ASPHALTIC CONCRETE PAVEMENT SURVEY

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ASPHALTIC CONCRETE PAVEMENT SURVEY

SYNOPSIS

One of the assumptions made in the Marshall Method of asphaltic concrete mix design is that the laboratory compactive effort is comparable to the actual traffic loading. The observed behavior of excessive traffic densification and wheel path rutting of hot mix overlays in Louisiana led to the belief that the compactive effort was lower than that imposed by traffic subsequent to construction. An effort for a quantitative analysis of this problem was made by obtaining cores and measuring longitudinal grooves at tire paths of projects 4 to 12 years old and located in various sections of the State.

Analysis of the density measurements of cores showed that, based on an annual average daily traffic volume of 5500, the compaction of the pavement increases rapidly for the first 6 million vehicles (approximately 3 years) and then becomes gradual to reach a peak during the next 4 million vehicles (about 2 years). Further increase in traffic actually decreases the compaction with evidence of flushing. No evidence was found to indicate that wheel path rutting is caused by the horizontal instability of the pavement until flushing occurs, but rather by an additional compaction of the pavement. Surface conditions showed presence of raveling, cracking and in some instances, flushing. It was also observed that excessive minus No. 40 material affects the densification of the pavement.

Further analysis of the data showed road roughness to be related to stability and compaction.

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Introduction

The ever increasing problem of wheel path rutting and excessive densification of asphaltic concrete pavement has been the subject of asphalt technology for quite sometime. It is known that the density of the pavement, which is significant for several reasons, increases subsequent to construction because of the traffic. Also, to be satisfactory, a pavement must contain some air voids, even in the state of ultimate densification; since the most obvious consequence of attaining zero air voids mass would be the flushing of bitumen to the surface which may result either due to temperature rise or the action of traffic.

The Marshall Method of asphaltic concrete design has been used to advantage for a number of years. In this, assumptions are made that the laboratory molded specimen is comparable to the actual pavement in regard to particle orientation, density, etc., and that the test itself is comparable to the actual traffic loading. It is further assumed that the limiting values set up for Marshall Method distinguish between good and poor mixes in reference to shoving, rutting and probably raveling. Needless to say, the validity of these assumptions rests to a certain degree on the compactive effort applied in the laboratory as well as the field. Could it be then that this problem of excessive densification is due to insufficient compactive effort either in the field or in the laboratory, and could wheel path rutting be associated more with the additional compaction of the pavement due to traffic than the horizontal instability of the asphaltic concrete pavement? Investigation of these and many other pertinent factors associated with the design of asphaltic concrete mixtures formed the basis of the quantitative analysis of this study.

Purpose of the Study

The purpose of this investigation was to determine the changes in physical characteristics of asphaltic concrete pavement with traffic and compare the compactive effort applied in the laboratory with that induced by traffic.

Scope of the Study

In 1961 the project was set up as a research survey with funds made available by the Bureau of Public Roads and the Louisiana Department of Highways. Highways of different age groups, located in all parts of the State under all types of traffic and climatic conditions were included in this survey.

Procedure

Considerable preliminary work was done before the field work was started. This included selection of nineteen projects of hot mix, hot laid dense graded gravel-sand mixtures ranging in age from 4 to 12 years and carrying a considerable volume of traffic, examination and compilation of construction test records, and any other pertinent information necessary for the investigation. Figure 1 is a map showing the location of survey projects. Upon completion of the preliminary work, the field crew was sent out to measure longitudinal grooves and road roughness, cut pavement cores and estimate, by visual inspection,

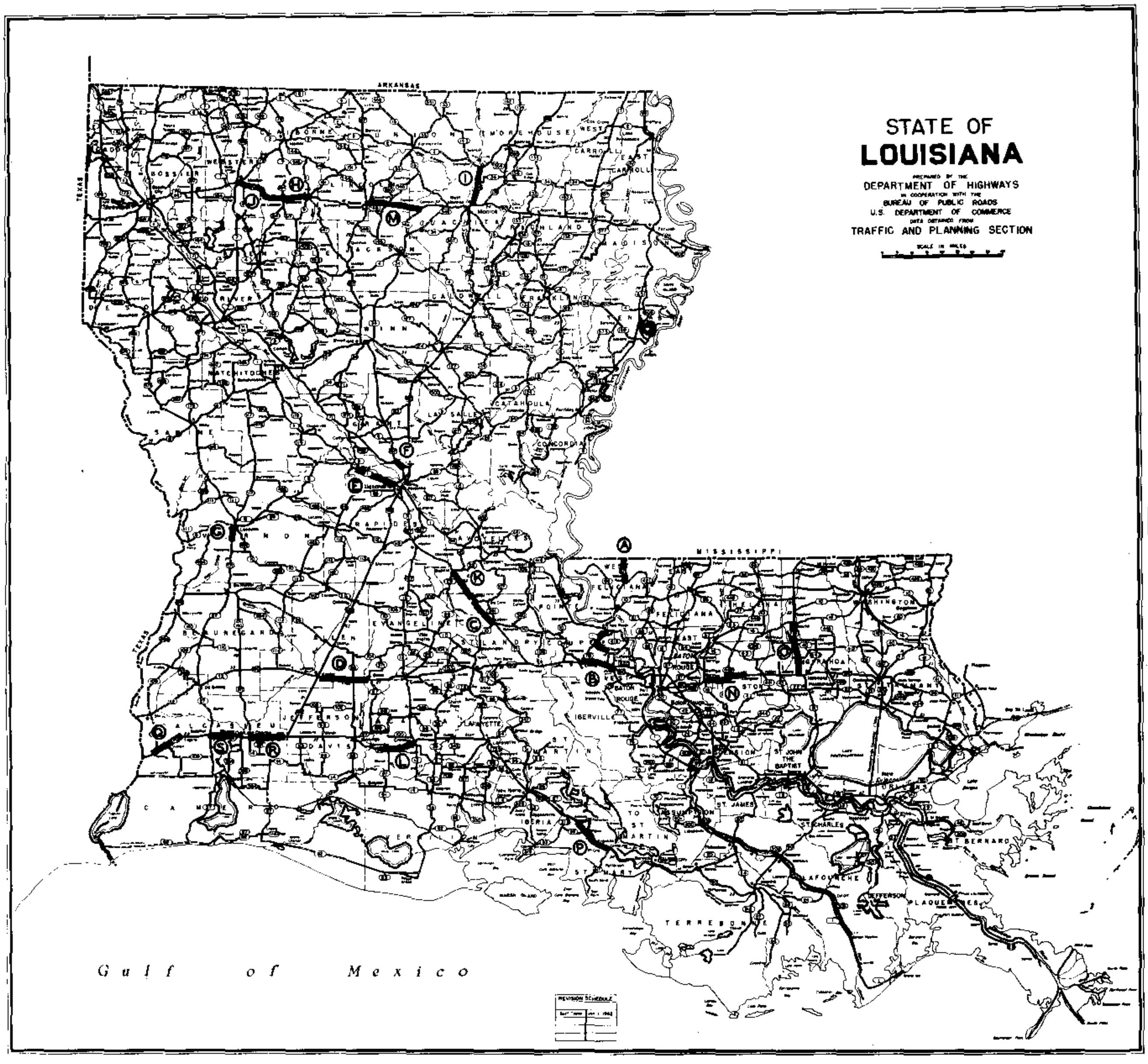

Figure 1 Map Showing the Location of Survey Projects.

the condition of the pavement in regard to cracking, shoving, flushing and raveling. The methodology used in accomplishing the aforementioned field investigation is described in the following paragraphs.

Measurement of Longitudinal Grooves - Longitudinal depressions at the tire paths were measured by means of a scale graduated in millimeters and a wooden straight edge, 12 feet long, placed horizontally the width of one lane. This was repeated every half mile at six different locations 100 feet apart. A diagrammatic sketch of the location of points of rut (depressions, grooves) measurements is shown in Figure 2. Thus, every half a mile, 12 measurements were made in each lane (six at each wheel path). A minimum of at least 60 such measurements in one lane were made on each project. Care was exercised to eliminate measurements at patches, bridges, railroad tracks and intersections. Table II shows the computed arithmetic mean for each lane and also the entire project.

Pavement Cores - Cores were obtained using a high speed diamond core drill from sections previously classified according to their physical appearance as "good" and "poor." A set of 12 cores were taken from each section, giving a minimum of 24 cores to a project for each condition and a maximum of 48 for four sections, two "good" and two "poor." Figure 3 is a sketch of the location of cores. The same order, as shown in the figure, was followed in cutting the cores from each project, namely, Core 1 at the outside edge of the right lane and continuing with Cores 2 and 3 in the same lane and Cores 4, 5 and 6 across in

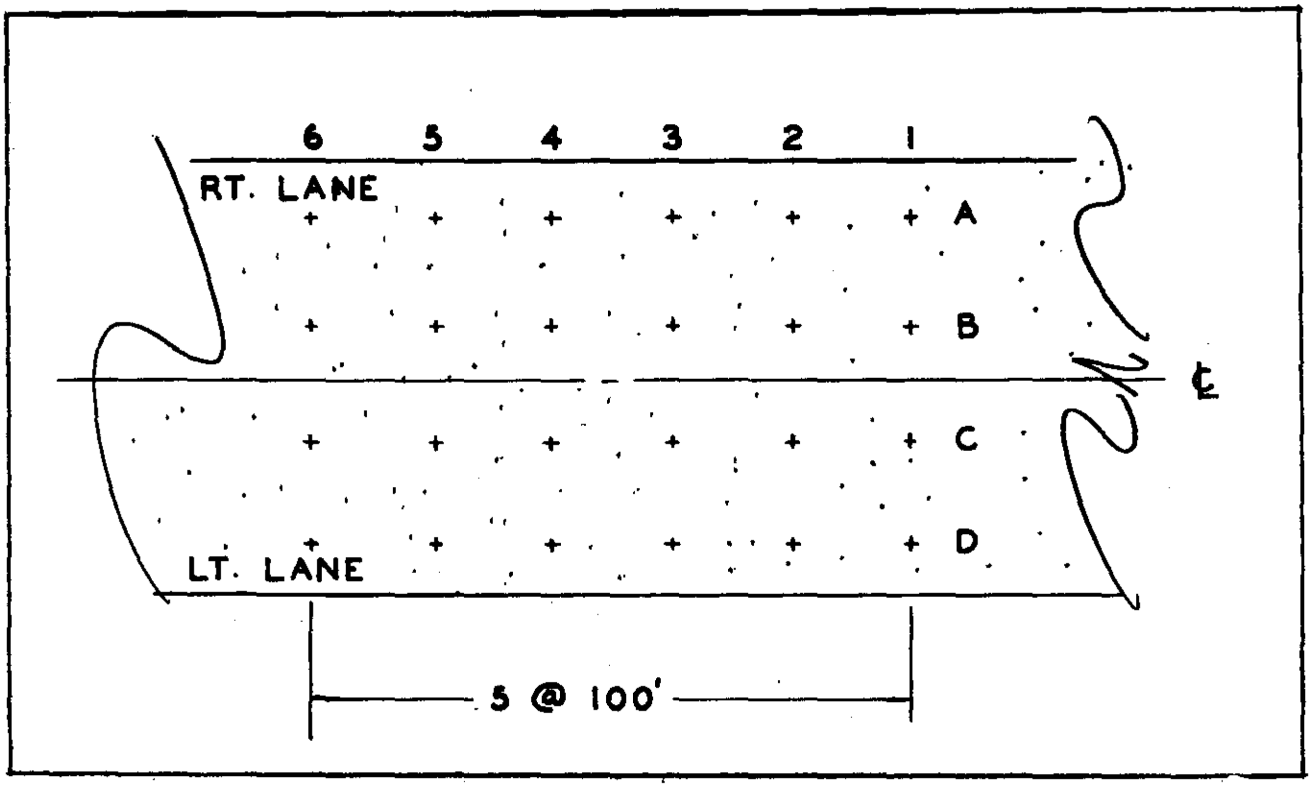

Figure 2 *Location of Points of Measurement of Longitudinal Grooves.*

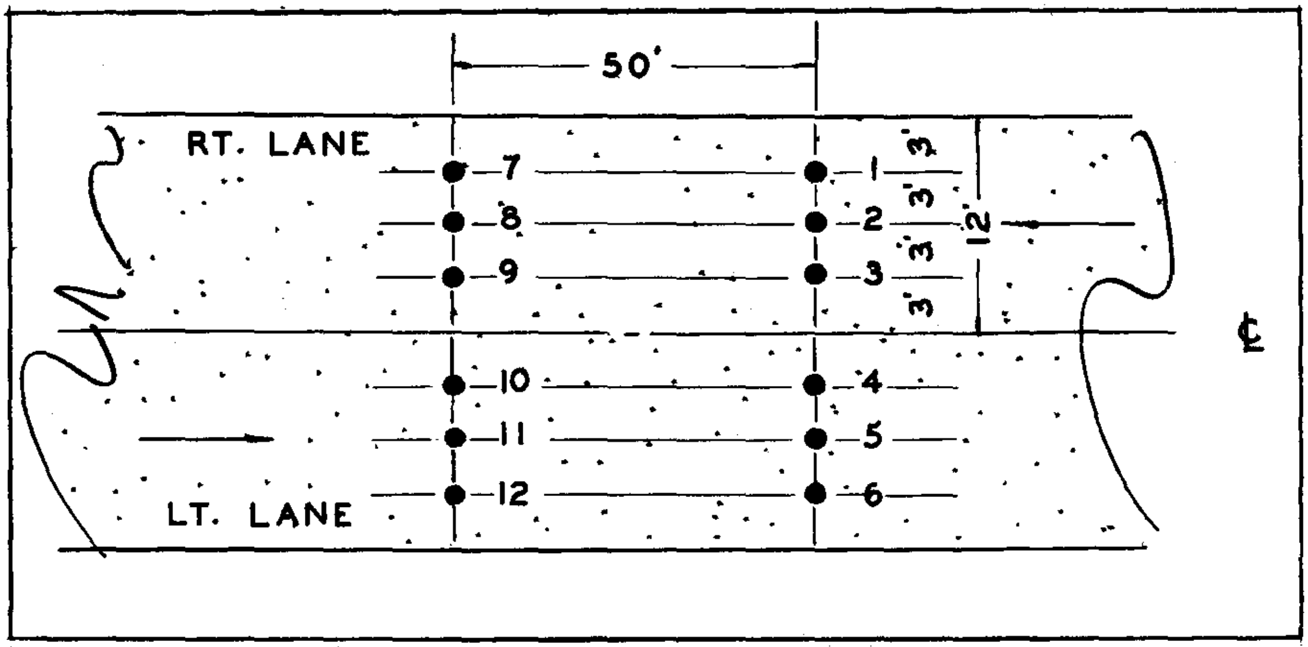

Figure 3 *Location of Pavement Cores.*

the opposite lane.

Road Roughness Measurements - Roughness measurements were made using the Louisiana Department of Highways B.P.R. Road Roughness Indicator. A minimum of two measurements were made at the centerline of each lane and the average roughness was reported in inches per mile. It is the ratio of total roughness for each lane to the total distance in miles. The average roughness for each lane and the entire project (both lanes) is shown in Table II.

Laboratory Investigation - Upon completion of the field investigation, the wearing and binder course layers of the cores were separated using a diamond saw. The separated layers were then tested for:

1. Specific Gravity - LDH Designation TR 304-58
2. Marshall Stability and Flow - LDH Designation TR 305-58
3. Thickness
4. Bitumen Content and Gradation Analysis - LDH Designations TR 307-58 and TR 309-58 respectively
5. Recovery of Asphalt by Abson Process - ASTM Designation 762-49
6. Penetration of the Recovered Asphalt - ASTM Designation D 5-52

The recovery of the asphalt was not fully realized mainly because the cores on some of the projects were not saved for this test since it was not originally included in the investigation. The results of the penetration of the recovered asphalt is shown in Table II.

TABLE I PER CENT COMPACTION AND PER CENT VOIDS ON ROADWAY SPECIMENS

Proj Iden	Age, Yrs	Traffic Vol, (10^6)	Axles, (10^6)[a]	Asph Grade	Wearing Course						Binder Course					
					Per Cent Compaction[b]			Per Cent Voids[c]		Per Cent Change in Flow[d]	Per Cent Compaction			Per Cent Voids		Per Cent Change in Flow
					Orig	Final	Incr	Orig	Final		Orig	Final	Incr	Orig	Final	
A	4	2.0	0.43	85-100	97.3	99.8	2.5	6.5	3.9	- 25.0	96.9	100.3	3.4	6.9	4.1	- 23.1
B	6	5.4	1.71	85-100	96.0	100.6	4.6	7.8	3.6	- 23.1	96.8	100.9	4.1	7.8	3.7	- 23.1
C	7	7.8	3.23	85-100	96.4	102.3	5.9	8.2	2.8	0.0	95.9	100.7	4.8	7.1	2.6	- 23.1
D	5	8.3	2.45	85-100	96.8	102.2	5.4	7.0	1.9	- 16.7	97.5	101.3	3.8	6.2	2.5	- 9.1
E	5	9.7	1.66	85-100	97.4	101.7	4.3	6.0	1.9	- 21.4	97.2	99.9	2.7	6.6	4.0	- 33.3
F	10	10.8	2.83	60-70	97.2	101.4	4.2	5.7	1.6	- 25.0	96.1	102.1	6.0	7.7	2.1	- 26.7
G	7	11.7	1.04	60-70	94.9	100.6	5.7	9.5	4.0	+ 20.0	97.1	101.5	4.4	6.4	2.2	- 8.3
H	8	11.8	2.86	60-70	95.4	101.5	6.1	8.0	1.8	- 25.0	95.9	101.2	5.3	8.5	3.7	- 33.3
I	7	12.0	1.48	85-100	96.8	102.1	5.3	9.4	3.4	+ 16.7	96.8	100.7	3.9	7.8	4.3	+ 20.0
J	8	12.9	0.75	60-70	94.8	102.2	7.4	8.8	2.0	0.0	96.2	101.5	5.3	7.5	2.7	- 18.2
K	9	13.1	3.01	60-70	94.0	101.7	7.7	9.5	2.9	+ 9.1	95.1	101.6	6.5	8.6	3.8	- 15.4
L	8	13.6	1.19	85-100	95.8	102.1	6.3	7.9	1.7	+ 16.7	95.1	101.0	5.9	6.2	2.3	- 14.3
M	9	15.5	0.84	60-70	96.1	100.0	8.4	13.8	5.8	+ 7.7	95.5	100.2	4.7	9.4	5.1	- 14.3
N	8	15.5	2.80	60-70	96.6	101.2	4.6	7.0	3.0	+ 11.1	95.7	101.5	5.8	7.8	2.7	- 28.6
O	8	15.8	2.48	60-70	96.6	100.6	4.0	7.8	4.4	0.0	95.5	102.0	6.5	9.0	3.4	0.0
P	8	15.9	3.27	85-100	93.2	98.4	5.2	10.9	6.5	+ 45.5	94.3	100.7	6.4	10.3	4.7	+ 27.3
Q[e]	8	16.3	2.77	85-100	-	-	-	-	-	-	94.2	101.4	7.2	9.6	2.7	- 30.8
R	10	30.5	21.20	60-70	94.9	101.9	7.0	7.4	0.6	- 35.7	94.9	100.0	6.1	7.7	2.3	- 42.9
S	12	47.2	10.90	60-70	-	97.7	-	-	6.0	- 46.7	-	101.2	-	-	3.4	- 21.4

a Number of axles in the 10-20 kips/axle weight group
b Per cent of laboratory briquet gravity
c Using the apparent specific gravity of the aggregate
d Per cent change from the original construction data
e Construction data not available

TABLE II AVERAGE RESULTS OF LONGITUDINAL GROOVES AND ROUGHNESS

Proj Iden	Traffic Vol, 10^6	No of Axles, (10^6)	Longitudinal Grooves, MM			Roughness, Inches/Mile			Pen of Recovered Asphalt	
			Rt Lane	Lt Lane	Avg	Rt Lane	Lt Lane	Avg	W C	B C
A	2.0	0.43	4.1	2.7	3.4	64.9	67.7	66.3	-	-
B	5.4	1.71	11.2	-	11.2	142.4	-	142.4	-	-
C	7.8	3.23	7.7	7.5	7.6	102.6	100.8	101.7	29	37
D	8.3	2.45	17.5	17.7	17.6	88.7	93.4	91.1	-	-
E	9.7	1.66	9.7	9.3	9.5	94.1	88.5	91.3	40	44
F	10.8	2.83	6.7	5.5	6.1	110.6	115.3	113.0	48	33
G	11.7	1.04	-	-	-	-	-	-	31	35
H	11.8	2.86	8.7	10.5	9.6	119.5	121.7	120.6	-	-
I	12.0	1.48	8.0	8.7	8.4	94.0	95.1	94.6	-	-
J	12.9	0.75	9.4	8.7	9.1	119.2	116.3	117.8	-	-
K	13.1	3.01	7.9	9.0	8.5	116.3	111.5	113.9	46	35
L	13.6	1.19	11.0	10.0	10.5	139.6	136.0	137.8	46	54
M	15.5	0.84	7.1	11.3	9.2	120.8	117.2	119.0	-	-
N	15.5	2.80	10.7	6.9	8.8	106.0	97.0	101.5	15	-
O	15.8	2.48	5.6	10.1	7.9	84.5	93.3	88.9	19	-
P	15.9	3.27	6.6	6.7	6.7	94.0	95.2	94.6	30	46
Q	16.3	2.77	8.1	12.6	10.4	107.7	112.9	110.3	35	60
R	30.5	21.20	11.9	10.9	11.4	123.0	123.0	123.0	22	22
S	47.2	10.90	7.2	6.3	6.8	134.0	132.5	133.3	13	13

Test Results

Detailed test results on the 19 projects are listed in the Appendix. A summary of these results appears in Tables I through V. The projects are identified by letters A through S with their respective ages in column 2 of Table I. The age of each project is the number of elapsed years from the beginning of the project construction to the year of completion of field investigation, which was 1961. No attempt was made to break down the ages into fractions since practically the same age differential exists in all the age groups. In the third column of Table I, the traffic volume for each project is listed. It is the product of the total annual average daily traffic of all elapsed years and the age of the project in days. The average annual daily traffic for each year and also for the entire project is shown in Table III. The number of axles in the 10-20 kips weight per axle class are listed in column 4 of Table I. These figures, based on 1962 data, were arrived at by multiplying the number of axles per day in the selected weight group for the project by the age in days. The error involved in using such an approach seems obvious since no pavement carries the same number of axles in any weight group every year. Another serious error resulting from this approach has been the 1962 condition not being representative of the previous years because of the traffic diversion to the parallel Interstate Routes (Projects J and M for example). The ratio of core specific gravity of wheel path specimens to the laboratory briquet specific gravity expressed as per cent compaction is shown in column 6 of Table I.

Throughout this report, the term "compaction" will be synonymously used to mean subsequent densification. Table V shows overall surface condition of the projects.

Use of Electronic Digital Computer

The results presented in Tables I and II are shown graphically in Figures 4 through 13. Rather than using the method of averaging a group of dependent values within a certain chosen interval of independent ones, a polynomial curve fitting method was used in establishing these graphical relationships. The method, in brief, is based on the assumption that a set of experimental data can be fitted to a polynomial of the form $Y=A_o + A_1 x + A_2 x^2 \ldots + A_n x^n$. An IBM 1620 electronic digital computer at the Louisiana Department of Highways Computer Center was used to calculate the coefficients A_o, A_1, A_2...etc. The polynomial best fitting the observed data was used for final evaluation of the relationship. Also in each case, the standard error and the standard deviation of the dependent variable were obtained from which correlation coefficients were computed. A value of zero for these coefficients indicates poor relationship and that of unity indicates perfect relationship. In some cases the points were too scattered to indicate any logical relationship between the variables. The problem of multiple correlation was not considered in this approach since it involves a more sophisticated method of regression analysis which is beyond the scope of this report. The observed values are indicated in the figures to give an idea of the scatter of points about the line or curve of regression.

TABLE III AVERAGE ANNUAL DAILY TRAFFIC TRENDS

Proj Iden	Yearly Trend 1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	Traff Vol,(10^6) (Total x 365)
A	-	-	-	-	-	-	-	-	1200	1220	1680	1475	2.0
B	-	-	-	-	-	-	2409	2400	2393	2415	2700	2522	5.4
C	-	-	-	-	-	2790	2690	2725	2780	3530	3550	3205	7.8
D	-	-	-	-	-	-	-	4429	4648	4758	4512	4448	8.3
E	-	-	-	-	-	-	-	4800	4883	5330	5658	5790	9.7
F	-	-	2830	2700	2550	2870	2870	2915	2960	3270	3420	3200	10.8
G	-	-	-	-	-	3903	3090	5479	7867	5423	3943	2283	11.7
H	-	-	-	-	3795	3630	4220	4083	3945	3655	4580	4290	11.8
I	-	-	-	-	-	4035	4225	4575	4925	5020	5215	4875	12.0
J	-	-	-	-	4100	4105	4625	4380	4135	4410	4975	4470	12.9
K	-	-	-	3990	4330	3660	3530	3865	4200	4500	4130	3675	13.1
L	-	-	-	-	4244	4375	4458	4452	4428	5073	5580	4623	13.6
M	-	-	-	4032	4438	4518	4980	5019	5058	4888	5503	4022	15.5
N	-	-	-	-	4380	4480	4847	5237	5627	5770	6557	5650	15.5
O	-	-	-	-	5232	4780	5033	5389	5745	5265	5890	5835	15.8
P	-	-	-	-	4560	4640	5173	5516	5858	5870	6005	5925	15.9
Q	-	-	-	-	5080	4345	5021	5396	5770	7210	6260	5493	16.3
R	-	-	6070	7080	7840	8060	8260	8600	9060	9350	9310	9865	30.5
S	6480	7960	8800	9950	10240	9940	12510	12808	13105	13855	12790	12000	47.2

Discussion of Results

Figure 4 shows relationship between traffic volume and per cent compaction, per cent voids at wheel paths for a wearing course mixture. Results of only 16 projects were used in studying these relationships. Projects Q, R, and S were not considered mainly because no construction data on Project Q was available and hence, the per cent compaction per cent voids, etc. could not be calculated. As for the last two projects, the high traffic volume for these projects left a wide gap between the last point (P) on the curve and R, thereby resulting in an uncertain behavior of the curve between these points. As mentioned before, only the observed values of Y are shown in the figure. In this case, the second order polynomial could best be fitted to the observed data, giving an index of correlation of 0.661 indicating a significant relationship to exist. The curve clearly illustrates the rapid rate of increase of per cent compaction up to a traffic volume of 6 million vehicles. Further increase of traffic diminishes this rate reaching a minimum (maximum value of 102%) at 10 million vehicles. From here on, the curve assumes a negative trend to give a value of 100.1% at 15.9 million vehicles. Thus it is seen that the first increase of 4 million vehicles increases the compaction by 2.0%, whereas an increase of only 0.5 in per cent compaction is obtained for the next 4 million vehicles. Assuming 2 million vehicles to represent one year of average annual daily traffic of 5,500 (a close figure for primary highways in Louisiana), it would indicate that most of the increase in compaction can be expected

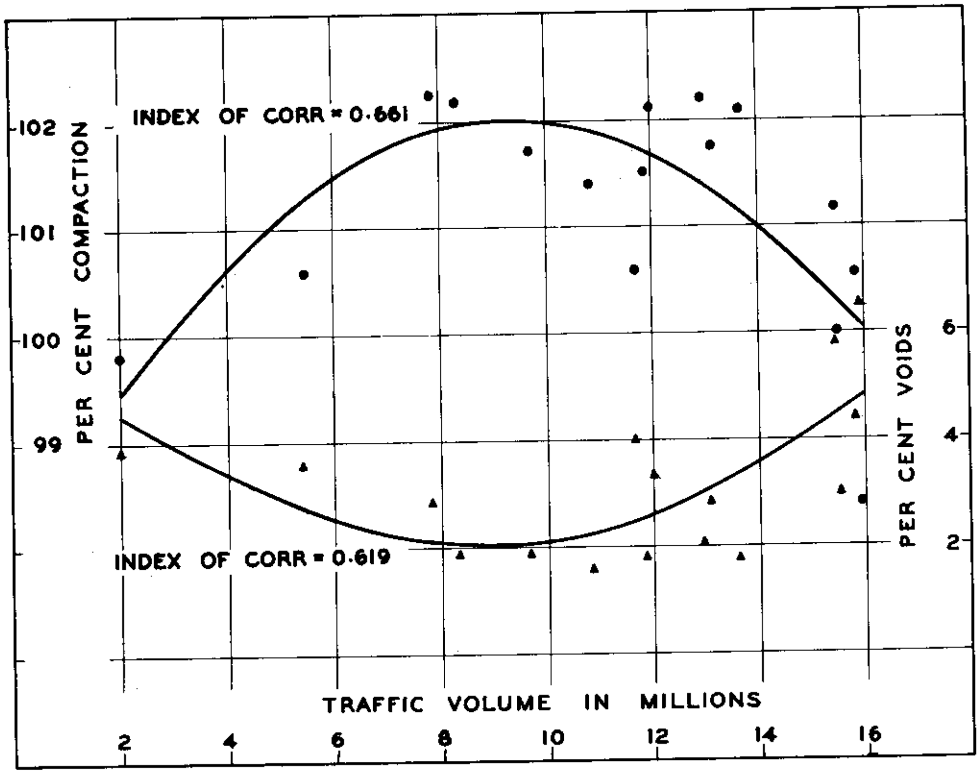

Figure 4 ***Relationships of Traffic Volume Versus Per Cent Compaction and Per Cent Voids for Wearing Course Specimens.***

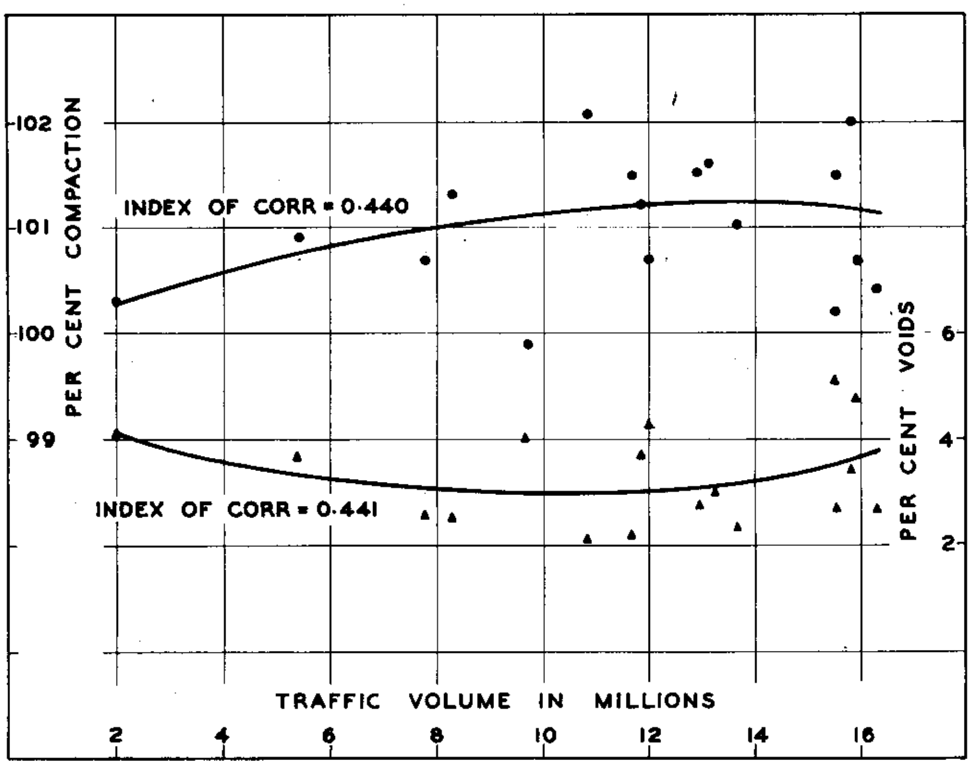

Figure 5 ***Relationships of Traffic Volume Versus Per Cent Compaction and Per Cent Voids for Binder Course Specimens.***

to occur during the first 3 years after construction and after that, this increase would be gradual, reaching a peak at 10 million vehicles (approximately 5 years of total traffic). Further increase in traffic volume which produces a negative trend in the curve, may be due to the flushing of asphalt from the mix. It should, however, be mentioned at this juncture that the purpose of this report is to indicate the existing conditions and point out relationships between different conditions. No specific attempt shall be made to isolate the causes of the observed conditions.

The lower curve for traffic volume - per cent voids relationship also has a parabolic trend with 0.619 for index of correlation. The ordinate values decrease with increase in traffic volume showing a minimum of 2.0% at 10 million vehicles; from this point, the trend becomes positive. Here again, as in the per cent compaction relationship, the same differential exists during the interval of 8 million vehicles, namely 2.5% the initial 2.0% change of which occurs during the first 4 million vehicles.

When a similar relationship for a binder course mix was investigated, Figure 5 was obtained. For reasons similar to that explained before for Figure 4, observations from Projects R and S were not used in this analysis. Fitting the curve to the fourth order polynomial gave an index of correlation of 0.441 and 0.440 for these relationships. The upper curve for per cent compaction shows an increase from 100.3% at 2 million vehicles to 101.3% at 13.5 million vehicles. This means an increase of

11.5 million vehicles increases the per cent compaction by one. Further increase of 2.8 million vehicles in the independent variable reduces the densification by only 0.1%. This occurs at 16.3 million vehicles. The lower curve for per cent voids indicates decreasing air voids with increasing traffic volume, reaching a low of 3.1 per cent at 10.5 million vehicles. After this point, the ordinate value increases with increasing value of abscissa reaching 3.6% at 16.3 million vehicles.

From Figures 4 and 5, it becomes evident that the initial rate of increase in compaction is greater for wearing course than for binder course. The wearing course compaction not only ceases once the peak is reached, but shows a considerable drop from this peak with additional increase in traffic volume. Such a tendency is very slight in binder course mix. The numerical value for per cent compaction for wearing course mix is also higher than for binder course. It was mentioned before that the drop in compaction may very well be due to flushing of asphalt. Table I shows the percentage change in flow of wheel path specimens as based on flow values of plant compacted specimens during construction. It is seen that this change in flow is negative and remains so until a traffic volume of 12 million is reached, whence the change suddenly jumps up into the positive region. It is interesting to note that Project P which shows the lowest per cent compaction at 15.9 million vehicles has the greatest percentage of positive change in flow value. Furthermore, all of the projects except G, having traffic volume of between 2 and 12 million vehicles, show negative change (increasing compaction), whereas those between 12 and 16 million vehicles show a positive change (decreasing compaction) which is indicative of flushing. Project G showed excessive joint filler on the surface which may have been the cause of the increased flow value.

Figure 6 shows the effects of traffic volume on the rutting of pavement. Data from four projects had to be eliminated in the correlation analysis. Rutting on Project D with only 8.3 million vehicles was considered too excessive as compared to others and hence, had to be eliminated. Rut measurements on Project G were not obtained because of excessive joint filler, as mentioned before, and excessive settlement of widening section and Projects R and S for reasons explained before. The final computed curve shows an increase of only 4 mm in longitudinal grooves with an increase in traffic volume from two million to ten million. Further increase in the independent variable does not affect the value of the dependent variable to any extent. The index of correlation for the second degree parabola is 0.326. Although the curve does not show excessive rutting with traffic volume, measurements as high as 24 mm were recorded on Project D for which the overall average was 17.6 mm or 0.7 inch, which is fairly deep depression.

A study of the preceding relationships indicates that, at an abscissa value of approximately 10 million vehicles, maximum conditions are obtained. Although the binder course continues to show an increase up to about 13.5 million vehicles, this, however, is so slight that it would be safe to assume the maximum

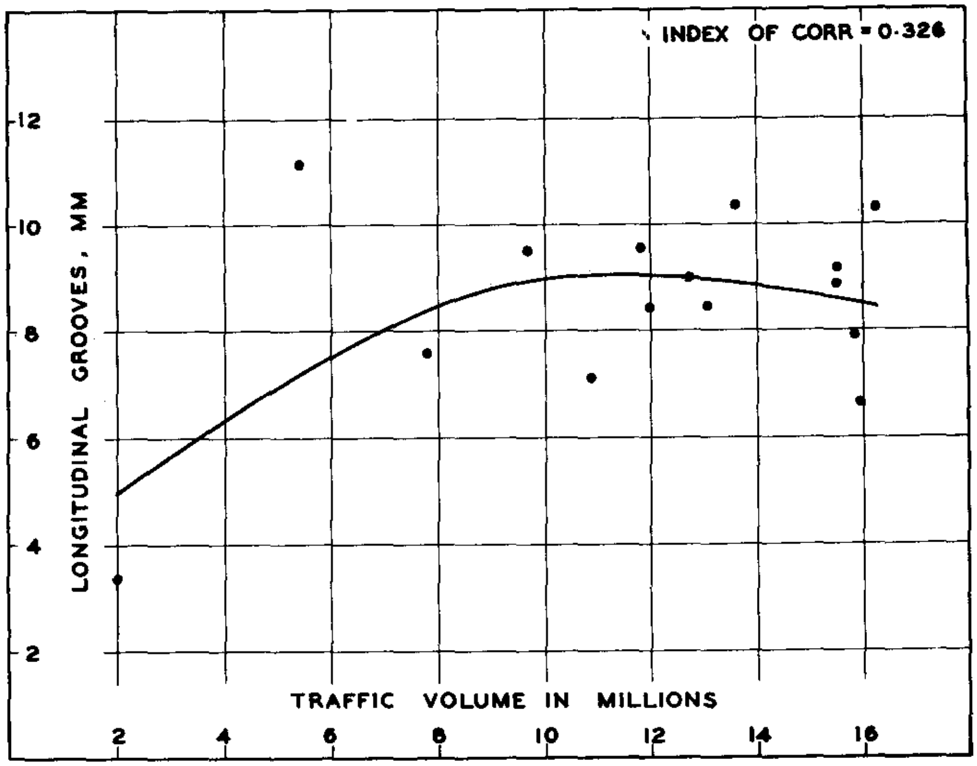

Figure 6 Traffic Volume - Longitudinal Grooves Relationship.

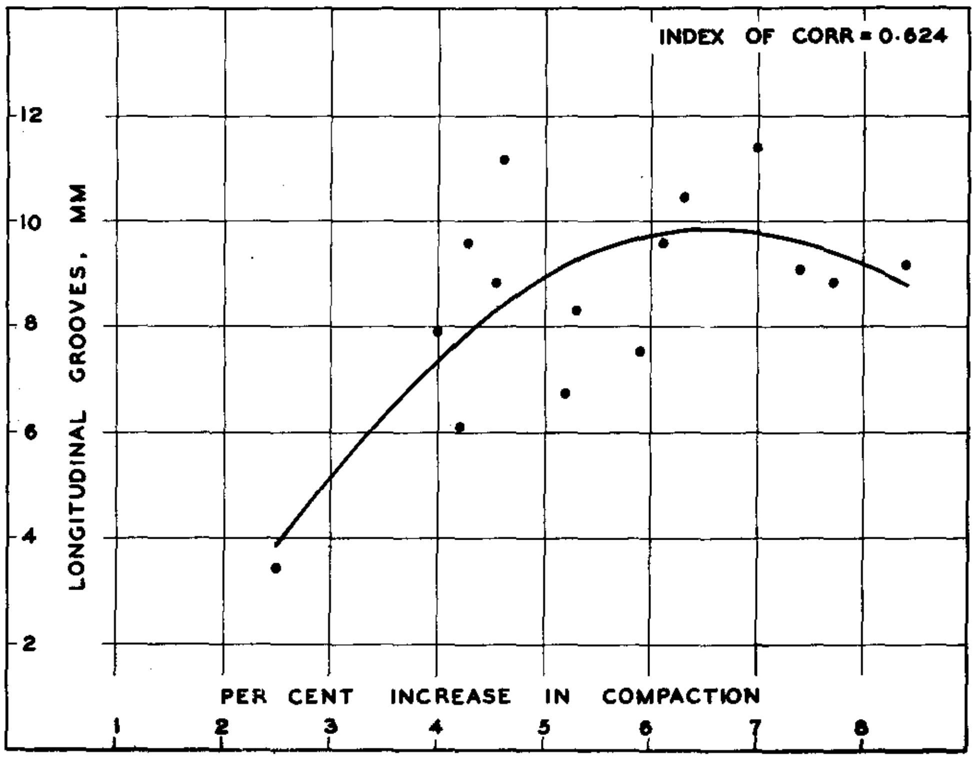

Figure 7 Per Cent Increase in Compaction - Longitudinal Grooves Relationship.

conditions to occur at approximately 10 million vehicles. The per cent compaction for the wearing course mix ceases to increase after about 10 million vehicles, with similar trend for per cent voids and longitudinal grooves relationship. This also indicates that wheel path rutting is more a measure of the compaction of the pavement than the instability or shoving of same until flushing occurs. In other words, up to a certain point, excessive increase in per cent compaction is likely to show corresponding increase in longitudinal grooves. Once the compaction ceases and begins to drop, due to flushing of asphalt, the mix probably changes into an unstable state which would tend to cause lateral movement rather than vertical as indicated by densification without affecting the longitudinal grooves. This occurs after about 10 million vehicles. In support of the above statement, Figure 7 is presented. Here, the effect of the percentage of increase in compaction from that obtained during construction is shown. The second order polynomial has an index of correlation of 0.624.

Because of lack of representative data on axle loads, the observed values of the dependent variables, namely, per cent compaction and per cent voids, were too scattered to arrive at any significant relationship. In spite of this inaccuracy, Figure 8 was prepared to show the effect of number of axles in the 10-20 kips weight group on the longitudinal grooves of the pavement. The depth of grooves increase as the number of axles increase, reaching a peak at 1.6 million axles. However, as in Figure 6, the ordinate values do not remain constant but drop off

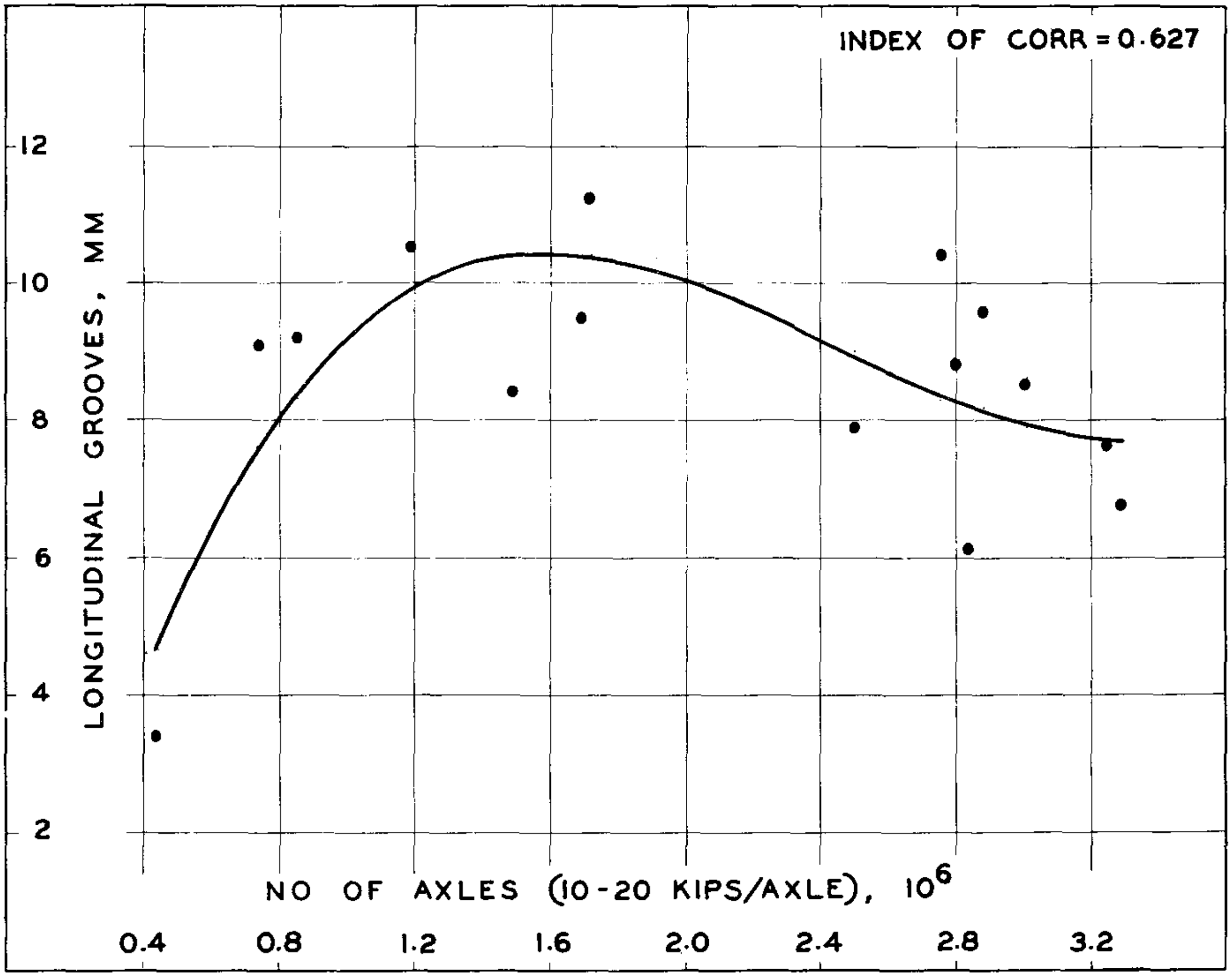

Figure 8 Axle Load - Longitudinal Grooves Relationship.

with further increase in number of axles. This occurs at 2.8 million axles, after which the curve flattens out. The fitted curve is of the third order polynomial having an index of correlation of 0.627.

Further analysis of the data showed Marshall stability to be related to minus No. 4 material (Figure 9), and stability to be related to road roughness of the pavement (Figure 10). Since presence of loose and protruding gravel or mineral crack filler is reflected on the road roughness indicator, it would seem that excessive stabilities among other things, may cause brittleness in the pavement mix which in turn would induce cracking and raveling in the pavement when subjected to traffic. This condition of cracking and raveling was quite pronounced on Projects J, M, N, O, R and S. Likewise, the pavement cores also showed excessively high stabilities. However, the evidence is not sufficient enough to draw any positive inference regarding the association of the above two properties. It can be noted that the roughness and wheel path rutting are significantly related as illustrated by Figure 11 with a correlation coefficient of 0.580. It has also been shown that wheel path rutting is a function of compaction (Figure 7). When roughness was plotted against compaction, Figure 12 was obtained with a coefficient of correlation of 0.709. Thus, we have roughness to be a function of not only the stability of the pavement, but compaction and longitudinal grooves as well. In all probability, the factor of age may have an important bearing on these interrelated properties, but that remains a matter of conjecture.

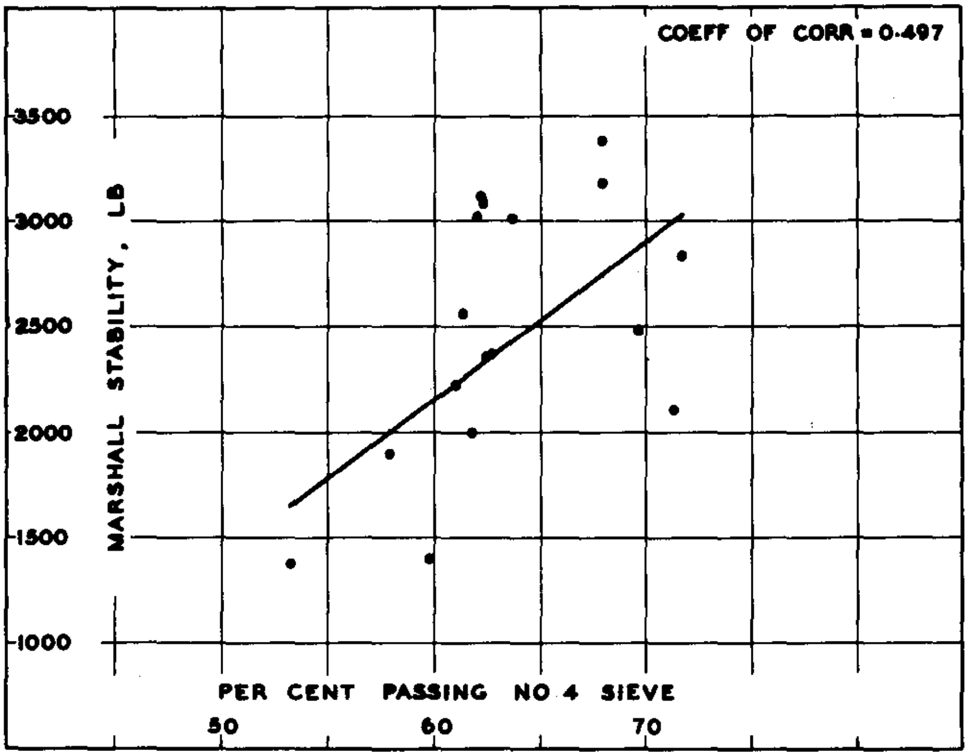

Figure 9 *Relationship of Per Cent Passing No. 4 Sieve and Marshall Stability for Wearing Course Roadway Specimens.*

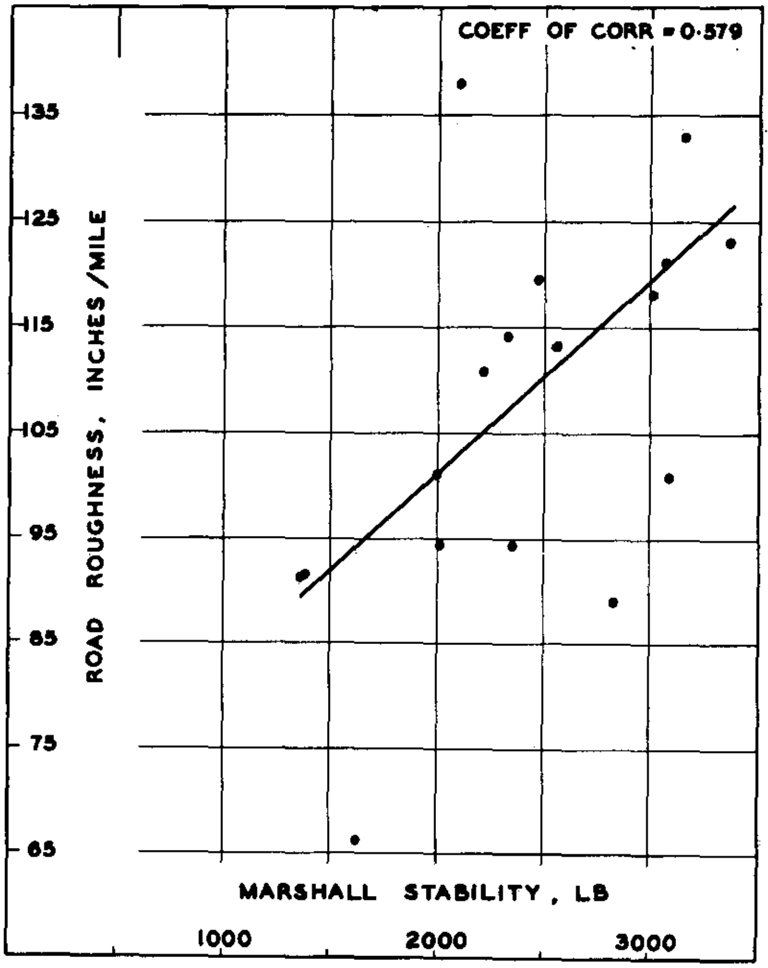

Figure 10 *Relationship of Marshall Stability of the Roadway Specimens (Wearing Course) and Road Roughness.*

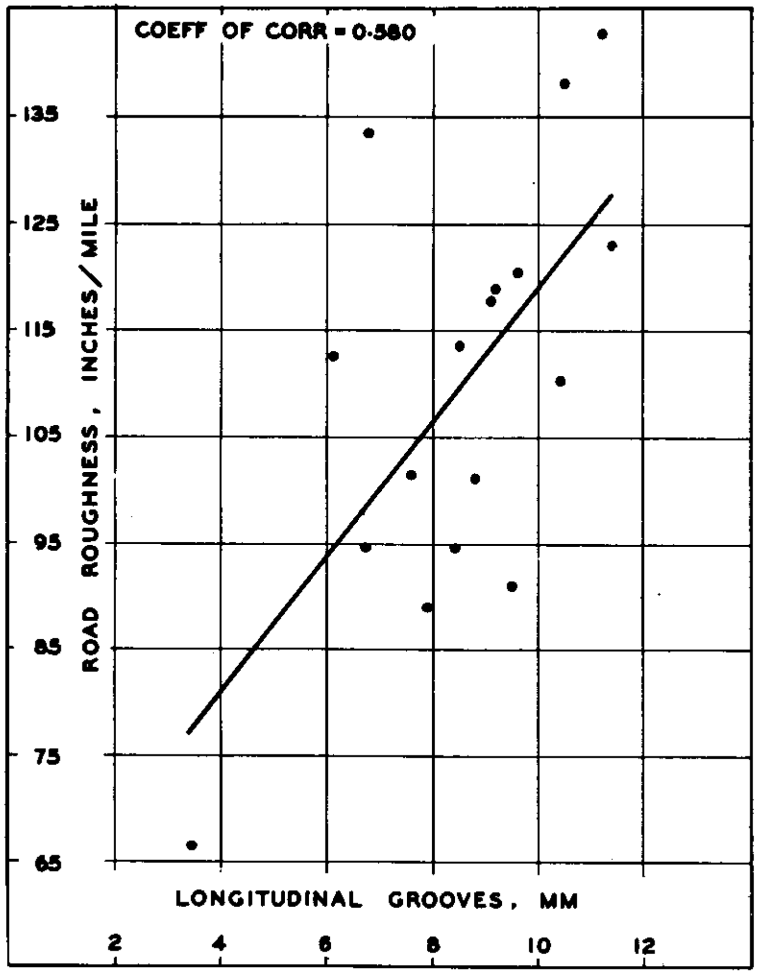

Figure 11 Relationship of Longitudinal Grooves and Road Roughness of the Pavement.

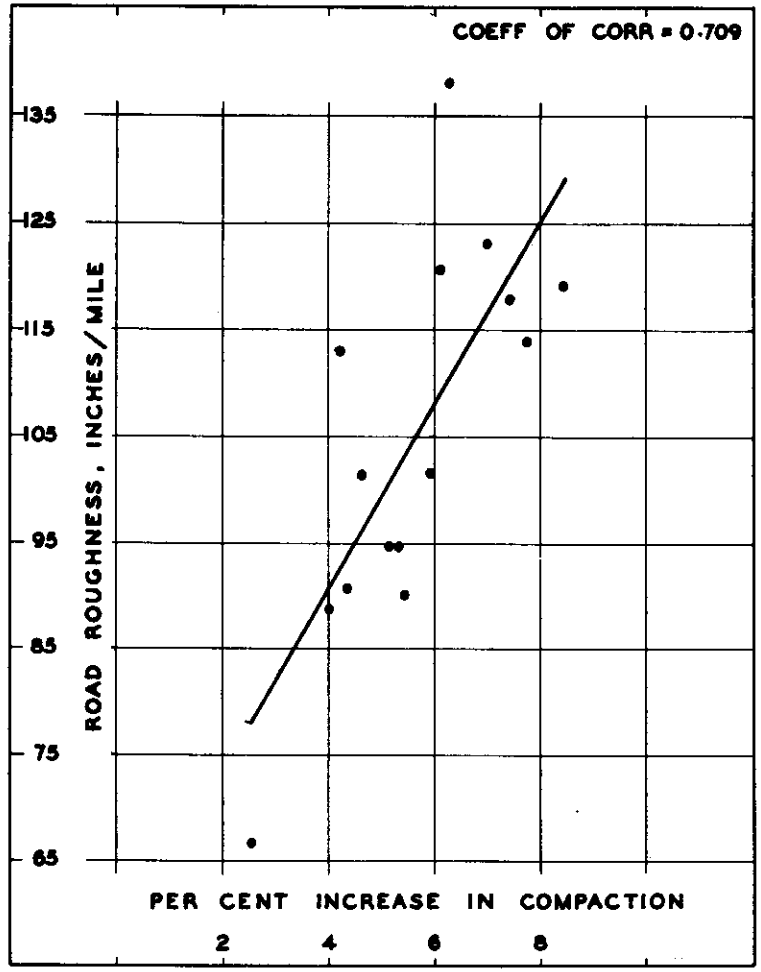

Figure 12 Relationship of Per Cent Increase in Compaction and Road Roughness of the Pavement.

Presence of material finer than No. 40 sieve in the asphaltic concrete mixture also affects the densification of the pavement as illustrated in Figure 13. A differential of 10.0% in the independent variable produces a corresponding differential of 3.0% in the dependent variable. No relationship could be obtained for per cent passing No. 4 sieve and per cent increase in compaction.

The effect of age and traffic upon the gradation of the extracted aggregate could not be analysed because of lack of original construction data on the aggregate gradation. The asphalt content, when compared with the original, showed wide fluctuations (Table IV). In a few cases, the drop in asphalt content from the original was quite significant and yet in a few, an increase from the original was obtained. The latter complexity may be due to the dispersion of added asphalt from the asphalt crack filler, which would tend to increase the quantity. However, lack of positive evidence does not justify this statement. Table II shows penetration of asphalt recovered from the specimens. In all but two cases, the penetration of asphalt from wearing course specimens was lower than from binder course specimens. Projects R and S showed identical values in both cases. This indicates that for a given film thickness, the rate of oxidation varies inversely with depth and time, faster for upper layers of the pavement, decreasing slowly with depth until a time is reached when this equalizes. This further indicates that reduction in asphalt film thickness, although an asset as far as increasing the stability is concerned, may prove

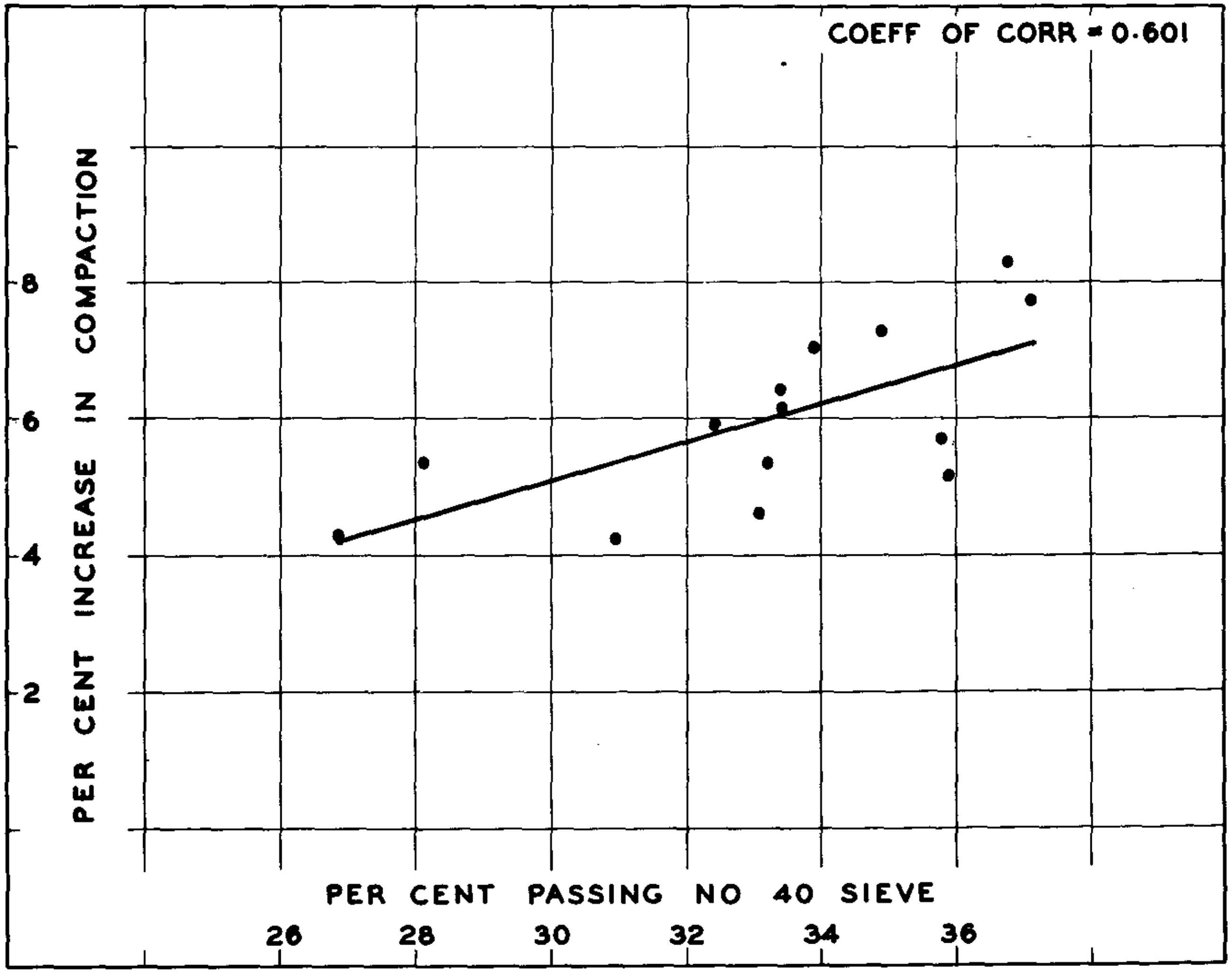

Figure 13 *Relationship of Per Cent Passing No. 40 Sieve and Per Cent Increase in Compaction for Wearing Course Specimens.*

TABLE IV ASPHALT AND MINERAL FILLER CONTENT

Proj Iden	Wearing Course				Binder Course			
	Per Cent Asphalt				Per Cent Asphalt			
	Job Mix	Extraction Orig	Extraction Final	Per Cent Filler	Job Mix	Extraction Orig	Extraction Final	Per Cent Filler
A	5.5	5.8	-	3.8	4.5	4.8	-	2.9
B	5.3	5.9	-	4.7	4.8	4.6	-	3.8
C	5.5	5.9	6.1	4.7	5.3	4.8	4.8	2.9
D	5.0	5.8	5.0	3.9	4.3	4.5	4.3	3.6
E	5.4	5.5	5.2	4.7	4.5	4.4	4.6	1.9
F	6.0	6.4	6.0	5.0	4.8	4.7	4.5	3.8
G	6.0	5.8	4.9	-	4.6	5.1	4.5	-
H	5.6	5.9	5.5	4.7	4.2	5.0	4.6	3.8
I	6.2	6.5	6.0	2.8	5.4	4.8	5.3	1.9
J	5.3	5.7	5.3	4.7	4.7	4.9	4.2	4.3
K	5.5	6.0	5.8	3.8	4.8	5.2	4.5	2.9
L	5.9	5.9	5.9	3.8	5.0	5.1	5.0	2.8
M	5.2	6.1	6.0	5.5	4.7	5.5	4.0	3.0
N	5.5	5.3	5.9	4.7	5.0	5.0	-	3.8
O	5.5	5.5	6.0	7.0	4.8	5.1	4.8	4.5
P	6.3	6.8	6.9	3.8	5.3	5.5	5.3	-
Q	-	5.9	5.7	-	4.7	4.6	4.9	3.7
R	6.3	5.8	6.2	6.7	4.8	4.5	4.3	3.3
S	5.6	5.2	4.7	6.0	5.0	4.9	4.4	-

TABLE V OVERALL SURFACE CONDITION

Proj Iden	Surface Condition			
	Reflection Cracking	Raveling	Shoving	Flushing
A	Light	Light	None	None
B	Medium	Medium	None	None
C	Medium	Light	None	Very Light
D	Light	Medium	None	None
E	Light	Light	None	None
F	Medium	Light	None	Very Light
G	Heavy	Heavy	Light	Light to Med
H	Heavy	Heavy	Light	Light
I	Medium	Light	None	Medium
J	Heavy	Heavy	Light	Light
K	Heavy	Heavy	None	Medium
L	Heavy	Heavy	Light	Medium
M	Heavy	Heavy	Light	Light
N	Heavy	Medium	Light	Light to Med
O	Heavy	Heavy	None	None
P	Heavy	Light	None	Med to Heavy
Q	Medium	Medium	None	Light
R	Heavy	Heavy	Light	Medium
S	Medium	Heavy	Light	Medium

detrimental in the long run due to faster rate of oxidation. The brittleness resulting from this characteristic would enhance the phenomena of cracking and raveling, and an obvious loss in flexibility.

Summary and Conclusions

The preceding quantitative analysis of the problem of service behavior of asphaltic concrete pavement brings up a question of the significance of the relationships, since the physical properties so analysed seem to be interrelated. It was seen that subsequent to construction, the traffic induces additional compaction and wheel path rutting. The latter also showing a relationship with the former (compaction). It was also shown that compaction affects the roughness of the pavement which in turn is related to the stability and the longitudinal grooves or wheel path rutting of the pavement. Furthermore, the percentage of material finer than No. 4 was shown to have an appreciable effect upon the stability and the densification of the pavement. Thus we see that the design of asphaltic concrete mixture, although simple in application, can become complex if the assumptions inherent in the design procedure are not proven valid by sufficient service behavior study and tests. Also, the limiting values on stability set up in the laboratory have to be proven valid or else there is danger of overemphasizing stability at the expense of flexibility.

The entire approach to the analysis was done on the assumption of functional relationship between the independent and the dependent variables, while isolating the effect of others.

In other words, assumptions had to be made that the errors involved in grouping data from pavements with different designs and construction features are negligible. The fact that the principal variable was the traffic volume or number of load repetitions, the above assumption of identical features of design (all on concrete base except A) and construction seemed relevant.

Conclusions

From the analysis of data and surface conditions obtained from the survey, it is concluded that:

1. The densification of the wearing course increases rapidly during the first 6 million vehicles (about 3 years) and then becomes gradual reaching a maximum at traffic volume of 10 million vehicles (about 5 years). Further increase in traffic tends to reduce the density.

2. The rate of compaction for binder course is much slower than wearing course, the maximum condition occuring at approximately the same traffic volume, i.e. a traffic volume of 10 million vehicles (about 5 years).

3. The numerical values of per cent compaction are much higher for wearing course than for binder course. However, both showing compaction in excess of 100 per cent of a 50 blow Marshall Design.

4. The preceding three conditions indicate the need for a higher compactive effort in the laboratory and during construction.

5. Longitudinal grooves or wheel path rutting is more a function of the additional compaction of the pavement than the stability of the pavement.

6. Evidence of flushing of asphalt was indicated by visual inspection as well as by an increase in flow values and consequently, a drop in per cent compaction from the peak (Figure 4).

7. Presence of excessive material finer than No. 4 sieve induces additional stability and compaction, excessive values of which show detrimental effects on the pavement by way of cracking, raveling and in some instances, shoving.

8. Although excessive values of rutting were not observed throughout this study, with very few exceptions, the puddling of water in wheel paths observed on all these projects, in all probability is due to lack of transverse drainage of water from the pavement surface. The required surface slope or crown for proper and rapid drainage of water should be studied and same adjusted to remedy this condition of puddling.

Future Work Planned

This study established that approximately 10 million vehicles or five years of equivalent traffic induces a minimum of two per cent voids (using an apparent specific gravity of the aggregate) in the surface course. Assuming an average life of an asphaltic concrete pavement to be 15 years or, expressed as traffic volume, 30 million vehicles, it would seem that the condition of two per cent voids at the end of five years of service is attained much too soon. This condition causes flushing of asphalt and consequently, a reduction in densification. A concurrent research project "Gyratory Correlation Study," is underway, in which an attempt will be made to investigate the number of gyrations and pressure necessary to obtain a void content of two per cent. This should represent an equivalent of ten million vehicles or five years of service. Based on this information, the number of gyrations equivalent to 30 million vehicles will be computed. Specimens would then be compacted, using this computed value for number of gyrations and pressure and the final evaluation made from this data regarding the criteria for per cent voids using 75 blow Marshall compaction.

Bibliography

1. "Symposium on Asphalt Paving Mixtures," Highway Research Board, Research Report No. 7-B, 1949.

2. Brownlee, K. A., "Statistical Theory and Methodology in Science and Engineering," John Wiley and Sons, Inc., New York, 1960.

A P P E N D I X

APPENDIX TABLE I TEST RESULTS OF WEARING & BINDER COURSE SPECIMENS PROJECT A (4 years)

Marshall Properties	Wearing Course								Binder Course							
	Construction Results*	Pavement Cores							Construction Results*	Pavement Cores						
		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg		Max	Min	C.L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg
Specific Gravity	2.336	2.356	2.283	2.331	2.335	2.329	2.332	2.332	2.342	2.374	2.288	2.350	2.350	2.350	2.350	2.350
Theoretical Gravity	2.428	2.428	2.428	2.428	2.428	2.428	2.428	2.428	2.450	2.450	2.450	2.450	2.450	2.450	2.450	2.450
% Theoretical Gravity	96.2	97.0	94.0	96.0	96.2	95.9	96.1	96.0	95.6	96.9	93.4	95.9	95.9	95.9	95.9	95.9
% Voids	3.8	3.0	6.0	4.0	3.8	4.1	3.9	4.0	4.4	3.1	6.6	4.1	4.1	4.1	4.1	4.1
% V.F.A.	76.8	80.9	67.2	75.9	76.8	75.4	76.3	75.9	70.1	77.2	60.5	71.7	71.7	71.7	71.7	71.7
Stability @ 140F, lb	1202	2511	1161	1626	1758	1918	1838	1768	1083	1205	500	998	967	890	929	951
Flow, 1/100 inch	12	11	7	9	9	9	9	9	13	15	6	10	9	10	10	15

Gradation of the Extracted Aggregate from Roadway Specimens				
U. S. Sieve	Per Cent Passing		Per Cent Passing	
1 Inch		**	100.0	**
3/4 Inch	100.0		93.7	
1/2 Inch	95.4		76.1	
3/8 Inch	-		-	
No. 4	65.1		46.7	
No. 10	53.1		38.6	
No. 40	34.8		25.1	
No. 80	12.8		9.2	
No. 200	8.4		5.9	
A. C. Per Cent	5.8		4.8	

* Average of results from Daily Plant Reports
** Samples not available for gradation analysis

APPENDIX TABLE II TEST RESULTS OF WEARING & BINDER COURSE SPECIMENS PROJECT B (6 years)

Marshall Properties	Wearing Course								Binder Course							
	Construction Results*	Pavement Cores							Construction Results*	Pavement Cores						
		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg
Specific Gravity	2.330	2.373	2.269	2.320	2.348	2.338	2.343	2.335	2.340	2.390	2.320	2.350	2.360	2.360	2.360	2.360
Theoretical Gravity	2.430	2.430	2.430	2.430	2.430	2.430	2.430	2.430	2.450	2.450	2.450	2.450	2.450	2.450	2.450	2.450
% Theoretical Gravity	95.9	97.6	93.4	95.5	96.6	96.2	96.4	96.0	95.5	97.6	94.7	95.9	96.3	96.3	96.3	96.3
% Voids	4.1	2.4	6.6	4.5	3.4	3.8	3.6	4.0	4.5	2.4	5.3	4.1	3.7	3.7	3.7	3.7
% V.F.A.	74.7	83.7	64.1	72.8	78.2	76.2	77.2	75.2	71.0	82.4	67.3	73.0	75.0	75.0	75.0	75.0
Stability @ 140F, lb	1249	2995	1067	1724	2197	1671	1934	1850	1089	3114	798	1776	1752	1949	1851	1823
Flow, 1/100 inch	13	14	7	9	11	9	10	10	13	11	9	11	10	10	10	10

Gradation of the Extracted Aggregate from Roadway Specimens				
U. S. Sieve	Per Cent Passing		Per Cent Passing	
1 Inch		**		**
3/4 Inch				
1/2 Inch				
3/8 Inch				
No. 4				
No. 10				
No. 40				
No. 80				
No. 200				
A. C. Per Cent	5.9		4.6	

* Average of results from Daily Plant Reports
** Samples not available for gradation analysis

APPENDIX TABLE III TEST RESULTS OF WEARING & BINDER COURSE SPECIMENS PROJECT C (7 years)

Marshall Properties	Wearing Course								Binder Course							
	Construction Results*	Pavement Cores							Construction Results*	Pavement Cores						
		Max	Min	C L	Tire Tracks			Proj Avg		Max	Min	C L	Tire Tracks			Proj Avg
					3'	9'	Avg						3'	9'	Avg	
Specific Gravity	2.300	2.370	2.285	2.331	2.358	2.347	2.353	2.345	2.340	2.381	2.295	2.348	2.358	2.355	2.357	2.354
Theoretical Gravity	2.420	2.420	2.420	2.420	2.420	2.420	2.420	2.420	2.420	2.420	2.420	2.420	2.420	2.420	2.420	2.420
% Theoretical Gravity	95.0	97.9	94.4	96.3	97.4	97.0	97.2	96.9	96.7	98.4	94.8	97.0	97.4	97.3	97.4	97.3
% Voids	5.0	2.1	5.6	3.7	2.6	3.0	2.8	3.1	3.3	1.6	5.2	3.0	2.6	2.7	2.6	2.7
% V.F.A.	71.3	85.9	68.8	77.3	83.0	80.8	81.9	80.3	78.5	88.4	69.5	80.3	82.4	81.8	82.4	89.8
Stability @ 140F, lb	974	3075	1206	2000	1649	1833	1766	1844	1036	2485	1000	1505	1244	1533	1389	1464
Flow, 1/100 inch	13	16	10	12	13	12	13	12	13	12	8	10	10	10	10	10

Gradation of the Extracted Aggregate from Roadway Specimens

U. S. Sieve	Per Cent Passing		Per Cent Passing	
1 Inch				100.0
3/4 Inch		100.0		98.3
1/2 Inch		96.9		84.5
3/8 Inch		85.9		67.4
No. 4		61.9		44.9
No. 10		51.2		38.7
No. 40		32.4		25.6
No. 80		17.5		15.3
No. 200		6.7		7.6
A. C. Per Cent	5.9	6.1	4.8	4.8

* Average of results from Daily Plant Reports

APPENDIX TABLE IV TEST RESULTS OF WEARING & BINDER COURSE SPECIMENS PROJECT D (5 years)

Marshall Properties	Wearing Course								Binder Course							
	Construction Results*	Pavement Cores							Construction Results*	Pavement Cores						
		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg
Specific Gravity	2.333	2.402	2.300	2.365	2.385	2.385	2.385	2.378	2.367	2.416	2.360	2.375	2.400	2.393	2.397	2.387
Theoretical Gravity	2.430	2.430	2.430	2.430	2.430	2.430	2.430	2.430	2.459	2.459	2.459	2.459	2.459	2.459	2.459	2.459
% Theoretical Gravity	96.0	98.8	94.7	97.3	98.1	98.1	98.1	97.9	96.3	98.3	96.0	97.0	97.6	97.3	97.5	97.1
% Voids	4.0	1.2	5.3	2.7	1.9	1.9	1.9	2.1	3.7	1.7	4.0	3.0	2.4	2.7	2.5	2.9
% V.F.A.	74.1	90.7	68.0	81.1	86.0	86.0	86.0	84.7	72.7	85.9	71.1	76.7	80.6	78.7	80.0	77.4
Stability @ 140F, lb	1037	1931	925	1369	1268	1362	1315	1333	1120	1165	698	883	865	884	875	883
Flow, 1/100 inch	12	16	8	10	10	10	10	10	11	12	7	9	11	8	10	9

Gradation of the Extracted Aggregate from Roadway Specimens				
U. S. Sieve	Per Cent Passing		Per Cent Passing	
1 Inch	100.0		99.8	99.0
3/4 Inch	99.3	100.0	94.6	91.9
1/2 Inch	92.3	84.9	81.0	74.5
3/8 Inch	-	72.9	-	60.7
No. 4	63.0	53.3	45.8	41.9
No. 10	53.5	44.6	37.7	35.3
No. 40	34.9	28.1	24.9	22.0
No. 80	15.0	12.1	12.1	11.2
No. 200	4.9	4.2	4.4	5.5
A. C. Per Cent	5.8	5.0	4.5	4.3

* Average of results from Daily Plant Reports

APPENDIX TABLE V   TEST RESULTS OF WEARING & BINDER COURSE SPECIMENS   PROJECT E (5 years)

Marshall Properties	Wearing Course								Binder Course							
	Construction Results*	Pavement Cores							Construction Results*	Pavement Cores						
		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg
Specific Gravity	2.334	2.380	2.325	2.353	2.372	2.373	2.373	2.366	2.355	2.378	2.330	2.357	2.346	2.356	2.351	2.353
Theoretical Gravity	2.418	2.418	2.418	2.418	2.418	2.418	2.418	2.418	2.448	2.448	2.448	2.448	2.448	2.448	2.448	2.448
% Theoretical Gravity	96.5	98.4	96.2	97.3	98.1	98.1	98.1	97.9	96.2	97.1	95.2	96.3	95.8	96.2	96.0	96.0
% Voids	3.5	1.6	3.8	2.7	1.9	1.9	1.9	2.1	3.8	2.9	4.8	3.7	4.2	3.8	4.0	4.0
% V.F.A.	77.9	88.7	76.4	82.2	86.9	86.9	86.9	85.6	73.2	78.3	68.2	72.9	71.2	73.2	72.2	72.2
Stability @ 140F, lb	1239	2176	848	1377	1558	1478	1518	1471	1286	1625	603	1167	1151	987	1069	1091
Flow, 1/100 inch	14	13	10	11	11	11	11	11	15	14	7	11	9	10	10	10

Gradation of the Extracted Aggregate from Roadway Specimens

U. S. Sieve	Per Cent Passing		Per Cent Passing	
1 Inch	100.0	100.0	100.0	100.0
3/4 Inch	100.0	98.0	94.0	90.6
1/2 Inch	93.9	89.5	80.7	79.4
3/8 Inch	-	78.2	-	66.3
No. 4	66.0	59.9	43.8	44.1
No. 10	54.2	48.5	33.9	34.4
No. 40	30.5	26.9	18.3	19.4
No. 80	17.2	15.5	11.0	12.3
No. 200	6.4	7.5	5.0	7.7
A. C. Per Cent	5.5	5.2	4.4	4.6

* Average of results from Daily Plant Reports

APPENDIX TABLE VI TEST RESULTS OF WEARING & BINDER COURSE SPECIMENS PROJECT F (10 years)

Marshall Properties	Wearing Course								Binder Course							
	Construction Results*	Pavement Cores							Construction Results*	Pavement Cores						
		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg
Specific Gravity	2.330	2.380	2.297	2.351	2.360	2.364	2.362	2.358	2.340	2.400	2.350	2.378	2.389	2.388	2.389	2.385
Theoretical Gravity	2.400	2.400	2.400	2.400	2.400	2.400	2.400	2.400	2.400	2.400	2.440	2.440	2.440	2.440	2.440	2.440
% Theoretical Gravity	97.1	99.2	95.7	98.0	98.3	98.5	98.4	98.3	96.0	98.4	96.3	97.5	97.9	97.9	97.9	97.7
% Voids	2.9	0.8	4.3	2.0	1.7	1.5	1.6	1.7	4.0	1.6	3.7	2.5	2.1	2.1	2.1	2.3
% V.F.A.	82.5	94.6	75.9	87.4	89.1	90.3	89.7	89.1	73.4	87.6	74.9	81.7	84.3	84.3	84.3	83.0
Stability @ 140F, lb	1566	3897	1800	2560	2566	2446	2506	2516	1233	2306	1473	1732	1651	1638	1645	1678
Flow, 1/100 inch	16	15	7	12	12	12	12	12	15	12	8	12	10	11	11	11

Gradation of the Extracted Aggregate from Roadway Specimens				
U. S. Sieve	Per Cent Passing		Per Cent Passing	
1 Inch				100.0
3/4 Inch		100.0		94.3
1/2 Inch		97.4		73.0
3/8 Inch		89.6		60.4
No. 4		61.5		42.9
No. 10		48.1		35.3
No. 40		30.9		24.7
No. 80		15.0		11.9
No. 200		8.1		6.1
A. C. Per Cent	6.4	6.0	4.7	4.5

* Average of results from Daily Plant Reports

APPENDIX TABLE VII TEST RESULTS OF WEARING & BINDER COURSE SPECIMENS PROJECT G (7 years)

Marshall Properties	Wearing Course								Binder Course							
	Construction Results*	Pavement Cores							Construction Results*	Pavement Cores						
		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg
Specific Gravity	2.310	2.380	2.215	2.292	2.315	2.331	2.323	2.313	2.350	2.400	2.340	2.370	2.380	2.390	2.385	2.380
Theoretical Gravity	2.420	2.420	2.420	2.420	2.420	2.420	2.420	2.420	2.440	2.440	2.440	2.440	2.440	2.440	2.440	2.440
% Theoretical Gravity	95.5	98.3	91.5	94.7	95.7	96.3	96.0	95.6	96.3	98.4	95.9	97.1	97.5	98.0	97.8	97.5
% Voids	4.5	1.7	8.5	5.3	4.3	3.7	4.0	4.4	3.7	1.6	4.1	2.9	2.5	2.0	2.2	2.5
% V.F.A.	75.1	89.2	60.5	71.8	76.0	78.8	77.4	75.6	74.1	87.0	72.0	78.6	81.0	84.3	83.0	81.0
Stability @ 140F, lb	1013	2742	1171	1791	2148	1939	2044	1921	955	2240	884	1541	1505	1395	1450	1480
Flow, 1/100 inch	10	16	9	11	12	12	12	12	12	11	10	10	10	11	11	10

Gradation of the Extracted Aggregate from Roadway Specimens

U. S. Sieve	Per Cent Passing		Per Cent Passing	
1 Inch				100.0
3/4 Inch		100.0		93.0
1/2 Inch		86.3		76.8
3/8 Inch		71.8		64.6
No. 4		58.1		45.5
No. 10		50.8		39.1
No. 40		35.8		28.8
No. 80		13.6		13.5
No. 200		6.7		7.3
A. C. Per Cent	5.8	4.9	5.1	4.5

* Average of results from Daily Plant Reports

APPENDIX TABLE VIII TEST RESULTS OF WEARING & BINDER COURSE SPECIMENS PROJECT H (8 years)

Marshall Properties	Wearing Course								Binder Course							
	Construction Results*	Pavement Cores							Construction Results*	Pavement Cores						
		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg
Specific Gravity	2.340	2.417	2.268	2.350	2.379	2.373	2.376	2.367	2.340	2.392	2.323	2.359	2.377	2.358	2.368	2.364
Theoretical Gravity	2.420	2.420	2.420	2.420	2.420	2.420	2.420	2.420	2.460	2.460	2.460	2.460	2.460	2.460	2.460	2.460
% Theoretical Gravity	96.7	99.9	93.7	97.1	98.3	98.1	98.2	97.8	95.1	97.2	94.4	95.9	96.6	95.9	96.3	96.1
% Voids	3.3	0.1	6.3	2.9	1.7	1.9	1.8	2.2	4.9	2.8	5.6	4.1	3.4	4.1	3.7	3.9
% V.F.A.	79.4	99.2	66.1	81.5	88.4	87.2	87.8	85.4	66.3	77.8	63.3	70.3	74.2	70.3	72.9	71.4
Stability @ 140F, lb	1160	4234	2108	3071	3085	2947	3016	3024	1103	1545	940	1337	1392	1259	1326	1310
Flow, 1/100 inch	12	14	6	10	8	10	9	9	12	11	6	9	7	8	8	8

Gradation of the Extracted Aggregate from Roadway Specimens

U. S. Sieve	Per Cent Passing		Per Cent Passing	
1 Inch		100.0		97.2
3/4 Inch		99.5		91.3
1/2 Inch		92.0		74.4
3/8 Inch		83.1		60.3
No. 4		62.5		48.0
No. 10		45.4		40.8
No. 40		33.4		30.0
No. 80		17.0		17.2
No. 200		6.8		6.0
A. C. Per Cent	5.9	5.5	5.0	4.6

* Average of results from Daily Plant Reports

APPENDIX TABLE IX TEST RESULTS OF WEARING & BINDER COURSE SPECIMENS PROJECT I (7 years)

Marshall Properties	Wearing Course								Binder Course							
	Construction Results*	Pavement Cores							Construction Results*	Pavement Cores						
		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg
Specific Gravity	2.270	2.366	2.218	2.274	2.314	2.322	2.318	2.303	2.300	2.344	2.260	2.290	2.311	2.320	2.316	2.306
Theoretical Gravity	2.400	2.400	2.400	2.400	2.400	2.400	2.400	2.400	2.420	2.420	2.420	2.420	2.420	2.420	2.420	2.420
% Theoretical Gravity	94.6	98.6	92.4	94.8	96.4	96.8	96.6	96.0	95.0	96.9	93.4	94.6	95.5	95.9	95.7	95.3
% Voids	5.4	2.4	7.6	5.2	3.6	3.2	3.4	4.0	5.0	3.1	6.6	5.4	4.5	4.1	4.3	4.7
% V.F.A.	71.9	85.9	63.9	72.7	79.6	81.5	80.6	77.8	70.9	80.0	64.4	69.2	73.1	75.0	74.1	72.2
Stability @ 140F, lb	1358	3360	1782	2355	2753	2727	2740	2583	1229	2372	1028	1607	1654	1554	1604	1600
Flow, 1/100 inch	12	17	9	13	14	14	14	13	10	17	8	13	12	11	12	12

Gradation of the Extracted Aggregate from Roadway Specimens

U. S. Sieve	Per Cent Passing		Per Cent Passing	
1 Inch				100.0
3/4 Inch		100.0		96.0
1/2 Inch		89.6		81.4
3/8 Inch		77.1		68.1
No. 4		62.9		51.6
No. 10		56.4		45.6
No. 40		33.2		30.4
No. 80		15.6		14.3
No. 200		8.2		7.1
A. C. Per Cent	6.5	6.0	4.8	5.3

* Average of results from Daily Plant Reports

APPENDIX TABLE XI TEST RESULTS OF WEARING & BINDER COURSE SPECIMENS PROJECT K (9 years)

Marshall Properties	Wearing Course							
	Construction Results*	Pavement Cores						
		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg
Specific Gravity	2.300	2.385	2.190	2.266	2.341	2.338	2.340	2.315
Theoretical Gravity	2.410	2.410	2.410	2.410	2.410	2.410	2.410	2.410
% Theoretical Gravity	95.4	99.0	90.9	94.0	97.1	97.0	97.1	96.1
% Voids	4.6	1.0	9.1	6.0	2.9	3.0	2.9	3.9
% V.F.A.	72.9	92.8	56.5	67.1	81.3	80.8	81.3	76.2
Stability @ 140F, lb	1233	3429	1731	2335	2364	2528	2446	2418
Flow, 1/100 inch	11	14	9	12	12	12	12	12

Marshall Properties	Binder Course							
	Construction Results*	Pavement Cores						
		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg
Specific Gravity	2.330	2.390	2.320	2.366	2.369	2.364	2.367	2.366
Theoretical Gravity	2.440	2.440	2.440	2.440	2.440	2.440	2.440	2.440
% Theoretical Gravity	95.5	98.0	95.1	97.0	97.1	96.9	97.0	97.0
% Voids	4.5	2.0	4.9	3.0	2.9	3.1	3.0	3.0
% V.F.A.	70.7	84.8	[illegible]8.8	78.6	79.2	78.0	78.6	78.6
Stability @ 140F, lb	1158	2307	833	1664	1547	1628	1588	1626
Flow, 1/100 inch	13	14	8	12	10	12	11	12

Gradation of the Extracted Aggregate from Roadway Specimens				
U. S. Sieve	Per Cent Passing		Per Cent Passing	
1 Inch				98.6
3/4 Inch		100.0		86.7
1/2 Inch		93.8		63.0
3/8 Inch		82.1		52.7
No. 4		62.7		39.2
No. 10		54.3		34.8
No. 40		37.2		19.7
No. 80		14.8		8.5
No. 200		8.4		4.7
A. C. Per Cent	6.0	5.8	5.2	4.5

* Average of results from Daily Plant Reports

APPENDIX TABLE XII TEST RESULTS OF WEARING & BINDER COURSE SPECIMENS · PROJECT L (8 years)

Marshall Properties	Wearing Course								Binder Course							
	Construction Results*	Pavement Cores							Construction Results*	Pavement Cores						
		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg
Specific Gravity	2.310	2.388	2.282	2.330	2.362	2.356	2.359	2.349	2.350	2.397	2.336	2.355	2.367	2.379	2.373	2.366
Theoretical Gravity	2.400	2.400	2.400	2.400	2.400	2.400	2.400	2.400	2.430	2.430	2.430	2.430	2.430	2.430	2.430	2.430
% Theoretical Gravity	96.3	99.5	95.1	97.1	98.4	98.2	98.3	97.9	96.7	98.6	96.1	96.9	97.4	97.9	97.7	97.4
% Voids	3.7	0.5	4.9	2.9	1.6	1.8	1.7	2.1	3.3	1.4	3.9	3.1	2.6	2.1	2.3	2.6
% V.F.A.	78.1	96.5	72.7	82.2	89.5	88.3	88.8	86.0	77.7	89.4	74.6	78.8	81.7	84.1	83.5	81.7
Stability @ 140F, lb	888	3444	1107	2108	1994	2212	2103	2129	1059	2153	1007	1438	2152	1386	1769	1505
Flow, 1/100 inch	12	18	10	14	14	14	14	14	14	16	10	14	10	13	12	13

Gradation of the Extracted Aggregate from Roadway Specimens				
U. S. Sieve	Per Cent Passing		Per Cent Passing	
1 Inch				100.0
3/4 Inch		100.0		91.7
1/2 Inch		90.8		75.5
3/8 Inch		82.8		67.4
No. 4		71.3		52.3
No. 10		63.1		47.2
No. 40		35.1		23.9
No. 80		19.3		10.9
No. 200		6.8		5.7
A. C. Per Cent	5.9	5.9	5.1	5.0

* Average of results from Daily Plant Reports

APPENDIX TABLE XIII TEST RESULTS OF WEARING & BINDER COURSE SPECIMENS PROJECT M (9 years)

Wearing Course

Marshall Properties	Construction Results*	Pavement Cores Max.	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg.
Specific Gravity	2.290	2.357	2.201	2.229	2.291	2.288	2.290	2.269
Theoretical Gravity	2.430	2.430	2.430	2.430	2.430	2.430	2.430	2.430
% Theoretical Gravity	94.2	97.0	90.6	91.7	94.3	94.2	94.2	93.4
% Voids	5.8	3.0	9.4	8.3	5.7	5.8	5.8	6.6
% V.F.A.	66.6	79.9	54.2	57.8	67.0	66.6	66.6	63.7
Stability @ 140F, lb	1301	3903	1929	2477	2677	3440	3059	2760
Flow, 1/100 inch	13	17	10	14	15	13	14	14

Binder Course

Marshall Properties	Construction Results*	Pavement Cores Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg
Specific Gravity	2.320	2.358	2.269	2.295	2.319	2.328	2.324	2.314
Theoretical Gravity	2.450	2.450	2.450	2.450	2.450	2.450	2.450	2.450
% Theoretical Gravity	94.7	96.2	92.6	93.7	94.7	95.0	94.9	94.5
% Voids	5.3	3.8	7.4	6.3	5.3	5.0	5.1	5.5
% V.F.A.	66.9	74.1	62.4	62.7	66.9	68.2	67.7	66.0
Stability @ 140F, lb	1168	2487	764	1895	1416	1692	1554	1751
Flow, 1/100 inch	14	18	10	14	12	12	12	13

Gradation of the Extracted Aggregate from Roadway Specimens

U. S. Sieve	Wearing Course Per Cent Passing (Construction)	Wearing Course Per Cent Passing (Cores)	Binder Course Per Cent Passing (Construction)	Binder Course Per Cent Passing (Cores)
1 Inch				100.0
3/4 Inch		100.0		96.1
1/2 Inch		95.1		84.7
3/8 Inch		85.4		75.1
No. 4		69.6		60.5
No. 10		59.1		50.5
No. 40		36.7		27.7
No. 80		18.8		14.5
No. 200		7.8		7.4
A. C. Per Cent	6.1	6.0	5.5	4.4

* Average of results from Daily Plant Reports

APPENDIX TABLE XIV TEST RESULTS OF WEARING & BINDER COURSE SPECIMENS PROJECT N (8 years)

Marshall Properties	Wearing Course								Binder Course							
	Construction Results*	Pavement Cores							Construction Results*	Pavement Cores						
		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg
Specific Gravity	2.320	2.369	2.299	2.338	2.351	2.345	2.348	2.345	2.340	2.400	2.330	2.350	2.370	2.380	2.375	2.360
Theoretical Gravity	2.420	2.420	2.420	2.420	2.420	2.420	2.420	2.420	2.440	2.440	2.440	2.440	2.440	2.440	2.440	2.440
% Theoretical Gravity	95.9	97.9	95.0	96.6	97.2	96.9	97.0	96.9	95.9	98.4	95.5	96.3	97.1	97.5	97.3	96.7
% Voids	4.1	2.1	5.0	3.4	2.8	3.1	3.0	3.1	4.1	1.6	4.5	3.7	2.9	2.5	2.7	3.3
% V.F.A.	75.1	85.8	71.0	78.6	81.8	80.2	80.7	80.2	73.7	88.0	71.7	75.7	80.0	82.4	81.1	77.8
Stability @ 140F, lb	1301	6509	1916	3086	2854	3733	3294	3224	1181	1693	1907	1488	1695	1577	1636	1587
Flow, 1/100 inch	11.7	16	9	12	13	13	13	12	14	10	12	11	9	11	10	11

Gradation of the Extracted Aggregate from Roadway Specimens

U. S. Sieve	Per Cent Passing		Per Cent Passing	
1 Inch				**
3/4 Inch		100.0		
1/2 Inch		97.3		
3/8 Inch		87.7		
No. 4		62.5		
No. 10		50.5		
No. 40		33.1		
No. 80		15.4		
No. 200		8.6		
A. C. Per Cent	5.3	5.9	5.0	

* Average of results from Daily Plant Reports
** Samples not available for gradation analysis

APPENDIX TABLE XV TEST RESULTS OF WEARING & BINDER COURSE SPECIMENS PROJECT O (8 years)

Marshall Properties	Wearing Course								Binder Course							
	Construction Results*	Pavement Cores							Construction Results*	Pavement Cores						
		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg
Specific Gravity	2.310	2.363	2.222	2.267	2.315	2.330	2.323	2.322	2.320	2.385	2.276	2.349	2.389	2.343	2.366	2.360
Theoretical Gravity	2.430	2.430	2.430	2.430	2.430	2.430	2.430	2.430	2.450	2.450	2.450	2.450	2.450	2.450	2.450	2.450
% Theoretical Gravity	95.1	97.2	91.4	93.3	95.3	95.9	95.6	95.6	94.7	96.2	92.9	95.9	97.5	95.6	96.6	96.3
% Voids	4.9	2.8	8.6	6.7	4.7	4.1	4.4	4.4	5.3	3.8	7.1	4.1	2.5	4.4	3.4	3.7
% V.F.A.	71.8	82.0	58.2	64.6	72.6	75.4	74.0	74.0	67.3	74.5	60.1	73.0	81.8	71.5	77.7	74.5
Stability @ 140F, lb	1251	4300	1783	2829	2910	3017	2963	2919	1113	2913	1018	1896	1571	1582	1577	1696
Flow, 1/100 inch	12	14	9	12	12	12	12	13	11	15	8	12	11	11	11	11

Gradation of the Extracted Aggregate from Roadway Specimens				
U. S. Sieve	Per Cent Passing		Per Cent Passing	
1 Inch				100.0
3/4 Inch		100.0		93.2
1/2 Inch		96.4		76.9
3/8 Inch		89.6		63.3
No. 4		71.6		42.4
No. 10		58.8		33.7
No. 40		40.9		24.3
No. 80		17.3		11.6
No. 200		10.5		5.5
A. C. Per Cent	5.5	6.0	5.1	4.8

* Average of results from Daily Plant Reports

APPENDIX TABLE XVI TEST RESULTS OF WEARING & BINDER COURSE SPECIMENS PROJECT P (8 years)

Marshall Properties	Wearing Course								Binder Course							
	Construction Results*	Pavement Cores							Construction Results*	Pavement Cores						
		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg
Specific Gravity	2.260	2.338	2.117	2.184	2.214	2.234	2.224	2.211	2.300	2.365	2.244	2.311	2.322	2.308	2.315	2.313
Theoretical Gravity	2.380	2.380	2.380	2.380	2.380	2.380	2.380	2.380	2.430	2.430	2.430	2.430	2.430	2.430	2.430	2.430
% Theoretical Gravity	95.0	98.2	88.9	91.8	93.0	93.9	93.5	92.9	94.7	97.3	92.3	95.1	95.6	95.0	95.3	95.2
% Voids	5.0	1.8	11.1	8.2	7.0	6.1	6.5	7.1	5.3	2.7	7.7	4.9	4.4	5.0	4.7	4.8
% V.F.A.	73.5	88.8	53.9	62.0	66.0	69.2	67.7	65.6	69.1	81.9	60.0	70.8	73.1	73.8	76.3	71.3
Stability @ 140F, lb	1215	3207	1195	2008	2034	1939	1987	2056	1179	2568	1158	1857	1646	2307	1977	1585
Flow, 1/100 inch	11	22	12	17	15	16	16	16	11	19	15	15	13	15	14	15

Gradation of the Extracted Aggregate from Roadway Specimens

U. S. Sieve	Per Cent Passing		Per Cent Passing	
1 Inch				99.3
3/4 Inch		100.0		90.3
1/2 Inch		92.3		69.5
3/8 Inch		81.0		56.5
No. 4		62.3		41.8
No. 10		55.8		37.2
No. 40		35.9		24.7
No. 80		16.1		10.7
No. 200		9.9		5.4
A. C. Per Cent	6.8	6.9	5.5	5.3

* Average of results from Daily Plant Reports

APPENDIX TABLE XVII TEST RESULTS OF WEARING & BINDER COURSE SPECIMENS PROJECT Q (8 years)

Marshall Properties	Wearing Course								Binder Course							
	Construction Results*	Pavement Cores							Construction Results*	Pavement Cores						
		Max	Min	C.L.	Tire Tracks 3'	9'	Avg	Proj Avg		Max	Min	C.L.	Tire Tracks 3'	9'	Avg	Proj Avg
Specific Gravity		2.395	2.312	2.356	2.377	2.372	2.375	2.368	2.360	2.412	2.353	2.376	2.391	2.397	2.394	2.387
Theoretical Gravity									2.460	2.460	2.460	2.460	2.460	2.460	2.460	2.460
% Theoretical Gravity									95.9	98.0	95.7	96.6	97.2	97.4	97.3	97.0
% Voids									4.1	2.0	4.3	3.4	2.8	2.6	2.7	3.0
% V.F.A.									71.8	84.2	70.7	75.5	79.0	80.3	79.6	77.8
Stability @ 140F, lb		3478	1255	2219	2351	2480	2416	2333	1113	2460	1210	1743	1869	2042	1956	1696
Flow, 1/100 inch		15	6	9	10	9	10	10	13	15	5	9	10	8	9	9

Gradation of the Extracted Aggregate from Roadway Specimens				
U. S. Sieve	Per Cent Passing		Per Cent Passing	
1 Inch				100.0
3/4 Inch		100.0		97.2
1/2 Inch		96.1		84.1
3/8 Inch		83.2		71.0
No. 4		61.1		54.0
No. 10		51.8		45.0
No. 40		33.4		27.9
No. 80		16.2		12.8
No. 200		7.1		7.2
A. C. Per Cent	5.9	5.7	4.6	4.9

* Average of results from Daily Plant Reports
(Results for wearing course mix not available)

APPENDIX TABLE XVIII TEST RESULTS OF WEARING & BINDER COURSE SPECIMENS PROJECT R (10 years

Marshall Properties	Wearing Course								Binder Course							
	Construction Results*	Pavement Cores							Construction Results*	Pavement Cores						
		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg
Specific Gravity	2.330	2.390	2.257	2.326	2.372	2.378	2.375	2.352	2.360	2.398	2.306	2.332	2.378	2.388	2.383	2.358
Theoretical Gravity	2.390	2.390	2.390	2.390	2.390	2.390	2.390	2.390	2.440	2.440	2.440	2.440	2.440	2.440	2.440	2.440
% Theoretical Gravity	97.5	100.0	94.4	97.3	99.2	99.5	99.4	98.4	96.7	98.3	94.5	95.6	97.5	97.9	97.7	96.6
% Voids	2.5	0.0	5.6	2.7	0.8	0.5	0.6	1.6	3.3	1.7	5.5	4.4	2.5	2.1	2.3	3.4
% V.F.A.	85.1	100.0	71.2	84.1	97.8	96.7	96.0	90.0	76.9	86.8	66.1	71.2	81.6	84.1	82.8	76.4
Stability @ 140F, lb	1526	4927	1771	3365	4080	2208	3144	3404	1228	2528	483	1793	1643	1634	1639	1727
Flow, 1/100 inch	14	13	7	10	10	8	9	10	14	18	5	9	7	8	8	8

Gradation of the Extracted Aggregate from Roadway Specimens				
U. S. Sieve	Per Cent Passing		Per Cent Passing	
1 Inch				100.0
3/4 Inch		100.0		94.1
1/2 Inch		95.4		79.4
3/8 Inch		85.5		67.6
No. 4		68.0		50.6
No. 10		55.9		41.5
No. 40		33.9		25.1
No. 80		18.5		11.4
No. 200		8.9		5.9
A. C. Per Cent	5.8	6.2	4.5	4.3

* Average of results from Daily Plant Reports

APPENDIX TABLE XIX TEST RESULTS OF WEARING & BINDER COURSE SPECIMENS PROJECT S (12 years)

Marshall Properties	Wearing Course								Binder Course							
	Construction Results*	Pavement Cores							Construction Results*	Pavement Cores						
		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg		Max	Min	C L	Tire Tracks 3'	Tire Tracks 9'	Tire Tracks Avg	Proj Avg
Specific Gravity	2.310	2.309	2.186	2.239	2.254	2.259	2.257	2.250	2.320	2.406	2.275	2.342	2.333	2.360	2.347	2.345
Theoretical Gravity	2.400	2.400	2.400	2.400	2.400	2.400	2.400	2.400	2.430	2.430	2.430	2.430	2.430	2.430	2.430	2.430
% Theoretical Gravity	96.3	96.2	91.1	93.3	93.9	94.1	94.0	93.8	95.5	99.0	93.6	96.4	96.0	97.1	96.6	96.5
% Voids	3.7	3.8	8.9	6.7	6.1	5.9	6.0	6.2	4.5	1.0	6.4	3.6	4.0	2.9	3.4	3.5
% V.F.A.	77.4	76.9	57.4	64.7	67.0	67.8	67.4	66.6	71.6	91.5	63.6	76.1	74.1	80.0	77.2	76.7
Stability @ 140F, lb	1199	4245	2452	3161	3424	3340	3382	3292	1034	3661	1459	2745	2387	2719	2553	2663
Flow, 1/100 inch	15	10	6	8	8	8	8	8	14	18	7	12	10	12	11	11

Gradation of the Extracted Aggregate from Roadway Specimens

U. S. Sieve	Per Cent Passing		Per Cent Passing	
1 Inch				100.0
3/4 Inch		100.0		96.4
1/2 Inch		94.3		80.4
3/8 Inch		86.9		68.3
No. 4		68.0		52.0
No. 10		53.7		42.6
No. 40		28.2		25.7
No. 80		6.3		9.1
No. 200		4.1		6.0
A. C. Per Cent	5.2	4.7	4.9	4.4

* Average of results from Daily Plant Reports