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15. Supplementary Notes The panel members were T. Paul Teng, Mississippi State Highway Department, Gene R. Morris, Arizona DOT, and Wade L. Gramling, Pennsylvania DOT, panel chairman. Mr. Joe P. Sheffield replaced Mr. Teng when he joined the FHWA staff. Dr. Floyd Stanek served as FHWA technical representative and exofficio panel member.

16. Abstract

This report discusses the performance of four full scale prestressed concrete pavements built between 1971 and 1979 in different parts of the United States in various climatic areas carrying a range of traffic. The information was developed by a panel made up of representatives from each of the four States where a full scale prestressed pavement was constructed. These representatives were familiar with the design and construction. Details of construction, prestressing, and jointing are given for the projects at Dulles International Airport, Va., Hogestown, Pa., Brookhaven, Miss., and Tempe, Ariz.

The panel performed a close inspection of the condition of these projects in March of 1981 and developed appropriate conclusions and recommendations after carefully considering the performance and characteristics of the four projects which have a total length of 22 lane miles. Some research needs in prestressed pavements were also identified.

It was concluded that prestressed concrete has performed adequately. On the basis of its performance and economics, prestressed pavement is a viable alternate type. Some design guidelines are suggested and desirable future project characteristics are indicated.

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Unclassified	Unclassified	34	

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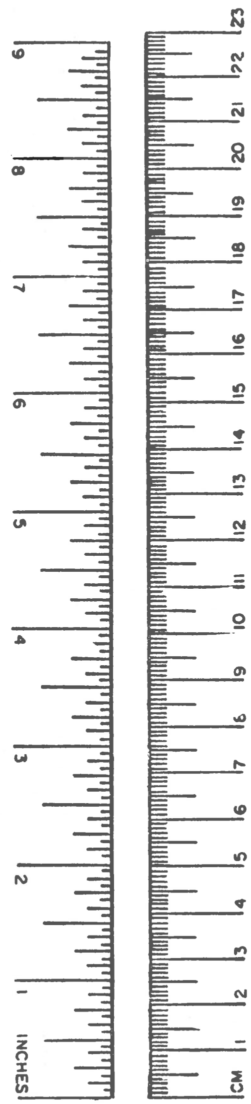
METRIC CONVERSION FACTORS

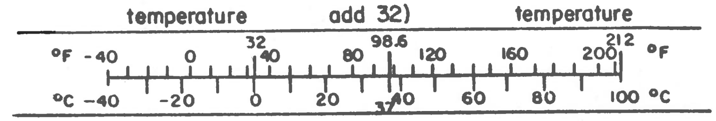
APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.6	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons(2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares(10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	8.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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"Prestressed Pavement Performance in Four States"

I. Development of Prestressed Pavements

A prestressed concrete pavement 3,200 feet long was built in 1971 at Dulles International Airport (1)* in Virginia. The completed pavement is part of the airport road network and was built under the Federal Highway Administration (FHWA) Demonstration Projects Program No. 17.

A prestressed slab (2) was also built prior to the Dulles pavement (Virginia Project) during July of 1971 near Milford, Del. The Milford slab is 6 inches thick with seven plastic-encased, 0.6-inch-diameter tendons. The 14-foot-wide slab is located on a ramp. The tendons had an initial tensioning force of 40 kips each. This was the first prestressed pavement of this kind constructed and was the predecessor of the kind described in this report.

During the summer of 1972, a prestressed slab two lanes wide (3) was placed as part of conventional mainline pavement being placed with normal slip-form paving operations on U.S. Route 222 near Kutztown, Pa. The slab was the forerunner of a full-scale project built later in Pennsylvania and was a result of a contractor's experience on the Dulles project and his initiative to make a similar installation in Pennsylvania. The slab was 6 inches thick, 24 feet wide, and 500 feet long. It was placed on a 3-inch-thick hot mix bituminous base course laid on a 9-inch granular subbase. Two layers of polyethylene film were placed under the slab. The slab was post-tensioned with 10 tendons, 0.6 inches in diameter, which were encased in a polypropylene jacket.

The initial trial prestressed pavements built in Milford, Dulles, and Kutztown were followed by the design and construction of three full-scale mainline roadway projects in different parts of the United States. Prestressed pavements were built in Pennsylvania (4) in 1973, in Mississippi (5) in 1976, and

*Numbers in parentheses designate references on page 32.

in Arizona (6) in 1977. The pavements were all 6 inches thick and used encased wire tendons. The pavements were all constructed on treated bases.

The prestressed pavement projects were built under State sponsorship with FHWA Region 15 support under the Demonstration Projects Program No. 17. Because the pavements were constructed between 1971 and 1977 and had 4 to 10 years performance history, it was appropriate to undertake a performance study during 1981 to assess the conditions of the pavements, draw conclusions, and make recommendations based upon the project performance to date.

The FHWA initiated a project for a performance study by a panel made up of one research engineer from the State highway agencies of Arizona, Mississippi, and Pennsylvania. The FHWA contract manager served as an exofficio member of the panel and also provided input for the Virginia project.

This is a summary report of the study panel's appraisal and comparison of the design and construction of these projects. The performance reports are based upon observations made as a group during inspections of the four sites.

II. Potential for Prestressed Pavement

The use of prestressed pavements has been of interest for some time because of the potential for savings in materials and improved performance at lower cost. Observations of experimental pavements show that adequate performance can be obtained with prestressed pavements only 40 to 60 percent as thick as conventional pavements. Significant savings of steel can be realized with prestressed pavements requiring 2 1/4 lb/yd^2 compared to 15 to 20 lb/yd^2 for continuously reinforced concrete pavements.

The problems associated with transverse cracks and joints are minimized because only one joint might be needed every 500 or 600 feet. A conventionally jointed pavement might have 9 or 10 joints if the pavement contained distributed steel or 25 or more if the pavement was a plain concrete design. The fewer joints required should reduce routine maintenance requirements for joint sealing and the absence of joints should provide better long term ride quality.

Special joints are required for prestressed pavements since larger joint movements must be accommodated due to very long slab lengths. There is also a need to provide "gaps" when the pavements are placed to provide access for the jacking operations which tension the prestressed strands. Each of the projects discussed in this report used variations in the jointing and jacking procedures, and each project has illustrated some of the details that work and some which should be avoided.

It should be possible to build upon the experience gained from these projects and to specify construction and jointing details which have a high degree of performance potential.

A potential long time performance comparison exists for each of the prestressed pavements with the adjacent pavements which were constructed at about the same time. The Pennsylvania project is next to a 9-inch-thick conventional reinforced pavement carrying the same traffic. The Mississippi prestressed project was built in conjunction with a continuously reinforced project. The Tempe, Ariz., project is on the Superstition Freeway, which includes several modern conventional pavement designs. However, more time will be required for these comparisons because little pavement distress has been noted in either the prestressed or the conventional pavement to date, and there has been no apparent significant loss in serviceability up to this time.

III. Project Characteristics

A. General

The geographic location of the four projects falls into three of the four climatic zones generally accepted by pavement researchers for the United States. The zones delineate areas of expected similar pavement performance as influenced by temperature and climatic classifications. The Virginia and Pennsylvania projects are in the wet-freeze zone with an average 40 inches annual rainfall, and the Mississippi project falls in the wet-no freeze zone with 57 inches average annual rainfall. The Arizona project is in the dry-no freeze zone with 7 inches average annual rainfall. Figure 1 shows an outline of the United States with the climatic zones and the prestressed pavement locations.

Some of the general physical characteristics of the pavements are shown in Table 1.

The cross sections of the four projects are reasonably similar as shown in figures 2, 3, 4, and 5. All of the 6-inch pavements were constructed with the prestressing strands 3 1/2 inches deep. The prestressing strands were all greased and encased in extruded polypropylene jackets except in three of the six slabs in the Virginia project. Those three slabs had bare prestressing strands encased in a flexible metal conduit, which was later filled with grout using injection parts spaced at 100-foot intervals.

A double layer of polyethylene sheeting was placed under nearly all of the pavement slabs to function as a

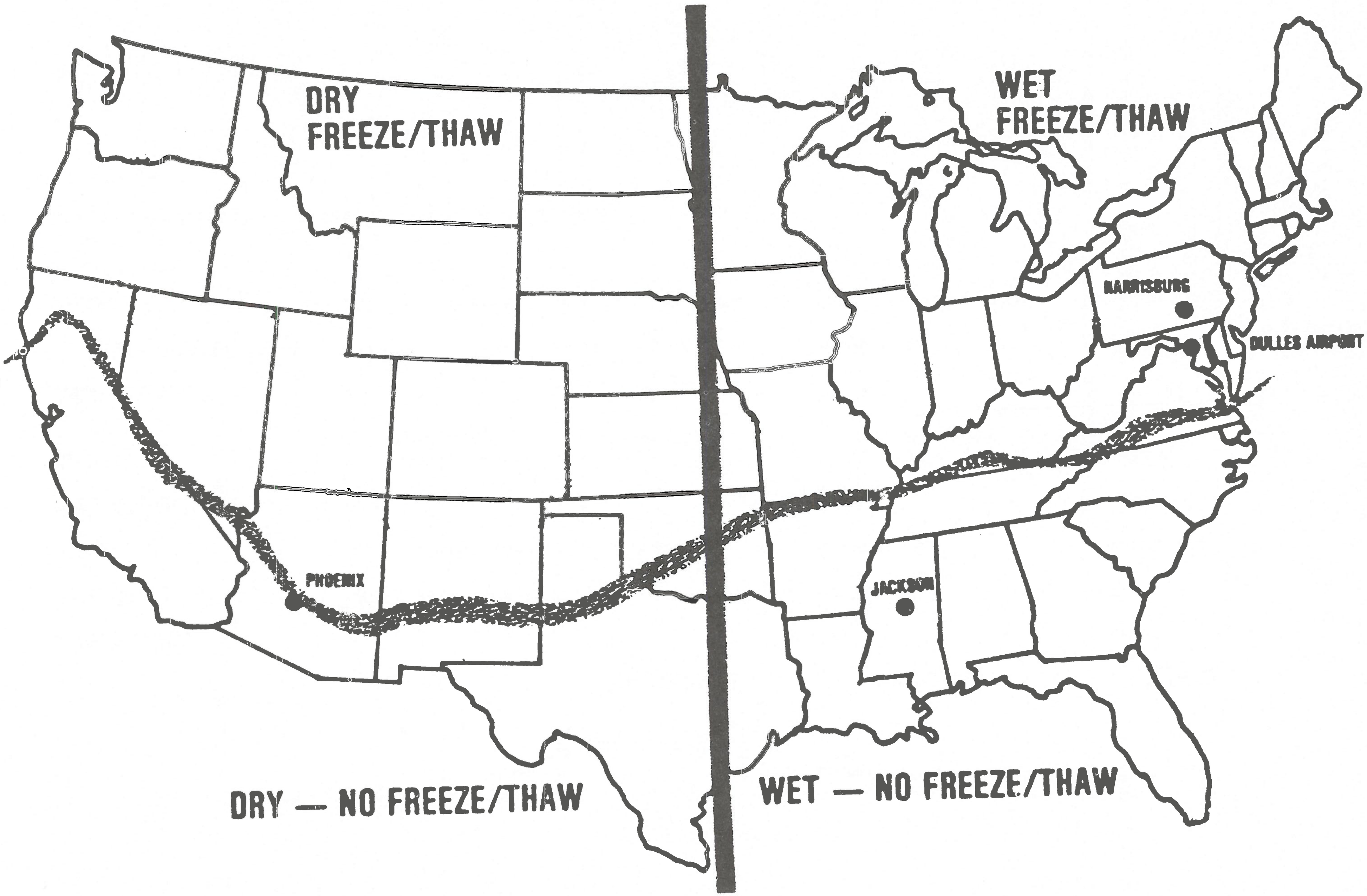


Figure 1. Location map and weather zones.

Table 1 - Project Data

	Virginia	Pennsylvania	Mississippi	Arizona
Length-Miles	0.6	1.5	2.5	1.2
Year Built	1971	1973	1976	1977
Lanes	2 (One Direction)	4 (Divided)	4 (Divided)	4 (Divided)
Slab Thickness-Inches	6	6	6	6
Subbase	6" Cement Treated Aggregate	6" Agg. Bit. Base Course	4" Hot Mix Bit. Concrete	4" Lean Concrete
Subgrade - CBR	3	4	20 (a)	3
Soil Classification	Clay	Silty Clay	Sandy Clay	Silty Clay
Climate	Wet, Freeze-Thaw	Wet, Freeze-Thaw	Wet, No Freeze-Thaw	Dry, No Freeze-Thaw

(a) Improved subgrade layer on A-2 to A-7 subgrade.

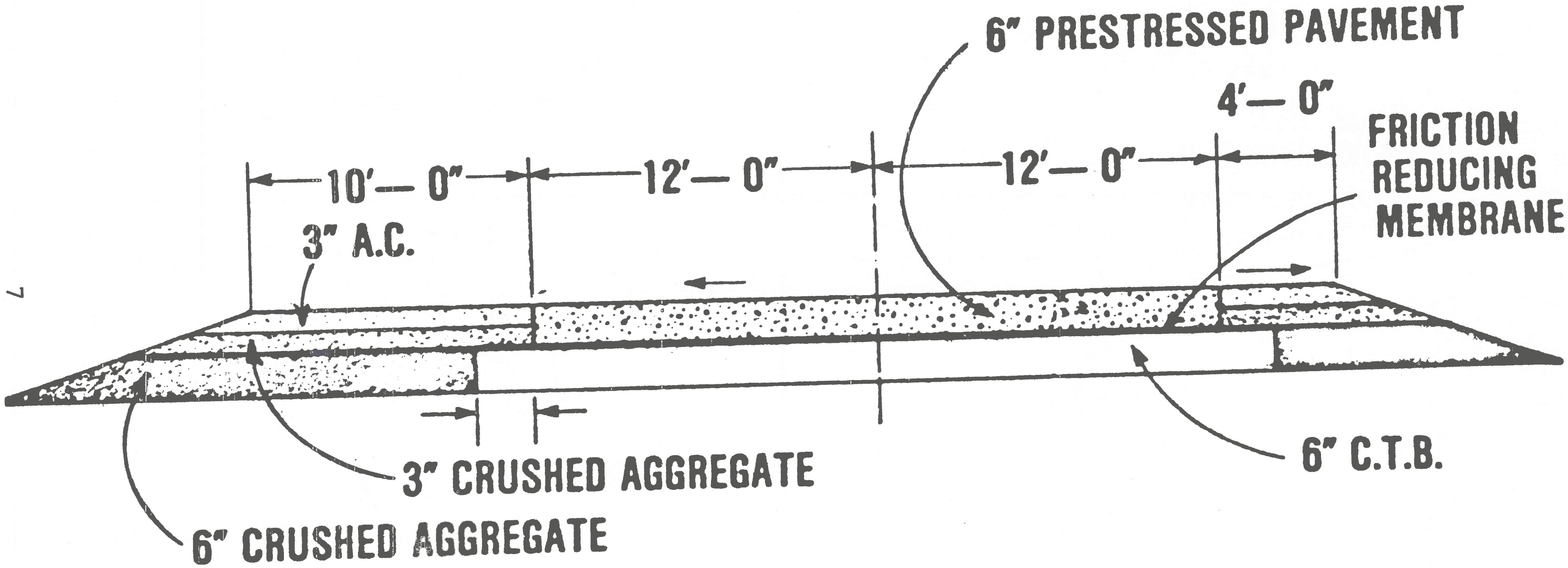


Figure 2. Virginia pavement cross section.

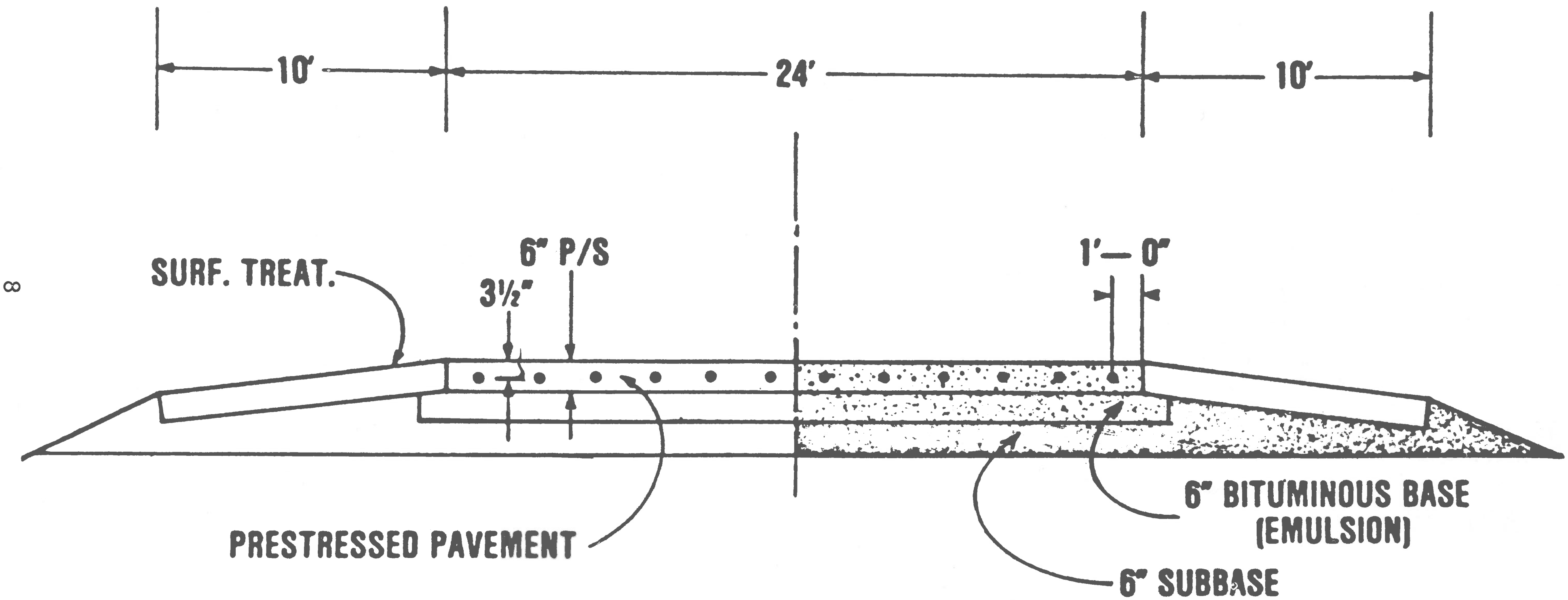


Figure 3. Pennsylvania pavement cross section.

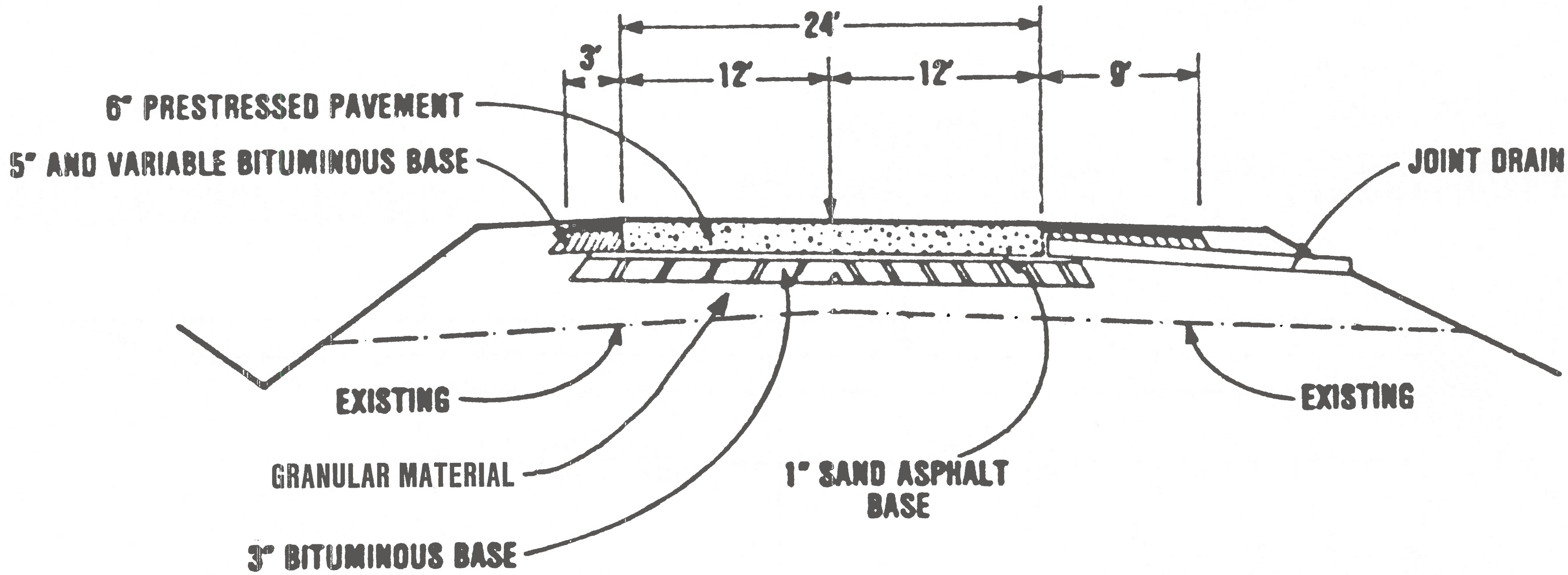


Figure 4. Mississippi pavement cross section.

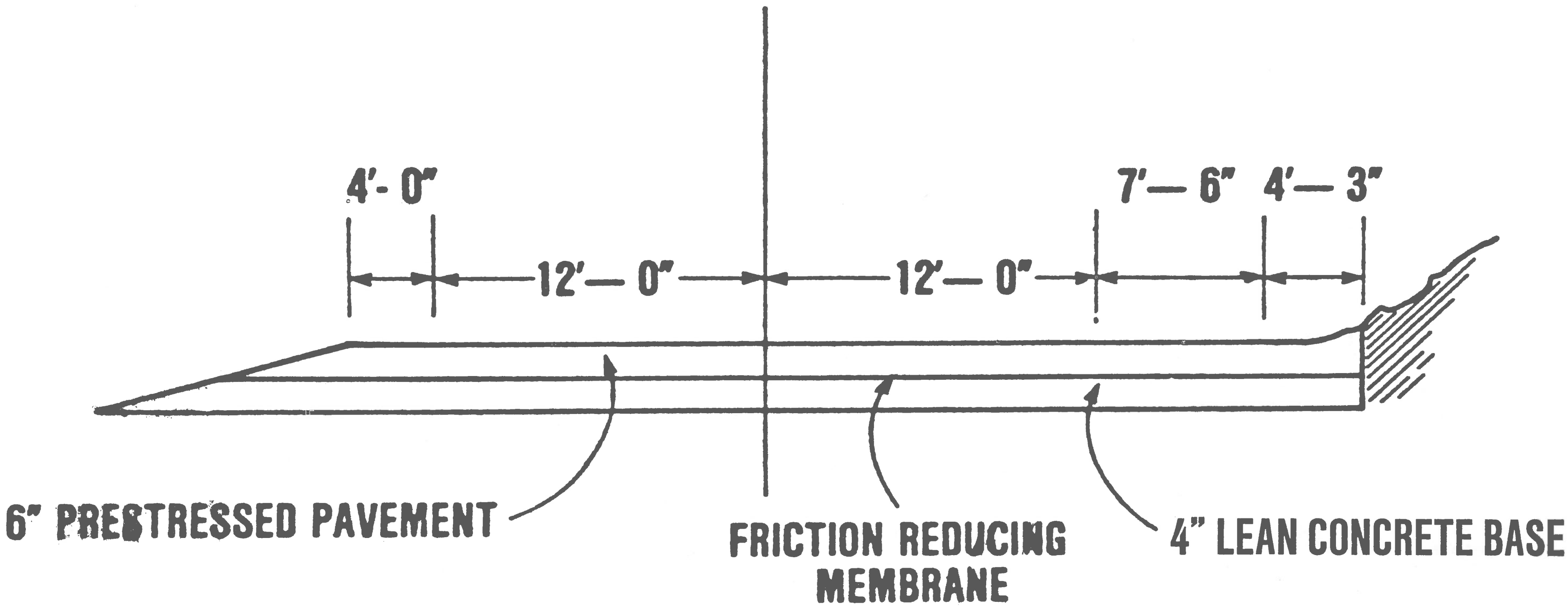


Figure 5. Arizona pavement cross section.

bond breaker. One slab with no polyethylene sheeting was built as part of the Mississippi project. This slab developed five relatively uniformly spaced transverse cracks. Four of the cracks were hairline and the fifth crack was opened to an unacceptably wide condition.

In both the Mississippi and the Arizona projects, one slab was built with a single layer of polyethylene.

All of the projects were built on treated bases, however, there was a wide variety in the types of treatment.

B. <u>Prestressing Steel</u>

The Virginia project had twelve 0.5-inch-diameter wire longitudinal prestressed strands of ASTM Designation A-416, 270 Grade, on 2-foot centers. The Pennsylvania project had the same strand arrangement, however, 0.6-inch-diameter strands were used. The Mississippi and Arizona projects had the same strand details as Virginia, except Arizona had 16 strands. The extra four strands were needed for the 7 1/2-foot-wide shoulder lane placed at the same time as the two 12-foot main traffic lanes.

B(1) <u>Prestressing Procedures</u>

Stressing procedures were similar for all of the projects with jacking taking place from both ends. The jacking was done in stages which were related to concrete strength gain as defined by cylinder breaks. Some of the prestressing data is contained in Table 2. More complete discussions of the prestressing procedures are described in the project reports listed in the references. No particular or unusual difficulties were encountered in the stressing operations and in the specific instances when problems did occur they were solved without undue effort, such as the concrete discussed in Section III - E of this report.

Table 2 - Prestressing Data

	Virginia	Pennsylvania	Mississippi	Arizona
Pavement Width-feet	24	24	24	31.5
No. of Strands	12	12	12	16
Strand Spacing-feet	2	2	2	2
Diameter-inches (7 wire - 270 psi)	0.5	0.6	0.5	0.5
Prestress Procedures - Force in Kips at concrete strength.				
First Stage	10 k @ 1000 psi (1st day)	14 k @ 1000 psi (a) (1st day)	14 k @ 1000 psi (1st day)	11 k @ 1300 psi (1st day)
Second Stage	10 k @ 2000 psi	46.9 k @ 2500 psi	33 k @ 2500 psi (5th day)	24 k @ 2400 psi (2nd day) (b)
Third Stage	9 k @ 3000 psi	---	---	31 k @ 3000 psi (3.5 days)

(a) Changed during project to 20 k @ 1500 psi

(b) Jacking forces varied with concrete strength

C. Joints

Jointing procedures for conventional concrete pavement types have always been a concern from both a construction and performance standpoint. Prestressed pavement joints are of similar concern, and the movements which must be accommodated are several times larger. The four projects inspected have two general joint designs, however, each project had differences in details. The Virginia, Mississippi, and Arizona projects used a gap slab design which allowed jacking access and provided two areas to accommodate movement at the prestressed slab ends. Longitudinal typical cross sections from the transverse joints used on each project are shown in figures 6, 7, 8, and 9.

The Virginia project had 8-foot-long, 6-inch-deep gap slabs with a double I-beam at each end of the gap slab and the adjacent prestressed slab. Black steel dowel bars 1 1/4 inches in diameter were used for load transfer. The I-beams were "spaced" during construction based upon prevailing temperatures and with an opening generally about 1 1/2 inches. The opening between the I-beams was filled with a foamed-in-place polyurethane.

The Mississippi project was similar to the Virginia project, however, a steel bulkhead and mandrels were used to form the ends of the prestressed slabs. The mandrels provided voids to receive the tendon anchors and 1 1/4-inch-diameter stainless steel dowels. The dowels were epoxy embedded one-half their length into the prestressed slabs.

Styrofoam was used at each end of the gap slab to provide space for movement. Polysulphide joint filler was used to seal the joint.

The Arizona project was also much like the Virginia project, however, a temporary steel bulkhead was used in place of the I-beams. The bulkhead held the stainless steel dowels and sleeves. The bulkhead also positioned

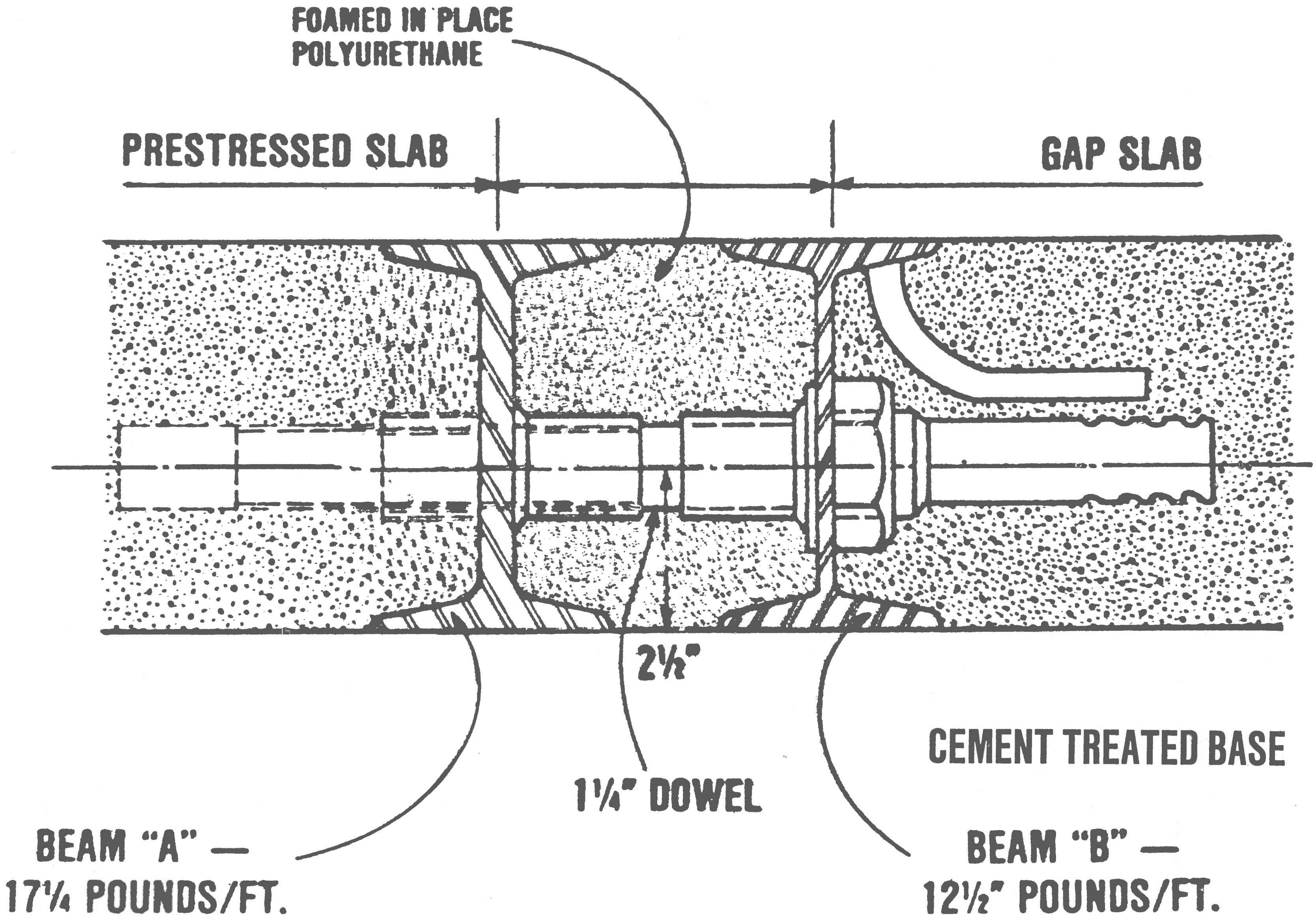
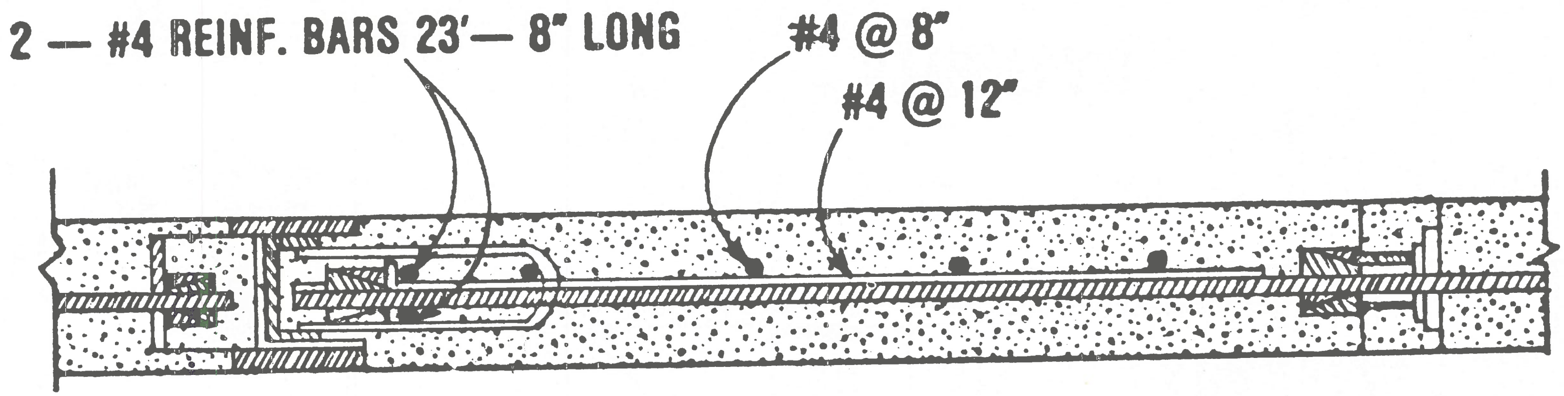
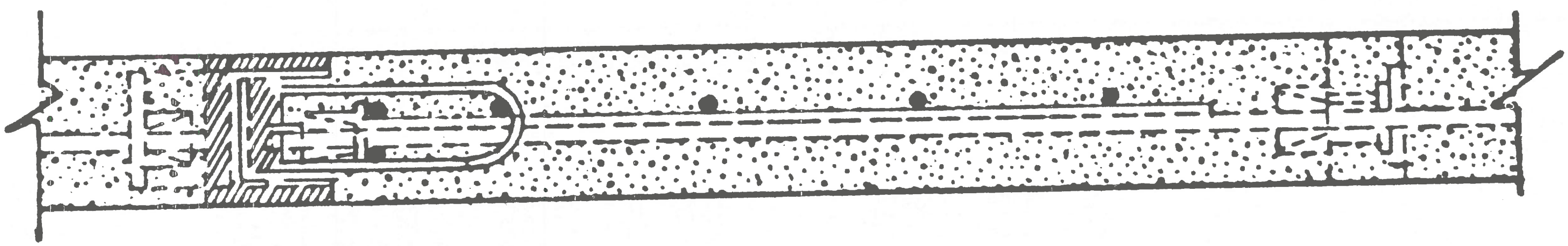


Figure 6. Virginia joint detail.



SECTION THROUGH TENDON CENTERLINE AT JOINT



SECTION THROUGH VERTICAL MEMBER OF THE FEMALE BEAM

Figure 7. Pennsylvania joint detail.

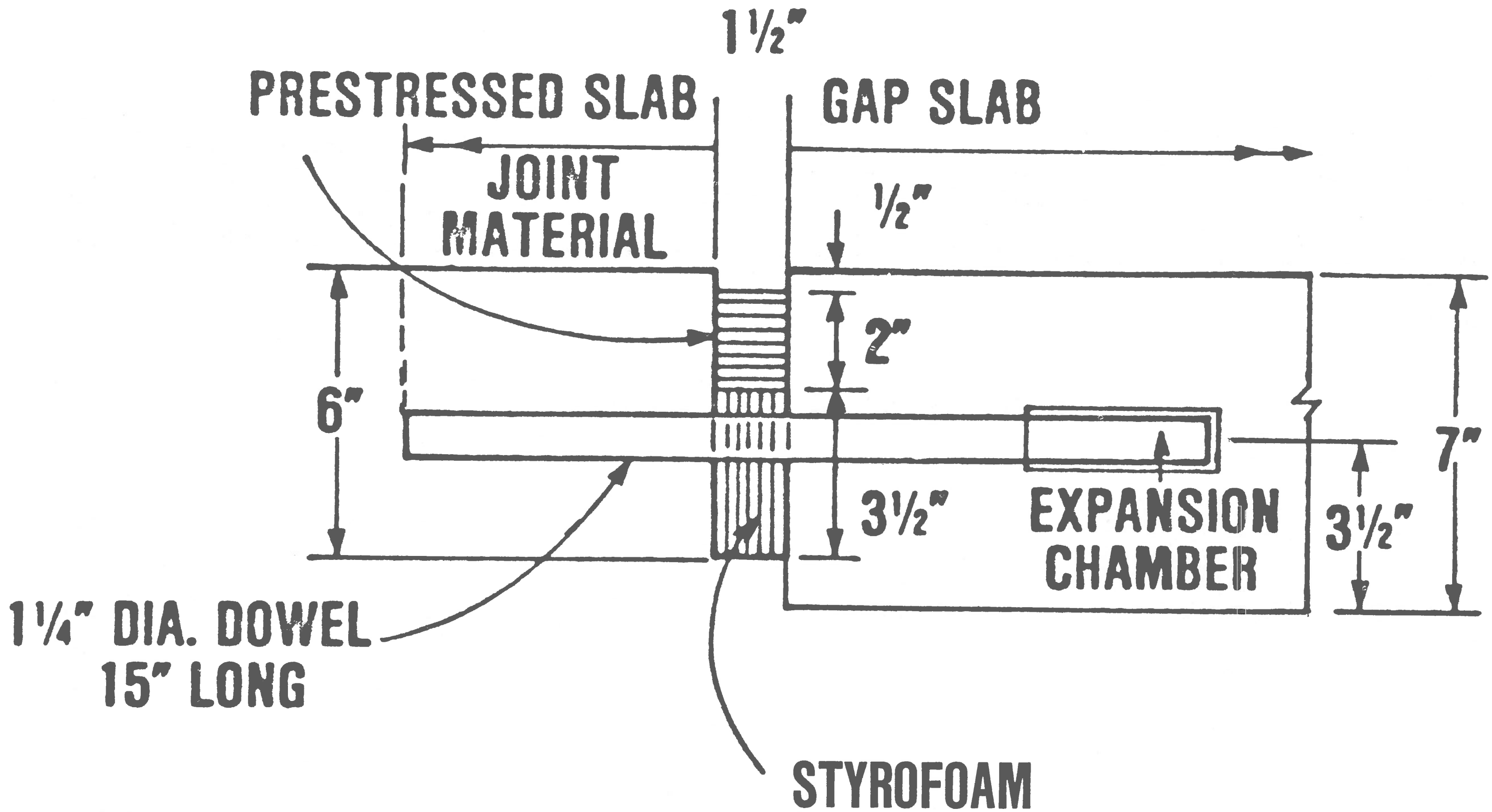


Figure 8. Mississippi joint detail.

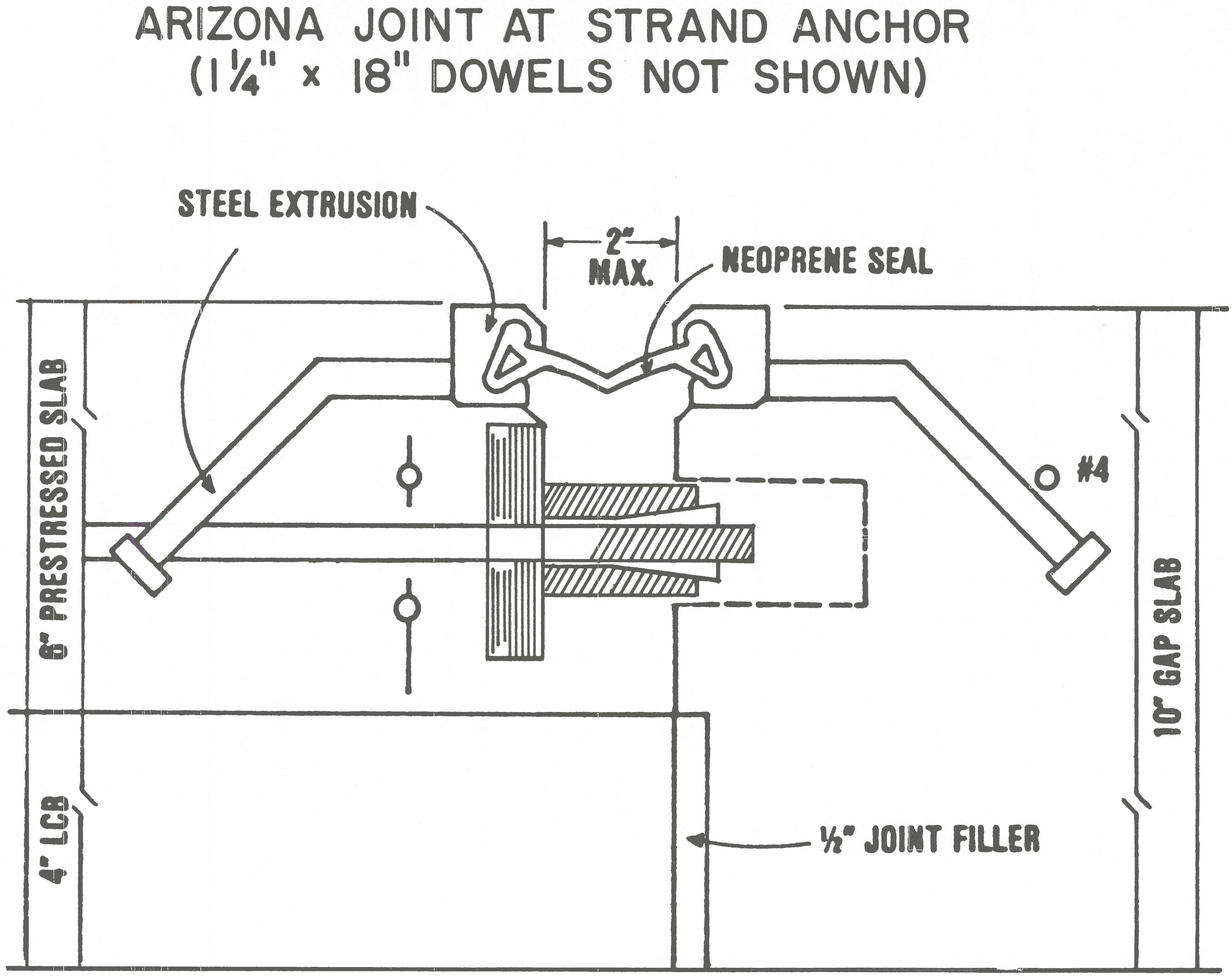


Figure 9. Arizona joint detail.

forms for the prestress anchor bearings and an extruded steel anchorage for a neoprene strip seal. The steel extrusions for the strip seal were spaced to accommodate a 2-inch movement.

After the Arizona project was completed, the elongation measurements taken during strand tensioning were evaluated. All of the elongation measurements exceeded the calculated values and further investigation showed that strand friction was not as great as had been designed for. If the strand friction, or wobble factor "K", determined from the elongation measurements had been used, the slab lengths could have been extended to 600 feet with the same mid-slab prestress force desired originally.

The Pennsylvania project has joints which used a prefabricated steel tongue and groove assembly placed in a sequence which provides only one opening and has prestress force in the adjacent slabs. A temporary jacking space 3 feet long is provided in the concrete during the paving operation. The jacking space is formed with the permanent female steel assembly on one end and a temporary steel bulkhead on the other end. The temporary steel bulkhead is removed and the slabs are stressed using temporary jacking bridges to hold the strand anchors on the end where the bulkhead was removed. Permanent strand anchors are placed on the end of the gap where the female steel assembly was cast in place.

The male steel assembly is later placed in position and the permanent anchors are placed next to the joint assembly. The male assembly is positioned to allow for the proper movement using prevailing temperatures. The gap slab is placed and allowed to cure.

After the gap slab has cured, the jacking bridge anchors are cut releasing the temporary strand anchors and transferring the tendon forces to the anchors at the male joint and establishing a full prestressed pavement condition to each side of the single joint opening.

D. Costs

The nature and requirement of the Virginia demonstration project did not permit a reasonable economic assessment of the construction costs for prestressed pavement. The Pennsylvania project involved a negotiated price to substitute the 6-inch prestressed pavement for the planned 9-inch doweled joint reinforced concrete pavement on a 6-inch granular subbase.

The Mississippi project did confirm that prestressed concrete pavements are competitive with conventional pavements. The project was 5 miles long with prestressed concrete specified for half the project and an 8-inch continuously reinforced concrete pavement specified for the other half. The adjusted prices based upon the competitive bidding procedures used were $8.21/yd^2 for prestressed pavement and $9.07/yd^2 for the continuously reinforced concrete pavement. The prices are relative to Mississippi in 1976.

The Arizona project was bid as a normal project with a prestressed concrete pavement specified. Cost comparisons for this project were obscured somewhat. However, a price of $15.97/yd^2 was given for the prestressed slab and treated base. The conventional ramp sections were 8 inches thick on 4 inches of base for $14.66/yd^2.

E. Construction

The Virginia project was paved with typical slip-form paving procedures, however, the prestress strands and strands in conduit were placed on #3 transverse bars at 30-inch centers. The transverse steel bars served as chairs, which is a normal practice when continuously reinforced pavements are built using preset steel.

The Pennsylvania, Mississippi, and Arizona projects were paved with normal slip-form paving equipment and procedures in a single lift placement. The prestressed tendons were slip-formed into the slab using tubes or "J" bars to guide the tendons.

Construction problems were encountered on each of the projects. Tendons and anchors were occasionally lost due to bearing failure during tensioning operations in both Pennsylvania and Mississippi. The tendons were recovered, bearing areas were restored, and normal tensioning was introduced with a relatively minimal effort. During paving operations in Pennsylvania, a tendon was accidently broken in the middle of a slab. The tendon was recovered and spliced in a temporary area. The box out was later filled with concrete after tensioning.

An area of defective concrete was found in the Arizona project sometime after the pavement was placed. The pavement in the area was removed and replaced full width for the 16-foot-long defect. Prestress force was maintained in the slab by installing a series of pipes in slots cut into the pavement in the area to be repaired. The pipes acted as column struts during the removal and replacement of the defective concrete. After the defective concrete was replaced, the pipe columns were removed and the slots were filled with sound concrete.

The repair procedure took 8 days and was very effective. The patch is structurally adequate, has a good appearance, and has no noticeable effect on ride quality.

The Mississippi project had a road crossing within the prestressed pavement construction and traffic flow had to be maintained. One-half of the slab length of the prestressed pavement was placed at a time with the traffic directed to the other half. A keyed construction joint was built and the first half-slab cast was stressed from one end only. Later the tendons were extended through the other half and the second half-slab was cast. The construction joint anchors were loosened and removed during the stressing at the second end.

The preceding paragraphs relate some of the construction problems which might be encountered on any project and which have been successfully dealt with during prestressed pavement construction. The paving experienced with the four projects indicate normal procedures can be used and the problems usually encountered can be handled with existing techniques.

IV. Traffic

The four projects carry approximate traffic volumes with percentages of trucks as shown in Table 3. The Pennsylvania project continues to carry a high volume of truck traffic. Originally, the pavement was planned as a feeder to the Interstate system for several years until a major direct connection was constructed to complete the system. The planned connection has been delayed and the prestressed pavement is expected to carry the volumes shown for several more years.

Table 3

Traffic Data

State	Opened to Traffic	ADT	Percent Trucks
Virginia	Spring 1972	500	10
Pennsylvania	June 1974	11,900	13
Mississippi	October 1977	3,180	14
Arizona	Fall 1977	62,000	2

V. Performance

The projects were inspected during March 1981 by the panel members. The projects were driven at slow speeds several times so panel members could become familiar with the project. Then the panel walked the projects, stopping as necessary to discuss various observations. Slides were taken to document the conditions at the time of inspection. The panel then took several hours to review the notes and discuss the inspection results.

The performance observations and notes recorded after the inspections for each project follow.

A. Slab Condition

None of the limited transverse cracking observed appears to be actively working or moving, except for the transverse cracks in the 760-foot-long Virginia slab and the Mississippi slab without polyethylene film. Cracking appears to happen relatively early in the pavement life and then remains relatively stable. All of the projects have very good ride characteristics.

1. Virginia - The project is in generally good condition. The most serious distress was found in the 760-foot slab where several wider transverse cracks have occurred recently. The cracks were discolored and had the most serious spalling of any observed on all the projects. The spalling was nominally one-half inch wide and occurred uniformly for the length of the cracks. The alinement profile in the area where the cracks occurred is in a cut-to-fill transition suggesting a possible frost heave condition. All of the other slabs had one or more very tight transverse cracks with no spalling.

There was one minor tight longitudinal crack about 50 feet long running about 1 foot off of the centerline. It appears to be a typical uncontrolled longitudinal crack.

2. Pennsylvania - The Pennsylvania project was in good condition after carrying heavy truck traffic for 7 years. The route serves as a feeder for a number of freight terminals and provides access to Interstate 81.

Most of the transverse cracks in the project are very tight with little or no spalling. The northbound lanes have 13 cracks and the southbound lanes have 17 cracks. Most of the cracking occurred early in the life of the pavement, as shown by the periodic inspection records.

Several longitudinal cracks with a total length of 760 linear feet were repaired in the fall of 1978. The development and subsequent evaluation of the causes for these cracks were reported (7) in 1979. Most of the longitudinal cracking occurred during the unusually cold winters of 1976-77 and 1977-78. A re-examination of the soil surveys and subbase design indicated some potential frost effects which led to frost heave measurements during 1977-78 and 1978-79. Frost heave was measured at each of the areas with longitudinal cracking during both winters and differential vertical movement was recorded. Longitudinal crack repairs consisted of epoxy pressure injection and tiebar installation at selected locations.

The repairs were undertaken as a precautionary step before any serious longitudinal crack distress had occurred. No additional distress has developed.

3. Mississippi - The Mississippi project is in excellent condition with some minor, tightly closed transverse cracks. Twenty-four of the present fifty-eight transverse cracks occurred the day after paving. All of the cracks closed during tendon stressing except those in the slab built without polyethylene sheeting as previously discussed.

A longitudinal crack did occur in 15 slabs as a result of problems with the polystrip inset used to form the longitudinal centerline joint. No subsequent distress has developed.

4. Arizona - The Arizona project is in good condition with only minor tight transverse cracks. Most of the transverse cracks occurred prior to final prestress with 39 visible cracks in 30 slabs, generally located

within the middle third of the slab. All of the cracks closed after final prestress and have remained tight.

B. Joint Conditions

Joint design for prestressed pavements continues to be troublesome, however, considerable performance information has resulted from the variables used in the joints of the four projects inspected. A better joint could be designed and built by combining the good, workable features of the joints from the four projects.

1. Virginia - The joints as originally constructed were altered in 1975 by removing and replacing the gap slab. The black steel dowel bars were corroded and frozen. The dowels on one end of the joint were replaced with new stainless steel dowels. When the gap slab was replaced, only a 3-inch joint opening was provided on the end with the new dowels. A neoprene gland-type seal with steel anchors was placed at the doweled end of the gap slab, while the other end was made integral with the end of the prestressed slab.

The retrofitted joint appeared to be performing well with daily movements of 0.5 to 0.75 inches over a 25° to 30° F change in temperature. The annual movement is less than 1 inch.

2. Pennsylvania - The tongue and groove joints used in the Pennsylvania project have generally performed well and have retained a good ride quality. Movements have been measured at about 0.25 inches for 25° F temperature change with a seasonal movement of about 1.5 inches.

A problem developed in two of the transverse joints in the fall of 1974. Apparently the male end of the joints at the outside shoulder edge became lodged so tightly in the female beam that when the temperature dropped and the slab contracted, the steel welds and the tendon anchor pockets were broken loose. Repairs (8) were made in December of 1975 by Pennsylvania Department of Transportation maintenance personnel. Minor distress of the same type is now apparent at several other joints.

The joint problems are confined to the fabricated steel assemblies and the ends of the prestressed slabs at the joints, and the ride quality over the joints continues to be good.

3. Mississippi - The joints on the Mississippi project are performing well with no structural distress and with a good ride quality. There may be some slight gap slab rocking, however, the observation was not supported by any actual measurements and was more of an estimate.

A joint seal problem did occur almost immediately with the cold poured joint material (polysulfide). The material failed by expanding and bubbling out of the joints. The material was removed from 100 joints and replaced with a 3 1/2-inch preformed neoprene seal. Cold poured polyurethane material was placed in an additional 16 joints.

During 1979 the polyurethane joints were again cleaned and the polyurethane was replaced with a preformed joint material (Evazote). Several additional joints have been filled with this material when a preformed neoprene seal has not stayed in place. The Evazote material has performed very well to date and it is planned to place the material in all joints.

Net seasonal joint movements appear to be about 1.25 inches and daily joint movements of nearly 0.5 inches are observed for a 25° F change in temperature.

4. <u>Arizona</u> - In the Arizona project, some joint distress has occurred when the steel shape holding the neoprene glands cracks and breaks. The failure appears to be in the weld between the anchors and the steel extrusion.

Most of the distress appears to be occurring in the eastbound lanes, which were constructed first. No problems were found in the westbound lanes; possibly some unnoted change in construction techniques eliminated the problem. Repairs have been made by rewelding the steel extrusions and patching the area with epoxy.

No other distress was found in the joints, which have very good ride quality and appear to be accommodating the slab movements with no problem.

The slab end seasonal movements appear to be less than 1 inch on the Arizona project. There also appears to be a variation of movement across the joint. Much less movement was observed in the joint opening on the right side of the pavement, which is keyed to a 4 1/4-foot-wide curb and gutter section. The curb and gutter was placed after the slabs were tensioned and after much of the initial shrinkage in the mainline concrete had occurred. This detail may help limit the annual slab movement and contribute favorably to maintaining a higher stress condition year round. This type of treatment may be of interest in future design work.

5. <u>Joint Summary</u> - The overall performance of the joints has been less than satisfactory but the problems have been more annoying than serious. It appears possible to design a joint that would be easy to build and perform well by combining the joint components and construction techniques that have worked in the four projects. The joint might use the

Pennsylvania techniques as described in Section C and shown in figure 7 to eliminate the isolated gap slab and provide prestress on either side of a single joint opening. The opening might be armored similar to the Virginia I-beam in figure 6 using diaphragm seal, or steel channels could be used with stainless steel dowels similar to the Mississippi and Arizona projects. The opening could be sealed with a neoprene gland similar to the one retrofitted in Virginia. The preformed material that was retrofitted in Mississippi and continues to perform well could also be used to fill the joint opening.

VI. Conclusions

The panel members carefully compared the observations made during their inspection and offer the following conclusions:

1. Prestressed concrete pavements are competitive on a "first-cost" basis and provide a viable design alternative to other pavement types. Performance to date would indicate lower maintenance costs will be incurred and prestressed slab lengths up to 600 feet appear practical.
2. The 6-inch-deep prestressed concrete pavements which have been built are performing adequately for the in-service range of traffic loads and volumes, and for the subgrade conditions encountered with the good subbases used.
3. Normal procedures could be used in the construction of prestressed pavements and no unusual problems should be encountered which could not be adequately corrected.
4. Based upon the inspection of the projects in service, no lateral prestress is required.
5. A single layer of polyethylene film may be an adequate subgrade friction-reducing layer for prestressed slabs up to 600 feet long.

6. Joint openings associated with slabs up to 600 feet are not detrimental to ride quality. Slab lengths in excess of 600 feet will require special attention to joint design.

VII. Recommendations

The following recommendations are offered as a result of the inspections:

1. Because of the good performance achieved with these thinner than "normal" concrete pavements, the construction of additional prestressed concrete pavement should be encouraged.
2. The use of prestressed concrete pavements should be considered for overlays being planned for existing pavements.
3. A 6-inch prestressed concrete pavement should be built and subjected to higher traffic volumes and loads to gain additional performance experience.
4. As in all engineering systems, there is always room for improvement. Accordingly, the following research needs have been identified for consideration in developing future projects:
    a. Develop a fuller understanding of moisture-temperature-volume relationships.
    b. Explore other methods for prestressing concrete pavements.
    c. Sections thinner than 6 inches should be evaluated for possible use as overlays.
    d. The role of deflections in prestressed pavement performance should be studied.
    e. Once prestressing forces are applied, shrinkage has occurred, and low temperatures have contracted the concrete slabs, it appears feasible to eliminate the expansion capability by blocking movement of the slab ends. This type of action would result in the pavement being in a higher state of compression

during warmer temperatures and reducing movements occuring at the joints. The Arizona project demonstrated a similar restraining effect from the friction caused by the attached curb and gutter cast later.

f. Another approach to accomplish reduced slab movement would be to develop a self-destruct friction-reducing layer. The layer would function during the initial shrinkage and stressing period, but then become ineffective and develop increased subgrade friction to retard slab expansion.

REFERENCES

(1) "Prestressed Concrete Pavement Dulles International Airport," U.S. Department of Transportation, Federal Highway Administration, November 1971.

(2) B. F. Friburg and T. J. Pasko, "Prestressed Concrete Highway Pavement Slab," Milford, Del., April 27, 1971 (unpublished).

(3) R. J. Brunner, "Post-tensioned Concrete Pavement," Research Project 72-22, Pennsylvania Department of Transportation, October 1972.

(4) R. J. Brunner, "Prestressed Pavement Demonstration Project," Transportation Research Board, 1975, pp. 62-72.

(5) G. E. Albritton, "Prestressed Concrete Highway Pavement: Construction--As Built Performance," RD-65-1, Mississippi State Highway Department, August 1978.

(6) G. R. Morris and H. G. Emory, "The Design and Construction of Arizona's Prestressed Concrete Pavement," DOT-FH-15-174, Arizona Department of Transportation, October 1977.

(7) R. J. Brunner, "Prestressed Pavement Demonstration Project--Investigation and Repair of Longitudinal Pavement Cracking," Research Project 72-22 (2), Pennsylvania Department of Transportation, April 1979.

(8) R. J. Brunner, "72-22, Prestressed Pavement Repair," Pennsylvania Department of Transportation, January 1976.