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16. Abstract

Hydrated fly ash is produced by allowing powder fly ash (Class C) from coal power plants to cure with moisture. The hydrated (cured) fly ash becomes a stiff material that can be crushed to form a synthetic aggregate. When properly processed and compacted to optimum moisture content, the hydrated fly ash continues to gain strength after placement as a base material.

The Atlanta District has constructed six pavement sections since 1993 using hydrated fly ash as the flexible base material. This research project was initiated to evaluate and monitor performance and changes in material properties for these six pavements through the year 2001 and to evaluate a problem experienced during construction where the asphalt surface treatment did not bond well to the base.

Evaluation of pavement base performance was based on visual documentation, falling-weight deflectometer tests, ground penetrating radar, and compressive strengths of field cores. This report is an interim report documenting the performance evaluations conducted in the spring of 1999. This report covers the third annual evaluation in a series of five.

All of the test pavements are continuing to perform well at this time. Laboratory and field testing data indicate that the pavement bases are not exhibiting any significant sign of deterioration.

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FIELD PERFORMANCE EVALUATION OF HYDRATED, FLY ASH BASES IN THE ATLANTA DISTRICT: YEAR 3

by

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Report 2966-3
Project Number 7-2966
Research Project Title:
Durability of Surface Treatments as the Wearing Course
Placed on Crushed Fly Ash and Long-Term Performance
of Crushed Fly Ash for Flexible Base

Sponsored by the
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BACKGROUND

Hydrated fly ash is produced by allowing powder fly ash (Class C) from coal power plants to cure with moisture. The hydrated (cured) fly ash becomes a stiff material that can be crushed to form a synthetic aggregate. When properly processed and compacted to optimum moisture content, the hydrated fly ash continues to gain strength after placement as a base material (1).

The Atlanta District constructed six pavement sections in 1993 through 1995 using hydrated fly ash as the flexible base material. District personnel are pleased thus far with the performance of this industrial by-product as a base material; however, its long-term performance is in question. While performance of the material as a base has been acceptable, the district has encoutered problems with surface treatments separating from the base course. This research project was initiated to evaluate and monitor performance and changes in material properties for these six pavements through the year 2001. Evaluation of performance shall be based on the following types of data:

- visual evaluations of surface distress,
- nondestructive field testing (falling weight deflectometer, as a minimum), and
- compressive strength of field cores.

Results of a laboratory investigation into the cause of and cure for the failure of the surface treatments on the hydrated fly-ash base courses is presented in Research Report 2966-2.

HISTORY

The Atlanta District first began evaluating crushed fly ash in 1990. The district laboratory's initial investigation of the material found the following material properties for the fly ash:

- Triaxial classification: *Super* Class 1,
- Unconfined compressive strength: 220 psi,
- Dry loose unit weight: 68.0 lb/ft^3,

- Compacted dry density at optimum moisture of 28.6%: 85.5 lb/ft^3,
- Los Angeles abrasion: 47, and
- 5 cycles of freeze-thaw (15 hours freeze-thaw at room temperature for 9 hours) showed no damage and no volume change.

Based on promising test results from the laboratory investigation, the district worked with Southwestern Electric Power Company (SWEPCO) to construct a test section for the power plant haul road. This was a successful venture and performance of the pavement was promising, which led to the construction of six test pavements throughout the district. These six test pavements are the subject of this study.

Table 1 includes a description of each of the six test sites, their locations, and typical cross sections. At the time these pavements were constructed, the final surface for all of the pavements (except the IH-20 frontage road which was designed for a surface treatment followed by an asphalt concrete surface course) was to have been a one/two course surface treatment directly over the primed fly-ash base. However, several problems occurred soon after placement of surface treatments whereby the surface treatment delaminated from the underlying base material. It should be noted also that the projects on SH 154, FM 1326, and FM 1520 did not have these delamination problems except in some isolated spots. These problems eventually subsided.

Table 1. Test Site Descriptions.

Roadway	County	Project Length	Location		Project Designation	Job Completion Date	Typical Pavement Cross Section
			From	To			
LP 390	Harrison	2.5 mi	US 59 in Marshall	0.3 mi S. of SH 43	1575-05-005 STP 92(7)UM	12/10/93	Grade 4 Seal Coat 2.0 in. Type C Hot Mix MC-30 Prime 10.0 in. Fly-Ash Base 8.0 in. Lime/FA Subgrade
IH 20 (FR)	Harrison	3000 ft	1.0 mi E. of Gregg Co. Line	0.6 mi W. of Loop 281	0495-08-056 CC 495-8-56	7/13/94	2.0 in. Type C Hot Mix One-Course Surface Trt. MC-30 Prime 11.0 in. Fly-Ash Base 8.0 in. Lime/FA Subgrade
SH 154	Upshur	2000 ft	0.1 mi E. of US 259	0.5 mi E. of US 259	0402-02-018 HES 000S(661)	6/8/93	Grade 4 Seal Coat One-Course Surface Trt. MC-30 Prime 6.5 - 13.0 in. FA Base
FM 1326	Bowie	400 ft	3.0 mi N. of US 82	3.0 mi N.	1570-02 Maint. Forces	9/93	CRS-2p Grade 5 CRS-2p Grade 4 5.5 in. Fly-Ash Base 2.0 in. Asphalt Concrete 5.0-7.0 in. Indeterminate (LRA or Black Base?)
FM 1520	Camp	7800 ft	0.1 mi E. of Picket Spring Branch	FM 1521	1232-03-09 A 1232-3-9	8/9/93	One-Course Surface Trt. MC-30 Prime 9.0 in. Fly-Ash Base 8.0 in. Lime/FA Subgrade
FM 560	Bowie	2300 ft	Barkman Creek and Relief	2300 ft N.	1021-01-007 BR 90(241)	4/28/95	1.8-2.5 in. Hot Mix MC-30 Prime One-Course Surface Trt. 6.0 - 12.0 in Fly Ash Base 0-6.0 in. Bank-Run RG

VISUAL CONDITION SURVEYS

In this research study, visual condition surveys are performed annually in late spring on all six test pavements. The most recent survey was performed during the last week of April 1999. The manual survey was conducted in accordance with the procedures set up for a Strategic Highway Research Program (SHRP) Long Term Pavement Performance (LTPP) distress survey (2). In addition to measuring the quantity of each distress at each severity level, a map showing the location of crack-distress was also produced.

LOOP 390

This project begins at US 59 in Marshall and extends to 0.5 km south of SH 43. The total length of the project is about 4.0 km. For visual condition surveys, the project was evaluated at 13 locations (200 ft survey length per location) in the eastbound travel lane. In 1997 there were three types of distress beginning to be evident on Loop 390: alligator cracking, a slight flushing of the seal coat surface, and rutting. However, between the 1997 and 1998 evaluations, a Grade 4 chip seal was placed on the surface and there is no longer evidence of alligator cracking at this time. Table 2 shows quantities of distress at each survey location.

The surface exhibits flushing at some locations. There is also an increase in rutting over previous years; however, the pavement is in good condition overall.

IH-20 FRONTAGE ROAD

The IH-20 frontage road project begins 0.9 miles east of the Gregg County line and continues eastward for 3000 feet. This pavement is in very good condition. Distress which was evident at the first evaluation in 1997 has not progressed any further thus far as shown in Table 3. The project was evaluated at three locations (200 ft length at each location) in the eastbound lane. Table 3 shows the quantity of distress present at each location.

Table 2. Loop 390 Distress.

Location (each location represents a 200 ft length)	Alligator* Cracking (sq ft)			Flushing (sq ft)			Rutting (in)					
							Left Wheelpath			Right Wheelpath		
	1997	1998	1999	1997	1998	1999	1997	1998	1999	1997	1998	1999
1	0	0	0	0	590 (s)	1080 (m)	0	0.1	0.4	0	0.3	0.6
2	0	0	0	0	97 (s)	960 (m)	0	0.2	0.6	0	0.3	0.4
3	0	0	0	0	260 (s)	720 (s)	0.1	0.1	0.2	0.1	0.1	0.1
4	0	0	0	0	330 (s)	600 (s)	0.1	0.1	0.3	0.1	0.1	0.2
5	0	0	0	0	260 (s)	720 (s)	0.2	0.2	0.8	0.2	0.3	0.8
6	600 (s)	0	0	600 (s)	800 (s)	860 (s)	0.4	0.6	0.5	0.5	0.6	0.4
7	1000 (s)	0	0	1200 (s)	400 (s)	480 (s)	0.5	0.5	0.7	0.5	0.5	0.4
8	1000 (s)	0	0	1200 (s)	600 (s)	600 (s)	0.4	0.4	0.6	0.4	0.4	0.6
9	600 (s)	0	0	1000 (s)	300 (s)	300 (s)	0.4	0.3	0.4	0.4	0.4	0.2
10	0	0	0	400 (s) 200 (m)	250 (s)	200 (s)	0.1	0.1	0.2	0.1	0.1	0.3
11	0	0	0	600 (s)	0	0	0.1	0.1	0.1	0.1	0.1	0.2
12	0	0	0	0	0	0	0.1	0.1	0.1	0.1	0.1	0.1
13	0	0	0	0	0	0	0	0	0	2	0	0.1

Severity Levels : (s) slight, (m) moderate.

* A Grade 4 seal coat was constructed on the pavement between the 1997 and 1998 evaluations.

Table 3. IH 20 Frontage Road Distress.

Location (each location represents a 200 ft length)	Raveling (sq ft)			Alligator Cracking (sq ft)		
	1997	1998	1999	1997	1998	1999
1 Core Location 1	43 (s)	43 (s)	43 (s)	0	5 (s)	5 (s)
2 Core Location 2	54 (s)	54 (s)	54 (s)	0	3 (s)	3 (s)
3 Core Location 3	43 (s)	43 (s)	43 (s)	0	0	0

Severity Level: (s) slight, (m) moderate.

SH 154

This project is located in Diana, beginning 0.1 mi east of US 259 and extending to 0.5 mi east of US 259. The entire length of this pavement was visually evaluated in the westbound lane. The primary distress of interest on this pavement is some slight transverse cracking. These cracks begin in the shoulder and most have not progressed all the way across the main lanes of travel; however, the cracks are very evenly spaced (every 12 to 13 ft) and might be attributable to shrinkage of the fly-ash base. Table 4 shows a summary of the distress. Note that there is no appreciable increase in the amount of cracking observed from 1997 through 1999. In fact, it appears that some of the cracks originally observed in 1997 healed by 1998 and have not reappeared in 1999.

Table 4. SH 154 Distress.

Location (beginning at east end of project)	Transverse Cracking in westbound lane (linear ft)			Longitudinal Cracking in westbound lane (linear ft)		
	1997	1998	1999	1997	1998	1999
0 - 200 ft (1st core location)	6 (s)	8 (s)	10 (s)	0	0	24 (s)
200 - 400 ft	24 (s)	24 (s)	3 1 (s)	0	0	0
400 - 600 ft	12 (s)	12 (s)	16(s)	0	0	12 (s)
600 - 800 ft	17 (s)	7 (s)	7 (s)	0	0	0
800 - 1000 ft (2nd core location)	8 (s)	8 (s)	8 (s)	8 (s)	7 (s)	50 (s)
1000 -1200 ft	38 (s)	38 (s)	42 (s)	56 (s)	36 (s)	36 (s)
1200 -1400 ft	6 (s)	0	2 (s)	0	0	0
1400 - 1600 ft	0	0	0	0	0	0
1600 - 1800 ft (3rd core location)	0	0	0	0	0	0
1800 - 2000 ft	26 (m)	44 (m)	48 (m)	22 (m)	22 (m)	28 (s)

Severity Level: (s) slight, (m) moderate.

FM 1326

The FM 1326 project begins about 3.0 mi north of US 82. It was constructed by district maintenance forces and is about 400 feet in length. The entire length of pavement (both lanes) was evaluated visually. No distress of any kind is evident in the seal-coat surface.

FM 1520

The FM 1520 project is located in Camp County and begins 0.1 miles east of Pickett Spring Branch extending to FM 1521. Its total length is about 7800 feet. This project was visually evaluated at eight locations as shown below in Table 5. There is very little change in the pavement since last year; however, a slight amount of rutting is beginning to appear.

Table 5. FM 1520 Distress.

Location (each location represents a 200 ft length)	Flushing (sq ft)			Rutting (in)					
				1997		1998		1999	
	1997	1998	1999	LWP	RWP	LWP	RWP	LWP	RWP
1	1000 (s)	1000 (s)	1000 (s)	0	0	0	0	0	0.1
2	1200 (s)	1200 (s)	1200 (s)	0	0	0	0	0	0.1
3	1500 (s)	1500 (s)	1500 (s)	0	0	0	0	0.1	0.1
4	320 (s)	320 (s)	320 (s)	0	0	0	0	0.1	0.1
5	0	0	0	0	0	0	0	0.1	0.1
6	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0

FM 560

The FM 560 project is located near Hooks and begins at Barkman Creek and Relief and extends north for 2300 feet. This pavement received an overlay prior to the 1999 evaluation; therefore, there was no evidence of any distress during the April 1999 evaluation. Previous distress data is shown in Table 6 below.

Table 6. FM 560 Distress.

Location (each location represents 200 ft in length)	Flushing (sq ft)			Longitudinal Cracking (linear ft)			Transverse Cracking (linear ft)		
	1997	1998	1999*	1997	1998	1999*	1997	1998	1999*
1 Core Location 1	1000 (m)	1000 (m)	0	0	12 (s)	0	0	23 (s)	0
2 Core Location 2	150 (m) 120 (s)	150 (m) 120 (s)	0	5 (s)	5 (s)	0	10 (s)	10 (s)	0
3 Core Location 3	0	0	0	0	0	0	0	0	0

Severity Level: (s) slight, (m) moderate.

* An overlay was constructed on the pavement between the 1998 and 1999 evaluations.

FIELD CORE AND FIELD TESTING DATA

TxDOT staff attempted to obtain three cores from each of the six test pavements. Laboratory staff from the Atlanta District performed the coring operations using district coring equipment. Water was used to cool the bit during the coring operations. It was not possible to obtain as many cores as desired because, in some cases, the cores were not retrievable. They broke into pieces when attempting to remove them from the pavement or core bit.

Texas Transportation Institute (TTI) performed unconfined compressive-strength testing on the field cores. Plaster was used to cap the ends of the specimens prior to testing. For unconfined compressive strength, it is desirable to have a sample length (L) to diameter (D) ratio of at least 2. However, some of the cores were very short. Adjustment factors were used to facilitate comparing cores of different thickness as described in Tex 418-A . Table 7 shows results of the field core strength tests. Figure 1 compares results with previous year's results.

At the time the pavements were visually evaluated, falling weight deflectometer (FWD) testing was also performed by the Atlanta District personnel. The FWD is a test that nondestructively measures stiffness and relative deflection of the various layers of a pavement system. A load that simulates a truck load is applied to the pavement through a 12-inch-diameter load plate. Pavement deflection is measured by geophones placed at various distances from the plate, yielding a "deflection bowl." Deflection magnitudes and bowl shape are used to calculate stiffness and relative deflection of each layer. In general, the lower the deflection and higher the stiffness, the better the pavement's ability to distribute and carry load without rutting and cracking. FWD deflections were measured at regular intervals along the length of each test pavement.

Moduli values of the pavement layers were calculated using the TTI Modulus Analysis System (Version 5.1). Results of the analysis are presented in Tables 8 through 13. The moduli values for the base (E2) are of particular interest for this project.

Table 7. Field Cores - Unconfined Compressive Strengths and Moisture Contents.

Sample ID	Sample Height (in)	Failure Load (lbs)	Adjustment Factor	Corrected Failure Stress (psi)	Moisture Content (%)
FM 1520 Core 1	5.6	21,550	0.86	655.6	33.2
FM 1520 Core 2	5.1	25,560	0.82	741.4	
FM 1520 Core 3	9.1	25,670	0.96	871.7	
IH20 Core 1	5.5	25,520	0.84	758.3	34.9
IH20 Core 2	6.3	23,200	0.87	714.0	
IH20 Core 3	5.8	22,970	0.86	698.8	
SH 154 Core 1	12.5	11,500	1.00	406.8	25.2
SH 154 Core 2	12.5	15,950	1.00	564.2	
SH 154 Core 3	10.8	19,040	0.99	666.8	
FM 1326 Core 1	5.5	25,200	0.84	748.8	31.8
FM 1326 Core 2	5.4	25,440	0.82	737.9	
FM 1326 Core 3	5.3	26,500	0.81	759.3	
FM 560 Core 1	5.5	15,270	0.84	453.7	36.3
FM 560 Core 2	8.2	20,790	0.94	691.3	
FM 560 Core 3	11.0	19,100	1.00	675.6	

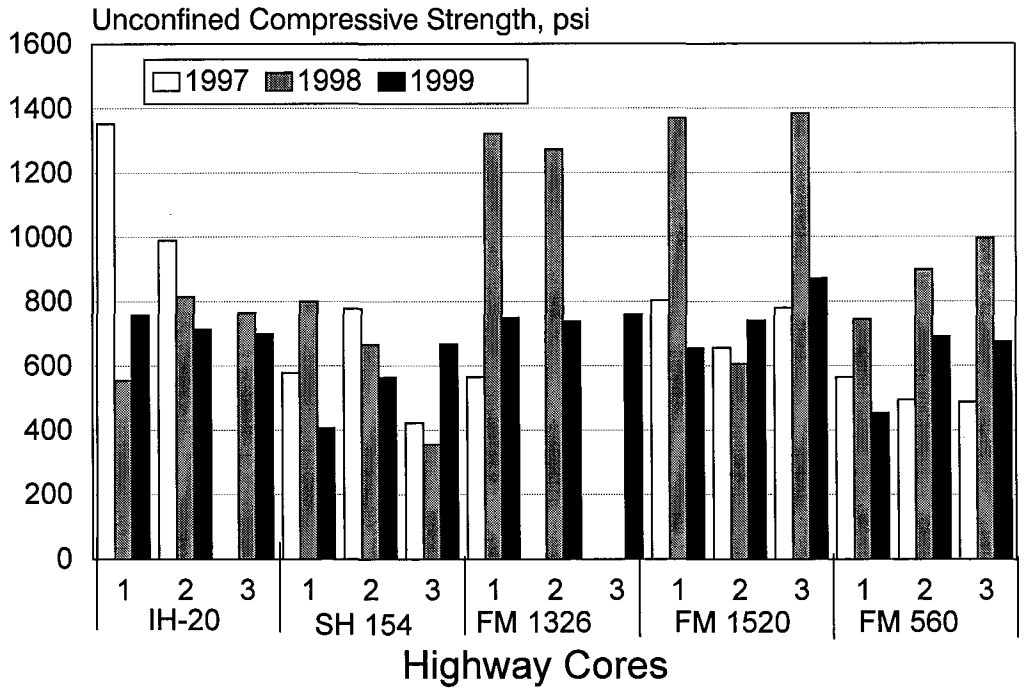

Figure 1. Unconfined Compressive Strength of Highway Cores

Table 8. FWD Data Analysis - Loop 390.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District: 19
County: 103
Highway/Road: SL 039

	Thickness(in)	MODULI RANGE(psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	2.00	199,980	200,020	H1: 0.35
Base:	10.00	30,000	500,000	H2: 0.30
Subbase:	8.00	5,000	500,000	H3: 0.25
Subgrade:	186.60	23,500		H4: 0.45

Station	Load (lbs)	Measured Deflection (mils): R1	R2	R3	R4	R5	R6	R7	Calculated Moduli values (ksi): SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	Absolute Dpth to ERR/Sens	Bedrock
314.000	9,978	23.27	15.61	8.85	5.41	3.50	2.39	1.71	200.	101.6	5.0	13.2	4.00	175.61
842.000	11,051	6.76	4.17	2.78	1.97	1.35	0.96	0.67	200.	488.1	75.0	34.3	0.88	171.10
1370.000	11,249	12.51	7.18	4.00	2.52	1.67	1.23	0.98	200.	180.2	24.5	29.1	3.32	184.64
1898.000	10,900	14.87	10.74	7.30	5.00	3.47	2.56	1.81	200.	269.8	14.7	12.9	2.44	285.23
2426.000	10,816	11.07	7.00	3.99	2.40	1.56	1.17	0.89	200.	251.6	16.2	30.4	4.57	164.33
2960.000	10,065	16.02	11.22	5.94	3.34	2.15	1.56	1.12	200.	158.5	6.3	21.9	7.41	126.80
3482.000	10,645	10.10	7.20	4.71	3.17	2.22	1.64	1.22	200.	407.1	19.2	20.3	3.10	236.89
4011.000	9,835	20.57	12.31	7.25	4.63	3.04	2.24	1.66	200.	92.5	11.8	13.6	2.69	186.00
4538.000	10,749	15.16	9.85	6.01	4.00	2.86	2.26	1.52	200.	171.4	21.2	16.0	4.90	300.00
4959.000	10,991	13.74	7.20	4.02	2.76	1.97	1.56	1.17	200.	122.5	46.2	24.9	4.80	300.00
5088.000	12,564	14.91	6.84	3.70	2.95	1.74	1.32	1.96	200.	107.2	63.7	30.2	4.05	300.00
5594.000	10,411	11.96	7.76	4.47	2.85	1.87	1.33	1.01	200.	228.7	15.0	24.6	3.53	174.94
6022.000	10,324	8.63	4.26	2.87	2.29	1.83	1.44	1.14	200.	158.8	500.0	27.0	4.53	300.00
6650.000	10,852	14.61	9.62	6.11	4.09	2.77	1.99	1.46	200.	204.9	16.7	16.5	2.03	224.61
7178.000	10,904	10.76	6.55	3.92	2.70	1.94	1.55	1.27	200.	222.7	46.4	24.4	4.91	300.00
7706.000	11,277	16.61	7.32	3.74	2.65	1.97	1.54	1.28	200.	77.6	48.7	26.3	5.86	300.00
8236.000	10,630	13.19	8.28	4.97	3.29	2.40	1.83	1.50	200.	183.9	27.1	19.4	4.98	300.00
8763.000	9,652	18.65	10.80	5.38	3.09	1.91	1.39	0.98	200.	89.6	8.7	21.6	5.35	132.17
9290.000	10,939	8.57	5.02	2.94	2.05	1.54	1.17	0.91	200.	268.6	72.2	32.3	5.50	300.00
9819.000	9,728	7.54	4.80	3.21	2.24	1.56	1.13	0.87	200.	374.6	55.9	26.0	1.05	234.14
10346.000	10,208	15.91	10.42	6.09	3.58	2.27	1.76	1.39	200.	161.3	8.6	19.7	5.41	149.54
10874.000	9,859	10.72	7.40	4.94	3.39	2.31	1.65	1.23	200.	320.1	19.5	17.8	1.53	220.96
11403.000	11,094	12.54	6.63	3.43	2.02	1.35	0.93	0.68	200.	153.1	21.7	36.4	3.74	164.30
11930.000	10,578	8.63	5.81	4.23	3.01	2.07	1.44	0.92	200.	500.0	11.7	29.4	10.99	138.07
12460.000	10,340	9.55	5.32	3.92	2.81	1.96	1.42	1.00	200.	195.8	146.3	22.2	1.74	179.73
12988.000	11,074	11.60	6.61	3.52	2.18	1.44	1.10	0.81	200.	185.8	25.1	33.1	4.59	179.64
13521.000	10,379	24.34	15.41	7.32	3.74	2.15	1.54	1.28	200.	74.7	5.0	20.2	8.85	87.15
Mean:		13.44	8.20	4.80	3.12	2.11	1.56	1.20	200.	213.0	49.3	23.8	4.32	206.65
Std. Dev:		4.51	3.03	1.58	0.90	0.59	0.43	0.34	0.	117.3	95.2	6.7	2.27	80.36
Var Coeff(%):		33.54	36.98	32.96	28.95	27.84	27.29	28.23	0.	55.0	100.0	27.9	52.53	38.89

Table 9. FWD Data Analysis - IH 20 Frontage Road.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District: 19
County: 103
Highway/Road: IH0020

	Thickness(in)	MODULI RANGE(psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	2.00	199,980	200,020	H1: 0.35
Base:	11.00	100,000	6,000,001	H2: 0.35
Subbase:	8.00	20,000	700,000	H3: 0.25
Subgrade:	37.10	10,300		H4: 0.40

Station	Load (lbs)	Measured Deflection (mils): R1	R2	R3	R4	R5	R6	R7	Calculated Moduli values (ksi): SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	Absolute Dpth to ERR/Sens	Bedrock
200.000	9,466	24.87	12.04	4.53	2.32	1.51	1.14	0.70	200.	100.0	20.0	7.5	26.00	65.42
402.000	10,165	2.97	2.18	1.71	1.34	1.03	0.80	0.61	200.	3987.8	206.4	10.6	3.01	36.00
673.000	11,027	2.83	1.97	1.48	1.13	0.84	0.65	0.50	200.	4513.8	128.1	15.3	4.80	24.00
800.000	10,391	3.45	2.39	1.74	1.29	0.92	0.68	0.49	200.	1622.8	335.4	13.4	2.32	36.00
1000.000	10,443	3.29	2.41	1.87	1.44	1.11	0.87	0.71	200.	3096.2	261.1	10.2	3.53	36.00
1204.000	10,423	10.02	5.74	3.98	2.89	2.04	1.45	1.09	200.	164.2	385.0	5.3	3.60	207.41
1235.000	9,942	10.96	6.85	4.37	3.15	2.21	1.68	1.26	200.	157.1	235.1	4.8	6.49	294.32
1400.000	10,558	7.61	4.74	3.15	2.37	1.77	1.36	1.19	200.	268.5	499.6	6.4	4.91	300.00
1602.000	10,423	11.04	6.66	4.04	2.91	2.04	1.48	1.16	200.	147.4	272.7	5.5	6.97	238.11
2010.000	10,097	6.14	5.47	3.40	2.35	1.75	1.31	1.01	200.	811.0	117.0	6.8	7.98	288.30
2199.000	10,248	10.12	6.01	3.24	2.30	1.71	1.34	1.12	200.	140.1	403.2	6.6	11.13	300.00
2400.000	11,063	10.89	6.22	3.18	2.18	1.66	1.32	1.07	200.	130.6	434.9	7.6	13.25	300.00
2599.000	10,157	10.26	6.22	3.58	2.47	1.83	1.40	1.08	200.	149.1	309.9	6.1	9.56	290.69
2801.000	10,165	11.13	5.99	3.20	2.22	1.66	1.28	1.02	200.	111.7	440.9	6.9	11.87	300.00
3001.000	10,776	13.74	6.22	2.42	1.42	1.00	0.76	0.58	200.	100.0	150.0	13.0	22.10	36.00
3171.000	10,260	11.90	6.07	2.87	1.56	1.13	0.93	0.75	200.	100.0	165.8	10.6	17.18	36.00
3400.000	9,835	3.11	1.57	1.00	0.67	0.48	0.39	0.33	200.	2631.7	33.2	33.2	12.56	16.00
3601.000	9,573	3.20	1.94	1.18	0.71	0.44	0.33	0.27	200.	813.6	260.7	27.1	6.74	24.00
3806.000	9,636	2.78	1.65	1.13	0.78	0.56	0.42	0.37	200.	1200.3	570.4	21.2	2.59	24.00
Mean:		8.44	4.86	2.74	1.87	1.35	1.03	0.81	200.	1065.6	275.2	11.5	9.29	58.07
Std. Dev:		5.54	2.65	1.15	0.78	0.56	0.41	0.32	0.	1430.9	154.3	7.8	6.67	52.71
Var Coeff(%):		65.61	54.62	41.81	41.51	41.22	40.12	40.33	0.	100.0	56.1	68.3	71.78	90.77

Table 10. FWD Data Analysis - SH 154.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District: 19
County: 230
Highway/Road: SH0154

	Thickness(in)	MODULI RANGE(psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	0.50	199,980	200,020	H1: 0.35
Base:	13.00	15,000	1,500,000	H2: 0.30
Subbase:	0.00	0	0	H3: 0.25
Subgrade:	220.10	18,500		H4: 0.40

Station	Load (lbs)	Measured Deflection (mils): R1	R2	R3	R4	R5	R6	R7	Calculated Moduli values (ksi): SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	Absolute ERR/Sens	Dpth to Bedrock
100.000	9,533	48.01	21.76	7.45	4.11	3.13	2.43	1.91	200.	20.7	0.0	12.1	11.65	56.92
200.000	9,982	35.57	15.56	4.11	1.78	1.39	1.17	0.98	200.	25.3	0.0	21.7	21.33	59.87
299.000	9,342	48.52	25.25	9.35	3.97	2.31	1.81	1.53	200.	19.6	0.0	12.0	22.44	65.71
400.000	12,036	8.88	6.46	4.84	3.52	2.57	1.95	1.55	200.	533.0	0.0	21.8	1.59	300.00
512.000	12,258	8.46	5.87	4.36	3.27	2.38	1.81	1.44	200.	549.2	0.0	24.5	2.84	300.00
610.000	12,441	5.78	4.95	4.05	3.09	2.35	1.83	1.43	200.	1438.7	0.0	23.4	3.58	300.00
702.000	13,033	4.41	3.95	3.31	2.66	2.13	1.76	1.24	200.	1500.0	0.0	35.4	14.26	174.90
801.000	12,270	5.32	4.87	3.93	3.07	2.35	1.87	1.48	200.	1500.0	0.0	24.2	4.08	300.00
900.000	11,694	5.26	4.81	3.87	3.07	2.40	1.91	1.54	200.	1500.0	0.0	22.4	3.56	300.00
1036.000	11,551	5.00	4.81	4.11	3.42	2.74	2.24	1.84	200.	1500.0	0.0	22.3	10.99	300.00
1100.000	11,102	6.21	5.81	4.19	3.10	2.43	1.99	1.60	200.	1074.4	0.0	20.0	5.49	300.00
1200.000	11,742	6.76	5.93	4.74	3.71	2.88	2.29	1.85	200.	1209.3	0.0	18.1	3.05	300.00
1251.000	11,694	7.29	6.10	4.72	3.64	2.76	2.17	1.72	200.	917.1	0.0	19.2	2.31	300.00
1300.000	11,607	5.65	5.41	4.43	3.57	2.77	2.17	1.74	200.	1500.0	0.0	19.1	3.94	300.00
1400.000	10,256	6.31	5.63	4.43	3.46	2.72	2.15	1.75	200.	1129.1	0.0	16.8	3.30	300.00
1500.000	11,631	5.21	4.87	3.53	2.81	2.21	1.80	1.50	200.	1500.0	0.0	23.5	4.91	300.00
1600.000	11,885	6.33	5.69	4.58	3.62	2.87	2.35	1.91	200.	1473.7	0.0	18.2	3.39	300.00
1700.000	11,611	9.18	6.36	4.33	2.97	2.27	1.80	1.40	200.	402.2	0.0	23.7	5.07	300.00
1800.000	11,607	10.58	5.83	4.36	3.44	2.48	1.90	1.37	200.	323.6	0.0	23.7	11.16	194.77
1902.000	11,480	13.84	7.90	5.06	3.83	2.87	2.23	1.75	200.	206.1	0.0	19.1	9.61	300.00
2001.000	12,334	15.39	9.43	6.18	4.20	3.18	2.45	2.06	200.	202.1	0.0	17.7	5.65	300.00
2079.000	12,127	17.20	9.47	5.31	3.60	2.47	1.85	1.21	200.	137.1	0.0	19.8	6.13	243.51
2201.000	11,384	22.28	12.96	5.94	2.79	1.85	1.63	1.06	200.	72.4	0.0	18.8	13.29	70.90
Mean:		13.37	8.25	4.83	3.33	2.50	1.98	1.56	200.	814.5	0.0	20.8	7.55	233.60
Std. Dev:		13.13	5.57	1.34	0.54	0.40	0.29	0.28	0.	609.7	0.0	4.7	5.86	212.51
Var Coeff(%):		98.22	67.50	27.72	16.10	16.11	14.84	17.86	0.	74.8	0.0	22.5	77.64	90.97

Table 11. FWD Data Analysis - FM 1326.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District: 19
County: 19
Highway/Road: FM1326

	Thickness(in)	MODULI RANGE(psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	0.50	199,980	200,020	H1: 0.35
Base:	5.50	20,000	800,000	H2: 0.30
Subbase:	8.00	4,000	180,000	H3: 0.35
Subgrade:	95.80	12,100		H4: 0.40

Station	Load (lbs)	Measured Deflection (mils): R1	R2	R3	R4	R5	R6	R7	Calculated Moduli values (ksi): SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	Absolute ERR/Sens	Dpth to Bedrock
5.000	9,529	44.32	18.79	6.56	3.74	2.39	1.90	1.58	200.	41.9	9.9	11.6	8.26	57.65
50.000	9,783	51.80	22.59	8.33	4.50	3.13	2.60	2.03	200.	37.3	9.4	9.3	10.95	64.24
101.000	11,261	18.11	11.88	6.02	3.30	2.07	1.47	1.19	200.	357.3	35.0	15.5	3.98	110.39
150.000	11,178	14.43	11.39	7.58	4.87	3.01	2.01	1.46	200.	800.0	80.5	10.6	2.54	132.38
200.000	11,170	16.82	10.91	6.89	4.67	3.00	2.10	1.57	200.	230.3	114.8	12.5	1.74	157.17
250.000	11,273	14.69	10.62	6.42	4.00	2.67	2.00	1.53	200.	491.8	87.6	13.0	4.91	203.63
300.000	11,015	16.18	11.06	6.39	3.96	2.65	2.03	1.58	200.	326.9	77.4	13.2	5.30	208.35
350.000	11,821	15.69	11.51	6.94	4.08	2.61	1.98	1.30	200.	639.4	61.2	13.0	5.21	156.52
400.000	10,697	21.12	14.48	8.20	4.72	2.65	1.75	1.34	200.	431.9	24.8	10.9	1.60	100.04
Mean:		23.68	13.69	7.04	4.20	2.69	1.98	1.51	200.	373.0	55.6	12.2	4.94	109.78
Std. Dev:		14.09	4.23	0.82	0.52	0.33	0.30	0.24	0.	254.0	37.5	1.8	3.07	51.43
Var Coeff(%):		59.48	30.90	11.69	12.37	12.32	15.16	15.93	0.	68.1	67.4	15.0	62.14	46.85

Table 12. FWD Data Analysis - FM 1520.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District: 19
County: 32
Highway/Road: FM1520

	Thickness(in)	MODULI RANGE(psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	0.50	199,980	200,020	H1: 0.35
Base:	10.00	20,000	400,000	H2: 0.30
Subbase:	8.00	4,000	150,000	H3: 0.25
Subgrade:	129.50	16,800		H4: 0.40

Station	Load (lbs)	Measured Deflection (mils): R1	R2	R3	R4	R5	R6	R7	Calculated Moduli values (ksi): SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	Absolute ERR/Sens	Dpth to Bedrock
0.000	12,810	23.75	11.43	5.44	3.43	2.11	1.49	1.20	200.	81.2	26.8	21.9	4.01	125.80
224.000	12,362	15.72	10.01	5.65	3.46	2.24	1.72	1.07	200.	224.8	16.6	22.5	2.51	162.72
600.000	11,774	15.31	10.67	6.68	4.96	3.30	2.21	1.46	200.	270.8	25.2	14.7	2.70	150.63
1200.000	11,611	11.78	6.18	4.28	2.76	2.26	1.80	1.45	200.	240.2	72.8	22.3	10.67	300.00
2075.000	11,940	38.23	23.46	11.67	6.87	5.14	2.85	2.01	200.	70.4	6.9	10.7	6.05	187.82
2425.000	13,049	18.70	12.26	7.78	5.22	3.20	2.69	2.42	200.	218.8	20.5	15.4	3.89	125.82
2999.000	11,551	21.59	16.56	9.07	5.42	3.26	2.16	1.68	200.	209.2	4.0	17.4	3.77	122.08
3600.000	11,925	19.78	13.24	7.09	3.55	2.13	1.53	1.22	200.	178.7	6.4	24.9	4.16	81.48
4210.000	11,766	15.85	5.83	2.85	1.80	1.35	1.18	0.85	200.	126.6	43.9	33.8	18.19	300.00
4801.000	12,433	21.37	11.26	6.01	4.65	3.34	2.37	1.71	200.	104.7	45.6	16.3	8.48	300.00
5400.000	11,579	19.63	13.70	7.87	4.93	2.59	1.46	1.07	200.	232.2	4.0	24.0	3.43	86.25
6000.000	11,913	16.48	7.80	4.79	3.09	2.14	1.57	1.05	200.	135.2	46.7	22.5	5.72	155.23
6610.000	11,881	10.70	6.31	4.63	3.53	2.64	1.97	1.48	200.	309.1	150.0	17.6	6.01	242.10
7201.000	12,600	14.53	8.88	5.20	3.31	2.15	1.59	1.14	200.	234.8	24.7	23.3	1.72	163.87
7800.000	11,654	29.67	15.48	9.53	4.94	3.76	3.12	2.30	200.	73.5	17.6	12.7	6.72	92.33
8401.000	12,290	15.24	7.64	3.53	2.69	1.85	1.32	1.06	200.	146.0	41.6	28.4	10.62	223.01
8988.000	10,741	18.48	14.93	9.29	5.50	3.35	2.22	1.56	200.	264.3	4.0	15.0	3.76	129.80
Mean:		19.22	11.51	6.55	4.12	2.75	1.96	1.45	200.	183.6	32.8	20.2	6.02	148.01
Std. Dev:		6.68	4.54	2.39	1.31	0.90	0.56	0.45	0.	75.1	35.8	6.0	4.10	61.31
Var Coeff(%):		34.77	39.49	36.49	31.65	32.79	28.74	31.14	0.	40.9	100.0	29.6	67.99	41.42

Table 13. FWD Data Analysis - FM 560.

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District: 19
County: 19
Highway/Road: FM0560

	Thickness(in)	MODULI RANGE(psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	4.00	199,980	200,020	H1: ō = 0.35
Base:	6.50	20,000	1,000,000	H2: ō = 0.30
Subbase:	6.00	10,000	700,000	H3: ō = 0.35
Subgrade:	283.50	15,700		H4: ō = 0.40

Station	Load (lbs)	Measured Deflection (mils): R1	R2	R3	R4	R5	R6	R7	Calculated Moduli values (ksi): SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	Absolute Dpth to ERR/Sens	Bedrock
0.000	10,042	20.83	14.00	8.67	5.74	4.12	3.31	2.62	200.	108.8	19.7	11.5	3.31	300.00
150.000	9,958	23.46	14.14	8.31	5.52	3.94	3.05	2.51	200.	52.5	26.9	11.8	2.20	300.00
299.000	10,185	7.24	5.69	4.84	4.00	3.16	2.50	2.01	200.	1000.0	175.8	20.3	15.37	300.00
450.000	10,026	14.32	9.89	7.18	5.13	3.61	2.63	1.99	200.	300.4	48.8	13.3	0.61	300.00
600.000	10,069	13.97	9.96	7.29	5.22	3.64	2.67	2.02	200.	416.8	37.2	13.3	0.62	300.00
759.000	10,053	13.26	9.52	6.96	5.10	3.67	2.67	2.09	200.	426.1	56.8	13.3	0.36	300.00
899.000	10,010	12.80	8.79	6.10	4.35	3.13	2.37	1.88	200.	303.4	63.1	15.4	1.34	300.00
1050.000	9,990	13.63	8.01	5.10	3.57	2.58	2.02	1.68	200.	113.2	86.6	18.8	2.02	300.00
1200.000	9,946	11.20	6.85	4.04	2.76	2.10	1.71	1.47	200.	186.5	67.2	23.7	5.52	300.00

TTI MODULUS ANALYSIS SYSTEM (SUMMARY REPORT) (Version 5.1)

District: 19
County: 19
Highway/Road: FM0560

	Thickness(in)	MODULI RANGE(psi) Minimum	Maximum	Poisson Ratio Values
Pavement:	4.00	199,980	200,020	H1: ō = 0.35
Base:	9.50	20,000	1,000,000	H2: ō = 0.30
Subbase:	3.50	5,000	400,000	H3: ō = 0.35
Subgrade:	283.00	15,800		H4: ō = 0.40

Station	Load (lbs)	Measured Deflection (mils): R1	R2	R3	R4	R5	R6	R7	Calculated Moduli values (ksi): SURF(E1)	BASE(E2)	SUBB(E3)	SUBG(E4)	Absolute Dpth to ERR/Sens	Bedrock
1350.000	10,010	8.72	5.87	4.17	3.07	2.24	1.74	1.46	200.	447.0	66.0	21.8	2.13	300.00
1500.000	9,879	10.80	7.45	5.37	3.88	2.81	2.13	1.69	200.	349.1	20.3	17.4	1.37	300.00
1650.000	9,851	13.86	8.13	4.87	3.46	2.59	2.00	1.52	200.	95.0	69.0	19.0	3.73	300.00
1800.000	9,859	11.80	6.66	3.58	1.95	1.01	0.44	0.34	200.	89.4	11.9	39.6	25.13	36.00
1950.000	9,720	13.67	8.65	4.88	2.94	2.12	1.65	1.36	200.	119.3	6.9	23.0	4.94	236.45
2100.000	9,744	13.10	8.76	5.30	3.41	2.36	1.79	1.34	200.	159.1	6.2	20.6	3.66	300.00
2250.000	9,744	17.91	11.02	6.52	3.97	2.69	2.07	1.70	200.	81.6	5.3	17.5	2.84	259.55
2400.000	9,446	25.33	15.65	8.48	4.76	2.96	2.15	1.71	200.	34.9	5.0	13.5	5.44	136.17
2550.000	9,537	27.31	17.30	10.17	5.97	3.67	2.53	1.99	200.	36.2	5.0	11.1	6.05	141.05

TTI experience has shown that for stabilized bases, moduli values between 145,000 and 500,000 psi are optimum in terms of field performance. Bases with moduli values between 500,000 and 1,000,000 psi give variable field performance and values above 1,000,000 psi seem to be too stiff and exhibit transverse/shrinkage cracking. In Figures 2 through 7, the base moduli values are plotted for each test pavement and compared with previous years' data..

For subgrades, moduli values less than 4000 psi are considered poor while good values are those greater than 16,000 psi.

Below is a discussion of the FWD test results and the field core data.

LOOP 390

No cores were obtained from this pavement. Unsuccessful attempts were made in 1997, 1998, and again in 1999. As shown in Figure 2, there is some variation in the moduli values since 1997; however, it doesn't appear that the base is overall exhibiting a deteriorating strength. Some locations indicate an increase in stiffness while others show a decrease.

IH 20 FRONTAGE ROAD

Three cores were obtained from this pavement as shown in Figure 1. The pavement core strengths are similar to the core strengths measured last year. There is very little change in the FWD data exhibited in Figure 3 since 1997. Note in Figure 3 that the last data point may coincide with the beginning of a different type of pavement section..

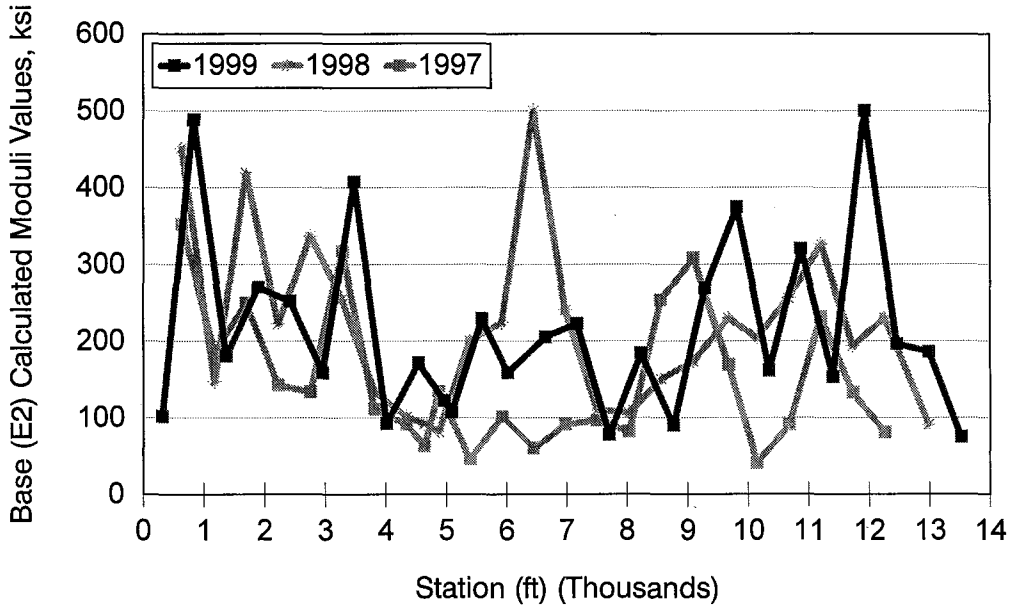

Figure 2. Base Moduli Values for Loop 390

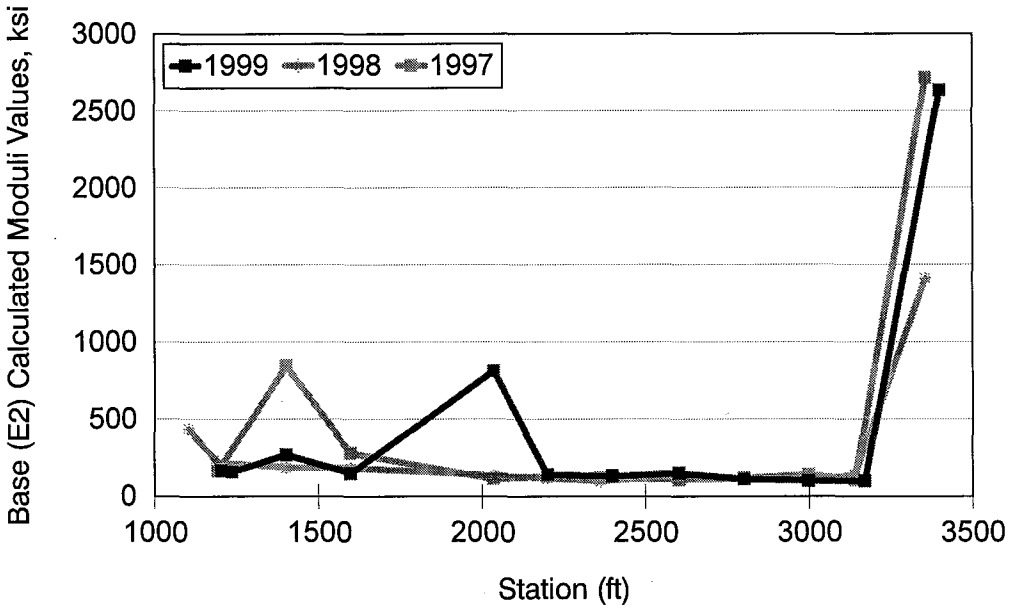

Figure 3. Base Moduli Values for IH 20 Frontage Road

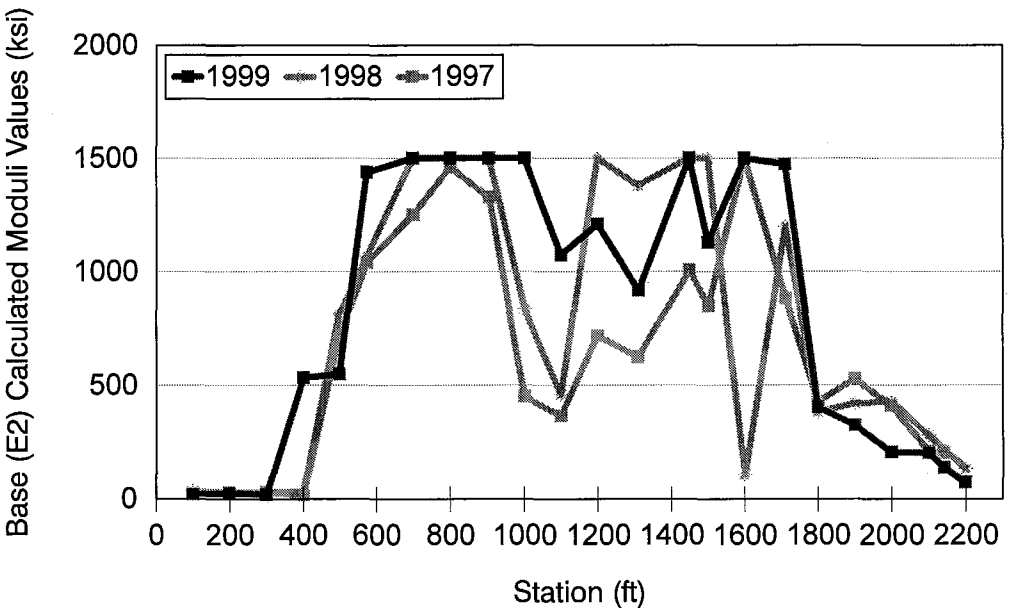

Figure 4. Base Moduli Values for SH 154

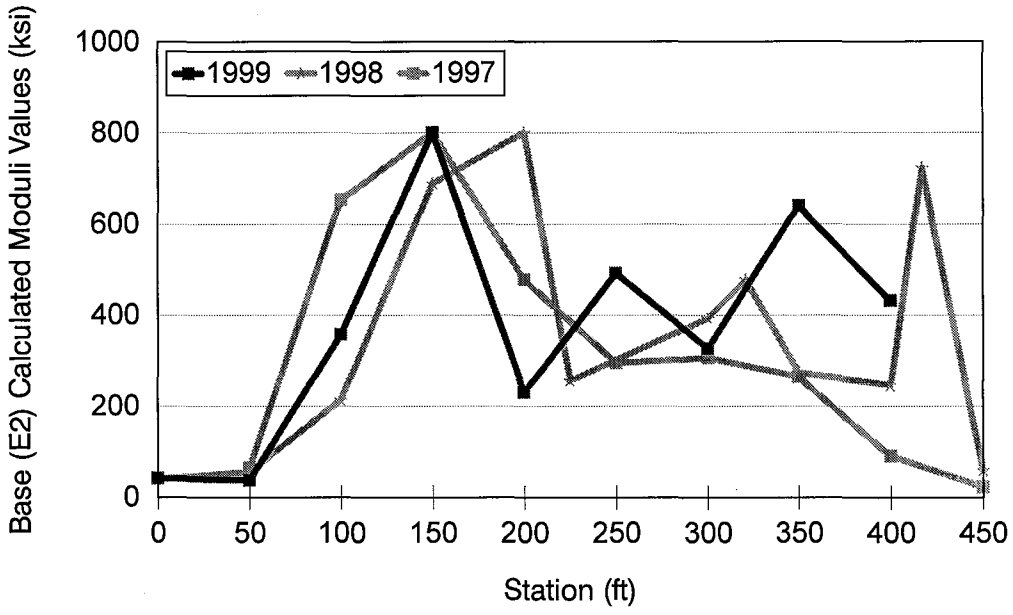

Figure 5. Base Moduli Values for FM 1326

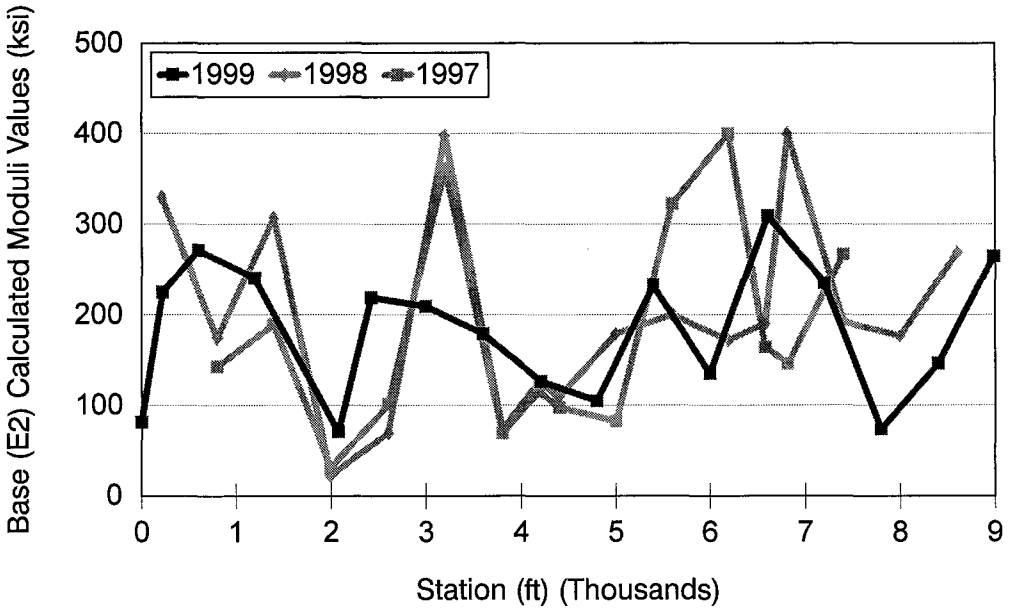

Figure 6. Base Moduli Values for FM 1520

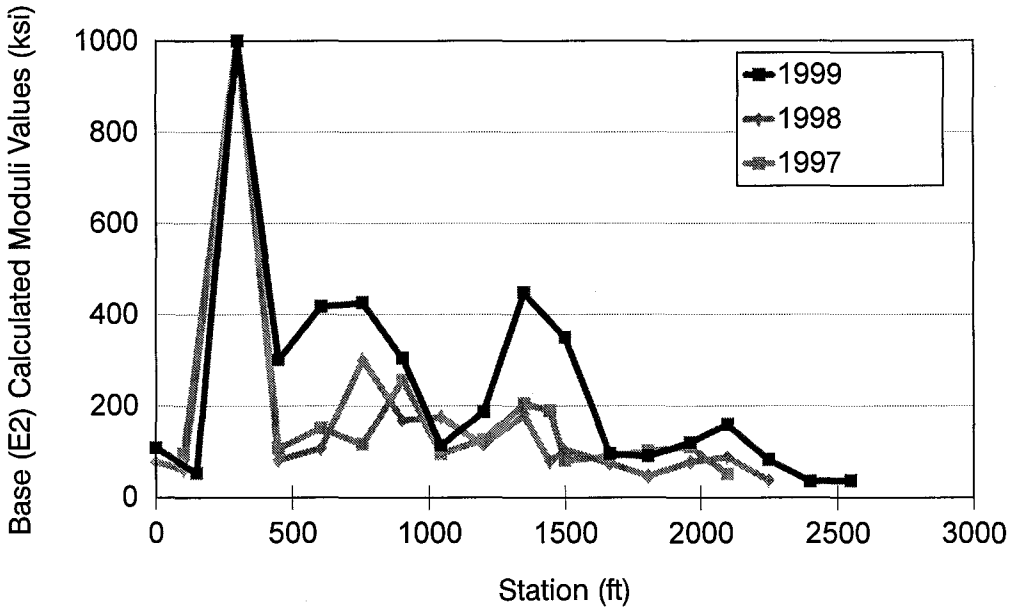

Figure 7. Base Moduli Values for FM 560.

SH 154

From what appears to be shrinkage cracking, one would expect this pavement to be the stiffest of the six. This is true in terms of FWD data (Figure 4). Base moduli values along the pavement exceed 1,000,000 psi in some locations. Base moduli values in 1999 appear to be similar to values in 1998 and 1997. Compressive strengths of the cores (on the average) are also close to the values obtained the previous year (Figure 1).

FM 1326

Cores obtained from FM 1326 in 1999 show a significant decrease in strength over that exhibited in 1998. However, the base moduli values as calculated from FWD data (shown in Figure 5) do not indicate a significant change is occurring in the pavement.

FM 1520

Three cores were obtained from FM 1520 and these cores had an average strength which was lower than last year's core data. However, the strengths are about the same as that measured in 1997. FWD data (Figure 6) on this pavement indicate that there may be a general decrease in moduli values; however, most of the values still fall between 100,000 and 300,000 psi as in previous years.

FM 560

All three cores obtained from FM 560 had lower compressive strengths than the cores obtained in 1998 but about two of the 1999 cores had higher strengths than the 1997 cores as shown in Figure 1. The base on this pavement has two different thicknesses along its length: 9 inches and 16 inches. Because of the difference in thicknesses, two separate FWD analyses were performed as shown in Table 13. Results from both analyses, however, were combined for Figure 7. Moduli values for this pavement are generally higher in 1999 than for the previous years.

CONCLUSIONS

- All of the hydrated fly-ash test pavement are continuing to perform well. No pavements are exhibiting significant distress at this time. For the pavements that do have some distress, that distress is generally in isolated areas, and the distress is not affecting the serviceability of the roadway.
- There has been little change observed in the performance of the six pavements since 1997. Two of the six hydrated fly-ash test pavements have exhibited distress that might be attributable to deficiencies in the fly-ash base material. In 1997 Loop 390 exhibited a small amount of alligator cracking in an area where the FWD data indicated the base is weak. However, by 1998 the surface had a new seal coat and there was apparent surface distress at the time of evaluation in 1998. SH 154 exhibits transverse cracking (which appears to be from shrinkage of the base), and the FWD data indicates this pavement is very stiff. Researchers observed that the cracking had not progressed further in 1998 or in 1999 and, in fact, there was slightly less cracking in 1998 than in 1997. This indicates there may be a tendency of the cracks toward autogenous healing in this type of base material.
- 1999 FWD data were compared to that taken in 1998 and 1997. Modulus of the fly-ash base materials were back-calculated from the FWD data. There is no indication of any significant weakening of these base materials with time.
- Cores were taken on all of the test pavements except Loop 390. No intact core could be obtained from Loop 390. Compressive strengths for IH-20 and SH-154 are similar (on the average) to those measured in 1998. Compressive strengths for FM 1326, FM 1520, and FM 560 are lower than those measured in 1998 but about the same as measured in1997.

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