

flowing along the top of the econocrete base. The stains left on the pavement surface and observations of water flow after rains indicated that water flow up the side of the hill began a few feet downhill from a crest and always occurred on the low side of the pavement slope. Field observations indicated that water was pushed out from under the slab by two forces -- hydrostatic pressure and traffic loading.

PERFORMANCE OF CONCRETE PAVEMENT WITH ECONOCRETE BASE

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Subgrade soils along this project are mixture of A-4, A-5, and A-7-5 materials. The A-7-5 materials predominate and are characterized by low permeability and volume sensitivity to moisture content.

ABSTRACT
A three-lane, 16 mile section of I-85 in Randolph and Davidson Counties, North Carolina, was opened to traffic in 1984. The spring following the opening of this section of highway, reddish-brown stains were visible on the concrete shoulders. Water was determined to be flowing under the slabs and blowing out through weak points along the joints.

The data collected in an attempt to understand this phenomenon included: horizontal and vertical movements of the slabs, static and dynamic pavement deflections, temperature gradients of the pavement system, location of dowels in the slabs, concrete and soil material properties, and field observations to identify water movement.

Possible causes of the problems were identified and methods to minimize damage to the pavement were recommended as a result of this study.

INTRODUCTION

A three-lane 16 mile section of Interstate 85 located in central North Carolina was constructed of plain doweled concrete pavement on a 5 in. econocrete base. Transverse joint spacings of 25, 23, 19, and 18 ft were utilized throughout the project. This section was opened to traffic in January 1984. In the spring of 1984, reddish-brown stains were observed on the pavement surface. Field investigations revealed that substantial amounts of water travelled within the pavement layers. Water blew out to the surface through weak areas along the joints due to hydrostatic pressure. The immediate question which arose was, "Is this a serious problem?" Because this same phenomenon was an early

Source of water
During initial discussions, it was suspected that two likely sources of water were either from rainfall through openings in pavement joints. Therefore, the first item the team inspected was the joint seals. After a complete inspection, there was no indication of any faults in the joint seals. Also, it was observed that water blew out from the joints in both cut and fill sections. Therefore, the team ruled out as a major water source.

Further inspection indicated that there are two likely sources of water infiltration -- the longitudinal joint and the concrete-soil interface at the edge of the slab. The team decided to treat this as a serious problem. Therefore, attempts were made to answer the following questions:
1. Where did water infiltrate the pavement structure?
2. How does the water travel in the pavement system?
3. Has any major damage to the pavement occurred?
4. Is pumping a problem?
5. Are there any signs of loss of support?
6. What can be done to relieve this problem?
7. What should be done in future designs to prevent the same from happening?
In an effort to answer these questions, several field investigations were performed. Findings from this study have led engineers in the North Carolina Department of Transportation (NCDOT) to revise their thinking regarding concrete pavement designs.

Several holes were drilled in the concrete pavement and filled with econocrete base. Red dye was introduced into the holes. Field investigations on this project were composed of three phases and activities in these phases are described as follows:
A. Field observation and destructive testing
The clarity of the water indicated that the source of the water was from the joints. Soon after it was reported that water was blowing out through the joints, a team of engineers was sent out to investigate the problem. The team was charged to find out the source of water, the path of flow and the current extent of pavement damage. Joints where water was blowing out were identified as a source of water. This evidence further supported the assumption that water was

Source of water

During initial discussions, it was suspected that two likely sources of water were either from existing ground water or from surface runoff through openings in pavement joints. Therefore, the first item the team inspected was the joint seals. After a complete inspection, there was no indication of any faults in the joint seals. Also, it was observed that water blew out from the joints in both cut and fill sections. Therefore, ground water was ruled out as a major water source.

Further inspection indicated that there are two likely sources of water infiltration - - the longitudinal joint and the concrete-soil interface at the edge of the concrete shoulders. As moisture content changes, the clay subgrade on which this pavement was constructed changes volume dramatically. As the moisture content decreases, the clay shrinks and openings of 0.5 to 1 in. wide were observed at the concrete-soil interface. Very large quantities of water can be admitted through these very wide openings.

The longitudinal joints of this project were formed by inserting a plastic strips to create weak planes in the fresh concrete. Since the joints formed by this method are fairly tight, no joint sealing was required in the specifications. This questionable practice has been adopted as a standard longitudinal joint alternative for years. Laboratory tests have indicated that water infiltration of a typical joint on this project is approximately 0.07 gal. per linear foot per minute or, stated differently, approximately 740 gallons of water can infiltrate into one mile of this three lane highway every minute.

Path of water

Several holes were cored in the concrete pavement to the top of the econocrete base. Red dye was introduced into the holes but results were inconclusive, and the path of water could not be determined with certainty. During a subsequent investigation, one of the holes cored in the concrete partially filled with water. As trucks passed by, the water level in the hole rose approximately 1 in. The clarity of the water indicated that the pumping action was not carrying fines from the subgrade level. From this observation, the belief that the water was flowing at the interface of the concrete slab and econocrete base seemed plausible. A light brown colored material deposited near the joints where water was flowing out was identified as curing compound used on the econocrete base. This evidence further supported the assumption that water was

flowing along the top of the econocrete base. The stains left on the pavement surface and observations of water flow after rains indicated that water flow up through the joints typically began a few hundred feet downhill from a crest and always occurred on the low side of the pavement slope. Field observations indicated that water was pushed out from under the slab by two forces -- hydrostatic pressure and pumping action resulting from traffic loading.

Subgrade soil

Subgrade soils along this project are mixture of A-4, A-5, and A-7-5 materials. The A-7-5 materials predominate and are characterized by low permeability and volume sensitivity to moisture content changes.

Typical section

A typical pavement section for this project is shown in Fig. 1. Since areas beneath the concrete shoulder were back filled with low permeability soils, the pavement structure is actually constructed in a trench or bathtub section. No shoulder drains were constructed; therefore, once water entered this system, it was trapped with no easy escape route.

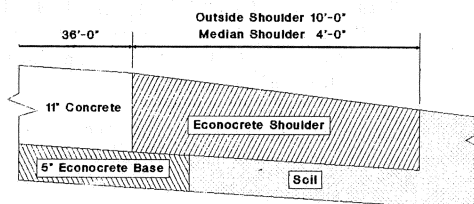


Fig. 1. - Pavement Design Detail

Summary of findings

Findings of this phase of study can be summarized as follows:

1. Water infiltrates the pavement structure through longitudinal joints and the concrete-soil interface at the edge of the shoulders.
2. Due to low permeability soils on the project, the trench section forms a bathtub that traps water in the pavement structure.
3. Water, under a combination of hydrostatic pressure and pumping action induced by traffic loading, exits upward through weak points in the joints.

4. Water flows along the concrete slab-econocrete base interface.
5. Currently, there are no visible signs of damage to the concrete slabs.

B. Shoulder drain testing

Results of the first phase of the study highlighted the need to provide drainage for the water trapped in the pavement structure. Engineers decided to install 5500 ft of shoulder drains in a section of this highway to evaluate the effectiveness in removing water from the pavement structure. The purpose of this test section was twofold -- to verify the findings of the first phase of the study and to evaluate the feasibility and effectiveness of the proposed modification.

Hydraway, a geocomposite shoulder drain produced by Monsanto, was installed in three different locations. Details of these different placements are shown in Figs. 2-4. In Design 1, the shoulder drain was installed two ft from the edge of pavement -- through the concrete shoulder and extending vertically to a point adjacent to the edge of the econocrete base. The purpose of this installation is to provide an outlet for water trapped in the bathtub. In Design 2, the shoulder drain was installed adjacent to the edge of the four ft concrete shoulder. The purpose of this installation is to intercept water that would normally infiltrate through the opening at the concrete-soil interface. The shoulder drain was installed adjacent

to the outside edge of the ten ft concrete shoulder in Design 3. The efficiency of this installation was to be compared with that of Design 1 to determine if trenching through the concrete shoulder could be avoided.

The shoulder drains were installed on October, 1985 by state personnel. A trencher cut a four in. opening through the concrete shoulder with little effort, and the shoulder drain installation went smoothly.

Subsequent field observations indicated that the Design 1 shoulder drain installation functions well. Throughout the entire section where this installation was used, there is no sign of water flowing up through the joints. Field personnel report that water runs out of the outlets within 10 to 15 min. after rain begins.

The Design 3 shoulder drain installation did not perform as well. Although an improvement over sections without shoulder drain installations, signs of water flowing up through joints is still noticeable where this design was utilized.

C. Field instrumentation and nondestructive testing

A series of tests were performed near milepost 92 on the southbound lanes of Interstate 85 in April and November 1987. These tests included temperature measurements, horizontal and vertical slab movements, Benkelman Beam and Falling Weight Deflectometer deflections, dowel locations, and determinations of concrete and soil properties. Illustrated in Fig. 5 is the general test layout.

Temperature Measurements

Thermocouples were implanted in the pavement structure at the surface, at a depth of 1 in. and at 2 in. intervals thereafter to the subgrade. Temperatures were recorded with a data logger at half hour intervals. Typical morning,

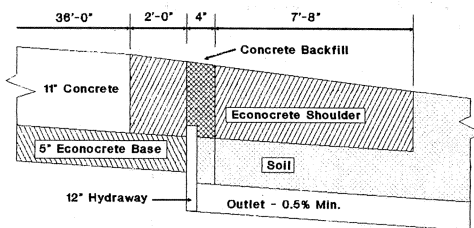


Fig. 2. - Hydraway Installation - Design 1

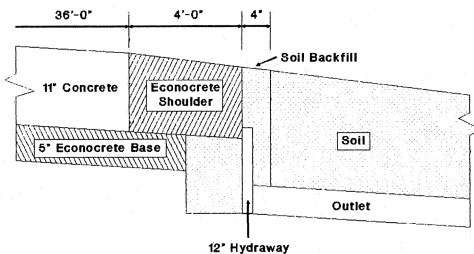


Fig. 3. - Hydraway Installation - Design 2

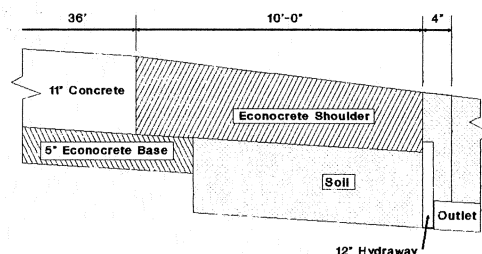


Fig. 4. - Hydraway Installation - Design 3

to the outside edge of the ten ft concrete shoulder in Design 3. The efficiency of this installation was to be compared with that of Design 1 to determine if trenching through the concrete shoulder could be avoided.

4. Water flows along the concrete slab-concrete base interface.
5. Currently, there are no visible signs of damage to the concrete slabs.

Slab No. (Length)
1 (25') 2 (23') 3 (19') 4 (18')

MP 92 SBL
Subsequent field observations indicated that the Design 1 shoulder drain installation functioned well. Throughout the test section where this installation was used, there is no sign of water flowing up the joints. Field personnel report that water runs out of the outlets within 100 ft of the joints.

The Design 1 shoulder drain produced no water flow in three different locations. Details of these different placements are shown in Figs. 2-4. In Design 1, the shoulder drain was installed two (2) ft from the edge of the concrete shoulder and extending vertically to a point adjacent to the edge of the concrete base. The purpose of this installation is to provide an outlet for water trapped in the path of the shoulder drain was installed adjacent to the edge of the four ft concrete shoulder. The purpose of this installation is to provide an outlet for water trapped in the concrete-soil interface.

A series of tests were performed near milepost 92 on the southbound lanes of Interstate 85 in 1987 and November 1987. These tests included temperature measurements, horizontal and vertical slab movements, Benkelman Beam and Falling Weight Deflectometer deflections, dowel location and determination of concrete and soil properties. Illustrated in Fig. 5 is the general test layout.

Temperature Measurements
Thermocouples were implanted in the pavement structure at the surface, at a depth of 1 in. intervals. Temperatures were recorded at half hour intervals from 7:00 a.m. to 5:00 p.m. on the morning of November 1, 1987.

Horizontal Measurement Locations
• Econocrete Vertical Measurement Locations
• Benkelman Beam Deflections
• Benkelman Beam and FWD Deflections
• Soil Samples
• Temperature Measurements

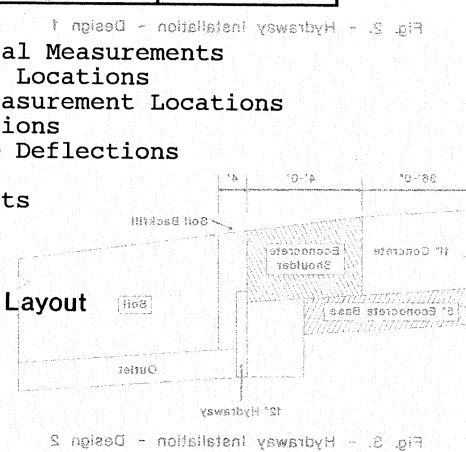
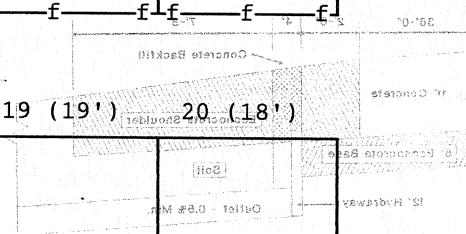
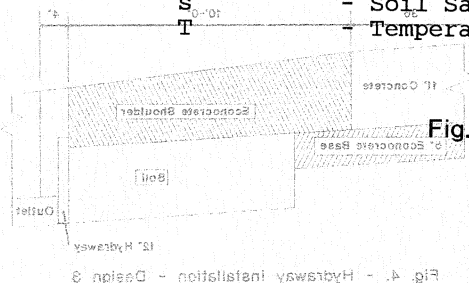


Fig. 5. - I-85 Test Layout

afternoon, and evening temperature distributions are shown in Figs. 6-8. Note the wide swings in temperature and the steep temperature gradients that can occur near the surface during the mid-afternoon and early morning hours as compared to the relatively minor changes which occur near the base.

Horizontal and Vertical Movements

For measurement of horizontal movements, steel inserts were epoxied in the concrete pavement at five consecutive transverse joint locations. Dial calipers were then used to measure the distance between inserts across both the longitudinal and transverse joint locations. The data are summarized in Tables 1 and 2. Measurements are consistent with those predicted theoretically, and indicate that the slabs move freely over the econocrete base.

Dial gauges placed on the pavement surface were used to monitor vertical slab movements to the nearest 0.001 in. These gauges were mounted on steel rods driven into the subgrade. Pavement surface movements are summarized in Tables 3 and 4. Additionally, the movement of the econocrete was monitored at four locations -- at the middle and both outside corners of slab 6 and at the middle of slab 7. Data from the movements of slab 6 are included in Table 5. At each of the three locations in slab 6, movements were monitored for three positions at the top of the slab, at the bottom of the slab, and at the top of the econocrete base. The movements were monitored over a two day period beginning the morning of Nov. 4. The effects of the temperature gradients in the slab are dramatic. During the early morning hours of Nov. 5, the temperature of the top of the slab was only a few degrees cooler than the bottom of the slab as depicted by the 7 A.M. temperature distribution in Fig. 7. As indicated in Table 5 and Fig. 11, there was no significant separation of the concrete and econocrete layers. However, on the following morning, the results are much different; the pavement surface temperature was 18 degrees cooler than the bottom of the slab -- resulting in complete separation of the concrete slab from the econocrete base at the corner locations. The separations reached maximum values of 0.018 and 0.023 in. at 7 A.M. These measurements were taken at a distance of approximately 20 in. from the intersection of the transverse and longitudinal joints and are significant in that they indicate that the corners of the slabs are left completely unsupported when the top of the slab is significantly cooler than the bottom of the slab.

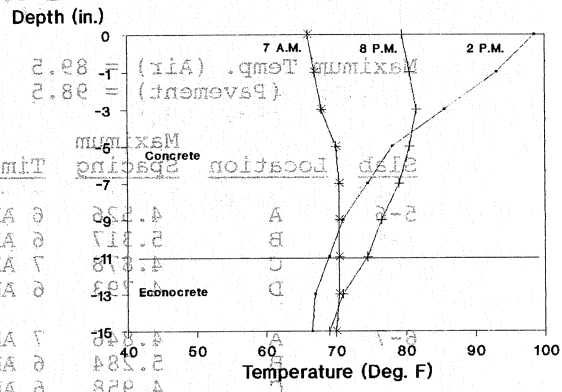


Fig. 6. - Pavement Temperature Distribution
I-85 SBL MP 92, 4/22-23/87

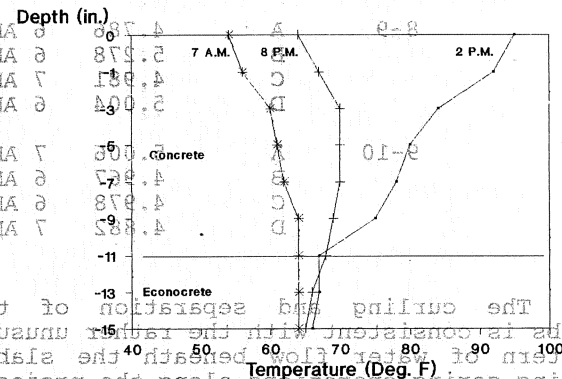


Fig. 7. - Pavement Temperature Distribution
I-85 SBL MP 92, 11/4-5/87

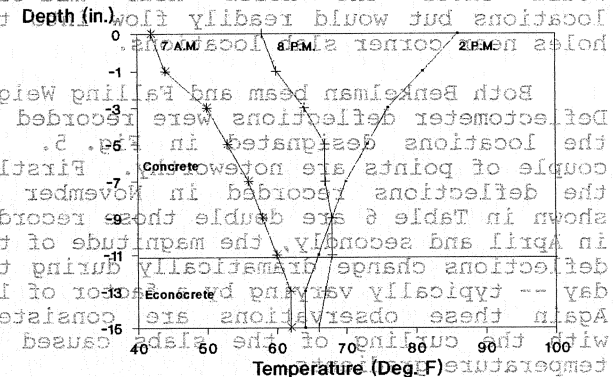


Fig. 8. - Pavement Temperature Distribution
I-85 SBL MP 92, 11/5-6/87

A Falling Weight Deflectometer was used to measure deflections at both sides

TABLE 1. - Horizontal Slab Movements
April 22-23, 1987
I-85 SBL, MP 92

Maximum Temp. (Air) = 89.5 Minimum Temp. (Air) = 62.5
(Pavement) = 98.5 (Pavement) = 66

Slab	Location	Maximum Spacing	Time	Minimum Spacing	Time	Total Change (in.)
5-6	A	4.526	6 AM	4.513	2 PM	0.013
	B	5.317	6 AM	5.304	3 PM	0.013
	C	4.878	7 AM	4.872	2 PM	0.006
	D	4.793	6 AM	4.783	2 PM	0.010
6-7	A	4.846	7 AM	4.835	2 PM	0.011
	B	5.284	6 AM	5.263	12 PM	0.021
	C	4.958	6 AM	4.748	3 PM	0.010
	D	4.936	6 AM	4.922	2 PM	0.014
7-8	A	4.982	7 AM	4.969	3 PM	0.013
	B	4.998	5 AM	4.986	2 PM	0.012
	C	4.677	5 AM	4.669	4 PM	0.008
	D	5.254	5 AM	5.242	4 PM	0.012
8-9	A	4.786	6 AM	4.777	2 PM	0.009
	B	5.278	6 AM	5.263	2 PM	0.015
	C	4.981	7 AM	4.969	3 PM	0.012
	D	5.004	6 AM	4.987	3 PM	0.017
9-10	A	5.006	7 AM	4.997	2 PM	0.009
	B	4.967	6 AM	4.952	2 PM	0.015
	C	4.978	6 AM	4.969	3 PM	0.009
	D	4.882	7 AM	4.867	3 PM	0.015

The curling and separation of the slabs is consistent with the rather unusual pattern of water flow beneath the slabs. During coring operations along the project, technicians observed that some water flowed into the holes cored near the middle of the slabs during the afternoon hours, but did not flow in the holes located near the slab corners. However, during the early morning hours, the reverse was true -- no water would enter the holes near mid-slab locations but would readily flow into the holes near corner slab locations.

Both Benkelman beam and Falling Weight Deflectometer deflections were recorded at the locations designated in Fig. 5. A couple of points are noteworthy. Firstly, the deflections recorded in November as shown in Table 6 are double those recorded in April and secondly, the magnitude of the deflections change dramatically during the day -- typically varying by a factor of 10. Again these observations are consistent with the curling of the slabs caused by temperature gradients.

Load Transfer Efficiency

A Falling Weight Deflectometer was used to measure deflections at both sides

of the joint. Two readings were taken at each joint. The first set of data was taken by setting the load plate (sensor 1) six in. from the edge of pavement and six in. from the joint on the approach side. The second sensor (sensor 2) was placed at the leave side of the joint symmetric to the loading plate. The second set of data was taken by placing the two sensors at the same location, except that the load plate was placed on the leave side of the joint. Deflections on five consecutive joints were measured. The efficiency of load transfer is defined as the ratio of deflection of sensor 2 to deflection of sensor 1.

Figures 9 and 10 illustrate the load transfer efficiency of two typical joints. The efficiency peaks at approximately 6 P.M. -- which corresponds to the time of day when the temperature difference between the top and the bottom of the slab is a minimum as shown in Fig. 11.

Baskets were used to properly position dowels (1.375 in. diam. x 18 in.) at mid-depth in the concrete at transverse joints. A metal detector was used to determine horizontal positions and to estimate the depth of cover. Several cores were taken to verify the depth readings. Results are presented in Figs. 12-16 and

TABLE 2. - Horizontal Slab Movements
November 4-5, 1987
I-85 SBL, MP 92

Maximum Temp. (Air) = 81 Minimum Temp. (Air) = 49
(Pavement) = 91 (Pavement) = 54

Slab	Location	Maximum Spacing	Time	Minimum Spacing	Time	Total Change (in.)
5-6	A	4.517	9 AM	4.498	3 PM	0.019
	B	5.322	9 AM	5.313	4 PM	0.009
	C	4.925	9 AM	4.915	2 PM	0.010
	D	4.809	9 AM	4.798	2 PM	0.011
6-7	A	4.865	9 AM	4.842	2 PM	0.023
	B	5.307	7 AM	5.295	2 PM	0.012
	C	4.768	9 AM	4.753	2 PM	0.015
	D	4.985	6 AM	4.975	2 PM	0.010
7-8	A	5.002	9 AM	4.982	3 PM	0.020
	B	5.008	6 AM	4.998	2 PM	0.010
	C	4.673	9 AM	4.658	2 PM	0.015
	D	5.274	7 AM	5.260	2 PM	0.014
8-9	A	4.800	7 AM	4.776	2 PM	0.024
	B	5.301	9 AM	5.287	2 PM	0.014
	C	5.000	9 AM	4.980	2 PM	0.020
	D	5.032	9 AM	5.016	1 PM	0.016
9-10	A	5.030	7 AM	5.002	2 PM	0.028
	B	4.987	9 AM	4.973	1 PM	0.014
	C	4.980	9 AM	4.965	2 PM	0.015
	D	4.885	6 AM	4.873	2 PM	0.012

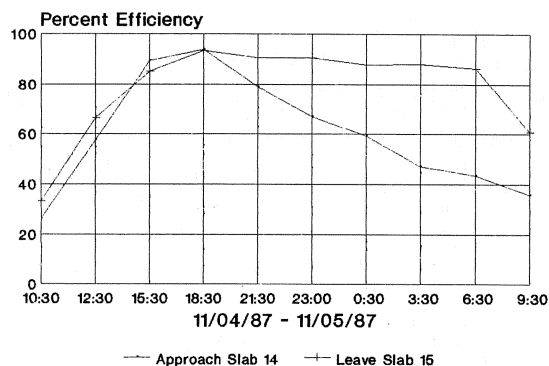


Fig. 9. - Joint Load Transfer Efficiency
Concrete Slabs 14 & 15

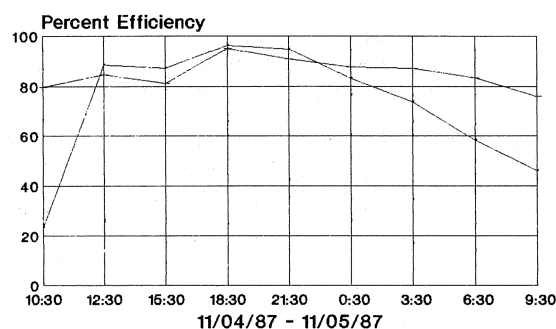


Fig. 10. - Joint Load Transfer Efficiency
Concrete Slabs 15 & 16

are shocking. Two of the five joints have dowels that are badly misaligned. As illustrated in Figs. 15 and 16, most of the dowels between slabs 8-9 and 9-10 completely miss the transverse joint. In November, these slabs exhibited more vertical movement than any of the other slabs. Later checks revealed that a significant number of the joints have misaligned dowels. As a result of these findings, dowel baskets have been strengthened and improved tie-down methods adopted.

Compression Tests

Compressive strengths of 4 in. concrete cores averaged in excess of 5,000 psi, while compressive strengths of 6 in. econocrete cores approached 2,000 psi. Dynamic moduli of elasticity as determined from vibration frequencies and field compression wave velocity tests averaged approximately 5×10^6 psi for the concrete and 3×10^6 psi for the econocrete.

SESSION 6: JOINTS, BASES AND DRAINAGE

TABLE 3. - Vertical Slab Movements
April 22-23, 1987
I-85 SBL, MP 92

Maximum Temp. (Air) = 89.5 Minimum Temp. (Air) = 62.5
(Pavement) = 98.5 (Pavement) = 66

Gauge No.	Slab	Slab Location	Slab Length	Time of Down	Time of Up	Max. Curl	Total Movement
3	5	Corner	25	MA 03 PM 12 7 AM		0.028	
4	6	Corner	23	MA 03 PM 12 7 AM		0.027	
17	6	Corner	23	MA 03 PM 12 7 AM		0.0435	
18	7	Corner	19	MA 04 PM 08 7 AM		0.0405	
28	7	Corner	19	4 PM 7 AM		0.034	
29	8	Corner	18	MA 04 PM 08 7 AM		0.035	
31	8	Corner	18	MA 04 PM 08 7 AM		0.039	
32	9	Corner	25	MA 03 PM 07 7 AM		0.0415	
34	9	Corner	25	MA 03 PM 07 7 AM		0.041	
35	10	Corner	23	3 PM 7 AM		0.0425	
10	6	Middle - Edge	23	MA 04 PM 00 7 AM		0.024	
21	7	Middle - Edge	19	MA 03 PM 07 7 AM		0.0135	
30	8	Middle - Edge	18	MA 04 PM 07 7 AM		0.0215	
33	9	Middle - Edge	25	4 PM 7 AM		0.019	

TABLE 4. - Vertical Slab Movements
November 4-5, 1987
I-85 SBL, MP 92

Maximum Temp. (Air) = 81 Minimum Temp. (Air) = 49
(Pavement) = 91 (Pavement) = 54

Gauge No.	Slab	Slab Location	Slab Length	Time of Down	Time of Up	Max. Curl	Total Movement
1	5	Joint - Middle	25	1 PM 9 AM		0.0215	
2	6	Joint - Middle	23	12 PM 7 AM		0.017	
15	6	Joint - Middle	23	1 PM 9 AM		0.017	
16	7	Joint - Middle	19	12 PM 9 AM		0.019	
3	5	Corner	25	2 PM 7 AM		0.0465	
4	6	Corner	23	2 PM 7 AM		0.0455	
17	6	Corner	23	2 PM 7 AM		0.053	
18	7	Corner	19	2 PM 7 AM		0.0375	
28	7	Corner	19	2 PM 7 AM		0.039	
29	8	Corner	18	2 PM 7 AM		0.044	
31	8	Corner	18	2 PM 7 AM		0.073	
32	9	Corner	25	2 PM 7 AM		0.070	
34	9	Corner	25	2 PM 7 AM		0.0645	
35	10	Corner	23	2 PM 7 AM		0.060	
5	5	Corner - Should.	25	2 PM 7 AM		0.028	
6	5	Corner - Should.	23	2 PM 7 AM		0.026	
19	7	Corner - Should.	19	2 PM 9 AM		0.030	
20	6	Corner - Should.	23	2 PM 7 AM		0.0335	
10	6	Middle - Edge	23	2 PM 7 AM		0.015	
21	7	Middle - Edge	19	2 PM 9 AM		0.0065	
30	8	Middle - Edge	18	2 PM 7 AM		0.019	
33	9	Middle - Edge	25	2 PM 7 AM		0.0195	

TABLE 5 - Separation of Slab, Econocrete Base
November 4-6, 1987
I-85 SBL, MP-92

Time	Pavmt. Surf. Temp.	Corner 8	Corner 9	Center 13	Center 14	Center 26	Center 27
11/4							
9 AM	-	0	0	0	0	0	0
11 AM	84	-6.5	-2.5	-4	7.5	6.7	1.5
1 PM	91	-9.5	-5.0	-4.5	8.5	9	-0.5
3 PM	84	-8.5	-4.5	-4.0	9.5	9.3	0.5
5 PM	74	-7.5	-3	-4.5	7.5	6.5	0
7 PM	67	-5	-1.5	-3.5	7	6	1
9 PM	64	-2.5	0	-2.5	6.5	5.5	1.5
11 PM	62	-1.0	0.5	-1.5	5.5	4.5	1
11/5							
1 AM	61	0	-1	-1	5.5	4	1.5
3 AM	59	1.5	1	0.5	5.5	3.5	2
5 AM	56	2.5	1.5	1	5.5	2.5	3
7 AM	54	4.5	1.5	3	3	1	1
9 AM	67	1.5	2.5	-1	2	2.5	-0.5

Gauges Reset

10 AM	78	0	0	0	0	0	0
11 AM	82	-1.5	-1.5	0	0	0	-2
1 PM	86	-3	-3	0	3	4	-1
3 PM	81	-2	-2	0	3.5	3	0.5
5 PM	68	-1.5	-1.5	0	2	2	0
6 PM	63	1	0	1	0	1	-1

11/6							
2 AM	47	17	3	14	-4	-5	1
7 AM	42	20.5	2.5	18	-7.5	-7	-0.5
8:30	42	16	2	14	-8.5	-7	1.5
9:15	57	10.5	2	8.5	-7.5	-5.5	-2.5
10:30	66	3	2	1	-6	-5	-1

Gauges 8,13,26 - Bottom of Concrete Slab
Gauges 9,14,27 - Top of Econocrete Base
Sep. - Separation of Concrete Slab and Econocrete (0.001 in.)

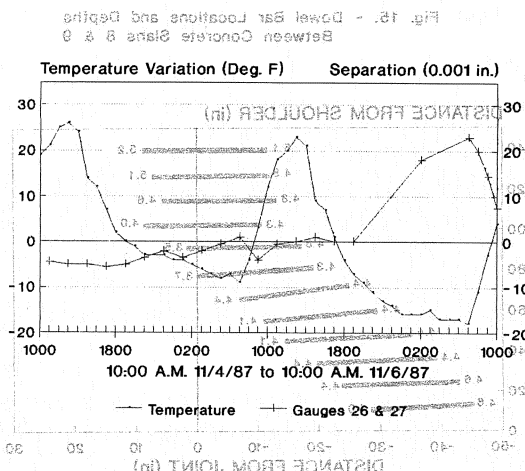


Fig. 11. - Pavement Temperature Variation/Slab Separation

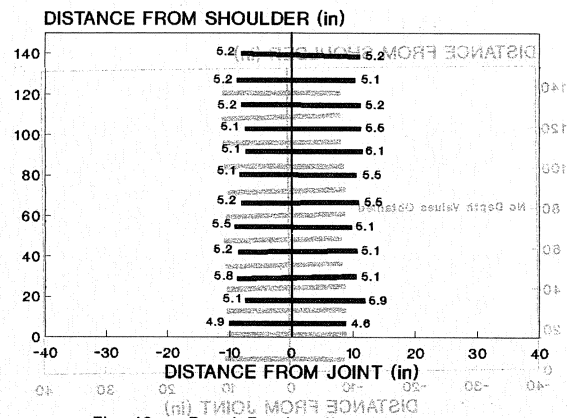


Fig. 12. - Dowel Bar Locations and Depths Between Concrete Slabs 5 & 6

CONCLUSIONS

1. Although the joints appear tight, longitudinal joints formed by plastic strips can be a major source of water infiltration.
2. Bathtub construction in low permeability soils will trap water and cause damage to the pavement system. Installation of shoulder drains can relieve this problem by providing outlets for the water.
3. A sealed joint that is perfectly waterproof is very difficult, if not impossible, to achieve. Provisions to discharge infiltrated water should be an integral part of pavement structure design.
4. Dowel baskets can be pushed out of place by paving operations. Misaligned dowels can result in many problems including loss of load transfer, locked joints, and spalling. A sturdy dowel basket that can hold dowels in the proper position is essential. Therefore, basket design and tie-down methods are important parts of the total design process.
5. Load transfer efficiency is related to temperature change. Further study and investigation of the effects of temperature change on load transfer efficiency could help in improving joint design.
6. Horizontal movements indicate the concrete slab moves freely on the econcrete base.
7. Warping of the concrete slabs forms a channel for water flow along the concrete-econcrete interface.
8. When the top of the slab is significantly cooler than the bottom, the warping effect will uplift the slab and completely separate it from the econcrete base -- leaving the corners and edges unsupported.
9. Benkelman Beam deflections undergo wide daily variations due to temperature changes.

RECOMMENDATIONS

Several actions have been recommended to relieve problems on this section of I-85. Two subsequent projects were let in an effort to prevent further damage to the

pavement. These preventive actions include the following:

1. Install shoulder drains.

Shoulder drains were installed along both outside and median sides of the pavement. Details of the shoulder drain installations are shown in Figs. 2 and 3. Shoulder drains installed on the low side of the pavement are to provide outlets for water that infiltrates into the pavement structure, while drains installed on the high side of the pavement are to intercept water that would normally infiltrate the pavement structure through the opening at the concrete-soil interface. The cost of shoulder drain installation is slightly over \$3.00 per linear ft.

2. Repair all damaged low modulus silicone joint seals.

Initially, the plan was to repair silicone joint seals that were damaged by hydrostatic pressure. This repair would reestablish a sealed pavement surface thus reducing the amount of water infiltration. However, as the repair operation proceeded, it was discovered that the silicone material used in part of this section was in such poor condition that all of the joints had to be resealed. Inferior sealant quality was the cause of these failures.

MODIFICATION OF DESIGN CONCEPTS

Water is a terrible enemy of pavements. Without the presence of water in the pavement structure, most pavements can perform well. Based on this study, it is realized that even the tight cracks along longitudinal joints can allow large quantities of water to infiltrate the pavement structure. Although there have been and continue to be major improvements in the effectiveness of joint sealants, it is unlikely that it will ever be possible to seal and maintain joints that are absolutely waterproof. Our experience has shown that eventually water will find its way into the pavement structure. It is certainly important to try to keep water from entering the structure, but it is equally, if not more important, to provide outlets which allow water to rapidly exit the system.

Placing two rigid layers, namely concrete pavement and econocrete base, against each other is a major concern among NCDOT engineers. As shown by the field measurements, when the top surface of the concrete slab is significantly cooler than the bottom, as would occur on any cold night, the concrete pavement will curl and lift from the base -- resulting in a complete loss of support along all edges of the slab. Depending on a variety of factors including traffic loading conditions and the concrete thickness, stiffness, and strength, this phenomenon could very dramatically reduce the fatigue life of the slab.

Information gained from this study has prompted NCDOT engineers to change their thinking regarding the concepts of concrete pavement design. Changes are summarized as follows:

1. Provide positive pavement drainage system.

An open graded aggregate base stabilized with approximately 2% asphalt was introduced to the family of base materials. This open graded base course was used in all concrete paving projects in the past two years. Water infiltrating the pavement system is picked up from the low side of this freely draining layer and discharged to a drainage structure or side ditch. This material is stable enough to support the weight of the paving train, and there has been no sign of any negative impact on ride quality. The coefficient of permeability of samples tested ranges from 6.2 to 8.6 ft/day. This open graded layer is able to drain water from the pavement structure within a couple of hours after rain stops.

2. Seal all joints.

Longitudinal and transverse joint are provided to control cracks induced by contraction of the fresh concrete. Tayabji and Colley (1) noted that, in order to function properly, concrete pavement joints must be sealed -- to keep incompressibles out of the joints and to prevent water infiltration. From this case study, it has been found that the unsealed longitudinal joint is one of the major sources of water infiltration. Using a plastic strip to generate a weak plane can effectively form a longitudinal joint. But it is very difficult,

if not practically impossible, to later seal a joint formed in this manner due to misalignment in both horizontal and vertical planes. Therefore, this practice has been discontinued and both longitudinal and transverse joints are formed by sawing and are sealed with a high quality low modulus silicone sealant.

3. Improve dowel basket.

Misaligned dowels can cause several problems, namely, loss of load transfer, locked joints, and the resulting cracking and spalling. Stronger dowel baskets and stronger hold downs for the baskets are now required. These steps were taken to reduce the likelihood of dowel basket deformation and misalignment occurring during the paving operation. Field application of grease on dowels has been poor and the quality of work has often been less than desirable. Conditions of core samples further proved this to be true. An uneven grease application can cause joints to lock or create cavities around dowel bars that reduce load transfer efficiency. Specifications were revised to require the whole basket be dipped in wax to achieve a uniform coating on the dowels.

4. Impose moratorium on the use of econocrete base.

While discussing rigid pavement design concepts, Yoder and Witczak (2) indicated that a rigid pavement is a thin slab on a foundation which can be either a stabilized base or subgrade soil. Stresses in the slab are induced from wheel loads and environmental factors such as temperature and moisture changes:

These changes tend to deform the slab, causing stresses of widely varying intensity. In addition, the magnitude of stress depends upon continuity of subgrade (foundation) support.

Analysis of rigid pavement stresses are based on the assumption that the modulus of elasticity of the slab is much greater than that of the foundation. Therefore, as the slab deforms, the foundation will

deform accordingly. This is not true for econocrete bases, and although the modulus of elasticity is typically lower than for the slab, it often is not dramatically so and still behaves as a very rigid unyielding and nonconforming layer. This study indicated that certain temperature changes can cause the slab to lift entirely from the econocrete base. Loads must then be carried entirely by the upper slab -- similar to a cantilevered beam without any support from the base. This phenomenon is disturbing and will have a negative impact on pavement performance -- the magnitude of which is unknown. Therefore, while studies of the relative advantages and disadvantages of econocrete bases continue, use of econocrete bases in North Carolina has been temporarily halted.

5. Restudy specification on low modulus silicone sealant.

Two different brands of low modulus silicone sealant were used in this section of highway. Although both sealants met the project specifications, it was found during the course of this study that joints sealed with brand "A" had a very low failure rate while brand "B" had almost a 100% failure rate. It is realized that the current specification can not assure performance of the material and further study to enhance the specification requirements for this type of material is required.

REFERENCES

1. Tayabji S. D. & Colley, B. E., Improved Rigid Pavement Joints, FHWA/RD-86/040, FHWA, Washington DC, 1986
2. Yoder, E. J. & Witczak, M. W., Principles of Pavement Design, 2nd Edition, John Wiley & Sons, Inc., New York, 1975