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Pavement Testing Facility: Design and Construction

Pennsylvania Transportation Inst., University Park

Prepared for:

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16. Abstract

The U.S. Accelerated Loading Facility (ALF), a full-scale accelerated pavement testing machine, has been installed at the Pavement Testing Facility (PTF) at the Turner-Fairbank Highway Research Center (TFHRC). This report describes the design and construction of the two PTF test pavements, the materials used in their construction, and the associated pavement instrumentation and data acquisition system. The two test pavements contain hot-mix asphalt concrete with a crushed-aggregate base. The pavements were designed to carry 250,000 and 3,500,000 18-kip ESAL. Instrumentation was designed to automatically record pavement deflection, strain, temperature, surface profile, and wheel load. Software modules to acquire, reduce, and store the data in standard computer file format were developed.

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Pavement Testing Facility--
Design and Construction

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

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1. INTRODUCTION

In May 1984, the Federal Highway Administration (FHWA) sponsored a Pavement Testing Conference to assess the adequacy of existing pavement data and testing methods, identify current and future pavement data needs, and develop a National Pavement Testing Program.[1] One of the recommendations that received a high priority at the workshop was the development of a capability for accelerated pavement testing using a mobile, linear-tracking, accelerated loading device.

In response to the conference recommendation, the FHWA undertook the development of a Pavement Test Facility (PTF) at the Turner-Fairbank Highway Research Center (TFHRC). The main component of the recommended facility was a full-scale accelerated pavement-testing machine similar to the device operated by the Australian Road Research Board.[2] According to the FHWA research plan, the U.S. version of the Accelerated Loading Facility (ALF) was to be evaluated initially on two test pavements constructed at TFHRC, with further evaluation to be conducted later on field pavement test sections.

In the summer of 1985, the FHWA contracted with Engineering Incorporated Services Co., Hampton, Virginia, to "shake down" and operate the ALF machine. The Pennsylvania Transportation Institute (PTI) was to provide pavement engineering services for the ALF testing program under a contract with EISC. This report documents the work performed by PTI under the first phase of the project. The design of the pavement test sections is discussed in chapter 2. Details regarding the pavement instrumentation and data acquisition are given in chapter 3. In chapter 4, the characterization of the materials used in the construction of the pavement is presented. Also discussed in chapter 4 are the placement of the instrumentation and the deflection measurements obtained during construction. A tentative laboratory and pavement testing schedule is presented in chapter 5.

2. DESIGN OF TEST PAVEMENTS

SITE LAYOUT

The site plan (figure 1) for the Pavement Testing Facility was developed by an architectural firm as part of a separate contract. Two asphalt concrete test pavements, each 13 ft (4.0 m) wide and 200 ft (61 m) long, were designed by engineers from the Pennsylvania Transportation Institute (PTI). Detailed drawings for the two test pavements are given in figures 2 and 3. The two test pavements are similar in construction; each contains an asphalt concrete wearing and binder layer and a crushed-aggregate base course placed on a prepared subgrade. The two pavements differ in thickness as shown in figures 2 and 3. The two test pavements are separated by a 13.5-ft-wide (4.11-m) median. Both test lanes have a longitudinal slope of 0.5 percent and a cross slope of 0.015 ft/ft (0.015 m/m) to facilitate surface drainage. The plans provide for a paved shoulder on the outside of each test lane to facilitate surface drainage and to provide an all-weather working platform.

PAVEMENT DESIGN

The pavement was designed to provide a stable working platform for the ALF testing machine during the shakedown testing and to provide test sections which would carry a realistic number of load applications before failure. Consequently, two pavement cross sections were selected. Lane 1 was designed to fail in a short period of time (250,000 equivalent single-axle loads (ESAL), while Lane 2 was designed to sustain a much larger number of axle loads (3,500,000 ESAL).

The AASHTO Guide for Design of Pavement Structures, 1986, was used to design the pavement.[3] Criteria used to design the pavement were

- Traffic - A three-month design period was selected for the pavement in Lane 1. This was considered an adequate length of time to identify and correct deficiencies in the ALF machine and the data acquisition system. Assuming that the machine would be operated 8 hours per day, that 380 repetitions per hour would be obtained when the machine was operating at

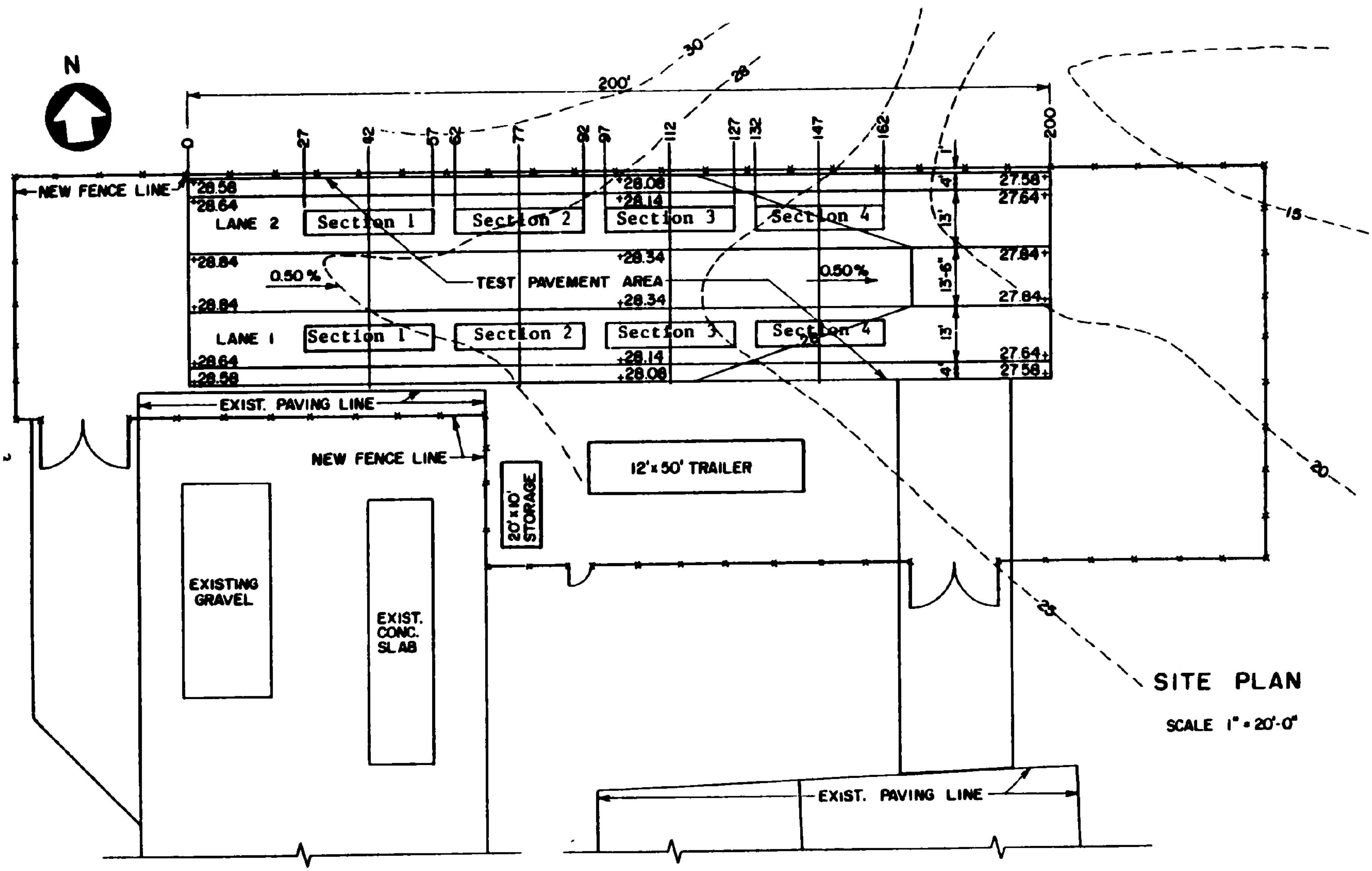

Figure 1. Site plan of pavement testing facility.

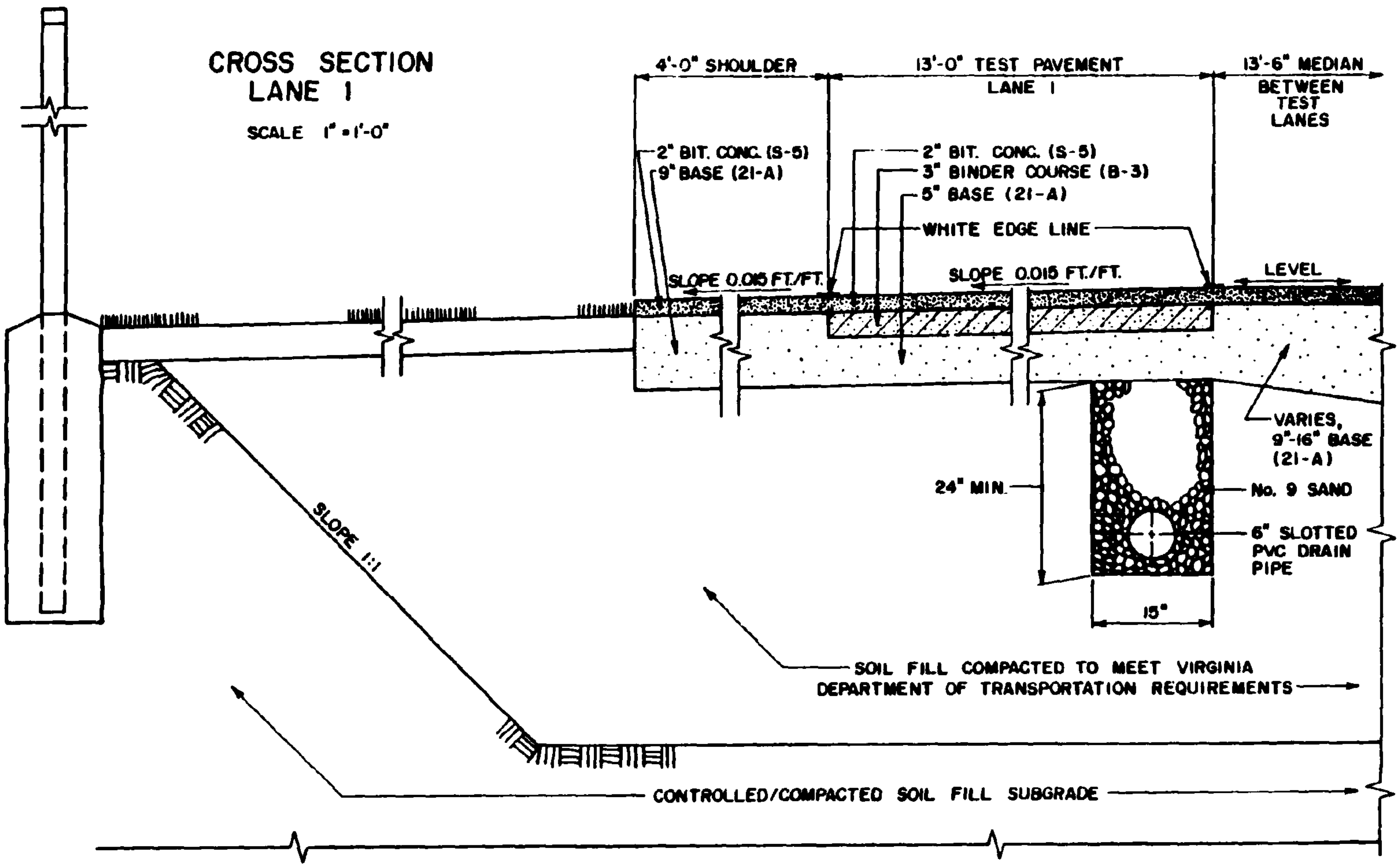

Figure 2. Details of lane 1 of pavement testing facility.

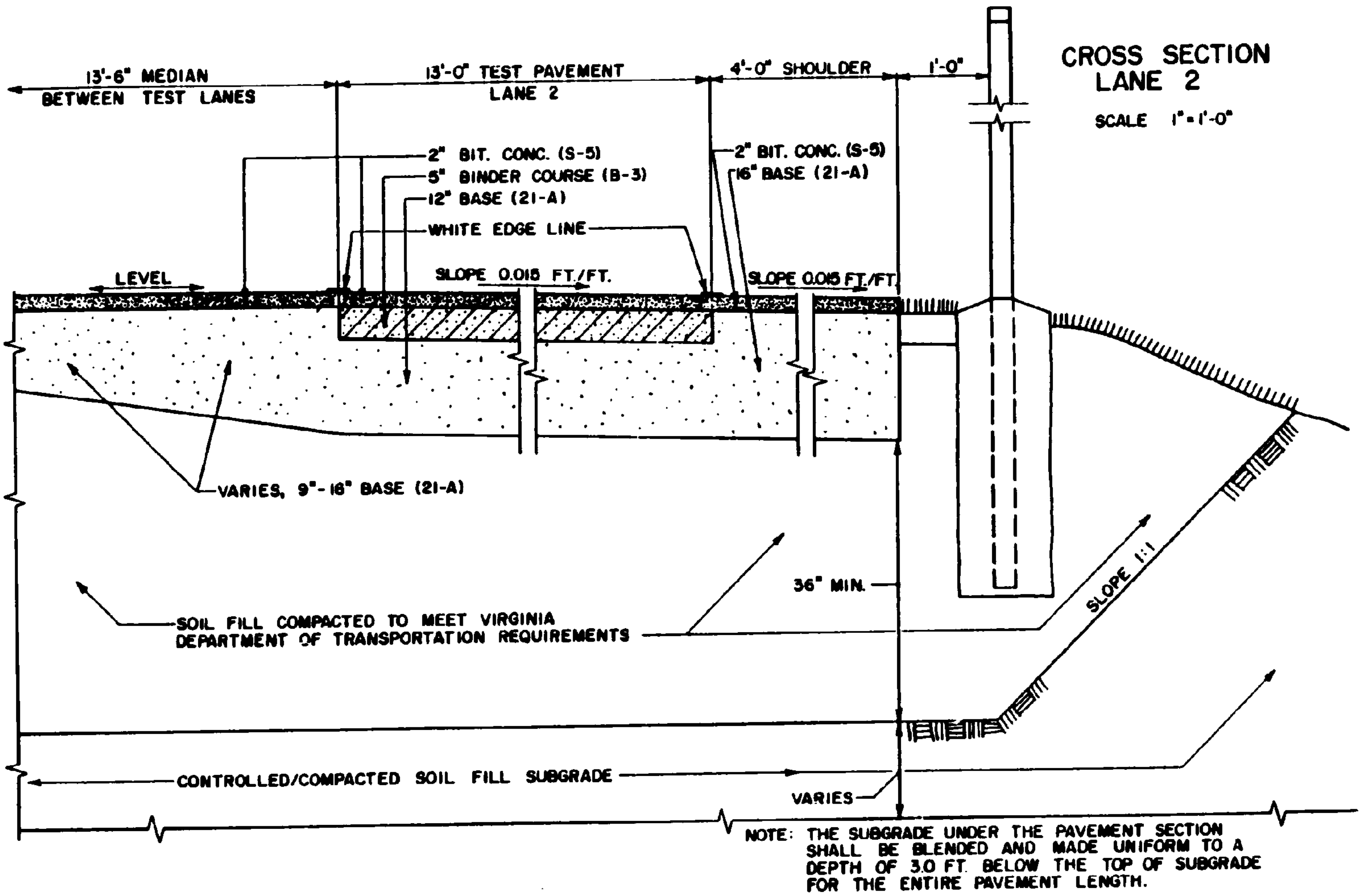

Figure 3. Details of Lane 2 of pavement testing facility.

full capacity, and that an 18-kip ESAL would be applied with each pass, approximately 80,000 18-kip ESAL would be applied per month, yielding 250,000 18-kip ESAL in the three-month design period.

• Reliability - In the AASHTO design procedure, design uncertainty is taken into account with a reliability factor, R. For an Interstate pavement, the AASHTO guide suggests a reliability factor in the range of 85 to 99.9 percent. Consequently, a value of 90 percent was selected.

• Standard Deviation - The AASHTO guide specifies a standard deviation, S_o, of 0.40 to 0.50 for flexible pavements. Consequently, the average of the range, 0.45, was selected for the design.

• Serviceability Loss - The amount of present serviceability index (PSI) that is lost during the life of the pavement is the serviceability loss. An initial PSI of 4.2 was assumed, with a terminal serviceability index of 3.0. Therefore, a loss of 1.2 was used for design purposes.

• Resilient Modulus of Subgrade Material - A commonly used, acceptable approximation for the resilient modulus (M_R) is[3]

$$M_R = 1{,}500\ (\text{CBR}),\ \text{lb/in}^2$$

A CBR of 5 was assumed for the subgrade on the basis of soil classification data and the experience of the researchers. This value was verified in later testing. Consequently, a resilient modulus of 7,500 lb/in^2 (52 MPa) was used for the design.

The AASHTO design nomograph for flexible pavements (figure 4), was used to determine a structural number. Using the traffic soil support and other design data given above, the required structural number (SN) for Lane 1 is 2.90. The AASHTO design equation for selecting pavement layer thicknesses is

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$$

NOMOGRAPH SOLVES:

$$\log_{10} W_{18} = Z_R{*}S_o + 9.36{*}\log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left[\dfrac{\Delta PSI}{4.2 - 1.5}\right]}{0.40 + \dfrac{1094}{(SN+1)^{5.19}}} + 2.32{*}\log_{10}M_R - 8.07$$

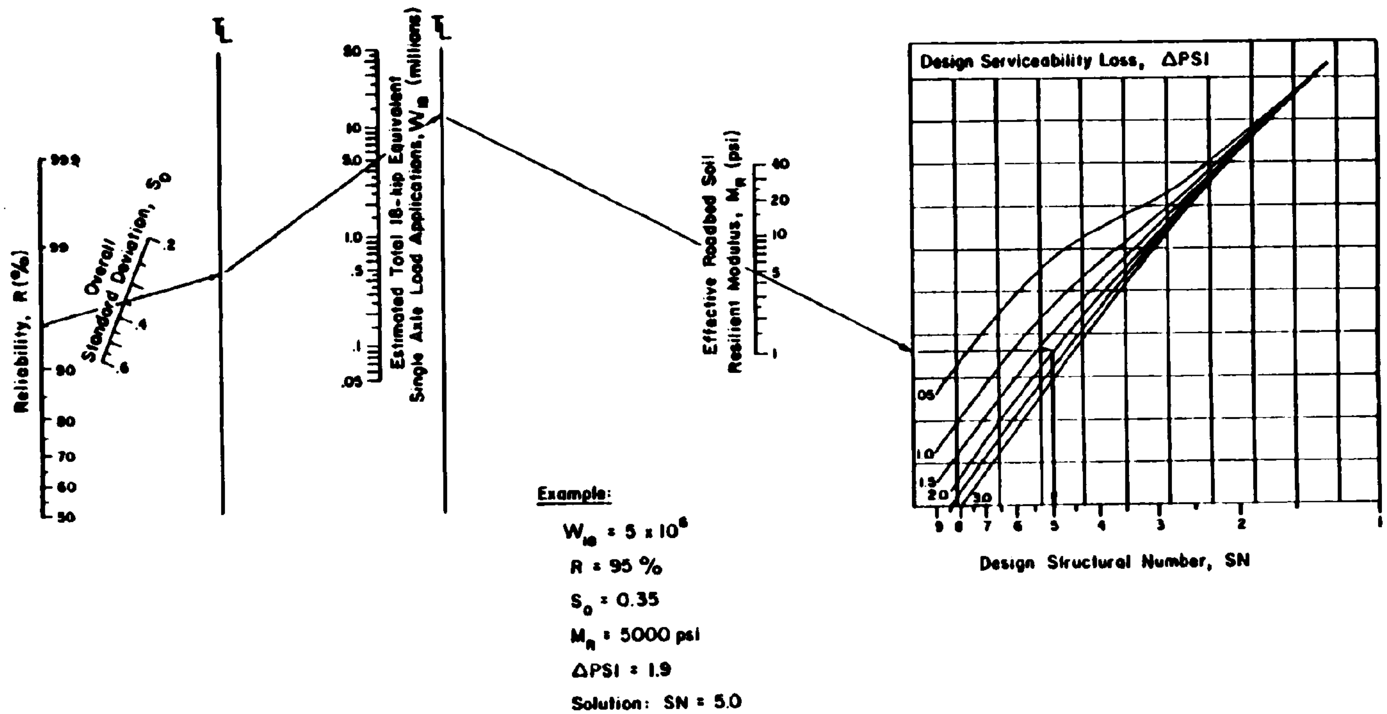

Figure 4. Design chart from 1986 AASHTO pavement design guide.[3]

where:

a_1, a_2, a_3 = structural coefficients for layers 1, 2, 3, respectively

D_1, D_2, D_3 = thicknesses of layers 1, 2, 3, respectively

m_2, m_3 = drainage coefficient

Because the drainage characteristics at the test site were considered to be similar to those at the AASHO test road, a value of 1.0 was chosen for the drainage coefficients.

The structural coefficients used in the design were a_1 = 0.44 for asphalt concrete and a_2 = 0.14 for crushed-aggregate base material. These values are typical and are generally accepted by pavement engineers. Given the above assumptions, allowable base-course thicknesses for 2, 3, and 4.5 inches (51, 76, and 102 mm) of hot-mix asphalt are as follows:

assume asphalt concrete = 2.0 inches (51 mm)
crushed-aggregate base = 14.5 inches (368 mm)

assume asphalt concrete = 3.0 inches (76 mm)
crushed-aggregate base = 11.3 inches (287 mm)

assume asphalt concrete = 4.5 inches (114 mm)
crushed-aggregate base = 6.5 inches (165 mm)

A 4 to 5-inch (102 to 127-mm) asphalt surface would be representative of field construction for a thin pavement section. Therefore, an initial design of 4.5 inches (114 mm) of asphalt concrete on 6.0 inches (152 mm) of crushed-aggregate base was recommended by the research team for Lane 1.

After discussion with the FHWA, some refinements were made to the pavement design for Lane 1. Because a 5.0-inch-thick (127-mm) hot-mix asphalt layer would be more typical of local construction practice, at the request of FHWA, the section adopted for Lane 1 consisted of 5.0 inches (127 mm) of hot-mix asphalt and 6.0 inches (152 mm) of crushed-aggregate base. The structural number for this section is 3.00 and, according to the AASHTO design guide, should carry 250,000 ESAL before failure (TSI = 3.0).

In further discussions with FHWA regarding the pavement design, it was decided that Lane 2 should have a significantly thicker cross section. Consequently, the thickness of the hot-mix asphalt layer was increased to 7.0 inches (178 mm) and the crushed-aggregate base was increased to 12.0 inches (305 mm). The structural number for this section is 4.76 with a design ESAL of 3,500,000. The final designs for the cross sections for Lanes 1 and 2 are shown in table 1.

MATERIALS AND CONSTRUCTION SPECIFICATIONS

The materials used in the construction of the pavement were specified in accordance with Virginia Department of Highways and Transportation "Road and Bridge Specifications" dated July 1982.[4] Tests conducted with the subgrade soil indicated an A-4 soil with an average CBR of 5 (see chapter 4). The subgrade was worked and blended to a depth of 3 ft (1 m) to ensure a uniform subgrade.

The dense-graded, crushed-aggregate base (21A) was specified in accordance with Section 209--Subbase and Aggregate Base Material and Section 309--Aggregate Base Course.[4] The gradation limits for 21A aggregate base are shown in table 2.

The asphalt concrete binder (B-3) and wearing course (S-5) were specified in accordance with Sections 212--Bituminous Concrete and 320--Bituminous Concrete Pavement.[4] Requirements for these materials are summarized in tables 3 and 4.

Table 1. Pavement design.

	Lane 1	Lane 2
Wearing Course, S-5 (inch)[1,2]	2.0 (51)	2.0 (51)
Binder, B-3 (inch)[1,2]	3.0 (76)	5.0 (127)
Crushed-Aggregate Base, 21A (inch)[2]	6.0 (152)	12.0 (305)
Structural Number	3.00	4.76

[1]Ref. 4.
[2]Measurements are provided also in metric units.

Table 2. Gradation limits for the crushed-aggregate base.[1]

Sieve Size	Percent Passing
2-inch (51-mm)	100
1-inch (25-mm)	94-100
3/8-inch (9.5-mm)	63-72
No. 10	32-41
No. 40	16-24
No. 200	8-12

[1]Aggregate size No. 21A (Ref. 4, p. 130).

Table 3. Specifications for binder mix.[1]

	Percent Passing	
Sieve Size	Design Range	Job Mix
1 1/2-inch (38-mm)	100	100
3/4-inch (19-mm)	73-85	75-83
No. 4	34-48	39-47
No. 8	28-35	28-36
No. 200	2-6	3.0-5.0

Percent Bitumen

Design 4.0 - 7.0%[2]

Job Mix 4.2 - 4.8%[2]

[1]Type B-3 (Ref. 4, p. 142).
[2]By weight of mix.

Table 4. Specifications for wearing-course mix.[1]

	Percent Passing	
Sieve Size	Design Range	Job Mix
1/2-inch (12.7-mm)	100	100
No. 4	53-67	60-68
No. 30	19-27	23-29
No. 200	4-8	4-6

Percent Bitumen	
Design	5.0 - 8.5%[2]
Job Mix	5.3 - 5.9%[2]

[1]Type 5-5 (Ref. 4, p. 142).
[2]By weight of mix.

3. PAVEMENT INSTRUMENTATION AND DATA ACQUISITION

The pavement instrumentation and data acquisition system is an integral part of the ALF system and includes three basic components: transducers, data acquisition and signal conditioning equipment, and software. An IBM PC-AT was selected as the primary computer for the acquisition of the pavement-related data. Signals from the various electronic transducers are directed through Series 9000 Daytronic signal conditioning equipment to several Data Translation A/D modules housed in the IBM PC-AT computer. Software supplied with the Data Translation modules was used to develop customized programs for acquiring, reducing, and storing the data. A schematic drawing of the system is shown in figure 5.

MEASUREMENTS

A variety of measurements must be obtained in order to characterize the structural performance of full-scale pavement test sections.[5] The instrumentation and data acquisition system was designed to accommodate these measurements and provide flexibility in the system as data needs change throughout the course of the project. The system will allow the addition of other A/D modules or signal conditioners so that measurements other than those described below can be obtained. The instrumentation and data acquisition are summarized below and will be more fully documented in a subsequent report.

1. Environmental measurements--Although a portable weather station was part of the original data acquisition plan, it was eliminated in favor of NOAA weather station data. The nearest weather station is located at Dulles International Airport, approximately 20 miles (32 km) west of the facility. An example of a NOAA weather report for the Dulles site is shown in figure 6. In addition to the NOAA weather data, other environmental data can be entered into the data files using the IBM PC-AT keyboard.

2. Subgrade moisture--This variable is important because it affects the shear strength and stiffness of the subgrade. Consequently, a series of moisture cells was installed in the subgrade. These moisture cells, Model MC-374 furnished by Soiltest Corporation, are essentially resistivity gages.

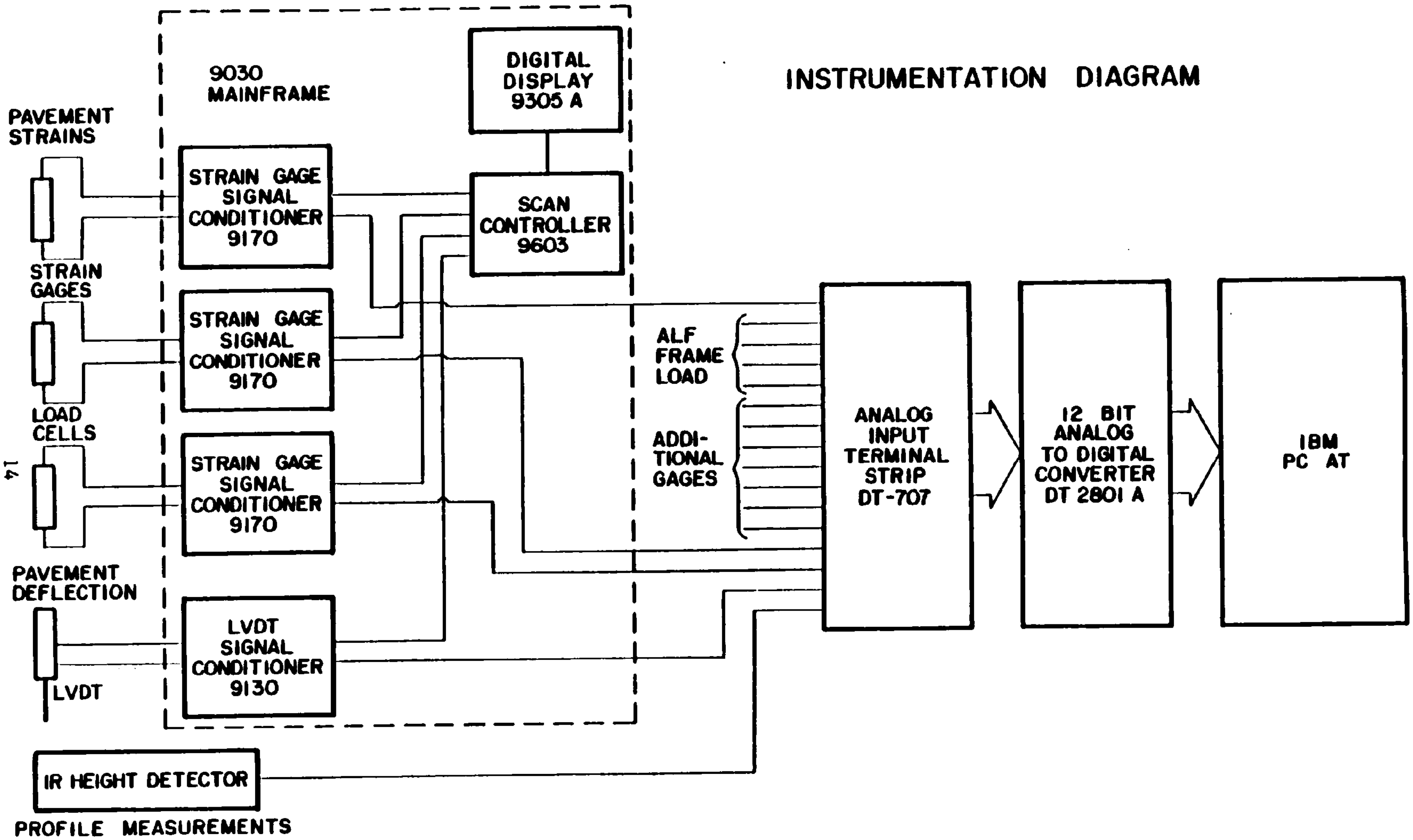

Figure 5. Instrumentation flow diagram.

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NAT'L WEA SER OFC
DULLES INT'L AIRPORT

ISSN 0198-1323

LOCAL CLIMATOLOGICAL DATA

Monthly Summary

DULLES INTERNATIONAL AIRPORT

LATITUDE 38°57' LONGITUDE 77°27' ELEVATION (GROUND) 290 FEET TIME ZONE EASTERN 93738

Date (1)	Temp. Maximum (2)	Temp. Minimum (3)	Temp. Average (4)	Departure from normal (5)	Average dew point (6)	Degree days base 65°F: Heating (season begins with Jul) (7A)	Cooling (season begins with Jan) (7B)	Weather types (8)	Snow, ice pellets or ice on ground at 0700 (inches) (9)	Precipitation: Water equivalent (inches) (10)	Snow, ice pellets (inches) (11)	Average station pressure in inches, Elev 323 feet above M.S.L. (12)	Wind: Resultant dir (13)	Resultant speed (14)	Average speed (15)	Fastest mile: Speed (16)	Fastest mile: Direction (17)	Sunshine: Minutes (18)	Percent of total possible (19)	Sky cover (tenths): Sunrise to sunset (20)	Midnight to midnight (21)	Date (22)
01	91	62	77	1	63	0	12	2 8	0	0.00	0.0	29.575	10	1.0	5.3	9	19			5	3	01
02	95*	60	82	6	60	0	17	1 3 8	0	0.16	0.0	29.570	10	4.1	7.2	15	19			6	6	02
03	87	67	77	1	67	0	12	1 8	0	T	0.0	29.650	16	3.2	4.6	10	17			9	9	03
04	89	62	76	0	60	0	11	1 8	0	0.00	0.0	29.770	09	1.4	4.8	12	14			4	5	04
05	89	61	75	-1	64	0	10	1 8	0	0.00	0.0	29.770	16	5.7	6.1	15	16			3	5	05
06	90	66	78	2	69	0	13	1 3 8	0	2.49	0.0	29.720	17	6.9	8.2	18	17			7	7	06
07	90	66	78	3	68	0	13	1 8	0	0.01	0.0	29.600	19	4.9	5.6	13	24			6	6	07
08	86	67	77	2	69	0	12	1 8	0	0.01	0.0	29.510	23	2.6	5.1	13	27			8	7	08
09	90	66	78	3	65	0	13		0	0.00	0.0	29.580	24	4.8	7.3	14	27			5	5	09
10	94	65	80	5	68	0	15	1 3 8	0	T	0.0	29.590	19	7.0	7.2	17	20			8	7	10
11	82	69	76	1	66	0	11	1	0	0.16	0.0	29.640	25	3.6	6.6	10	20			9	9	11
12	76	65	71	-4	58	0	6		0	0.00	0.0	29.840	03	6.5	6.8	13	04			10	10	12
13	80	61	71	-4	59	0	6		0	0.00	0.0	29.840	04	4.1	5.8	12	06			9	8	13
14	86	59	73	-2	61	0	8	1	0	0.00	0.0	29.760	13	3.2	5.3	9	17			5	5	14
15	89	67	78	3	70	0	13	1 8	0	0.00	0.0	29.660	17	7.2	7.7	12	15			8	7	15
16	92	71	82*	8	71	0	17	1 3	0	0.30	0.0	29.570	10	3.7	7.8	16	29			8	9	16
17	83	70	77	3	72	0	12	1 8	0	0.38	0.0	29.550	02	5.7	6.5	14	12			10	10	17
18	87	71	79	5	69	0	14	1	0	0.06	0.0	29.540	36	6.8	8.3	13	01			7	8	18
19	79	68	74	0	68	0	9	1 8	0	0.32	0.0	29.690	02	3.0	4.7	9	12			10	10	19
20	74	67	71	-3	68	0	6	1	0	0.60	0.0	29.700	06	8.4	8.9	15	08			10	10	20
21	70	67	69	-5	66	0	4	1	0	0.47	0.0	29.770	03	7.0	7.8	13	03			10	10	21
22	82	63	73	-1	64	0	8	1 8	0	0.00	0.0	29.830	35	3.5	4.6	9	02			6	6	22
23	84	62	73	0	66	0	8	1 8	0	0.00	0.0	29.650	20	8.8	9.4	18	20			9	8	23
24	80	60	70	-3	53	0	5	1 8	0	0.00	0.0	29.615	32	11.1	12.1	20	32			4	5	24
25	80	50	65	-8	51	0	0		0	0.00	0.0	29.700	29	1.6	5.2	9	34			6	5	25
26	86	56	71	-2	61	0	6		0	0.00	0.0	29.710	18	4.9	5.9	13	17			5	4	26
27	86	67	77	4	66	0	12	8	0	T	0.0	29.515	24	5.7	10.4	16	32			10	9	27
28	69	44	57	-16	49	8	0	1	0	0.68	0.0	29.685	33	7.9	9.2	20	34			8	6	28
29	68	41	55*	-17	42	10	0		0	0.00	0.0	29.900	01	3.5	5.4	14	01			1	1	29
30	73	41*	57	-15	46	8	0		0	0.00	0.0	30.030	15	2.7	4.4	9	14			2	1	30
31	76	44	60	-12	51	5	0	1	0	0.00	0.0	29.980	09	1.3	3.6	9	11			5	5	31
	SUM 2583	SUM 1913				TOTAL 31	TOTAL 273			TOTAL 5.72	TOTAL 0.0	For the month: 29.706	18	2.4	6.7	20	34	TOTAL	% of possible	SUM 213	SUM 206	
	AVG 83.3	AVG 61.7	AVG 72.5	DEP -1.9	AVG 62.5	DEP 31	DEP -15			DEP -1.56						DATE 28+				AVG 6.9	AVG 6.6	

Number of days				Season to date		Number of days		Greatest in 24 hours and dates			Greatest depth on ground of snow, ice pellets or ice and date
Maximum temp.		Minimum temp.		Total	Total	Precipitation ≥ .01 inch	12	Precipitation		Snow, ice pellets	
≥ 90°	≤ 32°	≤ 32°	≤ 0°	31	1076	Snow, ice pellets ≥ 1.0 inch	0	2.49	06-07+	0.0	0
7	0	0	0	DEP	DEP	Thunderstorms	4				
				31	225	Heavy fog	1				
						Clear 3	Partly cloudy 13	Cloudy 15			

* EXTREME FOR THE MONTH - LAST OCCURRENCE IF MORE THAN ONE.
T TRACE AMOUNT.
+ ALSO ON EARLIER DATE(S).
HEAVY FOG: VISIBILITY 1/4 MILE OR LESS.
BLANK ENTRIES DENOTE MISSING OR UNREPORTED DATA.

DATA IN COLS 6 AND 12-15 ARE BASED ON 21 OR MORE OBSERVATIONS AT HOURLY INTERVALS. RESULTANT WIND IS THE VECTOR SUM OF WIND SPEEDS AND DIRECTIONS DIVIDED BY THE NUMBER OF OBSERVATIONS. ONE OF THREE WIND SPEEDS IS GIVEN UNDER FASTEST MILE: FASTEST MILE - HIGHEST RECORDED SPEED FOR WHICH A MILE OF WIND PASSES STATION (DIRECTION IN COMPASS POINTS). FASTEST OBSERVED ONE MINUTE WIND - HIGHEST ONE MINUTE SPEED (DIRECTION IN TENS OF DEGREES). PEAK GUST - HIGHEST INSTANTANEOUS WIND SPEED (A / APPEARS IN THE DIRECTION COLUMN). ERRORS WILL BE CORRECTED AND NOTED IN SUBSEQUENT PUBLICATIONS.

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Figure 6. Sample NOAA weather report.

Measurements will be taken periodically with an analog meter (a minimum of one per week) and, therefore, it will not be necessary to interface this instrumentation with the automatic data acquisition system. Consequently, provisions have been made in the software to enter the soil moisture measurements through the keyboard of the IBM PC-AT.

3. Compressive stress in the subgrade--The compressive stress in the upper layer of the subgrade has traditionally been related to pavement rutting. Furthermore, compressive stress measurements can be used to validate linear elastic theory or other pavement models. Although a variety of pressure cells have been used by researchers over the years, careful attention to their design is needed to ensure reliability and accuracy.[6] Specially designed pressure cells were ordered for the project, but because of the short time allowed for their delivery, they were not available in time to be installed in the test pavement. Consideration will be given in subsequent tests to retrofitting the pavement to accommodate the pressure cells.

Most soil pressure cells are designed with a simple diaphram that deflects when subjected to normal pressure. These cells generally require two- or four-arm strain gage excitation. With proper signal conditioning they provide a DC signal which is proportional to the pressure normal to the surface of the cell diaphram.

4. Tensile strain in the underside of the asphalt layer--Researchers have related the tensile strain on the underside of the asphalt layer to the fatigue behavior of asphalt pavement sections. Therefore, a series of strain gages was placed in the lower bituminous layer of Lanes 1 and 2. Details of their placement are given in chapter 4. Two types of strain gages were used. The first, developed in Canada, is embedded in an asphalt mastic, and the gages and mastic form a transducer that is approximately 165 mm by 165 mm by 20 mm.[7] There are four gages in each transducer. The gages are used as a half bridge; the extra two gages are used as backups. A photograph showing the transducer in place on the top of the crushed-aggregate base course is shown in figure 7. No problems were encountered in installing these gages, and, in fact, all of the gages were operational after the pavement was

Figure 7. Canadian strain gages being installed.

constructed. In the Nardo study, these gages were classified as group 2.3 gages.[8]

European researchers have had considerable success with strain gages epoxied to a plastic strip.[8] This strip, in turn, is fastened to two anchors forming the shape of the letter "H." These gages were identified in the Nardo study as group 1.1 gages. A photograph of these gages in place on the top of the crushed aggregate is shown in figure 8. The gages were supplied by Kyowa Corporation. Although the long-term durability of the Canadian gages has been verified, the long-term durability of the H gages has not been established.[7] The two types of gages will be compared during future loading experiments to establish long-term durability.

The H gages and the Canada gages are used in a quarter- or half-bridge configuration, respectively, and interface with the Data Translation 2801A A/D boards. Because the gages are not temperature compensated, changes in temperature cause an apparent pavement strain. This strain poses no significant problem for transient measurements; however, the use of these gages for accumulated plastic deformation is not appropriate. No problems were encountered in the installation of the H gages or the Canadian gages, and, at the completion of the construction, all of the gages were operational. The same placement procedure was used for the H gages and the Canadian gages.

Careful placement is needed to ensure that the gages are not damaged during construction. The lead wires were placed in a shallow trench (1 inch (25 mm) deep) in the crushed-aggregate base and covered with the same material. Loose, hot binder mix was placed over the top of the gages just prior to paving over them. The rolling was done in one direction only, with the lead wires placed facing away from the paver or roller. The lead wires on the Kyowa gages were covered with silicone caulk at the point where they entered the plastic strip. This produced a bulb-like deposit of caulk approximately 1/2 inch (12 mm) in diameter. It was intended that this bead of caulk serve as a strain reliever and to help to waterproof the connection. Otherwise, no special precautions were taken during construction to protect the gages.

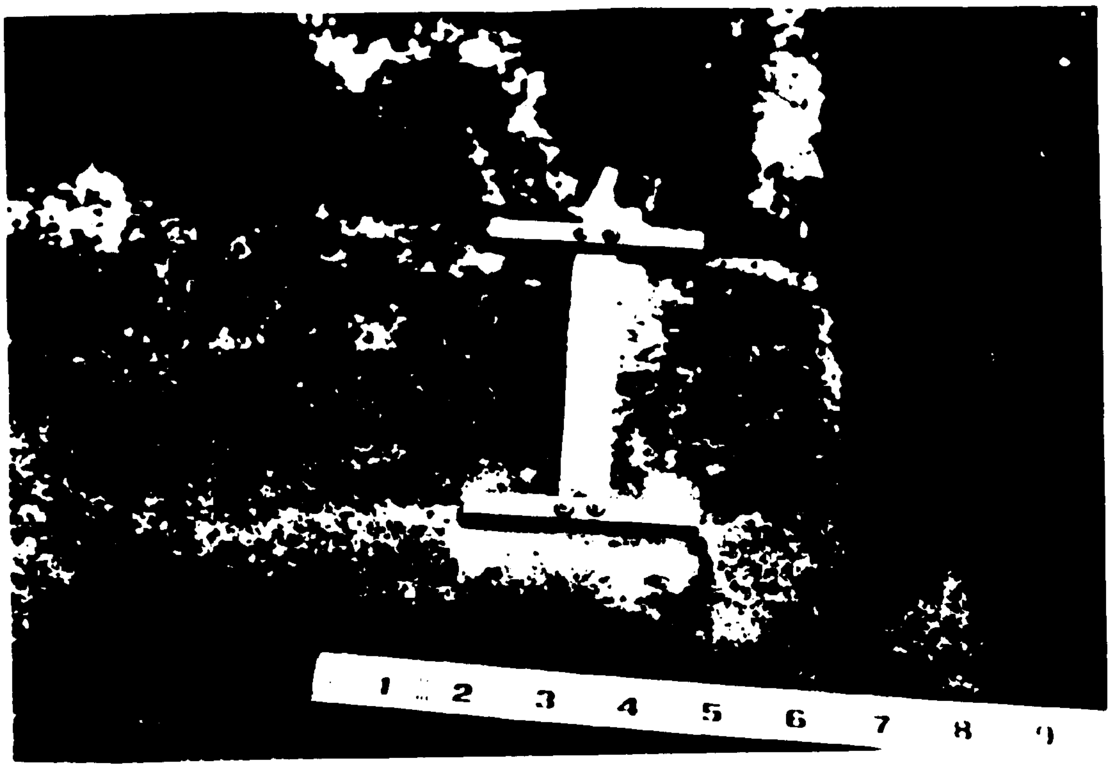


Figure 8. Photograph of H-beam strain gage during installation.

5. <u>Temperature of the pavement layers</u>--It is imperative that the temperature of the pavement layers be known in order to properly evaluate load-induced deflections in asphalt pavements. The temperature affects the modulus of the asphalt concrete layers, which in turn affects the pavement response. Therefore, thermocouples were installed in the hot-mix asphalt layers, crushed-aggregate base, and subgrade. The thermocouples are also designed to monitor frost penetration in the base and subgrade. Details regarding the placement of these thermocouples can be found in chapter 4. In all cases, copper-constantan type T thermocouples were used. The Data Translation DT 2805 A/D board used to interface the thermocouples can accommodate eight channels of input. One of these channels is used to measure ambient air temperature. The remainder are used to monitor thermocouples placed in the pavement system.

6. <u>Deflection of the pavement layers</u>--The structural performance of hot-mix asphalt pavements can be monitored by measuring the deflection of the pavement when it is loaded. Ideally, the transient and permanent deflection of each layer should be measured. The measurement of these deflections has historically caused researchers the greatest number of problems. Therefore, in situ deflection gages were not included as part of the initial instrumentation. Instead, surface deflections are being measured using a beam placed in the longitudinal direction alongside the wheels. An LVDT is mounted at the midpoint of the beam, and the deflection basin is monitored as the beam passes over the pavement. An LVDT signal conditioner has been provided for this measurement.

There are a number of viable and preferred alternatives to the beam that is currently being used for deflection measurements.[9] In future loading cycles, consideration will be given to in situ deflectometers or other techniques in order to provide appropriate measurements of pavement deflection, especially interlayer deflections.[10] Developments of in situ deflectometer techniques will be necessary if the ALF is deployed in the field. In situ deflectometers are probably better suited to retrofit situations than strain gages are. Therefore, it is expected that pavement deflectometers will be installed at the PTF at a later date.

7. Surface profiles--The longitudinal and transverse profiles of the pavement are important with respect to the calculation of roughness, PSI, and rut depth. A system has been developed for use with the Australian ALF whereby a series of steel plates is placed on the pavement surface on either side of the pavement section.[11] A transverse beam is then placed on the plates and the transverse profile is obtained from a contact probe mounted on a cart that traverses the beam. Because this procedure is laborious, alternative techniques for measuring longitudinal and transverse profiles were sought. As part of TWR 2, an infrared (IR) scanning system will be designed so that transverse and longitudinal profiles can be made in a rapid and reliable manner. In this scheme, two longitudinal beams will be anchored in the pavement at the pavement edge. The beams will contain supports for linear ball bushings that will in turn support a removable transverse beam. A carriage containing an infrared (IR) height detector will be mounted on the beam so that the carriage can be translated in the x/y plane. Consequently, one channel of the 2801A module has been reserved for receiving signals from the IR detector. The x/y position of the IR detector will be monitored with a simple shaft encoder which is mounted on the carriage and connected electrically to a Data Translation 2806 counter/timer board.

INSTRUMENTATION

A flow diagram for the data acquisition system was shown in figure 5. The IBM PC-AT provides a means for storing and manipulating the digitized signals from the various Data Translation boards mounted inside the computer. This computer was selected because it offered sufficient capacity to handle the data that would be collected as well as offering sufficient data acquisition speed. The research team has had considerable experience with IBM PC-AT compatible systems, and adequate software for data acquisition is available for this family of computers. An IBM PC-AT was also selected because parts and service are readily available and the data acquisition boards and software are 100 percent compatible with the computer.

A Series 9000 Daytronic mainframe and signal conditioners provide transducer excitation and a means for processing the signals from the transducers so that they can be interfaced with the A/D boards.

SOFTWARE

The diagram shown in figure 9 illustrates the software options available at the IBM PC-AT keyboard. The software consists of several different modules, each tailored to a particular set of measurements. Several of the modules rely on data that are manually typed into the computer through the keyboard.

Seven different options are available, as listed in table 5. These options are actually separate programs that are written in Basic. These programs, which have been compiled to speed execution, call assembly language routines contained in PC Lab, a program supplied by Data Translation.[12]

The LM module is used to acquire the load-associated measurements. The LP and TP modules are used to acquire the longitudinal and transverse profile measurements. Modules labeled TEMP and EC are used to acquire temperature and environmental data, respectively. The graph program can be used to graph the load-associated, temperature, or profiling data. The calibration module is designed for calibrating and zeroing the system.

The load-associated measurement module is the most sophisticated of the modules in that it acquires data on 16 or more channels while the wheels move along the pavement surface. Measurements are taken every 3.9 inches (100 mm), giving approximately 110 measurements per channel. Channels 1 through 9 are currently interfaced with strain gage conditioners; channel 10 is interfaced with an LVDT conditioner for obtaining deflection measurements; channels 11 through 14 are interfaced with the ALF Motorola VME-1000 microcomputer and receive signals from the four trolley load cells.[13] Channel 0 is reserved for profiling data, and channel 15 is not being used at the present time.

A set of measurements from one pass of the tires (trolley) constitutes one load-associated data acquisition file. The data acquisition is initiated by a signal passed to IBM PC-AT from the ALF Motorola VME-1000 computer. This

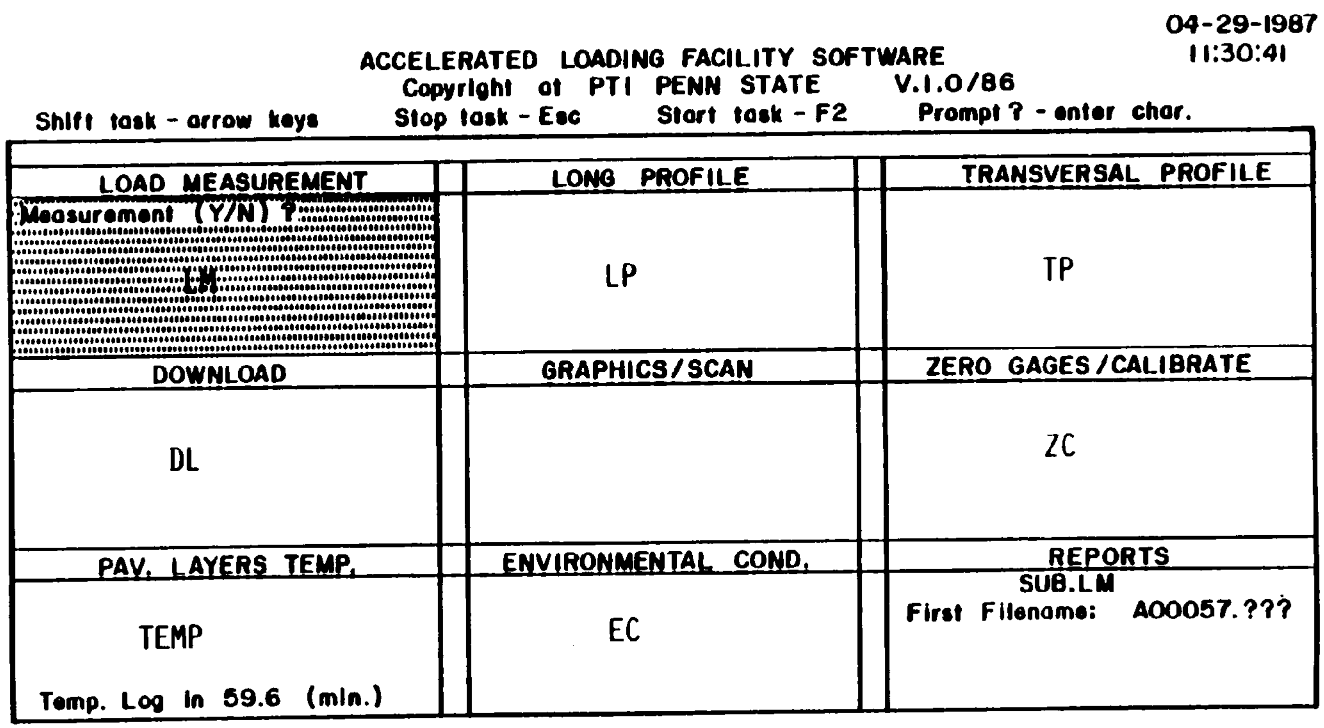


Figure 9. Software subroutine selection menu.

Table 5. Description of software modules.

Module Name	Description
1. LM	This module collects load-associated pavement response data and assembles the data on the hard disk in a file with a label *.LM[1]. The module also acquires a temperature profile immediately after taking the load-associated measurements and includes the temperature data in the file.
2. LP	This module collects longitudinal profile data and assembles the data in a file on the hard disk with a label *.LP.
3. TP	This module collects transverse profile data and assembles the data in a file on the hard disk with a label *.TP.
4. DL	This module is used to download the data from the hard disk to a floppy disk or to the modem. The resulting files are stripped of control characters and data acquisition codes so that they can be assembled on the mainframe.
5. Graphics/ Scan	This module allows any file on the hard disk or floppy disk to be plotted on the monitor, or the plotted data may be printed on the printer.
6. Z/C	This module is used to calibrate and zero the various transducers. It does not produce a file.
7. TEMP	This module is used to continuously sample pavement temperature data at intervals as small as 30 minutes. It produces a file on the hard disk with a continuous string of temperature data.
8. EC	This module can be used to enter environmental data from the keyboard.
9. SUB	This module is used for data acquisition control and does not does not produce any files.

[1]The asterisk indicates a series of sequential numbers that are incremented by one digit each time a new file (set of measurements) is created.

signal triggers the beginning of a pass, and the IBM PC-AT computer then initiates a series of data points for each channel. A series of alternating black and white stripes on the upper chord of the ALF frame is used to trigger the individual measurements. These stripes are spaced at 3.9-inch (100-mm) intervals, giving a set of load-associated measurements at 3.9 inches (100 mm). In this manner, a strain, load, or deflection profile can be obtained as the wheel passes across the length of the pavement.

The load and deflection data are assembled in a series of files which are titled *.LM, where the asterisk indicates a number that increases in single-digit increments for each set of recorded measurements. At the completion of the loading cycle, temperature measurements are recorded and integrated into the file. The file also contains the time and date when the measurements are taken and data that locate the x/y position of the wheel when each measurement is recorded. This file is then printed out as hard copy, stored on the hard disk, or down-loaded to a floppy disk for future use.

A separate module is included in the software for processing the surface profile measurements. These data are assembled in a separate file, titled *.LP or *.LT for longitudinal and transverse profiles, respectively.

Several provisions have been made for monitoring pavement and air temperature. Because the temperature history of the pavement is important, provision has been made for reporting pavement and air temperature on an hourly basis, or more frequently if needed. These data are assembled on a single temperature file. In addition, as noted above, pavement temperature measurements are automatically recorded after each load-associated measurement.

A separate module has been provided for plotting the profiling and the load- and deflection-related data acquisition files versus longitudinal trolley position. The graphing option may be selected once the data have been acquired and assembled on the hard disk. Because the Data Translation 2801A boards are set to receive ±5.0-V signals, the graphics program is also designed to plot on a ±5.0-V scale. The measurements for each channel may be plotted individually as a function of distance along the test section. The graphing option may also be called by referencing any load-associated or profile file that is stored on either the hard disk or a floppy disk. The graphing option may thus be used for data acquisition files that have been stored previously. This feature provides a means for verifying the raw data.

The down-loading module produces files that are in standard ASCII format. The data in these files (strain, load, x/y position, deflection, and temperature) are converted into engineering units and can be transferred to the mainframe or another PC for analysis purposes.

4. CONSTRUCTION TESTING AND INSTRUMENT PLACEMENT

As described in chapter 2, the pavement structure for each lane consists of the subgrade, a crushed-aggregate base course, and a hot-mix asphalt binder and wearing surface layer. Each layer was constructed in accordance with the Road and Bridge Specifications (July 1982) of the Virginia Department of Highways and Transportation.[4] During the construction of the facility, a series of destructive and nondestructive tests was conducted to estimate pavement and material characteristics, such as aggregate gradation, layer thickness, density, California bearing ratio (CBR), and resilient modulus. In addition, strain gages, soil moisture cells, and thermocouples were installed at selected locations in the pavement structure. These instruments will be used for the collection of data required to evaluate performance when the pavement is subjected to accelerated loading. This chapter describes the tests conducted during construction and the placement of the instruments in the pavement.

MATERIAL PROPERTIES

Materials used in the construction of the test facility were tested at the Turner-Fairbank laboratory and at the Pennsylvania Transportation Institute. This testing, which was performed to characterize the construction and not to provide quality control, is discussed below. A summary of the testing that has been conducted to date is given in table 6. Although some of the testing was conducted as part of TWR 2, all of the construction-related testing is presented in this report for the convenience of the reader.

Subgrade

The subgrade was moved from the adjacent Central Intelligence Agency (CIA) headquarters to the test facility, blended to ensure uniformity, and compacted in place. Compaction was obtained with a vibratory steel-wheeled roller.

Atterberg limits and gradation tests were conducted for the subgrade. The soil is essentially an A-4(0) nonplastic, reddish brown silt. The FHWA

Table 6. Laboratory testing plan.

Testing Procedure	TWR #1	TWR #2
Subgrade		
1. Atterberg Limits	XX	--
2. Moisture Density Relationship	XX	--
3. Gradation	XX	--
4. Resilient Modulus	--	XX
Granular Base		
1. Moisture Density Relationship	XX	--
2. Gradation	XX	--
3. Resilient Modulus	--	XX
4. Los Angeles Abrasion	--	XX
Asphalt Cement		
1. Viscosity, 140 F	--	XX
2. Viscosity, 275 F	--	XX
3. Penetration	--	XX
4. Softening Point	--	XX
5. TFOT	--	XX
6. Specific Gravity	--	XX
Bituminous Mix--Box Samples		
1. Gradation	XX	--
2. Marshall Data	--	XX
3. Resilient Modulus	XX	--
4. Tensile Strength	--	XX
Bituminous Mix--Lab. Prepared Specimens		
1. Marshall Data	--	XX
2. Resilient Modulus	--	XX
3. Tensile Strength	--	XX
Bituminous Mix--Cores		
1. Resilient Modulus	XX	--
2. Tensile Strength	--	XX
3. Thickness	XX	--

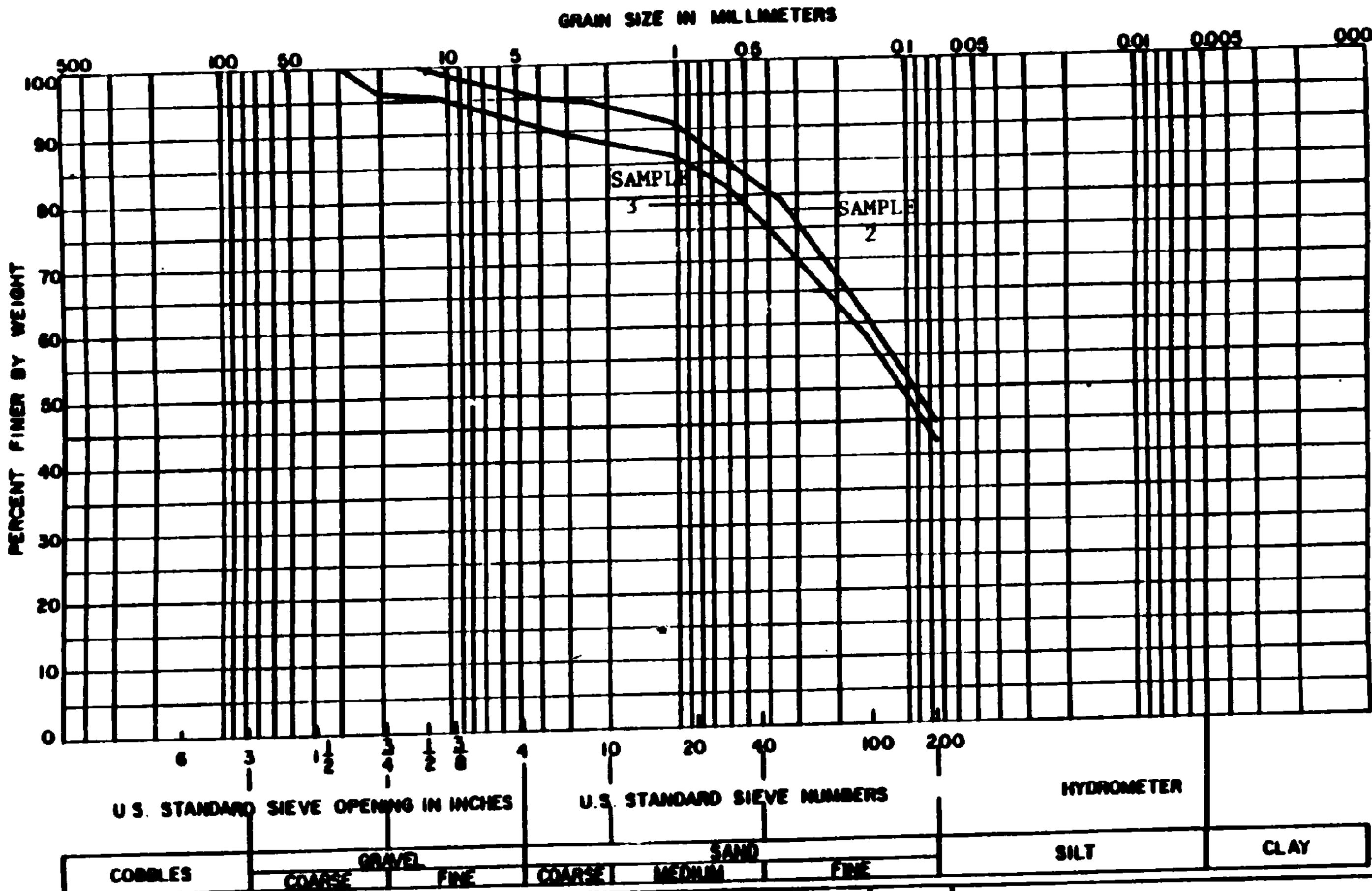
laboratory reported a plastic limit (PL) of 29 percent, and the PTI laboratory reported 30 percent. Gradation analyses for two random samples of the subgrade were done at PTI, and the resulting gradation curves are shown in figure 10. Approximately 90 percent of the soil particles are finer than 1/4 inch (6.35 mm), and approximately 45 percent are less than 75 µm in diameter.

Laboratory moisture/density curves for the subgrade soil are shown in figures 11 and 12. These data were obtained by PTI and FHWA, respectively. It should be noted that the FHWA sample was obtained from a stockpile at the CIA headquarters, whereas the PTI sample was obtained from the subgrade. Therefore, the PTI data, in figure 11, are considered more representative of the actual construction.

The California Bearing Ratio (CBR) test was conducted by FHWA on soaked specimens. The CBR for soaked specimens compacted to 95 percent of maximum dry density (116.3 lb/ft^3 (1,860 kg/m^3), 8.0 percent compaction moisture, figure 12) was reported as 6.7 percent, slightly larger than the 5.0 percent assumed in the initial design.

A Troxler nuclear gage was used to determine the in situ density of the compacted subgrade. The values obtained are reported in table 7. The average compaction density obtained was 119 lb/ft^3 (1,910 kg/m^3) and 121 lb/ft^3 (1,940 kg/m^3) for Lane 1 and Lane 2, respectively. Comparison with the moisture/density curves in figure 11 indicates that the subgrade was well compacted and that the as-compacted moisture content was very close to the optimum moisture content.

Repeated triaxial tests were conducted on 4-inch by 8-inch (102-mm by 203-mm) cylindrical specimens compacted in the laboratory. The average dry density and moisture content of these specimens was 108 lb/ft^3 (1,730 kg/m^3) and 10 percent, respectively. The specimens were conditioned with a minimum of 100 load repetitions before the measurements were obtained. Results of the testing for two specimens are shown in figure 13.



Sample No	Description	Natw%	LL	PL	PI
Bag 2	Reddish brown silty sand			30	--
Bag 3	Reddish brown silty sand			30	--

Section No

Lab Group No

Tested By ALF Test Pavement

Date of Testing

GRADATION CURVES

Figure 10. Gradation curve for subgrade soil.

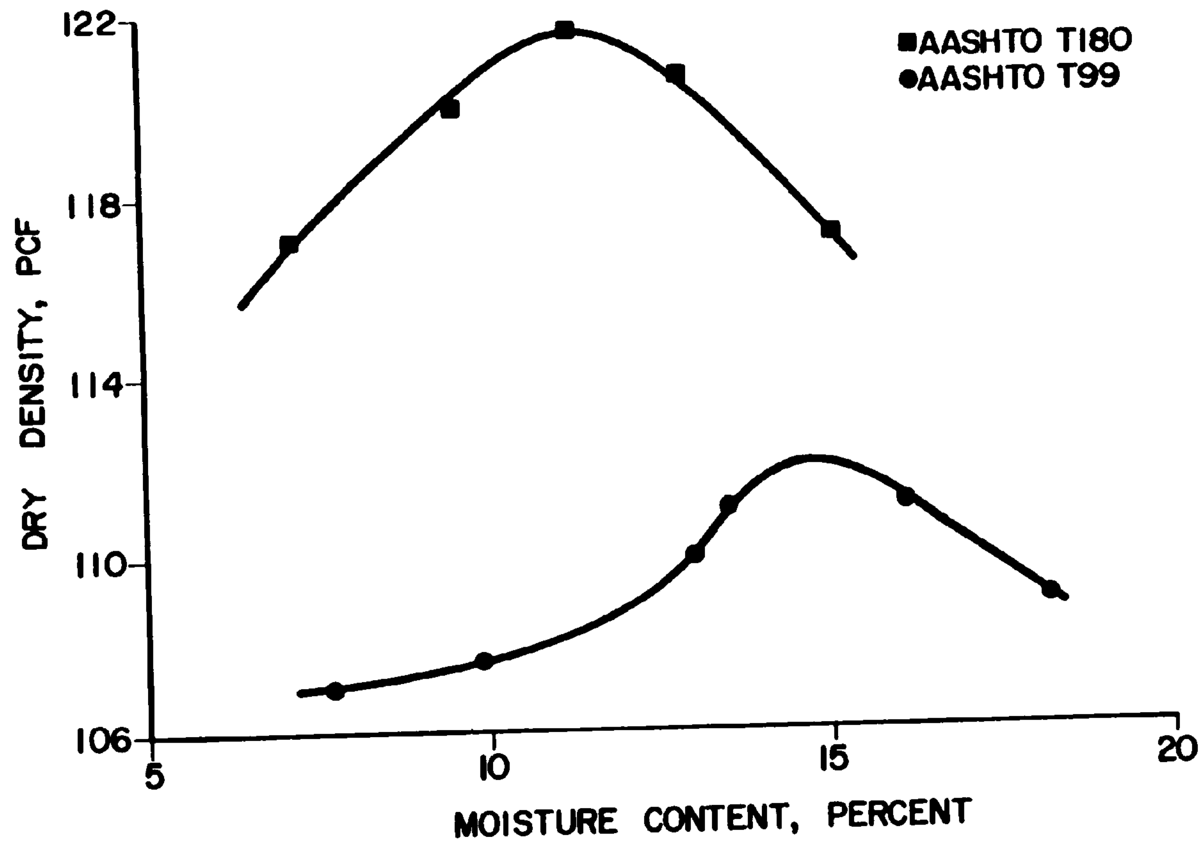


Figure 11. Moisture/density curve for subgrade soil, roadway sample.

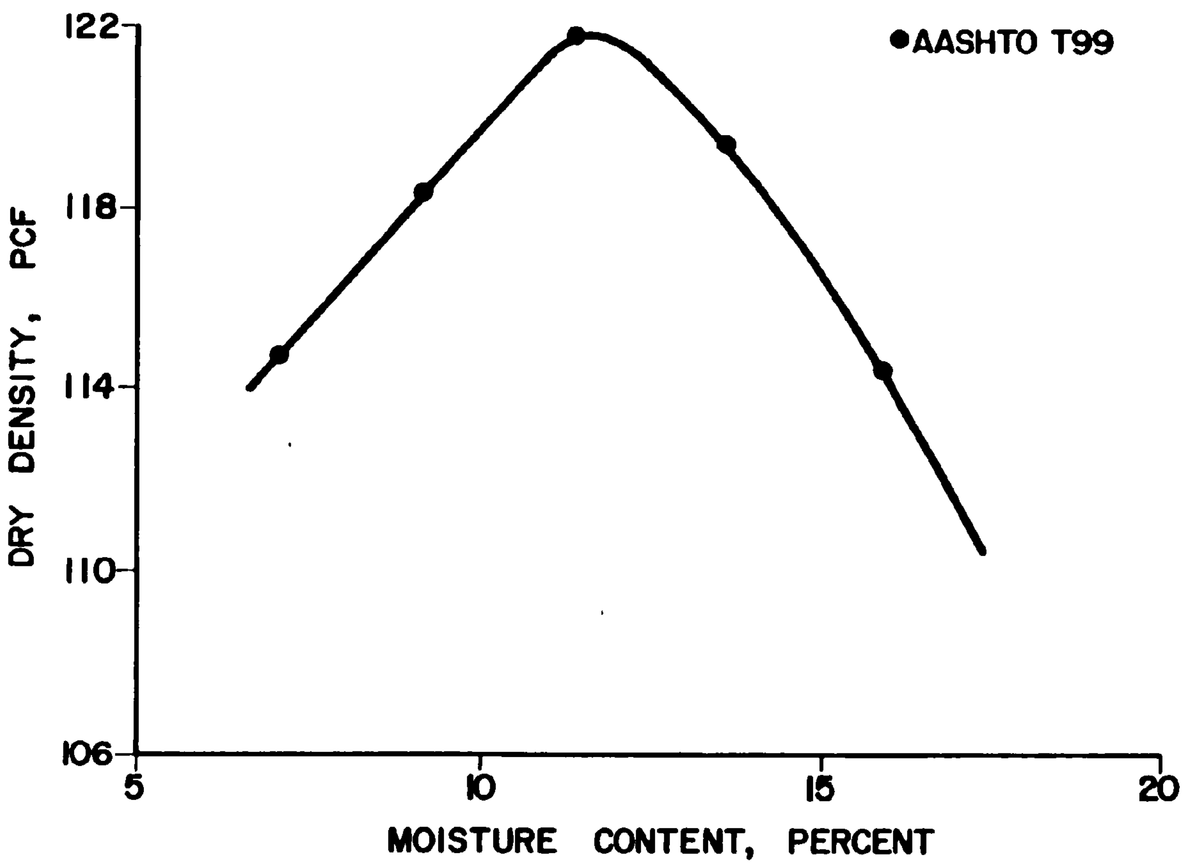


Figure 12. Moisture/density curve for subgrade soil, stockpile sample.

Table 7. Density and moisture content of subgrade measured with nuclear density gage.

Location		2 ft L of CL		CL		2 ft R of CL	
Lane	Station	Dry Density lb/ft^3	Moisture Content (%)	Dry Density lb/ft^3	Moisture Content (%)	Dry Density lb/ft^3	Moisture Content (%)
1	0+35	118.2	9.2	118.5	8.9	117.6	9.7
	0+42	121.7	8,2	123.2	7.1	120.1	9.1
	0+49	119.1	8.6	120.5	7.8	120.2	8.0
	0+70	117.9	9.8	118.2	10.0	116.9	11.1
	0+77	118.4	10.2	118.9	10.4	117.0	9.7
	0+84	119.2	10.1	117.9	10.2	118.7	9.6
	1+05	115.4	10.2	117.8	9.1	111.9	10.8
	1+12	118.6	8.6	115.4	9.0	112.9	8.2
	1+19	119.1	9.7	118.0	8.9	114.9	8.7
	1+40	117.8	12.0	120.7	10.9	119.3	11.7
	1+47	119.8	11.5	135.7	8.0	119.2	10.4
	1+54	122.0	10.5	119.4	10.2	114.0	10.6
	Avg.	118.9	9.9	120.4	9.2	116.9	9.8
2	0+35	127.8	7.6	124.6	9.4	128.4	9.0
	0+42	121.9	9.6	124.4	10.0	123.2	9.3
	0+49	121.5	9.5	124.3	9.2	125.1	8.3
	0+70	125.0	9.6	123.7	8.5	125.2	9.3
	0+77	122.5	10.1	127.5	8.6	124.3	9.5
	0+84	125.1	9.7	125.2	10.5	126.3	9.5
	1+05	117.9	11.4	118.2	11.0	121.5	10.8
	1+12	116.3	11.3	119.2	10.8	119.5	10.7
	1+19	120.5	10.8	121.0	11.6	121.0	11.3
	1+40	114.4	11.3	117.1	11.5	120.0	11.6
	1+47	114.5	11.2	116.4	12.2	117.5	12.5
	1+54	115.7	13.3	116.0	13.1	112.7	13.6
	Avg.	120.3	10.5	121.5	10.5	122.1	10.5

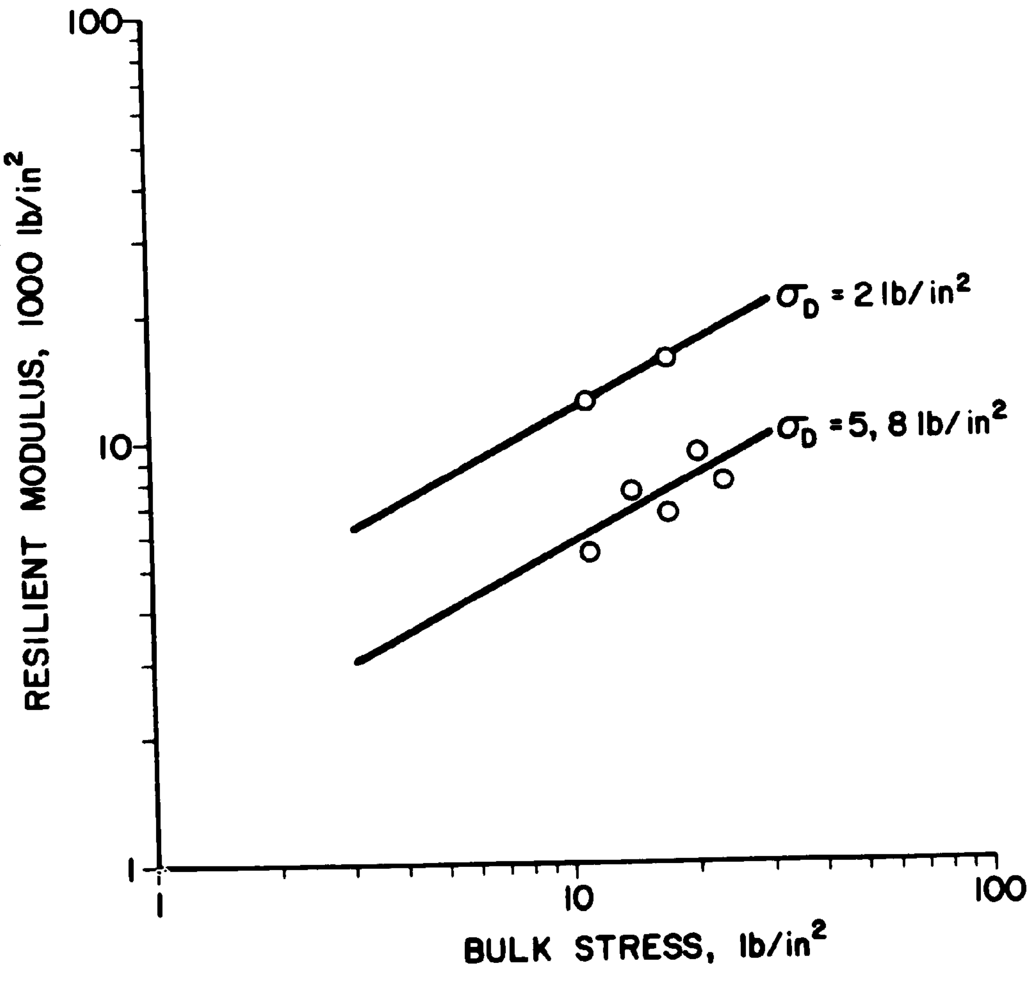


Figure 13. Resilient modulus test results, subgrade.

Crushed Aggregate Base

Cradation analyses were conducted on three randomly selected samples of crushed-aggregate base material. The results of the sieve analysis are given in table 8 and figure 14. It can be seen that, in the case of the samples tested, the percentage passing the No. 10, 40, and 200 sieves was substantially lower than the specified lower limit (table 2).

Moisture/density curves were obtained in the PTI laboratory for the crushed-aggregate base sampled from the roadway. The results for the AASHTO T90 and T180 procedures are shown in figure 15. A nuclear density gage was used to measure the in situ density of the crushed-aggregate base, and the results are given in table 9. The average density values were 155 and 151 lb/ft^3 (2,480 and 2,420 kg/m^3) for Lanes 1 and 2, respectively. However, during its use on the base-course, the nuclear gage was observed to behave erratically and was returned to FHWA for repair. The results obtained for the base-course layer are, therefore, suspect. Although a limited number of sand-cone density tests were also conducted on the subbase, the data were suspect and are therefore not reported. Based on visual observations, the base course was very dense and appeared to have been placed with a minimum of segregation. Rain water that ponded on the surface of the compacted crushed-aggregate base remained for several days, verifying that the compacted base was very dense and well compacted.

Triaxial resilient moduli were also measured for the subbase using the same equipment and procedure used for the subgrade. The specimens were compacted in five lifts using a hand-held electric impact hammer. The density and moisture content of the as-compacted specimens were approximately equal to values obtained in the field. Results of this testing are given in figure 16.

Bituminous Layers

An AC-20 asphalt cement was used for constructing both the binder and the wearing course. Test results for the as-supplied asphalt cement and for asphalt cement recovered from cores obtained at Lane 2, station 147+00 are given in table 10.

Table 8. Gradation data for crushed-aggregate base course.

Sieve Size	Sampling Location: Sample 1	Sample 2	Sample 3	Average	Specification Limits
1-1/2 in	100.0	100.0	100.0	100.0	-
1	94.2	95.1	95.9	95.1	94-100
3/4	86.6	83.0	84.7	84.8	-
1/2	76.2	74.0	75.4	75.2	-
3/8	71.6	68.7	69.1	69.8	63-72
No. 4	62.0	59.7	57.4	59.7	-
8	49.6	47.7	44.6	47.3	-
10	-	-	-	-	32-41
16	37.6	36.5	33.6	35.9	-
30	28.5	28.2	26.1	27.6	-
40	-	-	-	-	16-24
50	21.2	21.3	20.2	20.9	-
100	15.6	15.7	15.7	15.7	-
200	11.5	11.4	11.7	11.5	8-12

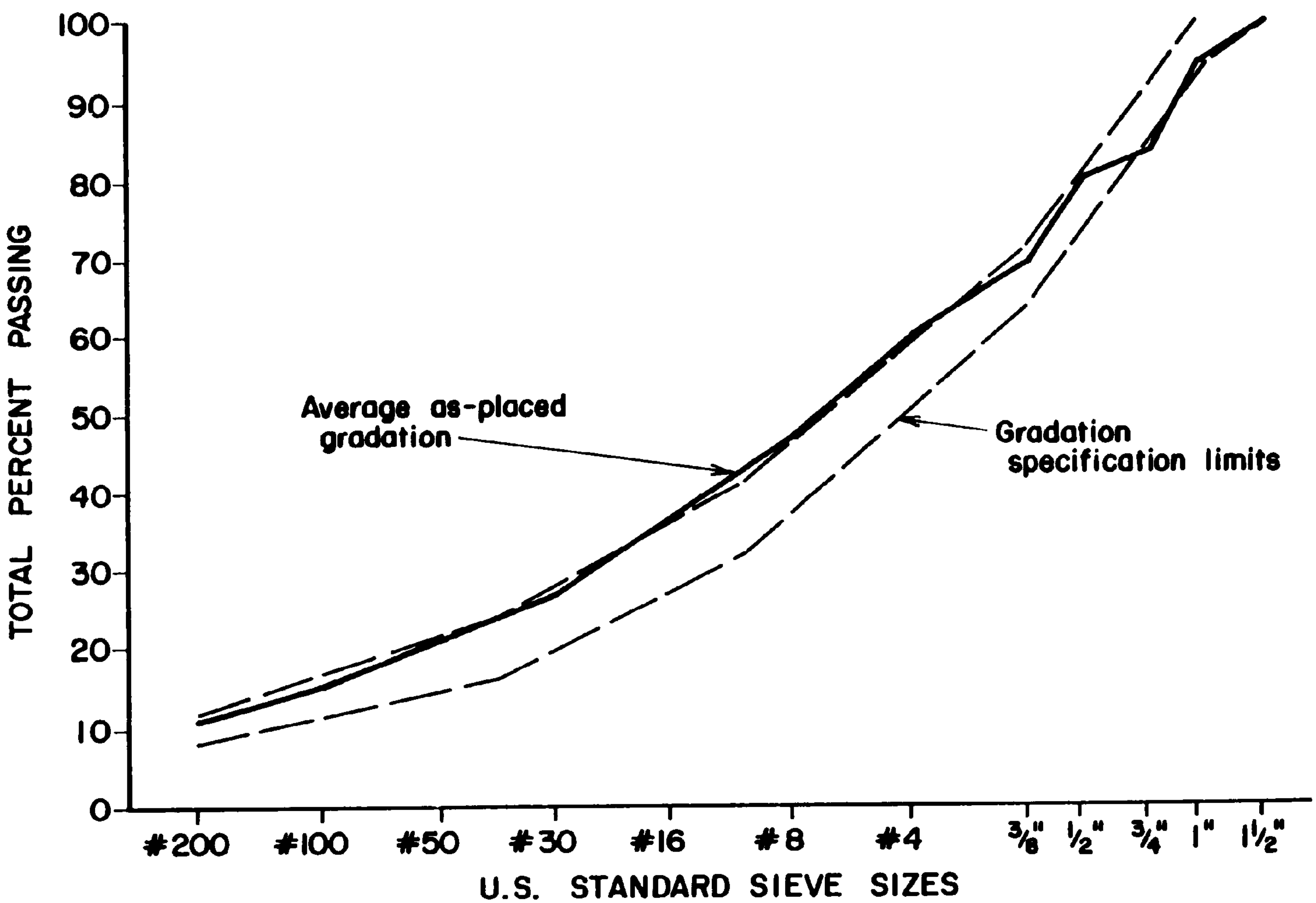


Figure 14. Gradation curves for crushed-aggregate base.

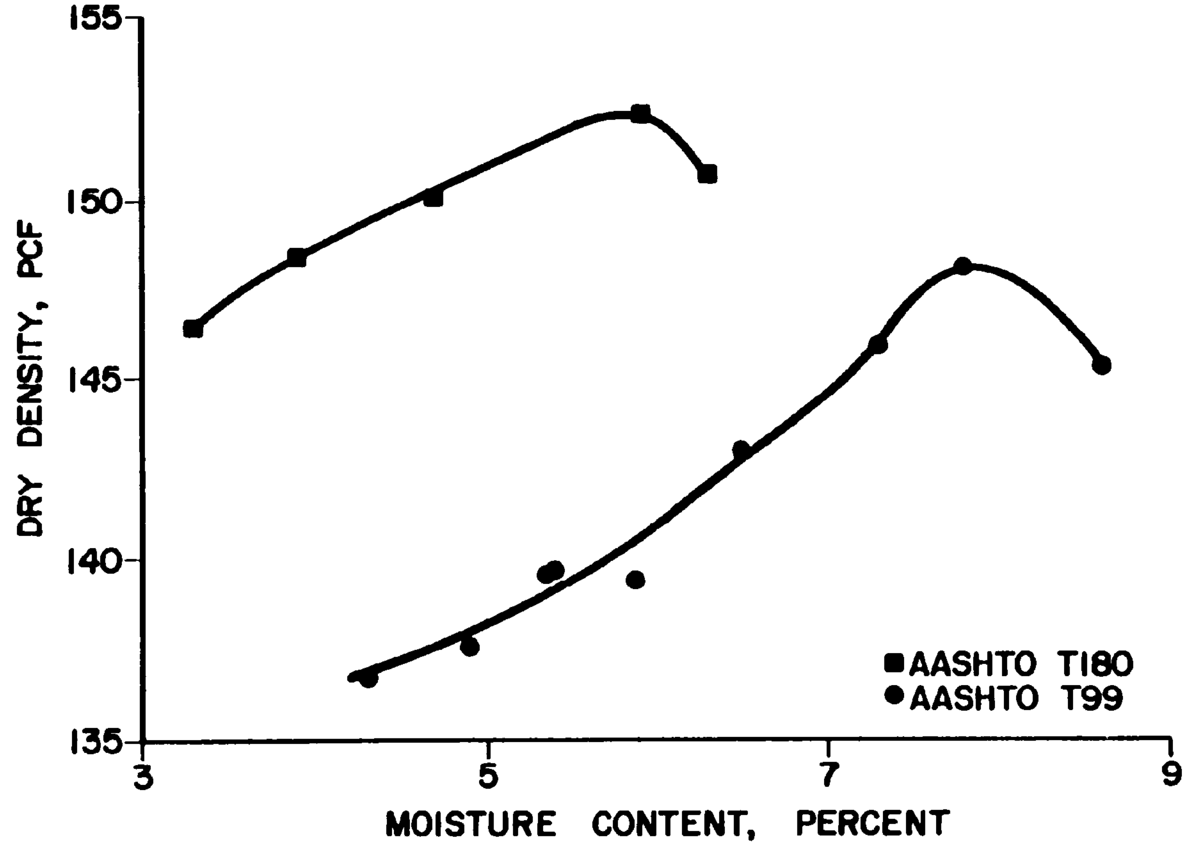


Figure 15. Moisture/density curves for crushed-aggregate base.

Table 9. Density and moisture content of base course measured with nuclear density gage.

Location		2 ft L of CL		CL		2 ft R of CL	
Lane	Station	Dry Density lb/ft^3	Moisture Content (%)	Dry Density lb/ft^3	Moisture Content (%)	Dry Density lb/ft^3	Moisture Content (%)
1	0+35	163.2	2.7	156.2	3.1	163.7	3.2
	0+42	156.4	2.8	155.9	3.3	155.2	3.6
	0+49	153.3	3.0	154.1	3.0	163.6	2.6
	0+70	153.0	3.1	149.4	3.1	154.5	3.0
	0+77	156.9	3.0	160.3	2.8	160.1	2.9
	0+84	149.7	3.0	152.9	3.3	150.6	3.4
	1+05	150.8	3.1	154.4	3.1	147.3	3.4
	1+12	148.5	3.3	156.1	3.1	150.6	3.4
	1+19	148.5	3.0	156.6	3.2	147.0	3.3
	1+40	157.3	3.6	-	-	154.5	3.9
	1+47	159.7	3.5	161.4	3.2	156.8	3.1
	1+54	134.6	3.7	152.4	3.4	154.9	3.6
	Avg.	153.4	3.2	155.4	3.2	154.9	3.3
2	0+35	153.4	3.4	157.7	3.2	151.1	3.3
	0+42	153.3	3.5	159.4	3.2	153.3	3.5
	0+49	165.8	3.6	160.9	3.5	157.6	3.4
	0+70	149.1	3.3	148.9	3.3	150.0	3.0
	0+77	135.8	3.4	151.2	3.1	148.1	3.0
	0+84	151.0	2.8	156.1	2.8	153.7	3.0
	1+05	145.9	2.9	145.7	2.8	143.2	3.0
	1+12	144.8	3.1	132.6	3.2	148.8	3.0
	1+19	150.7	3.2	147.9	2.9	156.0	3.1
	1+40	-	-	-	-	160.7	3.2
	1+47	-	-	-	-	-	-
	1+54	-	-	-	-	-	-
	Avg.	150.0	3.2	151.2	3.1	152.2	3.2

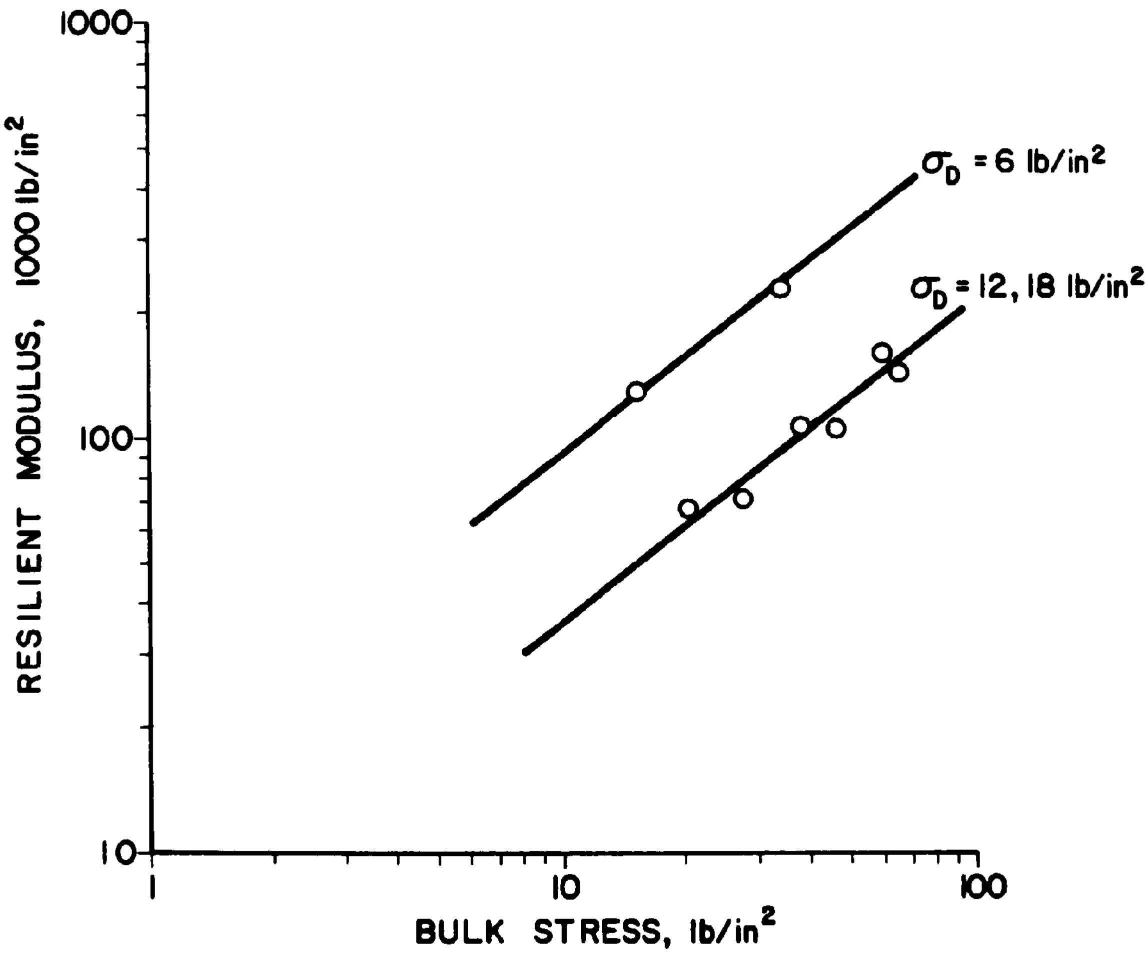


Figure 16. Resilient modulus test results, crushed-aggregate base.

Table 10. Asphalt cement properties.

FHWA sample number	B-5928 (C-8990)
Specific gravity, 77/77 F (25/25 C)	1.024
Flash point, COC, F (C)	595 (313)
Penetration, 77 F (25 C), 100 g, 5 s	78
Viscosity, 275 F (135 C), centistokes	413
Viscosity, 140 F (60 C), poises	2160
Solubility, trichloroethylene, percent	99.46
Thin film oven test, 325 F (163 C), 5 hours	
Loss, percent	0.21
Penetration on residue, 77 F (25 C)	48
Percent retained penetration	61.5
Viscosity on residue, 275 F (135 C), centistokes	600
Viscosity on residue, 140 F (60 C), poises	5145

Tests on recovered asphalts from test site No. 4 mixtures:

	FHWA No. B-5924 Binder	FHWA No. B-5925 Surface
Penetration, 77 F (25 C)	47	50
Viscosity, 275 F (135 C), centistokes	699	675
Viscosity, 140 F (60 C), poises	7397	5563

Mixtures contained 0.5 percent (by asphalt weight) Pave Bond Special Antistripping additive.

Hot-mix asphalt samples taken from the paver were compacted in the FHWA laboratory to determine mix properties. The compacted temperature was 250 F (120 C), and the 75-blow Marshall procedure was used. The results of the tests conducted on the Marshall specimens are summarized in table 11. In addition, the gradation of the aggregate extracted from samples of asphalt concrete mixes was used for the binder layer and the wearing course. The results of the extraction tests are given in tables 12 and 13 and are plotted in figures 17 and 18. In the case of both mixes, the percentage passing the No. 200 sieve was in excess of the specification limit (tables 3 and 4).

Two full-depth 4-inch-diameter (102-mm-diameter) field cores were obtained from Lane 1 and Lane 2 in the center line of the pavement at station 97. These cores were then tested with a Retsina Resilient Modulus device at PTI to determine the resilient modulus at 32 F, 77 F, and 100 F (0 C, 25 C, and 37.8 C). The test results are summarized in table 14.

The bulk specific gravity of the four field cores was also determined in the PTI laboratory. The average bulk specific gravity of the cores taken from the wearing course of Lane 1 and Lane 2 was 2.415 and 2.469, respectively. Using the maximum gravity from table 10, the respective air voids for Lanes 1 and 2 are 7.3 and 6.8 percent, respectively. Visual inspection of the cores showed that they were very dense and well compacted.

The effect of moisture conditioning was determined by testing conditioned and unconditioned samples of the mix for tensile strength and resilient modulus. The procedure recommended in NCHRP Report 274 was used by the FHWA laboratories for evaluating the susceptibility of the mix to moisture damage.[13] The wet/dry ratio of the test results obtained for these two parameters indicates that the bituminous concrete mix used in the surface did show some sensitivity to moisture damage (table 15). For the surface mix, 75.1 percent of the tensile strength and 73.7 percent of the modulus were retained after conditioning. This result is supported by the degree of stripping visually observed in the moisture-conditioned wearing-course mix. There was no significant loss in strength or modulus for the binder mix.

Table 11. Mixture properties (from site 4).[1]

	Surface	Binder[2] (Lower Lift)
Percentage Asphalt by Mix Weight	5.6	4.5
Bulk Specific Gravity	2.557	2.580
Maximum Specific Gravity	2.606	2.650
Voids (%)	1.9	2.6
Stability, lb (kg)	3330 (1510)	4880 (1850)
Flow, 0.01 in (0.25 mm)	14	Not obtainable
Density, lb/ft^3, kg/m^3	160 (2560)	161 (2580)
Effective Specific Gravity of Aggregate	2.867	2.865

[1]Marshall--75 blows per side at a compaction temperature of 250 F (120 C). Samples were taken from the paver and compacted in the laboratory.

[2]Binder contained plus 1-inch (25 mm) aggregate.

Table 12. Gradation of extracted aggregate, binder course.

Sieve Size	Percent Passing (Wet Gradations)												Average Top and Bottom Lift	Specification Limits	Job Mix
	Bottom Lift				Top Lift										
	Lane 2 Sect. 1	Lane 2 Sect. 2	Lane 2 Sect. 3	Lane 2 Sect. 4	Lane 2 Sect. 1	Lane 2 Sect. 2	Lane 2 Sect. 2	Lane 2 Sect. 2	Lane 1 Sect. 1	Lane 1 Sect. 2	Lane 1 Sect. 3	Lane 1 Sect. 4			
1.5-in	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100	100
1.0	99.3	98.3	95.5	92.8	93.7	90.6	95.6	95.7	94.0	94.4	95.4	92.1	94.8	-	-
3/4	81.3	80.7	81.7	73.8	82.0	76.4	83.0	77.4	77.8	76.9	84.7	71.7	79.0	78-83	75-83
1/2	51.2	51.7	49.5	52.2	61.3	49.7	60.2	50.4	54.9	52.9	65.3	46.9	53.9	-	-
3/8	43.4	42.8	42.7	45.8	53.2	42.3	52.7	44.3	48.1	46.5	58.8	39.9	46.7	-	-
No. 4	37.8	37.4	37.3	40.3	46.2	36.8	46.5	39.0	40.4	38.5	51.7	34.9	40.6	34-48	39-47
8	32.0	31.4	31.5	34.3	38.8	31.3	39.1	33.1	34.4	32.6	42.4	29.6	34.2	28-35	28-36
16	25.4	24.9	24.8	27.2	30.4	24.9	30.5	26.1	27.9	26.5	32.9	23.7	27.1	-	-
30	18.8	18.2	18.1	20.2	21.9	18.2	22.0	19.1	21.2	20.0	24.0	17.7	20.0	-	-
50	11.7	11.2	11.2	12.3	13.4	11.2	13.5	11.9	13.7	12.6	14.6	10.9	12.4	-	-
100	8.0	7.4	7.1	8.3	9.0	7.5	9.2	8.0	9.6	8.6	9.7	7.3	8.3	-	-
200	5.7	5.3	5.4	6.5	6.8	5.5	6.6	6.1	7.6	6.2	7.1	5.1	6.2	2.0-6.0	3.0-5.0
% AC[1]	4.3	4.4	4.3	4.5	5.1	4.2	4.9	4.4	3.9	4.4	5.2	3.5	4.4	4.0-7.0	4.2-4.8

[1]Percent asphalt cement by weight of mix

Table 13. Gradation of extracted aggregate, wearing course.

	Percent Passing											
Sieve Size	Lane 2 Sect. 1	Lane 2 Sect. 2	Lane 2 Sect. 3	Lane 2 Sect. 4	Lane 1 Sect. 1	Lane 1 Sect. 2	Lane 1 Sect. 3	Lane 1 Sect. 4	Median Sect. 1	Average	Specification	Job Mix
3/4-in	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	-	-
1/2	100.0	99.5	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	100	100
3/8	94.2	91,8	94.7	94.0	96.0	95.1	94.6	94.4	95.4	94.5	-	-
No. 4	58.4	58.1	60.6	61.6	64.0	64.1	62.2	60.4	65.1	61.6	53-67	60-68
8	42.5	41.3	42.9	43.7	45.6	45.9	44.3	43.0	46.5	44.0	-	-
16	33.1	31.8	32.9	33.3	34.0	34.3	33.5	32.9	34.8	33.4	-	-
30	24.2	23.8	24.5	24.6	24.7	24.9	24.5	24.6	25.4	24.6	19-27	23-29
50	14.5	15.8	16.1	16.0	16.0	16.1	16.0	16.4	16.4	15.9	-	-
100	9.4	10.9	11.3	11.2	10.9	11.0	11.0	11.5	11.4	11.0	-	-
200	7.8	8.3	8.2	8.1	8.9	9.1	8.3	9.5	8.2	8.5	4-8	4-6
% AC[1]	5.2	5.1	5.2	5.6	5.7	5.7	5.6	5.4	5.8	5.5	5.0-8.5	5 3-5.9

[1] Percent asphalt cement by weight of mix

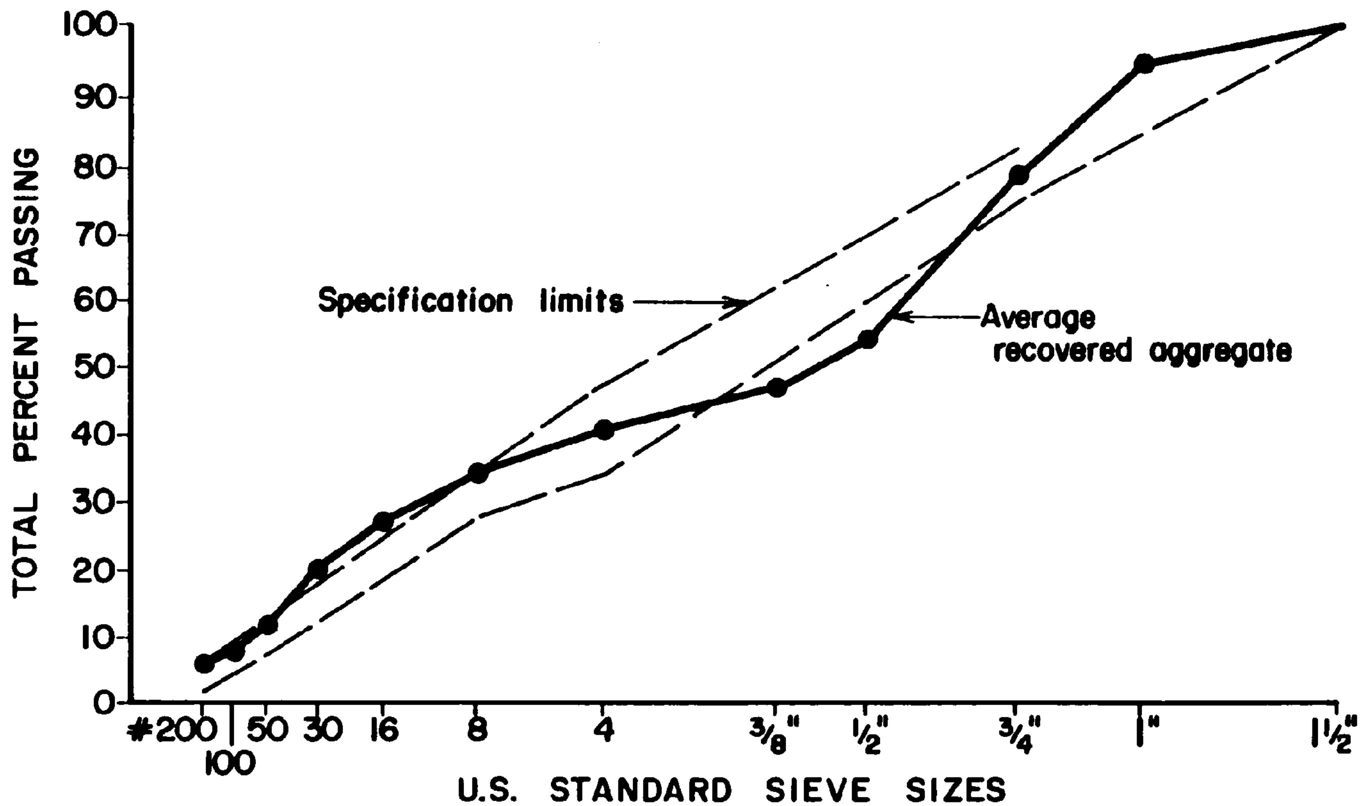


Figure 17. Gradation curve for extracted aggregate, binder course.

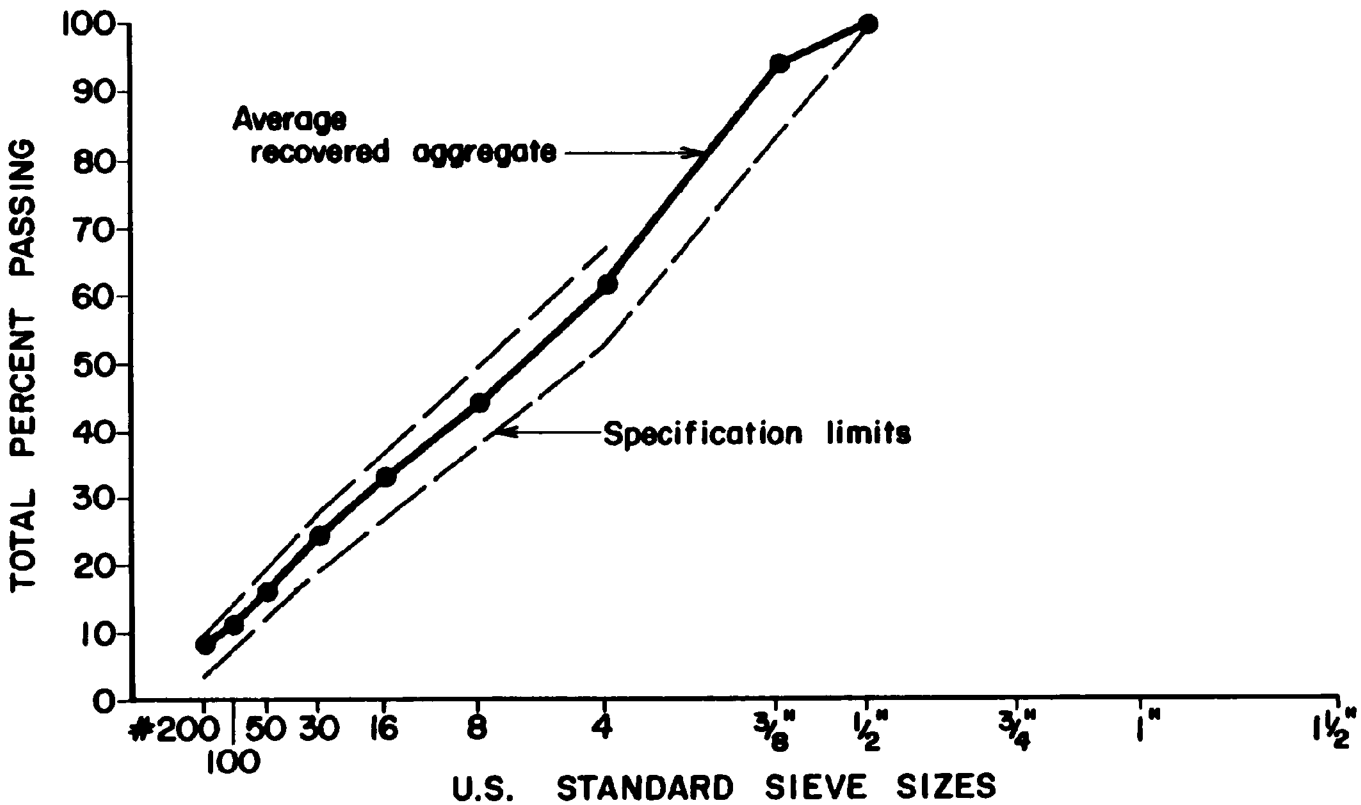


Figure 18. Gradation curve for extracted aggregate, wearing course.

Table 14. Laboratory measured values for resilient modulus, binder and wearing course mixes.

Sample No.	Mix Type	Test Temperature (F)	Wheel Path[1]	Modulus (10^6 psi) Test 1	Modulus (10^6 psi) Test 2	Average
1-W	Wearing	77	2-L	.319	.335	.327
2-W	Wearing	77	2-R	.311	.290	.300
3-W	Wearing	77	1-L	.234	.234	.234
4-W	Wearing	77	1-R	.286	.268	.277
1-T	Binder	77	2-L	.252	.260	.256
2-T	Binder	77	2-R	.187	.177	.182
1-B	Binder	77	2-L	.225	.209	.217
2-B	Binder	77	2-R	.200	.195	.197
3-B	Binder	77	1-L	.253	.244	.248
4-B	Binder	77	1-R	.395	.413	.404
1-W	Wearing	32	2-L	4.556	3.480	3.518
2-W	Wearing	32	2-R	3.747	3.428	3.587
3-W	Wearing	32	1-L	2.815	2.731	2.773
4-W	Wearing	32	1-R	3.097	3.172	3.134
1-T	Binder	32	2-L	4.662	5.030	4.846
2-T	Binder	32	2-R	2.933	2.885	2.909
1-B	Binder	32	2-L	2.979	3.294	3.137
2-B	Binder	32	2-R	2.149	2.245	2.197
3-B	Binder	32	1-L	2.695	2.376	2.536
4-B	Binder	32	1-R	5.148	5.118	5.133
1-W	Wearing	100	2-L	.043	.038	.040
2-W	Wearing	100	2-R	.041	.036	.039
3-W	Wearing	100	1-L	.033	.034	.034
4-W	Wearing	100	1-R	.034	.036	.035
1-T	Binder	100	2-L	.047	.045	.046
2-T	Binder	100	2-R	.032	.042	.037
1-B	Binder	100	2-L	.033	.036	.035
2-B	Binder	100	2-R	.035	.034	.035
3-B	Binder	100	1-L	.032	.033	.032
4-B	Binder	100	1-R	.061	.059	.060

[1]Note: 2-L = Lane 2, 1 ft (305 mm) left of center, station 97+00.
1-R = Lane 1, 1 ft (305 mm) right of center, station 97+00.
1.0 psi = 6.89 kPa.

Table 15. Moisture sensitivity test results.

	Surface[1]	Binder[1,2] (Lower Lift)
Voids (%)	7.3	5.4[3,4]
Dry Tensile Strength (psi)	125.9	138.9
Wet Tensile Strength (psi)	94.5	130.5
Tensile Strength Ratio (%)	75.1	94.0
Dry M_r (psi)	356,000	453,000
Wet M_r (psi)	262,000	442,000
M_r Ratio (%)	73.7	97.4
Visual Stripping	Slight, 10%	None

[1]Moisture damage test (Tunnicliff-Root) results at 77 F with M_r included. Mix included 0.5% Paver Bond Special.[13]

[2]Binder contained plus 1-in aggregate

[3]Inaccurate because mixture was very porous.

[4]Average percentage of voids calculated using the dimensions of specimens was 9.3.

Note: 1 psi = 6.89 kPa.

The nuclear density gage was also used to measure the in situ density of the binder course. The results of these measurements are shown in table 16; the average density is 145.8 lb/ft^3 (2,330 kg/m^3) for Lane 1 and 146.0 lb/ft^3 (2,340 kg/m^3) for Lane 2. Density measurements on the four cores tested at PTI gave an average density of 152.4 and 155.6 lb/ft^3 (2,440 and 2,490 kg/m^3) for the wearing and binder course, respectively. Using the 75-blow Marshall density from table 10 as a maximum density, the percentage of Marshall density for the two layers would be 95 and 94 percent, respectively.

As part of another project, researchers from the University of Nevada-Reno used five different nuclear gages to measure the density of the pavement. The results of these tests are given in table 17. Excellent agreement is shown between the PTI laboratory data and the University of Nevada-Reno laboratory and field data. As a consequence, the FHWA nuclear gage test result, 146.0 lb/ft^3 (2,340 kg/m^3), is considered suspect. This determination is reinforced by the observed erratic behavior of the gage when it was being used.

LAYER THICKNESS

In order to plot the profile and determine the thickness of the as-built pavement layers, precise leveling of the subgrade, the base course, and the wearing course was conducted. The precise levels were obtained in the field with reference to the project benchmark, which has an elevation of 229.59 ft (69.98 m). The results of the surveying and the associated pavement thicknesses are given in tables 18 and 19. Longitudinal profiles are shown in figures 19 and 20 for Lanes 1 and 2, respectively. As can be seen from the figures, the contractor did not provide good control of the longitudinal grade, and there is considerable variation in the thickness of the base and asphalt layers.

The location of the test sections is also shown in figures 19 and 20, and an average value of the thickness for each test section is given in table 20. Also shown in table 20 is the thickness of cores removed from Lanes 1 and 2 at station 97. The measured thickness of the cores agrees within the 0.1-inch (2.5-mm) thickness measured in the survey, verifying the thicknesses

Table 16. Nuclear density measurements made with FHWA nuclear density gage, binder course.

Station, Center line	Density, lb/ft^3	
	Lane 1	Lane 2
0+35	147.8	150.1
0+42	146.7	150.7
0+49	148.9	148.6
0+70	146.0	145.2
0+77	150.0	143.3
0+84	148.3	139.1
1+05	145.8	144.5
1+12	139.0	150.0
1+19	144.5	148.4
1+40	148.4	150.9
1+47	136.5	137.8
1+54	147.6	143.0
Avg.	145.8	146.0

Note: 1.0 lb/ft^3 = 16.0 kg/mg

Table 17. University of Nevada-Reno round robin density tests.

Gage	Bulk Density, lb/ft^3	Average Nuclear Density, lb/ft^3
1	158.5	155.8
2	154.5	155.4
3	155.0	155.4
4	155.6	156.8
5	155.3	151.0

Note: 1 psi = 6.89 kPa.

Table 18. Elevations and thicknesses of pavement layers, Lane 1.

Station	Top of Subgrade Elevation (ft)	Top of CAB Elevation (ft)	CAB Thickness (in)	Top of AC Elevation (ft)	AC Thickness (in)	Total Pavement Thickness (in)
0	227.92	228.31	4.7	228.62	3.7	8.4
25	227.76	228.22	5.5	228.57	4.2	9.7
50	227.74	228.08	4.0	228.45	4.4	8.5
75	227.54	227.94	4.8	228.35	4.9	9.7
100	227.43	227.80	4.4	228.21	4.9	9.4
125	227.21	227.72	6.1	228.10	4.6	10.7
150	227.14	227.57	5.2	227.97	4.8	10.0
175	226.94	227.47	6.4	227.86	4.7	11.0
200	226.66	227.45	9.5	227.72	3.2	12.7
Avg., Station 25 to 175			5.2		4.6	9.9

Note: Elevation measurements obtained along the center line of the pavement, i.e., the center line of the expected wheel tracks.
CAB = crushed-aggregate base course
AC = asphalt concrete wearing course
1.0 ft = 305 mm
1.0 in = 25.4 mm

Table 19. Elevations and thicknesses of pavement layers, Lane 2.

Station	Top of Subgrade Elevation (ft)	Top of CAB Elevation (ft)	CAB Thickness (in)	Top of AC Elevation (ft)	AC Thickness (in)	Total Pavement Thickness (in)
0	227.26	228.13	10.4	228.64	6.1	16.4
25	227.12	227.99	10.4	228.58	7.1	17.5
50	226.99	227.92	11.2	228.47	6.6	17.8
75	226.90	227.78	10.6	228.33	6.6	17.2
100	226.72	227.65	11.2	228.23	7.0	18.1
125	226.52	227.55	12.4	228.12	6.8	19.2
150	226.40	227.44	12.5	227.99	6.6	19.1
175	226.21	227.34	13.6	227.88	6.5	20.0
200	226.01	227.22	14.5	227.74	6.2	20.8
Avg., Station 25 to 175			11.7		6.7	18.4

Note: Elevation measurements obtained along the center line of the pavement, i.e., the center line of the expected wheel tracks.
CAB = crushed-aggregate base course
AC = asphalt concrete wearing course
1.0 ft = 305 mm
1.0 in = 25.4 mm

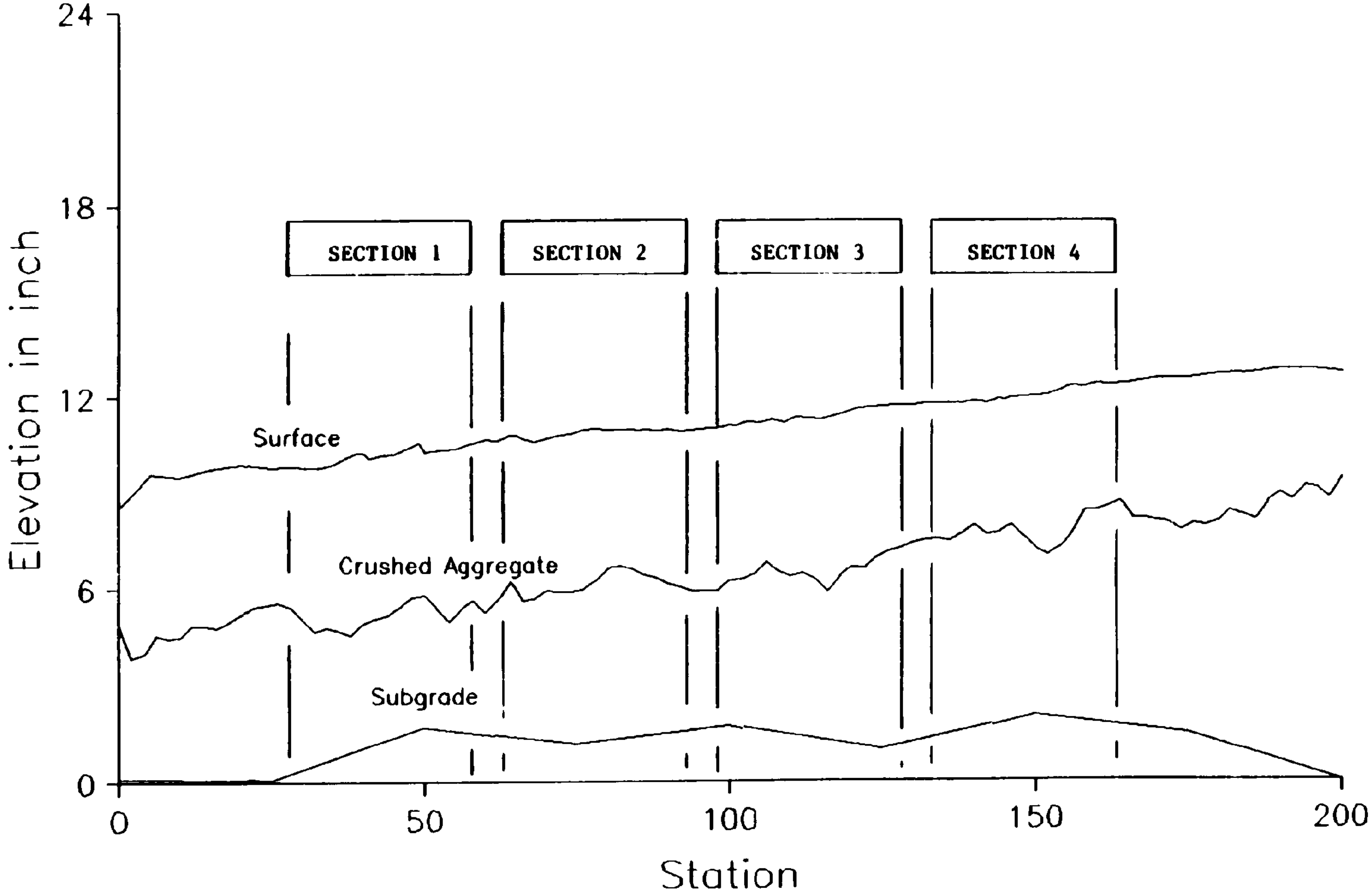


Figure 19. Longitudinal profiles of pavement layers, Lane 1.

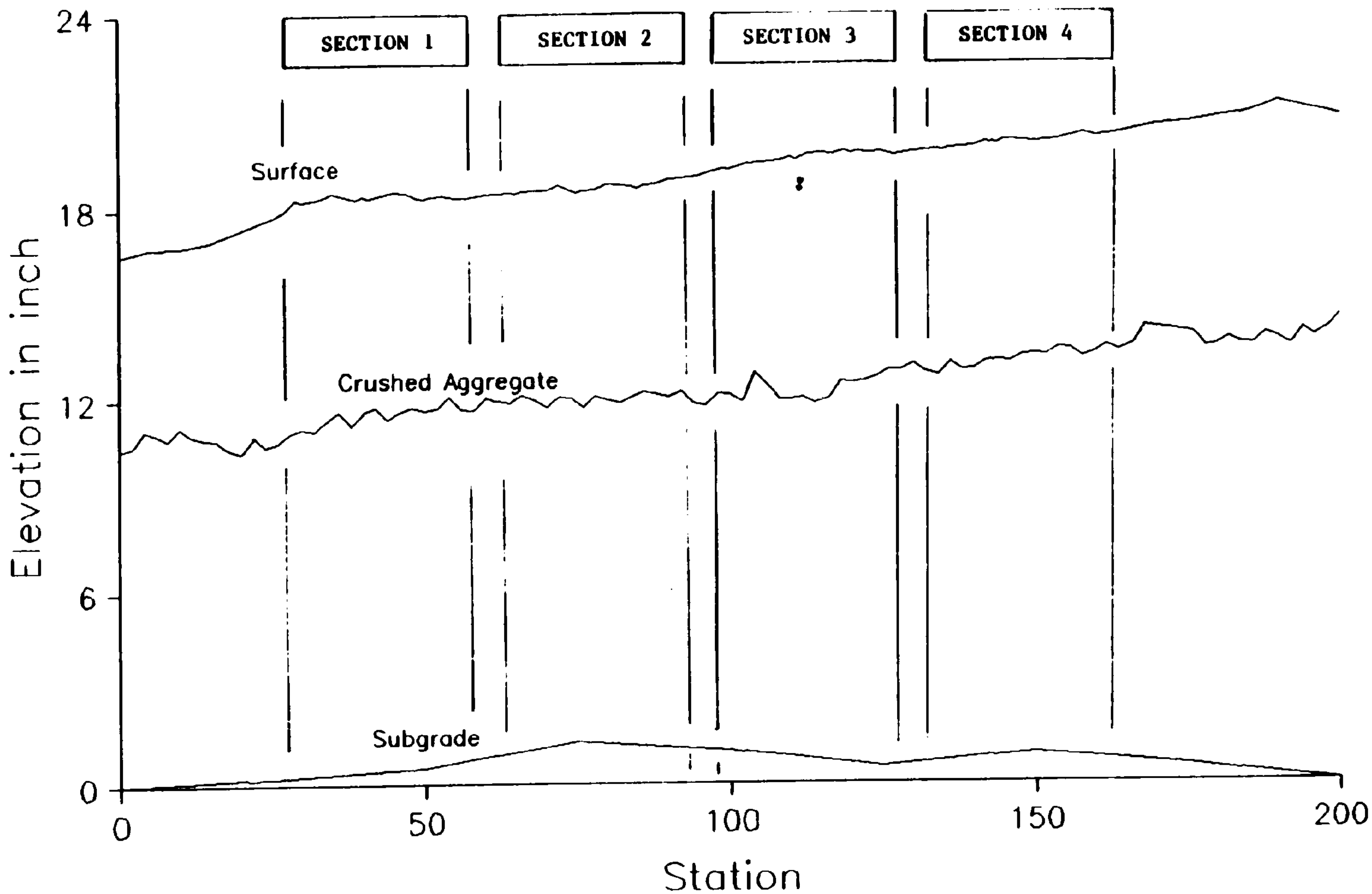


Figure 20. Longitudinal profiles of pavement layers, Lane 2.

Table 20. Measured thicknesses of pavement layers compared to design thickness.

		Thickness, inches		
Lane	Section	Crushed-Aggregate Base	Asphalt Concrete	Total
1	1	4.5	5.0	9.5
	2	4.8	5.0	9.8
	3	5.5	4.8	10.3
	4	6.5	4.2	10.7
	Rod/Level	5.3	4.8	10.1
	Cores[1]	-	5.1	-
	Design	6.0	5.0	11.0
2	1	11.3	7.0	18.3
	2	11.2	6.8	18.0
	3	11.8	7.3	19.1
	4	12.8	7.0	19.8
	Rod/Level	11.8	7.0	18.8
	Cores[1]	-	7.4	-
	Design	12.0	7.5	19.5

[1] Average of two cores in each lane at center line, Station 97.

Note: 1.0 in = 25.4 mm

calculated from the rod and level survey. The average thicknesses listed in table 20 should be used in future analyses of the pavement test sections. These estimates are better than the core thicknesses because they represent the averages of the entire section.

INSTRUMENT PLACEMENT

As indicated earlier, one objective of the ALF project is to verify the AASHTO design procedure for flexible pavements. To meet this objective, it will be necessary to collect and analyze various types of pavement data at regular intervals as the pavement is subjected to accelerated loading. To facilitate the collection of such data, an instrumentation plan was designed as discussed in chapter 3. In accordance with the instrumentation plan, the strain gages, soil-moisture cells, and thermocouples were installed in the pavement at the time of construction. The exact location and description of these instruments are provided in figures 21 through 24 and in tables 21 and 22.

The strain gages were placed in test sections 2 and 3 in both Lanes 1 and 2. Test section 3 in Lanes 1 and 2 contains nine gages, three of the Canadian gages and six of the H-beam Kyowa gages. Test section 2 in Lanes 1 and 2 contains the H-beam Kyowa gage. Each test section contains thermocouples at the interface of each layer. Moisture cells were placed in the subgrade in test section 3 in Lanes 1 and 2. Therefore, the section 3 portions of Lanes 1 and 2 are the most heavily instrumented and will be tested first.

DEFLECTION MEASUREMENTS

Deflections for each layer in the pavement were determined during construction with a falling weight deflectometer (FWD) and a Road Rater (RR). A Model ML 1000 falling weight deflectometer manufactured by Phoenix/Partner Technic Corp., Denmark, was used for the FWD measurements. The Road Rater measurements were obtained with a Model 2000 Road Rater produced by Foundation Mechanics, Inc., of El Segundo, California. The test plan specified deflection measurements at six locations in each test section, as shown in figure 25. Thus, for each pavement layer, 24 deflection measurements were

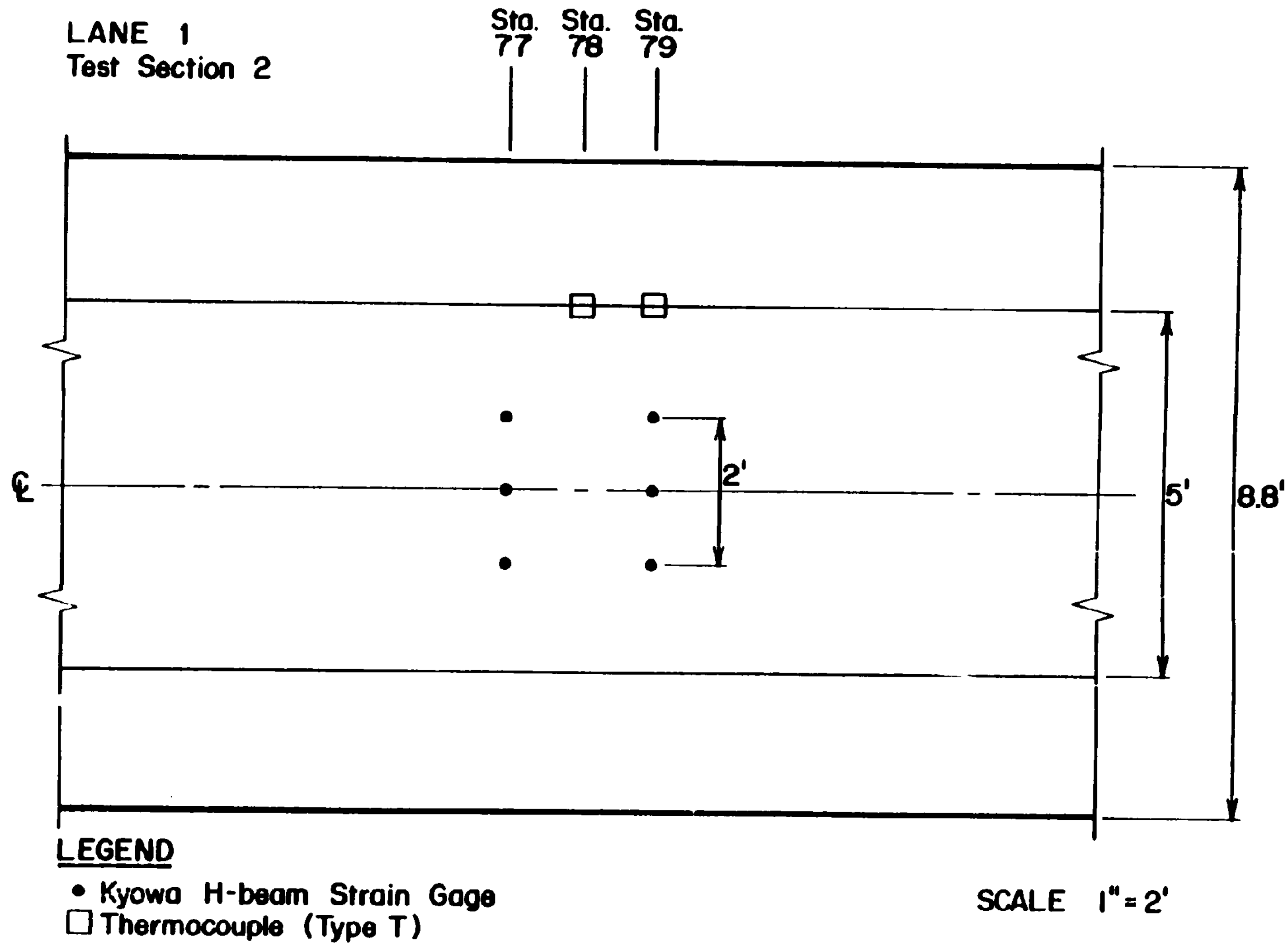


Figure 21. Location of gages in Lane 1, test section 2.

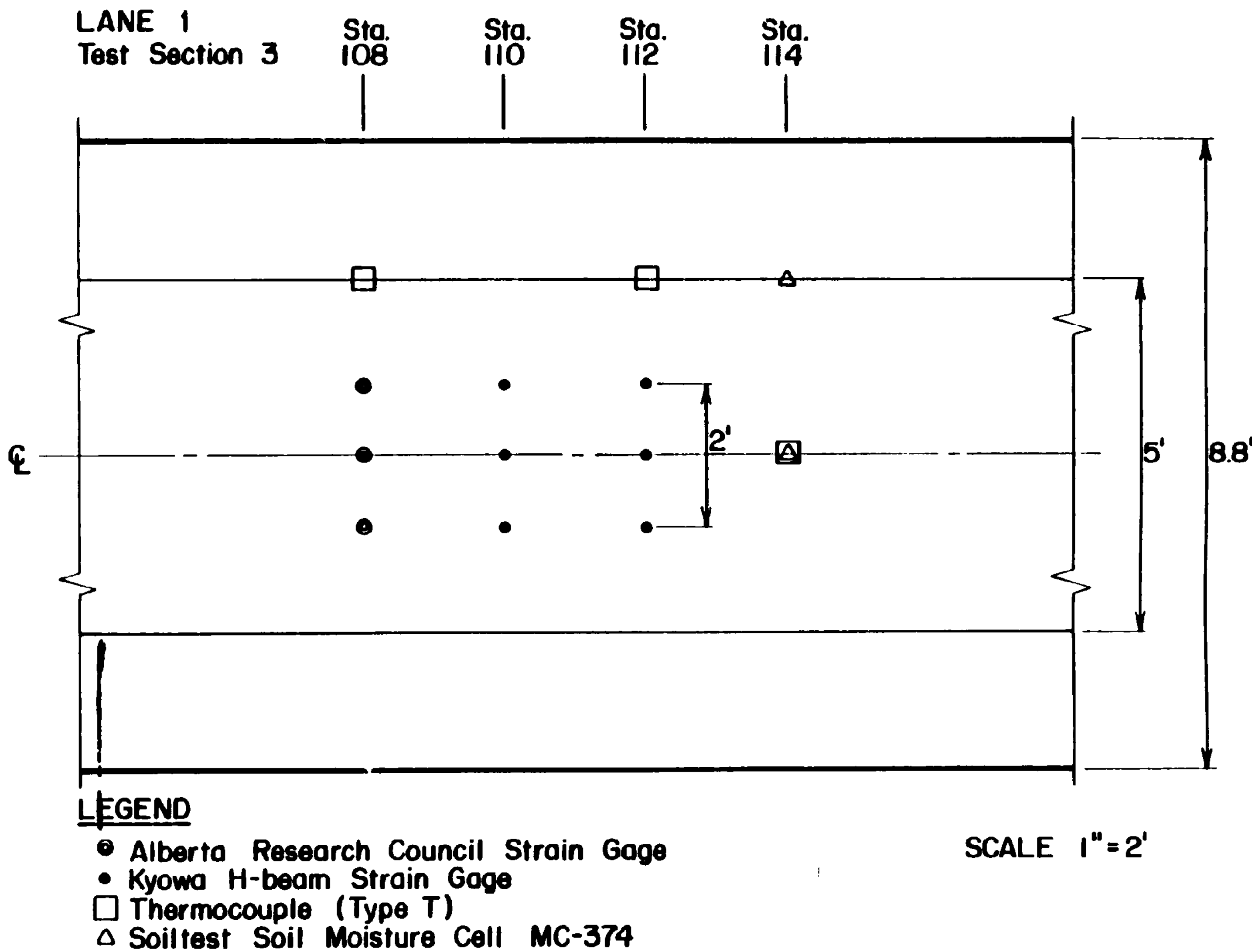


Figure 22. Location of gages in Lane 1, test section 3.

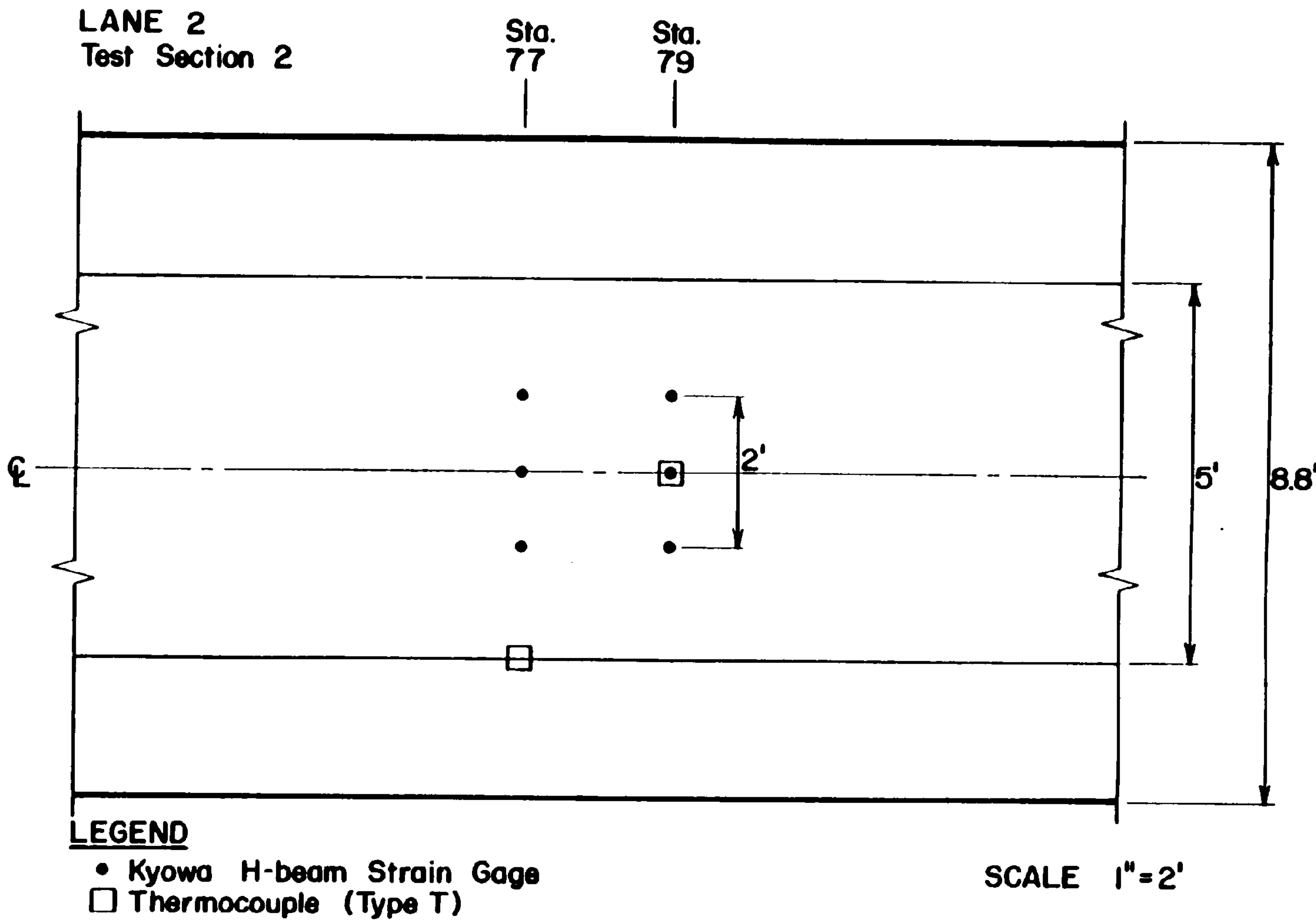


Figure 23. Location of gages in Lane 2, test section 2.

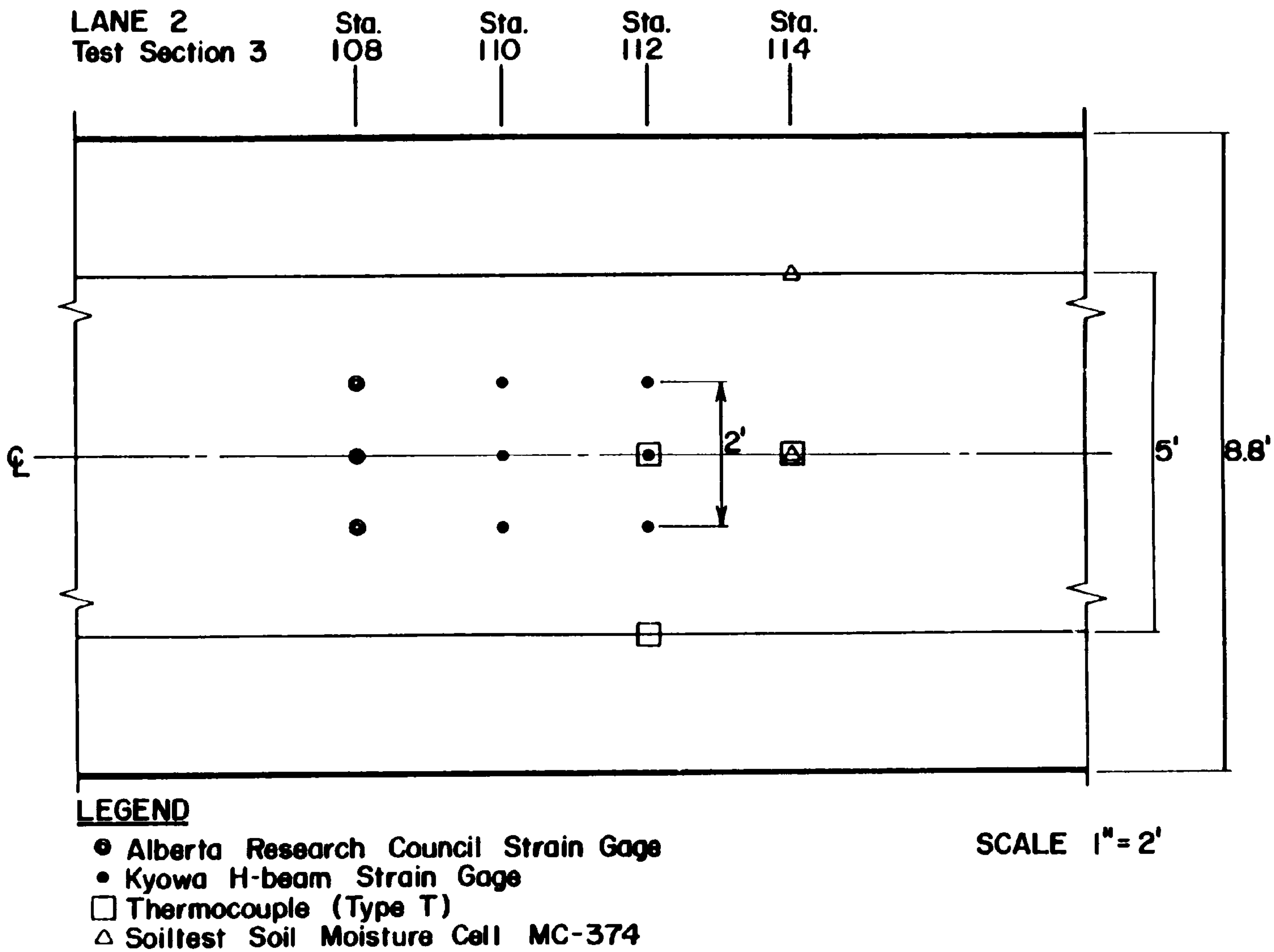


Figure 24. Location of gages in Lane 2, test section 3.

Table 21. Location of gages in Lane 1.

Test Section	Gage Type	Station	Gage No.	Offset from CL	Depth
2	H-strain	77	17	1 ft right	Top of base
	H-strain	77	18	CL	Top of base
	H-strain	77	19	1 ft left	Top of base
	TC	78	T31	2.5 ft left	Top of base
	H-strain	79	20	1 ft right	Top of base
	H-strain	79	21	CL	Top of base
	H-strain	79	22	1 ft left	Top of base
	TC	79	T22	2.5 ft left	Top of base
3	C-strain	108	1	1 ft right	Top of base
	C-strain	108	2	CL	Top of base
	C-strain	108	3	1 ft left	Top of base
	TC	108	T25	2.5 ft left	Top of base
	H-strain	110	5	1 ft right	Top of base
	H-strain	110	6	CL	Top of base
	H-strain	110	7	1 ft left	Top of base
	H-strain	112	8	1 ft right	Top of base
	H-strain	112	9	CL	Top of base
	H-strain	112	10	1 ft left	Top of base
	TC	112	T27	2.5 ft left	Top of binder
	MC	114	M6	CL	24 in below top of subgrade
	MC	114	M7	CL	12 in below top of subgrade
	MC	114	M8	CL	1 in below top of subgrade
	MC	114	M9	2.5 ft left	12 in below top of subgrade
	MC	114	M10	2.5 ft left	1 in below top of subgrade
	TC	114	T1	CL	48 in below top of subgrade
	TC	114	T2	CL	36 in below top of subgrade
	TC	114	T3	CL	24 in below top of subgrade
	TC	114	T4	CL	12 in below top of subgrade
	TC	114	T5	CL	1 in below top of subgrade
	TC	114	T11	CL	2 in below top of subgrade

H-strain: Kyowa H-beam strain gages
C-strain: Canadian strain gages
TC: Thermocouples
MC: Moisture cells

Table 22. Location of gages in Lane 2.

Test Section	Gage Type	Station	Gage No.	Offset from CL	Depth
2	H-strain	77	14	1 ft right	Top of base
	H-strain	77	15	CL	Top of base
	H-strain	77	16	1 ft left	Top of base
	TC	77	T29	2.5 ft right	Top of base
	TC	77	T30	2.5 ft right	Top of binder
	H-strain	79	23	1 ft right	Top of base
	H-strain	79	24	CL	Top of base
	H-strain	79	25	1 ft left	Top of base
	TC	79	T23	CL	Top of base
3	C-strain	108	6x	1 ft right	Top of base
	C-strain	108	5x	CL	Top of base
	C-strain	108	4	1 ft left	Top of base
	H-strain	110	1415	1 ft right	Top of base
	H-strain	110	2324	CL	Top of base
	H-strain	110	2526	1 ft left	Top of base
	H-strain	112	1627	1 ft right	Top of base
	H-strain	112	2624	CL	Top of base
	H-strain	112	1313	1 ft left	Top of base
	TC	112	T24	CL	Top of base
	TC	112	T26	2.5 ft right	Top of binder
	TC	112	T28	2.5 ft right	Top of base
	TC	114	T12	CL	47 in below top of subgrade
	TC	114	T13	CL	32 in below top of subgrade
	TC	114	T14	CL	12 in below top of subgrade
	TC	114	T15	CL	1 in below top of subgrade
	TC	114	T21	CL	2 in below top of base
	MC	114	M16	CL	24 in below top of subgrade
	MC	114	M17	CL	12 in below top of subgrade
	MC	114	M18	CL	1 in below top of subgrade
	MC	114	M19	2.5 ft left	12 in below top of subgrade
	MC	114	M20	2.5 ft left	24 in below top of subgrade

H-strain: Kyowa H-beam strain gages
C-strain: Canadian strain gages
TC: Thermocouples
MC: Moisture cells

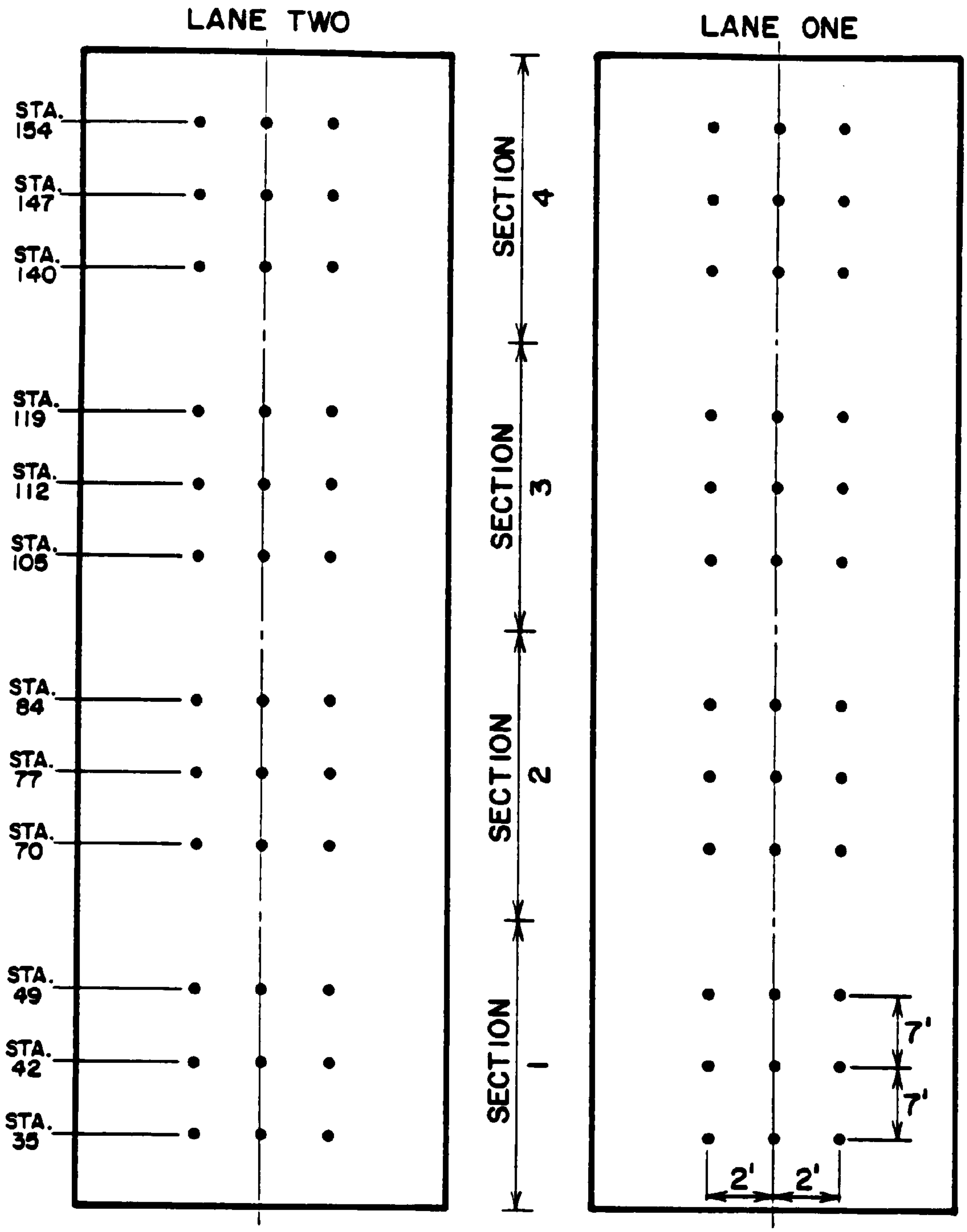


Figure 25. Location of deflection measurements in each test section.

anticipated. However, equipment problems precluded a complete set of measurements for each layer. The deflections obtained with the FWD are tabulated in tables 23 through 25. These deflections were used by Pavement Consultancy Services, Inc., to calculate a composite modulus and the CBR for each layer; these values are also reported in the tables. A proprietary program was used to make these calculations.

The deflections measured with the RR, and the associated moduli are given in tables 26 through 28. It should be pointed out that, as with the FWD data in tables 23 through 25, the temperatures given are air temperatures, and the moduli and deflections are not temperature corrected. Additionally, it should be pointed out that the moduli and CBR values are composite values, and, except for the subgrade, do not indicate the values for the individual layers.

Average values for the composite moduli for the two lanes are listed in table 29. The average subgrade CBR is 5.0 percent for both lanes, supporting the 5.0 percent figure that was estimated from the classification data. Although slightly smaller than the 6.7 percent value that was obtained in the laboratory, the 5.0 value is recommended for future analyses. The laboratory CBR value was obtained from a stockpile sample, however, and may not be representative of the material placed in the roadway.

The average composite moduli values obtained with the FWD and the RR differ considerably. The values obtained with the FWD are consistently larger than those obtained with the RR. Future back-calculations and laboratory testing will address the validity of these values.

Table 23. FWD deflection measurements, subgrade.

Location of loading plate				Deflection, mils								
Lane	Test Section	Station	Offset	* 0.0	* 8.3	* 13.0	* 20.1	* 31.9	* 50.0	Load lb	Temp. F	Composite Modulus ksi
1	1	35+00	2 ft R	70.00	44.90	18.20	10.00	4.60		5973.00	95.00	9.10
			2 ft L	67.40	44.10	19.60	8.40	4.20		7415.00	95.00	6.00
		42+00	2 ft R	78.50	46.40	23.40	10.30	12.60		5047.00	95.00	3.60
			2 ft L	74.90	41.80	17.80	8.40	4.60		5973.00	95.00	3.80
		49+00	2 ft R	71.30	40.40	18.40	12.80	4.70		6463.00	95.00	6.10
			2 ft L	64.60	41.50	18.20	11.40	7.40		5252.00	95.00	6.20
	2	70+00	2 ft R	87.60	38.70	18.70	9.40	4.40		7003.00	95.00	6.50
			2 ft L	90.70	39.60	18.40	8.50	4.40		6179.00	95.00	6.90
		77+00	2 ft R	91.50	43.00	20.60	9.60	4.70		5355.00	95.00	5.40
			2 ft L	74.40	39.20	18.70	9.80	5.00		4944.00	95.00	6.40
		84+00	2 ft R	88.70	38.30	18.30	8.50	4.50		6282.00	95.00	4.40
			2 ft L	74.10	34.10	15.90	8.50	4.50		6076.00	95.00	6.10
	3	105+00	2 ft R	87.80	41.10	17.30	8.10	6.30		4120.00	95.00	6.70
			2 ft L	87.40	34.10	15.90	7.80	5.30		5664.00	95.00	7.80
		112+00	2 ft R	61.00	38.30	17.00	7.50	3.80		3502.00	95.00	5.50
			2 ft L	87.20	34.80	15.10	7.20	3.60		5870.00	95.00	6.30
		119+00	2 ft R	89.80	37.10	16.00	8.40	4.30		6179.00	95.00	7.60
			2 ft L	88.10	33.00	15.00	8.20	3.80		6385.00	95.00	6.40
	4	140+00	2 ft R	82.50	30.30	16.30	7.70	12.00		5355.00	95.00	8.60
			2 ft L	88.90	32.20	16.50	8.20	3.90		5870.00	95.00	7.70
		147+00	2 ft R	91.10	33.50	15.90	8.00	3.80		3502.00	95.00	6.10
			2 ft L	87.10	34.90	17.80	8.40	3.90		3502.00	95.00	7.50
		154+00	2 ft R	91.70	29.20	16.00	8.10	3.90		7518.00	95.00	8.10
			2 ft L	90.80	38.10	15.40	7.80	3.70		5767.00	95.00	10.40
2	1	35+00	2 ft R	76.20	28.00	16.20	10.00	6.20		4429.00	95.00	10.60
			2 ft L	89.40	28.80	17.30	10.00	5.90		3708.00	95.00	7.60
		42+00	2 ft R	67.20	30.40	15.90	12.90	5.60		6179.00	95.00	7.40
			2 ft L	78.50	34.50	16.30	9.60	5.80		7106.00	95.00	10.30
		49+00	2 ft R	90.30	33.70	16.20	9.00	5.00		7621.00	95.00	5.40
			2 ft L	86.70	34.50	15.20	8.90	5.00		5150.00	95.00	6.30
	2	70+00	2 ft R	76.50	37.00	18.90	8.50	3.50		7209.00	95.00	6.90
			2 ft L	81.90	33.90	16.40	8.10	7.00		5767.00	95.00	9.60
		77+00	2 ft R	65.80	41.20	21.20	10.50	4.80		5870.00	95.00	7.60
			2 ft L	70.70	38.70	19.00	8.90	3.90		5252.00	95.00	7.90
		84+00	2 ft R	90.70	36.50	17.20	8.50	3.70		5973.00	95.00	9.50
			2 ft L	73.60	25.20	16.10	8.30	3.70		3708.00	95.00	9.20
	3	105+00	2 ft R	75.60	31.10	14.30	6.10	2.90		7621.00	95.00	6.20
			2 ft L	77.40	30.00	14.90	7.00	3.30		7518.00	95.00	4.80
		112+00	2 ft R	67.90	24.30	10.10	5.60	2.90		5458.00	95.00	8.40
			2 ft L	90.00	28.10	12.50	5.80	3.00		7518.00	95.00	7.00
		119+00	2 ft R	75.00	29.80	11.90	5.40	2.90		5458.00	95.00	8.90
			2 ft L	74.30	31.70	15.00	6.60	3.50		7518.00	95.00	6.70
	4	140+00	2 ft R	81.10	33.50	18.30	7.90	3.50		4635.00	95.00	8.00
			2 ft L	88.50	38.30	19.40	7.60	3.50		5870.00	95.00	5.60
		147+00	2 ft R	76.10	38.50	17.30	7.80	3.50		5973.00	95.00	8.70
			2 ft L	66.10	39.00	17.20	8.10	3.70		7209.00	95.00	8.60
		154+00	2 ft R	66.30	35.00	17.00	7.90	3.50		7415.00	95.00	5.50
			2 ft L	71.70	33.60	16.70	8.10	3.90		5767.00	95.00	3.90

* Numbers indicate distance of sensor from loading plate

Table 24. FWD deflection measurements, base.

Location of loading plate			Deflection, mils								
Lane	Test Section	Offset	* 0.0	* 8.3	* 13.0	* 20.1	* 30.9	* 50.0	Load lb	Temp. F	Composite Modulus ksi
1	1	2 ft R	68.50	38.01	17.32	7.94	3.92	2.18	6730.00	95.00	10.30
		2 ft L	71.95	35.20	16.43	6.94	3.62	2.16	6730.00	95.00	8.87
	2	2 ft R	83.83	33.46	17.05	7.64	4.13	2.12	6799.00	95.00	7.67
		2 ft L	78.55	34.08	15.26	7.69	5.60	3.47	6937.00	95.00	8.37
	3	2 ft R	80.28	34.77	16.30	7.18	3.57	2.05	6799.00	95.00	8.03
		2 ft L	71.82	31.68	17.40	7.16	3.65	1.90	6868.00	95.00	9.13
	4	2 ft R	47.43	27.32	15.40	6.85	3.42	1.95	7418.00	95.00	17.27
		2 ft L	58.93	28.97	15.56	7.11	3.40	1.84	6868.00	95.00	11.10
2	1	2 ft R	45.80	24.01	15.31	8.67	5.18	3.28	6730.00	95.00	18.30
		2 ft L	56.80	25.52	15.30	8.74	5.13	3.21	8727.00	95.00	15.23
	2	2 ft R	75.20	29.60	18.10	9.49	4.62	2.26	8451.00	95.00	11.07
		2 ft L	63.92	30.27	17.94	8.96	4.18	2.61	8520.00	95.00	12.97
	3	2 ft R	68.50	23.34	15.88	8.02	3.89	2.09	9060.00	95.00	12.67
		2 ft L	46.96	26.84	15.76	8.24	3.96	2.25	9031.00	95.00	18.23
	4	2 ft R	55.46	24.62	16.24	8.78	4.10	2.20	8859.00	95.00	16.47
		2 ft L	43.24	24.55	16.09	8.41	4.08	2.19	8520.00	95.00	18.66

* Numbers indicate distance of sensor from loading plate

Table 25. FWD deflection measurements, wearing course.

Location of loading plate			Deflection, mils								
Lane	Test Section	Offset	* 0.0	* 8.3	* 13.0	* 20.1	* 31.9	* 50.0	Load lb	Temp. F	Composite Modulus ksi
1	3	2 ft R	43.13	34.43	28.67	18.93	8.93	3.07	7449.00	72.00	16.37
		2 ft L	33.87	25.33	19.83	11.83	5.17	2.07	7380.66	72.00	20.60
2	1	2 ft R	9.70	7.50	6.20	4.70	3.20	2.10	8239.00	66.00	98.40
		2 ft L	14.70	11.80	10.00	7.30	4.40	2.50	8239.00	67.00	52.90
	2	2 ft R	13.10	10.60	9.20	7.00	4.20	2.00	8239.00	66.00	59.40
		2 ft L	17.10	13.50	11.60	8.50	4.90	2.20	8445.00	65.00	46.80
	3	2 ft R	10.70	8.60	7.40	5.60	3.50	1.80	8136.00	62.00	72.00
		2 ft L	14.80	12.30	10.90	8.30	5.20	2.50	7930.00	65.00	50.70
	4	2 ft R	8.90	6.70	5.60	4.10	2.60	1.40	8239.00	61.00	88.00
		2 ft L	13.50	10.70	9.10	6.70	3.90	1.90	7930.00	76.00	55.50

* Numbers indicate distance of sensor from loading plate

Table 26. RR deflection measurements, subgrade.

Lane	Test Section	Station	Offset	Deflection, mils				Load ksi	Temp. F	Composite Modulus ksi
1	1	35+00	2 ft R	9.25	4.04	2.13	1.22	2.32	80.00	2.50
			2 ft L	10.17	3.77	2.10	1.20	2.31	80.00	2.30
		42+00	2 ft R	9.48	4.21	2.09	1.14	2.24	80.00	2.40
			2 ft L	8.82	2.93	1.84	1.06	2.33	80.00	2.70
		49+00	2 ft R	9.63	3.10	1.80	1.65	2.22	80.00	2.30
			2 ft L	10.51	4.46	1.84	1.43	2.47	80.00	2.40
	2	70+00	2 ft R	9.06	3.78	2.35	1.15	2.46	80.00	2.70
			2 ft L	9.99	4.57	2.53	1.44	2.49	80.00	2.50
		77+00	2 ft R	9.13	4.59	2.50	1.36	2.55	80.00	2.80
			2 ft L	10.43	4.50	2.52	1.42	2.27	80.00	2.20
		84+00	2 ft R	8.50	4.05	2.19	1.27	2.48	80.00	2.90
			2 ft L	9.54	4.74	2.56	1.40	2.57	80.00	2.70
	3	105+00	2 ft R							
			2 ft L	9.55	3.96	2.33	1.19	2.48	80.00	2.60
		112+00	2 ft R							
			2 ft L	8.31	3.03	1.27	.84	1.89	80.00	2.30
		119+00	2 ft R	7.82	3.72	2.17	1.20	2.51	80.00	3.20
			2 ft L	7.60	3.26	1.27	.95	2.06	80.00	2.70
	4	140+00	2 ft R	8.24	4.12	2.22	1.18	2.60	80.00	3.10
			2 ft L	7.18	2.37	1.30	.82	2.24	80.00	3.20
		147+00	2 ft R	9.55	4.38	2.16	1.15	2.55	80.00	2.70
			2 ft L	6.80	3.40	1.60	1.02	2.48	80.00	3.60
		154+00	2 ft R	9.20	3.56	2.27	1.17	2.64	80.00	2.90
			2 ft L	7.19	3.20	1.74	1.03	2.52	80.00	3.50
2	1	35+00	2 ft R							
			2 ft L	4.76	2.03	1.96	.88	1.69	80.00	3.40
		42+00	2 ft R							
			2 ft L	7.77	4.92	2.53	2.17	2.30	80.00	2.60
		49+00	2 ft R							
			2 ft L	10.12	4.30	2.62	1.69	2.51	80.00	2.40
	2	70+00	2 ft R							
			2 ft L	8.63	4.56	2.43	1.22	2.78	80.00	3.20
		77+00	2 ft R							
			2 ft L	10.29	3.79	2.55	1.13	2.51	80.00	2.50
		84+00	2 ft R							
			2 ft L	8.87	3.73	1.58	.75	2.58	80.00	3.00
	3	105+00	2 ft R							
			2 ft L	8.25	3.78	1.76	1.14	2.63	80.00	3.20
		112+00	2 ft R							
			2 ft L	6.72	3.44	2.05	1.30	2.61	80.00	3.70
		119+00	2 ft R							
			2 ft L	7.43	3.74	1.62	1.13	2.76	80.00	3.70
	4	140+00	2 ft R							
			2 ft L	7.60	4.50	1.97	1.30	2.54	80.00	3.30
		147+00	2 ft R							
			2 ft L	10.09	4.07	1.97	1.15	2.34	80.00	2.40
		154+00	2 ft R							
			2 ft L	8.32	5.59	2.07	1.33	2.49	80.00	2.90

Table 27. RR deflection measurements, base.

Lane	Location of loading plate: Test Section	Station	Offset	Deflection, mils				Load ksi	Composite Modulus ksi
1	1	35+00	2 ft R	7.20	3.00	1.33	1.06	2.34	3.20
			2 ft L	8.18	3.45	1.50	.89	2.22	2.80
		42+00	2 ft R	7.02	3.25	1.08	1.04	2.19	3.10
			2 ft L	8.45	3.16	1.30	.89	2.28	2.80
		49+00	2 ft R	5.27	3.58	1.73	1.09	2.17	3.90
			2 ft L	7.53	4.21	1.22	1.14	2.32	3.10
	2	70+00	2 ft R	7.47	2.86	1.60	.88	2.39	3.20
			2 ft L	7.32	4.99	1.56	1.16	2.43	3.30
		77+00	2 ft R	6.93	2.98	1.21	.99	2.45	3.50
			2 ft L	8.39	4.17	1.32	1.23	2.40	2.80
		84+00	2 ft R	7.23	2.86	1.66	1.00	2.43	3.40
			2 ft L	7.70	3.37	1.36	1.11	2.45	3.20
	3	105+00	2 ft R	6.58	4.58	1.72	.84	2.42	3.70
			2 ft L	8.05	3.60	.95	.89	2.50	3.20
		112+00	2 ft R	7.96	3.51	1.92	.86	2.48	3.20
			2 ft L	8.05	4.30	1.72	.96	2.44	3.10
		119+00	2 ft R	6.97	4.24	1.10	1.04	2.51	3.60
			2 ft L	6.68	3.49	1.37	.96	2.44	3.60
	4	140+00	2 ft R	6.69	3.20	1.11	.89	2.56	3.80
			2 ft L	6.11	3.07	1.62	.87	2.50	4.10
		147+00	2 ft R	6.21	2.51	1.30	.87	2.56	4.10
			2 ft L	8.27	3.01	1.33	.92	2.59	3.20
		154+00	2 ft R	5.99	3.44	2.07	.85	2.41	4.03
			2 ft L	7.26	3.36	1.24	.88	2.53	3.50
2	1	35+00	2 ft R	5.33	3.68	1.67	1.55	2.45	4.10
			2 ft L	5.41	3.07	1.63	1.39	2.37	4.00
		42+00	2 ft R	5.21	3.30	1.69	1.50	2.52	4.30
			2 ft L	5.61	2.40	1.28	1.27	2.30	3.80
		49+00	2 ft R	4.31	2.59	1.11	1.03	2.37	5.10
			2 ft L	4.44	2.23	1.27	1.08	2.35	4.90
	2	70+00	2 ft R	4.27	2.74	1.52	.93	2.31	4.70
			2 ft L	4.74	2.79	1.38	.97	2.38	4.80
		77+00	2 ft R	5.27	3.38	1.20	.99	2.45	4.50
			2 ft L	5.51	2.98	1.49	.97	2.38	4.20
		84+00	2 ft R	4.98	2.73	1.05	.90	2.58	5.00
			2 ft L	5.47	2.70	1.43	.71	2.57	4.70
	3	105+00	2 ft R	4.85	2.98	1.15	.97	2.45	4.80
			2 ft L	4.53	2.60	1.36	.91	2.33	4.90
		112+00	2 ft R	4.89	2.11	.96	.90	2.47	4.90
			2 ft L	4.82	2.33	1.68	.80	2.35	4.80
		119+00	2 ft R	5.37	2.28	.88	.76	2.49	4.60
			2 ft L	3.87	2.73	1.08	.74	2.44	6.10
	4	140+00	2 ft R	4.55	2.52	1.43	.98	2.55	5.30
			2 ft L	4.42	2.18	1.50	.81	2.47	5.40
		147+00	2 ft R	4.82	3.16	1.49	.85	2.42	4.90
			2 ft L	4.24	2.21	1.15	.80	2.64	6.00
		154+00	2 ft R	4.44	2.41	1.67	.93	2.45	5.20
			2 ft L	4.59	2.39	1.43	.82	2.51	5.30

Table 28. RR deflection measurements, wearing course.

Lane	Test Section	Station	Offset	Deflection, mils				Load ksi	Composite Modulus ksi
1	1	35+00	2 ft R	6.73	3.38	1.61	.79	2.40	48.00
			2 ft L	5.85	2.84	1.86	.82	2.37	59.00
		42+00	2 ft R	5.72	2.47	1.24	.79	2.40	33.00
			2 ft L	6.01	2.98	1.74	.77	2.39	64.00
		49+00	2 ft R	5.90	2.47	1.16	.86	2.42	25.00
			2 ft L	5.67	2.98	1.70	.82	2.36	110.00
	2	70+00	2 ft R	4.92	2.58	1.70	.79	2.47	200.00
			2 ft L	6.27	2.94	1.72	.96	2.51	46.00
		77+00	2 ft R	5.57	2.52	1.56	.82	2.43	49.00
			2 ft L	5.25	2.70	1.42	.95	2.36	120.00
		84+00	2 ft R	5.12	2.52	1.55	.83	2.46	110.00
			2 ft L	6.29	2.78	1.61	.91	2.40	27.00
	3	105+00	2 ft R	5.80	2.57	1.42	.82	2.44	38.00
			2 ft L	5.05	2.45	1.46	.70	2.31	88.00
		112+00	2 ft R	5.37	2.56	1.41	.82	2.46	79.00
			2 ft L	5.90	2.37	1.27	.72	2.40	20.00
		119+00	2 ft R	4.95	2.42	1.31	.81	2.47	130.00
			2 ft L	4.46	2.33	1.23	.75	2.42	250.00
	4	140+00	2 ft R	5.24	2.32	1.27	.72	2.51	58.00
			2 ft L	5.32	2.15	1.24	.69	2.48	32.00
		147+00	2 ft R	3.70	1.94	1.64	.91	2.55	200.00
			2 ft L	5.48	2.16	1.09	.71	2.50	26.00
		154+00	2 ft R	3.54	1.60	1.34	.81	2.55	90.00
			2 ft L	5.61	2.37	1.17	.72	2.48	34.00
2	1	35+00	2 ft R	4.78	1.79	1.20	.97	2.34	8.80
			2 ft L	4.14	1.58	.82	.76	2.57	21.00
		42+00	2 ft R	3.28	1.95	1.11	1.09	2.42	650.00
			2 ft L	4.15	1.91	1.03	.92	2.52	57.00
		49+00	2 ft R	4.41	2.04	.97	.97	2.52	48.00
			2 ft L	4.64	1.73	1.12	.99	2.57	13.00
	2	70+00	2 ft R	5.19	2.11	1.29	.95	2.55	14.00
			2 ft L	3.56	1.69	1.25	.90	2.35	91.00
		77+00	2 ft R	3.76	2.27	1.42	.96	2.51	530.00
			2 ft L	4.32	1.89	1.15	.88	2.43	33.00
		84+00	2 ft R	3.85	2.00	1.36	.84	2.59	170.00
			2 ft L	4.45	1.95	1.27	.86	2.41	27.00
	3	105+00	2 ft R	4.50	1.90	1.13	.89	2.57	28.00
			2 ft L	3.55	1.66	1.09	.66	2.54	110.00
		112+00	2 ft R	4.51	1.80	.90	.78	2.53	19.00
			2 ft L	4.00	1.62	1.24	.81	2.48	29.00
		119+00	2 ft R	4.42	1.70	.97	.72	2.55	17.00
			2 ft L	3.06	1.60	1.08	.74	2.60	39.00
	4	140+00	2 ft R	3.32	1.64	.88	.76	2.59	200.00
			2 ft L	3.82	1.68	1.04	.70	2.62	65.00
		147+00	2 ft R	3.31	1.53	.89	.71	2.55	130.00
			2 ft L	3.04	1.50	1.05	.70	2.66	290.00
		154+00	2 ft R	4.14	1.58	.82	.76	2.57	21.00
			2 ft L	4.98	1.53	1.13	.68	2.67	4.40

Table 29. Average composite modulus and CBR determined from deflection measurements.

Lane	Deflection Method	Calculated Parameter	Subgrade	Base Course	Wearing Course
1	FWD	Modulus, ksi	6.6	10.9	18.5[1]
		CBR, percent	5.0	7.7	8.2
	RR	Modulus, ksi	2.7	3.4	80.7[1]
2	FWD	Modulus, ksi	7.5	15.5	65.5[1]
		CBR, percent	5.0	9.8	18.1
	RR	Modulus, ksi	3.0	4.9	109.0[1]

Note: $1.0 \ lb/in^2 = 6.89$ kPa

Note: Moduli are not temperature corrected

5. TESTING SCHEDULE

A testing schedule was established for the ALF device based upon the Australian experience. The suggested schedule is shown in table 30. During the initial phase of loading, the test frequency (every 10,000 cycles) is closely spaced to capture pavement conditions and changes as initial loading takes place. After the initial loading has taken place, the testing schedule is expanded to 50,000 cycles. During this phase of pavement life, the pavement condition does not change rapidly with load. During the end of the pavement life, conditions often change rapidly with additional loading. Therefore, the test frequency must be increased. This change in test frequency must be determined by the project engineer who is monitoring the operation on a daily basis.

It should be noted that the testing schedule serves only as a guideline. The testing schedule will be adjusted to coincide with other activities such as routine maintenance and other shutdown periods. The field testing program has been designed so that the tests conducted with the ALF wheel loads are coordinated with other field tests.

LOAD-ASSOCIATED MEASUREMENTS

Deflection testing will be done with a 15-ft-long (4.6-m) reference beam placed alongside the wheels of the ALF. An LVDT will be mounted at the midspan of the beam so that a vertical deflection basin can be obtained. The pavement deflection will be measured every 3.9 inches per 100 mm as the wheel traverses the pavement. Loading will be provided by the ALF tire loads. The deflection should be measured along the center line and 2 ft (0.61 m) right and left of the center line. Output will be in inches of deflection with a precision of 0.001 inch (.0254 mm).

Deflection measurements will also be taken with the falling weight deflectometer (FWD) and the Road Rater. Both devices will take measurements along the center line and 2 ft (.61 m) right and left of tne center line. The center of the deflection basin will be measured every 2 ft (.61 m) along the path of the ALF wheel.

Table 30. Testing schedule for routine pavement monitoring with the ALF device.

Test Number	Cycles of Loading
1	0
2	5,000
3	10,000
4	20,000
5	30,000
6	40,000
7	50,000
8	100,000
9	150,000
10	200,000
11	As needed

The loading for the FWD should be approximately 9,000 lb, which simulates an 18-kip single-axle load. The sensors on the FWD should be spaced 1 ft (.305 m) apart, with the first sensor directly under the load and a minimum of six sensors. A temperature profile within the pavement system must be measured each time a deflection test is done. The Road Rater will not be be used for routine deflection measurements.

The underside of the pavement in four of the test sections has been equipped with strain gages, and there are four strain gage load cell on the loading frame. Data from these strain gages will be monitored on selected passes of the wheels. The exact frequency of these measurements will be determined after trafficking is started, but initially the readings will be made on an hourly basis. Immediately after each set of measurements is taken, a set of thermocouple measurements will also be obtained.

The ALF strain and deflection profiles and the FWD deflections will serve as input for several mechanistic analysis programs. The BISAR, ELSYM5, and MODCOMP programs will be used to match measured deflections with theoretical deflections and to calculate in situ moduli. The back-calculated moduli will be used to monitor pavement performance.

RUT DEPTH MEASUREMENTS

Rut depth will be measured with the profiling device. The device will consist of a carriage supported on fixed rails so that the carriage can be translated in the x/y direction. The rails will be placed on the ALF frame or along the edge of the test pavement. The rut depth device will measure the profile in the transverse and longitudinal direction.

Transverse profile measurements will be obtained every 2 inches (50.8 mm) in the transverse direction for the full width of the pavement. These profiles will be measured every 2 ft (.61 m) in the longitudinal direction, giving a total of 16 profiles. Output will be in inches of rutting with a precision of 0.01 inch (.254 mm).

The rut depth information can be used to evaluate the permanent deformation in the pavement system. The data will also be used to validate computer models such as VESYS.

LONGITUDINAL PROFILES

The longitudinal profiles will be measured with the same device which is used for the transverse profile measurements. The pavement profile will be measured every 2 inches (50.8 mm) in the longitudinal direction. Profiles will be measured at the center line of the test section and 6 and 12 inches (.15 and .305 m) left and right of the center line. The profile should be converted to inches per mile for a roughness determination. The inches per mile can be converted to a Present Serviceability Index (PSI) value.

CONDITION SURVEY

A condition survey will be done visually using the testing schedule presented in table 30. This schedule should be supplemented with more frequent measurements if the project engineer observes that the pavement is deteriorating rapidly. The visual survey will be supplemented with a condition survey using 35-mm photographs. To determine the severity and extent of the pavement distress, the pavement will be periodically covered with a sheet of heavy gauge, clear plastic. Cracking and other distress manifestations are marked on the plastic. Each time a condition survey is done, the progression of the cracking and other forms of distress is marked on the sheet.

The types of distress which will be measured are the same as those recommended for the Long-Term Pavement Monitoring Program (LTPP): alligator/fatigue cracking, raveling, bleeding, block cracking, longitudinal cracking, transverse cracking, potholes, and reflection cracking. Any other distress that occurs will also be noted during the condition survey. The condition survey information can be used for the validation of pavement performance models and with other planned studies.

CLIMATE INFORMATION

Weather data will be obtained from the Dulles Airport NOAA weather station and assembled in a computer file for future reference. Data that will be recorded include rainfall/snowfall, air temperature, and humidity. These data will be gathered daily. The in situ pavement temperature will be measured with the instrumentation described in chapter 3.

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