Nine-Year Performance Evaluation of Arizona's Prestressed Concrete Pavement

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The Arizona Department of Transportation constructed an experimental prestressed pavement in 1977 and has monitored its condition for the past 9 years. The traffic volume on the pavement has greatly exceeded the design assumptions. Experiments conducted at the time of construction provide valuable data on curling and warping, shrinkage, elastic shortening, and so forth. Annual measurements of roughness and friction number have been collected, and periodic condition surveys have been made. The condition survey conducted in 1986 found that distress had developed in the pavement since the last survey in 1983.

Prestressed concrete pavements are an alternative to conventional concrete pavements. Prestressing the pavement provides two primary advantages, conservation of materials and greatly expanded joint spacing. Between 1971 and 1979, four full-scale experimental prestressed concrete pavements were constructed across the United States (*1*). One section constructed in Arizona in 1977 has been carrying high traffic volumes for the past 9 years. The performance of this pavement has been monitored periodically by the Arizona Department of Transportation (ADOT). The most recent distress evaluation was performed in the summer of 1986. Significant new distress had developed since the last condition survey 3 years before.

DESIGN AND CONSTRUCTION FEATURES

The experimental section of prestressed pavement is located on the Superstition Freeway (State Route 360) in Tempe, Arizona, beginning at Price Road and extending easterly to Dobson Road for a distance of approximately 1.2 mi. The main-line pavement consists of 30 prestressed slabs, 31.5 ft wide, 6 in. thick, and nominally 400 ft long (two slabs are 500 ft long). Each slab contains 16 strands 1/2 in. in diameter with 7 wires per strand. The strands were placed 1/2 in. below the slab center and were 24 in. on center. The slabs were stressed by the posttensioning method. The prestressed pavement cross section is composed of two 12-ft driving lanes and a 7.5-ft shoulder. A cross-sectional view of the prestressed pavement is shown in Figure 1 (*1*). Conventionally reinforced

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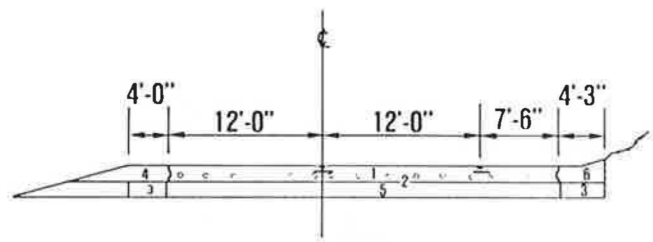


1. 6" P.C.C.P. W/16-1/2" Ø 270 ksi STRANDS
2. SAND LEVELING COURSE + DOUBLE LAYER H.S. 6 MILL POLYETHYLENE
3. 4" CEMENTED TREATED BASE COURSE
4. 6" ASPHALTIC CONCRETE
5. 4" LEAN CONCRETE BASE
6. SPECIAL CURB AND GUTTER

FIGURE 1 Cross section of prestressed pavement (*1*).

concrete slabs 8 ft long and 10 in. thick were placed between prestressed slabs to facilitate tensioning.

The joint design of prestressed concrete pavements is extremely important because the slabs are nominally 400 ft long. Thus extensive movement may be anticipated at the joints. On the basis of an assumed annual temperature variation of 100°F and a thermal coefficient of 6×10^{-6} in./in./°F, the calculated maximum differential movement at the slab ends was 1 1/2 in. An additional 1/2-in. gap was added to the design to ensure adequate joint width regardless of the time of year of construction. The details of the joint design are shown in Figures 2 and 3. A steel extrusion across the width of the pavement was selected to hold a neoprene seal. Stainless steel dowel bars 1 1/4 in. in diameter were used for load transfer. The dowel bars were spaced 12 in. on center.

Construction was conducted with a slip form paver modified to place the prestressing strands at the desired depth as it advanced down the roadway. The construction sequence was as follows (*2, 3*):

1. A sand leveling course and double-layer polyethylene sheet were placed on top of the lean concrete base (LCB) to reduce frictional resistance.
2. Steel prestressing cables were positioned on top of the polyethylene sheets.
3. A slip form paver was used to position the prestressing cables at a depth of 3.5 in. and to place the concrete on the roadway. A nylon bristle broom was dragged longitudinally along the pavement to provide surface texture.

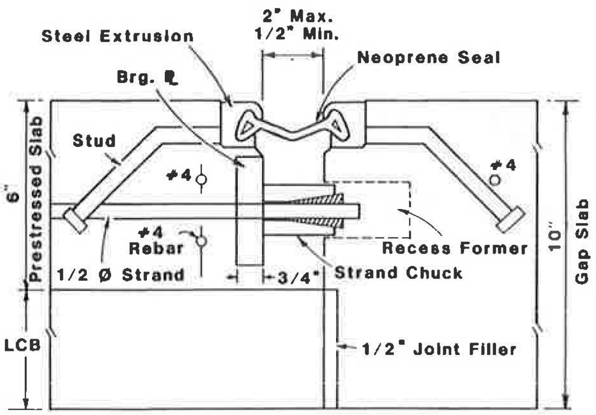


FIGURE 2 Joint detail: strand location.

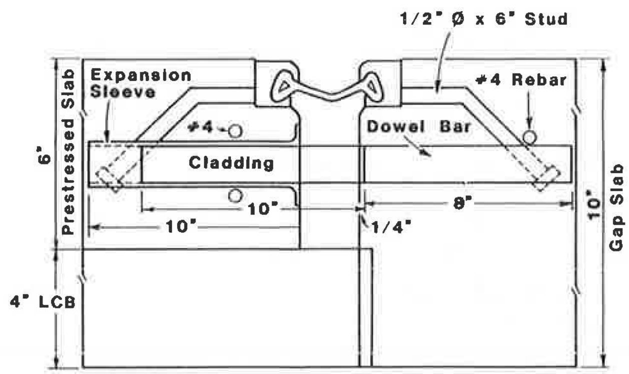


FIGURE 3 Joint detail: dowel bar location.

4. The following joint hardware was installed: dowel assembly, steel extrusion, bearing plates, reinforcing steel for bearing stress, and bulkhead.

5. Prestressing hardware was installed and the slabs were stressed in stages. The first stage of stressing was performed the day after concrete placement when the concrete had attained an average compressive strength of 1,300 psi. Second-stage stressing was performed 1 day after the initial stressing operation when average compressive strengths were approximately 2,400 psi. The final stage of prestressing was performed an average of 3 1/2 days after concrete placement when concrete cylinder strengths exceeded 3,000 psi. The actual amount of stressing depended on the concrete cylinder strength for each particular slab at the time the slabs were stressed. Table 1 gives the relationship between prestressed jacking force and concrete compressive strength used during construction of the slabs (*3*).

6. Gap slabs were constructed between consecutive prestressed pavement sections to facilitate prestress jacking operations. These slabs were conventionally reinforced concrete 31.5 ft wide, 8 ft long, and 10 in. thick. (These slabs are called gap slabs because they are used to fill the gap between adjacent prestressed slabs.)

7. The final items installed were the neoprene joint seals, used to prevent the intrusion of foreign objects into the joints.

The 30 prestressed slabs were placed between March 31, 1977, and April 13, 1977; installation took a total of 9 working days. Thirty-four gap slabs were placed from May 12, 1977, to May 17, 1977; this required a total of 4 working days. The installation of the neoprene joint seals took an additional 4 working days to complete (*3*).

TABLE 1 CONCRETE CYLINDER STRENGTH VERSUS JACKING FORCE

Cylinder Strength (psi)	Jacking Force (kips)
3,000	31
2,900	30
2,800	29
2,700	28
2,600	27
2,500	26
2,400	24
2,300	23
2,200	22
2,100	21
2,000	19
1,900	18
1,800	17
1,700	16
1,600	15
1,500	13
1,400	12
1,300	11
1,200	10
1,100	9

The major difficulty during construction was that the top sheet of the polyethylene film would slide over the bottom layer as the paver moved forward. The problem was at least partly resolved by nailing the sheet to the base layer.

Problems were encountered with the paving train as well. The paver broke down on several occasions causing undulations of the pavement profile. The nylon bristle broom was left stationary and induced transverse depressions across the entire width of the pavement at several locations.

Poor consolidation of the concrete material around the joint hardware was noted in most of the eastbound slabs. Apparently there was an unnoted change in the construction process for the subsequent construction of the westbound lanes; the consolidation problem is not as apparent in these slabs.

Approximate quantities and costs for the experimental section of prestressed pavement are given in Table 2 (*3*).

TRAFFIC VOLUMES

The Superstition Freeway primarily serves commuter traffic of three cities east of Phoenix. Design traffic was estimated to be 26,000 average daily traffic (ADT) with 1 percent trucks, with a 20-year total of 191 million vehicles (*3, 4*). The facility was constructed in the spring of 1977. In the fall of that year traffic was measured at 62,000 ADT with 2 percent trucks (*3, 4*). In 1984 the traffic count was 80,000 ADT with 3 to 4 percent trucks, and it increased to 98,000 ADT by 1986. Additional lanes were added to the facility to handle the

TABLE 2 APPROXIMATE PRESTRESSED PAVEMENT COST

Item	Unit	Quantity	Bid Price ($)	Total ($)
Prestressed concrete pavement (6 in.)	yd^2	40,700	9.00	366,300
Gap slab concrete pavement (10 in.)	yd^2	1,060	17.00	18,020
Prestressing concrete pavement	Lump sum	1	50,000.00	50,000
Polyethylene membrane	yd^2	40,700	0.75	30,525
Load transfer dowel assembly	Each	1,920	6.00	11,520
Expansion joint sealing	Linear ft	1,900	42.00	79,800
Total				556,165

Note: Total pavement area = 41,760 yd^2.

increased traffic volumes, but the majority of the truck traffic is on the prestressed concrete pavement. Thus the volume of truck traffic on this pavement was underestimated by an order of magnitude. The pavement has already carried more truck traffic than estimated for its entire design life.

EVALUATION OF PAVEMENT PERFORMANCE

The research plan for the experimental section called for two phases of pavement evaluation, a short-term study during and after construction and a long-term pavement performance evaluation. The short-term study consisted of measurement of temperature of the slab, slab movements due to stressing operations, joint width variations, and slab curling and cracking (*5, 6*). Long-term pavement performance evaluation consists of monitoring roughness, skid or frictional resistance, joint performance, and surface condition.

Short-Term Evaluation

Temperature

Concrete temperature measurements were made using thermistors embedded in the slab. Three locations were chosen to monitor variations in slab temperature. Two slabs were instrumented 4 ft from the shoulder and 4 ft from the expansion joint. The third location was midlength and 4 ft from the shoulder. The concrete temperature at each site was measured by six thermistors, two each at depths of 0.5, 3.5, and 5.5 in. An example of the temperature reading for one slab is given in Table 3 (*3*). The temperatures in the pavement were independent of pavement depth during the morning hours. As expected, the surface of the pavement was hotter than the bottom of the pavement during the afternoons. The maximum observed difference was 12° F.

TABLE 3 CONCRETE TEMPERATURE IN SLAB 15 *(3)*

Date	Time	Temperature (° F) Top	Middle	Bottom
06/08/77	7:00 a.m.	97	101	99
	3:00 p.m.	130	123	122
06/23/77	7:00 a.m.	106	105	106
	3:00 p.m.	143	133	131
07/07/77	7:00 a.m.	105	104	105
	3:00 p.m.	146	144	144
07/21/77	7:00 a.m.	98	101	101
	3:00 p.m.	137	131	127
08/04/77	7:00 a.m.	100	100	104
	3:00 p.m.	134	130	126
08/18/77	7:00 a.m.	99	99	100
	3:00 p.m.	131	127	123
09/01/77	7:00 a.m.	93	87	87
	3:00 p.m.	110	104	104
09/15/77	7:00 a.m.	85	81	80
	3:00 p.m.	104	98	97
09/28/77	7:00 a.m.	80	78	78
	3:00 p.m.	102	95	90
10/13/77	7:00 a.m.	69	70	71
	3:00 p.m.	100	93	90

TABLE 4 LENGTH MEASUREMENTS OF SLAB 27 (3)

Date	Time	Air Temperature (° F)	Slab Length Between Pins (ft)
4/13/77	11:00 a.m.	79	396.364
4/14/77	9:30 a.m.	79	396.340
4/15/77	8:30 a.m.	68	396.305
4/18/77	9:00 a.m.	75	396.301
4/19/77	8:20 a.m.	70	396.285
6/08/77	8:45 a.m.	87	396.270
9/28/77	1:15 p.m.	95	396.286

Note: Concrete placed 4/12/77. The first reading was taken before any slab prestressing. The reading on 4/18/77 was taken after final prestressing had been applied to the slab.

Slab Movement

Changes in slab length were measured before application of the prestress jacking force, after each stage of prestressing, after 28 days, and intermittently thereafter. The results of these measurements for one slab are given in Table 4 (*3*). As the data in the table indicate, the slab shortened 0.024 ft on initial prestressing, 0.063 ft after final prestressing, and 0.078 ft 5 months after construction. The initial shortening was caused by the application of the prestressing force to the slab (i.e., elastic shortening); the final 0.015 ft of shortening is due to the effects of long-term shrinkage and creep of the concrete section. The average change in slab length was 0.0575 ft with a low of 0.024 ft and a high of 0.10 ft.

The change in slab length is also a function of the frictional resistance between the LCB and the prestressed slab. When the prestressing force was high enough to overcome the friction, slab movement began; this explains the time lag between prestress application and recorded slab movement.

Joint Widths

Joint widths were monitored in conjunction with the slab length measurements. Joint movement data are provided for Slab 2 in Table 5 (*3*). The original design called for a 2-in. maximum joint opening and a 1/2-in. minimum joint opening. The data indicate a consistent joint width with time; however, temperatures are missing for cooler periods.

TABLE 5 JOINT MOVEMENTS FOR SLAB 2 *(3)*

Date	Concrete Temperature(°F)	Joint Opening (in.)	
		West	East
06/08/77	113	1.726	1.771
06/23/77	124	1.781	1.828
09/28/77	84	2.047	1.109
10/13/77	94	1.813	1.859
10/31/77		1.969	2.000
11/21/77		1.859	1.906

Note: Pavement placed 4/4/77; joint placed 5/12/77.

Slab Curling

Slab curling was also monitored after construction of the pavement. Two slabs were instrumented with elevation plates mounted at approximately 4-ft intervals on the pavement surface. The vertical movement due to warping was measured with a level and precise leveling rod. The results of these measurements for the corner of the slab are given in Tables 6 and 7 (*3*). Positive numbers indicate an upward curl and negative numbers indicate a downward curl. Air temperature and concrete temperature were recorded. The data were recorded for approximately 32 hr. As expected, the corner of the slab moved downward as the temperature increased.

Initial Cracking

Crack surveys were conducted after completion of concrete placement and periodically after the stressing operation. An

TABLE 6 SLAB CURL DATA: BEGIN SLAB 19 *(3)*

Time	Reading (in.)	Change (in.)	Air Temperature (°F)	Concrete Temperature (°F)
7:15 a.m.	0.700			
8:45 a.m.	0.740	-0.040		
9:30 a.m.	0.755	-0.015	76	80
10:30 a.m.	0.774	-0.019	76	
11:30 a.m.	0.788	-0.014	80	
12:30 p.m.	0.799	-0.011	82	
1:30 p.m.	0.804	-0.005	84	
2:30 p.m.	0.808	-0.004	86	
3:30 p.m.	0.810	-0.002	88	112
4:30 p.m.	0.805	+0.005	83	108
5:30 p.m.	0.798	+0.007	83	103
6:30 p.m.	0.780	+0.018	82	88
7:30 p.m.	0.752	+0.028	78	82
8:30 p.m.	0.736	+0.016	76	78
9:30 p.m.	0.721	+0.015	74	78
10:30 p.m.	0.713	+0.008	72	72
11:30 p.m.	0.709	+0.004	70	72
12:30 a.m.	0.705	+0.004	64	66
1:30 a.m.	0.700	+0.005	62	64
2:30 a.m.	0.695	+0.005	60	60
3:30 a.m.	0.690	+0.005	58	60
4:30 a.m.	0.686	+0.004	58	56
5:30 a.m.	0.685	+0.001	60	58
6:30 a.m.	0.688	-0.003	58	58
7:30 a.m.	0.711	-0.023	68	74
8:30 a.m.	0.741	-0.030	74	88
9:30 a.m.	0.769	-0.028	80	94
10:00 a.m.	0.777	-0.008	80	100
10:30 a.m.	0.783	-0.006	80	100
11:30 a.m.	0.799	-0.016	90	104
12:30 p.m.	0.805	-0.006	86	102
1:30 p.m.	0.806	-0.001	88	110
2:30 p.m.	0.803	+0.003	86	98
3:30 p.m.	0.805	-0.002	88	91

Note: Readings taken on 5/11/77. + = slab curling upward and - = slab curling downward.

TABLE 7 SLAB CURL DATA: END SLAB 20 *(3)*

Time	Reading (in.)	Change (in.)	Air Temperature (°F)	Concrete Temperature (°F)
7:30 a.m.	0.500			
8:45 a.m.	0.467	-0.033		
9:30 a.m.	0.452	-0.015	76	80
10:30 a.m.	0.435	-0.017	76	
11:30 a.m.	0.421	-0.014	80	
12:30 p.m.	0.418	-0.003	82	
1:30 p.m.	0.418	0.000	84	
2:30 p.m.	0.418	0.000	86	
3:30 p.m.	0.418	0.000	88	115
4:30 p.m.	0.424	+0.006	83	111
5:30 p.m.	0.431	+0.007	83	105
6:30 p.m.	0.444	+0.013	82	89
7:30 p.m.	0.459	+0.015	78	80
8:30 p.m.	0.467	+0.008	76	76
9:30 p.m.	0.479	+0.012	74	72
10:30 p.m.	0.484	+0.005	72	70
11:30 p.m.	0.490	+0.006	64	64
12:30 p.m.	0.496	+0.006	64	64
1:30 a.m.	0.500	+0.004	62	66
2:30 a.m.	0.506	+0.006	60	60
3:30 a.m.	0.513	+0.007	58	58
4:30 a.m.	0.515	+0.002	58	58
5:30 a.m.	0.516	+0.001	60	58
6:30 a.m.	0.515	-0.001	58	58
7:30 a.m.	0.509	-0.006	68	68
8:30 a.m.	0.468	-0.041	74	82
9:30 a.m.	0.455	-0.013	74	94
10:00 a.m.	0.439	-0.016	80	100
10:30 a.m.	0.431	-0.008	80	102
11:30 a.m.	0.419	-0.012	80	102
12:30 p.m.	0.417	-0.002	86	102
1:30 p.m.	0.416	-0.001	88	108
2:30 p.m.	0.420	+0.004	88	98
3:30 p.m.	0.426	+0.006	88	94

Note: Readings taken on 5/11/77. + = slab curling upward and - = slab curling downward.

example of the crack survey information for one slab is shown in Figure 4. As shown in the figure, the cracks were measured and recorded twice daily after placement of the concrete and periodically after final prestressing. This example shows two longitudinal joints and several transverse cracks. The longitudinal joints were formed between lanes and between the driving lane and shoulder by placing plastic strips in the pavement at the time of construction. The transverse crack widths are small, on the order of 1/64 to 1/4 in. The final prestressing force closed several of the transverse cracks as indicated in Figure 4.

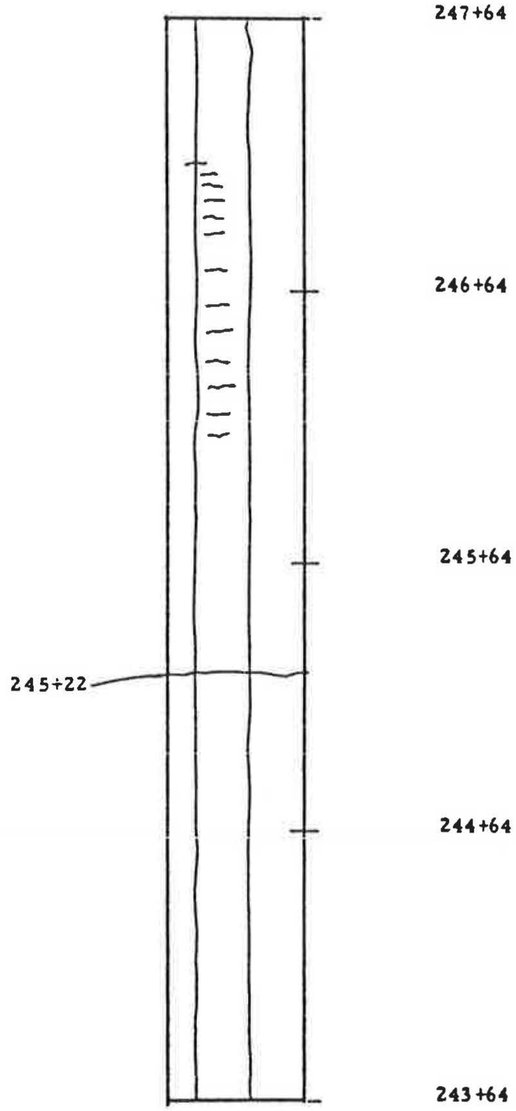
Long-Term Pavement Evaluation

The long-term performance of prestressed pavements is an important factor in the consideration of this method as a cost competitive alternative to conventional paving techniques. The life-cycle costs must be determined in order to evaluate the overall effectiveness of the prestressed pavement alternative. Four measures of long-term performance are monitored: (*a*) longitudinal profile characteristics or roughness, (*b*) surface skid or frictional resistance, (*c*) joint performance, and (*d*) surface distress.

Roughness

The ride quality of the experimental section of prestressed pavement was found to be considerably poorer than that of conventional concrete pavement sections immediately after construction. The initial roughness as measured by the Mays ride meter ranged from 180 to 270 in./mi whereas that of conventional concrete pavements generally ranges from 100 to 150 in./mi (*4*). This initial roughness is attributable to the type of surface texture used on the prestressed pavement section and problems encountered during construction.

The variation of surface roughness with time for the prestressed section based on Mays meter results is shown in Figure 5. For 3 years after construction, the roughness apparently increased significantly. In 1981 the roughness measurements dropped significantly and then were stable but highly variable from year to year. Much of the variability in the roughness measurements may be attributed to variations



04-12-77	9:15 A.M. - No apparent cracks.
	3:15 P.M. - No apparent cracks.
04-13-77	7:45 A.M. - STA 245 + 22 ± full transverse 3/32" to 1/4" ±.
	4:00 P.M. - STA 245 + 22 ± full transverse 1/64" to 1/32" ±.
04-14-77	8:00 A.M. - STA 245 + 22 ± full transverse barely visible.
	31k
04-15-77	7:30 A.M. - STA 245 + 22 ± full transverse hairline.
04-18-77	10:30 A.M. - STA 245 + 22 ±.
04-26-77	9:30 A.M. - STA 245 + 22 ± full transverse closed.
	STA 246 + 95 ± 28' from median 3' long 3/16 - 1/16.
06-28-77	245 + 22 crack closed.
	246 + 93 to 246 + 97 three transverse.
	Cracks 10' in from shoulder.
	Two 12" and one 3' long, width between 1/32" and 3/32".
	245 + 77 to 245 + 83 seven cracks both longitudinal and transverse 10' in from shoulder. Widths from hairline to 1/16".
09-21-77	Same as 06-28-77.
03-06-78	Same as 06-28-77.
	246 + 50 4 transverse cracks in travel lane only.
	246 + 25 transverse crack in distress lane.
	243 + 85 2' long crack in right W.P in travel lane.
05-31-79	245 + 80 6 small 1 1/2' cracks in D.L. otherwise same as last survey.
02-18-81	Many small cracks at about 8' from edge of prestress pavement.
04-12-83	Many small transverse cracks in drive lane. Transverse crack at STA 245 + 60 across drive lane.

FIGURE 4 Example of crack survey data (westbound Slab 23).

in the Mays meter. ADOT has an active program for maintaining the calibration of their Mays meter, so the measurements shown in Figure 5 are on a common scale.

Friction

Measurements of frictional (skid) resistance were conducted after completion of construction and annually thereafter with the use of a Mu-Meter. The results of friction measurements of the pavement are given in Table 8 (*3*). The initial friction number is high because traffic has not worn down the rough surface texture. The friction number appears to have reached a consistent value of approximately 45 for both the westbound and the eastbound roadway sections. This value is within the safe range of frictional resistance, and the pavement surface appears to be withstanding the heavy traffic volumes.

Joint Performance

The performance of joints has been a major problem for the prestressed pavement section. Maintenance forces have repaired these joints several times during the life of the pavement. The poor joint performance also partly explains why the roughness values are so high. Spalling of the joints has been the biggest problem to date. Poor consolidation of the concrete material around the joint hardware is probably the main cause of spalling at the joints. High stresses induced by truck loading also could have caused spalling at the joints. Most spalled areas have been repaired with epoxy. The steel extrusions were welded and the neoprene joint material was replaced by maintenance forces on several joints. Before repair, however, foreign material entered some of the joints and may pose a problem in the future. During the condition survey in 1986, it was noted that joint condition had again deteriorated. The neoprene seal is missing from practically all of the joints. The joints are filled with sand, gravel, and other

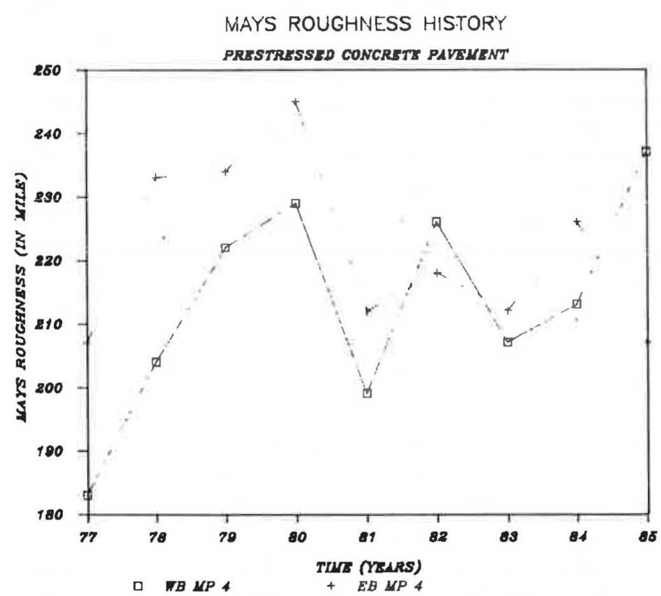


FIGURE 5 Roughness versus time for the prestressed pavement.

TABLE 8 MU-METER VALUES FOR PRESTRESSED PAVEMENT *(3)*

	1977	1978	1979	1980	1981	1982	1983	1984
Eastbound								
MP 4	89		54	38	50	43	43	58
MP 5			52	41	52	41	49	46
Westbound								
MP 4	82		46	38	45	32	39	40
MP 5			53	42	47	41	41	50

Note: Average values for both lanes. MP = milepost.

debris. The steel extrusion is broken at one joint. Many of the joints have spalling and corner breaks. Maintenance crews have placed asphalt patches in several locations.

Surface Condition Surveys

Condition surveys have been performed several times to monitor the performance of each slab with time. The location and severity of all cracks in the prestressed concrete slabs were recorded as shown in Figure 4. After completion of construction in 1977, subsequent crack surveys were conducted in 1978, 1979, 1981, 1983, and 1986. Figure 4 shows the history of each slab with time and the progression of cracks in the pavement section.

The prestressed pavement section was evaluated by the authors during July 1986. The surveys were conducted early in the morning when traffic volumes were relatively low and temperatures ranged between 90° F and 100° F. Even though the surveys were performed early in the morning, the traffic volumes forced the observation of distress from the shoulder.

Eastbound Roadway Section The most notable problem with the eastbound section was the number of joints patched the entire width with epoxy. This condition was probably caused by impact loading at the joints and underconsolidation of the concrete around the joint hardware, which resulted in premature cracking and spalling along the joint. Several of the welded steel extrusions have been broken and repaired by ADOT maintenance crews. Figure 6 shows the epoxy patches and the transverse cracks near the joint indicating impending joint failure. Figure 7 shows spalling typical of several of the slabs near the joints. This figure shows the effect of underconsolidation of the concrete; the steel extrusions have caused the spalling to accelerate. The condition survey indicated that 90 percent of the joints in the eastbound direction have been repaired with epoxy patches.

During the summer of 1985 one prestressing strand anchor failed on the east end of Slab 1. The bearing plate was removed, the strand cut, and an asphalt patch installed. This repair is shown in Figure 8. Figure 9 shows a close-up of the longitudinal crack located near the broken strand. The longitudinal crack between the shoulder and the driving lane is continuous along the section but has significantly widened near the broken strand. Heavy truck loading is applied in close proximity to the strand. It is assumed that the prestressing force has been entirely dissipated and is not contributing to the structural capacity of the pavement section. A detailed investigation of the effects of this failure will be undertaken.

A section of prestressed concrete pavement was removed and replaced in Slab 4 as shown in Figure 10. The repair appears to be performing well although new longitudinal cracks have appeared in the original pavement on either side of the repair. The continuity of the prestressing steel was maintained for this repair.

Several slabs and gap slabs have experienced corner breaks due to warping stress, restraint provided by the load transfer devices, and incompressible materials in the joints. In many cases the patches are also failing as shown in Figure 11.

Several surface defects were noted in the prestressed pavement slabs of the eastbound lanes including pop-outs, spalling of the cracks, poor concrete consolidation, depressions caused by the paving and texturing operations, map cracking, transverse cracking, and longitudinal cracking. The longitudinal cracks have appeared since the last condition survey in 1983. Several of the transverse cracks have opened and spalled since the previous survey.

Westbound Roadway Section The condition of the westbound section was much better than that of the eastbound section. Only a few of the joints had been repaired with epoxy patches across the entire roadway. The westbound section was constructed after the eastbound and special care was taken to provide adequate consolidation of the concrete near the joint hardware. Several of the joints are, however, beginning to show some cracking. Some of the joints were filled with debris. Longitudinal cracks are much less frequent than on the eastbound lanes.

One joint had experienced a corner break and was patched with asphalt. The patching material is damaged as shown in Figures 12 and 13. Note the size of the studs and their close spacing. The studs are 1/2 in. in diameter, 6 in. long, and spaced 6 in. apart. It is hypothesized that this design has resulted in stress concentrations in a plane 6 in. from the joint. Failure of both the concrete and the steel studs indicates that this is an inadequate design for the joints.

Several surface defects were noted in the westbound section including depressions caused by paving operations (Figure 14), poor concrete consolidation, polishing, transverse cracks with spalling (Figure 15), pop-outs, transverse cracks, crescent cracks in the wheel path, and longitudinal cracks.

FIGURE 6 Epoxy patch and transverse crack at a joint.

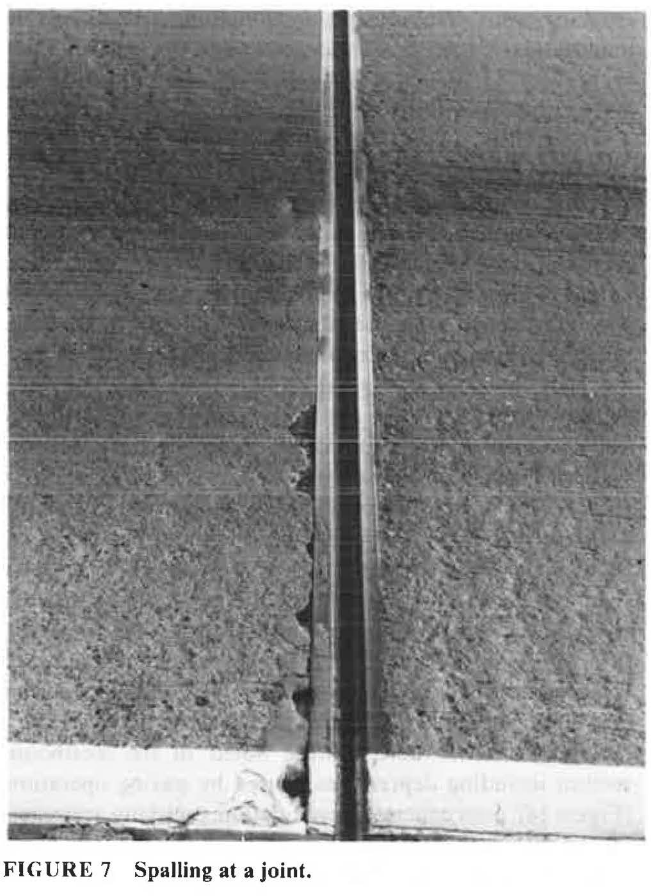


FIGURE 7 Spalling at a joint.

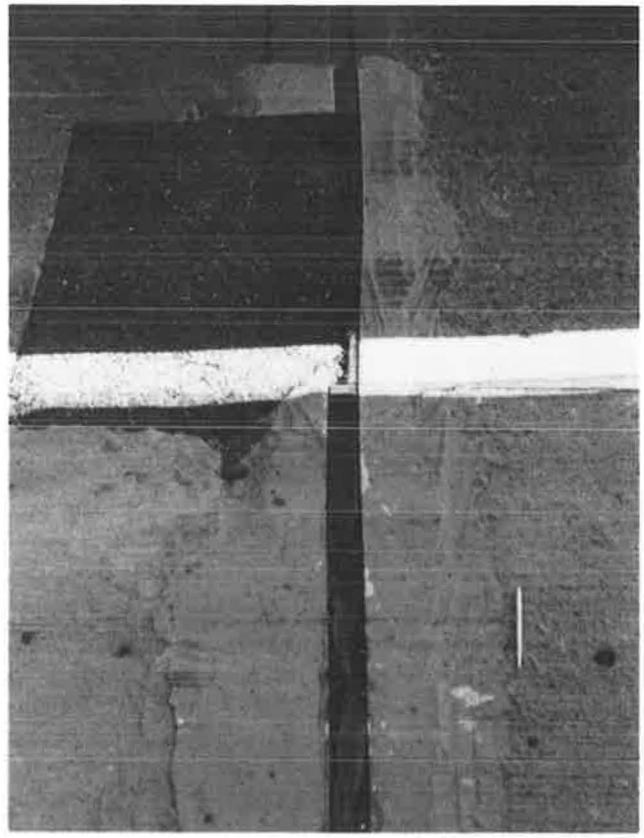


FIGURE 8 Repair patch at location of broken strand.

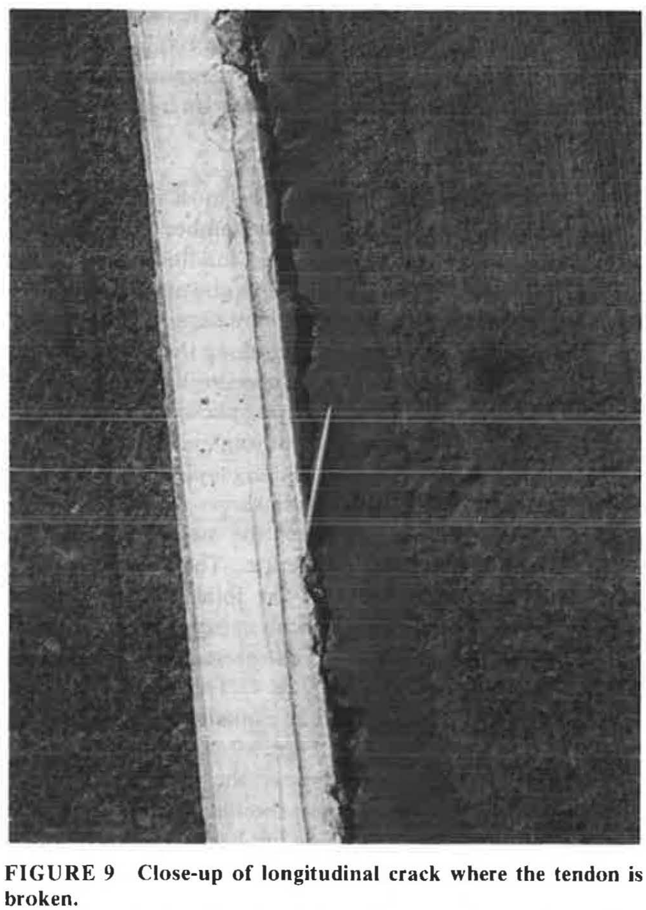


FIGURE 9 Close-up of longitudinal crack where the tendon is broken.

FIGURE 10 Repair of concrete.

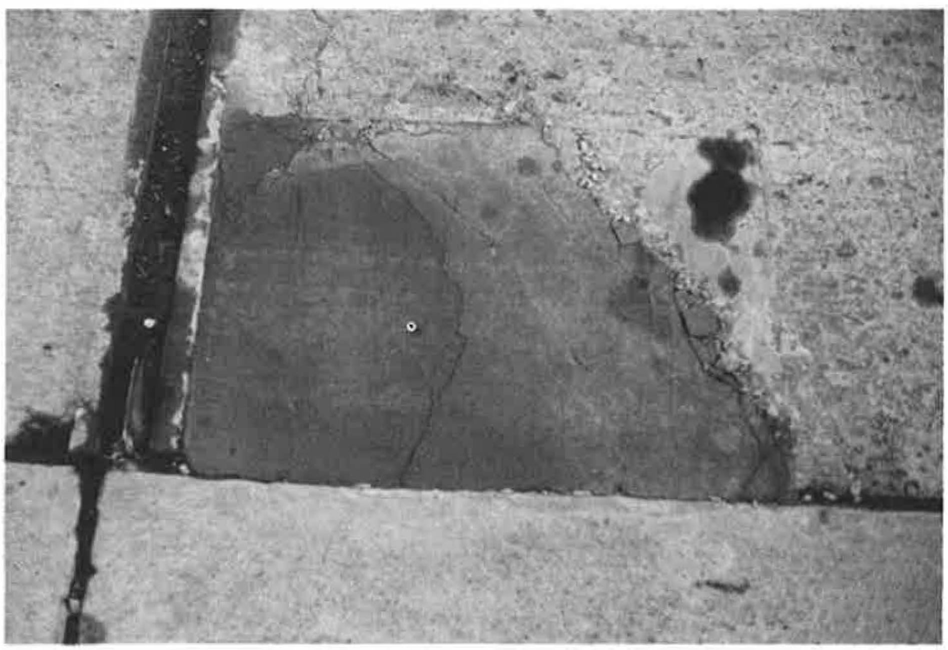


FIGURE 11 Example of failed patch at corner break.

CONCLUSIONS

Prestressed pavement in Arizona has performed well for the past 9 years but is now showing distress. Truck traffic volume on the facility has exceeded design assumptions. The pavement has carried more trucks than the volumes estimated during design.

The predominant maintenance problem is correction of spalling at the joints. This is particularly bad on the eastbound lanes, which were the first constructed. The distress at the joints may be attributed primarily to poor consolidation of the concrete. The joint design may further aggravate the failure problem at the joints.

The excessive roughness of the pavement may be attributed to construction problems. The problems with construction may be largely charged to the experimental nature of the project. There was a significant reduction in problems during construction of the second part of the project.

Although the levels of distress are relatively minor, there has been a significant increase in the amount of distress during the past 3 years. The most notable types of new distress are spalling of the midslab transverse cracks and

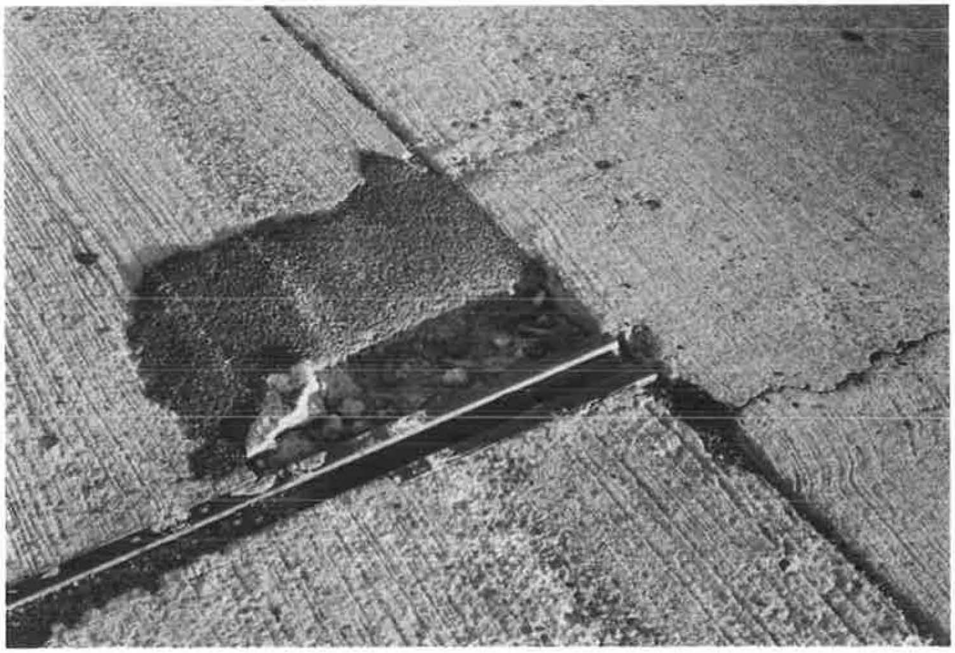


FIGURE 12 Failed asphalt patch at corner break.

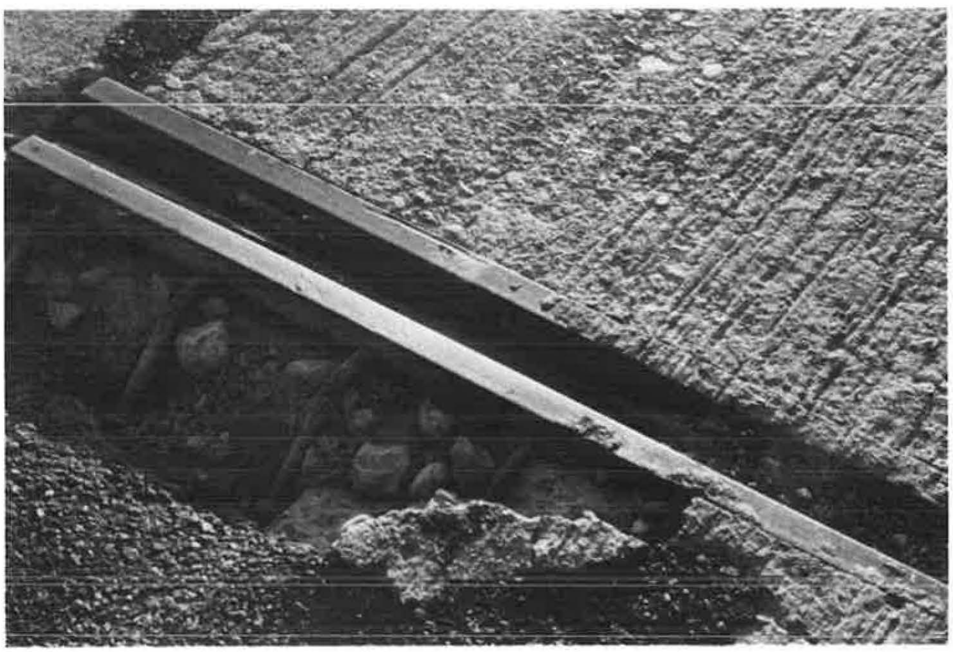


FIGURE 13 Exposed extruded steel at joint.

development of longitudinal cracks. These types of distress are of greater concern in a prestressed pavement than in a conventional pavement because of the thickness of the slab. For the pavement to continue to perform, aggregate interlock must provide load transfer across the longitudinal crack. The prestress design will not assist in maintaining the aggregate interlock of the longitudinal cracks.

The performance of the prestressed pavement could have been significantly improved through better design and construction. The paver train was stopped several times during construction; this contributed to the excessive initial roughness of the pavement. The gap slabs should be eliminated, thereby removing one-half of the joints. Actual joint design could be improved to facilitate construction. Slab length could be increased to further reduce the number of joints. The neoprene joint sealer was inadequate and a new method is required for sealing joints. The 500-ft-long slabs are performing as well as the other slabs.

These conclusions were derived with the benefits of hindsight. The performance of the prestressed pavement has been adequate, and the lessons learned from the pavement have made the experiment a success. Prestressed pavements

FIGURE 14 Depression caused when paving train stopped.

FIGURE 15 Spalling of transverse crack.

appear to be a viable alternative to conventional concrete pavements at least for the initial design period. Maintenance and rehabilitation of the structure are now primary concerns.

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