Compaction of Asphaltic-Concrete Pavement With High-Intensity Pneumatic Roller

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To increase the service life of asphaltic-concrete pavement and eliminate or minimize rutting, improvement in compacting procedures seems warranted. The results discussed herein emphasize the importance of compacting asphaltic-concrete pavements with pneumatic rollers having contact pressures similar to that of the rolling stock on the highways.

Results showed that in addition to high contact pressures, the optimum number of passes with the pneumatic roller is essential in obtaining high initial compaction thereby reducing the magnitude of longitudinal grooves over a period of time.

Periodic surveys indicated (a) that most of the increase in compaction occurs during the first 6 months of traffic after which time this rate decreases; (b) that the 85-psi section requires the least number of coverages for optimum conditions and has the least magnitude of rutting after three years traffic; and (c) that the void content after only 6 months of service had decreased 1. 2 percentage points below the 75-blow Marshall design void content indicating a need for higher laboratory design compactive effort.

•RECENT experience has indicated that, in general, rollers used in compacting asphaltic-concrete pavements should be capable of exerting pressures comparable to that used by the rolling stock on the highways.

A traffic survey conducted during the summer of 1959 indicated that axle loads of up to 24, 000 lb or wheel loads of 6, 000 lb having tire inflation pressures of 115 psi were being encountered on highways at service temperatures of 140 F. This would result in a contact pressure of 120 psi on the pavement for maximum conditions and 75-85 psi for average conventional loaded truck conditions. The compactive effort being used in Louisiana on asphaltic-concrete pavements at the time of this survey with the pneumatic roller was 2, 000 lb wheel loads with 55-psi tire inflation pressures exerting anywhere from 35 to 55-psi contact pressures.

It is obvious that the compactive effort in the field was not adequate to cope with the high pressures being exerted on the roadway. For this reason a study was initiated in 1961 by the Louisiana Department of Highways in cooperation with the Bureau of Public Roads on State Project 13-10-24, Robert Covington Highway on US 190 to equalize the rolling pressures with the pressure being encountered on the highways. This highway had an annual average daily traffic of 2800, 22 percent of this being truck traffic. The total number of axles per day in the 10 to 20-kip group is 395. Results of the preliminary field investigation including details of construction procedure, equipment, etc., were explained elsewhere (2).

Paper sponsored by Committee on Relation of Physical Characteristics of Bituminous Mixtures to Performance of Bituminous Pavements and presented at the 46th Annual Meeting.

TABLE 1

TYPICAL PROPORTION AND GRADATION OF WEARING COURSE MIX

U. S. Sieve	Percent Passing
1½ In.	100
⅜ In.	93
No. 4	69
No. 10	51
No. 40	32
No. 80	15
No. 200	8

Bin Proportions[a]	Percent
Bin 1—Fines	48.0
Bin 2—Intermediate gravel	23.0
Bin 3—Coarse gravel	23.5
Mineral filler (oyster shell dust)	5.5

[a] Bitumen 80-100 penetration.

The primary objective of this study was to minimize rutting due to traffic on asphaltic-concrete pavements which at the time was of major concern in Louisiana.

Three of the most important factors which influence the stability of asphaltic-concrete pavements in service other than the quality of the mixture are the following:

1. The magnitude of the compactive effort employed during construction;
2. The temperature of the mixture during construction; and
3. The number of passes applied with the compaction equipment.

The study consisted of constructing comparative test sections varying the

TABLE 2

COMPACTION TEMPERATURE OF WEARING COURSE MIXTURE

Section No.	Discharge (temp., °F)	Rolling Temperature, °F		No. of Passes (pneumatic roller)
		3 Wheel	Pneumatic	
(a) Asphalt Content 5.8 Percent				
Contact pressure, 55 psi				
34	300	225	160	15
35	295	207	189	17
36	270	196	172	19
Contact pressure, 75 psi				
18	325	168	134	11
17	325	231	193	15
16	315	236	161	17
15	310	241	189	19
Contact pressure, 85 psi				
27	340	193	183	7
28	305	225	193	9
29	305	188	175	11
30	310	214	185	15
(b) Asphalt Content 6.0 Percent				
Contact pressure, 55 psi				
31	370	219	192	15
32	345	233	172	17
33	330	209	171	19
Contact pressure, 75 psi				
22	310	265	160	11
21	315	243	165	15
20	310	253	176	17
19	295	273	191	19
Contact pressure, 85 psi				
23	340	190	179	7
24	340	230	165	9
25	310	215	180	11
26	305	228	180	15

TABLE 3

AVERAGE TEST RESULTS OF WEARING COURSE MIXTURE ON CONCRETE BASE

Section No.	No. of Passes	Bitumen (%)	75-Blow Compaction (%)					Voids (%)	36-Mo. Grooves (mm)	Compaction Increase (orig. to 36 mo., %)
			Original	6 Mo.	15 Mo.	24 Mo.	36 Mo.			
(a) Asphalt Content 5.8 Percent										
Contact pressure, 55 psi										
34	15	5.8	97.4	99.3	100.3	100.7	101.0	3.3	7.7	3.6
35	17	5.8	97.4	98.8	99.7	100.2	100.3	4.0	8.3	2.9
36	19	5.8	97.1	99.5	100.2	100.3	100.8	3.5	6.4	3.7
Contact pressure, 75 psi										
18	11	5.8	96.7	100.0	100.8	100.5	101.4	4.9	7.4	4.7
17	15	5.8	97.1	100.6	100.9	101.2	101.7	4.7	6.7	4.6
16	17	5.8	97.8	100.9	101.7	102.2	101.6	4.8	7.2	3.8
15	19	5.8	97.5	100.8	101.1	101.5	101.1	5.2	6.8	3.6
Contact pressure, 85 psi										
27	7	5.8	97.6	100.4	101.1	101.4	101.7	4.2	6.8	4.1
28	9	5.8	98.9	101.1	101.5	101.8	101.6	4.2	5.5	2.7
29	11	5.8	98.5	101.3	101.6	101.8	101.9	4.0	6.6	3.4
30	15	5.8	98.5	101.4	101.4	101.7	101.7	4.2	5.7	3.2
(b) Asphalt Content 6.0 Percent										
Contact pressure, 55 psi										
31	15	6.0	95.7	99.4	99.7	100.6	100.2	3.9	8.2	4.5
32	17	6.0	96.7	99.0	99.6	100.2	100.6	3.5	9.2	3.9
33	19	6.0	97.8	98.6	99.6	100.4	100.9	3.2	6.3	3.1
Contact pressure, 75 psi										
22	11	6.0	98.0	99.4	100.0	100.2	100.6	3.6	7.6	2.6
21	15	6.0	95.9	99.4	99.9	100.6	100.8	3.4	6.9	4.9
20	17	6.0	97.3	99.5	100.0	100.3	99.9	4.3	6.8	2.6
19	19	6.0	98.0	99.4	100.2	100.2	100.3	3.9	6.3	2.3
Contact pressure, 85 psi										
23	7	6.0	97.5	99.9	100.6	101.0	100.8	3.5	6.0	3.3
24	9	6.0	98.3	99.7	100.7	101.3	100.7	3.0	7.5	2.4
25	11	6.0	96.6	99.5	100.4	101.0	100.9	3.7	8.4	4.3
26	15	6.0	97.3	100.1	100.4	101.0	100.8	3.1	6.5	3.5

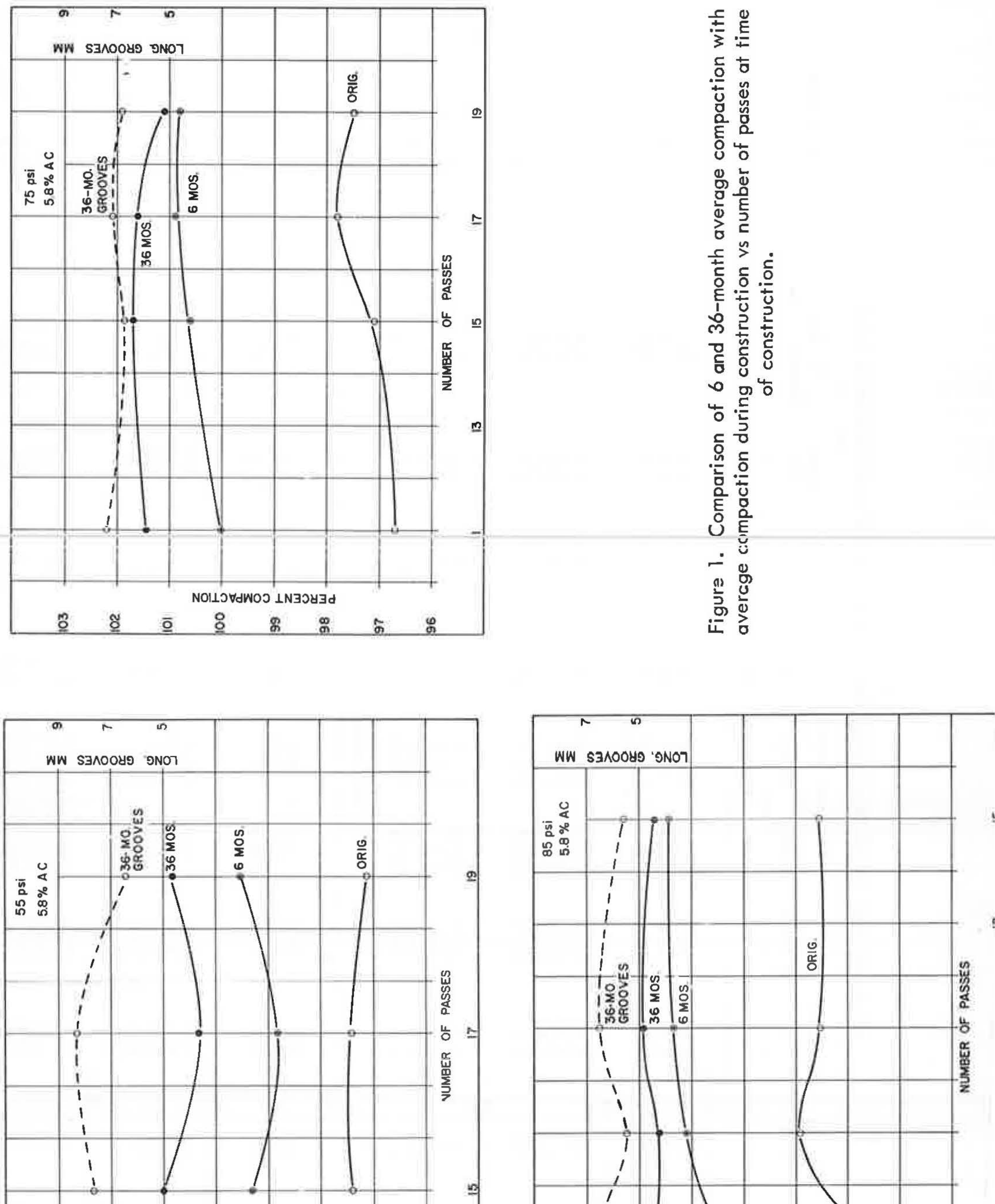

Figure 1. Comparison of 6 and 36-month average compaction with average compaction during construction vs number of passes at time of construction.

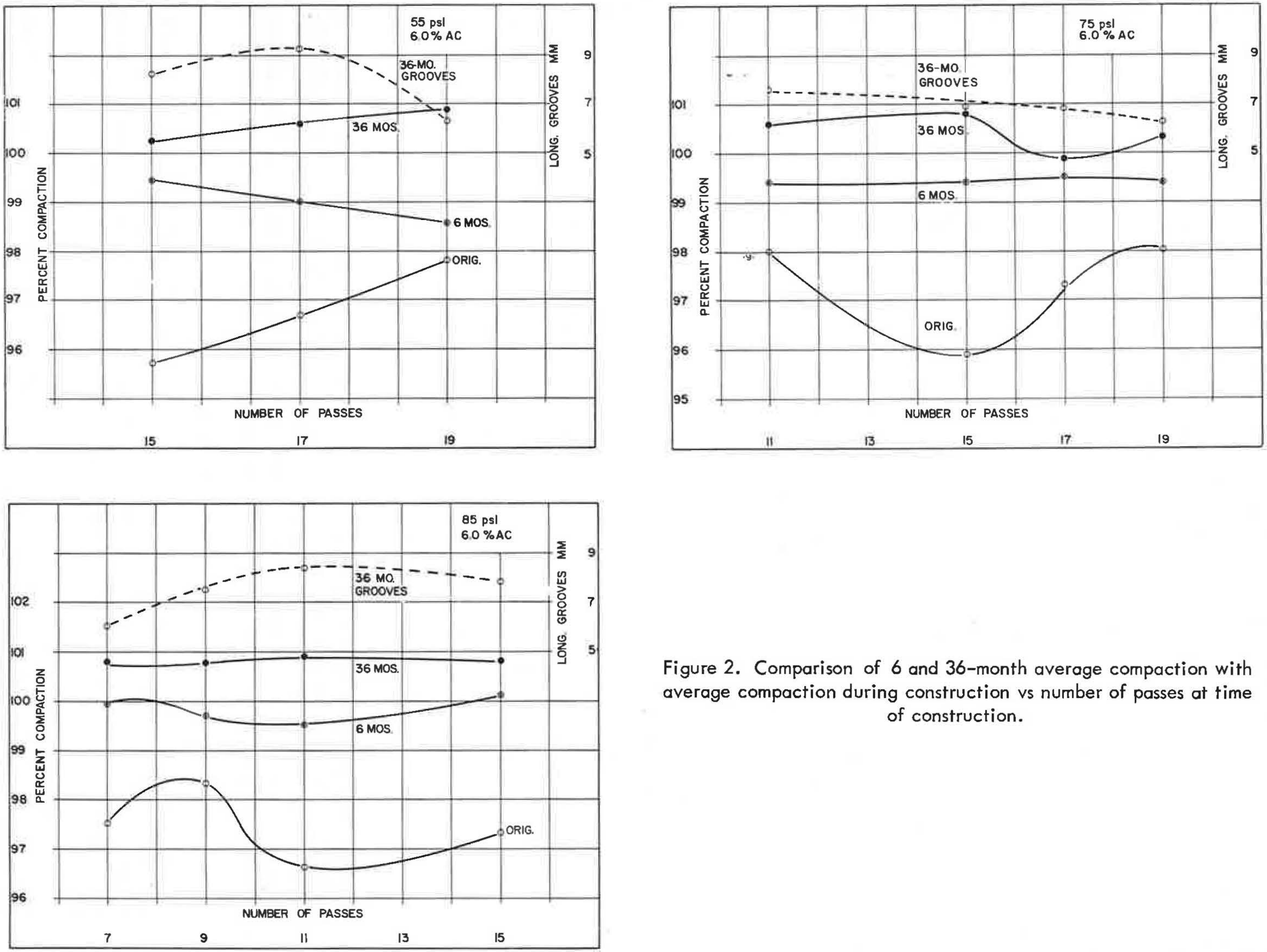

Figure 2. Comparison of 6 and 36-month average compaction with average compaction during construction vs number of passes at time of construction.

TABLE 4

STANDARD DEVIATION OF ROADWAY CORES FOR PERCENT COMPACTION ON VARIOUS TEST SECTIONS

Section No.	Standard Deviation				
	Original[a]	6 Mo.[b]	15 Mo.[c]	24 Mo.[d]	36 Mo.[e]
	(a) Asphalt Content 5. 8 Percent				
Contact pressure, 55 psi					
34	±0. 6	±0. 4	±0. 1	±0. 3	±0. 6
35	0. 3	0. 3	0. 4	0. 4	0. 7
36	0. 7	0. 5	0. 3	0. 6	0. 6
Contact pressure, 75 psi					
18	±0. 7	±0. 4	±0. 9	±1. 8	±1. 1
17	0. 5	0. 3	0. 7	1. 1	1. 6
16	0. 4	0. 3	0. 3	0. 4	0. 8
15	0. 3	0. 5	0. 5	1. 2	0. 7
Contact pressure, 85 psi					
27	±0. 9	±0. 6	±0. 4	±0. 8	±1. 1
28	0. 5	0. 1	0. 1	0. 3	0. 7
29	0. 2	0. 4	0. 5	0. 7	0. 6
30	0. 7	0. 5	0. 3	0. 6	1. 1
	(b) Asphalt Content 6. 0 Percent				
Contact pressure, 55 psi					
31	±1. 0	±0. 7	±0. 9	±0. 6	±1. 1
32	0. 3	0. 9	0. 9	1. 0	1. 1
33	0. 5	0. 9	0. 5	0. 7	0. 6
Contact pressure, 75 psi					
22	±0. 4	±0. 4	±0. 3	±0. 4	±0. 9
21	0. 7	0. 4	0. 3	0. 5	1. 2
20	0. 6	0. 3	0. 3	0. 6	1. 0
19	0. 4	0. 3	0. 3	0. 3	0. 4
Contact pressure, 85 psi					
23	±0. 9	±0. 3	±0. 3	±0. 4	±0. 8
24	0. 6	0. 4	0. 3	0. 5	0. 6
25	0. 3	0. 4	0. 8	0. 5	1. 0
26	0. 3	0. 6	0. 8	0. 5	0. 8
Note: No. of cores per section	[a]5	[b]9	[c]5	[d]5	[e]5

contact pressure and the number of passes of the pneumatic roller at controlled temperatures. The investigation was conducted on 61 test sections of hot-mix hot-laid asphaltic-concrete pavement consisting of a 1. 5-in. wearing course and a 2-in. binder course overlying an old existing concrete pavement. A typical gradation for the wearing course mix is given in Table 1. Only the wearing course will be discussed in this paper.

PROCEDURE

The pneumatic roller was a Bros-SP 54 having 14-ply tires in which the roller weight was kept constant at 2, 000 lb per wheel and the tire pressures were varied to give 55, 75 and 85-psi contact pressures. Conversion charts supplied by the tire manufacturers were used to obtain the necessary information on contact pressures from inflation pressures.

The rolling procedure consisted of a three-wheel roller, pneumatic roller and tandem roller in that order. Temperatures of the roadway mix were recorded at the start and finish of each of the rolling phases by means of a thermocouple and Leeds and Northrup potentiometer (Table 2). Rolling with the three-wheel and tandem rollers

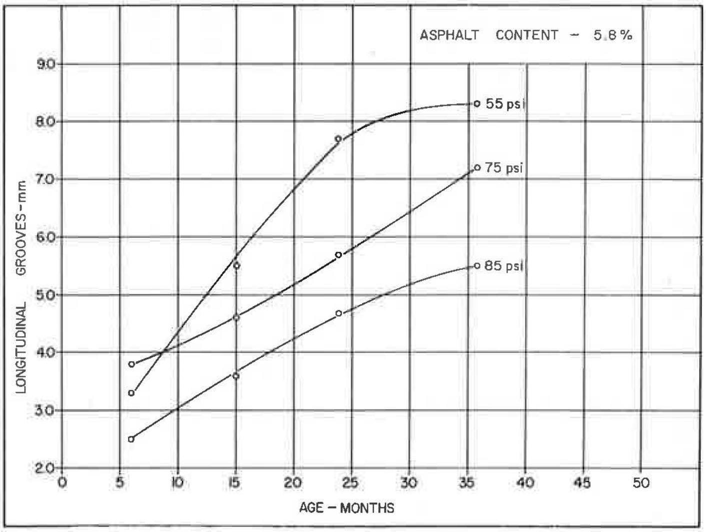

Figure 3. Longitudinal grooves vs age for various contact pressures at the optimum asphalt content.

was kept constant at seven passes on all test sections. The number of passes of the pneumatic roller and the contact pressures were the only variable in the investigation.

This paper is primarily concerned with the evaluation of roadway density as affected by traffic over a period of time after construction. Periodic surveys were made 6, 15, 24 and 36 months after the initial construction period including (a) cutting cores for density determination (b) measurement of longitudinal grooves and (c) visual observation of the surface condition.

A summary of roadway compaction results and wheelpath rutting for the wearing course mix is given in Table 3. Graphical relationships are shown in Figures 1 and 2. The calculated standard deviation for percent compaction and the number of roadway cores for each test section are given in Table 4.

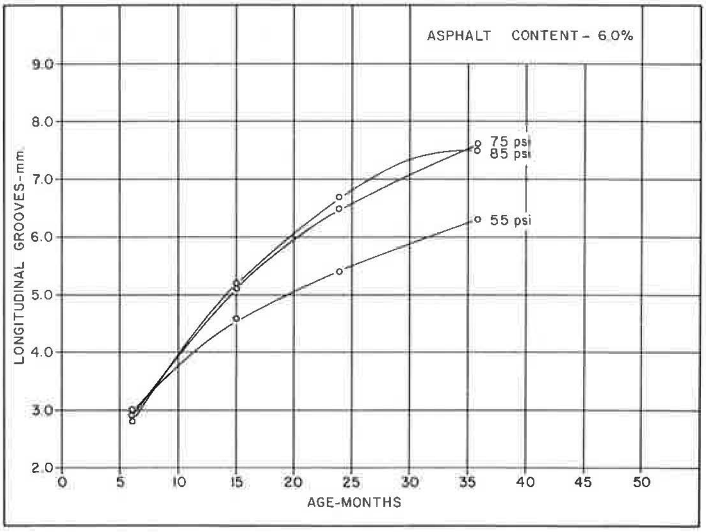

Figure 4. Longitudinal grooves vs age for various contact pressures at above optimum asphalt content.

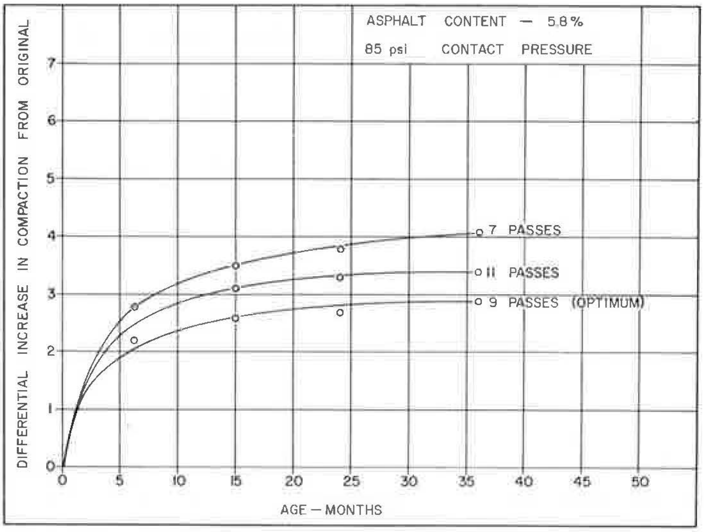

Figure 5. Differential increase in compaction from original vs age.

TEST RESULTS

Figure 1 shows the number of passes, percent compaction-longitudinal groove relationship for the wearing course mixture on concrete base using 55, 75 and 85-psi contact pressures at 5.8 percent asphalt. The average results for these sections are given in Table 3.

Most of the increase in compaction occurred during the first 6 months of traffic. Furthermore, the optimum number of passes for each of the curves shows less increase in compaction during the 6-month period than the corresponding increase at other compactive efforts for the same period. For each of the curves, the densification from the original to 36 months was less at the optimum number of passes. This also indicates the least amount of rutting with the exception of the curve for 55-psi contact pressure.

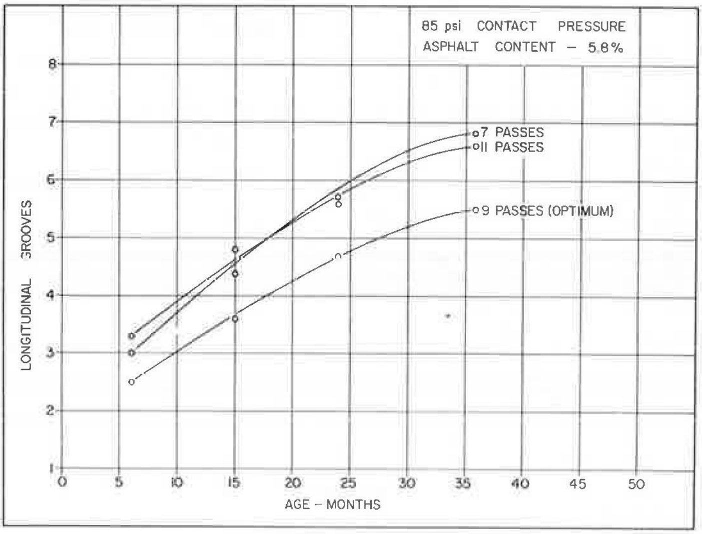

Figure 6. Longitudinal grooves vs age for various number of passes of pneumatic roller.

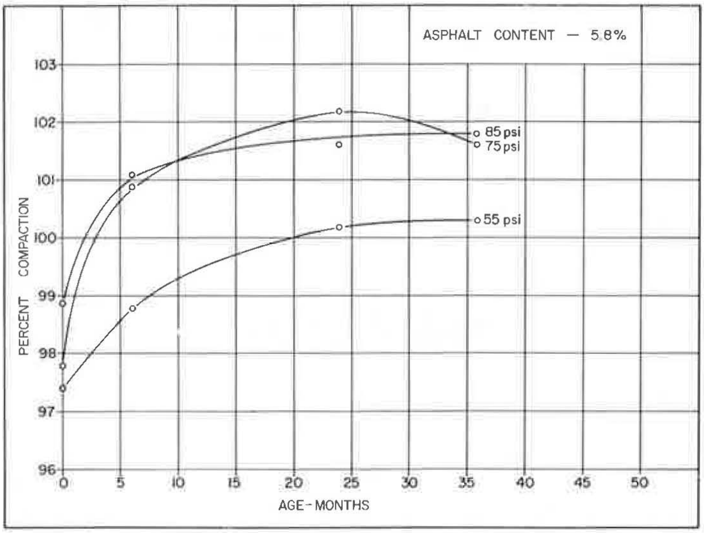

Figure 7. Percent compaction vs age for various contact pressures at optimum number of passes of pneumatic roller.

The magnitude of wheelpath-rutting has not been considered excessive after 3 years of traffic, however, the section using 85-psi contact pressure with 9 passes of the roller gave the lowest rut measurement of 5.5 mm or 0.21 in.

Figure 2 shows the number of passes, percent compaction-longitudinal groove relationship for an asphalt content of 6.0 percent. Again, the major increase in compaction occurred during the first 6 months of traffic. The lowest percent increase in compaction from the original to 36 months occurs at the optimum number of passes regardless of the contact pressure applied (Table 3).

Figure 3 shows the longitudinal grooves vs age relationship at the optimum number of passes for each of the various contact pressures at 5.8 percent asphalt. The test section compacted at a contact pressure of 55 psi showed considerably higher longitudinal grooves than did the 75 and 85-psi sections. The 85-psi sections showed the least rutting indicating that at optimum conditions the contact pressure most closely related to the pressures exerted on the highway by traffic, will result in the least amount of rutting in a 3-yr period.

Figure 4 shows similar relationship at an asphalt content 0.2 percent higher than the optimum. The 75 and 85-psi sections, which were almost identical, gave a larger magnitude of longitudinal grooves than did the 55-psi section. The increased asphalt content may have been excessive for such contact pressures, causing flushing and consequently higher rutting conditions. Although the longitudinal grooves at 55 psi and 6.0 percent asphalt were only 6.3 mm after 3 years of service, they were still higher than the grooves for the 85-psi section at 5.8 percent asphalt which was only 5.5 mm after 3 years of service.

Figure 5 also emphasizes the importance of using the correct number of passes of the pneumatic roller. Again, the largest increase in compaction occurs after 6 months of traffic.

At 9 passes of the pneumatic roller, which for this test section was considered optimum, the percent increase in compaction was less up to 3 years than the corresponding test sections constructed at 7 and 11 passes. It could be concluded that the lower amount of densification will result in lesser depths of rutting over a period of time. Figure 6 shows longitudinal grooves vs age for 7, 9 and 11 passes. The test section at 9 passes which gave the least increase in density also gave the least amount of rutting; therefore, the higher field compactive efforts give the highest initial compaction at optimum conditions, resulting in the least increase in compaction due to traffic and the least amount of rutting over a period of time.

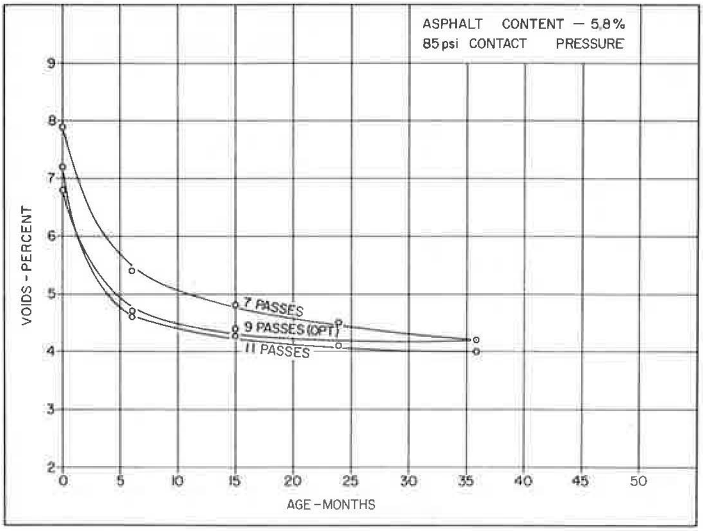

Figure 8. Percent voids vs age for various number of passes of pneumatic roller.

The foregoing results have indicated three important requirements for compaction of asphaltic-concrete pavements.

1. Select an adequate contact pressure for pneumatic rolling which is representative of the contact pressure encountered in service.
2. Obtain an asphalt content which will give the highest initial compaction for a given mix at a given contact pressure.
3. Select the optimum number of passes for the pneumatic roller to obtain maximum density.

One of the major problems in Louisiana with hot-mix construction is the inability to obtain a full design life for pavements. This was emphasized in one of the previous studies (1). In this study, it was concluded that the bituminous concrete pavements constructed in the 1950's were showing excessive rutting, flushing, cracking and lack of densification at the end of five years or equivalent to an estimated traffic volume of 10 million vehicles. The anticipated design life of these pavements was 15 years or a traffic volume of approximately 30 million vehicles; therefore, the actual life was only one third the anticipated life.

It is believed that by using higher contact pressures and optimum compactive effort in the field, rutting can be minimized. In this survey many of the failures were also due to deterioration and hardening of the asphalt. It is known that hot-mix pavements having low density and high void contents immediately after compaction are much more susceptible to hardening or oxidation of the asphalt than those with higher initial densities. In this case naturally a higher initial density would be desirable.

Figure 7 shows the percent compaction vs age relationship at the optimum conditions for the various contact pressures. The 75 and 85-psi contact pressures gave higher initial compaction than did the 55-psi pressure, with 85 psi giving the highest (98.9 %). Again, the largest increase in compaction occurred after the first 6 months of traffic.

Figure 8 shows percent voids vs age relationship. The percent voids for the various passes after 6 months tend to level off and at 36 months are approximately the same. However, the initial voids were lowest at 6.8 percent for the test section compacted at the optimum of 9 passes.

Although the percent voids after 36 months may be approximately equal, the critical time for oxidation and hardening of the asphalt is within the first year. Therefore, the optimum number of passes would give lower voids and help minimize oxidation and possible cracking of the pavement.

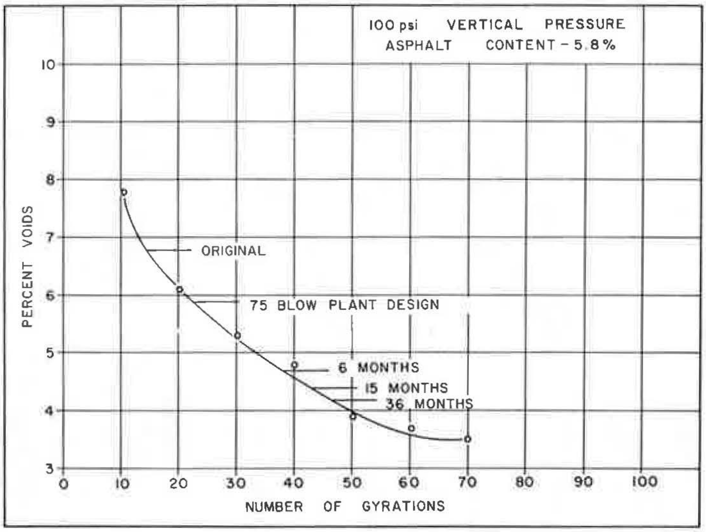

Figure 9. Laboratory design curve of percent voids of roadway specimens from original to 36 months.

To increase the design life of the pavement, it is also necessary to increase the compactive effort of the laboratory design which should require the void content on a hot-mix pavement after final rolling to be adequate to minimize oxidation of the asphalt and eliminate excessive rutting due to traffic.

Figure 9 shows the relationship of the void content on the roadway from the original to 36 months as compared to the void content of the same mix compacted with the gyratory compactor. The laboratory design was the Marshall method using 75 blows on both faces of the specimen. The void content after only 6 months had already decreased from an original 6. 8 percent to 4. 7 percent which was already well below the laboratory design of 5. 9 percent voids. From 6 months to 36 months the void content had only decreased from 4. 7 to 4. 2, indicating very little additional change in density.

It is believed that in order to minimize rutting and excessive hardening of the asphalt, as well as to increase the life of the pavement, higher compactive efforts in the laboratory and in the field will be necessary to obtain a lower initial void content, thereby keeping the voids in the pavement fairly constant for the first year after completion, which seems to be the most critical time for density to increase due to traffic.

To investigate a method of increasing the laboratory design compactive effort, specimens were compacted, using the same materials as used on the roadway, with a gyratory compactor (Fig. 9). If the same mix had been designed by the gyratory compactor at 100 psi 60 gyrations, the laboratory design would have had a void content of approximately 3. 8 percent in which case after 3 years of traffic the void content in the pavement would just be approaching the laboratory design. Even though the void content on the design mix is decreased due to higher laboratory compactive efforts, what effect would this have on the roadway?

The 75-blow laboratory design specific gravity at 5. 8 percent asphalt content was 2. 26 with the gyratory design giving a specific gravity of 2. 32 at 100 psi 60 gyrations. The original roadway specific gravity was 2. 24 for 9 passes, 85-psi section. Based on the 75-blow design this gave a percent of laboratory gravity of 99. 1 which was considered satisfactory and had rutting of only 5. 5 mm or 0. 2 in. and a void content of 6. 8 percent (Fig. 9) which, based on the satisfactory appearance of the roadway after 3 years, seems to be adequate. However, had the minimum limit of 95 percent of laboratory density been obtained, the specific gravity of the original compacted roadway would have been 2. 15 which would have given a void content of 10. 7 percent, whereas using a higher laboratory compactive effort such as the gyratory design, 95 percent of laboratory gravity would have given a roadway specific gravity of 2. 21 which would have allowed a maximum of 9. 1 percent voids or 1. 6 percent less than the 75-blow design.

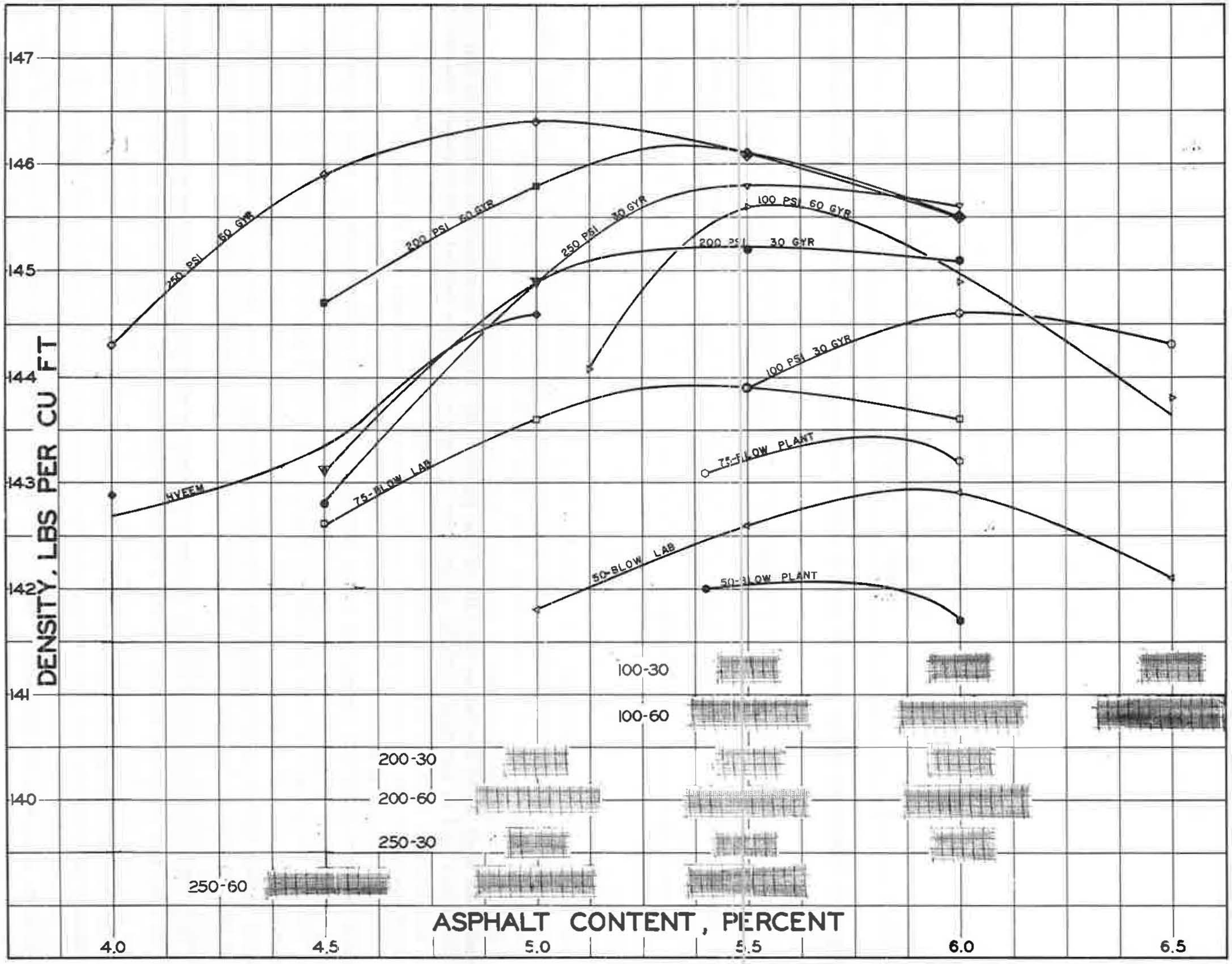

Figure 10. Comparison of wearing course densities for various types of laboratory compaction.

The 100 psi 60 gyrations compactive effort was used as an example only. It is possible that higher compactive efforts can be used in the laboratory and also in the field at optimum conditions. This should be studied further before selecting any laboratory compactive effort criteria.

As mentioned previously, this project did not have an appreciable amount of rutting and after 3 years appeared to be in very good condition.

In many cases at the start of a project the roadway inspector makes no special effort to establish the number of passes of the pneumatic roller that will give maximum density. As long as the minimum requirement of laboratory density is obtained, it is considered satisfactory even though at optimum conditions, 99 percent density could be obtained rather than 95 or 96. By increasing laboratory compaction, an extra effort will have to be made to establish maximum roadway results.

Because of the increase of traffic volume and loads it appears necessary that laboratory design methods be brought up-to-date. However, caution should be exercised to be sure that the laboratory design criteria are reasonable from a construction standpoint and can be met in the field.

In an attempt to establish some laboratory design criteria, laboratory specimens were molded at various compactive efforts and at various asphalt contents.

Figure 10 shows the density-asphalt content relationship at various compactive efforts. The curves indicate that as the compactive effort increases the optimum asphalt content tends to decrease. The optimum density at 100 psi 60 gyrations is considerably higher than the 75-blow plant or laboratory design. The gyrographs indicate whether or not a mix has too much asphalt for the compactive effort applied. Flushing of a mix due to excessive asphalt content is shown by widening of the gyrograph.

The gyratory compactor can provide a wide range of compactive efforts; however, each type of material reacts differently and if used as a laboratory design method it should be correlated very closely with actual field compaction.

CONCLUSIONS

On the basis of the data obtained in this study, the analysis can be summed up in the following statements.

1. In order to obtain maximum compaction of asphaltic-concrete pavement capable of withstanding high volumes of traffic, it is necessary to: (a) select an adequate combination of contact pressure-number of passes of the pneumatic roller which is representative of the contact pressures encountered in service, and (b) obtain through adequate laboratory design an optimum asphalt content.
2. The major portion of increase in compaction from the original occurs within the first 6 months of traffic.
3. The optimum number of passes for the 55, 75 and 85-psi sections showed the least increase in compaction during the 6-month period than the corresponding sections at other compactive efforts for the same period.
4. At the optimum asphalt content of 5. 8 percent, the 85-psi test section gave higher initial compaction and showed the least amount of rutting after 3 years of service.
5. At an asphalt content of 6. 0 percent, the 75 and 85-psi sections showed a greater magnitude of rutting than the 55-psi section after 3 years service, indicating an excessive amount of asphalt for the contact pressure applied by the roller and also by the heavy traffic encountered during service.
6. Periodic surveys have shown that the initial void content of the compacted pavement in only 6 months had decreased 1. 2 percent below the 75-blow laboratory design void content indicating the need for higher laboratory compactive efforts.
7. The void content from 6 months of service to 3 years had decreased only 0. 7 percent indicating a leveling off of the voids after the initial 6 months of traffic.
8. The laboratory compactive effort should be increased in conjunction with the field compactive effort to increase the actual life of the pavement by reducing the initial

void content, thereby, keeping the voids fairly constant for the first year of service, which appears to be the most critical time for rutting due to traffic and also hardening of the asphalt.

9. The gyratory compactor is capable of applying higher compactive efforts than the Marshall method. Furthermore, the kneading action of the compactor under a given pressure is more closely related to the actual field compaction. However, care should be taken in determining the design compactive effort desired.

ACKNOWLEDGMENTS

This study was conducted by Louisiana Department of Highways in cooperation with the U. S. Bureau of Public Roads, through the HPR program. The testing program was performed by the personnel of the bituminous research unit of the Louisiana Department of Highways. This paper is based on the findings reported in the Department's previous publications on the subject (2, 3).

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Appendix

TABLE 5

AVERAGE LONGITUDINAL GROOVES FOR WEARING COURSE ON TEST SECTIONS COMPACTED USING PNEUMATIC ROLLERS

Section No.	Contact Pressure (psi)	Opt. No. of Passes	Longitudinal Grooves			
			6 Mo.	15 Mo.	24 Mo.	36 Mo.
			(a) Asphalt Content 5.8 Percent			
35	55	17	3.3	5.5	7.7	8.3
16	75	17	3.8	4.6	5.7	7.2
28	85	9	2.5	3.6	4.7	5.5
			(b) Asphalt Content 6.0 Percent			
33	55	19	3.0	4.6	5.4	6.3
22	75	11	2.9	5.1	6.5	7.6
24	85	9	2.8	5.2	6.7	7.5

TABLE 6

DIFFERENTIAL INCREASE IN COMPACTION FROM ORIGINAL ON WEARING COURSE AT VARIOUS PASSES OF PNEUMATIC ROLLER

(Asphalt Content 5. 8 %)

Section No.	Contact Pressure (psi)	Opt. No. of Passes	Differential Increase			
			6 Mo.	15 Mo.	24 Mo.	36 Mo.
27	85	7	2. 8	3. 5	3. 8	4. 1
28	85	9 (opt.)	2. 2	2. 6	2. 7	2. 9
29	85	11	2. 8	3. 1	3. 3	3. 4

TABLE 7

AVERAGE LONGITUDINAL GROOVES FOR THE WEARING COURSE AT VARIOUS PASSES OF PNEUMATIC ROLLER

Section No.	Contact Pressure (psi)	Opt. No. of Passes	Longitudinal Grooves			
			6 Mo.	15 Mo.	24 Mo.	36 Mo.
27	85	7	3. 0	4. 8	5. 6	6. 8
28	85	9 (opt.)	2. 5	3. 6	4. 7	5. 5
29	85	11	3. 3	4. 4	5. 7	6. 6

TABLE 8

AVERAGE PERCENT VOIDS FOR WEARING COURSE AT VARIOUS PASSES OF PNEUMATIC ROLLER

Section No.	Contact Pressure (psi)	No. of Passes	Percent Voids				
			Original	6 Mo.	15 Mo.	24 Mo.	36 Mo.
27	85	7	8. 0	5. 4	4. 8	4. 5	4. 2
28	85	9(opt.)	6. 8	4. 7	4. 4	4. 1	4. 2
29	85	11	7. 2	4. 6	4. 3	4. 1	4. 0

TABLE 9

TEST RESULTS OF WEARING COURSE MIX USING THE MARSHALL, HVEEM AND GYRATORY METHODS

Comp. Effort	A. C. (%)	Sp. Gr.	Theo. Gr. (%)	Percent		Density (pcf)	Stab.	Flow
				Voids	V. F. A.			
50 Blow	5. 0	2. 265					1337	8
	5. 0	2. 272					1474	7
	5. 0	2. 281					1549	9
Average	5. 0	2. 273	93. 2	6. 8	62. 1	141. 8	1453	8
50 Blow	5. 5	2. 281					1477	9
	5. 5	2. 283					1322	10
	5. 5	2. 295					1454	8
Average	5. 5	2. 286	94. 4	5. 6	68. 8	142. 6	1418	9
50 Blow	6. 0	2. 292					1201	11
	6. 0	2. 290					1169	12
	6. 0	2. 288					1422	13
Average	6. 0	2. 290	95. 3	4. 7	74. 1	142. 9	1264	12
50 Blow	6. 5	2. 275					900	16
	6. 5	2. 277					790	16
	6. 5	2. 279					900	18
Average	6. 5	2. 277	95. 4	4. 6	75. 9	142. 1	863	17
75 Blow	4. 5	2. 289					1976	6
	4. 5	2. 282					1792	11
	4. 5	2. 284					1849	6
Average	4. 5	2. 285	93. 0	7. 0	59. 0	142. 6	1872	8
75 Blow	5. 0	2. 302					1849	8
	5. 0	2. 305					1959	9
	5. 0	2. 296					2006	6
Average	5. 0	2. 301	94. 3	5. 7	66. 4	143. 6	1938	8
75 Blow	5. 5	2. 304					1580	8
	5. 5	2. 309					1627	13
	5. 5	2. 304					1517	8
Average	5. 5	2. 306	95. 2	4. 8	72. 1	143. 9	1575	10
75 Blow	6. 0	2. 301					1217	13
	6. 0	2. 297					1232	13
	6. 0	2. 304					1280	13
Average	6. 0	2. 301	95. 8	4. 2	76. 3	143. 6	1243	13
100 Psi 60 Gyrations	5. 0	2. 314					1785	8
	5. 0	2. 309					1992	10
	5. 0	2. 306					1834	8
Average	5. 0	2. 310	94. 7	5. 3	68. 1	144. 1	1870	9
100 Psi 30 Gyrations	5. 5	2. 302					1375	17
	5. 5	2. 305					1691	11
	5. 5	2. 307					1596	8
Average	5. 5	2. 305	95. 2	4. 8	72. 1	143. 9	1554	12
100 Psi 60 Gyrations	5. 5	2. 330					1976	10
	5. 5	2. 334					1991	11
	5. 5	2. 338					1959	8
Average	5. 5	2. 334	96. 4	3. 6	77. 8	145. 6	1975	9
100 Psi 30 Gyrations	6. 0	2. 317					1580	12
	6. 0	2. 320					1660	12
	6. 0	2. 313					1691	14
Average	6. 0	2. 317	96. 4	3. 6	79. 1	144. 6	1644	13
100 Psi 60 Gyrations	6. 0	2. 324					1422	14
	6. 0	2. 319					1344	13
Average	6. 0	2. 322	96. 6	3. 4	80. 1	144. 9	1383	14
100 Psi 30 Gyrations	6. 5	2. 313					1517	9
	6. 5	2. 307					1248	16
	6. 5	2. 317					1596	11
Average	6. 5	2. 312	96. 8	3. 2	82. 2	144. 3	1454	12

TABLE 9 (Continued)

TEST RESULTS OF WEARING COURSE MIX USING THE MARSHALL, HVEEM AND GYRATORY METHODS

Comp. Effort	A. C. (%)	Sp. Gr.	Theo. Gr. (%)	Percent		Density (pcf)	Stab.	Flow
				Voids	V. F. A.			
100 Psi								
60 Gyrations	6.5	2.301					1043	18
	6.5	2.303					1059	18
	6.5	2.308					1138	24
Average	6.5	2.304	96.5	3.5	80.8	143.8	1080	21
200 Psi								
30 Gyrations	4.5	2.281					1884	8
	4.5	2.290					1929	7
	4.5	2.293					1911	11
Average	4.5	2.288	94.5	5.5	64.7	142.8	1909	9
200 Psi								
60 Gyrations	4.5	2.325					2160	8
	4.5	2.320					2464	8
	4.5	2.312					2622	8
Average	4.5	2.319	94.4	5.6	64.5	144.7	2415	8
200 Psi								
30 Gyrations	5.0	2.324					2006	10
	5.0	2.322					2087	8
	5.0	2.319					2038	11
Average	5.0	2.322	95.2	4.8	70.3	144.9	2044	9
200 Psi								
60 Gyrations	5.0	2.335					2292	11
	5.0	2.336					2339	10
	5.0	2.339					2306	12
Average	5.0	2.337	95.8	4.2	73.2	145.8	2312	11
200 Psi								
30 Gyrations	5.5	2.325					1880	9
	5.5	2.326					1818	14
	5.5	2.330					1911	13
Average	5.5	2.327	96.1	3.9	76.3	145.2	1870	12
200 Psi								
60 Gyrations	5.5	2.348					1864	15
	5.5	2.339					2118	8
	5.5	2.337					1729	26
Average	5.5	2.341	96.7	3.3	79.3	146.1	1904	16
200 Psi								
30 Gyrations	6.0	2.334					1722	13
	6.0	2.316					1564	14
	6.0	2.329					1596	15
Average	6.0	2.326	96.8	3.2	81.1	145.1	1627	14
200 Psi								
60 Gyrations	6.0	2.332					1580	13
	6.0	2.328					1422	14
	6.0	2.335					1481	10
Average	6.0	2.332	97.0	3.0	82.1	145.5	1494	12
250 Psi								
30 Gyrations	4.5	2.290					1911	8
	4.5	2.293					1818	7
	4.5	2.297					1896	8
Average	4.5	2.293	93.4	6.6	60.5	143.1	1875	8
250 Psi								
60 Gyrations	4.5	2.338					2480	8
	4.5	2.339					2434	5
	4.5	2.338					2592	10
Average	4.5	2.338	95.2	4.8	68.2	145.9	2502	8
250 Psi								
60 Gyrations	5.0	2.349					2470	9
	5.0	2.345					2401	9
	5.0	2.345					2355	7
Average	5.0	2.346	96.2	3.8	75.2	146.4	2409	8

TABLE 9 (Continued)

TEST RESULTS OF WEARING COURSE MIX USING THE MARSHALL, HVEEM AND GYRATORY METHODS

Comp. Effort	A. C. (%)	Sp. Gr.	Theo. Gr. (%)	Percent		Density (pcf)	Stab.	Flow
				Voids	V. F. A.			
250 Psi								
30 Gyrations	5.0	2.324					2160	11
	5.0	2.321					1834	8
	5.0	2.322					2070	10
Average	5.0	2.322	95.2	4.8	70.3	144.9	2021	10
250 Psi								
60 Gyrations	5.5	2.340					1880	7
	5.5	2.346					1910	11
	5.5	2.339					1691	12
Average	5.5	2.342	96.7	3.3	79.3	146.1	1827	10
250 Psi								
30 Gyrations	5.5	2.332					1959	5
	5.5	2.336					1818	10
	5.5	2.341					1864	9
Average	5.5	2.336	96.4	3.6	77.8	145.8	1880	8
250 Psi								
60 Gyrations	6.0	2.334					1432	14
	6.0	2.327					1406	16
	6.0	2.335					1517	15
Average	6.0	2.332	97.0	3.0	82.1	145.5	1452	15
250 Psi								
30 Gyrations	6.0	2.335					1596	13
	6.0	2.332					1390	13
	6.0	2.333					1643	14
Average	6.0	2.333	97.1	2.9	82.6	145.6	1543	13
250 Psi								
60 Gyrations	4.0	2.319					2449	8
	4.0	2.304					2306	13
	4.0	2.314					2276	8
Average	4.0	2.312	93.4	6.6	57.9	144.3	2344	10
							Cor. Stab.	Cohes Value
Hveem	4.0	2.30					40	162
	4.0	2.29					38	157
	4.0	2.28					49	239
Average	4.0	2.290	92.5	7.5	54.5	142.9	42	186
Hveem	4.5	2.30					45	277
	4.5	2.29					43	202
	4.5	2.29					43	183
Average	4.5	2.293	93.4	6.6	60.5	143.1	44	221
Hveem	5.0	2.32					36	308
	5.0	2.31					44	236
	5.0	2.32					45	303
Average	5.0	2.317	95.0	5.0	69.4	144.6	42	282