Field Compaction Studies on Asphaltic Concrete

W. GARTNER, JR., D. A. COBB, and R. W. LINDLEY, JR., respectively, Assistant Engineer of Research and In-Service Training, Assistant Research Engineer, and Civil Engineer Trainee III, State Road Department of Florida

This paper presents the results obtained from a project undertaken to evaluate the effect of varying the compactive effort of the intermediate rolling on asphaltic concrete. Both pneumatic-tired and steel-wheel vibratory rollers were used on a total of 26 test section.

Results of the tests made with the pneumatic-tired intermediate roller indicated that maximum compaction is attained with six coverages, and a slight tendency for the material to decompact with additional coverages was noted. Results from the three sections in which no intermediate rolling was used showed that the average density attained exceeded minimum specification requirements. When the intermediate rolling was omitted but two extra coverages of the final steel-wheel rolling were applied instead, the average density attained was nearly as great as the average maximum density attained with the optimum number of coverages.

The results of permeability tests indicate no detrimental effect resulting from omission of the intermediate rolling. The results obtained with the vibratory compactor were inconsistent and due to the lack of replication no evaluation of these results was attempted.

• THE PROBLEMS of pushing or shoving, and wheelpath rutting in asphaltic concrete pavements have been the subject of many studies by asphalt paving technologists and highway engineers in general. In any study undertaken with the objective of minimizing the amount of this type of deformation, all elements or variables connected with the construction of asphaltic concrete pavement must be considered. Some of the variables encountered include design mix, mix temperature, compaction temperature, and the compactive effort. A considerable amount of work has been reported on studies involving the design of the mix and the importance of temperature control. Lately, additional emphasis has been given to field studies of the effect of varying the compactive effort applied.

This latter variable has been investigated by Louisiana (1) and Ohio (2) highway departments among others. Their results indicate asphaltic concrete tends to reach a point of maximum density under optimum compactive effort, with any additional compaction tending to reduce the density or "decompact" the material. Louisiana found that this optimum compaction occurred with six to eight coverages of the same type of rollers used in Florida. After a thorough study of these results it was decided that the Florida State Road Department would benefit from a similar study. Recent literature also points out the need for using higher tire pressures than is the current practice and recommends pressures closer to the contact pressure expected from the more common type of truck tires (3). This seems reasonable and presents a further area of study beneficial to the Department.

Several manufacturers of compaction equipment have recently advocated the use of vibratory rollers for use on asphaltic concrete surface courses. It was though desirable to study the effectiveness of this type of roller as well as conventional rollers.

To accomplish these objectives the Division of Research and In-Service Training undertook an investigation of the effect of varying the amount of intermediate rolling with self-propelled pneumatic-tired and self-propelled vibratory rollers on the pavement density of asphaltic concrete.

PURPOSE

The objectives of this project were to investigate the following effects on the pavement density of Florida's type I asphaltic concrete surface course:

1. Varying the number of coverages with a pneumatic-tired roller meeting current Florida specification requirements.
2. Varying contact pressure exerted by pneumatic-tired rollers on the pavement.
3. Varying the number of coverages with one type of vibratory roller.
4. Ascertaining traffic for the period of one year following construction.
5. From the preceding studies, determining the optimum compactive effort required to produce a maximum density for this type of mix.

It was assumed that maximum density would produce the maximum stability of the asphaltic concrete mix. This was to be determined by studying the amount of distortion or additional compaction incurred by one year of traffic.

The study included a total of 26 test sections from which six density samples each were taken, two in each wheelpath and two inbetween the wheelpaths. One density sample in each location was used to study the construction compactive effort, the remaining sample will be used to study the effect of traffic.

The test sites were on a type I asphaltic concrete pavement located on Interstate 4, Project 92130-3402, just south of its intersection with Florida 530 fifteen to twenty miles West of Kissimmee, Florida. Construction of the test sections was started on January 24, 1961, and completed February 2, 1961. The test sections were located in both the traffic and passing lanes of the eastbound roadway on straight sections of the road, well clear of intersections. The design thickness of the surface course was 1.5 in. overlaying an open type of binder course with an average thickness of 3 in.

PROCEDURE

The equipment used for the test site construction was typical of that normally used for construction of asphaltic concrete pavements and included a portable continuous mix type of asphalt plant with two driers in series, a Barber-Greene model SA-40 paver, a Buffalo 5-ton tandem steel-wheel breakdown roller, three intermediate rollers (Bros SP-730B pneumatic-tired, Bros SP-54B pneumatic-tired, and Bros SP-54B rigged with two vibra pactors), and a Buffalo 9-ton tandem steel-wheel finish roller.

The equipment was all thoroughly checked for proper operation and adherence to Florida State Road Department specifications where applicable. Paving operations were stabilized by allowing several days of paving before the commencement of test site construction.

The 26 test sections were laid out before paving according to the diagrams in Figures 1 and 2. Each test section was constructed with material from a single truck load of asphalt mix, with adequate allowance made for the transition from the previous material in the spreader. For easy removal of the density samples, a double layer of aluminum foil was placed on the binder course on the spot from which the density samples were cut later (Fig. 3). This method was found to eliminate most of the troubles encountered in separating the surface from the binder course.

Each morning the asphalt plant was allowed to operate for a short time and checked for uniformity of production. The asphalt mix temperature was checked as it arrived

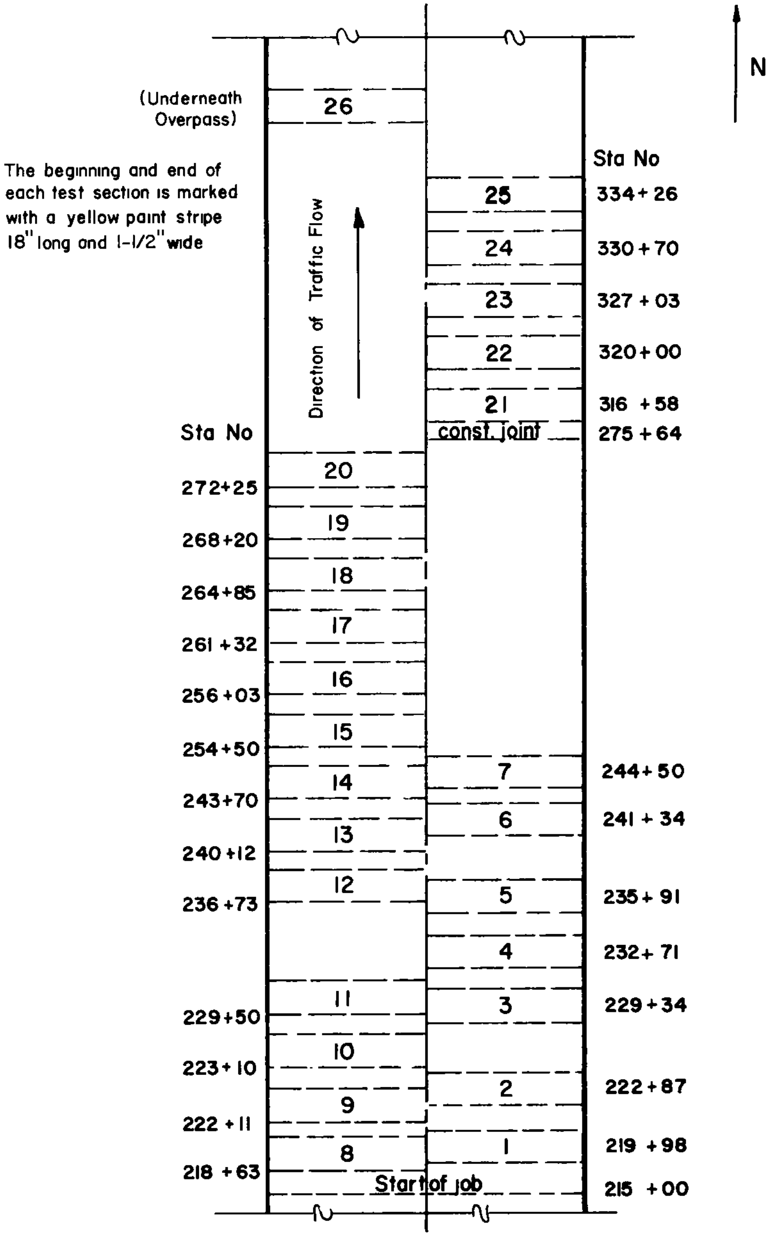

Figure 1. Location of test section.

at the spreader and only those truck loads with temperature in the range of 300 to 330 F were used in the construction of the test sections. As the mix was being spread a sample representative of the material in each experimental test section was obtained by continuous sampling of the load during the entire operation of unloading. These samples, consisting of approximately 50 lb of material packed in cardboard boxes, were taken to the laboratory and the material checked for uniformity using the following tests:

1. Density using Hubbard field procedure AASHO T-169, ASTM D-1138.
2. Density using Marshall procedure ASTM D-1559.

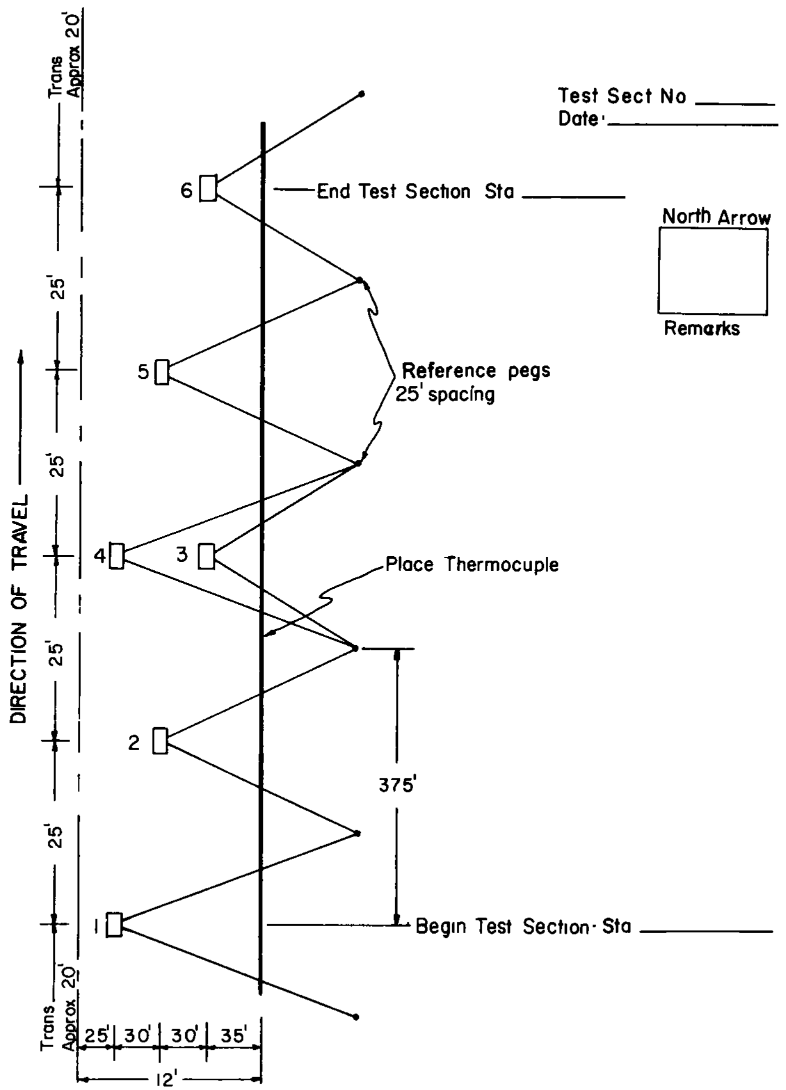

Figure 2. Layout of test section.

3. Asphalt content AASHO T-164, ASTM D-1097.
4. Gradation AASHO T-30.

Immediately after the mix was spread, a thermocouple was inserted midway in the layer of asphalt mix and the temperature recorded (Fig. 4). This entire operation was usually accomplished within 1 min and additional temperature readings were made at 3-min intervals thereafter, until finish rolling had been accomplished. The time of the initial and final pass of each type of rolling was also recorded on the same chart as the temperature records, so that the two could be related.

The procedures for initial or breakdown, and final rolling were conducted according to existing Florida specifications except that no finish roller was used in the sections

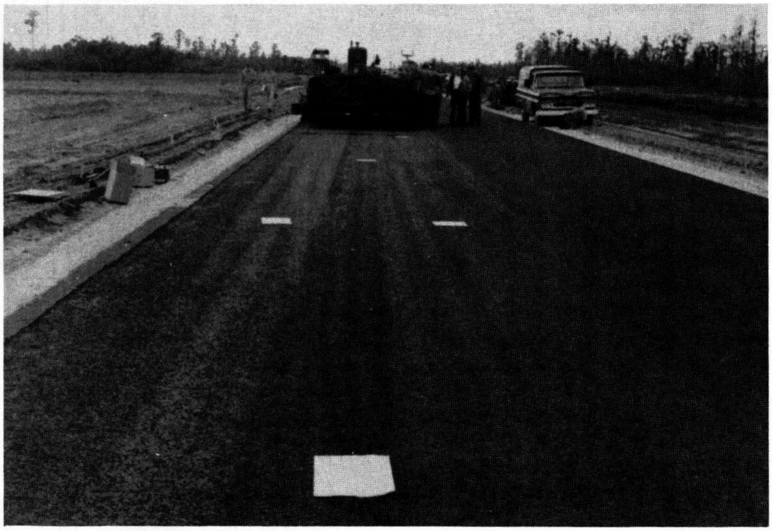

Figure 3. Location of aluminum foil under areas to be used as density samples.

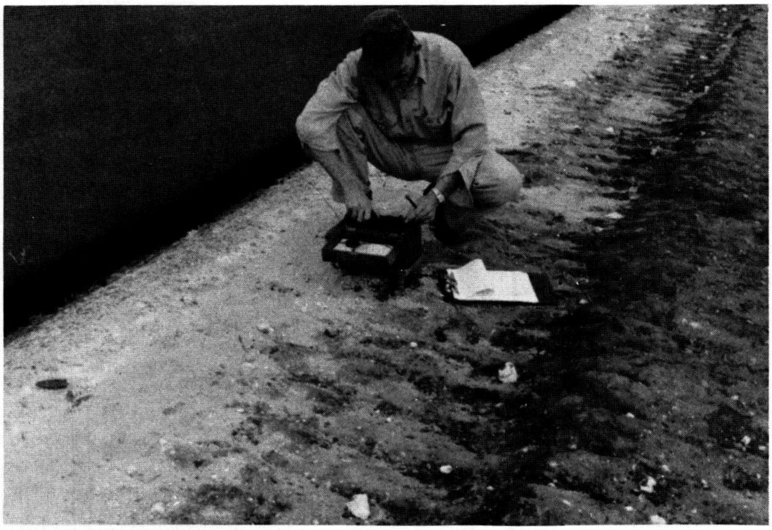

Figure 4. Thermocouple reading via a potentiometer calibrated to temperature in degrees fahrenheit directly.

with vibratory intermediate rolling and the temperature for finish rolling was between 140 and 130 F instead of 150+F. The existing temperature specifications for intermediate rolling were found to be unrealistic, as even with the lowest contact pressure used in the test, (40 psi) it was impossible to roll the asphalt mix at a temperature higher than 150 F without excessive displacement and pickup of the material. At the higher contact pressures (70 psi) an even lower temperature (140 F) was required to prevent this phenomenon from occurring. In an effort to acquire more uniform results each type of rolling was started at approximately the same temperature for each test section. The temperatures used are given in Table 1.

These temperatures were the maximum at which the mix was stable enough to support the rollers without excessive displacement or pickup occurring (Fig. 5).

Turning, parking, and the reversing of directions of all rollers was conducted on areas well clear of the test sections.

In the sections in which the effects of varying the compactive effort imparted by the self-propelled pneumatic-tired rollers (Fig. 6) were studied, the contact pressure and the number of coverages were varied as given in Table 2. Except for Section 16, where five extra passes of the final 8-ton steel-wheel roller were applied, initial and final rolling procedures were kept constant in all of the sections.

TABLE 1

TEMPERATURES USED FOR TEST SECTIONS

Type	Temperature (°F)
Initial	210
Intermediate:	
40 psi	150
50 psi	150
70 psi	140
Vibratory	150
Finish	140-130

In the sections in which the vibratory roller (Fig. 7) was evaluated, the vibratory roller was substituted for both the intermediate and final rollers. Sections were constructed with two, three, and four coverages with this equipment. Only one replicate section (with three coverages) was conducted as there was considerable trouble getting the equipment to function which caused extended delays in the paving operations.

On completion of the construction, the sections were surveyed and marked for future reference. The survey included measurement of the transverse profile by visually checking with a 10-ft straightedge and measurement of transverse displacement of the pavement incurred during rolling operations. This was accomplished by locating pins near the edge of the pavement in the mix immediately after spreading and checking the amount of transverse displacement during rolling operations.

No traffic was permitted on the test sections until the density samples were obtained on the day following construction. The density samples were removed from the pavement by sawing them out with a portable power saw using a carborundum blade. These samples were marked, individually boxed, and stored in such a manner as to

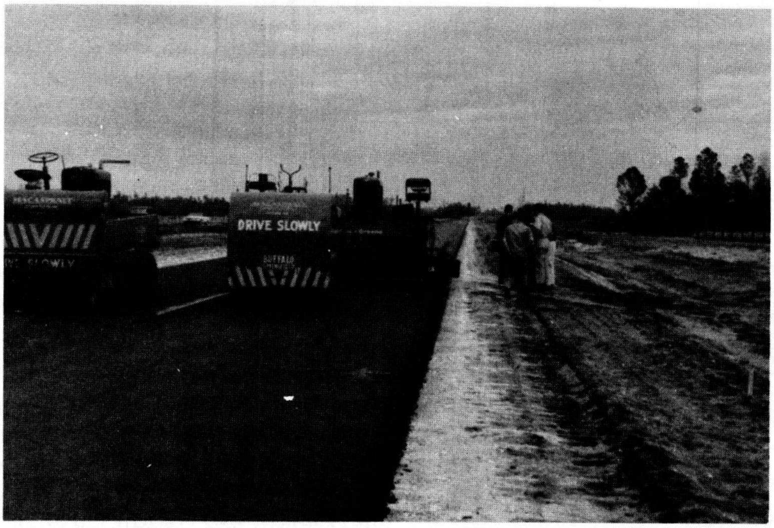

Figure 5. Barber Greene spreader, 5-ton tandem wheel roller, and Bros SP-54B pneumatic-tired roller parked between test sections during break in construction operations.

Figure 6. Bros SP-730B pneumatic-tired roller in operation.

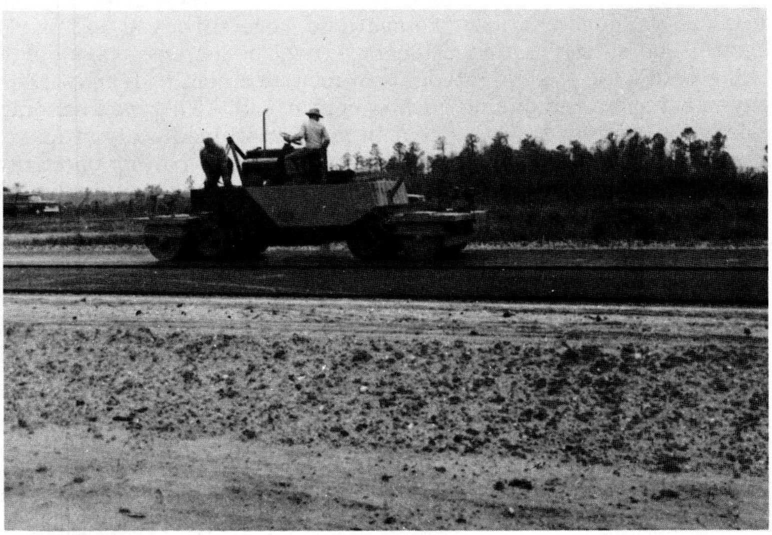

Figure 7. Vibratory roller in operation.

TABLE 2

COMPACTIVE EFFORT APPLIED IN EACH TEST SECTION

No. of	Test Section[a]			
Coverages	0 Psi	40 Psi	50 Psi	70 Psi
0	5, 11, 16[b]			
4		4, 9		
6		3, 8, 18	13, 15	20, 25
8		2, 7		
10		1, 6, 10, 7	12, 14	24, 26

[a]At four contact pressures.

[b]Five extra passes of final 8-ton steel-wheel roller applied in Section 16.

prevent any damage while being transported to the laboratory. In the laboratory the samples were measured, weighed, waxed, and weighed in water at room temperature and the specific gravity of each computed.

Additional field tests conducted on each test section included tests for skid resistance using the Tapley decelerometer in accordance with procedure described in Bulletin 29, "Skid Characteristics of Florida Pavements" and permeability tests as described in Bulletin 11 "Procedure

TABLE 3

SUMMARY OF FIELD DATA

Section Number	No. of Coverages	Tire Contact Pressure (psi)	Field Density (% lab avg. of 3)	Avg. Thickness (in.)	As Mixed	As Placed	Initial Rolling		Intermediate Rolling		Final Rolling	
							Begin	End	Begin	End	Begin	End
1	10	40	97.6	1.8	305	300	247	213	148	132	132	128
2	8	40	96.8	1 8	335	290	220	210	151	133	129	120
3	6	40	97.1	1.65	305	290	210	190	150	142	130	124
4	4	40	97.1	1.7	305	269	204	195	150	142	132	127
5	0	0	95.9	1.6	305	252	202	169			132	132
6	10	40	96.5	1.65	320	265	207	175	150	134	132	125
7	8	40	96.9	1.65	307	266	202	166	146	136	132	122
8	6	40	97.6	1.6	310	284	204	182	150	144	130	121
9	4	40	96.4	1.45	300	285	208	189	148	Thermocouple failed		
10	10	40H	96.3	1.575	335	290	207	190	142	130	130	122
11	0		94.7	1.5	285	266	201	194			144	133
12	10	50	96.4	1.55	300	275	210	191	147	130	130	126
13	6	50	96.2	1.5	305	283	205	191	140	128	128	122
14	10	50	96.7	1.6	290	270	207	194	148	126	126	122
15	6	50	97.3	1.6	310	285	211	200	151	134	129	125
16	0[a]	0[a]	96.9	1.6	330	285	208	194			150	137
17	10	40	96.0	1.7	320	285	210	198	150	124	120	114
18	6	40	97.1	1.55	295	272	210	193	145	130	127	121
19	3	V	96.4	1 45	300	272	210	198			174	139
20	6	70	96.9[b]	1.575	290	270	208	196	140	125	123	117
21	4	V[c]	96.2	1.6	315	298	213	184			150	139
22	2	V	95.9	1.6	315	298	205	183			149	144
23	3	V	94.6	1.6	305	288	194	177			150	141
24	10	70	96.2	1.6	305	290	201	176	140	117	115	111
25	6	70	97.3	1.6	305	280	216	200	142	132	126	122
26	10	70	96.4[b]	1.5	300	267	209	188	140	131	128	126

[a] Five extra passes of final 8-ton steel-wheel roller applied on Section 16.

[b] Average of two.

[c] Rear vibratory motor quit—third pass only.

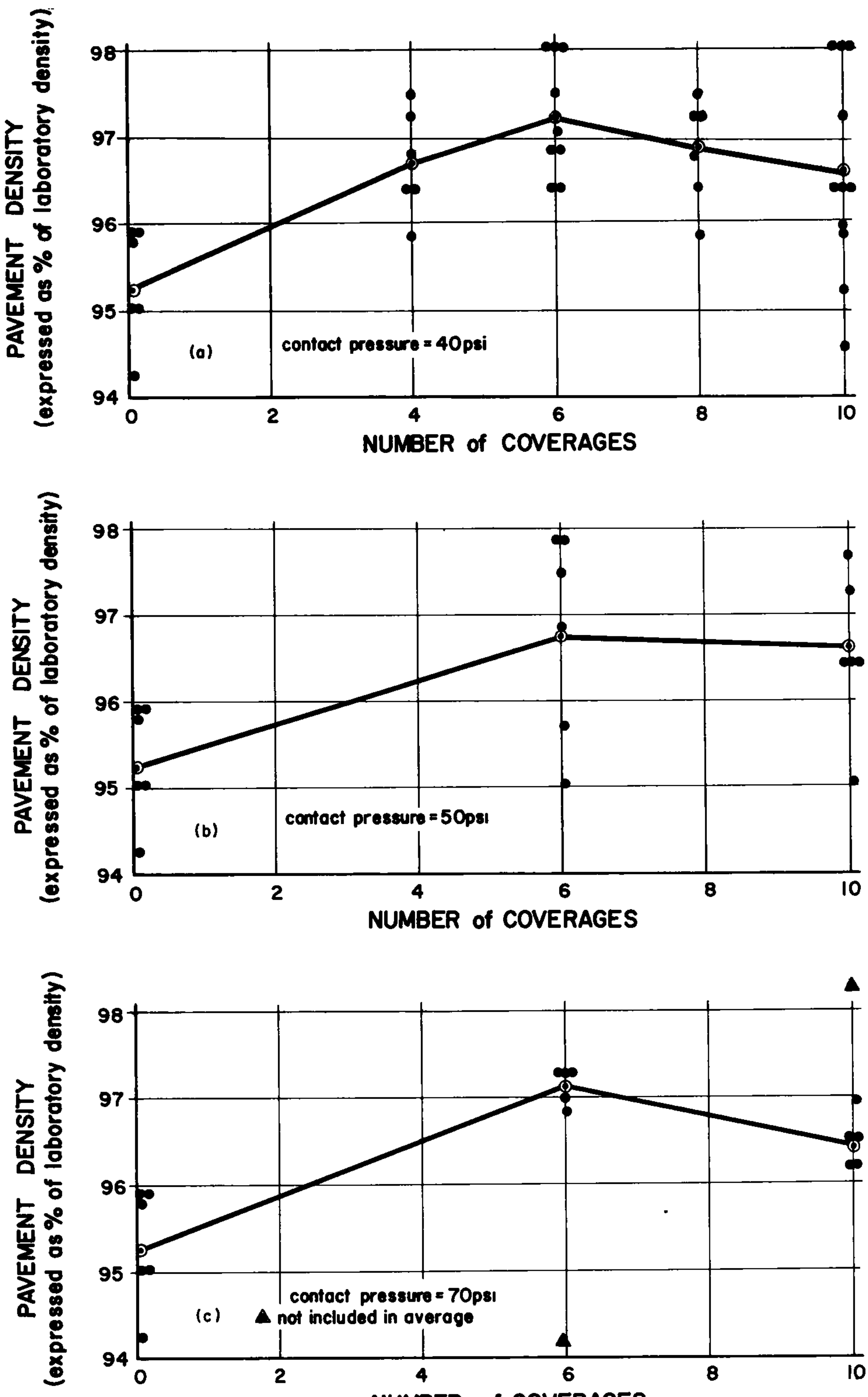

Figure 8. Pneumatic-tired rollers, pavement density vs number of coverages: (a) 40-psi contact pressure; (b) 50-psi contact pressure; and (c) 70-psi contact pressure.

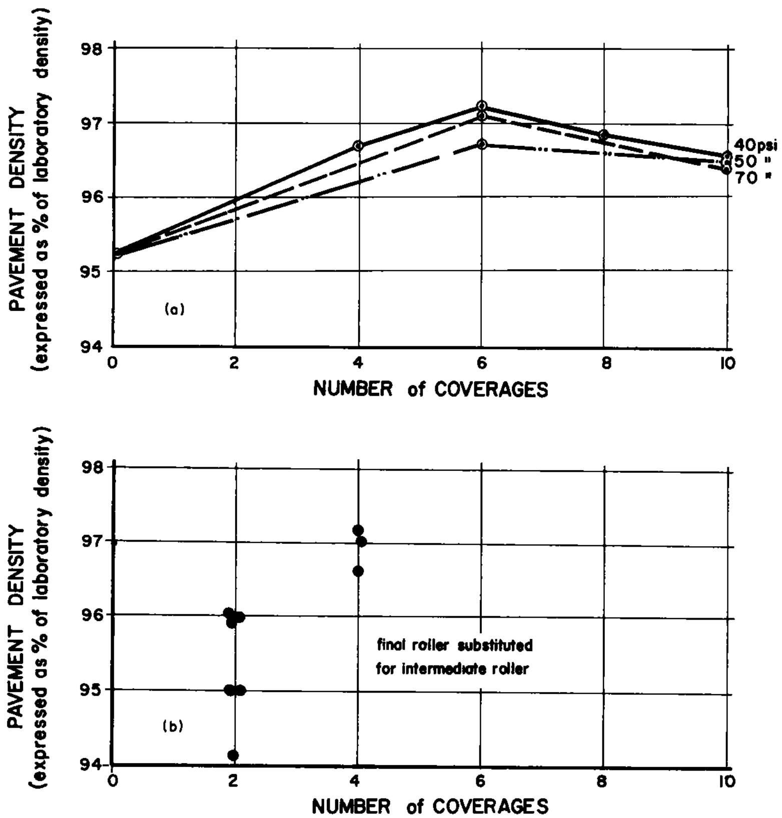

Figure 9. Pneumatic-tired rollers, pavement density vs number of coverages: (a) combined results; and (b) results from increasing number of coverages in section in which intermediate rolling was omitted.

for Conducting Permeability Tests." This was done to check the different test sections for honeycombing or flushing of asphalt from the mix caused by insufficient or excessive amounts of intermediate rolling during construction.

RESULTS

The results of the field and laboratory tests are summarized in this section. Details of the design mix and results of the extraction tests and laboratory compaction study are included in the Appendix.

The average field densities obtained, the compactive effort applied, and the temperature at which compaction was accomplished are given in Table 3. Relationships between the compactive effort applied and the densities obtained for pneumatic-tired rollers at the various contact pressures are shown in Figures 8a, 8b, and 8c. This same information is combined in Figure 9a to permit a direct comparison of the results. Figure 9b shows the results obtained by increasing the number of coverages with the final roller in the sections in which the intermediate rolling was omitted. Results of the skid tests, permeability tests, and the transverse profile measurements are summarized in Table 4.

Table 5 shows the laboratory density and the results of the extraction tests on the 26 truck samples obtained during the paving operations. A comparison of the individual density samples and the design mix density is also given in this table.

TABLE 4

PROPERTIES OF MIX

Section Number	Avg (2) Lab Density (% 2 21)	Specific Gravity: Avg (2) Hubbard Field	Specific Gravity: Avg (8) Marshall	Specific Gravity: Theoretical	Bitumen (%)
1	100 8	2 23		2 26	5 5
2	100 4	2 22		2 26	5 1
3	99 9	2 21		2 26	4 9
4	100 6	2 22	2 226	2 26	5 5
5	99 1	2 19		2 26	5 0
6	99 6	2 20		2 27	5 3
7	100 8	2.23		2 27	5 3
8	101 3	2 24		2 26	5 5
9	99 0	2 19	2 214	2 26	5 1
10	97 8	2 16		2 27	5 3
11	100 6	2 22		2 26	5 6
12	100 4	2 22		2 26	5 5
13	101 4	2 24		2 25	5 8
14	99.8	2 19		2 26	5 5
15	100.4	2 22		2 26	5 6
16	102 2	2 26	2 229	2 26	5 7
17	101 4	2 24		2 26	5 6
18	100 9	2 23		2.26	5 4
19	100 8	2 23		2 26	5 6
20	100 2	2 22		2 27	5 4
21	100 9	2 23		2 27	5 4
22	101 0	2 23		2 26	5 4
23	99 6	2 21		2 26	5 4
24	99.8	2 21		2 26	5 3
25	100 1	2 22		2 26	6 0
26	100 9	2 23	2 21	2 27	5 4
$\bar{x}$		2 22			5 4
Max		2 26			5 0
Min		2 16			4 9
		0 03			0 025
Limits					
Max		2 28			5 9
Min		2 16			4 9

TABLE 5

PROPERTIES OF SURFACE

Transverse Profile Check	Avg Skid Resistance Decelerometer Reading	Permeability of Surface
OK	63	Impervious
OK	69	"
OK	67	"
OK	71	"
OK	72	"
OK	71	"
OK	69	"
OK	65	"
OK	64	"
OK	70	"
OK	73	"
OK	68	"
OK	66	"
OK	65	"
OK	64	"
OK	66	"
OK	67	"
OK	69	"
OK	65	"
OK	66	"
Humped slightly[1]	67	"
Humped slightly[1]	63	"
Humped slightly[1]	65	"
Very slight rutting[2]	66	"
Humped, slight rutting[2]	64	"
OK	64	"

[1] Sections "humped slightly" were about 1/32 in high at centerline

[2] Slight rutting refers to visible but unmeasurable tire prints of traffic roller remaining after finish rolling

Density vs Compactive Effort

When the results of the field density tests are averaged and plotted against the compactive effort applied, they indicate that maximum compaction is obtained at approximately six coverages regardless of the contact pressure employed but that the mix apparently decompacts when additional coverages are applied. This tendency to decompact is not very pronounced and it should be recognized that individual density samples taken from sections in which ten coverages were made were found to have densities equal to the highest densities found in the sections compacted with only six coverages. However, the fact cannot be ignored that the average densities obtained in the various sections show a reduction when more than six coverages are applied. The same phenomenon was reported by Louisiana.

Changing the contact pressure apparently had no significant effect on the densities attained for a given number of coverages. Figure 9a shows that the maximum average density attained with six coverages varied only between 97.3 and 96.7 percent of laboratory density and the maximum average density attained with ten coverages ranged only from 96.6 to 96.3 percent. However, in every instance the highest densities were attained with the lower contact pressure. This fact coupled with the results of the Louisiana tests indicates that the 40-psi contact pressure (attained with a tire pressure of 55 psi) is probably an optimum.

It must be kept in mind that whenever reference is made to variation in compactive effort in the preceding discussion it refers only to the intermediate roller. As was previously stated, the initial rolling was held constant in all 26 test sections and the final rolling was kept constant in all sections except Nos. 16, 19, 21, 22, and 23. Sections 19, 21, 22, and 23 were compacted with a vibratory roller and discussion of these sections will be treated later.

No intermediate rolling was done in Section 16 but two extra coverages were made with the finish roller for comparison with the results obtained in Sections 5 and 11. Figure 9b shows that this extra finish rolling provided an increase in density of 1.6 percent (from 95.3 to 96.9 percent of laboratory density). This appears significant, but due to the variation observed throughout the test in this project and the lack of replicate sections to provide a measure of the significance of variation, an accurate evaluation cannot be made of these data. Based purely on general observations, however, this writer feels that this increase obtained with the two additional coverages with the finish roller is significant.

Variation in Results

The variation in the results obtained seemed excessive—particularly with respect to individual test sections. Density samples taken from the same section varied as much as 2.9 percent and two samples taken within 25 ft of each other varied by 2.7 percent (Section 20). The average variation was 1.4 percent but variations greater than this occurred in ten sections. This variation (shown in Fig. 8) appears to be significant and should be recognized when preparing specifications for the compaction of asphaltic concrete because it represents two-thirds of the maximum average net increase in density attributable to the intermediate roller. Moreover, in computing the average density in Figure 8c two density samples were omitted due to their great deviation from the other data in their group.

When the results of density tests conducted on individual samples from within a given section are averaged and compared with the average of results of other sections submitted to a like compactive effort the average variation is greatly reduced, most of the overlapping of results disappears, and some definite trends become apparent. For instance, the least average density provided by six coverages (40 psi contact pressure) is greater than the maximum density provided by either four or eight coverages. Likewise, the least density provided by four coverages is greater than the maximum provided by zero coverages and the least density provided by eight coverages is greater than the maximum provided in three of the four sections submitted to ten coverages—Section 1 being the exception.

In an effort to account for some of the variation just shown, an analysis was made of results of the extraction tests and the results of the laboratory compaction study. None of these test results showed any correlation with the field densities. The variation in the gradation of the samples taken from the trucks for each of the 26 test sections is shown in the Appendix and the variations found in the percent bitumen and the densities of the specimens compacted in the laboratory from the same samples are shown in Table 4. The distribution of results obtained in each of these studies indicates that the variation is due more to chance error than to any induced bias. The distribution appears normal for the small number of data available and every indication is that the same errors would recur in the same approximate proportions if the sample population was expanded. This indicates a need for a quality control study to establish specification limits and to determine the number of samples required to ascertain that specifications are being met.

Temperature

Because it is well-recognized that the temperature at which an asphaltic concrete is mixed and compacted has an important effect on the densities attained, every effort was made to hold the temperature of the mix within as small a range as possible for each phase of the construction operation. The temperature data given in Table 3 show the success of this endeavor.

The temperature distribution appears to be both normal and random just as does the density and inasmuch as no correlation was found to exist between these variables it is assumed that the close control of the temperature was apparently successful in mitigating the effect of this variable.

The temperature data collected on this project revealed that the temperature requirements listed in the standard specifications are unrealistic with respect to compaction. The standard specifications require that the intermediate rolling with pneumatic-tired rollers "shall be done while the pavement temperature is between 175 F and 240 F. . . " and that final rolling ". . . shall be done before the pavement temperature is lower than 150 F. . . ". Trials made on this project showed the maximum temperature at which this particular mix would support the pneumatic-tired roller without undue distortion or pick-up was 150 F for 40-psi contact pressure and 140 F for 70-psi contact pressure. The maximum temperature at which this mix would tolerate the 8-ton steel-wheel finish roller was 150 F. This information indicates the need for further study to determine the maximum temperature at which other mixes will properly support the compaction equipment. If future studies confirm the observations made on this project, the standard specifications should be revised accordingly.

Skid Resistance

The results of the skid tests summarized in Table 5 show that there apparently was no flushing of the asphalt in any section. The minimum skid resistance recorded was 63—well above the average for an asphaltic concrete. This can be expected to decrease with time due to the abrasive action of traffic and the accumulation of rubber, oil dripping, etc. Further tests will be made after traffic has used this section one year.

There was a very slight correlation between skid resistance and density with the lower skid resistance being generally associated with the higher densities. However, because the total range in density was so small, this correlation was not strong. In general, sections compacted with the higher contact pressures and the vibratory roller provided the poorest skid resistance with the results from the sections compacted with the vibratory roller going against the trend relating density and skid resistance as already noted.

Permeability

All sections were impermeable, showing that pneumatic-tired rolling is not necessary to achieve impermeability so long as 95 percent of the laboratory density is achieved.

Surface Irregularities

The only surface irregularities in any of the test sections were the slight tire marks noted in Sections 24 and 25 where 70-psi contact pressure was applied, and the slight "humping" noted in Sections 21, 22, and 23 where the vibratory roller was used. These distortions could be easily discerned immediately after construction but actually deviated from a straight plane by less than $\frac{1}{32}$ in. Most of the distortion noted is probably due more to construction procedure than to the particular equipment involved. Because both the rollers used in these sections were approximately $\frac{1}{2}$ the width of the pavement being placed, and because the compactive effort was carefully controlled in an attempt to provide the same compactive effort across each section of the pavement, no overlapping by the rollers was permitted and as a consequence rolling was highly channelized. All initial and finish rolling was lapped normally, but no finish rolling was done in the sections in which the vibratory roller was used.

Vibratory Roller

The results obtained with the vibratory roller in any one section were no more variable than those in any of the other sections, but the replicate sections with three coverages showed poor reproducibility of results. This particular equipment provided no direct control of the vibrating frequency and the change in the frequency-forward motion relationship may have changed between these sections. Due to the poor reproducibility of results demonstrated and the numerous mechanical difficulties that delayed paving operations and prevented the construction of additional test sites for further replication, no evaluation of the results obtained was attempted. Further study of vibratory rolling of asphaltic concrete will be undertaken when it has been demonstrated that the equipment available is suitable for this type of work and that positive control of the vibrating frequency and forward speed of the equipment can be maintained.

SUMMARY AND CONCLUSIONS

This project was undertaken to evaluate the effect of varying the compactive effort of the intermediate rolling on asphaltic concrete. Both pneumatic-tired and steel-wheel vibratory rollers were used. The number of coverages and the contact pressure was varied for the pneumatic-tired rollers used in 22 test sections. The number of coverages was varied in the four sections constructed with the vibratory compactor. The results obtained with the vibratory compactor were inconsistent and due to the lack of replication no evaluation of these results was attempted. The average compactive effort attained with the vibratory roller was considerably less than the average attained with the rubber-tired intermediate roller. In fact, the maximum compaction attained with the vibratory roller was less than the average compaction attained with no intermediate rolling at all but with two extra coverages of the 8-ton steel-wheel final roller.

Results of the tests made with the pneumatic-tired intermediate roller indicated that maximum compaction is attained with six coverages, and a slight tendency for the material to decompact with additional coverages was noted. Results from the three sections in which no intermediate rolling was used showed that the average density attained exceeded minimum specification requirements. When the intermediate rolling was omitted but two extra coverages of the final steel-wheel rolling was applied instead, the average density attained was nearly as great as the average maximum density attained with the optimum number of coverages and exceeded the average densities attained with eight and ten coverages of the intermediate roller.

Based on the results obtained in this study the following are concluded:

1. The optimum number of coverages with the pneumatic tired roller is six and that asphaltic concrete will tend to decompact with additional coverages beyond this optimum.
2. The optimum contact pressure that should be exerted by the pneumatic tired intermediate roller is 40 psi.
3. The densities exceeding the minimum specification requirements can be achieved without any intermediate rolling. The results of the permeability tests indicate no detrimental effect resulting from omission of the intermediate rolling.
4. The temperature requirements listed in the Florida standard specifications are unrealistic with respect to compaction. Further study should be made to determine the maximum temperature at which other mixes will properly support the compaction equipment, and, if these studies confirm the observations made on this project, the standard specifications should be revised accordingly.

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Appendix

TABLE 6

ASPHALT DENSITIES AS COMPUTED FROM SAMPLES REMOVED FROM ROADWAY

Section Number	Density (% of lab roadway) Inner Wheel-path	Between Wheel-path	Outer Wheel-path	Average	Contact Pressure[a] (psi)	Number Intermediate Roller
1	96 4	98 2	98 2	97.6	40(L)	10
2	95.9	97.3	97 3	96.8	40(L)	8
3	96.8	96.4	98.2	97 1	40(L)	6
4	96.4	97.7	97 3	97.1	40(L)	4
5	95.9	95.9	95 8	95 9		0
6	95 9	97 3	96.4	96.5	40(L)	10
7	96.4	97 7	96.8	96.9	40(L)	8
8	97 0	98.2	97.7	97 6	40(L)	6
9	96 4	95 9	96.8	96 4	40(L)	4
10	96.4	96 6	96.0	96.3	40(H)	10
11	95 0	95 0	94 2	94 7		0
12	97.7	96.4	95.0	96.4	50(H)	10
13	97 7	95 9	95 0	96.2	50(H)	6
14	97 2	96.4	96.4	96 7	50(H)	10
15	97.4	97 7	96 8	97.3	50(H)	6
16	97 3	96 4	97 2	96.9		0
17	98 2	95 3	94 6	96.0	40(H)	10
18	98.2	96.8	96 4	97.1	40(L)	6
19	95.5	96.8	96 8	96 4	Vibratory	3
20	97 0	96 8	94 1	96.0	70(H)	6
21	96.4	95 9	96 4	96 2	Vibratory	4
22	96.8	95 0	95.9	95 9	Vibratory	2
23	94.6	93 7	95.5	94.6	Vibratory	3
24	96.4	96.4	95 9	96.2	70(H)	10
25	97 3	97.3	97 3	97.3	70(H)	6
26	95.9	98 2	96 8	97 0	70(H)	10

[a]L = light roller, Bros SP-54B.
H = heavy roller, Bros SP-730B.

TABLE 7

DESIGN MIX DATA

Property	Avg (%)	Limit (%) Max.	Min.	Spec. Grav.
Percent passing				
1/2-in.	100	100	100	
3/8-in.	98	100	93	
No 4	63	68	58	
No. 10	43	47	39	
No. 40	33	36	30	
No. 80	16	19	13	
No 200	4	6	2	
Bitumen	5.7	6.1	5.3	1.02
Coarse aggregate	53.8			2 35
Fine aggregate	37 7			2 55
Mineral filler	2 8			2 71
Spec gravity·				
Theoretical				2 26
Laboratory				2 21
Lab. dens [a]	97.8			

[a]As percent of theoretical density.

TABLE 8

SUMMARY OF EXTRACTION GRADATIONS

Property	Avg.	Max.	Min.	Limit Max.	Min.
Cum. % Passing					
1/2 in	100	100	99	100	99
3/8 in.	98 5	99 8	96.7	100	96.7
No 4	64 2	76 2	57.2	71.2	57.2
No 10	41 4	49.0	35.8	47 2	35.6
No. 40	32 7	37.6	28.5	37.1	28.3
No 80	13 8	16 0	11.6	16.2	11 4
No. 200	3 2	4 2	2.3	4 2	2 2
Bitumen (5)	5.4[a]	6 0	4 9	5 9	4 9

[a]Four of 26 samples deficient in bitumen content

TABLE 9

GRADATION OF EXTRACTION SAMPLES TAKEN FROM TRUCK DURING PAVING OPERATIONS

Sieve Size	Cumulative Percent												
	Sec 1	Sec 2	Sec 3	Sec 4	Sec 5	Sec 6	Sec 7	Sec 8	Sec 9	Sec 10	Sec 11	Sec 12	Sec 13
3/4 in.						100.0							
1/2 in.	100.0	100.0	100.0	100.0	100.0	99.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0
3/8 in.	99.4	99.2	97.8	98.6	96.8	96.7	99.6	98.4	98.7	99.2	99.5	99.5	98.8
No. 4	74.0	66.7	65.0	64.0	57.2	62.9	67.7	64.8	64.9	76.2	64.7	64.8	58.5
No. 10	49.0	45.1	41.3	40.0	35.8	39.2	43.3	40.2	38.3	47.8	39.7	38.9	37.3
No. 40	37.6	36.1	33.5	31.3	28.5	30.5	33.9	30.9	29.2	36.5	30.9	30.5	29.1
No. 80	15.4	16.0	14.9	13.4	13.1	13.8	13.6	12.7	11.6	14.4	12.8	12.8	11.4
No. 200	4.1	3.6	3.7	2.6	3.5	3.6	3.3	3.2	2.8	3.4	3.4	2.3	2.3

	Sec 14	Sec 15	Sec 16	Sec 17	Sec 18	Sec 19	Sec 20	Sec 21	Sec 22	Sec 23	Sec 24	Sec 25	Sec 26
3/4 in.						100.0	100.0						
1/2 in.	100.0	100.0	100.0	100.0	100.0	99.2	99.2	100.0	100.0	100.0	100.0	100.0	100.0
3/8 in.	98.3	97.0	98.7	98.7	98.8	97.4	97.4	99.2	99.4	98.6	98.2	99.4	98.2
No. 4	62.3	60.7	64.5	62.5	63.8	61.9	63.1	66.2	65.4	59.5	63.9	69.1	56.2
No. 10	40.8	42.7	42.5	40.3	41.5	41.3	43.6	42.1	40.4	39.7	41.6	44.2	38.5
No 40	32.2	34.3	33.3	31.7	32.7	32.9	34.8	33.0	32.6	32.5	33.7	35.4	31.7
No. 80	12.3	14.9	13.5	13.2	13.0	14.0	14.3	13.2	15.0	14.8	15.0	15.8	14.9
No. 200	3.3	3.4	3.1	3.0	2.3	4.2	2.5	2.9	3.3	3.7	2.9	3.1	3.5