Long-Term Compaction of Asphalt Concrete Pavements

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Fifteen field test sites were selected in Texas in an attempt to define more accurately the influence of material properties, mix design, weather conditions, and traffic on the long-term density gain of pavements. Asphalt cores obtained from these test sections over a 2-year period indicate that the majority of these mixes were compacted to an air void content within 2 to 3 percentage points of each other regardless of the compactive effort employed, and the resulting densities after 2 years of service are within a range of 1 or 2 percentage points of each other regardless of the position of the core with respect to the wheelpaths of the traffic. Samples of field mixtures were compacted in the laboratory by use of the Texas gyratory compactor, and these results are compared with the density obtained in the field. These results show that 85 percent of the samples did not obtain 95 percent of the laboratory density during construction. After one week of traffic, approximately 50 percent of the test sections had reached 95 percent of laboratory density, and after 4 months, 80 percent had reached 95 percent laboratory compaction. Two years of service resulted in all except two of the test site pavements reaching greater than 95 percent relative compaction, and only 20 percent reached 100 percent relative compaction.

•THE IMPORTANCE of proper compaction of asphalt pavements has been recognized for many years. Investigators have shown that bituminous pavement stability, durability, tensile strength, fatigue resistance, stiffness, and flexibility are strongly influenced by density.

To ensure adequate compaction, several agencies specify "in-place" density requirements. These in-place requirements are commonly expressed as a percentage of a standard laboratory compaction density. Although laboratory tests are intended to give the engineer needed information about the density of the surfacing material as it ultimately appears on the roadway, there is evidence that an increasing number of bituminous concrete pavements in Texas as well as other states are not stabilizing at a density equal to that obtained in the laboratory design of a companion paving mixture.

The reasons for this unpredictable behavior are probably many and complex. In an attempt to define more adequately the variables that may affect the long-term density of a pavement, 15 test sites were selected throughout Texas, and compaction data were collected over a 3-year span, covering a maximum life span of 2 years for any individual pavement. The results of this study are presented herein.

TEST PROGRAM

The test program may be conveniently separated into field and laboratory phases, as discussed in the following sections.

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Field Testing Program

The field work included site selection, preparation and placing of the test section, and regular sampling of test sections.

Fifteen test sites were selected in 6 highway districts. The selection of the test sites was based on contract work in progress, traffic volume, climatic conditions, materials, pavement type (flexible or rigid), and construction type (new or overlay). In addition, the grade line was approximately level; there was no ingress or egress from the test sections; and all tests sites were on tangents.

Each test section was 600 ft in length and 1 traffic lane in width. The sections were further subdivided into subsections A, B, and C with each part or subdivision receiving a different amount of construction compaction as follows:

Subsection A—half the roller passes subsection B,
Subsection B—normal rolling procedure for a given project, and
Subsection C—double the roller passes of subsection B.

TABLE 1: COMPACTION PROCEDURE

Test Section	AGGREGATES: Aggregate	Source	Grading (Plant): +#4	-#4	-#40	-#200	Maximum Size (100% pass)	ASPHALTS: Asphalt Source	Asphalt Type	Asphalt Content, Percent: Design	Extraction	Original Viscosity: mega-poise 77°	stokes X10³ 140°	stokes 275°	Original Penetration at 77°F, dmm
Childress US 287 25-42-9	Siliceous CRS - 65% Fines - 35%	Local - Tucker Pit	36%	64%	16.6%	1.2%	1/2	01	AC-20	5.0	5.26	2.2	2.410	3.9	65
Matador US 70 25-145-8	CRS - 18.9% Int. - 23.2% Fine - 21.1% Sand - 36.8%	Local - Campbell Pit	45.5%	54.5%	23.1%	6.1%	7/8	01	AC-20	5.0	5.4	2.7	3.151	4.08	61.5
Sherman SH 5 1-47-3	3/8 crushed LS. - 65% Field Sand - 25% Conc. Sand - 10%	Crushers Inc. Bill Rldenour	43%	57%	25.5%	2.2%	1/2	09	AC-20	5.8	6.5	1.59	2.597	5.14	75
Cooper SH 24 1-136-3	L.S.S. - 18.1% Field Sand - 21.9% Pea Gravel - 55.2%	Bridgeport, Tex. Local - Backus Pit Van Pit Seegeville	38%	62%	31.1%	2.4%	1/2	03	AC-20	4.8	4.6	2.06	3.02	5.10	69.2
Cumby IH 30 1-9-13	L.S.S. - 18.1% Field Sand - 21.9% Pea Gravel - 55.2%	Bridgeport, Tex. Local - Backus Pit Van Pit Seegeville	39%	61%	27.5%	3.9%	1/2	03	AC-20	5.1	5.1	2.28	3.10	5.19	68.8
Clifton SH 6 9-258-7	D Rock - 32% Fine Sand - 28.3% Conc. Filler - 35%		41.8%	58.2%	19%	3.4%	1/2	01	AC-10	4.7	5.6	2.0	2.788	3.98	55
Waco US 84 9-55-8	Flex Base with one Course Surf Treat	Neilson Pit	41.7%	58.3%	21.7%	2.7%	1/2	09	85-100	4.8	4.95	0.87	2.28	5.12	75
Robinson US 77 9-209-1	River Gravel - 65% Field Sand - 20% Conc Sand - 15%	Neelleys Pit Simons Pit	49.2%	50.8%	22.1%	7.2%	1/2	03	AC-20	4.5	4.71	1.5	2.89	6.41	74
Milano SH 36 17-185-4	RSA - 70% RSA - 30% Rock Asphalt	Alcoa Uvalde Rockdale	5.4%	94.6%	18.4%	6.9%	3/8	06	AC-20	6.75	6.77	3.6	3.349	4.32	39
Bryan Spur 308 17-599-1	RSA - 75% L.S. screen - 20% Field Sand - 5%	Alcoa - Rockdale Georgetown	1.3%	98.7%	22.8%	4.3%	3/8	06	AC-20	6.2	6.1	2.16	3.188	4.55	45
Tamina IH 45 12-110-4	Iron Ore - 70% L. S. - 30%	Iron Ore Champion Pit (I-A)	44.8%	55.2%	26.0%	3.4%	1/2	06	AC-10	4.6	4.41	.77	1.672	3.1	85
Conroe FM 1485 12-1062-35	Iron Ore Field Sand	Gaylord Construction Company	42.0%	58.0%	26.1%	2.7%	1/2	11	AC-20	4.75	5.2	1.8	3.888	5.12	53
Baytown Spur 330 12-508-7	Limestone - 33% Sand Coarse - 30% Sand Fine - 37%		46.0%	54%	28.6%	3.5%	1/2	11	85-100	5.2	5.4	.72	1.529	3.41	72
Orange SH 12 20-499-3	L.S. - 35% Vido Field S. - 24% Helm's Screening- 41	Tex. Const. Mat. Burnet & Eagle Smith Pit-Vidor	35.7%	64.3%	25.9%	2.3%	1/2	05	AC-20	5.0	5.2	5.4	4.186	5.15	37
Bridge City IH 87 20-306-3	L. S. - 35% Vidov F. S. - 24% Helm's Scr. - 41%	Tex. Const. Mat. Burnet & Eagle Smith Pit-Vidor	32.4%	67.6%	27.6%	3.3%	1/2 1/2	05	AC-20	5.0	5.3	5.4	4.186	5.15	37

It was believed that this range of roller passes would span the range of compactive efforts encountered in practice. Compaction procedures are given in Table 1.

In order to obtain samples, aluminum foil was placed on the surface to be paved. A single 4-in. diameter core was removed from each prepared location according to the following schedule:

1 day	18 cores at 3 subdivisions = 54 samples
1 week	18 cores at 3 subdivisions = 54 samples
1 month	9 cores at 3 subdivisions = 27 samples
4 months	9 cores at 3 subdivisions = 27 samples
1 year	9 cores at 3 subdivisions = 27 samples
2 years	9 cores at 3 subdivisions = 27 samples

Total number of samples per test site = 216

The sequence of coring proceeded against the traffic flow.

TABLE 2: AGGREGATES AND ASPHALTS

Test Section	Compaction Equipment: Breakdown Rolling — Passes/Section A	B	C	Type Roller/Size	Compaction Equipment: Intermediate Rolling — Passes/Section A	B	C	Type Roller/Size	Compaction Equipment: Final Rolling — Passes/Section A	B	C	Type Roller/Size	Temperature, °F: Air	Breakdown	Final Roll	Field Initial Density (1 Day) Section B PWP
Childress US 287 25-42-9	4	3	6	3 wheel tandem, 12 ton; 5'-4' diameter	4	4	4	2 wheel tandem, 10 ton; 5'-4' diameter	14	14	14	Pneumatic, 25ton 60 psi	51	145	125	8.69
Matador US 70 25-145-8	11	11	11	3 wheel, 10 ton	5	11	21	Tandem 10 ton	7	13	25	Pneumatic, 25 ton 75 psi	63	225	145	7.68
Sherman SH 5 1-47-3	6	12	24	3 wheel 10 ton	5	5	9	Tandem 8 ton	10	20	40	Pneumatic, 12 ton 70 psi	80	200	135	8.26
Cooper SH 24 1-136-3	3	5	9	3 wheel 10 ton	3	5	9	Tandem 10 ton; 4' diameter	1	4	7	Pneumatic	82	155	75	10.85
Cumby IH 30 1-9-13	3	7	13	3 wheel 10 ton	3	5	9	Tandem 8 ton	3	5	9	Pneumatic, 22.3ton 102 psi	46	205	100	5.51
Clifton SH 6 9-258-7	3	3	6	3 wheel 10 ton, 60"-42" diameter	4	8	16	Pneumatic 16.3ton 75 psi	3	7	14	Tandem, 8.8ton, 60"-48" diameter	96	220	150	9.89
Waco US 84 9-55-8	4	3	9	Tandem, 8 ton, 54" diameter	4	4	4	Tandem, 8 ton, 54" diameter	15	15	15	Pneumatic, 8 ton, 44-52 psi	101	180	135	7.39
Robinson US 77 9-209-1	3	3	7	3 wheel, 10 ton, 60"-42" diameter	4	4	4	Tandem 8 ton, 54"-42" diameter	12	12	18	Penumatic, 25 ton, 60 psi	98	160	130	8.53
Milano SH 36 17-185-4	3	3	7	3 wheel, 10 ton, 60"-30" diameter	3	3	3	Tandem, 8 ton, 54" diameter	3	7	13	Penumatic, 25 ton, 60 psi	95	160	145	20.79
Bryan Spur 308 17-599-1	3	6	12	3 wheel, 10 ton, 60" diameter	3	3	3	Tandem, 8 ton, 54" diameter	4	4	8	Penumatic, 12 ton, 75 psi	95	170	135	18.76
Tamina IH 45 12-110-4	3	7	4	3 wheel, 10 ton, 42"-66" diameter	6	6	24	Penumatic, 10 ton 85 psi	2	2	2	Tandem, 10 ton, 54" diameter	97	185	145	12.72
Conroe FM 1485 12-1062-35	3	7	14	3 wheel, 10 ton, 60" diameter	10	10	20	Pneumatic, 25 ton 65-70 psi	3	3	6	Tandem, 8 ton, 60" diameter	95	155	135	12.34
Baytown Spur 330 12-508-7	3	6	12	3 wheel, 10 ton, 60" diameter	NONE				3	3	3	Tandem, 8 ton, 54" diameter	108	180	100	25.88
Orange SH 12 20-499-3	5	7	13	3 wheel, 10 ton, 5'-3' diameter	NONE				3	5	11	Tandem, 12 ton, 4 1/2' - 3 1/2'	90	200	170	10.02
Bridge City IH 87 20-306-3	5	9	15		NONE				5	7	11	Tandem, 8 ton, 5'-4'	85	200	165	13.83

Laboratory Testing Program

Samples of uncompacted asphalt mix were obtained from each test site in the field. These loose samples were compacted by using the gyratory compactor according to the procedures of the Texas Highway Department (1). Percentage of air voids, stability, and cohesiometer values were obtained from the compacted samples and are reported elsewhere (2).

MATERIALS

Different asphalts, aggregates, and aggregate grading were used at the 15 test sites.

Aggregates

Table 2 gives the type, source, grading, and maximum sizes of aggregates used in this study. Aggregate types included siliceous materials used on the Childress project, rock asphalt used on the Milano project (rockdale slag aggregate plus asphalt rock), iron ore aggregate used on the Tamina and Conroe projects, slag used on the Milano and Bryan project, and limestone, which was the predominant type of aggregate.

Asphalts

The asphalt source, type, content, viscosity, and penetration for the various test sites are given in Table 2. The viscosity and penetration of the asphalts recovered after service for various lengths of time were obtained and are reported elsewhere (2).

RESULTS

Variation in pavement densities with time has been studied by various groups including Kenis (3), Bright et al. (4), Palmer and Thomas (5), Campen et al. (6), Gallaway (7), and Pauls and Halstead (8). These and other studies have suggested that the following factors influence the long-term density of the pavement.

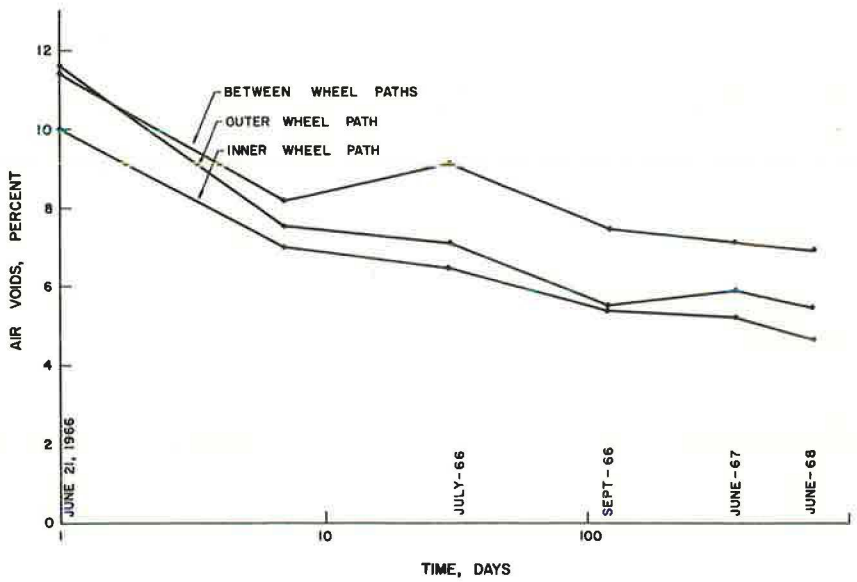

Figure 1. Pavement densification with time at various locations in the pavement, Orange test section.

1. Degree of initial compaction
2. Material properties
   a. Aggregate absorption
   b. Aggregate surface characteristics
   c. Aggregate gradation
   d. Asphalt temperature-viscosity relationship
   e. Asphalt susceptibility to hardening
3. Mix design
   a. Asphalt content (film thickness)
   b. Voids in mineral aggregate
4. Weather conditions
   a. Air temperature variations (daily and seasonally)
   b. Date of construction
5. Traffic
   a. Amount
   b. Type
   c. Distribution throughout the year
   d. Distribution throughout the day
   e. Distribution in lanes
6. Pavement thickness

Results selected from the 15 test sites (see reference 2 for complete data) in this study are shown in Figures 1 through 4. Figures 1 and 2 show air void contents for normal compactive efforts between the wheelpaths as well as the inner and outer wheelpath. Figures 3 and 4 show air void contents at the inner wheelpath for the 3 compactive efforts. As suggested previously the results shown in Figures 1 through 4 are dependent on several factors discussed in the following sections.

Initial Compaction

The initial density of the pavement is dependent on the compactibility of the mix or the ease with which it can be compacted, the type of compaction equipment, the rolling

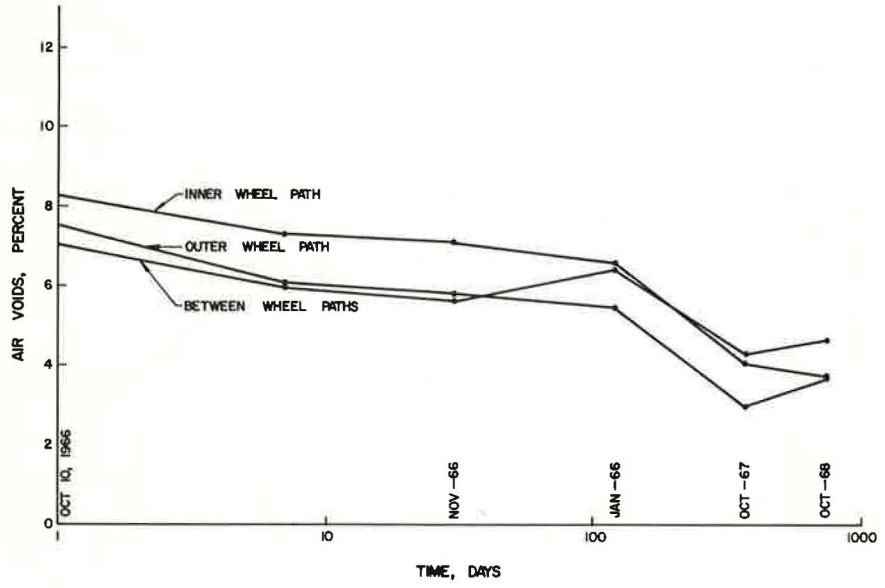

Figure 2. Pavement densification with time at various locations in the pavement, Sherman test section.

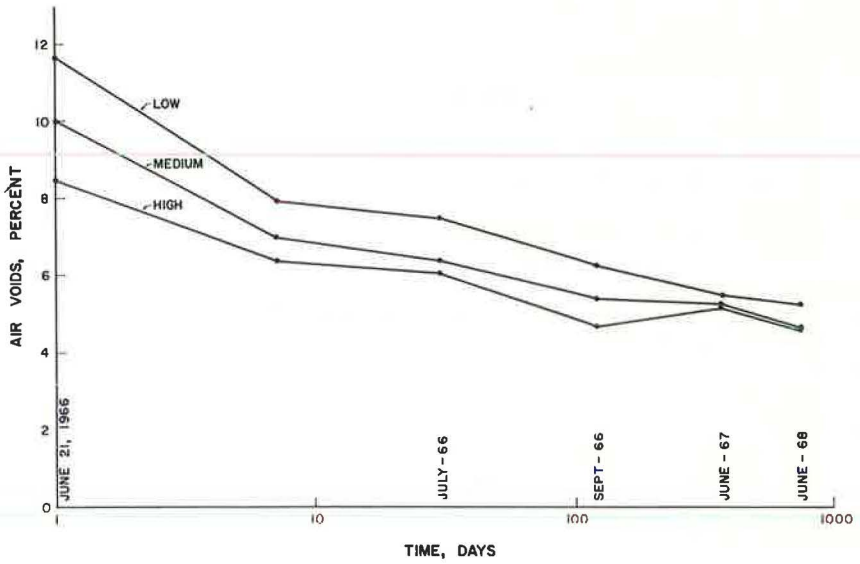

Figure 3. Pavement densification with time for various compactive efforts, inner wheel path, Orange test section.

sequence and procedure, and the timing of the compaction processes. Furthermore, the compactibility of a mix is dependent on material properties, mix design, subgrade support, thickness of lift, temperature of the surface and the mix, weather conditions during placement, and moisture in the mix. All of these factors must be considered if the relative compactibility of a mix is to be determined.

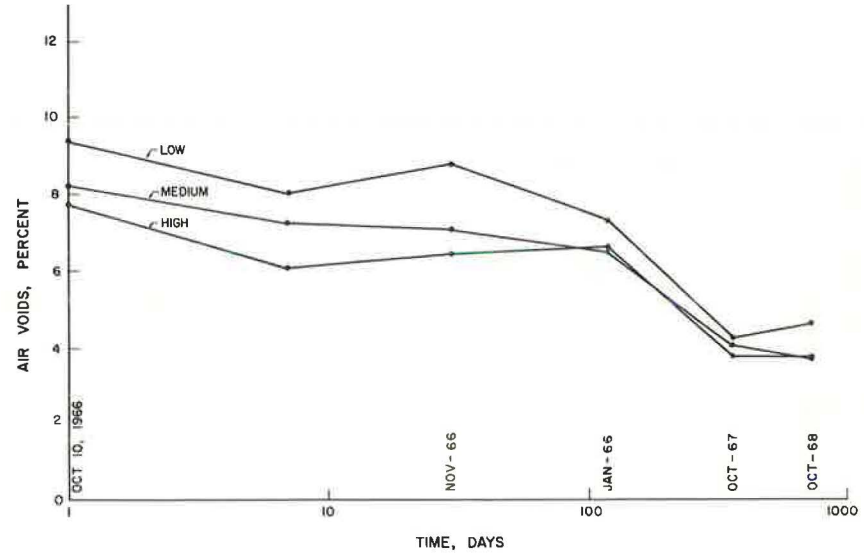

Figure 4. Pavement densification with time for various compactive efforts, inner wheel path, Sherman test section.

Because both the aggregate and asphalt characteristics varied widely, and the temperature at breakdown rolling was low (6 of 15 test sections, Table 1), little definitive information could be gained as to the factors controlling the initial density of pavements. However, these data indicate that it is important that compaction equipment follow the lay-down machine as closely as possible when thin lifts and cool weather are encountered during construction as the temperature drop of a mix increases its resistance to compaction.

As noted previously, individual test sites were subjected to different compactive efforts; however, little density variation was noted on most of the projects (Table 3). Furthermore, it is difficult to determine if the density of the pavements after 2 years

TABLE 3 PERCENT AIR VOIDS IN FIELD SAMPLES

Test Section	Sub-Section	Wheel Path	1 Day	1 Week	1 Month	4 Months	1 Year	2 Years
Childress US 287 25-42-9	A*	I**	10.20	9.34	7.16	4.20	4.15	3.70
		B**	9.62	9.66	8.73	5.92	6.23	5.23
		O**	10.53	9.84	7.60	4.55	4.17	3.90
	B*	I	8.69	8.45	5.60	3.39	3.90	3.32
		B	8.45	8.10	6.88	5.18	5.60	5.22
		O	9.20	8.15	6.26	3.97	3.93	4.08
	C*	I	8.58	8.33	6.81	3.81	3.84	3.98
		B	8.93	8.77	8.43	5.38	5.85	5.92
		O	9.03	9.72	7.80	5.11	5.11	4.70
Matador US 70 25-145-8	A	I	5.71	6.50	6.05	6.25	4.47	5.79
		B	6.25	6.42	6.02	5.94	4.62	4.57
		O	7.11	7.11	7.43	7.31	5.23	7.33
	B	I	7.68	7.79	8.77	7.47	5.36	6.77
		B	7.38	7.41	6.92	7.39	5.20	5.80
		O	9.06	8.58	9.19	9.88	7.90	8.92
	C	I	3.94	4.96	4.65	5.38	4.15	4.12
		B	5.56	6.40	6.16	6.19	3.50	4.11
		O	7.61	7.80	7.14	6.43	5.43	5.72
Sherman SH 5 1-47-3	A	I	9.32	8.05	8.80	7.39	4.29	4.66
		B	7.10	5.43	5.74	6.96	4.28	4.65
		O	7.19	7.21	5.62	5.64	2.70	3.33
	B	I	8.26	7.30	7.12	6.60	4.05	3.75
		B	6.99	5.96	5.63	6.45	4.36	4.75
		O	7.49	6.08	5.83	5.49	2.99	3.73
	C	I	7.77	6.14	6.49	6.72	3.80	3.79
		B	6.31	5.15	5.11	6.30	4.51	4.26
		O	6.82	5.78	4.66	5.09	3.13	4.31
Cooper SH 24 1-136-3	A	I	10.94	9.54	9.12	6.29	6.57	6.62
		B	10.43	9.30	9.23	6.70	6.33	6.30
		O	10.21	10.33	9.08	6.87	5.88	6.18
	B	I	10.85	9.54	9.29	6.92	6.32	6.17
		B	8.43	7.44	7.47	5.63	6.22	5.80
		O	10.82	9.34	8.63	7.04	6.72	6.50
	C	I	9.21	8.03	8.04	5.81	5.72	6.02
		B	7.93	8.00	6.91	5.54	5.33	5.72
		O	8.47	8.12	7.35	5.91	5.06	5.48
Cumby IH 30 1-9-13	A	I	8.02	6.92	6.94	3.06	1.95	1.79
		B	5.87	5.14	5.36	3.14	2.74	2.51
		O	7.11	6.27	6.22	3.40	1.88	1.59
	B	I	5.51	5.38	5.48	2.40	2.22	1.71
		B	4.08	4.64	4.77	2.87	2.31	2.05
		O	4.75	5.03	4.68	2.18	2.01	1.99
	C	I	4.77	6.01	4.84	2.85	1.56	1.60
		B	3.91	4.29	4.56	3.37	3.30	2.04
		O	4.50	4.28	4.59	2.20	1.64	1.52
Clifton SH 6 9-258-7	A	I	9.86	8.18	6.94	7.62	6.67	6.12
		B	9.65	8.97	8.90	8.45	7.39	8.45
		O	9.74	8.08	7.87	7.66	7.38	7.35
	B	I	9.89	7.02	6.47	6.07	5.46	6.23
		B	8.59	8.30	8.19	7.90	7.15	8.42
		O	9.13	7.98	6.96	7.19	6.82	6.59
	C	I	7.78	7.60	6.63	5.93	5.53	5.07
		B	7.68	7.62	7.21	6.93	6.60	6.61
		O	8.18	7.72	6.72	6.19	6.39	6.11
Waco US 84 9-55-8	A	I	7.23	5.52	2.48	1.80	2.59	1.95
		B	7.60	6.52	4.00	4.04	3.70	3.61
		O	7.58	5.89	2.53	2.57	3.01	2.36
	B	I	7.39	5.27	2.86	2.71	2.26	1.57
		B	6.77	5.18	3.75	3.07	2.76	2.30
		O	7.14	4.90	2.76	2.11	2.71	2.81
	C	I	6.35	4.55	3.05	2.57	2.22	1.89
		B	5.50	3.84	2.97	3.12	2.32	1.72
		O	5.55	3.85	2.34	1.97	2.34	2.25
Robinson US 77 9-209-1	A	I	9.41	7.79	8.56	6.34	5.08	5.03
		B	8.25	6.50	7.78	4.96	5.00	4.95
		O	8.71	7.34	6.75	6.07	4.06	5.05
	B	I	8.53	7.14	7.91	5.27	4.40	3.92
		B	7.62	6.90	9.31	5.72	4.91	4.77
		O	9.40	7.44	6.13	6.02	5.06	4.53
	C	I	7.01	6.86	7.43	4.50	5.42	4.73
		B	4.79	4.48	6.75	3.61	4.79	3.96
		O	6.39	5.89	4.99	4.62	5.66	3.73

TABLE 3 PERCENT AIR VOIDS IN FIELD SAMPLES
(Cont'd)

Test Section	Sub-Section	Wheel Path	1 Day	1 Week	1 Month	4 Months	1 Year	2 Years
Milano SH 36 17-185-4	A	I	19.23	17.96	18.00	16.77	16.31	16.85
		B	21.47	17.69	18.83	18.31	16.78	17.26
		O	19.71	18.55	18.10	17.55	17.14	17.35
	B	I	20.79	18.47	18.37	17.33	17.16	16.19
		B	21.39	18.36	17.97	17.89	17.41	16.80
		O	20.96	18.64	19.06	18.17	17.93	17.70
	C	I	17.85	17.46	17.60	17.21	16.59	17.12
		B	20.02	17.26	17.45	17.85	16.42	15.81
		O	18.54	16.75	16.93	17.83	15.42	15.17
Bryan Spur 308 17-599-1	A	I	21.46	17.38	16.90	15.91	14.22	14.48
		B	19.41	18.19	18.91	16.76	16.50	19.66
		O	17.31	16.21	17.37	15.61	13.85	17.98
	B	I	18.76	18.24	17.96	16.23	15.78	15.00
		B	17.40	16.94	18.45	16.16	15.98	15.60
		O	16.33	16.85	17.44	14.57	13.86	14.45
	C	I	18.73	17.68	17.45	14.95	14.97	18.11
		B	17.12	16.09	17.00	14.33	13.26	12.67
		O	16.69	15.59	15.79	14.06	13.94	13.67
Tamina IH 45 12-110-4	A	I	13.75	8.84	8.25	6.13	5.75	5.52
		B	13.07	9.32	7.48	6.39	6.39	5.90
		O	13.74	9.34	7.12	6.73	5.95	4.98
	B	I	12.72	8.80	7.80	6.18	5.55	5.00
		B	11.18	8.96	7.20	7.01	6.07	6.57
		O	13.56	9.12	6.94	5.92	5.44	5.68
	C	I	11.28	6.81	5.63	5.61	5.12	5.35
		B	10.01	7.91	6.89	7.36	5.84	6.14
		O	12.57	7.72	6.35	5.92	5.33	4.97
Conroe FM 1485 12-1062-35	A	I	11.53	11.59	11.65	9.38	9.44	9.96
		B	10.81	11.82	10.94	9.61	9.13	9.50
		O	9.81	10.28	8.93	8.88	7.89	7.51
	B	I	12.34	11.09	9.90	8.24	8.23	8.20
		B	10.54	10.42	10.02	8.13	7.94	8.50
		O	10.04	9.33	7.76	7.26	6.31	6.54
	C	I	11.87	11.09	10.10	9.08	8.58	8.56
		B	10.45	11.25	10.91	8.58	8.91	8.94
		O	9.68	9.03	8.38	7.52	7.08	6.33
Baytown Spur 330 12-508-7	A	I	19.71	11.45	7.18	5.97	4.91	5.52
		B	23.03	10.30	7.87	7.13	6.36	7.23
		O	23.55	11.94	7.64	6.34	4.73	5.42
	B	I	25.88	11.66	7.49	6.12	5.23	5.30
		B	25.12	10.35	8.53	7.60	6.78	8.05
		O	25.34	11.59	7.42	6.09	5.04	6.34
	C	I	11.70	11.31	7.77	6.00	4.97	4.75
		B	10.60	10.44	7.90	7.13	6.43	6.71
		O	11.38	10.80	7.71	5.90	5.15	3.48
Orange SH 12 20-499-3	A	I	11.69	7.97	7.58	6.28	5.49	5.27
		B	12.56	8.40	9.00	7.79	8.39	8.31
		O	12.33	7.67	6.08	6.06	6.49	5.70
	B	I	10.02	7.02	6.41	5.42	5.28	4.66
		B	11.50	8.20	9.11	7.53	7.16	6.95
		O	11.62	7.58	7.16	5.58	5.94	5.47
	C	I	8.51	6.43	6.09	4.68	5.27	4.63
		B	8.56	9.10	8.72	5.93	6.03	5.33
		O	7.92	7.24	6.78	4.92	4.71	4.48
Bridge City IH 87 20-306-3	A	I		8.22	8.97	8.11	8.76	8.45
		B	11.60	9.14	8.17	8.38	8.39	8.28
		O	12.10	9.49	7.83	7.95	8.27	7.58
	B	I	13.83	10.12	8.49	8.71	8.77	8.32
		B	13.63	11.36	9.83	9.96	9.36	9.32
		O	13.33	9.48	7.30	7.78	6.89	7.85
	C	I	13.51	10.30	9.47	8.80	8.54	7.28
		B	11.72	10.26	7.99		9.50	8.11
		O	14.12	9.27	7.36	8.26	7.43	9.10

*Subsection A - half as many roller passes as subsection B
*Subsection B - normal roller procedure for particular project
*Subsection C - twice as many roller passes as subsection B

** I - inner wheel path
** B - between wheel path
** O - outer wheel path

of service is dependent on initial density (Fig. 5). Thus, the majority of the pavements were compacted to an air void content within 2 to 3 percentage points of each other regardless of the initial compactive effort; and the resulting densities after 2 years of service are within a range of 1 or 2 percentage points of each other, having decreased from 4 to 6 percentage points during 2 years of service.

Material Properties

The properties of the asphalts and aggregates affect the long-term densification of a pavement as well as its initial densification. Those material properties that tend to increase the resistance of a pavement to initial compaction behave in the same manner for the long-term density increase because of mechanical and environmental loading.

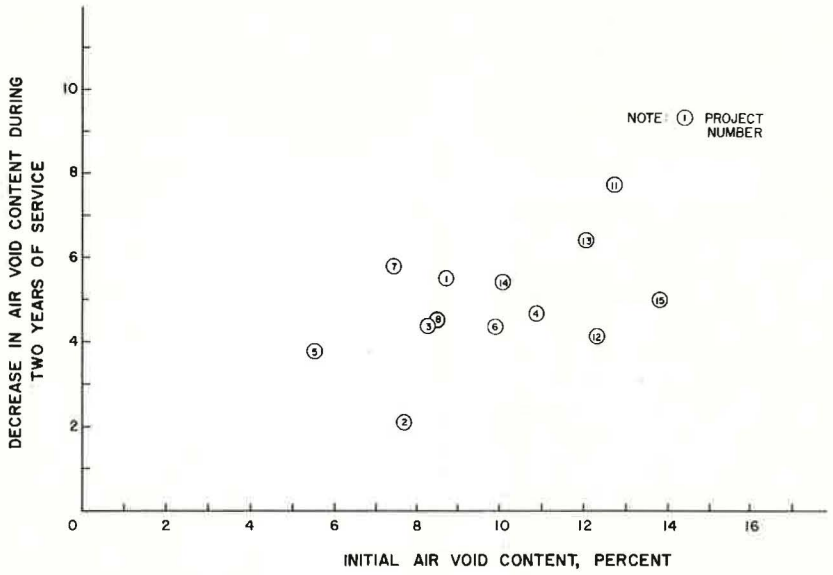

Figure 5. Density change as a function of initial compaction.

Insufficient data were available from these test sites to define accurately the effect of aggregate absorption, aggregate surface characteristics, aggregate gradation, asphalt temperature-viscosity relationship, and mix design on long-term densification of pavements.

Asphalt hardening has been correlated to a certain degree with air void content and degree of interconnectibility of air voids (9). In addition, data collected in this study suggest the same trend (Fig. 6).

Weather Conditions

Density increases between the wheelpaths have been noticed in several long-term density studies (5, 8) as well as this study (Figs. 1 and 2). These data indicate that the air void content between the wheelpaths is lower than either the inner or outer wheelpath in most cases; however, this difference is usually less than 2 percentage points.

Gallaway (10) has suggested that density gain between the wheelpaths may be due to thermal cycling. Therefore, both the seasonal variations and daily cycling in temperatures were obtained for the projects from information obtained from U.S. Weather Bureau stations near the test sites. These data suggest that the seasonal temperature extremes are greater in the northern part of the state (Childress, Matador, Sherman, Cooper, and Cumby) than in the more southerly and coastal projects (Tamina, Conroe, Baytown, Orange, and Bridge City). The summer average monthly temperatures are about the same for all locations.

Daily temperature variation for selected weeks in the winter, spring, summer, and fall was also obtained. These data indicate that daily temperature variation in the panhandle region of Texas (Childress and Matador) has a greater cyclic temperature change than the more southerly coastal areas throughout the year.

These temperature data do not satisfactorily explain the reason for densification between the wheelpaths. The amount of difference noted among the values of air void content in the various locations across the pavement cannot be simply related to the different seasonal and daily temperature environments (Table 3). These data together with data published by Palmer and Thomas (5) on pavements in New York indicate that the entire pavement cross section compacts to approximately the same degree of density

and at approximately the same rate independent of initial compaction, seasonal variations in temperature, and daily variation in temperature for the range of traffic and environments to which these pavements have been subjected.

The date of construction is important in that it determines the temperature of the pavement during its early life and thus its susceptibility to compaction by traffic. Three test sections were compacted in the late fall or early winter in the northern part of the state (Matador, Sherman, and Cumby, Table 3 and Fig. 2). All of these pavements remained at essentially the same density until the warmer spring and summer months elevated the pavement temperature to a level sufficiently high for compaction to continue.

As shown in the preceding, little pavement densification occurred during the colder months. Thus if thermal cycling is a cause of densification between the wheelpaths, it is not evident during the colder months on several of the projects.

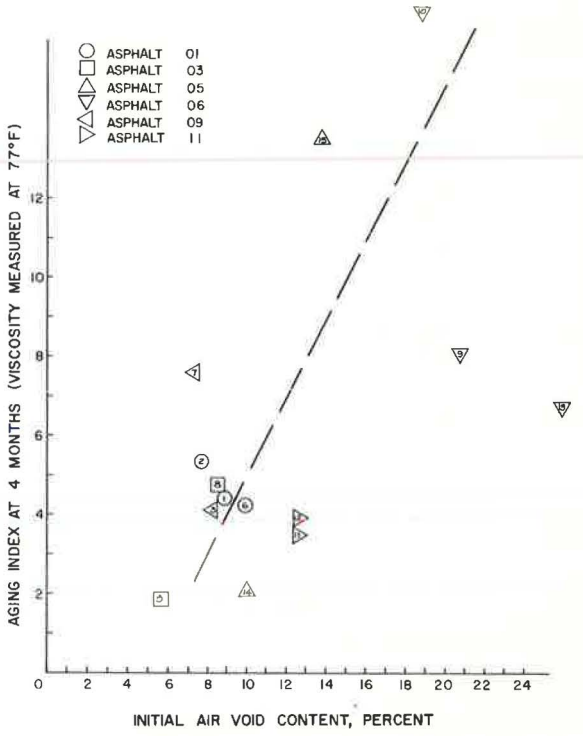

Figure 6. Relationship between asphalt hardening and initial air void content.

The calculated thermal strains in the pavement that are due to daily cycling in temperature are slightly greater in the winter as the daily temperature change is larger. However, the stiffness of the mix is much lower in the summer months, and therefore it is easier for the aggregate particles to arrange themselves in a more dense arrangement. Unfortunately the pavements that were constructed during the warmer months were subjected to traffic immediately after construction, and a check to determine if densification was due to a daily cycling in temperature during the warmer months could not be made.

Traffic

The effect of traffic on long-term pavement density has been established by a number of investigators, including Palmer and Thomas (5), Campen (6), Arena et al. (11), McLeod (12), and Zube (13). These data suggest that the pavement density is primarily related to traffic.

Volume of Traffic—Data reported in this study (Fig. 7) indicate that pavements densify a greater amount with increased traffic independent of the effects of other variables. This trend may explain the density increase in the wheelpaths; however, it does not explain the density increase between the wheelpaths. For example, 3 test sites were not subjected to traffic for various lengths of time after construction (Table 3). The Childress project was opened to traffic 1 week following construction, and consequently the pavement did not densify during the first week. The Cumby project was not open for traffic for 1 month. Little density change is noted during this period. Baytown was opened to traffic 1 month after construction; however, a large amount of densification occurred during this period because the contractor used this pavement as a haul road.

Type of Traffic—The distribution of wheel loads on a pavement will influence the density gain of a pavement with time. For pavements of adequate design, the greater

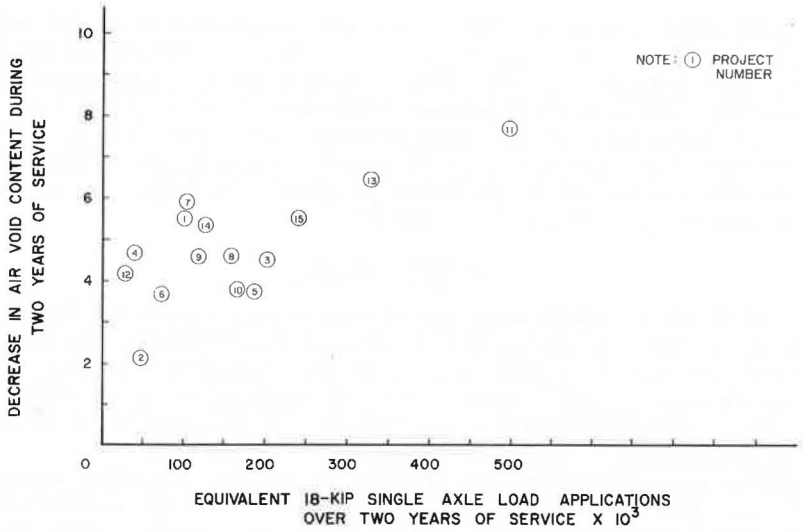

Figure 7. Relationship between increase in density and traffic during 2 years of service.

the number of heavy axle loads the greater the density increase due to traffic will be. This suggests that not only the percentage of trucks must be considered but also the wheel load distribution. The equivalent 18-kip wheel load concept considers both of these factors.

Yearly Distribution of Traffic—The distribution of traffic throughout the year will influence the compaction of a pavement. If the heavy traffic is predominant during the warm months, a greater amount of densification will occur than if the heavy traffic used the highway in the cold months. This is primarily due to differences in asphalt viscosity.

Traffic Distribution Across the Lane—The traffic distribution across the lane was investigated in hopes that it will explain the increase in density noted between the wheelpaths. Data have suggested (14) that 10 to 16 percent of the wheel loads a pavement experiences may be in the center of the pavement. The distribution used by the Portland Cement Association suggests that very little traffic uses the central part of the pavement. However, visual examination of several test sections with 13-ft-wide lanes suggests that these data may be incorrect as the vehicles seem to wander in the lane a significant amount, and therefore a larger portion of the wheel loads actually comes in contact with the center portion of the pavement than would otherwise be expected.

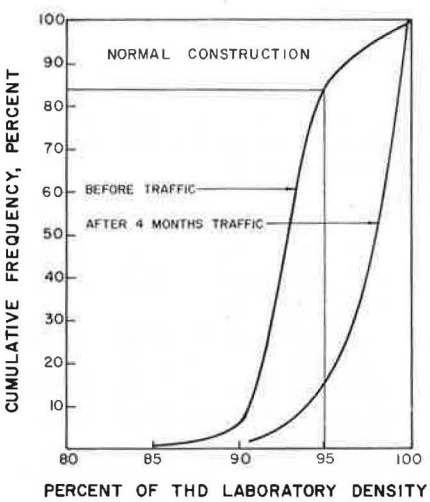

Figure 8. Cumulative frequency relative density.

Comparison of Field and Laboratory Results

If the data for all 15 test sections are considered collectively, a histogram can be prepared and a cumulative frequency distribution chart can be plotted. The chart for the relative densities before traffic and after 4 months of traffic is shown in Figure 8. From these curves it can be

seen that, after construction and before any traffic is allowed on the pavement, 85 percent of the pavement samples from the normal construction operations had not attained 95 percent of the laboratory density. After 1 week of traffic, approximately 50 percent of these pavements had reached 95 percent laboratory density. After 4 months, 80 percent had reached 95 percent of laboratory density. After 2 years of service, all except 2 of the pavements had reached at least 95 percent of this density. The data further show that one-third of the pavements did not densify to the desired 2 to 6 percent air void content after 2 years of service (Table 3).

CONCLUSIONS

1. Data collected in this study as well as others suggest that the long-term density gain of asphalt concrete pavements is a function of many factors. The most important factors as indicated earlier are the susceptibility of asphalt to hardening, the volume of traffic and its nature, and the time of year of construction. It is evident that most pavements will densify with time provided they do not have high initial density and provided they are subjected to heavy wheel loads in warm weather.
2. Densification noted between the wheelpaths closely paralleled the density gain in the wheelpaths. The reasons for this trend are not clear. A possible explanation exists if we consider thermal cycling as a cause of densification. This, however, implies that the predominant forces creating compaction in all sections of the pavement are due to thermal cycling and not traffic associated loads. It is believed that the compaction between the wheelpaths is predominantly related to wheel loads rather than thermal considerations as 2 of the pavements studied exhibited no density increase for periods of up to 1 month without traffic. If thermal cycling creates densification, the induced stresses should have been active during this period and a density increase should have taken place. None was noted.
3. The range of air void content decrease was 2 to 8 percentage points during 2 years of service. The voids in a majority of the pavements were reduced 3 to 6 percentage points.
4. Eighty percent of the total 2-year compaction, due to traffic and environmental effects, was complete within 1 year of service on all of the projects studied.
5. The majority of the pavements were compacted to an air void content within 2 to 3 percentage points of each other regardless of the compactive effort. The resulting densities after 2 years of service are within a range of 1 or 2 percentage points regardless of the location of the core with respect to the wheelpaths of the traffic.

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