monthly percentage ordinates for the two figures, plus the additional 13.9 per cent for differentials less than 1 deg. F., results in a total of 100 per cent. It may be seen that the principal durations of the larger differentials with top of slab warmer are during the spring and summer months. It may be seen that the time intervals with the top of slab colder are rather well distributed throughout the year, except for the intervals where the differential is more than 12½ deg. F. These latter represent only 0.40 per cent of the annual time.

SUMMARY OF DATA

Maximum temperature surface of slab	122 F.
Maximum temperature center of slab	111.5 F.
Average annual range in air temperature	112 7 F.
Average annual range in center of slab temperature	114.3 F.
Midpoint in average annual range in center of slab temperature	50.4 F
Average date for frost to penetrate 5 ft. below slab	Jan. 14
Average date for frost departure in spring	Mar. 23
Average number of freezing and thawing cycles per year:	
Top of slab	48
Bottom of slab	24
One foot below slab	2
Minimum subgrade temperatures:	
Two feet below slab	+10 F.
Five feet below slab	+23 F.
Maximum continuous drop in average slab temperature	35 F.
Duration of slab temperature differentials in percentage of the annual time:	
Top of slab colder: (67.83 per cent of time)	
1 deg. F. per inch	12.49%
2 deg. F. per inch	0.20%
Top of slab warmer. (32.17 per cent of time)	
1 deg. F. per inch	10.42%
2 deg. F. per inch	4.69%
3 deg. F. per inch	1.73%

DEPARTMENT OF MAINTENANCE

W. H. Root, *Chairman*

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

Harold Allen, *Chairman, Principal Materials Engineer, Public Roads Administration*

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SYNOPSIS

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

The North Carolina and Kansas surveys were made on a cooperative basis by the respective State highway departments and the Portland Cement Association. Abstracts of these reports are included as a part of this report. The full text of the reports will be published as a special Research Report supplementing the reports issued in 1945.[1] The conclusions presented in these reports are those of the authors and do not necessarily represent those of the committee.

[1] "Special Papers on The Pumping Action of Concrete Pavements," *Research Reports* No. 1-D, Highway Research Board, 1945

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

PUMPING OF CONCRETE PAVEMENTS IN NORTH CAROLINA

A COOPERATIVE STUDY BY NORTH CAROLINA STATE HIGHWAY AND PUBLIC WORKS COMMISSION AND PORTLAND CEMENT ASSOCIATION WITH 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-