is suggested that research be continued in an effort to develop a satisfactory material.

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

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

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

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

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

1. That research be undertaken to determine the limits of grain sizes which prevent intrusion of fine-grained soils into subbases.
2. That research be undertaken to determine the permeability, drainage, and compaction (rolling) characteristics of various subbase materials as they are related to pumping.

PUMPING OF CONCRETE PAVEMENTS IN NORTH CAROLINA

A COOPERATIVE STUDY BY NORTH CAROLINA STATE HIGHWAY AND PUBLIC WORKS COMMISSION AND PORTLAND CEMENT ASSOCIATION WITH SOILS TESTS BY THE PUBLIC ROADS ADMINISTRATION

ABSTRACT

This report gives the results of a study made during the spring of 1944 to determine the extent and nature of pumping on the principal highways of the Coastal Plains and the Piedmont Region of North Carolina, the types of subgrade soils associated with pumping, and the effectiveness of selected soil subbases in preventing pumping.

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

The field studies described in this report were limited to observations and tests of pavement slabs and subgrades where traffic was causing mud to be ejected at slab ends and edges. Before field observations were begun, design and construction data were assembled for a major portion of the concrete pavement projects on the most heavily traveled east-west and some north-south traffic routes.

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

Pumping was classified into three classes according to the progressive stages of its de-

velopment as follows: (1) Pumping at joints and cracks without noticeable faulting at slab ends or breaking of slabs as a result of pumping; (2) Pumping accompanied by faulting with no evidence of breaking of slabs as a result of pumping; and (3) Pumping and faulting accompanied by breaking of the pavement as a result of loss of subgrade support due to pumping.

During the reconnaissance study, sections which were representative of pumping on a project, or sections on which no pumping had occurred, were noted for further study. Representative samples of subgrade soils, and where used, samples of subbase materials, were taken from under pumping or non-pumping transverse joints or cracks, the existing soils were classified pedologically into series and type, and the soil samples were tested by the laboratory of the Public Roads Administration for liquid limit, plastic limit, field moisture equivalent, shrinkage limit, and mechanical analysis.

Three major factors which govern the life and behavior of roads were considered in the studies They are· (1) the pavement, its design features and maintenance condition; (2) subgrade soils and their condition; and (3) traffic, including both weight and number of axles. Data pertaining to each of these factors were obtained during the survey and the relationship of these data to the nature and amount of pumping are presented here.

THE PAVEMENT

Cross Section: Five pumping projects of 8–7–8 in. by 18 ft cross-section and having an average age of 19 yr , a total length of 44 mi. and constructed without expansion joints, showed 2.3 per cent of all cracks pumping. Five pumping projects of 9–7–9 in. by 20 ft. cross-section and having an average age of 5½ yr., a total length of 49 mi. and constructed with expansion joints at 90 or 120 ft. intervals showed 7 per cent of all joints and 3.3 per cent of all cracks pumping. Traffic, based only on the total number of trucks per day, was nearly similar. All ten projects were on soils, a major portion of which were considered to be conducive to pumping Here the newer, slightly heavier and wider pavements which had a shorter crack and joint interval pumped more than did the older pavements.

Joints and Cracks: There was little difference in either the amount or the severity of pumping at expansion joints compared to the pumping at contraction joints. Pumping was more prevalent and more advanced at transverse cracks than at joints on pavements having expansion and contraction joints A total of 21 projects built with expansion joints spaced at intervals of 90 and 120 ft. and having a combined length of 118 mi. were investigated for pumping during the survey. Ten of these projects, built on soils considered as being conducive to pumping showed pumping ranging from 0.4 per cent to as much as 20 5 per cent of all joints and cracks pumping. Tables are given which show the relative amounts and nature of pumping at expansion joints, contraction joints and cracks.

Older pavements which were constructed without expansion joints on subgrade soils conducive to pumping showed less pumping (only about one-tenth as much) than did newer pavements built on similar soils and having expansion joints at 90- or 120-ft. intervals and intermediate contraction joints at 30-ft. intervals, both with load transfer devices. Evidence was found from observations made during detailed examination of sections that transverse cracks in the older pavements having no expansion joints were, in some instances, filled with debris and the slabs appeared to be in compression, but there was no evidence of distress as a result of the compression.

Pavement Widening: Nine projects consisting of old pavements 16 and 18 ft. wide and widening ranging from 4 to 10 ft. wide, were studied in the reconnaissance survey. Regardless of differences in cross-section, more pumping was found in the newer jointed widening than in the original pavement. This is in agreement with the relationship found for full width pavements built with and without expansion joints.

SUBGRADE SOILS

Soil Series and Horizon: North Carolina is divided into three major physiographic subdivisions They are the Costal Plains, the Piedmont and the Mountain Regions. Each of the regions constitutes a different parent

material group and forms two great soil groups as follows:

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

Eight soil series, each with a characteristic variation in texture of the A horizon were encountered on projects located in the Coastal Plain. One soil series, the Norfolk, was identified on 13 of the projects. Other series were encountered on from one to six of the projects. Twelve series were encountered in the Piedmont region. Typical mountain soils were not encountered in these studies A tabulation of the major soil series identified on projects studied, the number of projects on which each occurred, the horizon samples and a description of the pumping with which the pumping soils were identified, is given.

Pumping was not encountered on soils of the Norfolk or Ruston series in the Coastal Plain. The two series were identified on 15 projects. Drainage is well established in both the Ruston and Norfolk series. Pumping occurred on both the Portsmouth and Plummer series having friable B horizons but having poorly established drainage. Likewise pumping occurred on soils of the Lufkin, Elkton and Coxville series also of the Coastal Plain but having plastic B horizons. Pumping was not encountered on A horizon soils of the Piedmont Region

Physical Characteristics and Texture: All soil samples from under pumping slabs were of a plastic nature. Liquid limits and plasticity indices ranged from a low of 32 and 17 for a clay loam soil having 27 per cent clay with 16 per cent colloids and associated with light pumping to a high of 93 and 64 for a fat clay soil causing severe pumping. Nine of the 25 samples of soil on which no pumping was found were of a non-plastic nature. An additional seven samples were moderately plastic having plasticity indices of 15 or less. Eight soils had plasticity indices in excess of 15, five of these being clay soils with indices of 19, 20, 21, 23 and 30. No soil densities nor water contents were obtained during the studies which might have shown adequate reason for the non-pumping condition of these five clay soils.

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

Traffic—The total number of trucks per 24 hours was nearly the same for the three groups of projects built on soils conducive to pumping, that is, pavements built without expansion joints and pavements having expansion joints at 90 or 120 ft. intervals. The projects which were built largely on soils considered not being conducive to pumping, and on which no pumping or very little pumping occurred had less truck traffic. Average truck traffic for the three groups of "pumpers" was 546 and for the three groups of "non-pumpers" it was 306 trucks per day. It cannot be said, however, that this pumping or lack of pumping is due to the difference in traffic. Traffic is unquestionably a factor but the data indicate that the type of soil is more important

THE USE OF SUBBASES

Nine projects constructed with subbases were visited and joint and crack data obtained. No pumping was found Subbases examined and sampled were built in trench section of pavement width The average thickness ranged from 3 to 4 in Pavements were of 8–6–8, 9–7–9 and 7- in. uniform thickness and were of 20-, 22-, 36- and 37-ft widths except one widening project which was 6 ft wide. All except one had either 90-ft or 120-ft. expansion joint spacing. All had ¾-in. dowels at expansion and contraction joints. Excepting the 6 ft. widening, which had 18 transverse cracks per mi , the projects which were constructed with subbases showed little transverse cracking

The materials used for subbase construction on the projects sampled consisted of selected soils of sand, loamy sand, and sandy loam tex-

ture. With one exception all subbase materials had combined sand and gravel contents of 70 per cent or more. Only three samples had clay contents in excess of 10 per cent. Subbase soils ranged from well graded materials to gradings having as much as 50 per cent of the total material between the No. 20 and 60 sieves. All had little or no volume change and all were densely graded to the degree that they restricted the downward movement of surface water and thus served to protect the underlying plastic subgrade soil.

PUMPING OF CONCRETE PAVEMENTS IN KANSAS

A COOPERATIVE STUDY BY KANSAS STATE HIGHWAY COMMISSION AND PORTLAND CEMENT ASSOCIATION

ABSTRACT

Pumping of concrete pavements in the vicinity of transverse cracks and joints was first observed in Kansas in the spring of 1935. Since 1935, pumping has become more widespread and has occurred in localities where the traffic includes concentrations of heavy industrial trucks.

A cooperative study was made during the spring and summer of 1945 by the State Highway Commission of Kansas and the Portland Cement Association to determine the extent of pumping, its causes, and means of preventing its occurrence on new construction. The study was divided into three phases; reconnaissance, detailed surveys of sections of non-pumping and pumping pavements, and load deflection studies at various locations selected during the detailed surveys. The reconnaissance was made during one of the wettest spring seasons on record in Kansas.

SURVEYS AND TESTS

The reconnaissance survey covered 237.6 mi. of concrete pavement on the heaviest traveled routes in Kansas and was made to assess the degree and extent of pumping on the principal traffic routes during the spring wet weather season when pumping is most widespread, most severe, and easiest to detect. Pumping was divided into three classes: (1) at slab ends at joints and cracks with no evidence of faulting at slab ends or breaking of slabs; (2) pumping accompanied by faulting but with no evidence of breaking of slabs; and (3) pumping accompanied by faulting and breaking of the slab. Sections of each project which appeared to be typical of pumping or non-pumping portions were noted for further observations during the detailed study.

After the reconnaissance survey, a detail study was made of the selected sections, which totaled 54 on 36 projects. Selection was based largely on uniformity of subgrade soil throughout a length sufficient for observing absence or presence of pumping, faulting, joint opening and related items.

The purpose of the detail study was to examine closely all the variables which may affect pumping. Considerable time and effort were expended in the examination of joints. Fillers were removed and excavations made at the edges of the slab to insure that pumping was observed even when it was in its earliest stages. Each section studied was mapped and the subgrade sampled.

Samples of the subgrade were taken from two locations. Those for determination of water content, density, and for routine tests were taken through core holes drilled through the pavement. Those for determining moisture-density relations in the compaction tests were taken under the edge of the slab.

Soil samples were tested in the central soils laboraory of the Kansas State Highway Commission. The following tests were made: liquid limit, plastic limit, mechanical analysis and specific gravity. Standard compaction and optimum water content determinations were made on the large samples taken from under the edge of the pavement.

All observations and measurements made on each section in the detail survey, test data on