Asphalt Pavement Temperatures

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The use of thicker asphalt paving courses in heavy-duty highways has resulted in the need for more information on temperature variations in pavement structures. Temperature data are necessary in studies of pavement deflections, stresses and strains under moving wheel loads. Pavement temperature data are of interest in any study or test involving the temperature-dependent mechanical properties of paving mixtures or paving asphalts.

The pavement temperature studies reported here were conducted to provide information on temperature variations in thicker asphalt-concrete pavements that would be applicable in many areas of the United States. Pavement temperatures were measured at the surface and at depths of 2, 4, and 6 in. in a 6-in. thick asphalt-concrete pavement, and at depths of 2, 4, 6, 8, 10 and 12 in. in a 12-in. thick asphalt-concrete pavement. A temperature recorder was used to record air and pavement temperatures at the test site in College Park, Maryland, from June 1, 1964, to May 31, 1965.

The durations of various temperature levels, and maximum, minimum and average temperatures based on hourly temperatures at the various depths, are reported for each month and for the entire year. Test data and information on daily pavement temperature changes with depth, and rates of temperature change, are also reported.

•ASPHALT PAVING courses totaling 6 in. or more in thickness are now being constructed on many heavy-duty highways. Because of these recent developments in asphalt paving structural design there is a need for more information on temperature variations in thicker asphalt pavements. Studies in Louisiana of pavement temperatures at depths of ½ and 2 in. have been reported by Arena (1). A method for calculating maximum pavement surface temperatures from weather reports has been presented by Barber (2), and pavement temperatures were considered by Monismith et al. (3) in their investigations of thermal stresses and deformations in asphalt concrete. However, little temperature data are available for thicker asphalt pavements. Pavement temperature data are necessary in studies of deflections, stresses and strains in pavements subjected to moving wheel loads. Pavement temperature data are also of interest in laboratory studies or testing involving the mechanical behavior of asphalts or paving mixtures.

This paper presents pavement temperature data obtained from a year-long study by The Asphalt Institute. The studies were made from June 1, 1964, to May 31, 1965, on pavement test sections located at College Park, Maryland.

DESCRIPTION OF TEST SECTION

An asphalt concrete test section 12 ft wide and 24 ft long was used for the study (Fig. 1). It was constructed in a location not shielded from the sun and wind. A 10-ft

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Figure 1. Asphalt-concrete pavement test section.

length of the section was constructed 6 in. thick. A transition section 2 ft long was used and the remaining 12-ft length of the section was constructed 12 in. thick. The test section was built adjacent to a parking lot which had a 4-in. thick asphalt-concrete surface. An asphalt curb was constructed over the joint between the test section and the parking lot. The section was built with conventional construction equipment. Asphalt concrete was used the full depth of the test section and was placed directly on the graded and compacted sandy-silt soil subgrade. The asphalt concrete was placed with a paver in 3-in. thick courses. Test results on the asphalt-concrete paving mixture and pavement core samples are given in Table 1.

INSTRUMENTATION

Standardized insulated iron and constantan thermocouple wires were installed with the temperature-measuring junctions at depths of 2, 4 and 6 in. in the 6-in. thick pavement, and at depths of 2, 4, 6, 8, 10 and 12 in. in the 12-in. pavement. The installations were made by cutting 4-in. diameter holes with a core drill to desired depths. The holes were dried, painted with hot asphalt, and the thermocouples were placed vertically with their temperature measuring junctions at the bottom of the holes. Paving mixture from the original construction, heated to 250 F, was placed in the holes and compacted with a Marshall Test Method compaction hammer. Hot asphalt cement was used to seal areas where the thermocouple wires emerged from the pavement surface. Periodic sealing of these areas and coating of exposed thermocouple wires with asphalt provided adequate thermocouple protection during the experiment. A surface temperature thermocouple wire was placed directly on the pavement surface with the temperature sensitive junction bent at a 90-deg angle and inserted about $\frac{1}{8}$ in. into the pavement. A small amount of asphalt used periodically to seal the thermocouple protected it during the experiment. The buried thermocouples were located in the middle of the two sections and were spaced 16 in. apart on centers. The surface temperature

TABLE 1

TESTS OF PAVING MIXTURES AND CORES

(a) Extraction Tests on Paving Mixture and Tests on Recovered Asphalt

Aggregate Analysis	Sieve Size	Percent Passing
	½ in.	100
	⅜ in.	78
	No. 4	55
	No. 8	45
	No. 16	37
	No. 30	30
	No. 50	12
	No. 100	7
	No. 200	5
Percent asphalt, total mix		4.9
Recovered asphalt penetration at 77 F (100 gm, 5 sec)		42
Recovered asphalt ductility at 77 F (5 cm/min)		142
Recovered asphalt softening point, deg F (ring and ball)		138

(b) Tests on Pavement Cores

Maximum specific gravity of paving mixture (ASTM test method D 2041)	2.509
Bulk specific gravity (avg for 8 cores)	2.281
Air voids, percent (avg for 8 cores)	9.1
Marshall stability at 140 F, lb (avg for 3 cores)	437
Marshall flow value, 0.01 in. (avg for 3 cores)	17
Hveem stability value at 140 F (avg for 2 cores)	23
Hveem cohesiometer value at 140 F (avg for 2 cores)	100
Unconfined compressive strength, psi (0.05 in./in. rate of loading):	
At 39 F	975
At 77 F	299
At 120 F	48
Tensile strength, psi (0.05 in./in. rate of loading):	
At 39 F	350
At 77 F	77
At 120 F	6

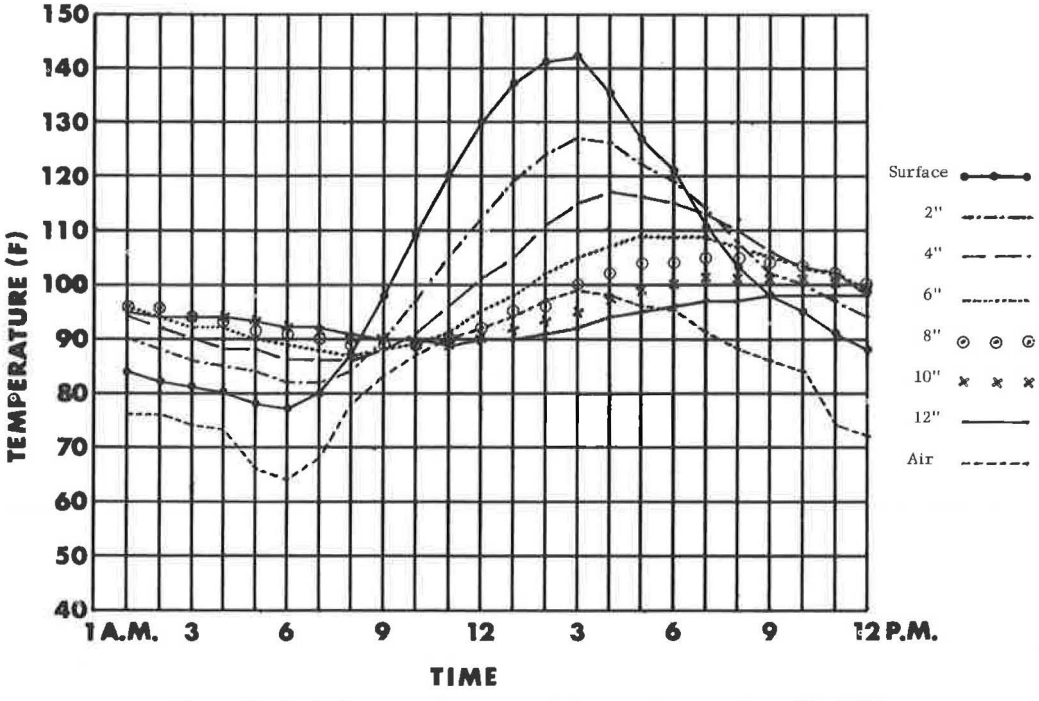

Figure 2. Asphalt-concrete pavement temperatures on June 30, 1964.

TABLE 2

HOURLY PAVEMENT TEMPERATURE (°F)
(June 30, 1964)

Time	Position Where Measurements Were Made										
	Air	Surface	12 In. Section (Depths, in.)						6 In. Section (Depths, in.)		
			2	4	6	8	10	12	2	4	6
1 AM	76	84	90	94	96	96	96	95	90	94	96
2 AM	76	82	88	92	94	96	96	94	88	92	94
3 AM	74	81	86	90	92	94	94	94	86	90	92
4 AM	73	80	85	88	92	93	94	94	84	88	92
5 AM	66	78	84	88	90	92	93	93	84	87	90
6 AM	64	77	82	86	89	91	92	92	82	86	89
7 AM	60	00	02	86	88	90	91	92	82	86	88
8 AM	78	87	84	86	87	89	90	91	84	86	87
9 AM	83	98	90	88	88	89	90	90	90	88	88
10 AM	87	109	97	91	89	89	89	90	97	91	89
11 AM	90	120	105	96	91	90	89	89	105	96	91
12 Noon	92	130	112	101	95	92	90	90	112	101	95
1 PM	94	137	119	105	98	95	92	90	119	106	98
2 PM	97	141	124	111	102	96	93	91	125	111	101
3 PM	99	142	127	115	105	100	95	92	128	115	105
4 PM	98	135	126	117	107	102	97	94	127	117	106
5 PM	96	127	122	116	109	104	99	95	122	116	108
6 PM	95	121	119	115	109	104	100	96	120	115	108
7 PM	91	111	114	113	109	105	101	97	115	113	109
8 PM	88	103	108	110	107	105	101	97	108	110	107
9 PM	86	98	102	106	105	104	101	98	103	104	105
10 PM	84	95	100	103	103	103	101	98	100	103	103
11 PM	74	91	97	102	102	102	100	98	97	102	102
12 PM	72	88	94	98	99	100	99	98	94	98	99

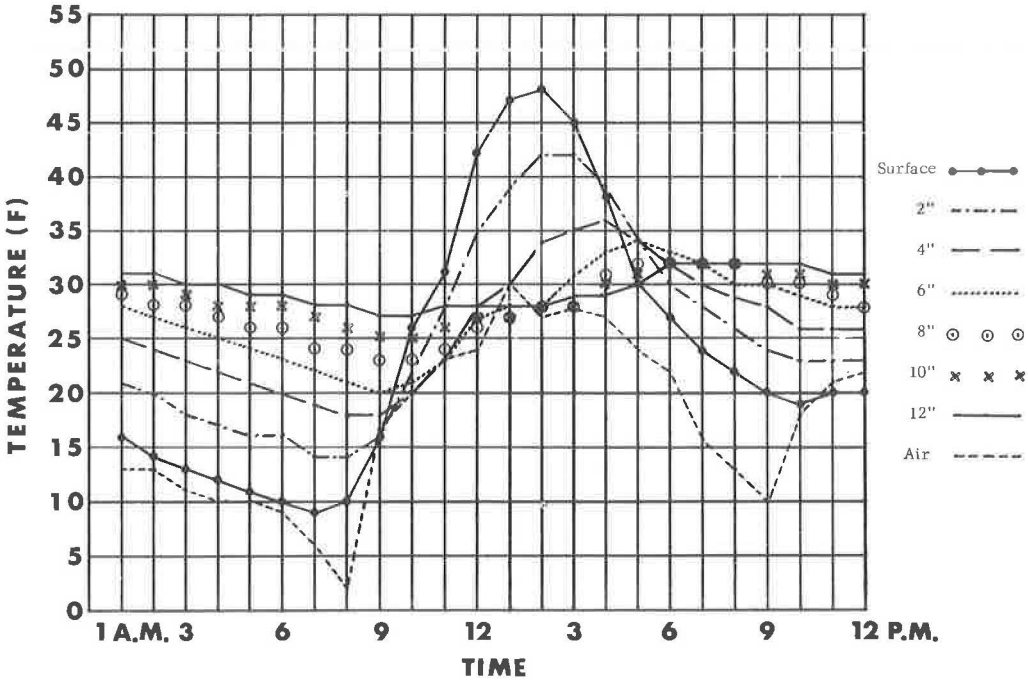

Figure 3. Asphalt-concrete pavement temperatures on January 19, 1965.

TABLE 3

HOURLY PAVEMENT TEMPERATURES (° F)
(January 19, 1965)

Time	Position Where Measurements Were Made							
	Air	Surface	12 In. Section (Depths, in.)					
			2	4	6	8	10	12
1 AM	13	16	21	25	28	29	30	31
2 AM	13	14	20	24	27	28	30	31
3 AM	11	13	18	23	26	28	29	30
4 AM	10	12	17	22	25	27	28	30
5 AM	10	11	16	21	24	26	28	29
6 AM	9	10	16	20	23	26	28	29
7 AM	6	9	14	19	22	24	27	28
8 AM	2	10	14	18	21	24	26	28
9 AM	17	16	16	18	20	23	25	27
10 AM	20	26	22	20	21	23	25	27
11 AM	23	31	28	23	23	24	26	28
12 Noon	24	42	35	28	27	26	27	28
1 PM	30	47	39	30	28	27	27	28
2 PM	27	48	42	34	28	28	28	28
3 PM	28	45	42	35	31	28	28	29
4 PM	27	38	39	36	33	31	30	29
5 PM	24	30	34	34	34	32	31	30
6 PM	22	27	30	32	33	32	32	32
7 PM	16	24	28	30	32	32	32	32
8 PM	13	22	26	29	30	32	32	32
9 PM	10	20	24	28	30	30	31	32
10 PM	18	19	23	26	29	30	31	32
11 PM	21	20	23	26	28	29	30	31
12 PM	22	20	23	26	28	28	30	31

TABLE 4

PAVEMENT TEMPERATURES (° F) DURING A RAIN STORM
(June 8, 1964)

Time (PM)	Position Where Measurements Were Made							
	Air	Surface	12 In. Section (Depths, in.)					
			2	4	6	8	10	12
1:00	84	124	106	93	87	82	80	79
2:00	85	120	108	97	90	85	82	80
2:05	84	117	108	98	90	85	82	80
2:10	77	110	108	98	91	85	82	80
2:15	68	102	107	98	91	85	82	80
2:20	64	93	105	98	91	86	82	80
2:25	63	86	103	98	92	86	83	81
2:30	65	83	99	98	92	86	83	81
2:35	66	83	97	98	92	86	83	81
2:40	66	83	95	97	92	87	83	81
2:45	66	83	93	96	92	87	84	81
2:50	66	83	92	96	92	87	84	81
2:55	66	82	91	95	92	87	84	81
3:00	66	80	91	94	92	87	84	81
3:05	66	80	90	94	92	87	84	81
3:10	66	80	89	93	91	87	84	81
3:15	66	81	88	93	91	88	84	82
3:20	67	82	88	92	91	88	84	82
3:25	68	83	88	92	91	88	84	82
3:30	68	83	87	91	90	87	84	82
4:00	74	93	89	89	89	87	84	82

TABLE 5

MONTHLY DURATION OF TEMPERATURE LEVELS, LOW, HIGH AND AVERAGE TEMPERATURES AT VARIOUS DEPTHS FOR 12-IN. ASPHALT CONCRETE PAVEMENT

Period During Which Measurements Were Made	Position Where Measurements Were Made	Percent of Month During Which The Temperature (° F) Was Between															Avg. Temp. (° F)	Avg. High Temp. (° F)	Avg. Low Temp. (° F)	High Temp. (° F)	Low Temp. (° F)
		0 & 9	10 & 19	20 & 29	30 & 39	40 & 49	50 & 59	60 & 69	70 & 79	80 & 89	90 & 99	100 & 109	110 & 119	120 & 129	130 & 139	140 & 149					
June 1964 (28 days)	Air	—	—	—	—	2	11	23	36	19	9	—	—	—	—	—	72	86	58	99	43
	Surface	—	—	—	—	—	1	10	23	22	12	10	8	8	5	1	93	124	69	142	55
	2-in. depth	—	—	—	—	—	—	5	21	29	17	15	9	4	—	—	90	112	73	127	61
	4-in. depth	—	—	—	—	—	—	2	17	35	26	15	5	—	—	—	89	104	77	119	65
	6-in. depth	—	—	—	—	—	—	1	16	41	29	13	—	—	—	—	88	98	79	109	68
	8-in. depth	—	—	—	—	—	—	—	16	44	32	8	—	—	—	—	88	95	81	105	70
	10-in. depth	—	—	—	—	—	—	—	17	49	31	3	—	—	—	—	87	92	82	101	71
	12-in. depth	—	—	—	—	—	—	—	16	58	26	—	—	—	—	—	86	89	82	98	72
July 1964 (25 days)	Air	—	—	—	—	—	4	29	35	26	6	—	—	—	—	—	75	86	63	98	53
	Surface	—	—	—	—	—	—	2	28	26	13	9	7	9	6	—	93	123	73	139	67
	2-in. depth	—	—	—	—	—	—	—	18	35	19	11	14	3	—	—	92	113	77	124	72
	4-in. depth	—	—	—	—	—	—	—	7	43	25	20	5	—	—	—	92	105	81	115	75
	6-in. depth	—	—	—	—	—	—	—	5	47	32	16	—	—	—	—	91	100	82	107	77
	8-in. depth	—	—	—	—	—	—	—	1	45	45	9	—	—	—	—	91	97	84	103	79
	10-in. depth	—	—	—	—	—	—	—	—	47	53	—	—	—	—	—	91	95	85	99	80
	12-in. depth	—	—	—	—	—	—	—	—	48	52	—	—	—	—	—	90	93	86	97	81
August 1964 (26 days)	Air	—	—	—	—	1	8	27	39	22	3	—	—	—	—	—	72	84	60	95	46
	Surface	—	—	—	—	—	—	11	31	21	12	12	8	5	—	—	88	116	69	133	60
	2-in. depth	—	—	—	—	—	—	4	29	31	17	13	6	—	—	—	87	106	73	120	65
	4-in. depth	—	—	—	—	—	—	—	21	42	25	12	—	—	—	—	87	99	77	108	70
	6-in. depth	—	—	—	—	—	—	—	16	53	28	3	—	—	—	—	86	94	78	103	70
	8-in. depth	—	—	—	—	—	—	—	7	62	31	—	—	—	—	—	86	92	81	98	74
	10-in. depth	—	—	—	—	—	—	—	4	71	25	—	—	—	—	—	86	90	82	96	76
	12-in. depth	—	—	—	—	—	—	—	1	82	17	—	—	—	—	—	86	89	83	93	78
September 1964 (30 days)	Air	—	—	—	—	3	27	28	24	14	4	—	—	—	—	—	67	79	53	94	43
	Surface	—	—	—	—	—	6	27	25	14	9	8	6	5	—	—	81	106	62	128	50
	2-in. depth	—	—	—	—	—	2	24	28	19	13	9	5	—	—	—	81	98	66	117	54
	4-in. depth	—	—	—	—	—	—	17	31	28	16	8	—	—	—	—	81	92	70	106	55
	6-in. depth	—	—	—	—	—	—	13	32	36	17	2	—	—	—	—	81	89	73	102	62
	8-in. depth	—	—	—	—	—	—	9	31	43	17	—	—	—	—	—	81	87	75	98	64
	10-in. depth	—	—	—	—	—	—	7	31	46	16	—	—	—	—	—	81	85	76	95	66
	12-in. depth	—	—	—	—	—	—	7	32	48	13	—	—	—	—	—	81	84	78	93	68
October 1964 (31 days)	Air	—	—	1	17	24	27	25	6	—	—	—	—	—	—	—	52	66	38	77	27
	Surface	—	—	—	1	21	29	23	13	9	4	—	—	—	—	—	61	84	46	105	36
	2-in. depth	—	—	—	—	12	34	33	14	7	—	—	—	—	—	—	61	78	50	95	40
	4-in. depth	—	—	—	—	3	33	46	16	2	—	—	—	—	—	—	62	72	53	87	44
	6-in. depth	—	—	—	—	2	32	56	10	—	—	—	—	—	—	—	62	69	55	82	47
	8-in. depth	—	—	—	—	—	25	67	8	—	—	—	—	—	—	—	63	68	58	79	50
	10-in. depth	—	—	—	—	—	20	75	5	—	—	—	—	—	—	—	63	67	59	76	52
	12-in. depth	—	—	—	—	—	12	85	3	—	—	—	—	—	—	—	64	66	61	75	54
November 1964	Air	—	1	6	23	24	25	18	3	—	—	—	—	—	—	—	48	62	33	76	16

	6-in. depth	—	—	—	4	19	62	15	—	—	—	—	—	—	—	—	53	59	47	67	33
	8-in. depth	—	—	—	—	17	71	12	—	—	—	—	—	—	—	—	54	58	49	64	30
	10-in. depth	—	—	—	—	16	73	11	—	—	—	—	—	—	—	—	54	57	51	63	40
	12-in. depth	—	—	—	—	14	77	9	—	—	—	—	—	—	—	—	55	57	53	62	42
December 1964	Air	—	3	17	30	32	14	3	1	—	—	—	—	—	—	—	39	47	30	72	14
(31 days)	Surface	—	1	11	32	35	18	3	0	—	—	—	—	—	—	—	41	52	32	70	17
	2-in. depth	—	—	11	35	43	11	—	—	—	—	—	—	—	—	—	40	47	33	58	20
	4-in. depth	—	—	2	36	47	15	—	—	—	—	—	—	—	—	—	42	47	38	57	26
	6-in. depth	—	—	1	34	56	9	—	—	—	—	—	—	—	—	—	41	45	37	52	27
	8-in. depth	—	—	—	29	60	11	—	—	—	—	—	—	—	—	—	43	45	40	52	30
	10-in. depth	—	—	—	24	69	7	—	—	—	—	—	—	—	—	—	43	45	40	50	33
	12-in. depth	—	—	—	16	77	7	—	—	—	—	—	—	—	—	—	44	45	42	51	35
January 1965	Air	1	14	27	31	21	5	1	—	—	—	—	—	—	—	—	32	43	20	62	2
(27 days)	Surface	—	5	28	35	20	11	1	—	—	—	—	—	—	—	—	35	50	24	61	9
	2-in. depth	—	1	24	43	25	7	—	—	—	—	—	—	—	—	—	35	47	26	56	14
	4-in. depth	—	1	19	47	32	1	—	—	—	—	—	—	—	—	—	36	43	30	53	18
	6-in. depth	—	—	15	52	32	1	—	—	—	—	—	—	—	—	—	37	42	31	52	20
	8-in. depth	—	—	8	55	36	1	—	—	—	—	—	—	—	—	—	37	41	34	50	23
	10-in. depth	—	—	5	57	38	—	—	—	—	—	—	—	—	—	—	38	40	35	49	25
	12-in. depth	—	—	2	58	40	—	—	—	—	—	—	—	—	—	—	38	40	36	48	27
February 1965	Air	1	4	23	33	24	11	4	—	—	—	—	—	—	—	—	37	47	26	68	6
(25 days)	Surface	—	3	12	24	31	19	7	3	1	—	—	—	—	—	—	43	63	30	84	12
	2-in. depth	—	1	9	26	39	18	6	1	—	—	—	—	—	—	—	43	57	32	72	16
	4-in. depth	—	—	5	27	48	19	1	—	—	—	—	—	—	—	—	43	51	35	64	20
	6-in. depth	—	—	3	26	58	13	—	—	—	—	—	—	—	—	—	42	48	36	56	23
	8-in. depth	—	—	3	22	67	8	—	—	—	—	—	—	—	—	—	43	47	38	54	26
	10-in. depth	—	—	2	20	74	4	—	—	—	—	—	—	—	—	—	43	46	39	52	28
	12-in. depth	—	—	—	18	81	1	—	—	—	—	—	—	—	—	—	42	45	40	50	30
March 1965	Air	—	—	12	38	39	9	2	—	—	—	—	—	—	—	—	39	49	29	72	11
(31 days)	Surface	—	—	3	24	36	14	11	8	4	—	—	—	—	—	—	49	71	34	89	19
	2-in. depth	—	—	1	18	43	18	15	5	—	—	—	—	—	—	—	49	65	36	80	23
	4-in. depth	—	—	—	11	46	32	10	1	—	—	—	—	—	—	—	49	59	40	70	28
	6-in. depth	—	—	—	7	52	37	4	—	—	—	—	—	—	—	—	49	56	41	69	30
	8-in. depth	—	—	—	3	54	40	3	—	—	—	—	—	—	—	—	48	54	43	62	34
	10-in. depth	—	—	—	1	60	38	1	—	—	—	—	—	—	—	—	48	52	44	60	36
	12-in. depth	—	—	—	—	64	36	—	—	—	—	—	—	—	—	—	48	51	45	58	39
April 1965	Air	—	—	3	8	40	31	11	7	—	—	—	—	—	—	—	50	60	37	76	22
(26 days)	Surface	—	—	—	4	26	33	14	9	6	5	3	—	—	—	—	60	84	42	110	29
	2-in. depth	—	—	—	3	20	37	19	12	6	3	—	—	—	—	—	59	76	45	98	32
	4-in. depth	—	—	—	1	14	45	25	11	4	—	—	—	—	—	—	59	69	48	88	36
	6-in. depth	—	—	—	—	12	49	30	9	—	—	—	—	—	—	—	58	65	50	80	39
	8-in. depth	—	—	—	—	9	54	31	6	—	—	—	—	—	—	—	58	63	51	76	42
	10-in. depth	—	—	—	—	7	59	31	3	—	—	—	—	—	—	—	57	62	52	74	43
	12-in. depth	—	—	—	—	6	69	25	—	—	—	—	—	—	—	—	57	60	53	70	45
May 1965	Air	—	—	—	—	8	32	28	19	12	1	—	—	—	—	—	64	77	49	91	40
(27 days)	Surface	—	—	—	—	—	9	28	20	12	8	8	10	4	1	—	82	113	60	131	52
	2-in. depth	—	—	—	—	—	6	24	26	16	12	12	4	—	—	—	80	101	63	118	53
	4-in. depth	—	—	—	—	—	2	19	33	23	18	5	—	—	—	—	79	93	67	106	57
	6-in. depth	—	—	—	—	—	4	18	34	29	15	—	—	—	—	—	78	88	68	99	58
	8-in. depth	—	—	—	—	—	—	19	38	36	7	—	—	—	—	—	77	84	70	95	59
	10-in. depth	—	—	—	—	—	—	21	40	37	2	—	—	—	—	—	76	82	71	91	60
	12-in. depth	—	—	—	—	—	—	23	43	34	—	—	—	—	—	—	75	79	71	88	60

TABLE 6

DURATION OF TEMPERATURE LEVELS, LOW, HIGH AND AVERAGE TEMPERATURES AT VARIOUS DEPTHS FOR 12-IN. ASPHALT CONCRETE PAVEMENT FOR ONE YEAR

Position Where Measurements Were Made	Percent of Year (June 1, 1964-May 31, 1965) During Which the Temperature (° F) Was Between															Avg. Temp. (° F)	Avg. High Temp. (° F)	Avg. Low Temp. (° F)	High Temp. (° F)	Low Temp. (° F)
	0 & 9	10 & 19	20 & 29	30 & 39	40 & 49	50 & 59	60 & 69	70 & 79	80 & 89	90 & 99	100 & 109	110 & 119	120 & 129	130 & 139	140 & 149					
Air	—	2	7	15	19	17	17	14	7	2	—	—	—	—	—	54	65	41	99	2
Surface	—	1	5	11	17	15	13	14	9	5	4	3	2	1	—	64	87	48	142	9
2-in. depth	—	—	4	11	18	15	12	13	11	7	5	3	1	—	—	64	83	51	127	14
4-in. depth	—	—	2	11	18	17	12	11	14	9	5	1	—	—	—	64	74	55	119	18
6-in. depth	—	—	1	10	20	18	12	10	16	10	3	—	—	—	—	63	71	56	109	20
8-in. depth	—	—	1	9	21	18	12	9	18	11	1	—	—	—	—	64	69	58	105	23
10-in. depth	—	—	1	8	22	18	13	8	20	10	—	—	—	—	—	63	67	59	101	25
12-in. depth	—	—	—	7	24	17	13	8	22	9	—	—	—	—	—	64	66	60	98	27

TABLE 7

MONTHLY DURATION OF TEMPERATURE LEVELS, LOW, HIGH AND AVERAGE TEMPERATURES OF THE SOIL BELOW AND ADJACENT TO THE PAVEMENTS

Period During Which Measurements Were Made	Position Where Measurements Were Made	Percent of Month During Which the Temperature (° F) Was Between						Avg. Temp. (° F)	Avg. High Temp. (° F)	Avg. Low Temp. (° F)	High Temp. (° F)	Low Temp. (° F)
		20 & 29	30 & 39	40 & 49	50 & 59	60 & 69	70 & 79					
November 1964	6-in. below 6-in. pavement	—	—	14	81	5	—	55	56	53	61	43
	12-in. depth in soil	—	1	35	64	—	—	50	52	48	56	38
	6-in. below 12-in. pavement	—	—	10	84	6	—	56	57	55	61	47
	18-in. depth in soil	—	—	27	73	—	—	51	52	50	56	42
December 1964	6-in. below 6-in. pavement	—	18	78	4	—	—	43	45	42	50	36
	12-in. depth in soil	—	43	57	—	—	—	40	42	38	49	33
	6-in. below 12-in. pavement	—	5	92	3	—	—	45	46	44	50	38
	18-in. depth in soil	—	20	80	—	—	—	42	43	41	48	36
January 1965	6-in. below 6-in. pavement	—	58	42	—	—	—	39	40	37	48	31
	12-in. depth in soil	—	80	20	—	—	—	35	36	34	45	30
	6-in. below 12-in. pavement	—	53	47	—	—	—	39	40	39	48	31
	18-in. depth in soil	—	67	33	—	—	—	37	37	36	45	31
February 1965	6-in. below 6-in. pavement	—	20	80	—	—	—	42	44	40	48	30
	12-in. depth in soil	—	51	49	—	—	—	39	40	37	46	30
	6-in. below 12-in. pavement	—	16	84	—	—	—	43	44	41	48	33
	18-in. depth in soil	—	38	62	—	—	—	39	40	39	46	33
March 1965	6-in. below 6-in. pavement	—	1	87	12	—	—	48	50	45	56	39
	12-in. depth in soil	—	11	88	1	—	—	43	44	40	50	36
	6-in. below 12-in. pavement	—	—	82	18	—	—	48	49	46	54	42
	18-in. depth in soil	—	1	99	—	—	—	43	44	42	48	38
April 1965	6-in. below 6-in. pavement	—	—	6	74	20	—	56	59	53	67	45
	12-in. depth in soil	—	—	43	57	—	—	49	51	47	59	40
	12-in. pavement	—	—	3	78	19	—	56	58	54	64	48
	18-in. depth in soil	—	—	45	55	—	—	49	50	48	56	42

thermocouple was located near the center of the test section. A thermocouple for the air temperature was located at a height of 5 ft and at a distance of 3 ft from the test section. It was shaded from the sun but exposed to free air circulation. A plastic pipe was used to protect and carry the thermocouple wires about 100 ft to a building housing the temperature recorder.

In the fall of 1964, additional thermocouples were installed. They were placed at a depth 6 in. below the 6-in. thick pavement and 6 in. below the 12-in. thick pavement. Thermocouples were also placed at depths of 12 and 18 in. in the natural soil, 9 ft from the test section.

A Leeds and Northrup Speedomax G, Model S, 12-point temperature recorder was used for the study. It operated on a print cycle of 24 sec per point. Temperatures from 12 thermocouples could therefore be recorded in slightly less than 5 min. The thermocouple wires and the recorder were checked before installation and periodically during the year, using an ice bath. Weekly checks of the system were made using a manually-operated portable temperature potentiometer. A glass mercury-filled thermometer mounted beside the air temperature thermocouple was used for daily checks.

TEMPERATURE DATA

The highest pavement temperatures during the study were recorded on June 30, 1964. The surface reached a maximum temperature of 142 F at 3:00 p.m. A maximum temperature of 98 F was reached at 9:00 p.m. at the 12-in. depth. Hourly temperatures for that day are shown in Figure 2 for the 12-in. test section. These hourly temperatures show typical cycles of daily pavement temperature changes at different depths. Before sunrise, the lowest pavement temperature is at the surface and temperatures increase with increasing depth. After sunrise, surface temperatures increase rapidly until in the afternoon the highest temperature is at the surface, and temperatures decrease with increasing depth. The hourly temperatures on June 30, 1964, given in Table 2 for both the 12-in. and 6-in. test sections show no significant difference in temperatures or temperature changes between the 12-in. and 6-in. thick pavement sections at depths of 2, 4 and 6 in. Continuous recordings for both test sections through the summer and fall, and periodic checks on the 6-in. thick pavement section for the rest of the study, confirmed this behavior.

The lowest pavement temperatures were recorded on January 19, 1965. The surface reached a minimum temperature of 9 F at 7:00 a.m. A minimum temperature of 27 F was recorded at 9:00 a.m. at the 12-in. depth. Hourly temperatures for that day are shown in Figure 3 and are tabulated in Table 3. The data show that daily temperature changes in the pavement follow similar cycles in warm weather and in cold weather. However, the ranges of temperatures from maximum to minimum on January 19 were only slightly more than one-half the temperature ranges on June 30.

The greatest rate of pavement temperature change during the study occurred at the pavement surface during warm weather, when the surface temperature was near maximum and a sudden rain occurred. Typical pavement temperatures for these conditions on June 8, 1964, are shown in Table 4. The pavement surface temperature decreased 37 F during a period of 30 min after the rain began at 2:00 p.m. During the same time, the temperature decrease was only 9 F at a 2-in. depth, and at a depth of 6 in. the pavement temperature increased 2 F. Rapid rates of temperature change occur only at or near the surface of the pavement under these conditions. Relatively low rates of temperature change at pavement depths of 6 in. or more were recorded during the study. Daily differences between maximum and minimum temperatures were generally less than 20 F at the 6-in. depth and less than 10 F at the 12-in. depth. The typical hourly rate of temperature change at depths of 6 to 12 in. was 1 F per hour, often less, but sometimes as much as 3 F or 4 F.

Hourly temperature data obtained during the study were used to calculate the percent of each month and of the year during which the temperature was between 15 equal levels, each spanning 10 F, between 0 F and 149 F. These calculations were made for air and surface temperatures, and for pavement temperatures at the various depths in

the 12-in. thick pavement. This method of expressing temperature durations is similar to the one described by Trott (4), except that durations of temperature levels were calculated from hourly readings rather than determined by temperature-classifying equipment. Determinations of temperature levels are very useful since it is of interest to know the duration of temperatures as well as maximum, minimum and average temperatures in studies of long-term pavement performance. The average temperatures, and average high and low temperatures, were calculated from the hourly temperature data for each month and for the entire year for air and pavement temperatures, as were temperatures at the different depths in the 12-in. thick pavement. The calculations were based on 8088 hourly temperature measurements during the study at each position where temperatures were measured.

Monthly durations of temperature levels, monthly average temperatures, average high and low temperatures, and monthly high and low temperatures for the 12-in. thick pavement are given in Table 5. The duration of temperature levels for the entire year, yearly average temperatures, yearly average high and low temperatures and the high and low temperature for the year for the 12-in. thick pavement are given in Table 6. Temperatures in the highest levels at or near the pavement surface occurred during relatively small fractions of the time throughout the year and throughout a month. Temperatures between 140 F and 149 F at the pavement surface occurred only 1 percent of the time during the month of June, and were not recorded during the rest of the year. At a depth of 6 in., temperatures did not exceed 109 F during the year and were between 100 F and 109 F for 16 percent of July, but for only 3 percent of the year. At a depth of 12 in., the pavement reached a maximum of 98 F during June and was between 90 F and 99 F for 26 percent of the time during June, but at that level only 9 percent of the time during the year.

The data in Tables 5 and 6 support the commonly used temperature of 140 F for paving mixture stability and for asphalt consistency testing, provided the mixtures are used near the pavement surface. It was approximately the maximum pavement surface temperature that occurred for a relatively short time at the test site. The data indicate that laboratory testing temperatures below 140 F should be considered for paving mixtures placed in the lower courses of the pavement. If it is desired to determine a temperature-dependent paving mixture property at the highest temperature expected at a 12-in. depth, the study indicates that a testing temperature of about 100 F would be appropriate. For temperature dependent paving mixture properties at the highest temperature expected at a 6-in. depth, data from the study show that a testing temperature of 110 F should be used.

Hourly temperatures were used to calculate the duration of various temperature levels and average temperatures during the last 2 months of 1964 and the first 4 months of 1965 for thermocouples installed in the subgrade beneath the 2 pavement sections, and in the soil adjacent to the test sections. The data for temperatures 6 in. below the 6-in. and 12-in. thick pavements, and for temperatures in the soil adjacent to the test sections at depths of 12 and 18 in., are given in Table 7. Average monthly temperatures in the soil 6 in. below the 6-in. pavement ranged from 3 F to 7 F higher than average temperatures at a depth of 12 in. in the soil adjacent to the pavement. The average monthly temperatures in the soil 6 in. below the 12-in. pavement were from 2 F to 7 F higher than the average temperatures at a depth of 18 in. in the soil adjacent to the pavement. During January, the coldest month, temperatures 6 in. below the 6-in. pavement were between 30 F and 39 F for 58 percent of the time. Soil temperatures during the same time at a depth of 12 in. adjacent to the pavement were between 30 F and 39 F 80 percent of the time. Temperatures during the winter and spring beneath the pavements were appreciably higher, and were at higher temperature levels for longer periods of time than were soil temperatures at corresponding depths adjacent to the pavements. During the winter months no temperatures below 30 F occurred 6 in. below the 6-in. and 12-in. thick asphalt concrete pavements.

SUMMARY

1. The temperatures at depths of 2, 4 and 6 in. in a 6-in. thick asphalt concrete pavement were essentially the same as temperatures at the same depths in a 12-in. thick asphalt concrete pavement.

2. The maximum temperatures during a period of one year at the surface and at depths of 2, 4, 6, 8, 10 and 12 in., respectively, were 142 F, 127 F, 119 F, 109 F, 105 F, 101 F and 98 F.

3. The minimum temperatures during a period of one year at the surface and at depths of 2, 4, 6, 8, 10 and 12 in., respectively, were 9 F, 14 F, 18 F, 20 F, 23 F, 25 F and 27 F.

4. The average temperature at the various pavement depths varied slightly with depth and season, but during the period of a year the average temperature at all depths was either 63 F or 64 F, while the average air temperature was 54 F.

5. The pavement temperatures above about 120 F, experienced only at depths of 4 in. or less, occurred for relatively small fractions of the time, even during the warmest summer months.

6. Average temperatures during cold weather months in the subgrade soil 6 in. below the 6-in. and 12-in. thick asphalt concrete pavements were appreciable higher, and remained at higher levels for longer periods of time than average temperatures at corresponding depths of 12 and 18 in. in the soil adjacent to the pavement.

7. The test data support the commonly used temperature of 140 F for paving mixture stability and asphalt testing, if the paving mixture or the asphalt properties are desired at the highest expected temperatures reached at or near the pavement surface. At lower pavement depths, lower testing temperatures were indicated for determining the temperature-dependent properties of paving mixtures and asphalt at the highest expected pavement temperatures. Testing temperatures of about 110 F for a 6-in. pavement depth and 100 F for a 12-in. pavement depth were indicated.

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