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16. Abstract

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. Evaluation of performance shall be based on visual documentation, falling-weight deflectometer tests and compressive strengths of field cores.

This report is intended to serve as an interim report documenting the performance evaluations conducted in the spring of 1997. This report covers the first annual evaluation in a series of five.

Most of the hydrated fly ash test pavements are performing very well at this time. Two of the six pavements are exhibiting minor distress which might be attributable to deficiencies in the fly ash base material.

Falling weight deflectometer testing revealed that there is variability in the moduli of these base materials which warrants investigation (i.e., weak spots and stiff spots within a single pavement section). Also, one pavement is considerably stiffer (overall) than the other five.

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# FIELD PERFORMANCE EVALUATION OF HYDRATED, FLY ASH BASES IN THE ATLANTA DISTRICT - YEAR 1

by

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Research Report 2966-1
Research Study Number 7-2966
Research Study 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
Texas Department of Transportation

November 1997

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

# IMPLEMENTATION STATEMENT

This report covers the first annual evaluation of hydrated fly ash test pavements in the Atlanta District. It is recommended that the district continue to monitor these pavements for the next four years as planned in this study. The information presented in this report is not ready for implementation at this time.

# DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation (TxDOT) or the Federal Highway Administration (FHWA). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes.

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# SUMMARY

The objective of this report is to present the findings of the performance evaluations of six pavement sections constructed in the Atlanta District using hydrated fly ash as the base material. Hydrated fly ash is classified as a flexible base material; however, the fly ash is still active enough that the base gains strength after placement. This causes the material to behave more like a stabilized base; therefore, in this report, it is compared against stabilized bases.

This document covers the first evaluation which occurred in the spring of 1997. Annual evaluations are scheduled for the next four years. Performance evaluations were based upon visual pavement evaluations, falling weight deflectometer testing and compressive strength of field cores.

Visual evaluations reveal that, in general, the pavements are performing very well. However, one pavement is exhibiting alligator cracking in some isolated areas and another pavement is exhibiting slight levels of transverse (shrinkage) cracking.

Falling weight deflectometer (FWD) data is consistent with the distress (mentioned above) which is apparent on the surface. FWD data also indicates that there is variability in the material within a single pavement section and between different pavements. Some of the bases appear to be weaker than desired; however, they are performing quite well at this time. This may indicate that applying stabilized base criteria to this material may not be appropriate as will be determined by future performance.

The researchers recommend that the pavements continue to be monitored and that this year's evaluation program include the use of ground penetrating radar (GPR) to determine if there is water in these base materials that coincides with the "weak" spots. This might explain the variability in the FWD data.

# 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. 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.

Table 1 provides a description of each of the six test sites and their locations.

**Table 1. Test Site Descriptions**

| Roadway | County | Project Length | Location | | Project Designation | Job Completion Date | Typical Pavement Cross-Section |
|---|---|---|---|---|---|---|---|
| | | | From | To | | | |
| LP 390 | Harrison | 4.0 km | US 59 in Marshall | 0.5 km S. of SH 43 | 1575-05-005<br>STP 92(7)UM | 12/10/93 | Grade 4 Seal Coat<br>50 mm Type C Hot Mix<br>MC-30 Prime<br>250 mm Fly Ash Base<br>200 mm Lime/FA Subgrade |
| IH 20 (FR) | Harrison | 900 m | 1.5 km E of Gregg Co. Line | 1 km W. of Loop 281 | 0495-08-056<br>CC 495-8-56 | 7/13/94 | 50 mm Type C Hot Mix<br>One-Course Surface Trt.<br>MC-30 Prime<br>280 mm Fly Ash Base<br>200 mm Lime/FA Subgrade |
| SH 154 | Upshur | 600 m | 0.16 km E. of US 259 | 0.8 km E. of US 259 | 0402-02-018<br>HES 000S(661) | 6/8/93 | Grade 4 Seal Coat<br>One-Course Surface Trt.<br>MC-30 Prime<br>165-330 mm FA Base |
| FM 1326 | Bowie | 120 m | 4.8 km N. of US 82 | 4.9 km N. | 1570-02<br>Maint. Forces | 9/93 | CRS-2p Grade 5<br>CRS-2p Grade 4<br>140 mm Fly Ash Base<br>50 mm asphalt concrete<br>125-175 mm Indeterminate<br>(LRA or Black Base?) |
| FM 1520 | Camp | 2400 m | 0.16 km E. of Picket Spring Branch | FM 1521 | 1232-03-09<br>A 1232-3-9 | 8/9/93 | One-Course Surface Trt.<br>MC-30 Prime<br>235 mm Fly Ash Base<br>200 mm Lime/FA Subgrade |
| FM 560 | Bowie | 700 m | Barkman Creek and Relief | 700 m N. | 1021-01-007<br>BR 90(241) | 4/28/95 | 45-63 mm Hot Mix<br>MC-30 Prime<br>One-Course Surface Trt.<br>150-300 mm Fly Ash Base<br>0-150 mm Bank-Run RG |

## VISUAL CONDITION SURVEYS

Visual condition surveys were performed on all six test pavements during the last week of April and first week of May in 1997. The manual survey was conducted in accordance with the procedures set up for a SHRP 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. Figure 1 shows an example of a completed form.

**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 (60 m survey length per location) in the eastbound lane. 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. Quantities of distress at each survey location are shown below in Table 2. A typical photograph of the alligator cracking is shown in Figure 2.

**IH-20 Frontage Road**

The IH-20 Frontage Road project begins 0.9 miles east of the Gregg Co. Line and continues eastward for 900 m. This pavement is in excellent condition. The only observed distress was a slight amount of raveling in the asphalt concrete surface. The project was evaluated at 3 locations (60 m length at each location) in the eastbound lane. The quantity of distress present at each location is shown in Table 3.

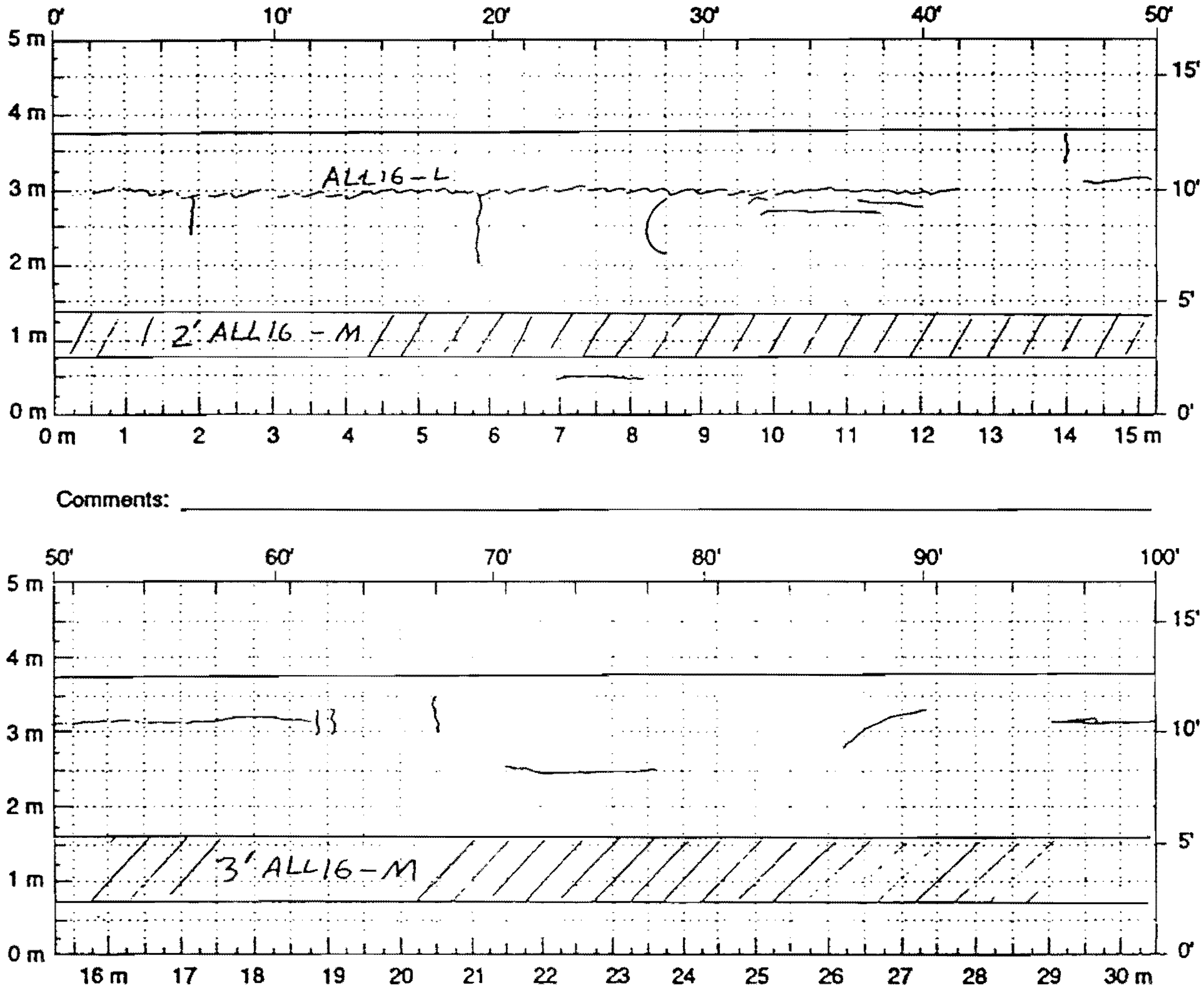


**Figure 1. Example of Completed SHRP LTPP Condition Survey Form**

**Table 2. Loop 390 Distress (April 1997)**

| Location (each location represents a 60 m length) | Alligator Cracking, sq m | Flushing, sq m | Rutting, mm | |
|---|---|---|---|---|
| | | | Left Wheelpath | Right Wheelpath |
| 1 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 2 | 2 |
| 4 | 0 | 0 | 3 | 2 |
| 5 | 0 | 0 | 4 | 4 |
| 6 (1st Coring Attempt Location) | 56 (Slight) | 56 (Slight) | 11 | 12 |
| 7 | 93 (Slight) | 112 (Slight) | 13 | 13 |
| 8 (2nd Coring Attempt Location) | 93 (Slight) | 112 (Slight) | 10 | 10 |
| 9 | 56 (Slight) | 93 (Slight) | 9 | 11 |
| 10 | 0 | 37 (Slight)<br>19 (Moderate) | 4 | 5 |
| 11 | 0 | 56 (Slight) | 3 | 3 |
| 12 | 0 | 0 | 5 | 4 |
| 13 | 0 | 0 | 0 | 2 |

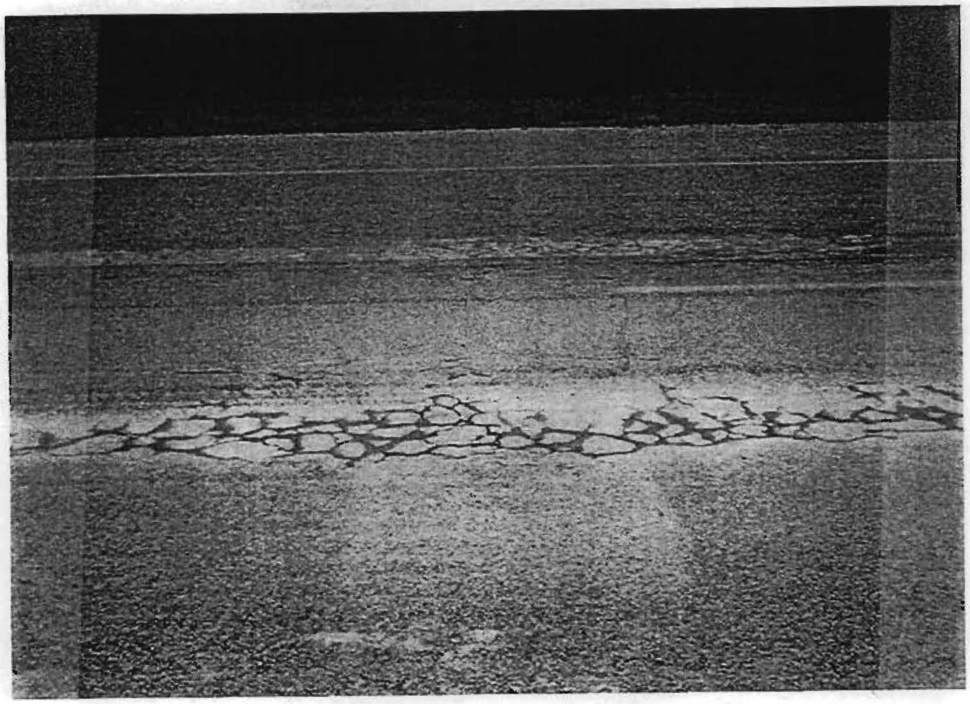

**Figure 2. Alligator Cracking on Loop 390**

**Table 3. IH 20 Frontage Road Distress (April 1997)**

| **Location (each location represents a 60 m length)** | **Raveling, sq m** |
|---|---|
| 1<br>Core Location 1 | 4 (slight) |
| 2<br>Core Location 2 | 5 (slight) |
| 3<br>Core Location 3 | 4 (slight) |

**SH 154**

This project is located in Diana beginning 0.16 km east of US 259 and extending to 0.8 km 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 are beginning 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 3.5 to 4 m) and might be attributable to shrinkage of the fly ash base. A summary of the distress is shown in Table 4 below.

**Table 4. SH 154 Distress (April 1997)**

| Location (beginning at east end of project) | Transverse Cracking in westbound lane, linear m | Longitudinal Cracking in westbound lane, linear m |
|---|---|---|
| 0 - 60 m (1st core location) | 1.8 (slight) | 0 |
| 60 - 120 m | 7.3 (slight) | 0 |
| 120 - 180 m | 3.6 (slight) | 0 |
| 180 - 240 m | 5.2 (slight) | 0 |
| 240 - 300 m | 2.4 (slight) | 2.4 (slight) |
| 300 -360 m | 11.6 (slight) | 17.0 (slight) |
| 360 - 420 m | 1.8 (slight) | 0 |
| 420 - 480 m | 0 | 0 |
| 480 - 540 m | 0 | 0 |
| 540 - 600 m | 8.0 (moderate) | 6.7 (moderate) |

**FM 1326**

The FM 1326 project begins about 4.8 km north of US 82. It was constructed by district maintenance forces and is about 120 m in length. The entire length of pavement (both lanes) was evaluated visually. No distress of any kind was evident in the seal coat surface.

**FM 1520**

The FM 1520 project is located in Camp County and begins 0.16 km east of Pickett Spring Branch extending to FM 1521. Its total length is about 2400 m. This project was visually evaluated at eight locations as shown below in Table 5.

**Table 5. FM 1520 Distress (April 1997)**

| Location (each location represents a 60 m length) | Flushing, sq m |
|---|---|
| 1 | 93 (slight) |
| 2 | 112 (slight) |
| 3 | 140 (slight) |
| 4<br>Core Location | 30 (slight) |
| 5 | 0 |
| 6 | 0 |
| 7 | 0 |
| 8 | 0 |

**FM 560**

The FM 560 project is located near Hooks and begins at Barkman Creek and Relief and extends north for 700 m. The primary distress evident on this pavement is a moderate amount of flushing in the wheelpaths. The surface treatment under the hot-mix overlay was constructed using a multi-grade asphalt (10W30) and appears to be flushing through the hot mix to the surface. There was also a very slight amount of cracking in the northbound lane. At about 457 m north of where the project begins (Barkman Creek), four transverse cracks appeared in the center of the northbound lane. Each crack was less than 1 m in length. There was also one longitudinal crack 1.5 m long. The project was evaluated at three locations (60 m length at each location) in the northbound lane. The quantity of distress present at each location is shown below in Table 6.

**Table 6. FM 560 Distress (April 1997)**

| Location (each location represents 60 m in length) | Flushing, sq m | Longitudinal Cracking, linear m | Transverse Cracking, linear m |
|---|---|---|---|
| 1<br>Core Location 1 | 93 (moderate) | 0 | 0 |
| 2<br>Core Location 2 | 14 (moderate)<br>11 (slight) | 1.5 | 3 |
| 3<br>Core Location 3 | 0 | 0 | 0 |

## FIELD CORE AND FALLING WEIGHT DEFLECTOMETER DATA

Attempts were made 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 many cases, the cores were not retrievable. They broke into pieces when attempting to remove them from the pavement or core bit.

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 and L/D ratios varied from 0.76 to 2.2. Adjustment factors were used to facilitate comparing cores of different thickness as shown in Table 7 (Tex 418-A) .

Dynamic cone penetrometer (DCP) testing was attempted on three of the six hydrated fly ash test pavements. A DCP test consists of dropping an 8 kg hammer on a spike with graduated markings. The relationship between the number of blows and depth of penetration is plotted and slope generated. The California Bearing Ratio (CBR) is related to the DCP slope, and Texas Triaxial Classification ratings can be derived from CBR values. This test was performed on Loop 390, SH 154 and IH 20 frontage road. Penetration of the DCP through the hydrated fly ash bases was almost impossible. Penetration rates on all three pavements averaged 0.5 mm per blow of the DCP hammer. Correlations only exist for as little as 3 mm/blow and greater. The fly ash pavements had a very low penetration which would correspond to a very high CBR value of 100%+ and an excellent Texas Triaxial Classification of 1+. Since penetration of the DCP was almost negligible in the fly ash bases, this testing was not continued on the other three pavements.

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 which non-destructively measures stiffness and relative deflection of the various layers of a pavement system. A load which simulates a truck load is applied to the pavement through a 305 mm 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 14. Of particular interest for this project is the moduli values for the base (E2). TTI experience has shown that for stabilized bases, moduli values between 1000 and 3500 MPa are optimum in terms of field performance. Bases with moduli values between 3500 and 7000 MPa give variable field performance and values above 7000 MPa seem to be too stiff and exhibit transverse/shrinkage cracking. In Figures 3 through 8, the base moduli values are plotted for each test pavement.

Another parameter which should be noted is the ratio of the base to the subgrade (E2/E4). It is desirable (in stabilized bases) for this ratio to be greater than 3. Between 2-3 is marginal and below 2 is considered poor.

For subgrades, moduli values less than 28 are considered poor while good values are those greater than 110.

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

**Loop 390**

No cores were obtained from this pavement. Multiple unsuccessful attempts were made at three locations along the length of the pavement, as well as transversely (between wheelpaths, in wheelpath and on shoulder).

FWD data shown in Table 8 and Figure 3 indicate that the base layer is weak in some areas which also happens to coincide with areas where alligator cracking is observed. Another concern here and on most of the other test pavements is the variability in moduli along the length of the pavement.

**IH 20 Frontage Road**

Three cores were obtained from this pavement but only two were tested as shown in Table 7 (one broke during sample preparation for testing). This pavement exhibited the highest compressive strength at an average of 8075 kPa.

The first four data points and last data point on the FWD (Table 9) show extremely high moduli values for the base material (seemingly uncharacteristic for this material). Therefore, researchers conclude that the data points at each end of the section are another type of pavement so these data points are excluded from Figure 4. The moduli values are not as variable on this pavement but are generally on the border or below that which is desired of at least 1000 MPa; however, this does not correlate with the high compressive strengths of the cores.

**SH 154**

With indications of 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 (Table 10). Base moduli values along the pavement exceed 7000 MPa in some locations. Also note the variability in the moduli values as shown in Figure 5. Average compressive strength of the three field cores was 4090 kPa.

**FM 1326**

One core was obtained from FM 1326 which could be tested and its compressive strength was 3902 kPa. FWD data (Table 11 and Figure 6) indicate some weak spots in the base layer but also some variability.

**FM 1520**

Three cores were obtained from FM 1520 with an average compressive strength of 5147 kPa. FWD data on this pavement also indicates that there are some weak areas where the moduli values drop below the minimum desired value of 1000 MPa, and again, there is variability along the length of the pavement (Table 12 and Figure 7).

**FM 560**

Three cores were obtained from FM 560 with an average compressive strength of 3359 kPa. The base on this pavement has two different thicknesses along its length: 24 cm and 16 cm. 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 8. The data point at station 96.3 is not shown in Figure 8 because it appears that it may not be representative. Moduli values for this pavement do not appear to be as variable as on some of the others; however, the values are lower than the desired minimum of 1000 Mpa.

# Table 7. Unconfined Compressive Strength of Field Cores

**District :** Atlanta **Material :** Hydrated Fly Ash

**Test :** Unconfined Compressive Strength, and Moisture Content

| Sample ID | Sample Date | Sample Dimensions | | | | | Load Adjustment Factor | Failure Load | | Failure Disp. in. | Failure Stress | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Diameter | | Height | | L/D | | Actual | Adjusted | | | |
| | | in | mm | in | mm | Ratio | | lbs | lbs | | psi | kPa |
| 154-1 | 4/23/97 | 6 | 152.4 | 13.19 | 335 | 2.20 | 1.000 | 16367 | 16367 | 0.1055 | 579 | 3991 |
| 154-2 | 4/23/97 | 6 | 152.4 | 11.25 | 286 | 1.88 | 1.000 | 21989 | 21989 | 0.078 | 778 | 5362 |
| 154-3 | 4/23/97 | 6 | 152.4 | 11 | 279 | 1.83 | 1.000 | 11963 | 11963 | 0.0705 | 423 | 2917 |
| IH20-1 | 4/23/97 | 6 | 152.4 | 5.59 | 142 | 0.93 | 0.845 | 38257 | 32327 | 0.085 | 1353 | 9328 |
| IH20-2 | 4/23/97 | 6 | 152.4 | 5.59 | 142 | 0.93 | 0.845 | 27979 | 23642 | 0.1125 | 990 | 6822 |
| IH20-3 | 4/23/97 | 6 | 152.4 | 5.62 | 143 | 0.94 | 0.848 | | 0 | | 0 | 0 |
| 1520-1 | 4/23/97 | 6 | 152.4 | 5.62 | 143 | 0.94 | 0.848 | 22729 | 19275 | 0.0695 | 804 | 5542 |
| 1520-2 | 4/23/97 | 6 | 152.4 | 4.56 | 116 | 0.76 | 0.784 | 18542 | 14537 | 0.0705 | 656 | 4521 |
| 1520-3 | 4/23/97 | 6 | 152.4 | 9.09 | 231 | 1.52 | 0.961 | 22058 | 21198 | 0.142 | 780 | 5378 |
| 560-1 | 5/1/97 | 6 | 152.4 | 5.56 | 141 | 0.93 | 0.845 | 15967 | 13492 | 0.086 | 565 | 3893 |
| 560-2 | 5/1/97 | 6 | 152.4 | 9.19 | 233 | 1.53 | 0.962 | 14013 | 13481 | 0.0795 | 496 | 3417 |
| 560-3 | 5/1/97 | 6 | 152.4 | 9.44 | 240 | 1.57 | 0.965 | 13806 | 13323 | 0.0715 | 488 | 3366 |
| 1326-1 | 5/1/97 | 6 | 152.4 | 5.72 | 145 | 0.95 | 0.852 | 16003 | 13635 | 0.062 | 566 | 3902 |

Note :

No adjustment for L/D between 1.8 and 2.2 c/s area ($in^2$) : 28.27

Adjustment Factors

| | | | | | |
|---|---|---|---|---|---|
| L/D : | 1.75 | 1.50 | 1.25 | 1.00 | 0.75* |
| Factor : | 0.98 | 0.96 | 0.93 | 0.87 | 0.78 |

* Extrapolated

# Table 8. FWD Data Analysis - Loop 390

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

District: 19
County: 103
Highway/Road: LP0390

| | Thickness (cm) | MODULI RANGE (MPa) Minimum | Maximum | Poisson Ratio Values |
|---|---|---|---|---|
| Pavement: | 5.08 | 1,379 | 1,379 | H1: = 0.35 |
| Base: | 25.40 | 207 | 3,448 | H2: = 0.30 |
| Subbase: | 20.32 | 34 | 3,448 | H3: = 0.25 |
| Subgrade: | 387.35 | 103 | | H4: = 0.40 |

| Station | Load | Measured Deflection (μ): | | | | | | | Calculated Moduli values (MPa): | | | | Absolute | Dpth to |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (N) | R1 | R2 | R3 | R4 | R5 | R6 | R7 | SURF(E1) | BASE(E2) | SUBB(E3) | SUBG(E4) | ERR/Sens | Bedrock (m) |
| 0.000 | 57,477 | 286.00 | 188.98 | 108.46 | 64.26 | 41.40 | 30.23 | 21.59 | 1379 | 2231.2 | 127.6 | 223.4 | 5.11 | 47.32 |
| 0.030 | 58,429 | 246.38 | 145.80 | 93.47 | 60.71 | 40.89 | 27.18 | 20.83 | 1379 | 2429.1 | 314.4 | 230.3 | 0.56 | 45.48 |
| 0.061 | 57,633 | 391.67 | 250.70 | 130.81 | 73.66 | 49.28 | 36.32 | 27.69 | 1379 | 1283.2 | 100.0 | 191.7 | 6.74 | 37.81 |
| 0.091 | 54,915 | 481.58 | 360.43 | 233.43 | 152.15 | 98.81 | 69.09 | 53.59 | 1379 | 1717.5 | 44.1 | 97.9 | 3.46 | 52.56 |
| 0.122 | 54,119 | 396.75 | 238.00 | 121.92 | 65.79 | 46.23 | 39.12 | 30.99 | 1379 | 981.8 | 129.6 | 183.4 | 8.58 | 30.82 |
| 0.152 | 56,045 | 480.06 | 321.06 | 145.54 | 80.01 | 53.34 | 37.85 | 31.50 | 1379 | 921.9 | 63.4 | 179.3 | 9.75 | 33.71 |
| 0.183 | 59,790 | 286.00 | 190.25 | 133.86 | 101.09 | 75.69 | 56.90 | 43.18 | 1379 | 2186.4 | 1148.0 | 120.7 | 2.03 | 78.69 |
| 0.213 | 57,441 | 441.45 | 234.95 | 122.94 | 76.96 | 56.39 | 44.20 | 33.53 | 1379 | 767.4 | 236.5 | 166.9 | 6.63 | 90.71 |
| 0.244 | 59,367 | 537.72 | 279.40 | 144.78 | 90.68 | 61.72 | 48.01 | 39.37 | 1379 | 630.2 | 167.5 | 151.7 | 4.65 | 70.19 |
| 0.274 | 53,269 | 821.44 | 478.28 | 260.60 | 154.18 | 99.82 | 71.88 | 55.63 | 1379 | 434.4 | 53.1 | 84.8 | 4.38 | 53.93 |
| 0.305 | 54,702 | 540.26 | 338.07 | 212.60 | 132.33 | 87.38 | 60.20 | 42.16 | 1379 | 923.9 | 87.6 | 98.6 | 1.96 | 57.61 |
| 0.335 | 52,437 | 914.91 | 457.45 | 277.37 | 166.12 | 103.63 | 73.41 | 55.63 | 1379 | 311.7 | 81.4 | 73.8 | 2.01 | 44.29 |
| 0.366 | 55,515 | 461.01 | 238.76 | 131.32 | 82.30 | 57.91 | 43.69 | 37.08 | 1379 | 700.5 | 222.7 | 154.4 | 4.14 | 91.44 |
| 0.396 | 56,859 | 658.11 | 347.98 | 157.23 | 112.52 | 89.41 | 72.64 | 53.09 | 1379 | 414.4 | 219.3 | 108.9 | 11.63 | 55.19 |
| 0.427 | 57,050 | 438.40 | 208.03 | 110.49 | 72.64 | 57.40 | 46.48 | 38.61 | 1379 | 627.4 | 437.8 | 168.9 | 7.99 | 91.44 |
| 0.457 | 55,142 | 511.56 | 277.11 | 144.02 | 91.19 | 63.50 | 45.21 | 37.34 | 1379 | 664.0 | 143.4 | 142.0 | 4.67 | 66.39 |
| 0.488 | 54,808 | 457.71 | 213.87 | 91.95 | 56.39 | 41.66 | 35.56 | 27.69 | 1379 | 564.0 | 197.9 | 213.7 | 8.81 | 35.27 |
| 0.518 | 65,924 | 279.65 | 159.26 | 89.66 | 63.75 | 47.24 | 35.05 | 26.16 | 1379 | 1747.9 | 690.9 | 233.7 | 5.33 | 69.96 |
| 0.549 | 60,902 | 232.16 | 131.32 | 83.06 | 57.91 | 40.39 | 33.02 | 26.92 | 1379 | 2124.3 | 857.7 | 236.5 | 4.04 | 81.57 |
| 0.579 | 56,396 | 451.87 | 284.99 | 184.91 | 124.21 | 83.82 | 60.71 | 45.97 | 1379 | 1163.9 | 187.5 | 103.4 | 1.94 | 66.58 |
| 0.610 | 59,897 | 306.58 | 215.14 | 136.14 | 90.42 | 63.50 | 43.18 | 31.50 | 1379 | 2803.5 | 147.6 | 160.0 | 2.71 | 50.79 |
| 0.640 | 63,326 | 375.16 | 126.75 | 65.28 | 43.69 | 32.51 | 24.89 | 19.05 | 1379 | 624.0 | 1021.1 | 341.3 | 5 | 10.97 |
| 0.671 | 58,024 | 220.47 | 107.19 | 70.36 | 49.02 | 36.58 | 26.42 | 19.30 | 1379 | 1593.4 | 1579.0 | 274.4 | 1.76 | 10.97 |
| 0.701 | 49,577 | 328.17 | 188.98 | 87.12 | 60.71 | 48.26 | 38.35 | 32.00 | 1379 | 912.9 | 327.5 | 180.0 | 11.5 | 67.32 |
| 0.734 | 45,921 | 544.83 | 335.03 | 157.73 | 83.82 | 55.37 | 43.69 | 34.54 | 1379 | 557.1 | 55.8 | 131.7 | 9.18 | 29.83 |
| Mean: | | 443.48 | 252.73 | 139.70 | 88.14 | 61.21 | 45.72 | 35.31 | 1379 | 1172.8395 | 345.4395 | 170.3065 | 5.38 | 52.61 |
| Std. Dev: | | 170.69 | 96.77 | 56.39 | 34.04 | 21.34 | 14.99 | 11.18 | 0 | 721.217 | 399.91 | 64.1235 | 3.17 | 43.88 |
| Var Coeff (%): | | 38.47 | 38.24 | 40.33 | 38.61 | 34.68 | 32.56 | 31.5 | 0 | 61.5 | 100 | 37.6 | 58.91 | 83.41 |

# 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 (cm) | MODULI RANGE (MPa) Minimum | Maximum |
|---|---|---|---|
| Pavement: | 5.08 | 1,379 | 1,379 |
| Base: | 27.94 | 690 | 41,370 |
| Subbase: | 20.32 | 138 | 4,827 |
| Subgrade: | 127.00 | 103 | |

Poisson Ratio Values
H1: = 0.35
H2: = 0.35
H3: = 0.25
H4: = 0.40

| Station (m) | Load (N) | Measured Deflection (μ): R1 | R2 | R3 | R4 | R5 | R6 | R7 | Calculated Moduli values (MPa): SURF(E1) | BASE(E2) | SUBB(E3) | SUBG(E4) | Absolute ERR/Sens | Dpth to Bedrock (m) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 128.930 | 48,603 | 80.52 | 59.94 | 47.75 | 36.83 | 28.19 | 21.59 | 16.76 | 1379 | 33087.0 | 410.3 | 100.0 | 1.34 | 10.97 |
| 201.778 | 50,654 | 66.80 | 47.75 | 36.83 | 28.70 | 22.61 | 17.53 | 13.97 | 1379 | 41370.0 | 317.9 | 146.2 | 2.73 | 7.32 |
| 271.882 | 48,728 | 118.62 | 95.76 | 72.64 | 52.58 | 38.10 | 27.43 | 20.57 | 1379 | 14551.9 | 337.9 | 82.1 | 2.28 | 67.29 |
| 305.714 | 47,740 | 83.82 | 60.96 | 47.24 | 36.83 | 28.70 | 22.86 | 18.29 | 1379 | 29822.3 | 188.2 | 111.0 | 2.06 | 10.97 |
| 365.760 | 47,438 | 234.70 | 131.57 | 86.61 | 63.25 | 48.51 | 36.32 | 27.69 | 1379 | 1135.6 | 4574.1 | 56.5 | 5.5 | 80.32 |
| 427.025 | 49,666 | 186.18 | 95.76 | 61.21 | 47.50 | 38.61 | 30.73 | 26.67 | 1379 | 5814.6 | 333.0 | 111.0 | 18.97 | 91.44 |
| 487.375 | 49,048 | 208.53 | 137.41 | 93.98 | 69.85 | 52.07 | 40.13 | 31.50 | 1379 | 1930.6 | 2953.8 | 53.1 | 5.79 | 91.44 |
| 617.830 | 49,560 | 322.58 | 190.50 | 91.19 | 61.47 | 48.51 | 36.83 | 28.96 | 1379 | 762.6 | 1321.8 | 69.6 | 13.87 | 91.44 |
| 670.560 | 47,949 | 254.00 | 136.14 | 72.90 | 52.83 | 40.39 | 33.02 | 28.19 | 1379 | 897.7 | 3213.1 | 75.8 | 11.19 | 91.44 |
| 731.520 | 48,799 | 306.07 | 181.86 | 90.93 | 59.69 | 46.48 | 37.34 | 30.99 | 1379 | 817.7 | 1396.2 | 69.6 | 13.38 | 91.44 |
| 793.394 | 45,654 | 338.84 | 195.58 | 109.73 | 71.88 | 50.55 | 36.58 | 28.96 | 1379 | 737.8 | 926.7 | 58.6 | 8.01 | 73.05 |
| 853.440 | 47,687 | 274.57 | 139.45 | 80.26 | 56.64 | 42.42 | 31.75 | 24.89 | 1379 | 814.3 | 2689.7 | 72.4 | 8.39 | 90.58 |
| 914.400 | 51,165 | 233.17 | 107.95 | 54.61 | 30.99 | 21.59 | 16.26 | 12.70 | 1379 | 981.2 | 2029.2 | 147.6 | 11.64 | 7.32 |
| 958.901 | 48,781 | 312.67 | 153.42 | 68.58 | 36.32 | 25.15 | 19.81 | 17.78 | 1379 | 714.3 | 747.4 | 121.4 | 16.6 | 10.97 |
| 1021.080 | 47,705 | 67.56 | 40.39 | 26.67 | 18.29 | 13.46 | 10.67 | 9.40 | 1379 | 18706.1 | 753.6 | 285.5 | 6.76 | 4.88 |
| Mean: | | 205.99 | 118.36 | 69.34 | 48.26 | 36.32 | 27.94 | 22.61 | 1379 | 10143.2 | 1479.7 | 104.1 | 8.57 | 21.65 |
| Std. Dev: | | 99.57 | 51.05 | 23.62 | 16.26 | 12.19 | 9.14 | 7.37 | 0 | 14034.8 | 1328.0 | 58.6 | 5.54 | 23.52 |
| Var Coeff (%): | | 48.29 | 43.24 | 33.87 | 33.46 | 33.6 | 32.94 | 32.24 | 0 | 100.0 | 89.8 | 56.7 | 64.63 | 108.66 |

# Table 10. FWD Data Analysis - SH 154

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

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| District: | 19 | | | | MODULI RANGE (MPa) | | | |
| County: | 230 | | | Thickness (cm) | Minimum | Maximum | Poisson Ratio Values | |
| Highway/Road: | | SH0154 | Pavement: | 1.27 | 1,379 | 1,379 | H1: | = 0.35 |
| | | | Base: | 33.02 | 103 | 10,343 | H2: | = 0.30 |
| | | | Subbase: | 0.00 | 0 | 0 | H3: | = 0.25 |
| | | | Subgrade: | 508.00 | 103 | | H4: | = 0.40 |

| Station | Load | Measured Deflection (μ): | | | | | | | Calculated Moduli values (MPa): | | | | Absolute | Dpth to |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (N) | R1 | R2 | R3 | R4 | R5 | R6 | R7 | SURF(E1) | BASE(E2) | SUBB(E3) | SUBG(E4) | ERR/Sens | Bedrock (m) |
| 30.480 | 43,426 | 1057.15 | 557.02 | 212.60 | 115.82 | 75.95 | 55.63 | 43.69 | 1379 | 185.5 | 0.0 | 79.3 | 13.27 | 21.37 |
| 60.960 | 46,909 | 854.20 | 403.86 | 100.58 | 29.72 | 29.46 | 28.70 | 23.88 | 1379 | 202.0 | 0.0 | 162.7 | 38.19 | 7.32 |
| 91.440 | 42,296 | 1359.92 | 647.70 | 201.17 | 78.74 | 56.90 | 54.86 | 39.88 | 1379 | 118.6 | 0.0 | 86.2 | 20.61 | 17.05 |
| 121.920 | 58,696 | 210.31 | 169.16 | 121.67 | 88.90 | 71.12 | 52.58 | 42.16 | 1379 | 4967.2 | 0.0 | 156.5 | 3.63 | 82.88 |
| 148.133 | 60,337 | 160.53 | 124.71 | 96.27 | 70.36 | 53.59 | 40.64 | 32.26 | 1379 | 7175.6 | 0.0 | 206.9 | 2.51 | 91.44 |
| 182.880 | 58,184 | 157.23 | 133.35 | 107.70 | 73.41 | 63.25 | 51.05 | 41.40 | 1379 | 8825.6 | 0.0 | 167.5 | 5.47 | 91.44 |
| 213.360 | 59,986 | 131.32 | 128.52 | 82.80 | 65.53 | 51.56 | 40.39 | 30.48 | 1379 | 10071.5 | 0.0 | 208.9 | 6.85 | 73.65 |
| 243.840 | 58,411 | 161.29 | 135.64 | 108.46 | 83.82 | 66.29 | 51.82 | 39.88 | 1379 | 9149.7 | 0.0 | 158.6 | 2.47 | 84.73 |
| 275.844 | 53,852 | 254.00 | 137.67 | 109.73 | 82.55 | 65.79 | 51.31 | 44.96 | 1379 | 3106.2 | 0.0 | 164.8 | 10.7 | 91.44 |
| 304.800 | 57,335 | 196.60 | 102.62 | 54.61 | 37.59 | 28.70 | 24.38 | 19.05 | 1379 | 2514.6 | 0.0 | 323.4 | 11.1 | 10.97 |
| 335.280 | 54,208 | 216.15 | 153.67 | 122.17 | 95.00 | 73.66 | 55.88 | 45.47 | 1379 | 4956.8 | 0.0 | 140.0 | 3.34 | 91.44 |
| 372.466 | 55,796 | 218.69 | 162.81 | 120.65 | 88.39 | 67.31 | 53.09 | 42.93 | 1379 | 4305.2 | 0.0 | 153.1 | 3 | 91.44 |
| 396.240 | 55,124 | 185.17 | 149.35 | 120.40 | 92.20 | 72.39 | 56.13 | 45.97 | 1379 | 6933.6 | 0.0 | 138.6 | 1.63 | 91.44 |
| 426.720 | 52,122 | 201.93 | 190.25 | 153.92 | 114.55 | 84.07 | 63.50 | 49.02 | 1379 | 5859.4 | 0.0 | 107.6 | 5.78 | 90.79 |
| 458.724 | 56,841 | 95.25 | 74.93 | 62.48 | 49.78 | 61.47 | 42.93 | 39.88 | 1379 | 10342.5 | 0.0 | 286.8 | 18.69 | 55.17 |
| 488.290 | 51,325 | 196.34 | 168.40 | 134.87 | 103.63 | 79.50 | 60.96 | 48.01 | 1379 | 6092.4 | 0.0 | 115.8 | 2.33 | 91.44 |
| 518.160 | 55,249 | 238.51 | 175.01 | 121.41 | 78.74 | 60.20 | 45.47 | 35.81 | 1379 | 2943.5 | 0.0 | 164.1 | 4.25 | 91.44 |
| 548.640 | 55,689 | 227.08 | 163.83 | 115.82 | 84.58 | 63.75 | 49.02 | 37.59 | 1379 | 3642.6 | 0.0 | 162.0 | 3.62 | 84.33 |
| 579.120 | 54,595 | 262.89 | 195.33 | 135.13 | 93.98 | 70.61 | 53.59 | 41.40 | 1379 | 2824.9 | 0.0 | 140.7 | 3.46 | 91.20 |
| 609.600 | 51,962 | 366.52 | 245.62 | 154.94 | 105.16 | 75.69 | 58.67 | 46.48 | 1379 | 1446.6 | 0.0 | 117.2 | 4.26 | 91.44 |
| 637.946 | 57,477 | 358.39 | 201.42 | 124.71 | 83.06 | 56.64 | 41.66 | 32.51 | 1379 | 1385.2 | 0.0 | 159.3 | 4.16 | 69.80 |
| Mean: | | 338.58 | 210.57 | 121.92 | 81.79 | 63.25 | 49.28 | 39.12 | 1379 | 4621.7 | 0.0 | 162.0 | 8.06 | 65.08 |
| Std. Dev: | | 330.71 | 146.30 | 37.59 | 22.35 | 14.22 | 9.91 | 7.87 | 0 | 3242.7 | 0.0 | 57.9 | 8.73 | 84.94 |
| Var Coeff (%): | | 97.71 | 69.46 | 30.8 | 27.33 | 22.41 | 20.12 | 19.96 | 0 | 70.2 | 0.0 | 35.8 | 108.27 | 130.50 |

# Table 11. FWD Data Analysis - FM 1326

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

District: 19
County: 32
Highway/Road: FM1326

| | Thickness (cm) | MODULI RANGE (MPa) Minimum | Maximum |
|---|---|---|---|
| Pavement: | 1.27 | 1,379 | 1,379 |
| Base: | 13.97 | 138 | 5,516 |
| Subbase: | 20.32 | 28 | 1,241 |
| Subgrade: | 243.33 | 103 | |

Poisson Ratio Values
H1: = 0.35
H2: = 0.30
H3: = 0.35
H4: = 0.40

| Station | Load | Measured Deflection (μ): | | | | | | | Calculated Moduli values (MPa): | | | | Absolute | Dpth to |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (N) | R1 | R2 | R3 | R4 | R5 | R6 | R7 | SURF(E1) | BASE(E2) | SUBB(E3) | SUBG(E4) | ERR/Sens | Bedrock (m) |
| 0.000 | 46,677 | 1117.35 | 565.91 | 241.30 | 123.19 | 84.84 | 67.82 | 56.13 | 1379 | 446.8 | 83.4 | 63.4 | 8.6 | 27.16 |
| 15.240 | 51,979 | 410.21 | 299.21 | 166.12 | 97.28 | 60.20 | 42.42 | 32.51 | 1379 | 4499.7 | 289.6 | 96.5 | 4.2 | 40.39 |
| 30.480 | 53,394 | 373.13 | 285.50 | 191.01 | 108.71 | 73.15 | 50.80 | 36.83 | 1379 | 5516.0 | 544.0 | 83.4 | 4.86 | 41.78 |
| 45.720 | 51,962 | 370.08 | 279.40 | 169.67 | 108.97 | 76.71 | 57.91 | 41.91 | 1379 | 3295.8 | 817.7 | 85.5 | 5.68 | 91.44 |
| 61.265 | 50,832 | 460.25 | 293.88 | 150.11 | 88.14 | 57.66 | 42.42 | 33.78 | 1379 | 2029.9 | 320.6 | 106.9 | 4.8 | 50.93 |
| 76.200 | 51,819 | 557.28 | 373.13 | 214.38 | 122.17 | 77.98 | 57.40 | 45.47 | 1379 | 2106.4 | 287.5 | 77.2 | 3.67 | 42.83 |
| 91.135 | 49,964 | 567.94 | 358.90 | 187.96 | 99.82 | 61.72 | 45.47 | 36.07 | 1379 | 1820.3 | 199.3 | 88.9 | 3.21 | 29.99 |
| 106.680 | 46,748 | 1085.60 | 578.87 | 268.22 | 123.70 | 74.68 | 54.36 | 41.40 | 1379 | 624.7 | 64.8 | 62.7 | 3.39 | 22.12 |
| 121.920 | 44,364 | 1882.90 | 667.51 | 170.69 | 92.71 | 71.12 | 56.64 | 46.23 | 1379 | 155.1 | 33.1 | 78.6 | 14.14 | 19.33 |
| Mean: | | 758.19 | 411.48 | 195.58 | 107.19 | 70.87 | 52.83 | 41.15 | 1379 | 2277.4 | 293.0 | 82.7 | 5.84 | 33.48 |
| Std. Dev: | | 510.79 | 150.62 | 38.86 | 13.72 | 9.14 | 8.38 | 7.37 | 0 | 1849.2 | 253.0 | 14.5 | 3.52 | 13.86 |
| Var Coeff (%): | | 67.35 | 36.81 | 19.83 | 12.7 | 12.92 | 15.89 | 18.08 | 0 | 81.2 | 86.2 | 17.4 | 60.2 | 41.38 |

# Table 12. FWD Data Analysis - FM 1520

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

| | | | | MODULI RANGE (MPa) | | | |
|---|---|---|---|---|---|---|---|
| District: | 19 | | | | | | |
| County: | 32 | | Thickness (cm) | Minimum | Maximum | Poisson Ratio Values | |
| Highway/Road: | FM1520 | Pavement: | 1.27 | 1,379 | 1,379 | H1: | = 0.35 |
| | | Base: | 25.40 | 138 | 2,758 | H2: | = 0.30 |
| | | Subbase: | 20.32 | 28 | 1,034 | H3: | = 0.25 |
| | | Subgrade: | 373.89 | 103 | | H4: | = 0.40 |

| Station | Load | Measured Deflection (μ): | | | | | | | Calculated Moduli values (MPa): | | | | Absolute | Dpth to |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (N) | R1 | R2 | R3 | R4 | R5 | R6 | R7 | SURF(E1) | BASE(E2) | SUBB(E3) | SUBG(E4) | ERR/Sens | Bedrock (m) |
| 183.185 | 59,474 | 478.03 | 258.57 | 124.97 | 105.66 | 82.04 | 55.63 | 47.24 | 1379 | 983.2 | 323.4 | 133.8 | 12.39 | 91.44 |
| 365.760 | 54,595 | 381.51 | 224.79 | 129.29 | 91.19 | 67.31 | 43.69 | 38.86 | 1379 | 1303.8 | 326.8 | 134.5 | 4.65 | 42.28 |
| 609.600 | 46,379 | 1399.79 | 781.05 | 305.82 | 160.27 | 106.93 | 83.06 | 71.88 | 1379 | 215.1 | 27.6 | 66.9 | 11.01 | 24.06 |
| 731.520 | 57,424 | 549.66 | 262.64 | 146.81 | 87.88 | 67.06 | 43.69 | 43.94 | 1379 | 695.7 | 235.1 | 142.7 | 5.33 | 59.02 |
| 914.705 | 52,989 | 405.38 | 304.04 | 195.33 | 114.30 | 70.10 | 48.01 | 36.32 | 1379 | 2491.9 | 31.0 | 162.7 | 3.02 | 39.44 |
| 1097.280 | 52,864 | 798.83 | 415.04 | 203.71 | 111.51 | 83.82 | 64.01 | 57.15 | 1379 | 472.3 | 82.1 | 106.2 | 7.46 | 34.10 |
| 1269.492 | 55,231 | 426.72 | 157.99 | 78.23 | 54.86 | 35.81 | 28.70 | 21.84 | 1379 | 797.8 | 289.6 | 220.6 | 15.23 | 91.44 |
| 1463.345 | 59,029 | 616.20 | 291.08 | 166.12 | 99.31 | 86.61 | 74.17 | 59.18 | 1379 | 672.3 | 229.6 | 123.4 | 12.74 | 58.94 |
| 1645.920 | 60,813 | 986.28 | 629.92 | 266.19 | 138.43 | 87.12 | 51.82 | 42.42 | 1379 | 567.5 | 27.6 | 135.8 | 7.89 | 28.25 |
| 1828.800 | 53,536 | 367.79 | 250.70 | 163.32 | 104.90 | 70.36 | 48.01 | 33.78 | 1379 | 2222.3 | 100.0 | 130.3 | 0.6 | 53.04 |
| 1996.745 | 54,452 | 230.12 | 147.32 | 109.98 | 80.77 | 61.72 | 47.50 | 38.10 | 1379 | 2758.0 | 581.2 | 153.8 | 9.37 | 91.44 |
| 2195.170 | 51,063 | 406.40 | 233.68 | 135.38 | 87.38 | 62.23 | 43.18 | 36.32 | 1379 | 1132.8 | 213.7 | 134.5 | 3.24 | 56.95 |
| 2379.878 | 50,498 | 610.87 | 390.40 | 223.01 | 125.48 | 75.69 | 51.31 | 35.31 | 1379 | 1006.0 | 37.9 | 120.0 | 1.38 | 37.91 |
| 2560.320 | 53,678 | 287.53 | 171.70 | 121.16 | 83.82 | 57.91 | 41.40 | 28.19 | 1379 | 1838.9 | 768.8 | 131.7 | 2.94 | 49.32 |
| Mean: | | 567.44 | 322.83 | 169.16 | 103.38 | 72.39 | 51.82 | 42.16 | 1379 | 1225.2 | 233.7 | 135.1 | 6.95 | 50.50 |
| Std. Dev: | | 312.93 | 181.86 | 63.25 | 26.42 | 16.76 | 13.97 | 13.21 | 0 | 795.7 | 220.6 | 33.1 | 4.64 | 22.25 |
| Var Coeff (%): | | 55.14 | 56.35 | 37.43 | 25.56 | 23.20 | 27.00 | 31.17 | 0 | 64.9 | 94.3 | 24.5 | 66.78 | 44.07 |

# Table 13. FWD Data Analysis - FM 560

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

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| District: | 19 | | | | MODULI RANGE (MPa) | | | |
| County: | 32 | | | Thickness (cm) | Minimum | Maximum | Poisson Ratio Values | |
| Highway/Road: | FM0560 | | Pavement: | 5.08 | 1,379 | 1,379 | H1: | = 0.35 |
| | | | Base: | 16.51 | 138 | 2,758 | H2: | = 0.30 |
| | | | Subbase: | 15.24 | 28 | 1,034 | H3: | = 0.35 |
| | | | Subgrade: | 690.63 | 103 | | H4: | = 0.40 |

| Station | Load | Measured Deflection (µ): | | | | | | | Calculated Moduli values (MPa): | | | | Absolute | Dpth to |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (N) | R1 | R2 | R3 | R4 | R5 | R6 | R7 | SURF(E1) | BASE(E2) | SUBB(E3) | SUBG(E4) | ERR/Sens | Bedrock (m) |
| 30.480 | 45,089 | 828.04 | 543.81 | 323.85 | 208.28 | 149.10 | 111.51 | 87.63 | 1379 | 654.3 | 90.3 | 56.5 | 2.96 | 91.44 |
| 96.317 | 48,639 | 138.43 | 121.16 | 106.43 | 89.92 | 75.18 | 60.71 | 49.02 | 1379 | 6895.0 | 4826.5 | 155.1 | 15.42 | 91.44 |
| 137.160 | 46,557 | 709.68 | 444.25 | 258.06 | 167.89 | 116.84 | 85.34 | 67.82 | 1379 | 729.5 | 106.2 | 74.5 | 1.88 | 91.19 |
| 184.709 | 45,565 | 627.38 | 413.51 | 280.92 | 186.18 | 123.70 | 88.65 | 68.83 | 1379 | 1043.9 | 179.3 | 66.9 | 1.55 | 65.40 |
| 231.038 | 43,995 | 700.79 | 448.31 | 280.16 | 179.07 | 119.89 | 85.34 | 65.28 | 1379 | 800.5 | 97.9 | 66.9 | 0.4 | 71.45 |
| 274.320 | 44,929 | 438.40 | 296.93 | 204.72 | 136.91 | 94.23 | 66.29 | 50.80 | 1379 | 1769.9 | 300.6 | 89.6 | 1.15 | 65.25 |
| 320.345 | 44,258 | 455.42 | 257.81 | 158.75 | 109.47 | 81.03 | 62.48 | 49.53 | 1379 | 654.3 | 600.6 | 108.9 | 3.27 | 91.44 |
| 365.760 | 44,311 | 364.49 | 201.42 | 117.86 | 80.26 | 60.96 | 49.28 | 41.40 | 1379 | 861.9 | 604.7 | 148.2 | 4.87 | 91.44 |
| Mean: | | 532.89 | 340.87 | 216.41 | 144.78 | 102.62 | 76.20 | 59.94 | 1379 | 1676.2 | 850.8 | 95.8 | 3.94 | 87.29 |
| Std. Dev: | | 225.04 | 144.02 | 81.79 | 47.75 | 29.72 | 20.07 | 14.99 | 0 | 2140.2 | 1620.3 | 37.9 | 4.85 | 21.85 |
| Var Coeff (%): | | 42.23 | 42.25 | 37.78 | 32.96 | 28.84 | 26.34 | 25.11 | 0 | 100.0 | 100.0 | 39.8 | 123.07 | 25.02 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| District: | 19 | | | | MODULI RANGE (MPa) | | | |
| County: | 32 | | | Thickness (cm) | Minimum | Maximum | Poisson Ratio Values | |
| Highway/Road: | FM0560 | | Pavement: | 5.08 | 1,379 | 1,379 | H1: | 3/4 = 0.35 |
| | | | Base: | 24.13 | 138 | 2,758 | H2: | 3/4 = 0.30 |
| | | | Subbase: | 8.89 | 28 | 1,034 | H3: | 3/4 = 0.35 |
| | | | Subgrade: | 505.97 | 103 | | H4: | 3/4 = 0.40 |

| Station | Load | Measured Deflection (µ): | | | | | | | Calculated Moduli values (MPa): | | | | Absolute | Dpth to |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (m) | (N) | R1 | R2 | R3 | R4 | R5 | R6 | R7 | SURF(E1) | BASE(E2) | SUBB(E3) | SUBG(E4) | ERR/Sens | Bedrock (m) |
| 411.480 | 44,613 | 278.89 | 179.32 | 118.87 | 81.79 | 61.21 | 49.02 | 40.39 | 1379 | 1406.6 | 1586.5 | 130.3 | 3.88 | 91.44 |
| 457.200 | 44,983 | 342.65 | 229.62 | 149.35 | 103.63 | 76.71 | 58.42 | 48.01 | 1379 | 1307.3 | 705.4 | 102.7 | 3.75 | 91.44 |
| 503.225 | 45,036 | 490.73 | 268.73 | 141.99 | 91.69 | 69.09 | 53.34 | 41.66 | 1379 | 550.2 | 213.7 | 119.3 | 6.34 | 91.44 |
| 549.859 | 45,089 | 312.67 | 137.92 | 58.67 | 43.69 | 39.62 | 33.27 | 29.21 | 1379 | 615.0 | 1262.5 | 245.5 | 14.33 | 32.24 |
| 594.055 | 44,275 | 413.51 | 225.04 | 118.87 | 75.18 | 52.83 | 41.15 | 33.78 | 1379 | 690.2 | 146.9 | 148.2 | 4.18 | 91.44 |
| 640.080 | 45,232 | 425.96 | 238.51 | 139.70 | 87.38 | 60.96 | 45.72 | 36.07 | 1379 | 759.8 | 171.0 | 131.0 | 2.55 | 90.93 |
| 685.495 | 43,906 | 720.09 | 397.76 | 189.99 | 103.38 | 74.93 | 67.82 | 35.05 | 1379 | 351.6 | 35.2 | 98.6 | 8.53 | 33.57 |
| Mean: | | 426.47 | 239.52 | 131.06 | 83.82 | 62.23 | 49.78 | 37.85 | 1379 | 811.5 | 588.8 | 139.3 | 6.2 | 65.29 |
| Std. Dev: | | 148.59 | 81.79 | 39.88 | 20.57 | 12.95 | 11.43 | 6.10 | 0 | 395.1 | 616.4 | 49.6 | 4.1 | 40.94 |
| Var Coeff (%): | | 34.82 | 34.15 | 30.42 | 24.54 | 20.96 | 22.84 | 16.27 | 0 | 48.7 | 100.0 | 35.8 | 65.74 | 62.71 |

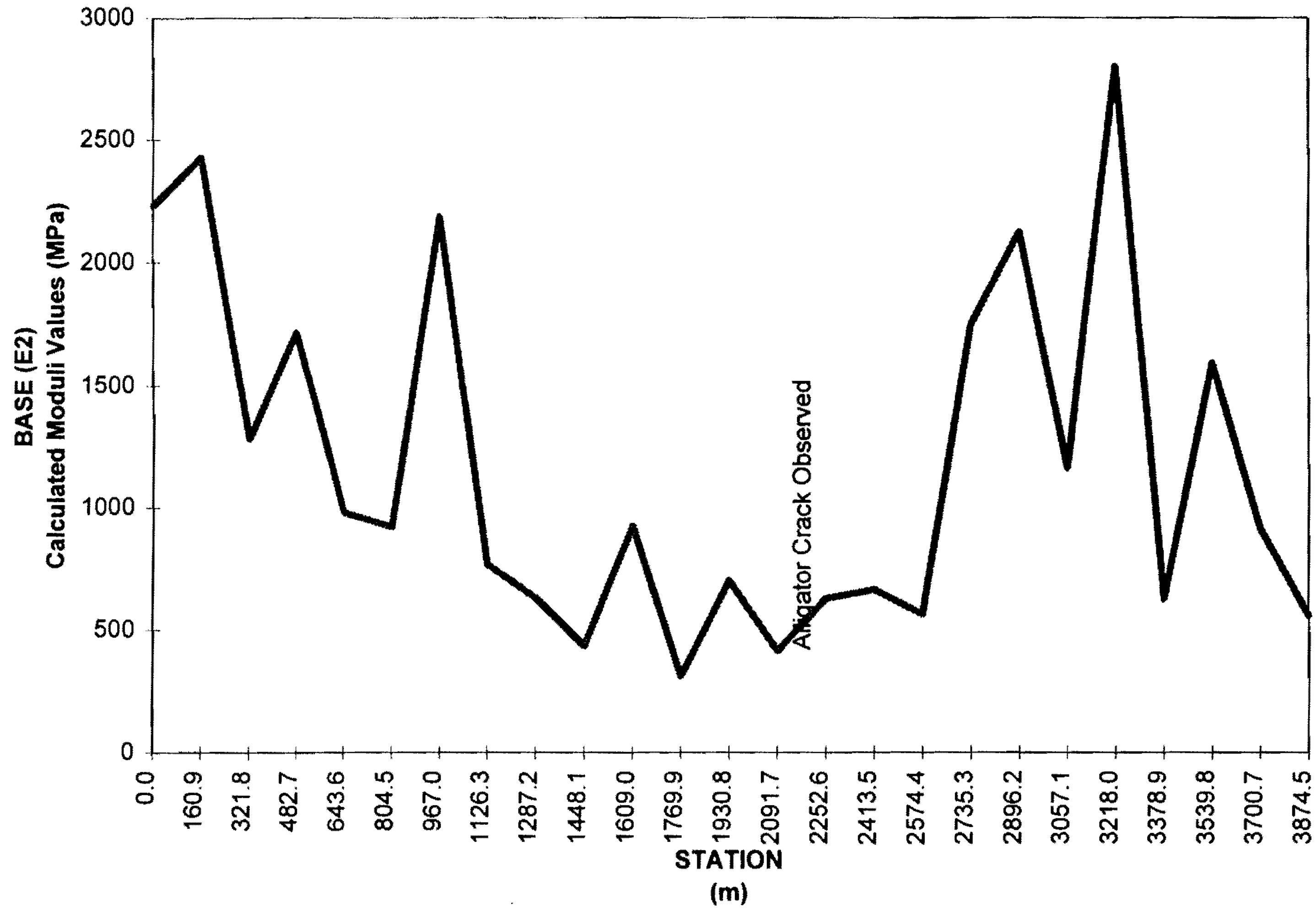


Figure 3. Base Moduli Values for Loop 390

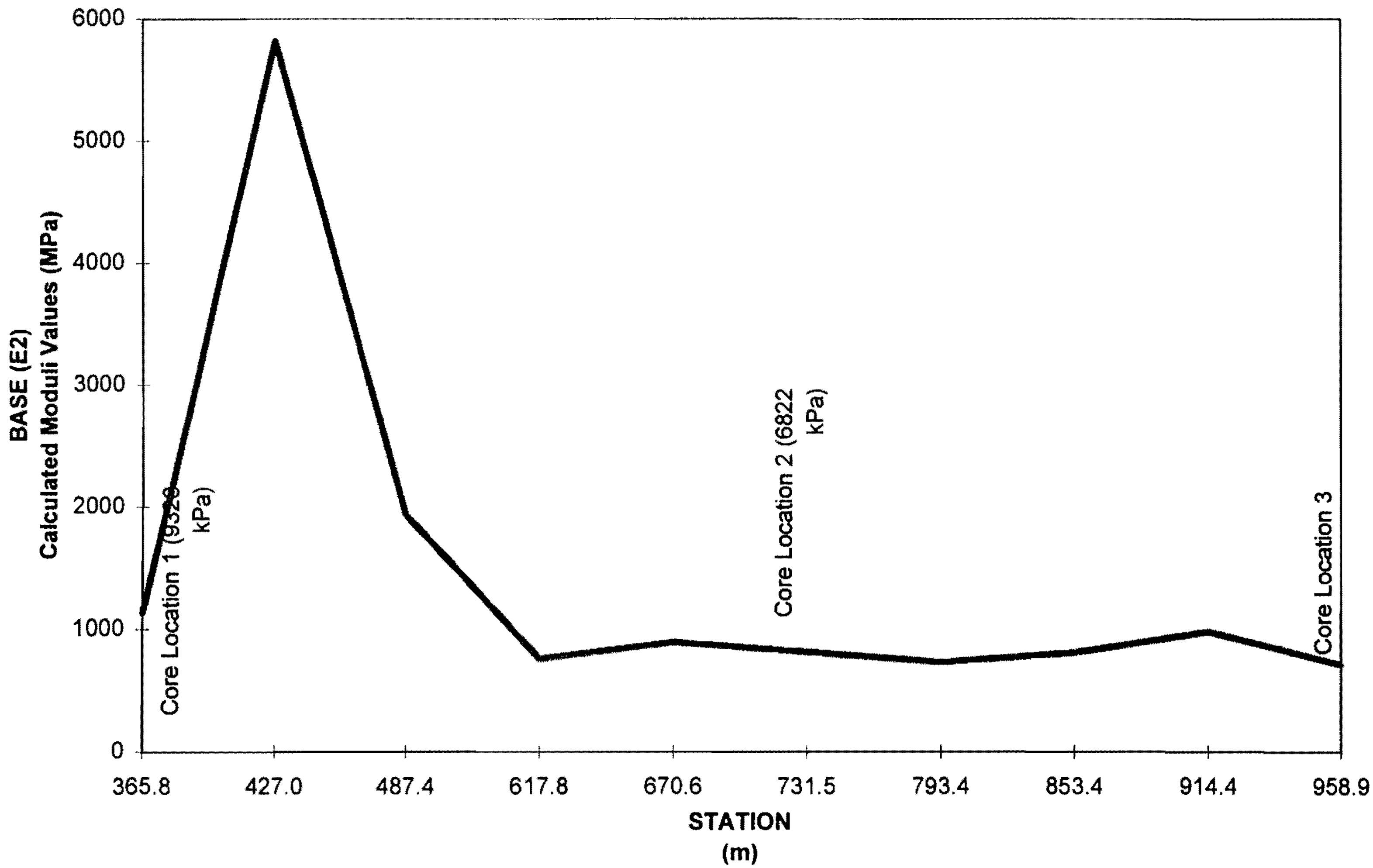


**Figure 4. Base Moduli Values for IH 20 Frontage Road**

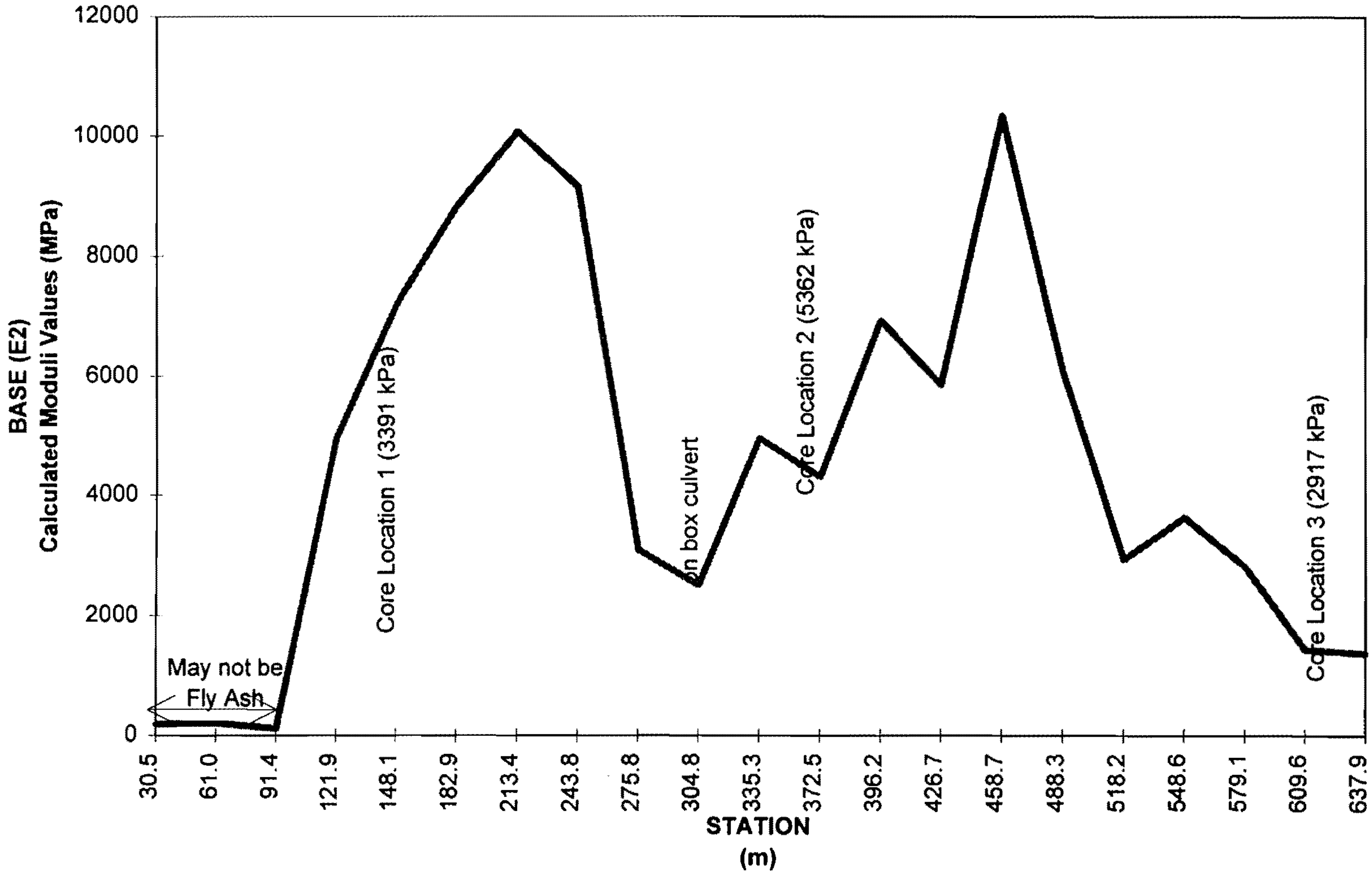


**Figure 5. Base Moduli Values for SH 154**

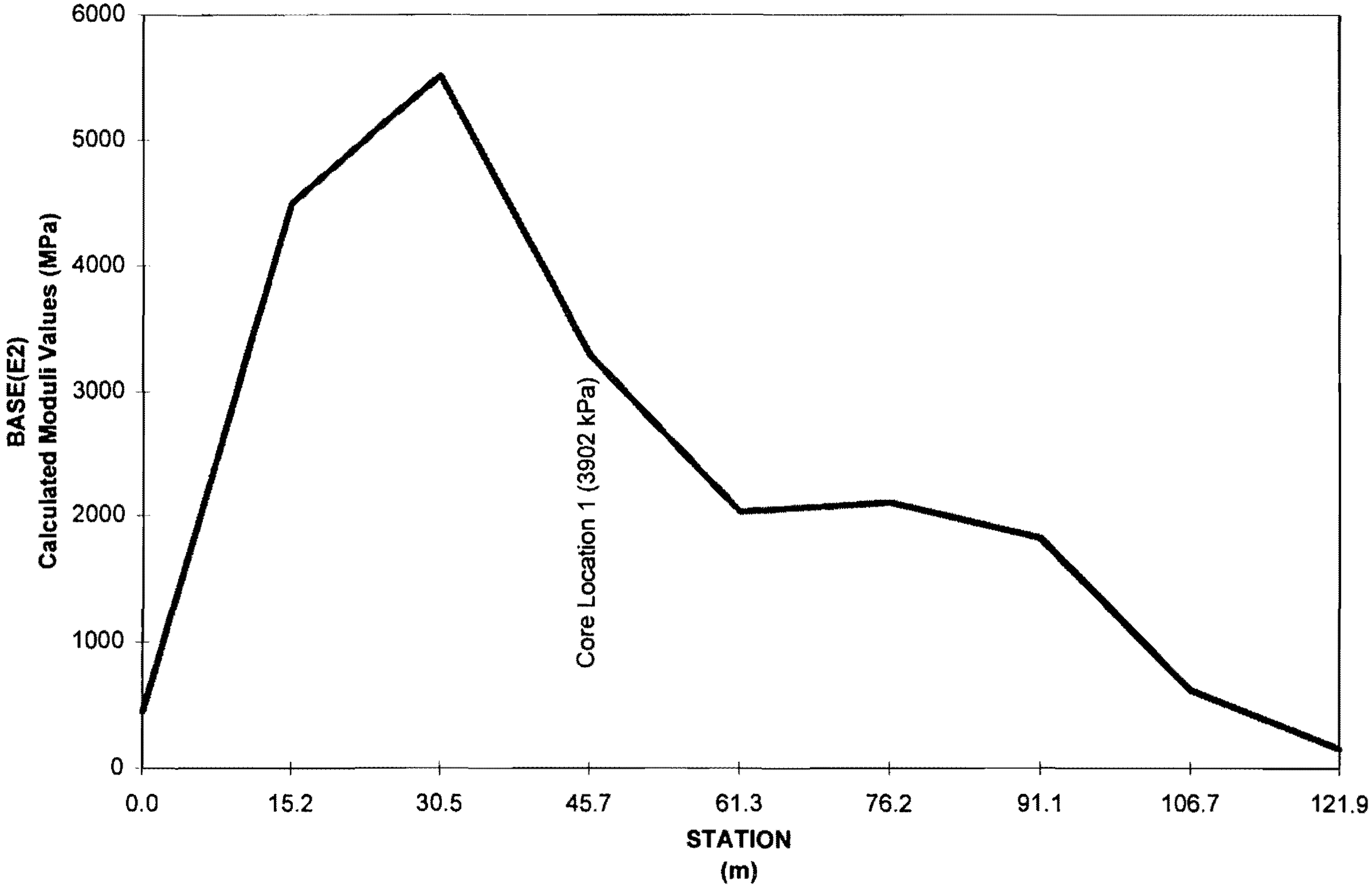


**Figure 6. Base Moduli Values for FM 1326**

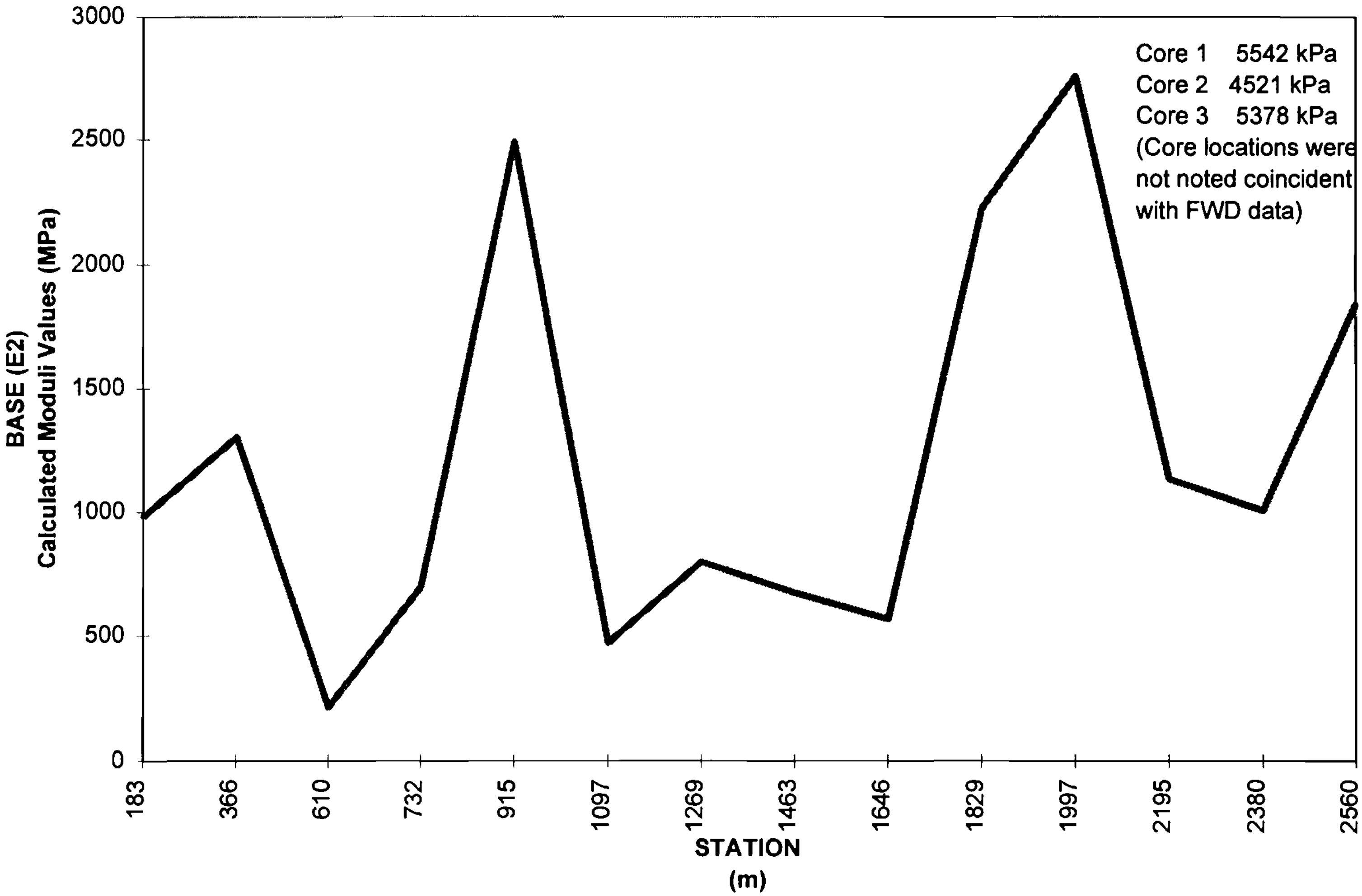


**Figure 7. Base Moduli Values for FM 1520**

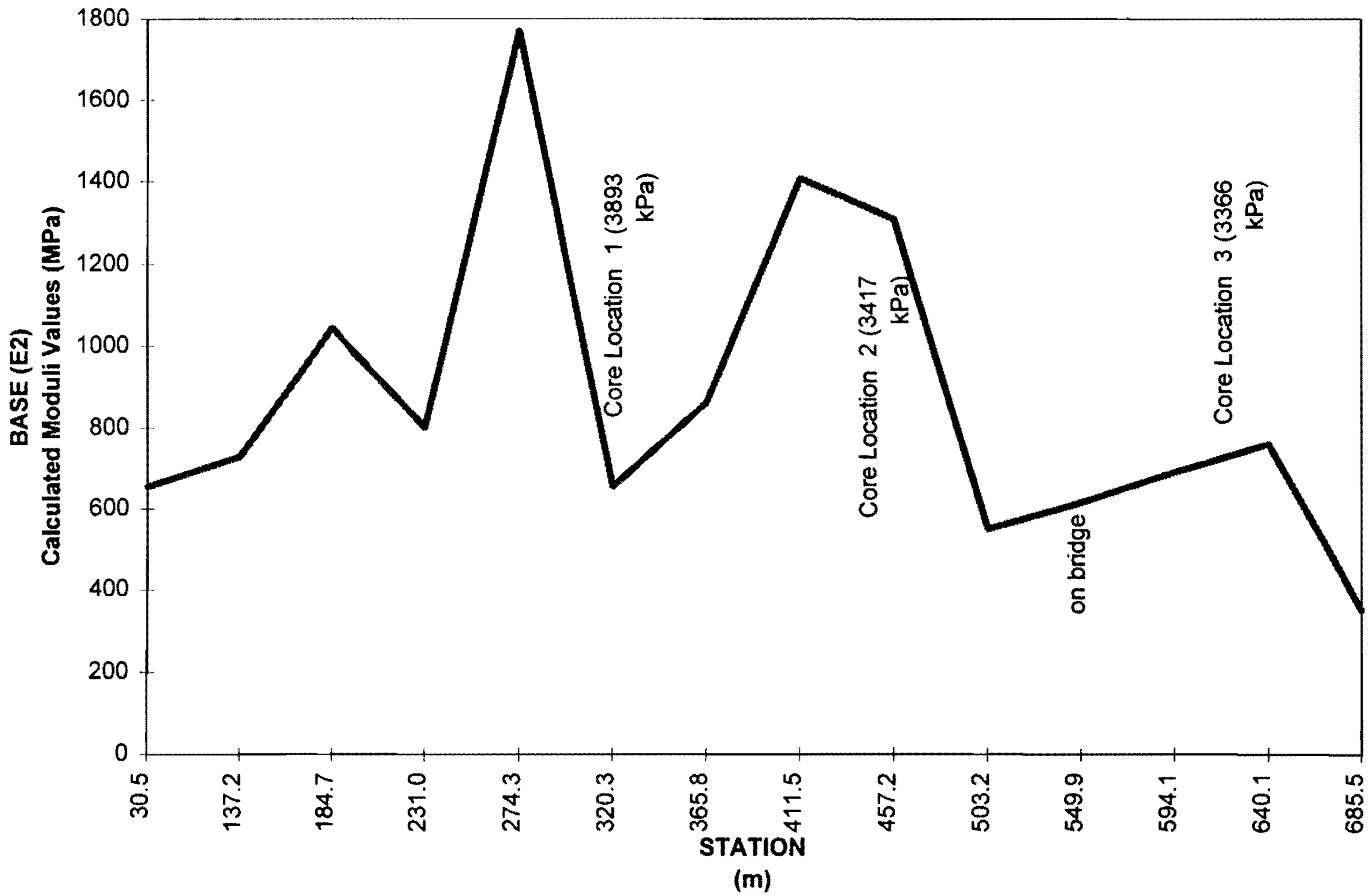


**Figure 8. Base Moduli Values for FM 560**

# SUMMARY

- Most of the hydrated fly ash test pavement are performing very well at this time. Those pavements which have distress are in isolated areas and the distress is not affecting the serviceability of the roadway.
- Two of the six hydrated fly ash test pavements are exhibiting distress which might be attributable to deficiencies in the fly ash base material. Loop 390 is exhibiting a small amount of alligator cracking in an area where the FWD data indicates the base is weak. SH 154 is exhibiting transverse cracking (which appears to be from shrinkage of the base) and the FWD data indicates this pavement is excessively stiff.
- While four of the test pavements are not exhibiting any base-related distress, some of the FWD data indicate that the bases are weaker than that typically desired of a stabilized material (as weak as the section of Loop 390 where alligator cracking is observed).
- Concern is warranted regarding the fly ash material variability as exhibited in moduli values from FWD data. There is variability along a single pavement length, as well as between different pavements (i.e., SH 154 is much stiffer overall than any other pavement). This variability is evident in Figure 9. Reasons for this variability are unknown but should be investigated. The material may have been inconsistent in its *as-received* condition, or the effect of the fly ash as a stabilizer may be deteriorating over time (perhaps due to water infiltrating the base in certain areas).
- Hydrated fly ash is a new material and is different from other stabilized base materials. Given this fact, it may not be appropriate to apply FWD criteria to this material as the researchers are attempting to do in this report. The moduli values for some of these pavements appear to be low when compared with criteria for stabilized bases; however, for this material and its respective traffic conditions, these values may be acceptable (since the pavements are performing very well). This will be evident as performance is monitored over the next four years with successive FWD testing.

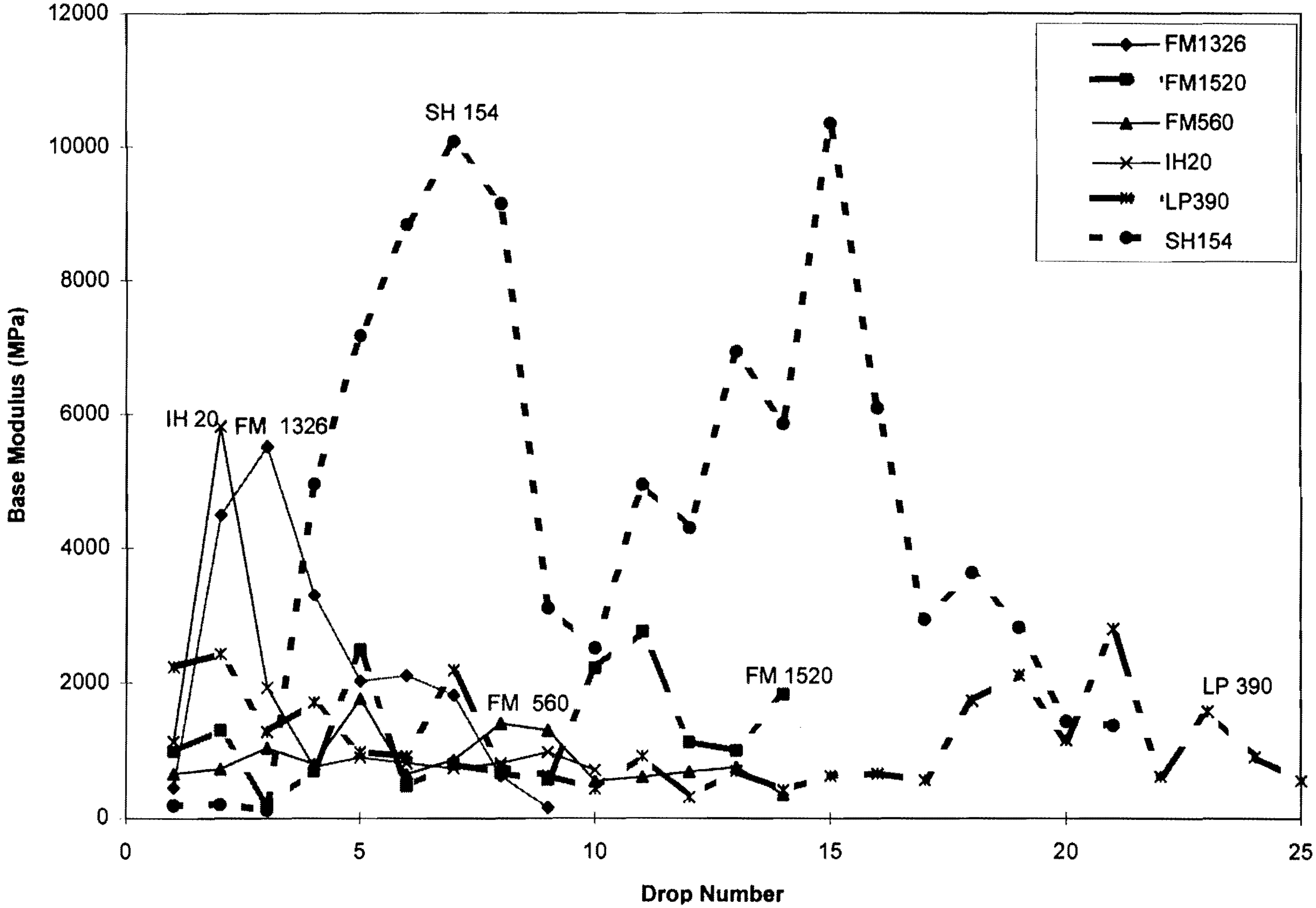


**Figure 9. Base Moduli Values for All 6 Pavement Sections.**

# RECOMMENDATIONS

Overall, the hydrated fly ash test pavements are performing very well; however, some of the data as discussed above is worthy of concern. The researchers recommend that the Atlanta District continue the current course of action: monitoring the performance of these pavements over the next few years. FWD data collection should continue as a part of the monitoring program since it provides a non-destructive tool to watch for changes that may be occurring in the base yet are not manifested on the surface.

It is also recommended that this year's monitoring program employ the use of ground penetrating radar (GPR) on all six test pavements. It is possible that the reason for the moduli variation in the base materials is due to the presence of water in the base which is causing a *weakening* of that layer. If so, this will be revealed through GPR. This additional work will not require any new allocation of research funds.

# REFERENCES


1. Nash, P. T., P. Jayawickrama, S. Senadheera, J. Borrelli, and A. Ashek Rana, 1995. *Guidelines for Using Hydrated Fly Ash as a Flexible Base,* Research Report 0-1365-1F, College of Engineering, Texas Tech University, Lubbock.

2. *Distress Identification Manual for the Long-Term Pavement Performance Project*, 1993. Report SHRP-P-338, Strategic Highway Research Program, National Research Council, Washington, D.C.