
		None	49.5	144	43.0	11.1						

(1) A few expansion joints were cut following construction.
(2) Construction stops classed as contraction joints.

TABLE 16

RELATIONSHIP BETWEEN FAULTING AND SUBGRADE TYPE

Type of Subgrade	Data From Reconnaissance Survey: Miles of Pavement	Data From Reconnaissance Survey: Per Cent of Faulted Joints & Cracks	Data from Detail Survey: Number of Joints & Cracks	Depth of Fault (Inches)*: 0-1/8"	Depth of Fault (Inches)*: 1/8"-1/4"	Depth of Fault (Inches)*: ¼"-½"	Depth of Fault (Inches)*: ½"+	Age of Pvt. (Yrs.)
Fine Grained Soil	186.2	35.9	4,333	66.9%	24.4%	8.1%	0.6%	15
Granular Soils (Predominantly)	45.9	31.8	1,448	74.5%	20.1%	5.1%	0.3%	18
Granular Subbase	57.7	26.7	1,171	83.1%	14.5%	2.4%	0	2½

*The maximum depth of fault at any one joint or crack was used in compiling the percentages.

TABLE 17

RELATIONSHIP BETWEEN FAULTING AND PUMPING

(For Pavements on Subgrades of Predominantly Fine-Grained Soils)

	Data from Reconnaissance Survey		Data from Detail Surveys				
	Number of Joints & Cracks	Percent Faulted	Number of Joints & Cracks	Depth of Fault (Inches)*			
				0-1/8"	1/8"-¼"	¼"-½"	½"+
Non-Pumping Joints & Cracks	36,475	24.5	3,252	71.2%	22.9%	5.7%	0.2%
Pumping Joints & Cracks	12,983	67.6	1,081	54.0%	29.0%	15.3%	1.7%

*The maximum depth of fault at any one joint or crack was used in compiling the percentages.

SUMMARY

The paragraphs that follow summarize the principal findings of the survey of pumping in Illinois.

1. Pavements Design Features and Pumping — Design features of pavements were found to have in most cases some influence on pumping. However, no single feature of group of features were found capable of preventing pumping under all conditions of soil, traffic and moisture prevailing during the survey. The following is a summary of the relative effects of the various pavement components, based on observations made during the Illinois survey:

   a. Pavement Width and Geometric Design — Pavements 18, 20, 22, 24, and 40 ft. in width; 18 ft. pavements with 9 ft. widenings on each side; and 20, 22, and 24 ft. pavements separated by parkways or median strips were observed during the survey. Greater effects of other variables obscured the effects, if any of pavement width and geometric design. However, it was noted that pumping on multi-lane and widened pavements was confined almost exclusively to the outer lanes used by heavy traffic.

   b. Pavement Thickness — Pavements ranged from 6 in. to 10 in. in interior thickness. There was no indication that for the prevailing conditions of traffic and subgrade, thicker pavements pumped less than the thinner ones, although there was some indication thicker pavements offered greater resistance to severe pumping.

   c. Reinforcing — Pavements containing marginal bars, pavements containing distributed mesh, and unreinforced pavements were examined during the survey. Marginal bars did not appear to have much effect on pumping. Distributed mesh reinforcement almost eliminated pumping at intermediate cracks. However, for comparable conditions of traffic it was indicated that expansion joints in mesh reinforced pavements would be more susceptible to pumping than for pavements without mesh.

   d. Expansion Joint Fillers — Metal air chambered, bituminous fiber fillers, and poured bituminous fillers were examined during the survey. There was no significant difference between the amount of pumping on pavement with the air chamber and bituminous fiber fillers. Under conditions of service no fillers, as such, were found to be effective in preventing pumping. Less pumping developed at joints with poured fillers but most of these joints were tight as a result of their long spacing (approximately 800 ft.) and were packed tightly with sediment impregnated in the filler which probably prevented free entrance of water to the subgrade.

   e. Contraction Joint Type -- Construction joints acting as contraction joints, and full depth metal joints were the only types of contraction joints encountered during the survey (aside from ribbon contraction joints used on a single project having a fine grained subgrade). Pumping was found to occur at both types. Construction joints were used only with a long spacing of expansion joint. The metal joints were used only with expansion joints spaced at 90 ft. intervals. These features prevent a direct comparison between the performance of the two types of contraction joints. The omission or long spacing of expansion joints was found to have a definite influence on pumping.

f. Load Transfer — Dowel bars, J-Bars and Translode devices were observed during the survey. Wide variations in traffic, and an inadequate mileage of pavement prevented an equitable comparison between some of these devices. Load transfer devices as a whole were not found to reduce pumping. However, pavements with joints having load transfer devices showed somewhat less severe (Class 2 and 3) pumping than did those without any provision for load transfer. This indicates that load transfer devices were of some aid in reducing faulting and cracking due to pumping.

g. Cracks -- Compared with Contraction Joints — On pavements built with contraction joints, less pumping was found at the contraction joints than at intermediate cracks. The greater ease with which contraction joints may be sealed and the seal maintained is probably responsible for the smaller amount of pumping at these joints.

h. Joint Spacing — Jointing arrangements of pavements placed on fine grained soils and represented in the survey by a sufficient mileage of pavement for comparative purposes consisted of the following four arrangements:

1. Construction joints only, acting as contraction joints;
2. Expansion joints spaced at 800 ft. intervals (approximately) with construction joints acting as contraction joints;
3. Expansion joints spaced at 90 ft. intervals with intermediate contraction joints at 30 ft;
4. Expansion joints spaced at 50 ft. with no intermediate contraction joints.

Pavements of the latter group were the only ones having distributed mesh reinforcement. All evidence indicates that a relatively long spacing of expansion joints serves to reduce pumping considerably. This is to be expected since a minimum of expansion space holds the pavement in restraint much of the time, increasing its structural capacity and minimizing the opening of intermediate joints and cracks through which water may reach the subgrade.

i. Joint and Crack Opening — General observations of openings at pumping and non-pumping joints and cracks, substantiated by actual measurements made in the case of expansion joints at which accurate measurement could be made, showed pumping joints and cracks to be generally more open than those at which pumping was not taking place.

2. Pavement and Road Maintenance — Prompt and continued roadway maintenance was found to be effective in controlling pumping. Pavements with well sealed joints and well drained shoulders were found to develop less pumping. Subsealing was found to be effective where erosion of the subgrade had already taken place. However, it appears that to be fully effective, the sub-sealing process must be repeated from time to time.

3. Rainfall — Well distributed precipitation averaging about 33 in. per year was sufficient to cause pumping under observed conditions of soil and traffic.

4. Traffic — The volume and weight of axle loads are variables which determine to a considerable extent the amount and severity of pumping. Available data did not permit the development of any precise relationships between traffic loads and pumping. However, that traffic has a considerable effect was demonstrated in a number of ways. A comparison of the amount and severity of pumping of pavements placed on similar subgrades but carrying traffic of a different intensity showed considerably more, and more severe, pumping on the pavements carrying the heavier loadings. Pumping was found to be confined almost exclusively to the more heavily loaded outer lanes of multi-lane pavements. On a pavement carrying a widely different intensity of axle loadings in opposite directions, more pumping developed in traffic lanes carrying the greater number of heavy axle loadings.

5. The Subgrade and Pumping — As in previous studies, it was found that a fine grained subgrade soil, along with free water and heavy axle loadings, is a major factor causing pumping. The following is a summary of the findings of the survey in regard to the effects of subgrade soils and subgrade conditions:

a. Glacial Features — Pumping was found to occur more frequently in the rougher morainal areas of the survey region. This is apparently due to the fact that in these areas pavements are laid extensively on subgrades of fine grained, plastic soils of the "B" and "C" horizons. Greater depths in cuts are necessary to establish a satisfactory grade line in this hilly country. The less plastic and somewhat coarser "A" horizon soils making up a large percentage of the subgrades in the flatter intermorainal area are less prone to pump. The least amount of pumping was found in outwash and glacial lake areas in which granular soils predominate.

b. Cut, Fill and Grade — There was little difference between the amount and severity of pumping in cuts as compared with the pumping on fills. Less pumping was found on subgrades following closely the original ground line (grade). This was probably due to the predominance of topsoil subgrades known to be less susceptible to pumping.

c. PRA Groups and Pumping — Pumping was found on soils of the A2-4, A4, A4-7, A6 and A7 groups. No pumping was found on A1, A2 and A3 soils.

d. Soil Texture and Pumping — No pumping was found on subgrade soils or subbases containing more than 55 percent sand and gravel (material retained on the No. 270 sieve). Pumping was found to occur and not to occur on soils containing less than this amount.

e. Atterberg Limits and Standard Compaction Test — No precise relationships were established between Atterberg limits and pumping, maximum standard density and pumping, or optimum moisture and pumping.

f. Relative Density and Field Water Content — Field density tests indicated that for fine grained soils susceptible to pumping, relative densities were usually greater at locations at which no pumping had developed. For a depth of 8 in. below the pavement, the field water contents at pumping locations differed little from those at non-pumping locations for potentially pumping soils. The average in both instances was slightly above the average plastic limit. The relative density of granular non-pumping subgrades was generally greater than for fine grained subgrades and field moisture contents were usually well below the corresponding plastic limits.

6. Subbases — All subbases investigated were relatively dense graded materials. A few had been provided with pipe and french drains, most of which did not effectively drain the slowly permeable subbase materials. Subbases were usually constructed 6 in. in thickness and two feet wider than the pavement. As little as 3 in. of thickness was used in cases where a new pavement overlay an old pavement. As much as 48 in. was used to correct for frost heave and as a replacement for soils of low bearing power. Subbase materials were all granular, containing more than the 55 percent sand and gravel (material retained on the No. 270 sieve) found sufficient to prevent pumping.

No soil stains on the pavement or ejection of subbase material were noted where granular subbases were used.

Some light faulting was found at joints of pavement placed on granular subbase. This is evidently the result of insufficient consolidation. Free water found in some instances in subbase material is also believed to have resulted from insufficient consolidation. Permeability tests indicated most of the subbase materials to be relatively impervious when compacted to maximum density at optimum moisture. In general, the coefficients of permeability decreased as the silt and clay content (material passing the No. 270 sieve) increased. No direct relationship was established between permeability and the plasticity of the soil fines in subbase materials, although the less plastic materials were usually more permeable.

Field water contents of subgrades under subbases were substantially the same as for similar subgrades supporting pavements with no subbases.

No intrusion of subgrade into subbase was noted.

7. Faulting — Faulting was found to be greater in amount and more severe at joints and cracks where pumping was taking place. Faulting of consequence was found on fine grained soils, granular subgrades and subbases. In all instances provisions for load transference reduced substantially the extent and severity of faulting at joints.

CONCLUSIONS

The following principal conclusions have been drawn from the data obtained during the Illinois pumping survey and are believed to hold for similar conditions of soil, traffic and moisture.

1. The texture of the subgrade soil will determine whether or not is is susceptible to pumping. Soil containing more than 55 percent sand gravel (material retained on the No. 270 sieve), was found to prevent pumping. Pumping was found to occur and not to occur on soils containing less than 55 percent sand and gravel. Increased compaction reduces pumping.

2. Granular subbases will prevent pumping. Trenched subbases constructed a few feet wider than the pavement and not provided with any drainage facilities will give satisfactory performance if they are constructed of well graded materials and are adequately compacted. Permeability tests indicated that most of the subbase materials used in Illinois would prevent undesirable accumulations of water if compacted to maximum density at optimum moisture content. All of the subbases studied contained sand and gravel in excess of the 55 percent found sufficient to prevent pumping. Six inches of subbase was found to give satisfactory performance under the existing conditions of traffic and service.

3. A minimum provision of expansion space will lessen the amount of pumping likely to take place. It tends to hold joints and cracks tightly together, effecting better load transfer, and permitting a more effective sealing of joints and cracks and thus reducing the amount of surface water which may enter the subgrade. In addition, the pavement is placed in compression most of the time, thereby increasing its structural capacity and reducing the deflection of slab ends under loads.

4. In pavement built without mesh reinforcement, contraction joints which retain an adequate seal are less likely to pump than cracks. Very little pumping was found at intermediate cracks in mesh reinforced pavements.

5. Load transfer devices do not reduce pumping but do lessen its severity. Load transfer devices reduce faulting resulting from causes other than pumping, as well as faulting caused by pumping.

6. Nominal increases of thickness beyond that required to satisfy structural needs will not prevent pumping.

7. Prompt pavement and shoulder maintenance is effective in controlling and reducing pumping. Sub-sealing will effectively control pumping.

8. Pumping is the result of heavy axle loadings and generally increases in amount and severity with an increase in the number and weight of axle loads. Passenger and light commercial traffic do not cause pumping.