Performance of Concrete Pavements as Related To Subgrades, Subbases and Structural Design

J. R. SCHUYLER AND RALPH STELLJES,
New Jersey State Highway Department

The evolution of concrete pavement in New Jersey over the past 35 years is traced to show how the current empirical design criteria were derived. In trying to prevent the pavement failures caused by an ever-increasing number of heavy trucks, it became apparent that the economical solution to the problem was to construct a more stable foundation rather than to increase the surface thickness. The influence of stabilized shoulders on pavement performance has also been recognized.

Sections of pavement on two of the major trucking routes are evaluated in this paper. For each section, pertinent information regarding the subgrade, subbase, pavement, and traffic is included.

• THE PERFORMANCE of concrete pavements is directly related to the weight and frequency of wheel loads and the nature of the foundation. Many of the problems encountered in concrete pavement foundations are directly related to the engineering properties of soils and the environment in which the soils exist or are placed. Evaluation by observation has developed the current empirical design criteria in New Jersey for concrete pavement and subbase. These criteria place considerable emphasis on weight and frequency of wheel loads, climate, and the engineering properties of soil in the pavement foundation.

TRAFFIC

A combination of several factors has produced unprecedented volumes of heavy commercial traffic and very high traffic densities. New Jersey is an urban state with a population density second only to that of Rhode Island. Although small (forty-fifth in size), it is rated sixth among the states in industrial capacity. Geographically, New Jersey lies at the hub of the Atlantic Seaboard between Boston and Washington and on the main corridor between New York and Philadelphia.

Highway traffic funnels into the state at the rate of 200,000,000 interstate crossings a year. At some locations on the 1,800-mile state system, peak loads of 135,000 vehicles a day are encountered with annual daily averages in excess of 100,000 vehicles. On the corridor routes heavy trucks average between 30 and 50 percent of the vehicular total. Therefore, to cope with the enormous volumes of heavy commercial traffic, pavements have to be designed to withstand, at present day volumes, the movement of a minimum of 350,000 tractor semi-trailers annually. By law, maximum axle loads are 32,000 lb on tandem axles or 22,400 lb on single axles. In brief, pavements must be practically indestructible to carry, for at least 20 years, an average daily volume of 11,000 vehicles per mile — seven times the national average. Maintenance or reconstruction of pavements under these circumstances is rather difficult, or almost impossible at some locations.

CLIMATE

New Jersey, situated on the Atlantic Seaboard, is in the humid continental or intermediate climatic zone with its southern boundary in close proximity to the northern extremity of the humid subtropical climatic zone. Climate is characterized by temperatures ranging between 0 and 100 F with average temperatures between 40 to 55 F, with an annual mean of approximately 50 F. Precipitation is between 40 and 60 in. annually, with relative uniformity throughout the year, except for slightly higher amounts of rainfall occurring during the summer months. The isoline of the mean freezing index of zero cumulative degree-days, determined on the basis of mean temperatures for a minimum period of 10 years, passes approximately east and west, slightly north of the center of the state. Average winters are characterized by cycles of freezing and thawing, which substantially affect the base beneath the pavements. Severe winters, occurring approximately every seven years, produce frost penetrations on the corridor highways between 1 and 4 ft for a duration of an average of two months. In addition, the ground surface and bases of pavements are subjected to the influence of cyclic freezing and thawing. The detrimental ramifications of the freeze-thaw cycle (such as heaving, loss of strength of subgrade, and trapped water) have had a pronounced influence on the evolution of the current empirical design criteria for concrete pavement subbases.

GEOLOGY AND PEDOLOGY

The southeast and east central portion of the state, commonly referred to as the Coastal Plain, is formed chiefly by clay, sand, sand and gravel, and marl beds overlain by sands and gravel of varying thickness. Pavement design problems are relatively simple in this region because the clay and marl beds are rarely encountered, due to the fact that excavations are relatively shallow in ground surface which is mostly flat or with slight relief.

Along the east bank of the Delaware River and extending in a northeast-southwest direction to Raritan Bay are deposits of clay, sand-clay and silty sand exposed at the ground surface as irregular parallel bands. Superimposed on the bedded clays are more recent sands and gravels, the product of cyclic deposition and errosion. These more recent unconsolidated deposits are most erratic in both depth and plan. This belt, commonly called the Inner Coastal Plain, is traversed by the principal north-south corridor route, carrying a very high percentage of trucks. Because of the erosion, the topography has been dissected to a subdued hilly region, with the consequence that modern highway alignment and profile seldom avoid the clays and sand-clays of this portion of the state. Pumping was first observed in pavements laid on these soils in 1931.

The unglaciated portion of the northwest central portion of the state is comprised of surface exposures of sedimentary and igneous rocks overlain by remnants of old glacial deposition. The igneous rocks appear as ridges and hills at higher elevations, and surround the sedimentary rocks, shale, sandstone, argillite, and limestone. The residual soils of this region, derived from the parent rock formations, are basically fine sands, silts, silty-clays, or clays, depending on the degree of degradation which has occurred.

It is interesting to note that some of these soils can be transformed from an A-2-4 to an A-7 HRB classification by construction manipulation and construction traffic with the aid of some rain. Two of the principal east-west highways traverse the valleys of this region where subgrade soil conditions can be classified as possibly the poorest in the state.

The most violent pumping has occurred in this area. Because of the large volume of heavy truck traffic, these very poor subgrade soils, generally supplied with adequate amounts of surface and underground water subjected to cyclic freezing and thawing, have presented the severest challenge to pavement designers during the past 25 years.

The northern part of the state is entirely glaciated. Throughout this portion, bedrock is overlain by deposits of the Wisconsin Glacier, which include the terminal moraine, recessional moraines, till and stratified drift. Due to the ruggedness of the topography, the depth of these deposits tends to be greatest in the valleys and thin to non-existent on the hills and ridges. Bedrock formations are predominately sedimentary, or conglomerate; however, some formations of igneous rock are present. Depending on bedrock formation and its proximity to the ground surface, generally the finer soil fractions are derived from the parent rock, whereas the coarser soil fractions may have originated from distant points and from entirely different formations. In this rather rugged terrain, control of grading operations by specifying granular soil in the upper portions of embankment, and an abundance of granular borrow, produce good to excellent subgrades.

PAVEMENTS

For many years, pavements on the New Jersey State Highway System have been constructed of reinforced concrete, uniform in cross-section, and with expansion joints at specific intervals. From the following brief history of the changes in pavement design during the past 35 years, it will be evident that the changes in structural design have generally been minor and that the performance of the pavement under heavy truck traffic is primarily a reflection of subgrade stability. Increased use of stabilized or bituminous surfaced shoulders in recent years, in place of stone or gravel shoulders with a maximum of 15 percent passing the No. 200 sieve, appears to have improved the performance of all pavements markedly.

Changes in the structural design of concrete pavements have been based on field observations of the performance of either standard or special experimental sections of pavement on the state highway system. The changes in design from 1920 to the present, together with the reasons for the changes, where known, are presented in the following discussion. For simplicity, the design has been broken down into its various components, such as, thickness, width, slab length, etc.

Thickness

From 1920 to 1923 the thickness of the concrete was 8 in. In 1923, in anticipation of heavier traffic, the standard was changed to 9 in. Because of damage which had been observed on certain of the truck routes, the standard thickness was increased in 1934 to 10 in. for pavements in metropolitan areas and on truck routes. In 1955, based on the equally satisfactory performance of both 8- and 10-in. pavement on one of the major truck routes, standard thicknesses were reduced to 9 in. in urban areas and 8 in. in rural sections.

Lane Width

Since 1920, lane-at-a-time construction has been standard practice. Generally from 1920 to 1942, the lane width was 10 ft. From 1927 to 1929, some three-lane roads were constructed 29 ft wide, with two 14.5-ft wide slabs. From 1942 to 1946 there was a period of transition, some projects being constructed with 11-ft lanes; on others a combination of 11- and 13-ft lanes was used. Since 1946, the standard width has been 12 ft.

Slab Length

The length of slab has been varied considerably over the years. Prior to 1925 the slabs generally ranged in length from 60 to 85 ft. From 1925 to 1930 the slabs were 33 to 37.5 ft long. During the next three years, slabs were generally 45 ft long. From 1934 to 1945, the standard length was 56 ft; from 1946 to the present, the standard has been 78 ft.

During this entire period some projects were constructed in which the length of slab differed from the standard. This was especially true during 1946 and 1947, when a number of projects were constructed with slabs ranging in length from 56 to 134 ft. Although slabs of all of the aforementioned lengths proved successful, the difficulty in sealing the joints between the longer slabs, with the development of restraint cracks, led to to the adoption of the current 78-ft standard.

Reinforcement

For the entire period, from 1920 to the present, the specified reinforcement has been ⅜-in., round deformed bars, at first on 8-in. centers, then later on 7½-in. centers. As an alternative, welded wire fabric with 00 longitudinal wires on 6-in. centers has also been permitted.

Welded wire fabric has been used regularly in the Northern New Jersey metropolitan area for at least 25 years. Since 1945, welded wire fabric has been used almost exclusively throughout the state. The extremely high cost of labor has made the use of deformed bar mats more expensive than welded wire.

Transverse Joints

Since 1920, standard designs have called for the installation of dowelled expansion joints at specified intervals. As described under "Slab Length," the interval has varied considerably over the years.

For many years, the filler employed to create the expansion space was of premolded asphalt. A thickness of ½ in. was required from 1920 to 1935. In 1936 and continuing until 1942, the thickness was ¾ in. From 1942 to 1945, because of the steel shortage, the few defense roads that were constructed were of plain concrete with contraction joints at close intervals. From 1945 to 1950, wood, cork, and bituminized fiber fillers were installed, a particular filler being specified for each project. Since 1950, the standard has been bituminized fiber.

From 1920 to 1932, the design standards required six ¾-in. round dowels per lane of pavement. In 1931, joint faulting was observed on certain truck routes. On these routes, pavements constructed during the next two years had 12 dowels across the joints instead of the customary six. During this period, a test circle was constructed to evaluate the performance of many different load-transfer devices. Heavy truck traffic was simulated by means of a truck-trailer that operated continuously. As a result of this test, the standard joint device from 1934 to 1944 had twelve channel-shaped dowels per 10-ft lane of pavement. These heavy channel sections effectively prevented faulting, but on very poor subgrades both sides of the joint became depressed, with a resultant sag in the pavement. This condition was eliminated by the use of subbase.

In 1944, an investigation of wide cracks in a section of pavement showed that corrosion of the channel-dowels had caused seizure. Investigations to determine the most satisfactory dowel size, shape, and method of corrosion-proofing resulted in the joint device that has been essentially standard since 1946. The 1¼-in. round dowels are encased on the sliding end in either stainless steel or monel metal. On stable subgrade with adequate subbase, these dowels seem to be performing satisfactorily.

Unreinforced Pavements

From 1942 to 1952, a limited number of projects were constructed without reinforcing steel. On truck routes, the pavement was 10 in. thick and the undowelled contraction joints were spaced about 15 ft apart. The performance of these pavements has varied considerably.

SUBBASE

In New Jersey, subbase is defined as one or more courses of soil or aggregate, or both, of planned thickness and quality placed immediately below the portland cement concrete pavement and above the foundation soil. The subbase is designed to accomplish one or all of the following functions:

1. Provide uniform, stable, and permanent support for the pavement.
2. Reduce the stresses imposed on the foundation soil.
3. Reduce the damaging effect of frost action, principally the loss of foundation support due to cyclic freezing and thawing.
4. Reduce the accumulation of water under the pavement.
5. Prevent all pumping of any nature.

6. Expedite construction.
7. Reduce volume changes in the subgrade.

For many years, a token quantity of subbase was included in most contracts, to be used at the discretion of the engineer in charge of construction. If very wet or unstable areas were encountered during construction, a relatively thin layer of subbase was used in these spots. In 1938, larger quantities of subbase were called for, but again, only in those areas where the engineer deemed it necessary. The thickness under these circumstances, however, was designated to be between 8 and 12 in.

In 1940, it was decided that subbase should be used on all projects and that the thickness should be 12 in. in the normally cooler northern half of the state and 8 in. in the southern half. This practice is still maintained and the results appear satisfactory. Specifications for subbase materials were progressively tightened in order to obtain increased stability under all conditions. The current specifications have been used, with minor modifications, for the last ten years, and appear to fulfill the New Jersey requirements.

The subbase is constructed of granular material in a drained trench extending the full width of pavement and shoulders. Since the material specified is porous, the subbase is provided with a drainage system which functions except when the subbase is frozen. Basically, the subbase drainage system at the low points in the grade (or every 600 ft) consists of outlet trenches, which are filled with a filter material, beneath and extending for the full width of the subbase. These trenches are drained by means of a pipe to the catch basin at the low point in the grade or to the slope of the embankment.

Observations by means of test pits at the edge of the pavement and removable plugs installed in the pavement have confirmed the findings of many others. During the frost-melting periods, and particularly in the spring, since the thaw progresses from the bottom of the pavement downward, at a more rapid rate than it does in the shoulder, excess moisture is released which cannot drain through the still frozen soil below, or into the shoulder and laterally beyond. When the subbase immediately below the pavement is subjected to cycles of freezing and thawing, with a layer of permanently frozen subbase and foundation soil below this, it becomes very evident, based on conditions described previously, that the availability of surface water must be reduced to the greatest extent possible by well-maintained shoulders and adequate sealing of all joints and cracks. As a result of a frozen barrier surrounding a saturated zone of subbase, and a large volume of heavy traffic, it is apparent that the design of the subbase should provide uniform and stable support for the pavement under the most adverse conditions.

It is assumed that a subbase in which a rather high maximum density can be produced will provide a uniform, stable support for the pavement. The performance of concrete pavements constructed on old macadam roads in New Jersey verifies this hypothesis. The limits of size, distribution of aggregate and soil mortar for the subbase are determined in the following manner. The theoretical grading curve for maximum density, as developed by A. N. Talbot, is first derived. The maximum size of coarse aggregate used for the calculation of this theoretical curve varies between 4 in. and ¾ in., commensurate with locally available bank-run sand and gravel deposits. After the ideal grading for maximum density has been derived, grain-size distribution curves of locally available bank-run granular materials are compared with the ideal curve. The maximum and minimum percentages of material allowed to pass given sieves for the specification of soil aggregate being developed are drawn parallel to the theoretical curve, with the various local sizes influencing but not governing the selection of the "band" for the tentative subbase specification.

The tentative subbase specification band is then altered, if necessary, in accordance with the Casagrande criteria,

TAB
CONCRETE PAVEMENT CONDITION AS RELATED TO

Route and Section	Foundation Soil: H.R.B. Soil Class	Foundation Soil: L. L.	Foundation Soil: P. I.	Subbase Thickness, in.	Pavement: Date Constructed	Pavement: Thickness and Type[1]	Pavement: Longitudinal Joint[2]
US 130 1B	A-2-4 A-4	26 35	6 10	12	1947	10 in. Uniform	Keyway
US 130 26	A-4 A-6 A-7-5 A-7-6	20-35 25-55	3-10 11-25	Varies 9 - 14 Also none	1936	9 in. Uniform	Plain butt
US 130 25C & 22D	A-2-4 A-4	0-25 20-30	0-6 3-10	12	1947	8 and 10 in. Uniform[9]	Keyway
US 130 25D	A-2-4 A-4	0-30 20-40	0-10 3-15	12	1948	10 in. Uniform	Keyway
US 130 33A	A-2-4 A-4	0-30 20-40	0-10 3-15	8	1941	10 in. Uniform	Plain butt
US 130 10A 11A	A-4 A-6	20-35 25-55	3-8 11-25	12 Subbase 6 Selected material	1949	10 in. Uniform[7]	Keyway
US 130 10A 11A	A-4 A-6	20-35 25-55	3-8 11-25	Same	1949	8 in. Uniform	Keyway
US 130 10A 11A	A-4 A-6	20-35 25-55	3-8 11-25	Same	1949	10 in. Uniform	Keyway
US 1 4	A-2-4 A-4	0-30	0-10	None	1931	9 in. Uniform	Plain butt
US 1 4	A-2-4 A-4	0-30	0-10	8	1940	10 in. Uniform	Plain butt
US 1 5	A-2-4 A-4	0-30	0-10	Tapered 4 to 8 Tapered 6 to 12	1945	9 in. Uniform	Plain butt
US 1 6	A-2-4 A-4	0-30	0-10	Tapered 4 to 12	1953	9 in. Uniform	Plain butt
US 1 8	A-4 A-7-5	30-50	8-15	6	1928	10 in. Uniform[9]	Plain butt

LE 1
SUBGRADE, SUBBASE, AND STRUCTURAL DESIGN

Transverse Joints			Traffic[4], 1955	Pavement Condition
Spacing, ft., and Type[3]	Filler	Dowels		
56 to 89	1" Cork	1¼" Galvanized 12" c-c	1,700	Very good; no faulting at joints; some 56-ft slabs cracked during the first night, but to date the cracks have remained tightly closed.
56	½" Premoulded bituminous	2" Channels[5] 12" c-c	1,900	Because of dowel seizure, there are many wide cracks in the pavement. Where subbase was used, the cracks have not faulted and the pavement is generally in good condition. Without subbase, the cracks have faulted and the pavement has required mudjacking.
None except tied construction joints			1,800	This pavement, in spite of the many closely-spaced cracks inherent in this design, still rides well, probably because of the subgrade support. Breaks at four locations are apparently the result of stresses rather than subgrade failure.
78	¾" Wood filler	1¼" 12" c-c Stainless clad	1,700	Excellent; no faulting of joints; no cracking.
56	¾" Premoulded bituminous	2" Channel bars[5] 12" c-c	1,700	Pavement generally very good structurally. Dowel seizure has caused several wide cracks between joints. More generally, cracks have occurred at the end of the dowels. Sheet metal flashings have caused serious spalling at many joints.
15[8]	Groove type	None	1,700	Pavement uncracked, joints faulted ⅛ in. average.
89	¾" Wood	1¼" Stainless clad 12" c-c	1,700	Excellent; no cracks or faulted joints.
78	¾" Wood	1¼" Stainless clad	1,700	Excellent; no faulting at joints. The few cracks in one area occurred during early life and may be due to inadequate curing. These cracks are still hairline in width.
35	½" Premoulded bituminous	¾" 10" c-c	3,000	Only small sections of the original pavement remain and these areas are generally fair to poor. Pumping and faulting was so severe and pavement deterioration so advanced that sections were removed and replaced with new pavement on subbase (1945, 1950, 1953).
51.5	¾" Premoulded bituminous	2" Channels[5] 12 dowels in 10 ft.	3,000	Widening lane, southbound. Generally in good condition. Some cracks because of seizure of the channel dowels. Where cracks are wide, there has been some faulting but no pumping.
38	¾" Wood, grain vert.	2" Channel bars 12" c-c	3,000	Generally good. Some of the slabs settled slightly, probably due to settlement of the poorly consolidated sand subbase.
70	¾" Bituminized fiber	Tubular stainless clad 12" c-c	3,000	Very good condition.
35	½" Premoulded bituminous	¾" Dowels 20" c-c	3,500	No shoulder. Curb-to-curb section. Structurally fairly good; some faulting; surface badly worn.

TABLE 1

CONCRETE PAVEMENT CONDITION AS RELATED TO

US 22 7B	A-4 to A-6	25-40	3-15	12	1951	10 in. Uniform	Keyway
US 22 (28-29)	A-4 to A-6	25-40	3-15	12	1949	10 in. Uniform	Keyway
US 22 25C	A-4 to A-6	25-40	3-10	12	1946	10 in. Uniform	Keyway
US 22 24B	A-4 to A-6	25-40	3-10	8	1946	10 in. Uniform	Keyway
US 22 30	A-4	33	10	12	1952	10 in. Uniform[7]	Keyway

[1] Reinforced unless otherwise noted.
[2] No ties unless otherwise noted.
[3] Expansion unless otherwise noted.
[4] One-way; A.A.D.T. tractor semi-trailer trucks.
[5] Sheet metal flashing.

so that not more than 3 percent of the grains of soil will be finer than the 0.02-mm size. This is done to eliminate or to reduce the potential intensity of ice segregation in the subbase when it becomes frozen.

One of the prerequisites for any type of pumping is free water at the bottom or edges of the pavement. If water which finds its way to the surface of the subbase by surface infiltration can percolate into the subbase and not saturate the subbase immediately below the pavement, it is probable that pumping can be eliminated. To satisfy this criterion, the maximum percentage of fines allowed to pass the No. 200 sieve for subbase is 7 percent. Extensive studies on many local run-of-bank gravels indicate that when the percentage of material passing the No. 200 sieve is less than 7 percent the rate of permeability is sufficient to keep water from accumulating at the bottom of the pavement when the subbase is not frozen.

The selected subbase specification is finally compared with the foundation soil on which it is to be constructed in accordance with the Vicksburg criteria for filter design. This is done to insure that no intrusion of foundation soil into the subbase will occur. If necessary, the "band" is modified to eliminate the possibility of intrusion, or another layer of subbase is designed which will act as a filter between the foundation soil and the top course of the subbase.

When all of these factors have been considered, a typical subbase course is granular, non-frost susceptible, and pervious, conforming to the following gradation:

Sieve Size	% By Weight Passing
4 in.	100
2 in.	80-100
¾ in.	60-100
No. 4	35-60
No. 40	15-40
No. 200	0-7

The thickness of subbase is determined on the basis of the combined thickness of pavement and subbase required to prevent substantial freezing of the foundation soil when it is frost-susceptible. Field investigation over a period of years, coupled with an analysis of the freezing index for many locations, has indicated that on the principal truck arteries in the northern part of the state, a combined thickness of pavement and subbase of 21 in. will prevent substantial freezing of frost-susceptible

(Continued)

SUBGRADE, SUBBASE, AND STRUCTURAL DESIGN

78	¾" bituminous fiber	1½" I-Section stainless steel 12" c-c	2,000	No faulting to date; no significant structural deterioration; excellent condition.
78	¾" Wood filler	Stainless clad[10] 12" c-c	1,600	Excellent condition; cracking negligible; no pumping or faulting.
56 to 89	1" Wood, grain vert.	1¼" Monel clad 12" c-c	1,600	No faulting to date; cracking practically nil; no maintenance on pavement in 10 years.
56 to 100	1" Wood, grain vert.	1¼" Monel clad 12" c-c	1,600	Excellent; no faulting; cracking practically nil; no maintenance on pavement in 10 years.
15[8]	Groove type	None	1,300	Some settlement; excessive faulting; some cracking.

[6] Continuously reinforced.
[7] Plain.
[8] Contraction only.
[9] Double-line reinforced.
[10] Tubular dowels.

foundation soils, for six years out of seven. For the primary truck arteries in the southern part of the state a combined thickness of pavement and subbase of 16 in. will also prevent substantial freezing of the frost-susceptible foundation soils for the same period. By this criterion more than 12 in. of frost appears in the frost-susceptible foundation soils approximately once every seven years during the life of the pavement.

If, after the subbase has been shaped and compacted, large aggregate is exposed at the surface of the subbase, which would cause bonding of the portland cement concrete and subbase, a thin layer of very clean sand is spread over these areas. The quality of the sand used for this fine-grading operation very closely approximates the quality of concrete sand. The importance of maintaining a high rate of permeability in this material to prevent accumulations of water directly beneath the pavement cannot be overemphasized.

SHOULDERS

Shoulders for the highways constructed of portland cement concrete pavement are built directly on the subbase described previously, for a width of 10 ft for undivided highways and 10 and 5 ft on dual highways. The thickness of the shoulders generally equals the thickness of the pavement. Shoulders are constructed of bank-run gravel, stone, or either of these materials with a bituminous surface treatment or surface layer of bituminous concrete. Gravel shoulders are bladed frequently to keep a trough from developing at the edge of the pavement. Properly maintained gravel or bituminous-treated stone shoulders have a pronounced influence on keeping surface water from infiltrating to the subbase, and providing longevity to pavements.

Table 1 gives evaluation of pavement conditions as related to heavy truck traffic, structural design, subbase and subgrade. From previous experience at these same locations, as manifested by pumping, faulting and cracking, it can be concluded that the foundation soils described in Table 1 did not provide adequate support for concrete pavements constructed without selected foundation treatment.

Where tapered subbase thicknesses are indicated, the design was employed to minimize differential frost heave in cases where concrete pavement was reconstructed adjacent to existing pavement which did not have subbase as a foundation. The annual average daily traffic volumes for tractor semi-trailer trucks presented in Table 1 represent volumes in one direction only.

From Table 1, it can be concluded that the current design criteria for a reinforced concrete pavement of 8- or 9-in. uniform thickness with expansion joints having a corrosion resistant dowelling system, and resting on a subbase which not only provides uniform stable support for the pavement, but also is non-frost susceptible and insulates the foundation soil against substantial freezing, is satisfactory for the volumes of tractor semi-trailer trucks carried.

Specifically, a 10-year service record of this design indicates:

1. There is no evidence of any type of pumping.
2. There is no evidence of longitudinal restraint cracks at expansion joints where these joints are approximately 78 ft apart.
3. There is no evidence of faulting at joints.
4. Cracking is practically non-existent.
5. There is no evidence of seizure of the dowels at the joints.

REFERENCES

1. VAN BREEMEN, W., "Current Design of Concrete Pavements in New Jersey." *Proceedings*, HRB, Vol. 28 (1948).
2. VAN BREEMEN, W., "Experimental Dowel Installations in New Jersey." *Proceedings*, HRB, Vol. 34 (1955).
3. ROGERS, F. C., "Engineering Soil Survey of New Jersey, Report No. 1." Eng. Research Bull. 15, Rutgers Univ., New Brunswick, N. J.
4. "Engineering Manual for Military Construction," Part XII, Chap. 4. Corps of Engineers, U. S. Army.
5. "Investigation of Filter Requirements for Underdrains." Tech. Memo. No. 183-1, U. S. Waterways Exper. Station, Vicksburg, Miss.