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EVALUATION OF AN EXPERIMENTAL CONTRACTION JOINTED PAVEMENT

FINAL REPORT
JULY, 1983

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New Jersey Department of Transportation
Division of Research and Demonstration
In Cooperation with
U.S. Department of Transportation and the Federal Highway Administration

NOTICE

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15. Supplementary Notes

Conducted in cooperation with the USDOT, FHWA. The construction phase of this study is documented in "Slipform Paving with an Experimental Contraction Jointed Design (Route I-80, Section 1P)".

16. Abstract

In 1973 the New Jersey DOT constructed an experimental contraction jointed concrete pavement on a section of Route I-80 using slipform paving techniques. The construction phase of the paving experiment was documented in a 1975 report. This follow-up report presents the findings of a long-term monitoring effort to evaluate the performance characteristics of the subject pavement relative to New Jersey's standard expansion joint design.

The performance monitoring program used in this study basically entailed conducting semi-annual condition surveys and collection of joint and anchor lug movement data. The collected study data indicates that neither the unsealed contraction joints nor the terminal end anchor devices used in the design have performed as intended. The contraction joints have progressively opened due to the intrusion of fine incompressibles, resulting in the development of excessive pavement pressures. Such pressures initially resulted in distress in the end anchor slabs (cracking, faulting, crushing) and are now creating problems in the mainline pavement (a unique roughness situation).

It is recommended that several relief cuts be made to reduce the level of pressure in a section of distressed pavement in the westbound roadway. In view of the overall poor performance of the experimental pavement after only nine years of service, it is recommended that the Department construct future concrete pavements with our proven expansion joint design.

17. Key Words	18. Distribution Statement
Concrete pavement performance, contraction joints, slipform paving, end anchor slabs, pavement distress, pressure relief cuts	

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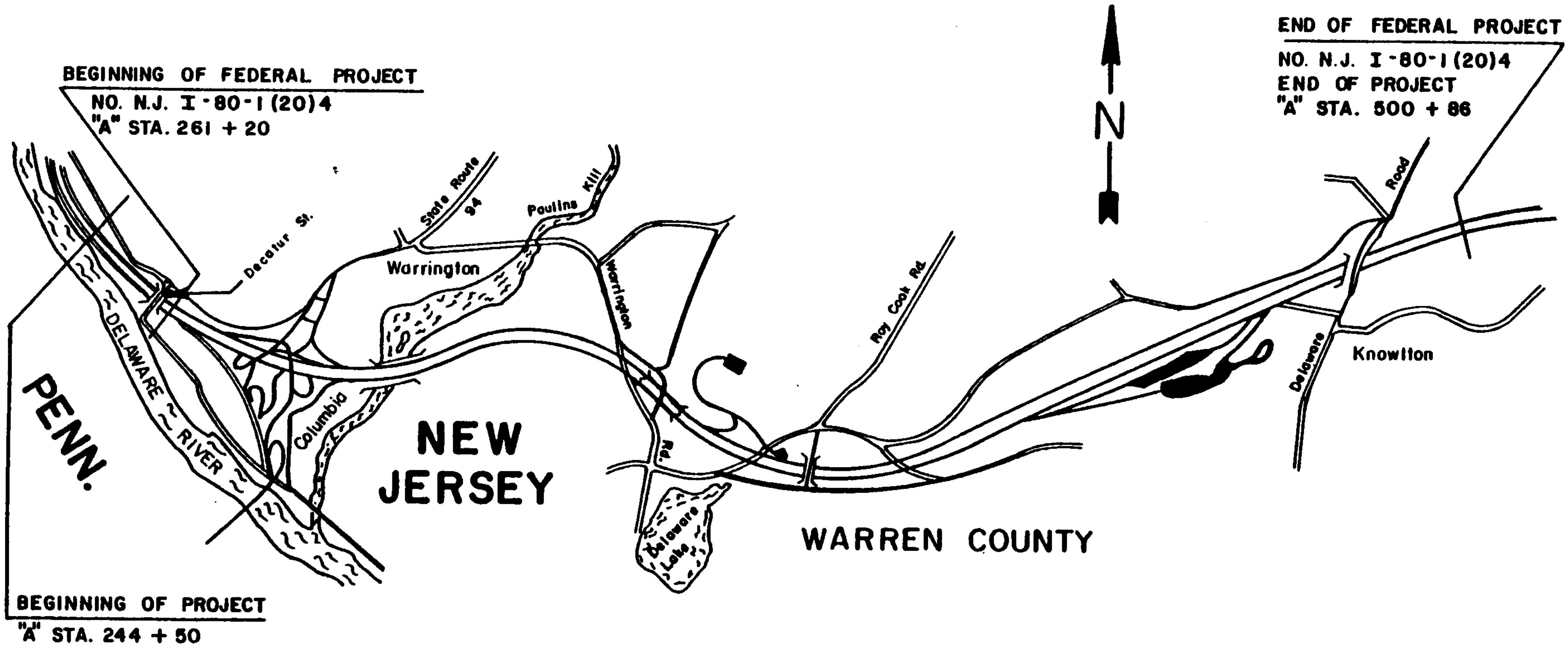
ROUTE I-80, SECTION 1P



KEY MAP

TOTAL LENGTH OF PROJECT: 25,636 LINEAR FT. = 4.855 MI.
LENGTH OF FEDERAL PROJECT: 23,966 LINEAR FT. = 4.539 MI.

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ACKNOWLEDGMENTS

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The contribution of former Research Engineer, Donald Ray, who supervised the early phase of the field monitoring program, is hereby acknowledged. Division technicians and draftspersons are commended for their data collection and recordation efforts.

Research Bureau Chief Kenneth C. Afferton and Research Engineer Jack Croteau, provided valuable advice during the conduct of this study and on review of the draft report.

SUMMARY OF OBSERVATIONS AND CONCLUSIONS

1. Overall Pavement Performance: Based on the nine year performance history of the experimental contraction jointed pavement studied on this project, it is concluded that this design is not a viable alternate to New Jersey's proven standard expansion joint system. Significant performance deficiencies observed to date include:

A. The narrow, unsealed contraction joints used on this project permitted the intrusion of fine incompressibles and a consequent progressive increase in joint widths resulting in "pavement growth".

B. The end anchor lugs were not capable of maintaining intermediate contraction joints in essentially a closed condition and thus did not perform their desired function of restraining pavement growth. As a result, destructive stresses developed in the pavement at several project locations. Such pressures initially resulted in distress in the end anchor slabs (cracking, faulting, crushing) and are now manifesting as problems in the mainline pavement (in the form of a unique roughness situation).

2. Trends in Pavement Growth: Various observations made during this study yield conflicting indications as to trends which may be expected in pavement growth and associated pavement distress. On the one hand, measurements obtained from gauge plugs installed at a sampling of project locations indicate that most of the movement at contraction joints and end anchors occurred within five years after pavement construction

and now appears to have somewhat stabilized. In contrast, the fact that a portion of the westbound roadway of the project -- a location where movement was not monitored -- only recently began manifesting distress suggests that pavement growth has not in fact abated.

3. Behavior of End Anchor Systems:

A. Observations of end anchor performance indicate that the ability of these devices to restrain movement and to resist failure varied considerably with project location. To illustrate, certain anchor lugs exhibit little or no distress while others are in a rather severe state of distress. Informal observations during construction suggest that these differences in end anchor performance, particularly the mode of failure when it occurs, may be partially attributable to the material (soil and/or rock) in which the lugs are constructed.

B. The behavior of adjoining pavement slabs at both ends of the mainline pavement was affected by the end anchor systems constructed on the study project. That is, slabs from the older, abutting pavement section have migrated into the expansion space intended to accommodate movement of the experimental pavement.

4. Pumping Distress: Although rather severe pumping of the pavement/shoulder joint occurred at one location within the study project, such distress is not solely attributable to the experimental pavement design. Rather, the pumping observed here is viewed as confirming the findings of a previous New Jersey research study wherein it was found that the subbase materials currently used for New Jersey concrete pavements often provide inadequate drainage.

RECOMMENDATIONS

1. It is recommended that relief cuts be constructed to reduce the level of pressure in the section of pavement between Paulin's Kill and Warrington Road in the westbound roadway. A plan should be developed through a cooperative effort of the Department's Research, Maintenance and Geotechnical Units detailing the number, location and methods of constructing the necessary pressure relief cuts.

2. Despite the disappointing performance of the experimental pavement design on the study project, there are some in the Department that feel further experimentation with a modified contraction joint design is warranted. Based on our experience on this project, the following elements would appear to be essential requirements in any such modified contraction joint design:

- With the intent of preventing or at least minimizing pavement growth, all transverse joints should be sealed and maintained in a sealed condition. Compliance with the latter provision is doubtful. Realistically, it is unlikely that our maintenance unit would be able to maintain the relatively large number of joints resulting from this type design in a sealed condition.
- An end treatment that permits rather than attempts to restrain pavement end movement. One possible approach would be an asphalt strip over a "sleeper" slab similar to that employed by other states.
- To avoid pumping problems, an open-graded drainage layer (as recently developed in another New Jersey study) should be placed directly under the pavement.

• To prevent corrosion, load transfer devices (dowels) should be fully clad with stainless steel.

A rationale that could be offered for further experimentation with this type pavement design is that such would be amenable to slipform techniques and there would be associated savings in construction costs, as well as improved rideability. Unfortunately, thus far, these potential benefits have been elusive: no significant savings in construction costs or rideability have been realized in New Jersey. In contrast, it is a certainty that maintenance costs -- for repairs to end anchor slabs and pressure relief cuts -- for the study pavement will be higher than for our average conventionally placed expansion joint pavements.

Considering the fact that any further use of a contraction joint design in New Jersey (albeit a modified design) would at best be an experiment, that needed joint maintenance for such a design appears unattainable, and the few remaining candidate projects for concrete paving, it is recommended that future concrete pavements be constructed using our proven expansion joint design. No further use of contraction joint pavements should be attempted.

3. It is recommended that several transverse expansion joints in the older, abutting pavement section immediately adjacent to the end anchor systems at each end of the study project be resealed.

4. Although the contraction joints on the study project have been relatively stable over the last several years (i.e., since about 1977), there is a strong possibility that they will continue to open and create

further distress. To verify whether this is the case or if in fact they have attained a state of equilibrium, it is recommended that some limited future monitoring of study contraction joints, end-anchor lugs and pavement/bridge joints be performed at least once in the next 3-5 years. Hopefully, the latter data will be sufficient to resolve the question and in conjunction with periodic smoothness surveys and an overall assessment of pavement condition should facilitate timely decisions regarding future preventive maintenance.

PART I: INTRODUCTION

1.1 BACKGROUND

The findings of an earlier New Jersey research study[1] indicated the need for a general improvement in the rideability of our newly constructed concrete pavements. That is, measurements obtained with a BPR roughometer on some 15 New Jersey concrete pavements constructed during the period of 1966 through 1972 showed an average as-constructed roughness index of 122 inches/mile, corresponding to an FHWA adjective rating of "Fair to Poor".

Transverse joint construction was found to have the most significant effect on the rideability of New Jersey's concrete pavements. On a typical project, about 40% of the pavement's surface irregularities were observed to be associated with the construction of transverse expansion joints.

Attempts to improve riding quality on several projects through the application of slipform paving techniques and the modification of standard procedures for constructing transverse expansion joints (including the use of "sawing" rather than conventional hard forming methods), did not yield the desired improvement. Generally, these failures were attributed to the inherent incompatibility of slipform paving techniques with the Department's standard expansion joint design.*

*The Department's standard design employs 3/4" wide, dowelled expansion joints spaced at 78'2" intervals.

In view of the above, the Department developed a contraction joint pavement design as an alternate to our standard, specifically to accommodate slipform paving equipment and methods.

In 1972 the contractor for Route I-80, Section 1P, a project located near Columbia in Warren County, requested a change order to permit the construction of mainline concrete pavement on the project by slipform rather than conventional formed methods. The Department granted the request and with the contractor's cooperation, seized the opportunity to implement and evaluate the newly developed contraction joint design. Paving on the project which involved the slipforming of some four miles (about twenty-eight lane miles or 190,000 square yards), was conducted during the summer of 1973.

The construction phase of the I-80 paving experiment is documented in a 1975 research report[2]. As noted in the cited report, despite various changes from New Jersey's standard design and construction methodology, the hoped for significant improvement in pavement smoothness was not achieved on the study project.

This follow-up report documents the performance of the experimental pavement over its first nine years service.

1.2 OBJECTIVES

To evaluate the overall performance of the new contraction joint design implemented on Route I-80, a special research monitoring effort was initiated soon after construction. The objectives of that effort were:

1. To determine the desirability of adopting the studied contraction joint design as an alternate to New Jersey's standard expansion jointed system.

2. To determine the capability of the end anchor systems employed on this project to prevent significant pavement growth and the associated potential for severe damage to bridge abutments and/or pavement "blow-ups".

3. To detect any specific pavement distress condition such as faulting, slab cracking, pumping, or significant pavement growth in its earliest stages and to provide recommendations for appropriate preventative maintenance.

PART II: PROJECT DETAILS

2.1 PAVEMENT DESIGN

The essential features of the pavement design employed on the study project are:

· Unreinforced concrete, 9 inches thick, with unsealed, sawed contraction joints (3" deep, 1/8"-3/16" wide) at 15 foot intervals.

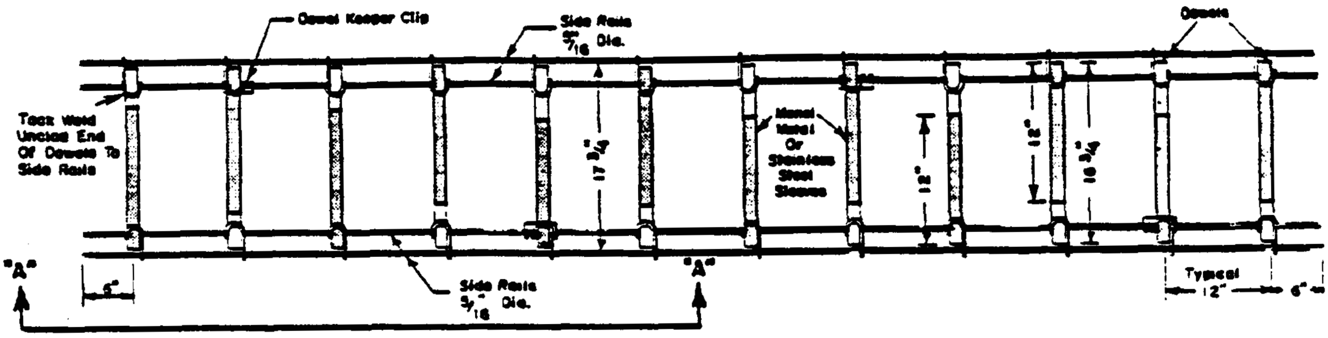
· Load transfer devices, consisting of steel dowels partially clad with corrosion resistant stainless steel sleeves, installed at each joint (see Figure 1).

· End anchoring systems adjoining structures and existing pavements to restrict pavement growth (see Figures 2 and 3).

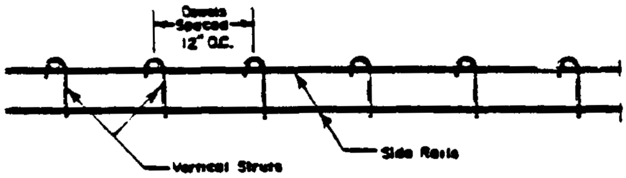
The Department opted for unsealed contraction joints for two reasons. First, the short slab lengths (having minimal seasonal movements) combined with narrow joints would preclude entrance of large incompressibles into joint spaces. Second, it was believed that the narrowness of the joint openings and the gradual accumulation of fines therein would act to reduce the amount of surface water entering the pavement through transverse joint areas.

2.2 MONITORING PROGRAM

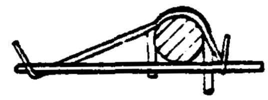
To gauge the performance of the experimental contraction joint design employed on the 1P section it was necessary to develop a special monitoring program. This involved installing and subsequently obtaining



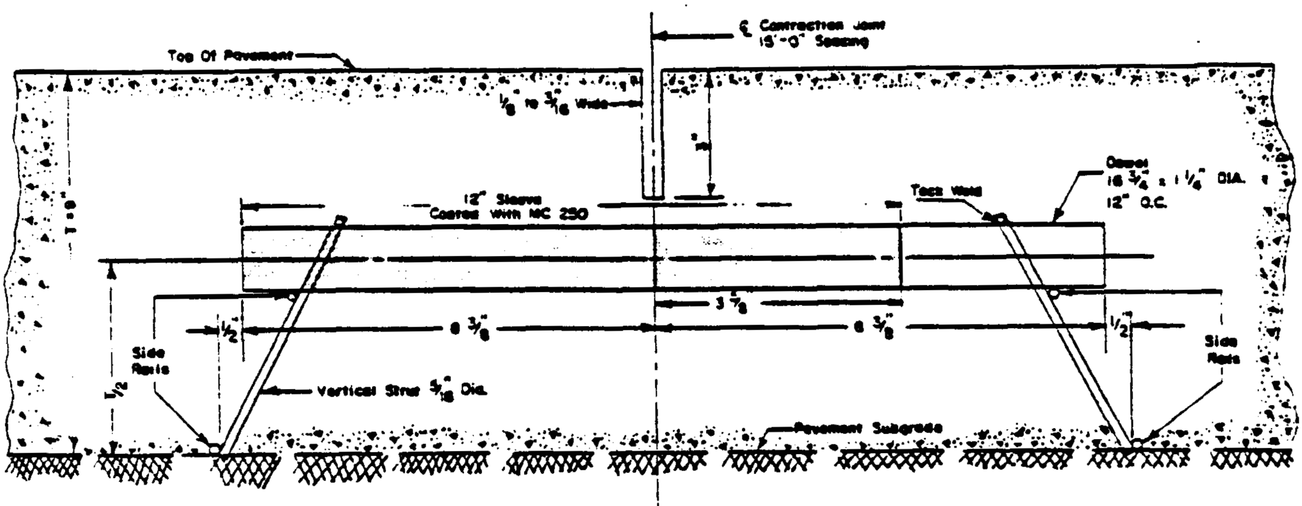
PLAN VIEW (12' JOINT)



ELEVATION A-A



DOWEL KEEPER CLIP



TYPICAL CROSS SECTION THRU CONTRACTION JOINT

(NOT TO SCALE)

Notes:

1. EACH UNIT TO BE STAKED FIRMLY IN PLACE BY A MINIMUM OF 8 PINS (10" x 1/2" DIA.) ALONG BOTH SIDE RAILS AS SUBGRADE CONDITIONS WARRANT.
2. DOWELS SHALL CONSIST OF 16 3/4" x 1 1/4" DIA. CARBON STEEL BARS ENCASED FOR THEIR FULL LENGTH (MODIFIED TO MINIMUM OF 12" AS SHOWN) IN MONEL METAL OR STAINLESS STEEL 0.01 INCHES THICK. THE TIGHTNESS OF FIT SHALL BE SUCH AS TO PRECLUDE THE OCCURRENCE OF CORROSION

FIGURE 1 : DETAIL OF LOAD TRANSFER DEVICE

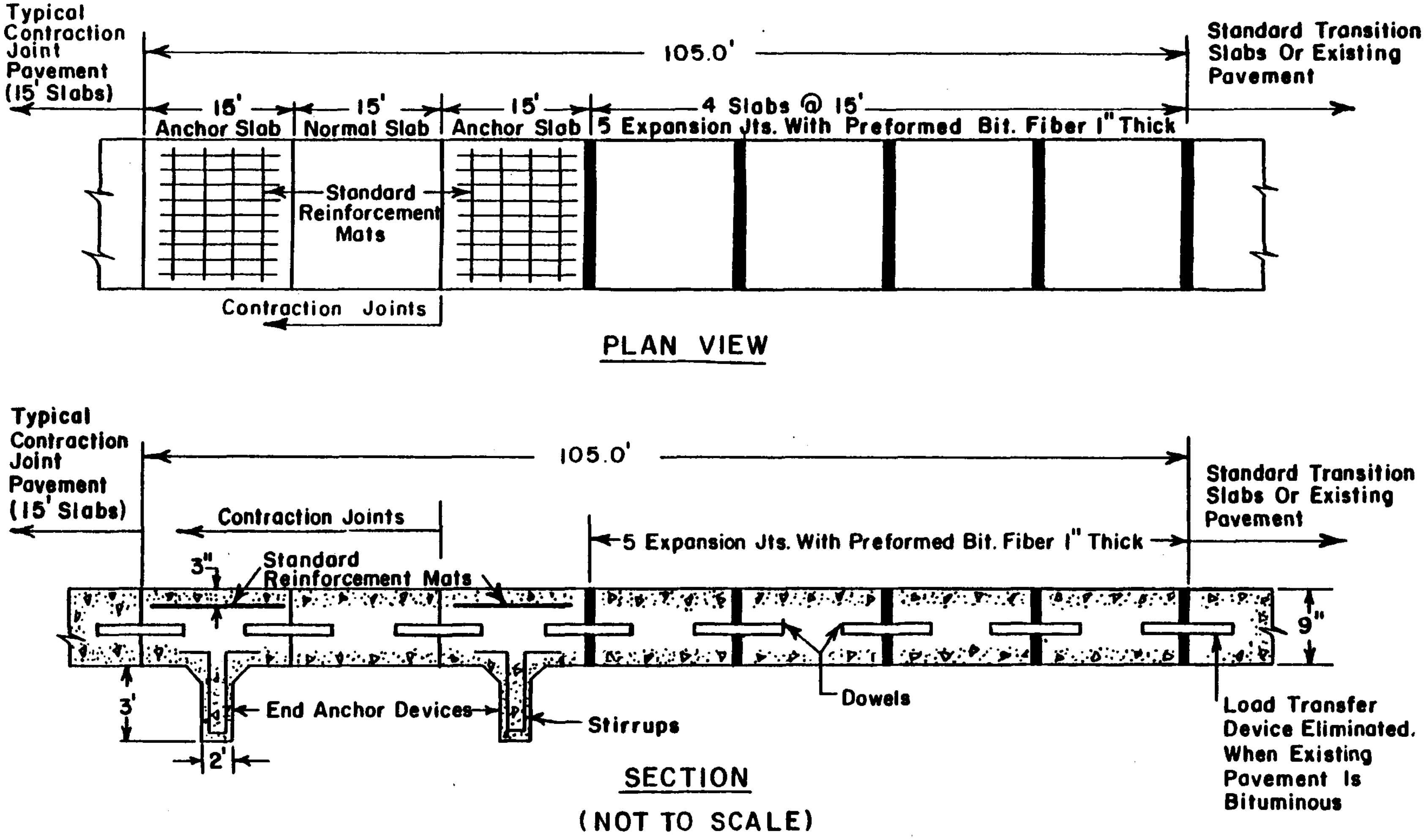


FIGURE 2: DETAIL OF TYPICAL END ANCHOR SYSTEM

(Installed Between Normal Contraction Joint Pavement And Standard Transition Slabs Or Existing Pav't)

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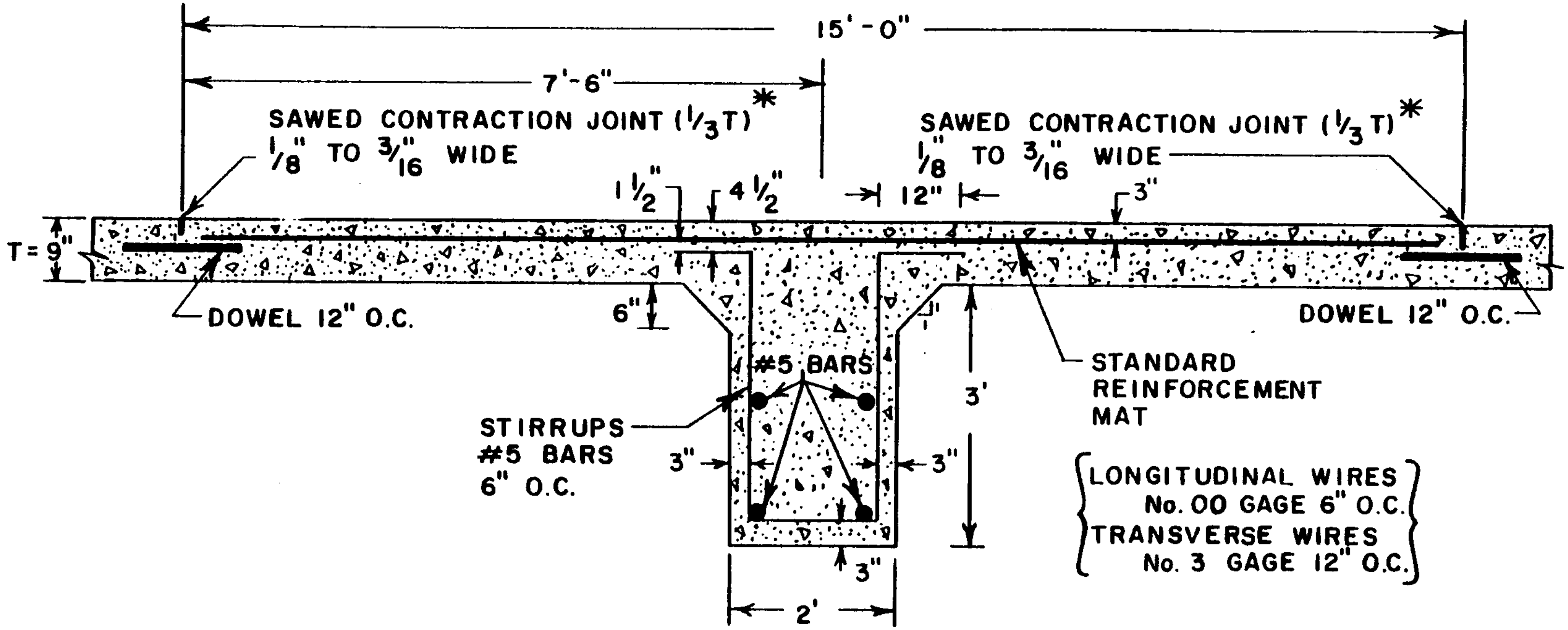

* DEPTH OF TRANSVERSE SAWCUT
MODIFIED TO 2 in. ON 7/17/73

NOT TO SCALE

FIGURE 3: DETAIL OF END ANCHOR DEVICE

A-514-3

measurements from various reference devices (i.e., monuments and gauge plugs) at selected study locations adjacent to structures, existing pavements and at intermediate areas throughout the project.

These devices are utilized to study several variables including individual joint movements (both expansion and contraction joints), changes in pavement length (pavement "growth") and lateral pavement displacement on horizontal curves. A summary description of the monitoring program is given in Table 1. Measurements were obtained from these special devices on a semi-annual basis (summer and winter) and then compared to as-built condition measurements to determine the significance of changes in the pavement's behavior. In addition, an overall assessment of the pavement, based on visual inspection for pumping, cracking, etc., was performed at least yearly.

Possibly the most critical area of this study involved the monitoring of end anchor systems and the immediately adjacent pavement. A sketch of a typical monitoring system, installed at selected end anchor locations, is shown in Figure 4. These end anchor systems, constructed at structures and existing pavements, were intended to provide the restraint necessary to maintain intermediate contraction joints in essentially a closed condition. Their failure to perform as designed would permit pavement growth with contraction joints opening progressively from the infiltration of incompressible material. This condition would then facilitate the development of excessive pressure at these locations which could result in severe damage to bridge abutments and/or pavement blow-ups.

NATURE OF TEST SAMPLES	VARIABLE(S) BEING STUDIED	MONITORING PROCEDURES
Selected slabs at three (3) locations (east and west ends of project and the westerly side of the Route 94 W.B. structure).	Behavior of end anchor systems and typical contraction joint pavement in immediate vicinity.	Invar tape, transit, level, and ames dial to: 1. Detect presence/absence of horizontal and/or vertical movement of individual slabs and overall test area. 2. Determine individual expansion and contraction joint movement.
Intermediate contraction joints at three (3) locations on the W.B. roadway between western end of project and Route 94 W.B. structure).	Movement of typical contraction joint (spaced @ 15 ft. intervals) @ intermediate locations.	Ames dial measurements to determine changes (opening/closure) in individual contraction joints.
Intermediate contraction joints at one (1) location (vertical curve, Stations 447+60 to 450+60 E.B. roadway).	Behavior of experimental design at crest of vertical curve.	Ames dial measurements to detect excessive contraction joint openings due to curvature.
Two (2) areas of typical contraction joint pavement at horizontal curves. (Roy Cook Road and vicinity of relocated Warrington Road W.B. roadway).	Behavior of experimental contraction joint slabs located at the midpoint of horizontal curves.	Invar tape measurements to detect lateral displacement of pavement.
Pavement/bridge joints @ three (3) structure locations (added 8/77).	Behavior of pavement/bridge joints.	Ames dial measurements to detect excessive closure of pavement/bridge joints.

TABLE 1: DESCRIPTION OF MONITORING PROGRAM DEVELOPED TO EVALUATE THE EXPERIMENTAL CONTRACTION JOINT DESIGN ON ROUTE I-80, SECTION 1P

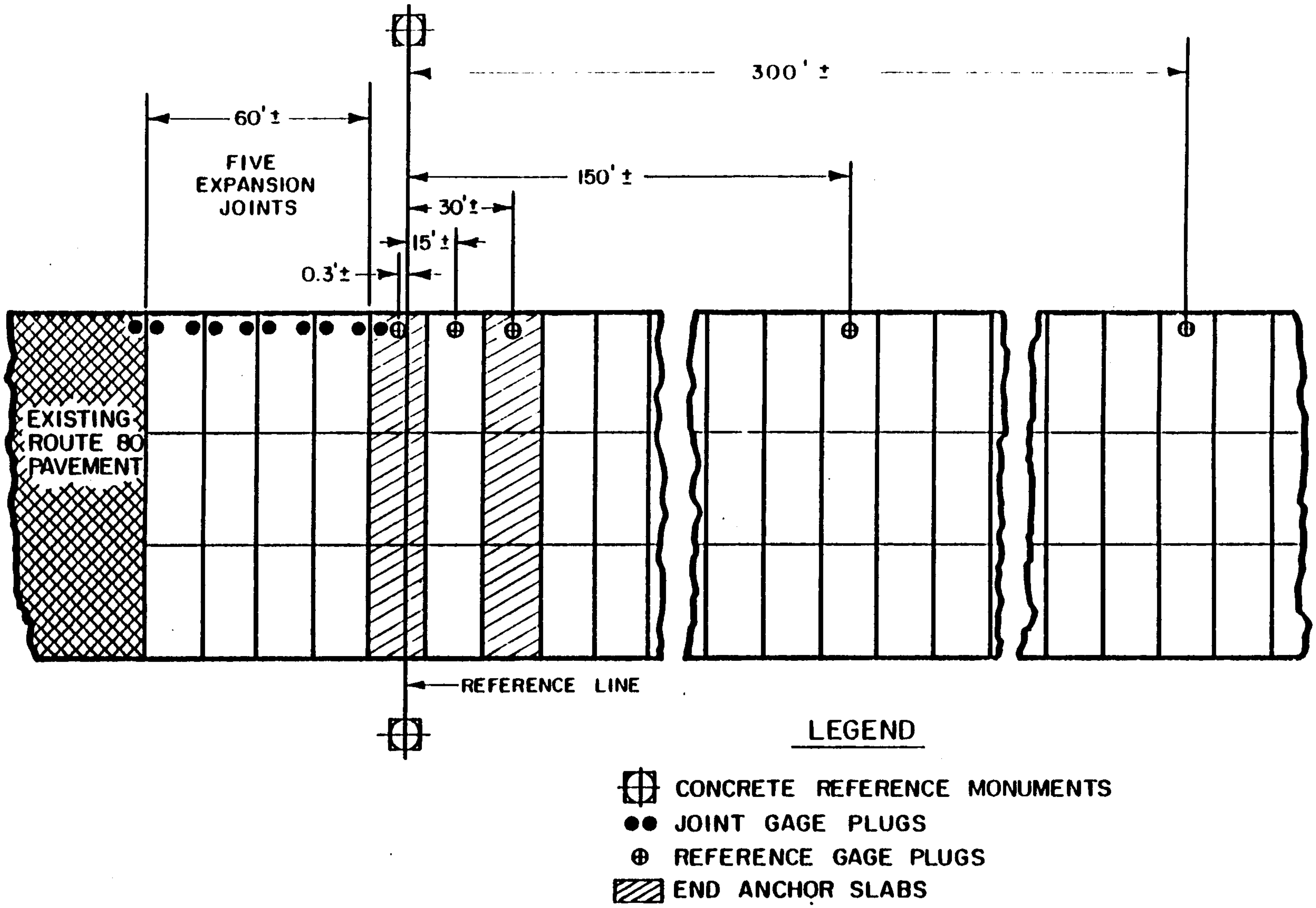

FIGURE 4 : Typical Monitoring System Installed at Selected End-Anchor Locations on Route I - 80, Section IP

PART III: FINDINGS AND ANALYSIS

Although the monitoring program for this project involved numerous types of measurements, only those relevant to the pavement's performance will be discussed herein.

3.1 CONTRACTION JOINT MOVEMENTS

Movement at contraction joints was determined from measurements obtained at least twice yearly (summer and winter) from gauge plugs installed during pavement construction or shortly thereafter.

The average measured changes in contraction joint width for several dates and study locations on the project is presented in Table 2. Measurement Areas B through D are in the westbound roadway near the west end of the project while Area H is at the crest of a hill near the center of the section in the eastbound roadway. A general review of the data shows that the joints at each location have gradually, yet progressively, increased in width.

Due to the infiltration of incompressibles into the joints during cold cycles, application of normalizing techniques (i.e., correction of measurements to account for temperature variations) proved inappropriate. Accordingly, the joint width increases tabulated in Table 2 represent actual measured changes.

TABLE 2: AVERAGE INCREASES IN CONTRACTION JOINT WIDTHS (INCHES)

		AREA			
DATE	TEMP (^{o}F)	B	C	D	H
1973 (Summer)	80	0.00	0.00	0.00	0.00
3/74	47	0.04	0.04	0.05	0.04
8/74	96	0.04	0.02	0.01	0.02
2/75	42	0.07	0.06	0.06	0.05
8/75	94	0.05	0.03	0.01	0.00
2/76	43	0.07	0.05	0.05	0.06
8/76	96	0.06	0.03	0.02	0.01
1/77	34	0.09	0.07	0.07	0.07
8/77	79	0.07	0.03	0.03	0.04
2/78	37	0.09	0.06	0.06	0.07
8/78	94	0.07	0.02	0.01	0.02
2/79	32	0.10	0.06	0.06	0.09
8/79	93	0.07	0.03	0.02	0.02
2/80	26	0.11	0.07	0.07	0.09
8/80	81	0.08	0.03	0.03	0.05
2/81	20	0.13	0.07	0.08	0.09
8/81	102	0.08	0.04	0.01	0.04
2/82	36	0.11	0.07	0.05	0.08
8/82	86	0.09	0.04	0.02	0.04

N for: Areas B and C = 15, D = 16 and H = 21

In an effort to eliminate to some extent the effect of the temperature variable, only summer survey data will be considered in the following discussion. Since joint widths are the narrowest during the summer, limiting the discussion to such data will yield conservative estimates of joint width increases.

The data of Table 2 indicate that during the first year (summer 1973 to summer 1974) the opening of studied contraction joints in these areas ranged from 0.01" (Area D) to 0.04" (Area B). Except for Area C, comparison of summer data within each area over the next three years (1974 to 1977) reveals a general trend for these joints to open, by roughly about 0.01 inches per year. Over the last five years (1977 to 1982) the summer averages indicate that the joints in Area B continued to open but at a lesser rate than that previously observed, while those at other study locations (Areas C, D and H) remained essentially unchanged. To determine whether the contraction joints on this project have in fact attained a state of equilibrium -- or only a stage of relative inactivity, after which they will continue to open resulting in additional pavement growth -- follow-up data should be obtained from a sample of these joints within the next three to five years.

3.2 <u>END ANCHOR SYSTEMS</u>

To prevent the buildup of potentially damaging pressures at structures and existing pavements, end treatments consisting of two anchor lugs (i.e., two "T" sections cast monolithic with pavement slabs) coupled with a series of five, one inch expansion joints was constructed (see Figure 2). These end anchors were intended to provide the restraint necessary to maintain intermediate contraction joints in an essentially <u>closed</u> condition and thus prevent significant pavement growth.

In view of the typical behavior of a contraction jointed pavement -- to undergo a progressive increase in length due to the intrusion of incompressibles into joint spaces -- some movement of end anchor lugs was expected prior to the soil developing full resistance. A measure of the effectiveness of the end anchor devices to prevent significant pavement growth is provided by the amount of movement observed at these locations.

3.2.1 <u>End Anchors</u>

To determine the magnitude of longitudinal displacement of end anchor slabs at selected project locations, measurements were obtained in accordance with the (summer/winter) schedule described in Section 3.1. Basically, this data was obtained at each study location by measuring the distance from a line-of-sight between two concrete reference movements and a gauge plug in the pavement. The measured distance or offset reduced by the as-built measurement for the given location indicates the amount of pavement lengthening or "growth". Data compiled since the experimental pavement was constructed (1973) is shown in Table 3. Area A is the west end of the project; Area I is the east end; and Area E is on the west side of the structure carrying Route I-80 over Route 94. As expected, anchor slab movement has been in the growth direction and hence toward expansion joints at each of the monitored locations.

As with the contraction joints, summer end anchor slab movement was generally progressive until the summer of 1978, with the observed amount of movement ranging from about 0.5 to 1.7 inches. Thereafter, summer measurements indicate that except for Areas A (EB) and I (WB) anchor movement continues in the growth direction at a somewhat diminished rate compared to that observed previously. The most recent summer data shows anchor displacement at monitored locations ranges from about 0.7 to 2 inches. It is not surprising that the largest anchor movement occurred in relatively close proximity (about 150 feet) to Area B, which displayed the largest average increase in contraction joint width (see Table 2).

Several factors can influence the amount of anchor displacement or growth exhibited by a contraction joint pavement (e.g., slab length, coefficient of subgrade friction, type end treatment, amount of fine incompressible material available to enter joint spaces*, etc.). Since

*Although the transverse contraction joints on this project were unsealed, they were sufficiently narrow -- basically the width of a saw blade or about 1/8 inch -- to preclude entrance of large incompressibles into joint spaces. However, it is obvious from the data of Table 3 that the effect of the accumulated fines within the joints were sufficient to cause pavement growth.

TABLE 3: LONGITUDINAL DISPLACEMENT AT END ANCHOR LUGS (INCHES)

		AREA A		AREA E		AREA I	
DATE	TEMP (^{o}F)	WB	EB	WB	EB	WB	EB
1973 (Fall)	70	0.00	0.00	0.00	0.00	0.00	0.00
3/74	47	0.16	0.02	0.04	0.05	0.01	0.13
8/74	84	0.37	0.13	0.36	0.07	0.23	0.10
2/75	44	0.16	-0.01	0.40	0.01	-0.28	0.05
8/75	95	0.78	0.31	0.41	0.08	0.89	0.18
2/76	44	0.55	0.24	0.48	0.13	0.49	0.18
8/76	100	1.12	0.64	0.48	0.31	0.71	0.30
2/77	36	0.91	0.35	0.54	0.28	0.71	0.19
8/77	107	0.84	0.71	0.71	0.35	1.19	0.43
2/78	27	1.34	0.92	1.62	0.49	1.31	0.25
8/78	95	1.66	1.08	1.08	0.48	1.68	0.55
2/79	32	1.34	0.73	0.74	0.43	1.07	0.53
8/79	92	1.74	0.97	1.18	0.56	1.06	0.50
2/80	21	1.54	0.74	1.26	0.48	1.33	0.35
8/80	88	1.82	0.86	1.14	0.70	1.25	0.46
2/81	20	1.63	0.80	0.72	0.58	1.31	0.43
8/81	103	1.88	0.94	1.62	0.84	0.96	0.52
2/82	28	1.79	0.82	1.12	0.79	1.00	0.46
8/82	93	1.99	0.85	1.34	1.00	0.95	0.68

it appears reasonable to assume these factors are essentially constant on this project, a strong possibility for the differences in anchor displacement observed here is the varying resistance offered by the particular material (soil and/or rock) in which these terminal devices were constructed.

It should be mentioned here that although none of the anchor slabs monitored for movement have failed to date, two failures have occurred at other locations on the project. These anchor slab failures are subsequently discussed in report section 3.5.

3.2.2 Expansion Joints

Joint width measurements obtained from gauge plugs installed on a sample of expansion joints on the experimental project are presented in Table 4. The tabulated values represent the average change in expansion space per joint based on measurement of five joints at each test location. Review of this data indicates a pattern of progressive decreases in the amount of expansion space available relative to that provided in the as-constructed pavement. As in the case of the anchor lug data then, the expansion joint measurements indicate that the contraction joint pavement is "growing" towards structures as well as toward the existing pavement at each end of the project.

Since anchor lug movements and expansion joint closure are both measures of overall pavement growth, it might be expected that these two types of data (i.e., Tables 3 and 4) would generally be in agreement. Comparison of the most recent data for Area "E" in the westbound roadway indicates this is generally the case for end anchor systems constructed

TABLE 4: AVERAGE WIDTH CHANGES OF EXPANSION JOINTS AT STRUCTURES AND EXISTING PAVEMENTS (INCHES)*

DATE	TEMP (^oF)	AREA A EB	AREA A WB	AREA E WB	AREA I WB
1973 (Summer/Fall)	70	0.00	0.00	0.00	0.00
3/74	47	0.01	-0.09	0.03	0.01
8/74	84	-0.12	-0.20	-0.05	-0.11
2/75	44	-0.09	-0.15	-0.01	-0.08
8/75	96	-0.23	-0.32	-0.09	-0.18
2/76	44	-0.21	-0.27	-0.06	-0.14
8/76	106	-0.32	-0.40	-0.16	-0.23
2/77	42	-0.30	-0.31	-0.07	-0.16
8/77	107	-0.36	-0.45	-0.16	-0.21
2/78	27	-0.34	-0.39	-0.12	-0.20
8/78	92	-0.40	-0.50	-0.20	-0.29
2/79	31	-0.38	-0.43	-0.14	-0.26
8/79	92	-0.44	-0.52	-0.22	-0.30
2/80	23	-0.41	-0.46	-0.16	-0.27
8/80	90	-0.51	-0.53	-0.22	-0.31
2/81	15	-0.46	-0.48	-0.17	-0.28
8/81	103	-0.50	-0.54	-0.31	-0.31
2/82	28	-0.47	-0.50	-0.19	-0.49
8/82	82	-0.48	-0.57	-0.33	-0.48

*Values represent average of five joint measurements (corrected for temperature) at each location.

adjacent to bridges. That is, Table 3 shows that the anchor lug in Area "E" (WB) was displaced +1.34 inches while the total closure for the expansion joints based on Table 4 was -1.65 inches (5 joints x 0.33 inches/joint), for a difference of only about 0.3 inches (1/4 inch). The remaining areas on the project where both anchor lug and expansion joint movements were monitored (Areas A and I) do not, however, display such agreement. A similar analysis for the latter areas indicates a disparity ranging from about 0.9 to 1.6 inches for Area "A" west and eastbound, respectively. At each of these locations, the total decrease in expansion space exceeds the amount of anchor displacement measured.

It is important to note that both the latter areas -- where the amount of pavement growth indicated by the anchor lug and expansion joint data disagree - involve an end anchor system constructed adjacent to existing pavements. The larger differences observed in Areas A and I are, for the most part, attributed to the migration of adjacent existing pavement slabs into the new expansion space provided for the experimental pavement.

It is apparent from the most recent data of Table 4 that at each study location a good deal of the available expansion space has been utilized. Since the point of refusal for 1 inch thick expansion paper is about 60% or 0.6 inches, some 55-95% of the available space has been consumed. Whether or not the remaining expansion space is sufficient to accommodate future growth (if any) of the contraction joint pavement will obviously depend on the magnitude of such pavement growth.

3.3 BRIDGE JOINTS

In 1977, in an effort to detect movements at bridge joints having the potential for causing serious damage, gauge plugs were installed across the pavement/bridge joint at each structure on the project. This decision to install additional monitoring devices was based on early study data obtained from both contraction joints and anchor lugs which indicated a trend for pavement growth and the fact that only a portion of the experimental pavement was being monitored for longitudinal movement. In short, the measurements at bridge joints provide the only means for detecting any potentially serious movement problems in certain areas of the project.

To date, measurements obtained from these devices show no significant closure of bridge joints. Thus, the anchor systems (terminal lugs and expansion joints) employed on the project next to structures have to date performed satisfactorily with regard to preventing damage to adjoining bridges.

3.4 ESTIMATED PAVEMENT COMPRESSIVE STRESSES

The preceding analyses of contraction joint and end anchor behavior clearly indicate that some growth of the experimental pavement has occurred since it was constructed in 1973. Given that this growth creates a state of compression in the pavement, it obviously would be of interest to know precisely the magnitude of pressure that exists throughout the pavement, particularly at critical locations such as at structures. Unfortunately, the relatively simple monitoring program employed in this study precludes any such exacting assessment of pavement stresses. This is due to the fact that the present monitoring system is oriented to movements, rather than stresses. Had a more sophisticated (and expensive) stress-oriented monitoring program been employed, such information could have been obtained directly.

Notwithstanding the above limitations, a rough estimate of the current level of stress in the pavement can be provided. This assessment is based on application of the fundamental stress-strain relationship:

$$S = E\varepsilon$$

Where:

S = Stress

E = Modulus of elasticity = 4.5×10^6 for concrete

ε = Strain = Unit change in length

In this application, pavement strain is computed as the ratio of the amount of pavement growth to the pavement's original length. The amount of pavement growth in turn is determined from the most recent average width increase of the contraction joints in a given area (see Table 2).

The estimated stresses in the pavement at various locations as computed by the above described procedure are presented in Table 5.

TABLE 5: ESTIMATED STRESS IN PAVEMENT

Study Location	Av. Contraction Joint Opening $\bar{X}$	Strain[1] $\varepsilon = \bar{X}/L$	Estimated Stress $S = E\,\bar{X}/L$	Equivalent Force[2] Per Unit Width of Pavement $F = SA$
B	0.09 in.	0.00050 in/in	2250 psi	243,000 lbs/ft
C and H	0.04 in.	0.00022 in/in	990 psi	106,920 lbs/ft
D	0.02 in.	0.00011 in/in	495 psi	53,460 lbs/ft

[1] L = Original slab length = 15 ft. = 180 in.

[2] Area, A = 9" x 12" = 108 in^2

While the calculated stresses presented in Table 5 are indeed only approximations, the relatively high levels indicated for three of the four test areas is believed to be cause for concern. Simply, even if the true pavement stress level is substantially less than the calculated values, those stresses would translate as very substantial, potentially destructive, forces across the pavement width. For example, if in the case of Area B, the actual pressure is only one-half that estimated (i.e., 1000 psi) it would correspond to a force in excess of 108,000 lbs. per linear foot of pavement width.

Although no significant pavement damage has yet occurred in the areas considered in Table 5, the fact that <u>other</u> project end anchors have failed through cracking, crushing, "tenting" and/or rotation, (see Figures 6 and 8) demonstrates that the potential for the development of destructive forces in these areas is more than a mere possibility. As previously indicated, the progress of pavement growth in these areas should be monitored periodically to determine the need for timely corrective action (pressure relief cuts) by our maintenance forces.

3.5 PAVEMENT PERFORMANCE PROBLEMS

Two performance deficiencies were observed within the first year after completion of pavement construction. The first was a pumping condition while the second involved transverse hairline cracking in a number of anchor slabs. The nature of these early performance problems is discussed in the first report[2] on the study project.

The purpose of this report section is to update the performance information contained in the first report and to provide an account of pavement distress that has subsequently occurred.

3.5.1 Pumping

Although various degrees of pumping were observed along the pavement/shoulder joint at several project locations during the first year after construction, pumping has persisted in only one area. This continuing pumping condition involves about a half mile of the pavement/shoulder joint in the eastbound roadway and has resulted in numerous cracked slabs, some minor pavement faulting and three to four slabs have deteriorated to the point that an overlay may be necessary within the next two to three years.

It should be noted that it is not uncommon for New Jersey concrete pavements to pump initially and then subside. Generally, this is attributed to our subbase materials which typically lack adequate drainage properties.[3] This, of course, may have been aggravated by the subject experimental pavement design which employed unsealed contraction joints at close, fifteen foot intervals. However, this particular location also presented a ground water problem during construction operations which necessitated installation of an underdrain. Although the latter satisfied construction requirements, it may not have been completely effective in preventing ground water from subsequently entering the pavement section in this area. In view of this and the fact that the remainder of the pavement is not pumping,* it is likely the pumping in this area can be largely attributed

*From this, it is apparent that the effectiveness of the low-cost, commercial polyethylene installed to alleviate or forestall pumping cannot be assessed on this project. As indicated in the earlier report(2), a double thickness of this material (3 ft. strips of 4 mil polyethylene) was placed under a portion or the full length of four transverse joints at or in the vicinity of low points.

to the combination of a ground water problem and our subbase materials, rather than to some general deficiency of the experimental pavement design per se.

3.5.2 <u>End Anchor Failures</u>

Two to four years after construction, essentially all the anchor slabs on the project exhibited cracks similar to those first noted in 1974. Typically, these cracks occurred about six feet from the transverse joint which is approximately over the "return" (or end) of the reinforcement bars (stirrups) extending up from the anchor lug to the pavement (see Figure 3). This cracking distress has now progressed to the point that the cracks typically extend across the full pavement width (up to four lanes) and several have begun to scale and/or spall at the edges. In an effort to forestall further distress, our Maintenance forces, on at least two occasions and at various project locations, including those in the pumping area, have sealed pavement cracks and patched the most severely spalled areas.

Nonetheless, in 1976 the crack distress at one anchor location progressed to the faulting condition shown in Figure 5.

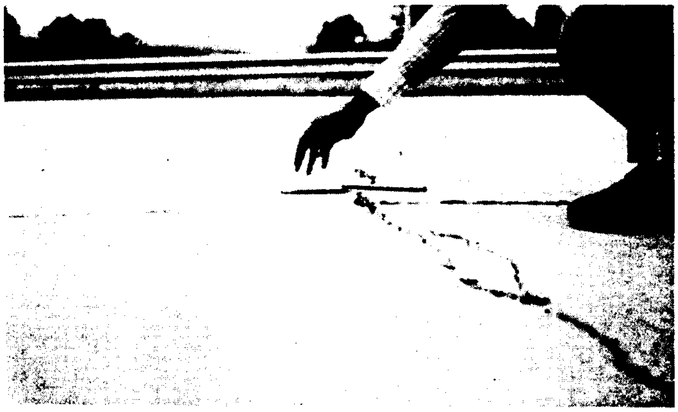

FIGURE 5: Faulting Condition at End Anchor (east side of Route 94 structure, westbound roadway - 1976).

Although the exact cause of this condition is not known, it is likely that compression developed in the pavement induced a slight rotation of the anchor lug, resulting in the "riding up" of one slab portion over the other. This faulting or "tenting" condition is particularly likely to occur when the heel or bottom of the lug is bearing on or near rock while the remainder is in soil.

By 1978 this anchor was in the severe state of distress shown in Figure 6.

FIGURE 6: Appearance of Tenting/Faulting Condition (east side of Route 94 structure, westbound roadway - 1978).

The condition which then appeared to stabilize for several years, worsened during the last year to the extent that in June, 1982 corrective measures were necessary to restore a tolerable riding surface. This was accomplished by removing a portion of the pavement slab and/or overlaying with asphaltic mixture, as shown in Figure 7.

During this repair work, a void condition was found under the "tented" part of the slab. This void was subsequently filled by mudjacking methods to insure adequate support.

FIGURE 7: Appearance of End Anchor Location after Overlaying with Asphaltic Mixture (east side of Route 94 structure, westbound roadway - 1982).

Even with the described deficiencies, the experimental pavements' overall performance as of early summer, 1982 (after nine years service) was considered generally satisfactory. However, observations in early August, 1982 indicated the pavement is undergoing some rapid and disquieting changes in behavior in several areas.

Basically, there are two problems. First, various degrees of faulting and/or rotation of anchor slabs now exist at several locations, one of which is relatively severe, as shown in Figure 8.

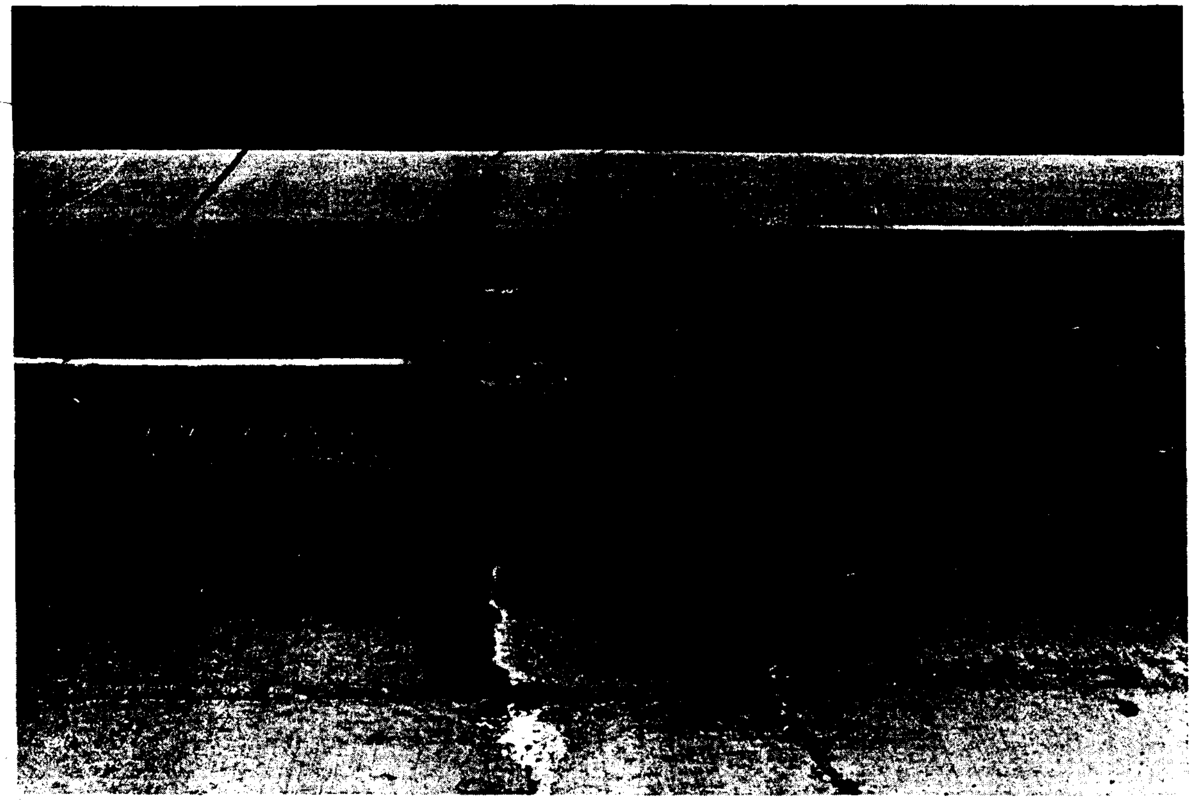

FIGURE 8: Faulting/Tenting Condition (east side Paulin's Kill Structure, eastbound roadway - 1982).

Second, the surface of one section of pavement -- approximately 3/4 mile of the truck lane in the westbound roadway between Paulin's Kill and Warrington Road -- displays a unique type of surface roughness relative to its as-built state and in comparison to the pavement on the remainder of the project. The severity of the roughness in this area is very perceptible to vehicle occupants. Further, certain of the surface irregularities are so pronounced that they are visibly observable.

While there is little doubt the faulting and/or rotation of anchor slabs is the result of excessive pressure -- due to the buildup of fines in the unsealed contraction joints -- the cause of the newly emerging roughness problem was not as clear. Since most of the pavement displaying the described roughness was in a fill area, unequal fill settlement rather than pressure may have been the cause. In an effort to resolve this matter, measurements were obtained in the affected area with a 10 ft. rolling straightedge capable of measuring surface defects of 1/8 inch or more in 1/8 inch increments. Results of this roughness testing indicated a pattern of surface defects, the majority of which (about 70%) occurred at transverse contraction joints. This strongly suggests that the problem is being caused by pressure developed in the pavement since fill settlement would be expected to result in <u>random</u> surface irregularities.

In view of the above, relief cuts will be made to reduce the level of pressure in this section of pavement. A detailed plan for this work will be developed through a cooperative effort of the Department's Research, Maintenance, and Geotechnical units.

In an attempt to detect this type problem should it occur in another area of the project (at an earlier stage of its development), it is planned to perform periodic smoothness surveys with a Mays ride meter. Based on this data and that obtained from the established monitoring program, a decision will be made concerning the need for pressure relief cuts at other project locations.

REFERENCES

[1]Croteau, J. R. "Pavement Riding Quality", New Jersey Department of Transportation, Research Report 74-001-7713 (1974).

[2]Santoro, R. R. "Slipform Paving with an Experimental Contraction Jointed Design (Route I-80, Section 1P), New Jersey Department of Transportation, Research Report 75-007-7779 (1975).

[3]Cosaboom, B. and Mottola, V. "Permeabilities and Load Support Characteristics of Materials Used as Base or Subbase Courses in New Jersey Highways", New Jersey Department of Transportation, Research Report 78-014-7775 (1978).