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COMPARISON OF LABORATORY AND FIELD DENSITY OF ASPHALT MIXTURES

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ABSTRACT

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The objective of this paper is to investigate the relationships between the measured density of the mixture obtained in the mix design, during quality control of the mixture (laboratory compaction of field produced mix), after initial compaction (cores obtained after construction and before traffic), the final or ultimate density obtained from pavement cores after densification by traffic and the density of recompacted samples. Primary concern is the relationship between density after traffic, mix design density and density of laboratory compacted samples during construction. Eighteen different pavements were sampled from six states. Thirteen of the pavements *were* experiencing premature rutting and five of the pavements were performing satisfactorily. Construction history including mix design data, quality control and/or quality assurance data, traffic data and laboratory data of the physical properties of the pavement cores were analyzed from each site. The results show that in-place air void contents below 3% greatly increase the probability of premature rutting and the in-place unit weights of the pavements after traffic usually exceed the *mix* design unit weight resulting in low air voids and hence premature rutting.

COMPARISON OF LABORATORY AND FIELD DENSITY OF ASPHALT MIXTURES

I. INTRODUCTION

Density or in-place unit weight is an important component of a properly designed and constructed asphalt pavement. Selection of the proper compaction level during the mix design phase is critical for proper pavement performance. The Asphalt Institute in MS-2 (1) recommends that the mix design density should closely approach the maximum density obtained in the pavement under traffic. The Marshall mix design method as originally developed by the US Army Corps of Engineers at the Waterways Experiment Station (2), in the late 1940's, was based on evaluation of samples compacted to a relative density that approximated that density developed by a number of repetitions of a selected aircraft. The original method called for compacting samples to 50 blows per side for tire pressures up to 100 psi and 75 blows per side for pressures over 100 psi. Over the years the Marshall method has been adapted to highway use with 50 blows per side being utilized for medium traffic and 75 blows per side being utilized for heavy traffic (l).

In recent years, studies have been made that show typical truck tire pressures are approaching 120 psi (3) and that higher truck tire pressures and increased truck traffic has led to an increase in premature rutting (4). The problem could very well be that the mix design density is being exceeded by the in-place density. This excess density in the field results in low in-place air voids. The relationship between low air voids and rutting is well established in the literature (5,6&7).

The objective of this paper is to investigate the relationships between the measured density of the mixture obtained in the *mix* design, during quality control of the mixture (laboratory compaction of field produced mix), after initial field compaction (cores obtained after construction and before traffic), the final or ultimate density obtained from pavement cores after densification by traffic and the density of recompacted samples. Primary concern is the relationship between density after traffic, mix design density and density of laboratory compacted samples during construction.

Eighteen pavements were selected for study out of the 30 pavements sampled as a part of NCAT's rutting study. The eighteen pavements were all of the pavements where traffic data, mix design data and quality control and/or quality assurance data were available. Thirteen of the eighteen pavements had experienced premature rutting. The ages of these rutted pavements ranged from 1 to 6 years at the time of sampling. Five of the eighteen pavements were identified by the various states as performing satisfactorily (Sites 4,8,10,18 and 24). These five pavements ranged in age from 5 to 16 years at the time of sampling.

II. TEST PLAN

The overall test plan for the rutting study is shown in Figure 1. A complete listing of the overall test plan can be found in the report by Brown and Cross (5). The field testing consisted of obtaining 4-inch and 6-inch diameter cores, rut depth measurements and, in a majority of the rutt ed pavements, viewing the pavement layers in a trench cut across the traffic lane. In general, eleven to twelve 4-inch and 6-inch diameter cores were obtained on 1 foot intervals across the traffic lane at each site. The 4-inch cores were saved for further testing while the 6-inch cores were tested and the relevant results reported herein.

Rut depth measurements were obtained using a 12 foot elevated straight edge to establish a horizontal reference line. The distance from the straight edge to the pavement surface was then recorded to the nearest 1/16 inch at l-foot intervals over the core locations. Rut depth measurements at each core location along with measurements of each core allowed the determination of the relative elevation of each pavement layer. The maximum rut depth at the surface was determined by measuring the vertical distance between a straight line connecting high points on opposite sides of the rut and the low point near the middle of the rut. Rut depths along with the traffic information are shown in Table 1.

Tests were conducted in the laboratory to characterize the material and mixture properties. The 6-inch diameter cores were first measured to determine the layer thickness of each core. Next, the cores were sawed into their respective pavement layers and the bulk specific gravity determined (ASTM D2726) for each layer. The bulk specific gravities were evaluated across the pavement lane for each layer to determine the average in-place unit weight and the standard deviation of the measured unit weights. This data was utilized to determine the 80th percentile in-place density. Two cores were then selected and the maximum theoretical specific gravity determined (ASTM D204 1). From the average maximum theoretical specific gravity, the average and 20th percentile in-place air void contents were determined. Previous research at NCAT (5) has shown the 20th and 80th percentiles to be reasonable to use to compare in-place air voids and density after traffic to air voids and density of recompacted samples. The two cores were then extracted to determine the asphalt content (ASTM D2172).

The remaining 6-inch diameter cores were reheated, broken-up and recompacted using two compactive efforts. The compactive efforts utilized in this study were 75 blows per side with the manual Marshall hammer (standard compactive effort) and 300 revolutions on the Gyratory Testing

Machine (GTM) set at 120 psi and 1 degree angle. The 75 blow Marshall and the GTM compaction process produce samples that have densities approximately equal to the mix after several years of heavy traffic. Hence recompacted densities are approximately equal to mix design densities if the materials are the same and the proper procedures are utilized. The recompacted samples were tested for unit weight, air void content, Marshall stability and flow. The average results of the tests performed on the 6-inch cores are shown in Table 2 and the average results of the recompaction analysis are shown in Table 3.

Construction history and mix design information for the pavements evaluated were provided by the various states. The data reported is all of the data available to NCAT at the time this report was prepared. A summary of the mix design information relevant to this study is shown in Table 4. The construction history data is shown in Table 5.

III. ANALYSIS OF TEST RESULTS

Design of asphalt mixtures by the Marshall method is based on the assumption that the laboratory compacted test samples will approximate the density of the mixture in service after several years of traffic. If the mix design density is too low, rutting could develop as a result of low air voids due to pavement densification under traffic. The purpose of this study was to evaluate the physical characteristics of asphalt pavements, mainly density and air voids, during the various stages of the pavement's life and relate these characteristics to rutting. The stages investigated were mix design, construction, after construction and before traffic, after traffic and recompacted in the laboratory. An attempt was made to relate the rut depth of the pavement to the density and void properties of the mixtures. However, there is some scatter in the data and this scatter is caused by several factors. Some of the major factors contributing to the scatter in the data include the varying amounts of traffic, the different aggregate properties of the mixtures and the temperature of the pavement surface when traffic was first applied. These factors were not addressed in this report. To help alleviate the problem of different traffic loadings on the various layers of pavements, the analysis was performed on mixtures of the same layer in the pavement structure. In addition, only data from original pavement layers or the latest overlays were utilized in the analysis. This was done to remove the effects of various surface preparation techniques such as milling prior to overlaying on the relationship between rut depth and mixture properties. Open graded friction courses were present on five (Sites 2,3,5,18&20) of the eighteen pavements selected for analysis. The friction courses were not evaluated due to their porous nature and their small effect on rutting.

AIR VOIDS AND RUTTING

Figure 2 shows the relationship between air voids recompacted to 75 blows per side with the manual Marshall hammer and the total rut depth at the surface expressed as rut depth per square root of million equivalent 18-kip single axle loads (ESAL's) for the mixtures in layer 1. An analysis of rutted pavements has shown that rut depth divided by the square root of million ESALs is a good way to quantify rate of rutting. A rate of rutting of less than 2 X 10^{-4} inches per square root of total ESALs has been shown as a good separation between good and poor performing pavements (8). There is enough scatter in the data to make the correlations poor (R-square = O. 12). However, the correlation does show a trend of lower recompacted air voids associated with higher rut depths and higher traffic. The same plot is shown in Figure 3 for the layer 1 mixtures recompacted on the GTM. The R-square value is nearly identical to the 75 blow samples and the same trend is evident. It can be seen that the rut depth generally increases with a decrease in recompacted air void content. The relationship between air voids and rutting is well documented in the literature (5,6&7).

Figures 2 and 3 do show an important relationship between recompacted air void content and the probability of rutting. For the layer 1 mixtures shown in Figure 2 the chance of having a rate of rutting greater than 0.20 inches per square root million ESAL's is 69% (9 of 13) if the 75 blow recompacted air voids are 3.0%. Only 1 of the 5 sites with air voids above 3.0% had a rate of rutting significantly above 0.2 and this site had a recompacted air void content only slightly greater than 3.0%. The layer 1 mixtures recompacted in the GTM show similar results with 67% (10 of 15) of the sites having rut depths greater than 0.20 inches per square root million ESAL's with less than 3.0% air voids and none of the sites with a rate of rutting significantly greater than 0.2 with recompacted air voids greater than 3.0%. From this data it can be seen that mixtures should be designed to have air voids above 3.0% and preferably around 4.0%.

PAVEMENT DENSIFICATION and TRAFFIC

Figures 4 and 5 show the relationship between traffic, expressed as total equivalent 18-kip single axle loads in millions, and pavement densification expressed as air voids. The air void content is the 20th percentile in-place air void content of the pavement at the time of sampling. The traffic is the total estimated equivalent 18-kip wheel loads applied to the original pavement or the last overlay for overlaid pavements. The figures show a trend for a reduction in air voids, or pavement densification, with an increase in traffic.

A straight line regression analysis was used to develop the correlations between densification and traffic. The relationship is poor with an R square of 0.08 for layer 1 and 0.11 for layer 2 (Figure 4 & 5). A good correlation however would mean that traffic alone and not mix properties controlled rutting.

A somewhat more useful methodology for investigating the relationship between traffic and pavement densification is to utilize both the in-place data and the recompaction data. By dividing the in-place unit weight by the recompacted unit weight an idea of the relative amount of densification obtained for a particular mixture can be established. By plotting this value against the traffic an estimate of the amount of traffic necessary to reach the recompacted density can be made. The pavement layers were recompacted using both the GTM and the manual Marshall hammer with 75 blows per side. The data shows that 75-blow compaction (for recompacted samples) produces a density equal to that expected after 5.4 million ESAL's for the top layer and equal to that expected after 6.3 million ESAL's for the second layer. The data also shows that the GTM compaction produces a density equal to that expected after 9.1 million ESAL's for the top layer and after 8.63 million ESAL's for the second layer. The data for both the GTM and 75-blow recompacted samples are shown in Table 3 and the results of the plots in Figures 6-9.

MIX DESIGN, IN-PLACE **and QC/QA MIX PROPERTIES**

Table 4 shows the relevant mix design information for the pavements evaluated in this study. Of the eighteen sites investigated in this study, sixteen were designed using a 50-blow Marshall mix design and two sites used a 75-blow Marshall mix design. Most of the pavements investigated were high volume roads. Mix designs for high volume roads should use a 75-blow Marshall mix design. The utilization of 50-blow mix designs on the majority of these pavements could be a major cause of the rutting that has been observed. The two sites that utilized the 75-blow mixes in this study rutted severely (approximately 1.5 inches). The poor performance of these 75-blow mixes could be related to the high GSI (greater than 1.3), low recompacted air voids (1.0 to 2.8%) and low mix design air void contents (3.0 to 3.8%). The mix design air void contents for the mixes in layer 1 ranged from a high of 7.3% to a low of 2.1 % (Table 4). Two of the layer 1 mixes were designed with an air void content of less than 3.0% with 50-blow compaction and two with 3.0 and 3.1 % with 75-blow compaction. The design air void contents for the layer 2 mixes ranged from a high of 7.4% to a low of 2.4910. Three of the layer 2 mixes were designed with air void contents of less than 3.0% again with 50-blow compaction.

The quality control data supplied by the various states is summarized in Table 5. Quality control data was available for fifteen of the sites. At the time of preparation of this report, the mix design information from sites 22-24 was available, however, the construction data was not available. The lab compacted data represents testing performed on samples of the mix obtained from either the plant or the roadway, returned to the lab, and compacted to duplicate the mix design.

One of the most important observations that can be made with regards to construction testing is the lack of data. Construction history data from asphalt cores was available from fourteen of fifteen sites, however this data is incomplete for many of the sites and pavement layers. The data from the asphalt cores represented extractions for asphalt content, gradation analysis, and unit weights to check initial compaction. Of the fourteen sites with in-place density data, six sites contained extraction and gradation analysis data only, six sites contained both extraction and gradation analysis data and unit weight and air void data, and two sites contained only unit weight and air void data. Only five of the fifteen sites utilized lab compacted samples as a part of QA/QC procedures and this represented only eight of thirty-two mixtures evaluated. This lack of information represents either information that was not obtained or information that was not available in the project files. Probably the most important test that can be conducted during QC/QA is to compact plant mixed material in the laboratory and determine and evaluate the air voids of the laboratory compacted mixture.

The results of the testing performed on the 6-inch diameter cores obtained from each project are summarized in Tables 2 and 3. Table 2 gives the results of the testing performed on the pavement cores after traffic loadings and are referred to as in-place data. Table 3 gives the results of the recompaction analysis performed on the cores from each site. The in-place cores (Table 2) show sixteen of the thirty-eight mixtures with in-place air voids below 3.0% with ten of the low air void contents occurring in layer 1. This indicates that the in-place density was higher than the mix design density or that something in the mix had changed. Thus the mix design compactive effort was likely too low, probably due to 50-blow compaction or other causes, or something in the mix, such as the amount of fines, had changed after design of the mix.

The recompaction data contains data from both the 75-blow Marshall hammer and the GTM. For the GTM thirty of thirty-eight mixtures and twenty-seven of thirty-eight mixtures for the Marshall hammer had air void contents below 3.0%. These low voids are typical for rutted pavements. The above data shows that mixtures are exceeding the mix design densities after traffic and that these high densities and low air voids are leading to premature rutting.

The differences between the in-place air void contents at the 20th percentile and the mix design air void content are shown in Figures 10 and 11 for layers 1 and 2 respectively. Fourteen of eighteen mixtures or 78% for layer 1 and eight of fifteen or 53 % for layer 2 of the mixtures showed the in-place air void content to be lower than the mix design air void content. The same was true for the unit weight at the 80th percentile (Figures 12 and 13), with 78% of the mixtures from layer 1 and 53% of the mixtures from layer 2 exceeding the mix design unit weight. This indicates that the mix design compactive effort, especially for the near surface mixtures, is too low for the current level of traffic. In many cases the in-place air voids are 1 to 3 percent lower than the mix design air voids. Since mixes are typically designed to have 4% air voids and rutting is expected to be a problem at 3% air voids these lower in-place air voids are a major problem.

The above data shows that the in-place unit weight exceeds the mix design unit weight and that the in-place void content is below the mix design air void content. To try and verify that the mix design compactive effort is indeed low and that the voids are not being overfiied by adding asphalt cement to facilitate compaction an analysis of variance (ANOVA) was performed on the asphalt contents reported in the mix design, in the QC data and from extractions performed on the 6-inch diameter cores (in-place) obtained from each site. The results of the ANOVA are shown in Table 6. The analysis showed no significant difference between the means of the asphalt contents of the mix design, QC and in-place values with a confidence interval of 75%.

To statistically show that the mix design density is being exceeded by the in-place density an ANOVA was performed on the unit weights obtained from the mix design, the in-place data and the recompaction (GTM and 75 Blow) data. The results are shown in Table 7. The analysis of variance showed a significant difference at the 95% confidence level in the means of the unit weights from the above data sets. Duncan's multiple range test was performed with alpha = 0.05 to determine the rank and significant differences between the means. Duncan's test ranked the means from highest to lowest as GTM, 75 Blow, in-place after traffic, and mix design with a significant difference between each group of means except GTM and 75 Blow recompacted.

The difference between the initial in-place air void content and the mix design air void contents for layers 1 and 2 are shown in Figures 14 and 15. All of the initial in-place air void contents were above the mix design void content as they should be. However, site 20 indicates the initial in-place density to be very close to the mix design density which results in low in-place air voids after traffic. Figure 10 shows that for site 20 the in-place air voids after traffic is indeed approximately 2% lower than the mix design value. The rut depth at site 20 was only 5/ 16 inch and this low rut depth is due in part to the low level of traffic (0.38 million ESAL's). Figure 16 shows the results of the limited data available on the QC lab compacted samples. Five of the nine mixtures had air void contents significantly below the mix design value and four of the mixtures were within 0.5% of the mix design air void content. With this information it can be seen that five of the mixtures should have been modified to raise the air void content to minimize rutting.

IV. CONCLUSIONS

Based on the data obtained in this study the following conclusions are warranted.

1. In-place air void contents above 3.0% are needed to decrease the probability of premature rutting throughout the life of the pavement. The voids in laboratory compacted samples are used to estimate the ultimate void content of the mixture.
2. In-place air void content below 3.0% greatly increases the probability of premature rutting.
3. Compaction utilizing the GTM set at 120 psi, 1 degree angle and 300 revoultions gives sufficient design density and void content for up to 9 million ESAL's.
4. Compaction utilizing 75 blows per side with the manual Marshall hammer gives sufficient design density and void content for up to 6 million ESAL's.
5. Construction quality control documentation is not adequate on many paving projects. Samples of asphalt mixtures from the mixing plant should be compacted in the laboratory during construction to verify that the air voids are within an acceptable

range. If the air voids are not within an acceptable range adjustments to the mix should be made.

6. Most of the pavements evaluated in this study utilized a 50-blow Marshall mix design. Mixtures to be exposed to high traffic volumes should utilize a 75-blow Marshall mix design to insure adequate voids throughout the life of the pavement.
7. The in-place unit weight of the pavement after traffic usually exceeded the mix design unit weight resulting in low air voids and hence premature rutting.

V. RECOMMENDATIONS

Based on the data obtained from this study the following recommendations are made.

1. Samples of the field produced mixture should be compacted using the specified mix design compactive effort to ensure that the mix being produced has acceptable air voids and other properties. If there is a significant difference between the field produced samples and the mix design modifications to the field produced mix must be made.
2. Efforts must be made to ensure the mix design produces a density approximately equal to the in-place density after several years of traffic. The results of this study show that this is not the case. For heavy duty pavements with significant truck traffic such as most Interstate highways it is recommended that either a 75-blow Marshall mix design or the GTM be utilized. For the Marshall mix design compaction should be performed with either the manual Marshall hammer or another hammer calibrated to give the same density as the manual hammer.

3. Pavements should be designed to ensure 4.0% air voids in-place after several years of traffic to help prevent premature rutting. Mixes with design air voids much less than 4.0% are likely to rut.

VI. REFERENCES

1. Mix Design Methods for Asphalt Concrete, Manual Series No. 2, printed March 1974.
2. McFadden, Gayle and W. C. Ricketts, "Design and Control of Asphalt Paving Mixtures for Military Installations," Proceedings, The Association of Asphalt Paving Technologists, Volume 17, 1948, pp. 93-113.
3, Hudson, Stewart W. and Stephen B. Seeds, "Evaluation of Increased Pavement Loading and Tire Pressure," Paper presented at 67th Annual Transportation Research Board Meeting, January 1988.
4. Federal Highway Administration, "Proceedings of a Symposium/Workshop on High Pressure Truck Tires," Austin, Texas, 1987.
5. Brown, E.R. and Stephen A. Cross, "A Study of In-Place Rutting of Asphalt Pavements,"Proceedings, The Association of Asphalt Paving Technologists, Volume 58,1988.
6. Huber, G.A. and G.H. Heiman, "Effect of Asphalt Concrete Parameter on Rutting Performance: A Field Investigation," Proceedings, The Association of Asphalt Paving Technologists, Volume 56, 1987, pp. 33-61.
7. Ford, Miller C. "Pavement Densification Related to Asphalt Mix Characteristics," Paper presented at 67th Annual Transportation Research Board Meeting, January 1988.
8. Parker, Frazier, Jr. and E. R. Brown, "Effects of Aggregate Properties on Flexible Pavement Rutting in Alabama," Paper prepared for presentation at 70th Annual Transportation Research Board Meeting, January 1991.

Table 1. Summary of Rut Depth Calculations and Traffic

SITE	LAYER	MIX TYPE	AVERAGE LAYER THICKNESS (in)	MAXIMUM SURFACE RUT DEPTH (in)	MAXIMUM RUT IN EACH LAYER (in)	TOTAL 18-kip ESAL'S (millions)	TRUCK TRAFFIC (%)
1	1	SURFACE	2.4318	1.5000	1.0000	11.80	50
1	2	BINDER	2.0682	1.5000	0.0000	11.80	50
1	3	SAND	7.9659	1.5000	0.5000	11.80	50
2	N/T	OGFC	0.8000	0.8958	0.1667	2.05	20
2	1	SURFACE	1.2750	0.8958	0.4583	2.05	20
2	N/T	OLD PVM'T	14.2750	0.8958	0.2708	2.05	20
3	N/T	OGFC	0.6932	0.3750	0.1250	3.12	22
3	1	SURFACE	1.5682	0.3750	0.2500	3.12	22
3	2	BINDER	2.4306	0.3750	0.0000	3.12	22
4	1	SURFACE	1.1818	0.2500	0.0000	2.74	12
4	2	BINDER	2.2045	0.2500	0.1000	2.74	12
4	3	BINDER	2.5000	0.2500	0.0000	2.74	12
4	4	BASE	2.2614	0.2500	0.0250	2.74	12
4	5	BASE	4.8068	0.2500	0.1250	2.74	12
5	N/T	OGFC	0.7676	0.6250	0.1250	5.25	41
5	1	SURFACE	1.2045	0.6250	0.3125	5.25	41
5	2	BINDER	1.5511	0.6250	0.1250	5.25	41
5	N/T	OLD PVM'T	9.0057	0.6250	0.0000	5.25	41
6	1	SURFACE	1.4271	0.5750	0.2000	2.00	23
6	2	BINDER	1.9115	0.5750	0.3750	2.00	23
7	1	SURFACE	1.5710	0.3439	0.1563	4.81	34
7	2	BINDER	1.6080	0.3439	0.1563	4.81	34
7	3	LEVEL	1.1534	0.3439	0.0313	4.81	34
8	1	SURFACE	1.2500	0.4000	0.2000	13.34	34
8	2	BINDER	1.8177	0.4000	0.2000	13.34	34
10	1	SURFACE	0.7955	0.1250	0.0125	2.72	21
10	2	BINDER	1.7216	0.1250	0.0000	2.72	21
10	3	BASE	2.4773	0.1250	0.0000	2.72	21
10	4	BASE	1.2102	0.1250	0.1125	2.72	21

N/T = Not Tested

Table 1. (Con't.) Summary of Rut Depth Calculations and Traffic

SITE	LAYER	MIX TYPE	AVERAGE LAYER THICKNESS (in)	MAXIMUM SURFACE RUT DEPTH (in)	MAXIMUM RUT IN EACH LAYER (in)	TOTAL 18-kip ESAL'S (millions)	TRUCK TRAFFIC (%)
11	1	SURFACE	1.0966	0.5500	0.2500	0.68	16
11	2	BINDER	1.3523	0.5500	0.1250	0.68	16
11	3	BINDER	2.5739	0.5500	0.1125	0.68	16
11	4	BASE	3.3693	0.5500	0.0250	0.68	16
11	5	BASE	3.2443	0.5500	0.0375	0.68	16
12	1	SURFACE	1.7212	1.4500	0.5000	0.31	5
12	2	BINDER	3.0192	1.4500	0.9500	0.31	5
12	3	LEVEL	1.0139	1.4500	0.0000	0.31	5
13	1	SURFACE	1.5962	1.6563	0.8125	0.30	12
13	2	BINDER	2.4896	1.6563	0.8438	0.30	12
18	N/T	OGFC	0.8580	0.2000	0.0000	1.55	21
18	1	SURFACE	1.7898	0.2000	0.1500	1.55	21
18	2	SURFACE	2.1136	0.2000	0.0500	1.55	21
18	N/T	OLD SUR	1.8281	0.2000	0.0000	1.55	21
19	1	SURFACE	1.5280	0.3900	0.2250	0.26	3
19	2	SURFACE	1.7216	0.3900	0.0125	0.26	3
19	3	BINDER	2.7500	0.3900	0.1525	0.26	3
20	N/T	OGFC	0.8409	0.3167	0.0417	0.38	19
20	1	SURFACE	1.4091	0.3167	0.0000	0.38	19
20	2	SURFACE	2.1932	0.3167	0.2750	0.38	19
20	N/T	OLD SUR	5.7273	0.3167	0.0000	0.38	19
22	1	SURFACE	2.0375	0.5000	0.3250	4.40	50
22	2	BINDER	2.7938	0.5000	0.1750	4.40	50
23	1	SURFACE	1.4205	0.5858	0.3024	3.30	40
23	2	BINDER	1.4432	0.5858	0.1667	3.30	40
23	N/T	OLD SUR	2.0208	0.5858	0.1167	3.30	40
24	1	SURFACE	1.2750	0.3150	0.0712	5.30	9
24	2	BINDER	2.6438	0.3150	0.2437	5.30	9

N/T = Not Tested

Table 2. In-Place Data (NCAT Cores)

SITE	LAYER	ASPHALT CONTENT (%)	VTM AVG (%)	VTM 20th PCT'L (%)	UNIT WEIGHT AVG (pcf)	UNIT WEIGHT 80th PCT'L (%)
1	1	7.8	1.5	0.7	150.1	151.2
1	2	4.0	2.3	0.9	151.1	153.2
2	1	6.0	4.0	3.6	144.9	145.6
3	1	5.2	6.3	5.7	142.9	143.9
3	2	4.8	3.9	3.3	147.0	148.0
4	1	5.6	4.3	3.1	145.3	147.1
4	2	4.3	3.6	3.2	148.1	148.8
5	1	6.8	3.8	3.1	146.6	147.7
5	2	6.5	3.6	2.8	147.6	148.8
6	1	4.8	5.4	4.6	144.7	146.0
6	2	5.4	4.0	3.4	146.4	147.3
7	1	5,3	3.2	2.2	147.3	148.9
7	2	4.7	3.8	3.1	148.1	149.1
8	1	4.5	3.2	2.1	149.7	151.4
8	2	4.2	4.0	3.0	151.4	153.1
10	1	6.8	6.1	5.1	139.5	141.0
10	2	4.3	11.6	10.9	137.2	138.2
10	3	4.5	13.0	12.5	134.7	135.5

Table 2. (Con't.) In-Place Data (NCAT Cores)

SITE	LAYER	ASPHALT CONTENT (%)	VTM AVG (%)	VTM 20th PCT'L (%)	UNIT WEIGHT AVG (pcf)	UNIT WEIGHT 80th PCT'L (%)
11	1	6.3	4.1	2.7	145.6	147.7
11	2	5.2	4.1	2.4	147.0	149.6
11	3	4.4	10.0	8.5	139.2	141.4
12	1	6.5	1.9	1.3	145.3	146.2
12	2	5.0	4.7	3.6	147.4	149.0
13	1	6.2	4.9	3.5	146.6	148.7
13	2	4.1	8.3	6.4	148.7	151.9
18	1	4,3	6.9	5.2	142.8	145.5
18	2	4.7	5.2	4.0	144.2	146.0
19	1	5.7	1.4	0.9	151.1	151.9
19	2	5.3	3.7	4.2	146.8	147.6
19	3	5.1	6.0	6.9	142.7	144.0
20	1	5.6	2.1	1.8	149.3	149.7
20	2	5.2	3.6	2.5	148.1	149.7
22	1	5.2	2.0	1.5	155.4	156.2
22	2	5.9	2.2	1.9	151.8	152.3
23	1	5.0	2.7	1.8	151.6	153.0
23	2	5.0	4.3	3.7	149.5	150.4
24	1	6.3	2.8	1.4	158.8	161.1
24	2	4.5	2.0	1.5	156.7	157.5

Table 3. Recompaction Data

SITE	LAYER	GTM 300 VTM (%)	GTM 300 UNIT WEIGHT (pcf)	GSI	75 BLOWS VTM (%)	75 BLOWS UNIT WEIGHT (pcf)
1	1	0.6	151.1	1.37	1.8	149.3
1	2	3.2	149.7	1.01	5.6	146.0
2	1	2.4	147.4	1.29	3.1	146.3
3	1	6.1	143.3	1.00	6.1	143.2
3	2	2.1	149.5	1.07	3.1	148.0
4	1	2.9	147.3	1.04	3.7	146.1
4	2	2.2	150.3	1.13	2.8	149.3
5	1	2.3	148.9	1.27	1.7	149.8
5	2	1.1	151.4	1.37	1.2	151.3
6	1	2.9	148.4	1.08	2.8	148.7
6	2	1.8	149.8	1.43	1.6	150.0
7	1	2.1	149.0	1.04	2.2	148.9
7	2	1.3	151.9	1.39	1.8	151.1
8	1	2.3	151.1	1.07	2.7	150.5
8	2	3.2	152.7	1.12	3.7	152.0
10	1	5.7	140.1	1.00	6.0	139.7
10	2	8.9	141.3	1.00	9.1	141,0
10	3	9.3	140.5	1.00	9,6	140.1

Table 3. (Con't.) Recompaction Data

SITE	LAYER	GTM 300 VTM (%)	GTM 300 UNIT WEIGHT (pcf)	GSI	75 BLOWS VTM (%)	75 BLOWS UNIT WEIGHT (pcf)
11	1	2.4	148.1	1.37	2.6	147.9
11	2	2.2	149.9	1.28	1.9	150.4
11	3	4.1	148.3	1.03	3.6	149.1
12	1	1.0	146.7	1.63	1.1	146.5
12	2	1.6	152.1	1.53	2.2	151.2
13	1	1.9	151.2	1.43	1.8	151.2
13	2	2.8	157.6	1.33	2.8	157.6
18	1	4.3	146.7	1.02	4.1	147.1
18	2	1.7	149.7	1.50	1.6	149.7
19	1	1.2	151.5	1.36	0.7	152.3
19	2	2.5	149.5	1.50	2.4	149.6
19	3	2.8	149.0	1.25	2.5	149.4
20	1	0.8	151.4	1.53	1.5	150.3
20	2	1.4	151.4	1.44	1.9	150.6
22	1	1.3	157.2	1.47	1.3	156.6
22	2	0.8	153.9	1.72	0.6	154.3
23	1	1.7	153.3	1.41	1.8	153.0
23	2	2.4	152.5	1.32	2.5	152.4
24	1	1.8	160.4	1.53	1.3	161.2
24	2	1.2	157.9	1.67	0.8	158.6

Table 4. Mix Design Data

SITE	LAYER	ASPHALT CONTENT (%)	VTM (%)	UNIT WEIGHT (pcf)	BLOWS PER SIDE	3/4	1/2	3/8	#4	#8	#16	#30	#50	#100	#200
						SIEVE SIZE (Percent Passing)									
1	1	6.3	6.0	141.1	50	100	97	90	67	56	--	35	--	14	6.0
2	1	5.8	5.4	143.7	50	100	98	93	68	57	--	34	--	10	5.0
3	1	5.4	3.9	145.5	50	100	98	93	70	52	--	35	--	7	4.0
3	2	4.2	--	--	50	96	78	--	41	32	--	--	--	--	--
4	1	6.0	5.4	144.4	50	100	98	90	68	56	--	29	--	11	6.0
4	2	4.8	3.2	150.5	50	85	68	--	43	35	--	--	--	--	--
5	1	6.2	3.8	145.8	50	100	98	94	68	54	--	33	--	13	6.0
5	2	5.2	3.6	149.8	50	95	70	--	40	32	--	--	--	--	--
6	1	4.8	4.2	146.3	50	100	99	90	60	44	34	25	10	7	5.6
6	2	5.3	3.2	147.3	50	100	99	84	57	41	32	24	9	6	5.0
7	1	5.0	4.1	147.2	50	100	99	89	70	58	48	36	18	8	6.0
7	2	4.8	3.5	148.1	50	100	95	90	67	49	37	28	13	6	4.7
8	1	4.8	5.4	147.4	50	100	99	88	60	45	36	23	13	8	5.8
8	2	4.3	6.8	148.3	50	100	98	90	78	61	51	40	26	14	8.6
10	1	7.0	7.3	135.4	50	100	100	99	73	63	49	33	19	10	2.0
10	2	6.5	5.9	139.9	50	100	90	84	69	52	33	17	8	5	3.0

"--" = Data Not Available

Table 4. (Con't.) Mix Design Data

SITE	LAYER	ASPHALT CONTENT (%)	VTM (%)	UNIT WEIGHT (pcf)	BLOWS PER SIDE	SIEVE SIZE (Percent Passing) 3/4	1/2	3/8	#4	#8	#16	#30	#50	#100	#200
11	1	6.5	4.1	142.7	50	100	100	96	71	53	40	24	16	11	8.0
11	2	4.4	7.4	142.9	50	100	96	87	67	52	34	24	16	10	6.0
11	3	3.5	5.1	142.9	50	98	90	84	71	58	41	27	18	12	8.0
12	1	6.5	3.0	144.3	75	100	100	92	62	42	31	25	17	9	5.0
12	2	4.8	3.2	150.4	75	77	64	53	37	25	20	18	12	6	4.0
13	1	6.4	3.1	148.9	75	100	100	92	65	45	26	16	10	9	5.0
13	2	4.3	3.8	153.2	75	73	63	54	44	30	17	10	7	5	4.0
18	1	5.8	3.5	147.7	50	100	93	79	53	39	28	22	14	9	6.1
18	2	5.8	3.5	147.7	50	100	93	79	53	39	28	22	14	9	6.1
19	1	6.4	3.5	146.3	50	100	88	78	55	38	27	21	14	10	6.2
19	2	6.0	4.8	145.0	50	100	84	72	54	44	35	28	18	10	5.2
20	1	5.8	3.6	146.4	50	100	89	75	53	38	28	21	14	10	5.9
20	2	5.8	3.6	146.4	50	100	89	75	53	38	28	21	14	10	5.9
22	1	5.8	2.6	152.6	50	100	97	84	55	42	--	--	19	--	7.6
22	2	6.7	2.7	151.1	50	100	98	88	61	46	--	--	15	--	6.9
23	1	5.3	3.5	150.8	50	100	97	81	51	37	--	--	18	--	7.9
23	2	6.0	2.6	150.7	50	99	--	68	--	47	--	--	16	--	6.9
24	1	6.7	2.1	159.9	50	100	100	100	99	80	54	36	26	20	15.2
24	2	4.5	2.4	156.4	50	--	84	--	53	40	--	--	16	--	9.8

"--" = Data Not Available

Table 5. Quality Control Data

SITE	LAYER	ASPHALT CONTENT AVG (%)	INITIAL IN-PLACE VTM AVG (%)	INITIAL IN-PLACE AVG UNIT WEIGHT (pcf)	LAB COMPACTED VTM AVG (%)	LAB COMPACTED AVG UNIT WEIGHT (pcf)
1	1	6.1	---	---	---	-A-
1	2	---	---	---	---	---
2	1	5.8	---	---	3.6	---
3	1	5.4	---	---	4.5	144.9
3	2	---	---	---	---	---
4	1	6.0	---	---	---	---
4	2	4.8	---	---	---	---
5	1	6.2	---	---	3.8	145.1
5	2	5.2	---	---	---	---
6	1	5.2	8.0	141.6	---	---
6	2	5.3	5.8	144.1	---	---
7	1	5.2	6.9	142.2	---	---
7	2	4.7	6.4	142.7	---	---
8	1	4.8	---	---	---	---
8	2	---	---	---	---	---
10	1	---	---	---	---	---
10	2	---	---	---	---	---
10	3	---	---	---	---	---

"---" = Data not Available

Table 5. (Con' t.) Quality Control Data

SITE	LAYER	ASPHALT CONTENT AVG (%)	INITIAL IN-PLACE VTM AVG (%)	INITIAL IN-PLACE AVG UNIT WEIGHT (pcf)	LAB COMPACTED VTM AVG (%)	LAB COMPACTED AVG UNIT WEIGHT (pcf)
11	1	5.5	---	---	1.3	149.1
11	2	5.5	---	---	3.6	147.7
11	3	---	---	---	---	---
12	1	6.4	4.7	141.4	---	---
12	2	4.7	4.7	149.0	---	---
13	1	6.1	6.1	143.8	---	---
13	2	4.3	4.5	152.1	---	---
18	1	5.8	5.6	144.3	3.53	147.7
18	2	6.1	5.6	144.3	3.48	147.70
19	1	---	6.7	143.0	---	---
19	2	---	7.4	142.3	---	---
19	3	---	7.4	142.3	---	---
20	1	5.7	3.7	146.7	2.56	148.88
20	2	5.8	3.7	146.7	2.48	148.69
22	1	---	---	---	---	---
22	2	---	---	---	---	---
23	1	---	---	---	---	---
23	2	---	---	---	---	---
24	1	---	---	---	---	---
24	2	---	---	---	---	---

"---" = Data not Available

Table 6. Results of l-Way ANOVA on Asphalt Content

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F-VALUE
Total	93	13.0462		
Mode 1	2	0.5790	0.2895	2.11
Error	91	12.4672	0.1370	

Table 7. Results of l-Way ANOVA on Unit Weight

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	F-VALUE
Total	145	476.9889		
Mode 1	3	213.3884	71.1295	38.32
Error	142	263.6005	1.8563	

Duncan's Multiple Range Test

Model	Duncan's* Grouping	Mean	Number Observations
GTM	A	1.186	37
	A		
75 Blow	A	0.881	37
In-Place	B	-0.241	37
Mix Design	c	-1.931	35

* Means with the same letter are not significantly different.

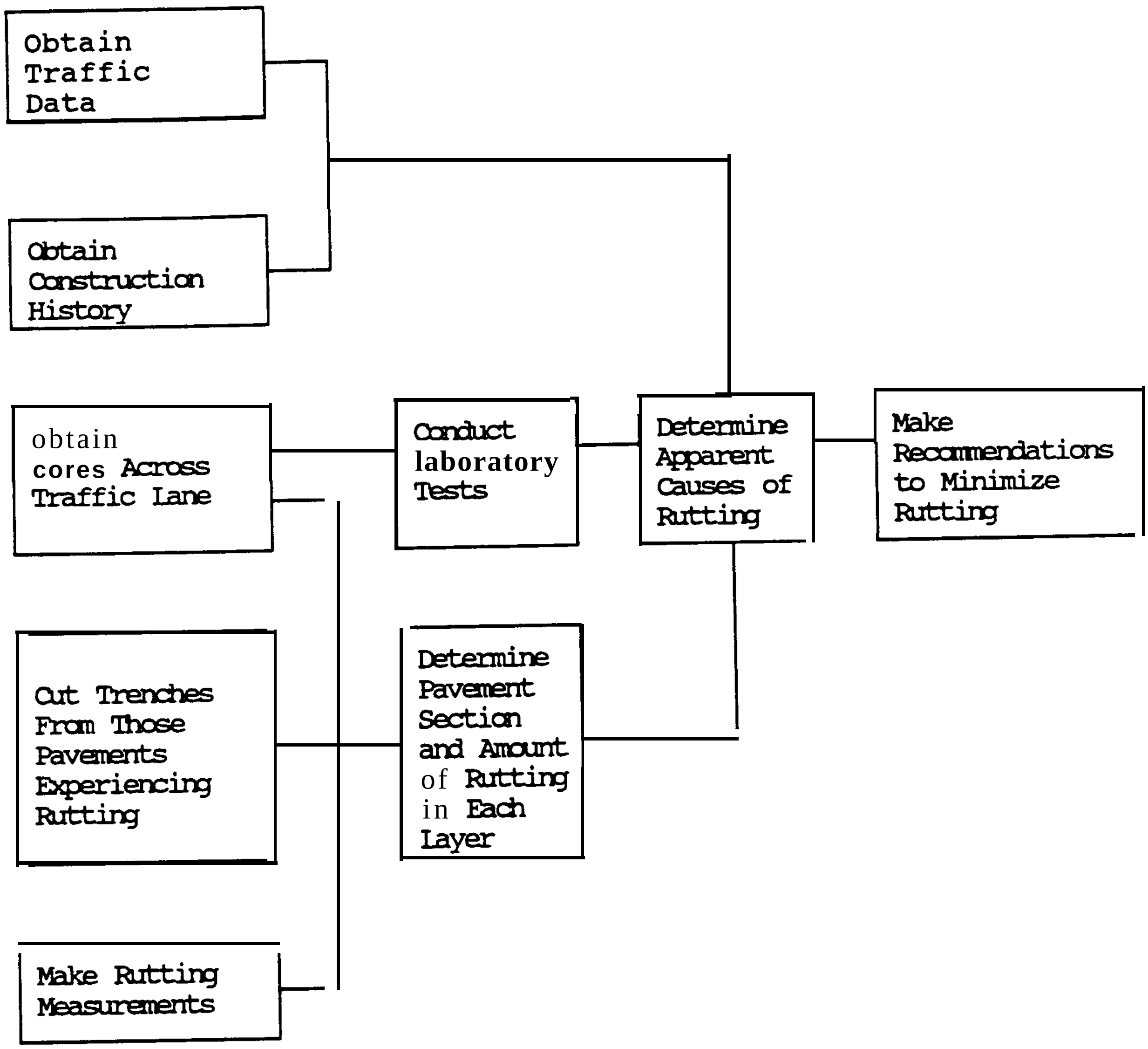

Figure 1. Overall Test Plan

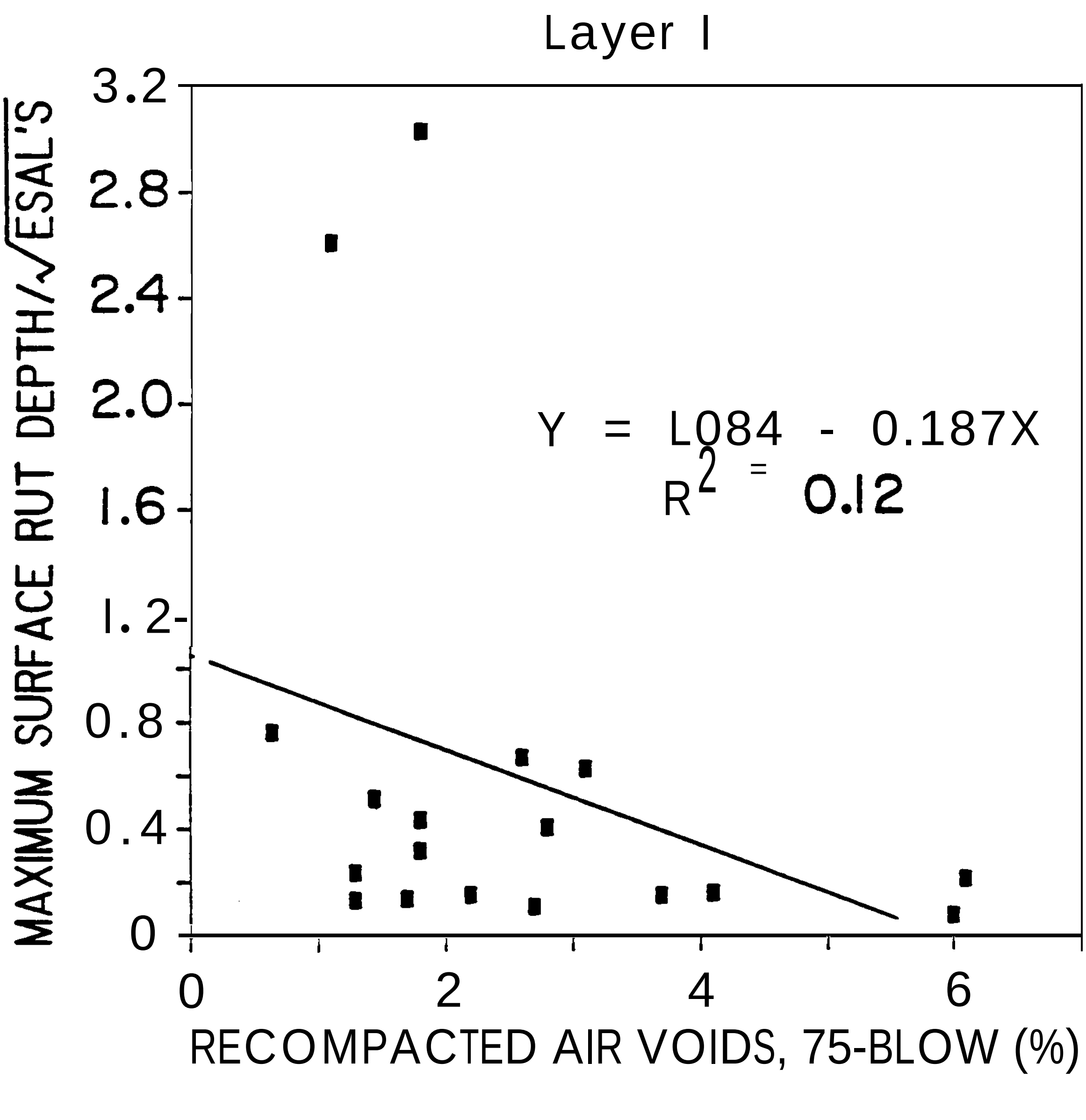

Figure 2. 75-Blow Recompacted Air Void Content vs Maximum Surface Rut Depth ÷ Square Root of Traffic in Million ESAL's

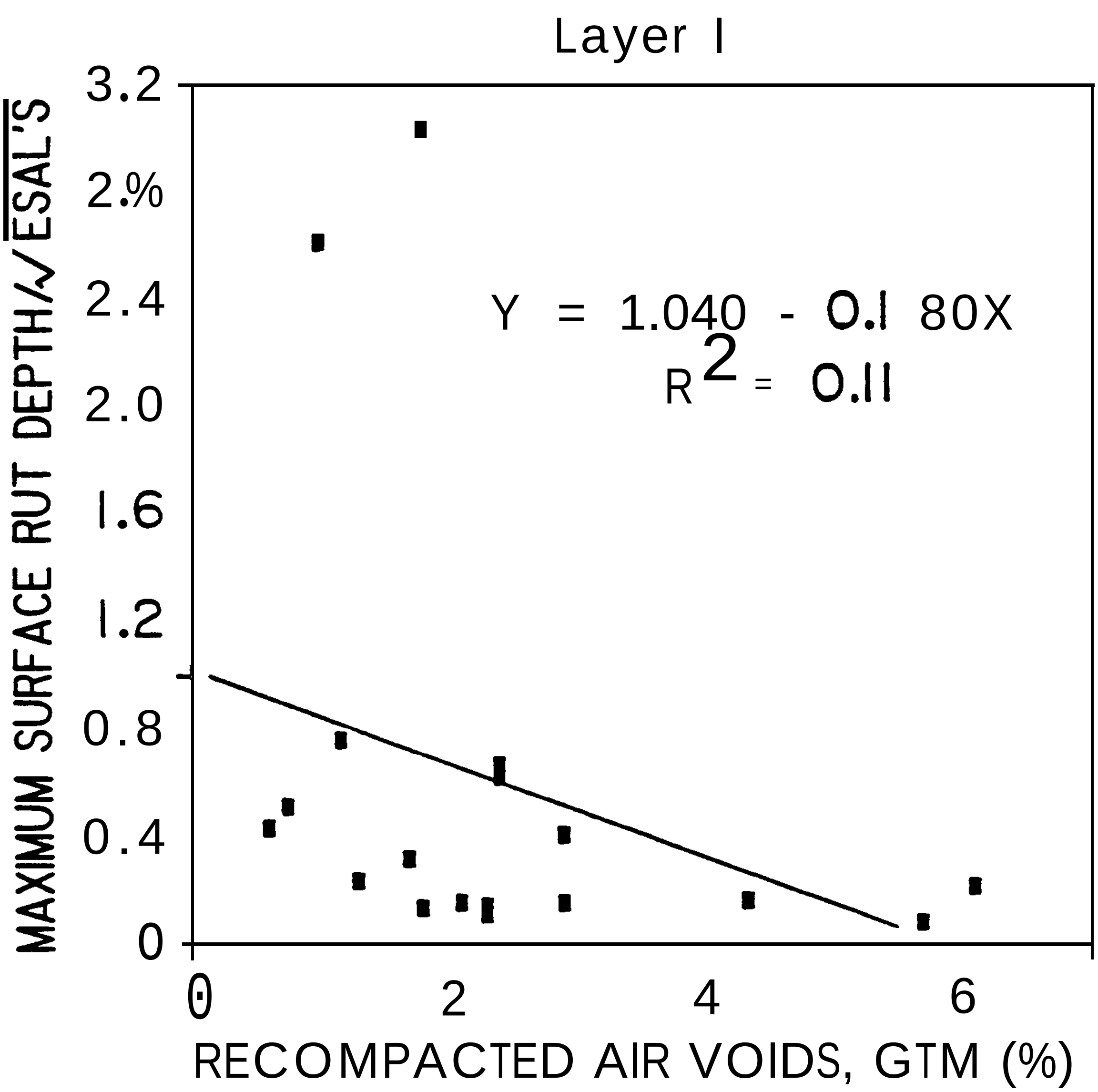

Figure 3. GTM Recompacted Air Void Content vs Maximum Surface Rut Depth ÷ Square Root of **Traffic in Million ESAL's**

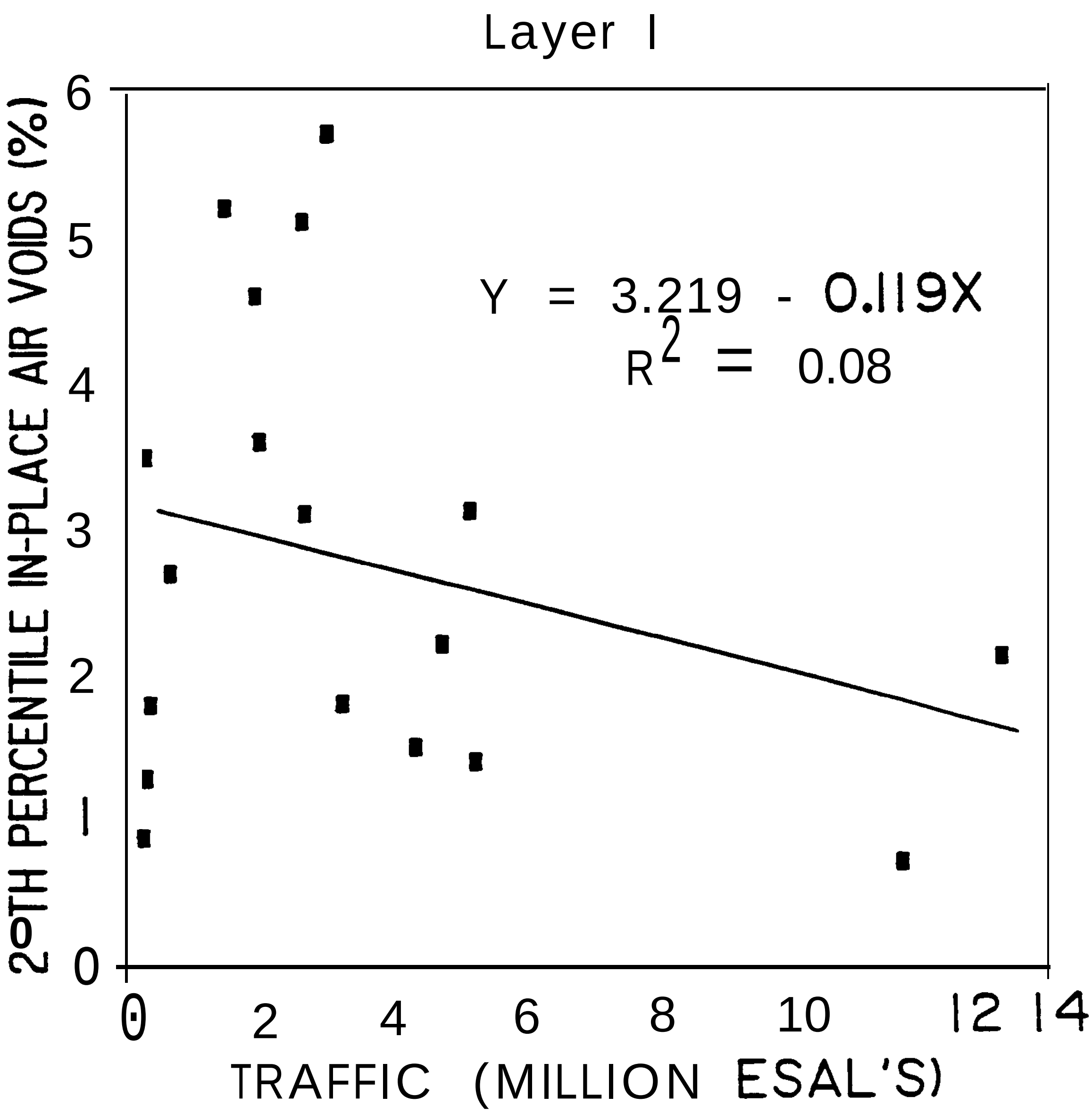

Figure 4. Traffic vs. 20th Percentile In-Place Air Void Content for Layer 1 Mixtures

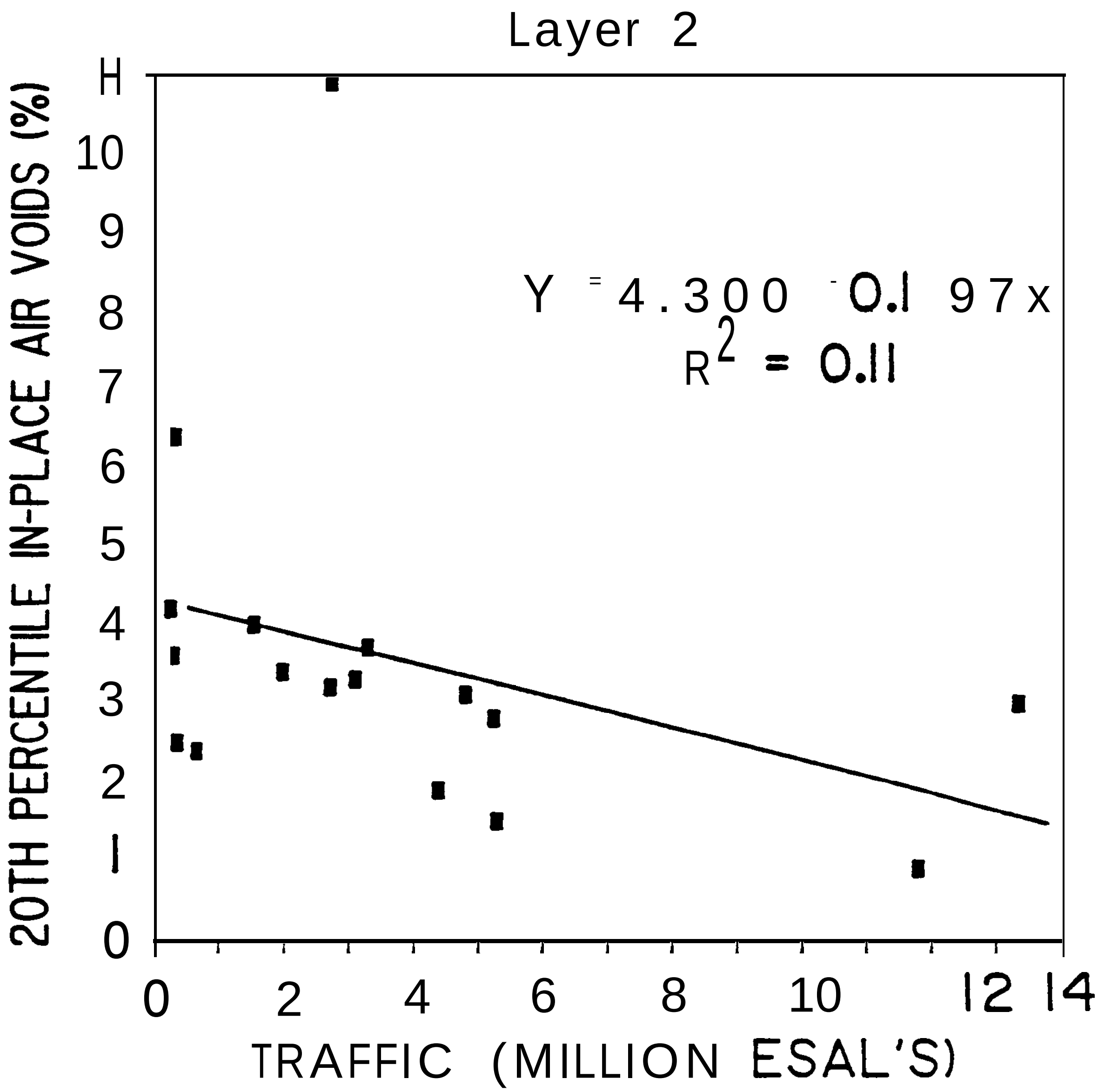

Figure 5. Traffic vs. 20th Percentile In-Place Air Void Content for Layer 2 Mixtures

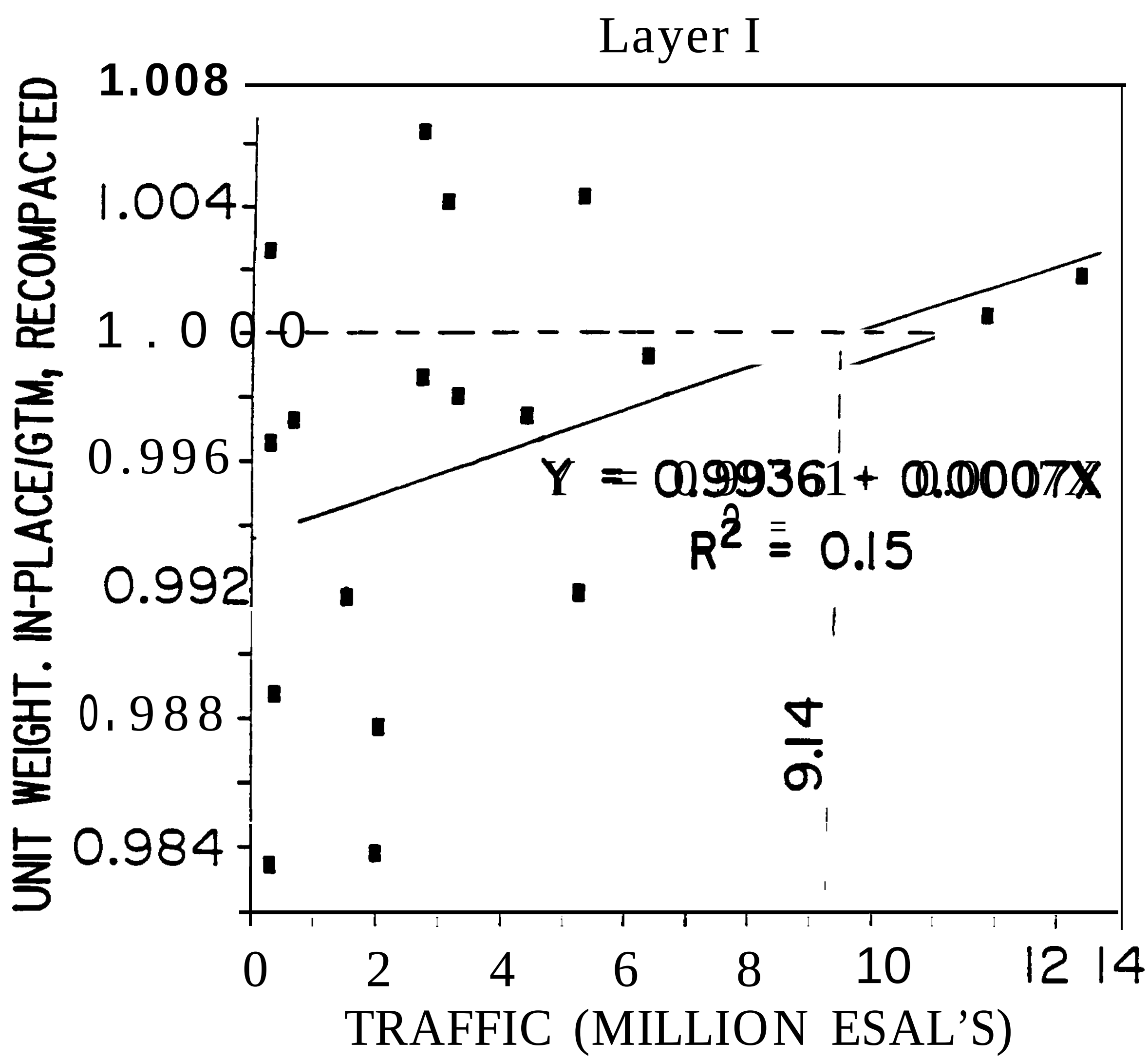

Figure 6. Traffic vs. Ratio of In-Place to GTM Recompacted Unit Weight for Layer 1 Mixtures

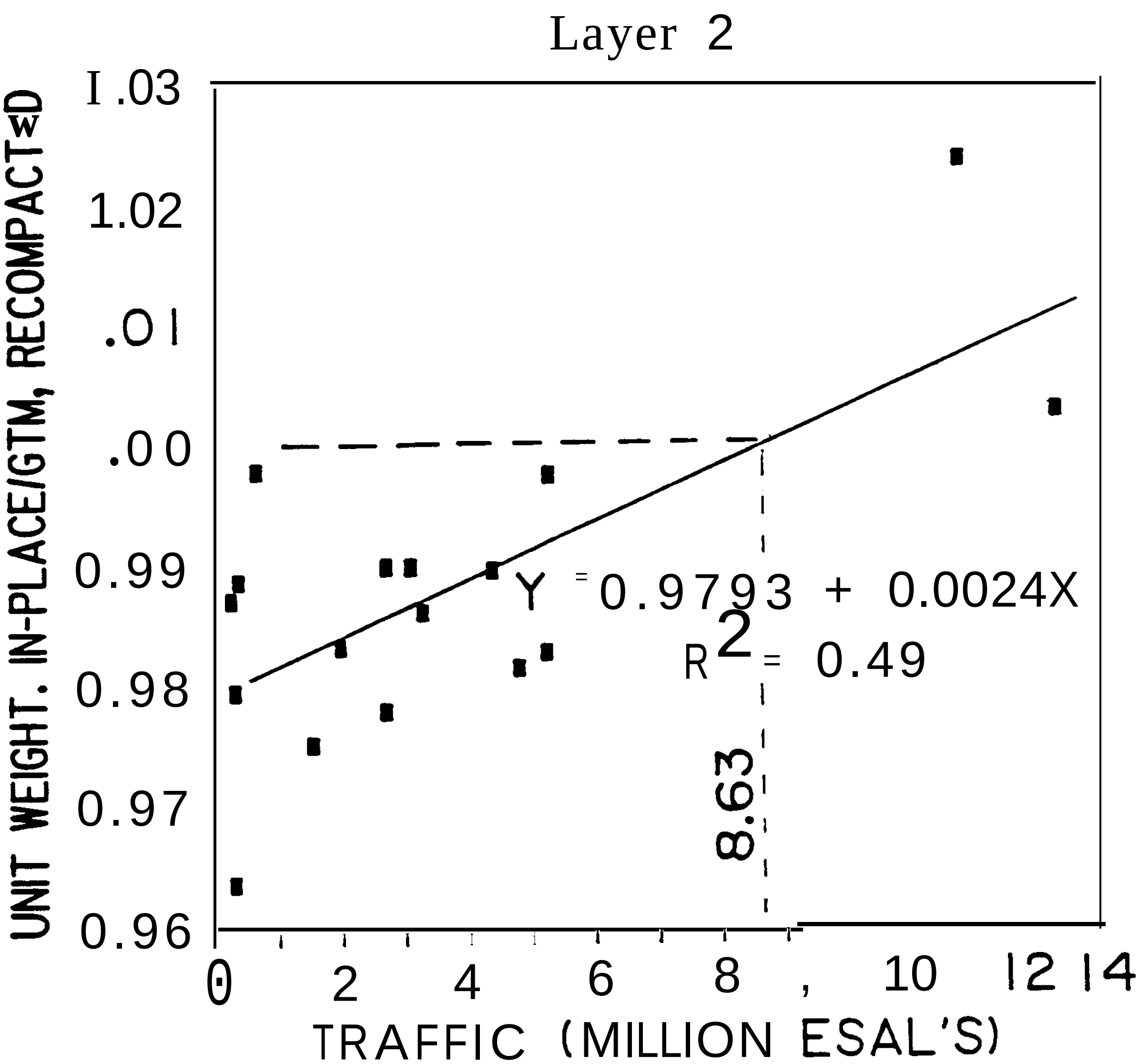

Figure 7. **Traffic vs. Ratio of In-Place to GTM Recompacted Unit Weight for Layer 2 Mixtures**

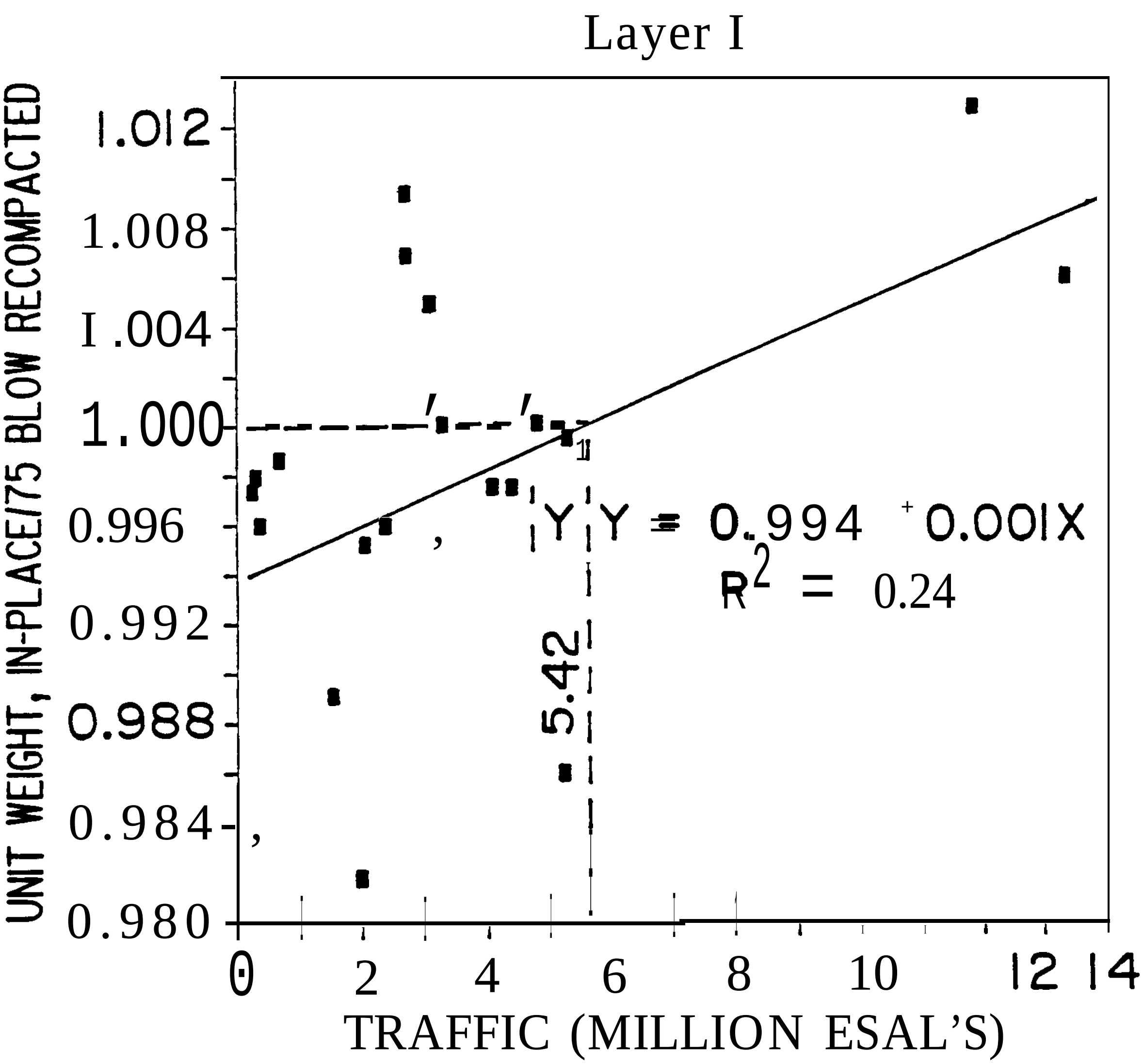

Figure 8. **Traffic vs. Ratio of In-Place to 75 Blow Recompacted Unit Weight for Layer 1 Mixtures**

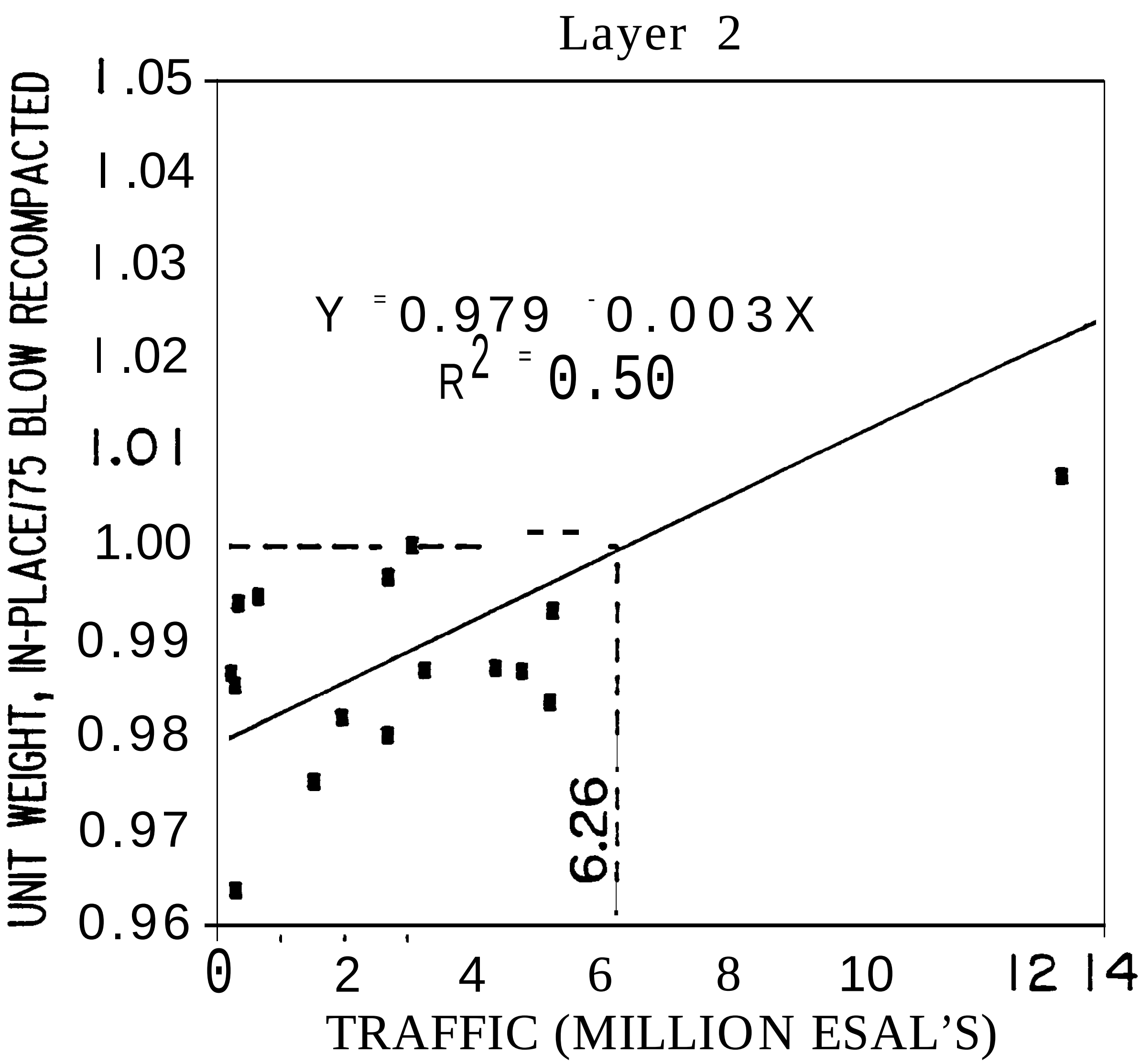

Figure 9. Traffic vs. Ratio of In-Place to 75 Blow Recompacted Unit Weight for Layer 2 Mixtures

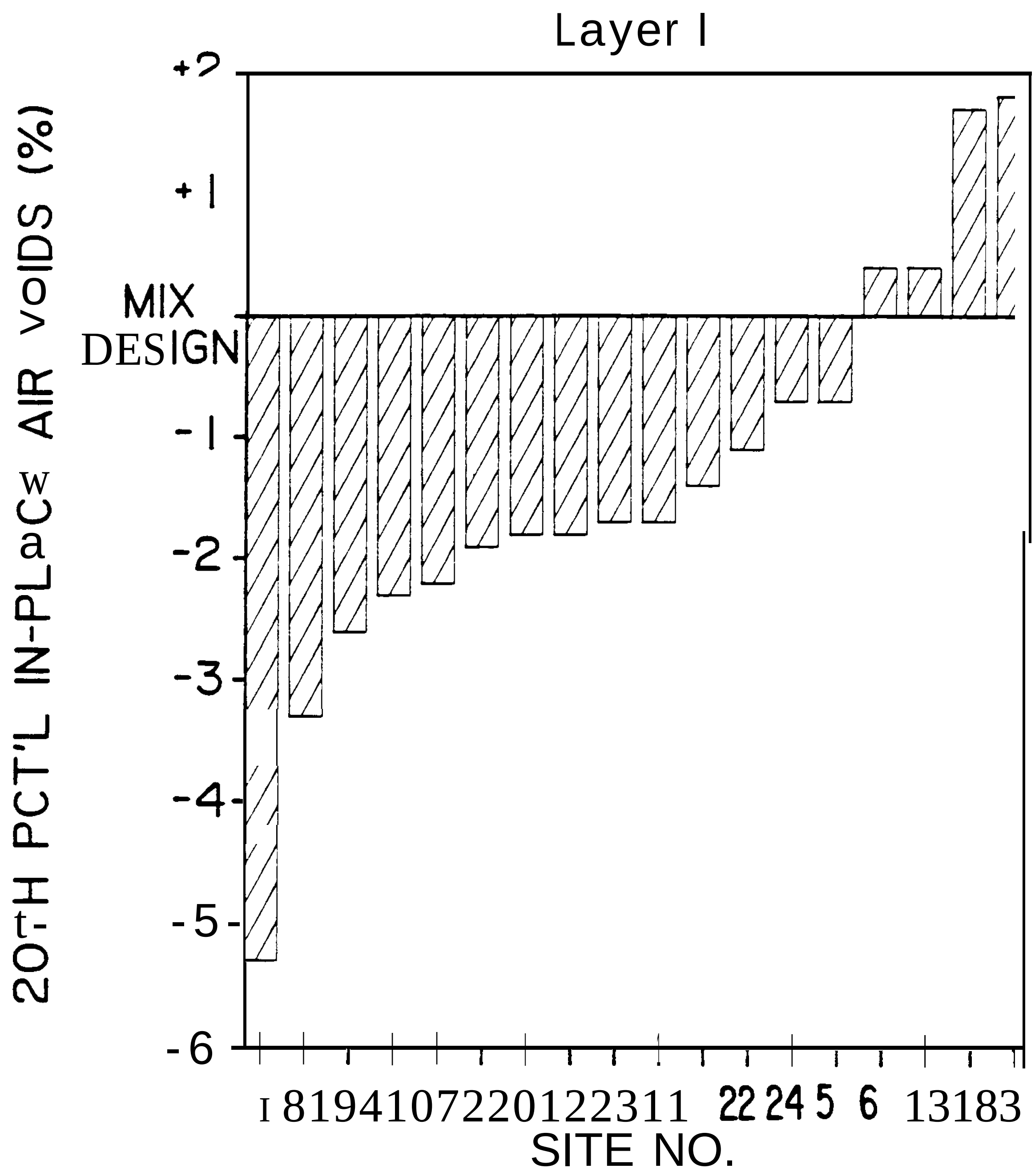

Figure 10. **Comparison of 20th Percentile In-Place Air Void Contents to Their Mix Design Air Void Contents for Layer 1 Mixture**

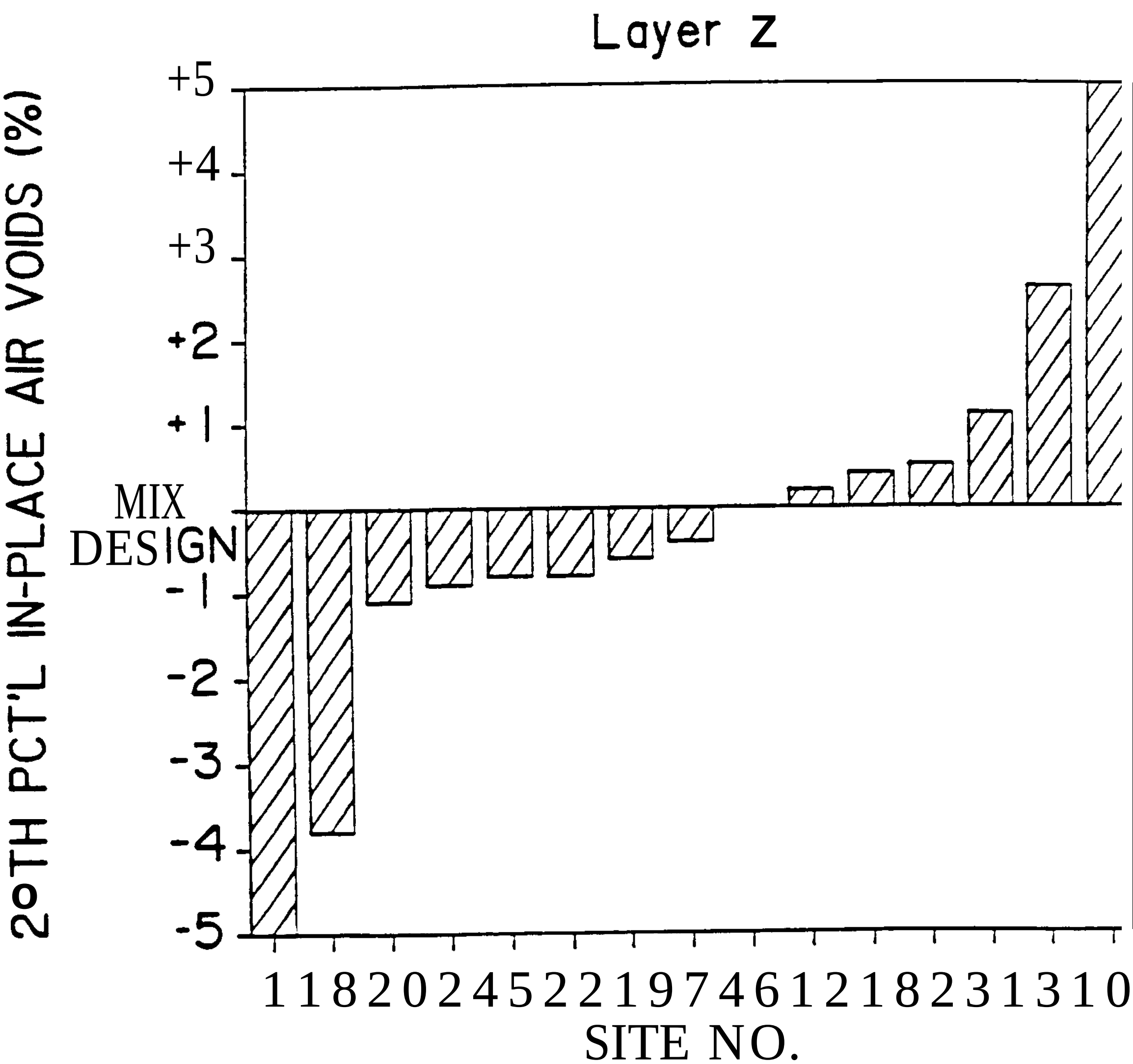

Figure 11. **Comparison of 20th Percentile In-Place Air Void Contents to Their Mix Design Air Void Contents for Layer 2 Mixtures**

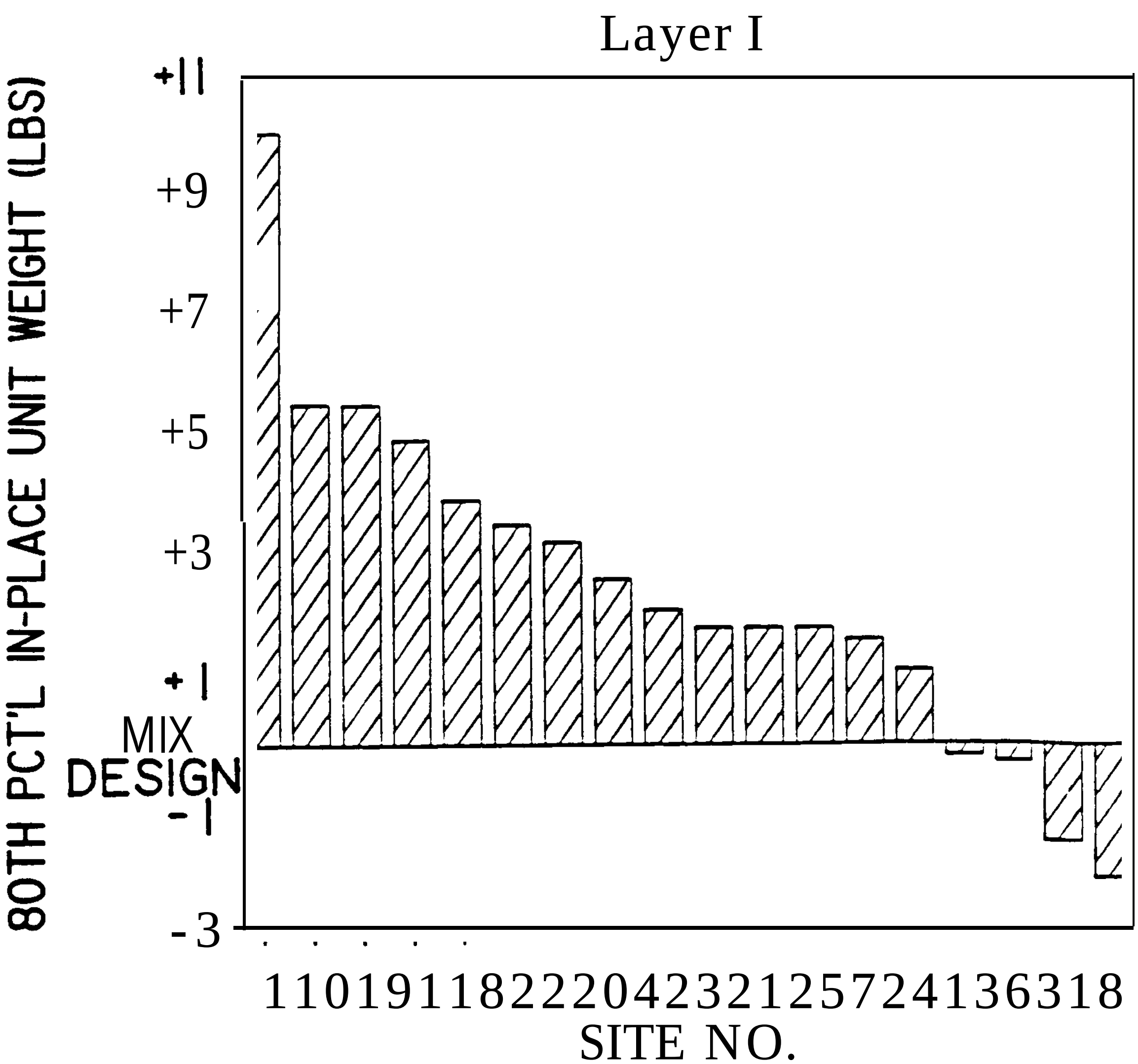

Figure 12. Comparison of 80th Percentile Unit Weights to Their Mix Design Unit Weights for Layer 1 Mixtures

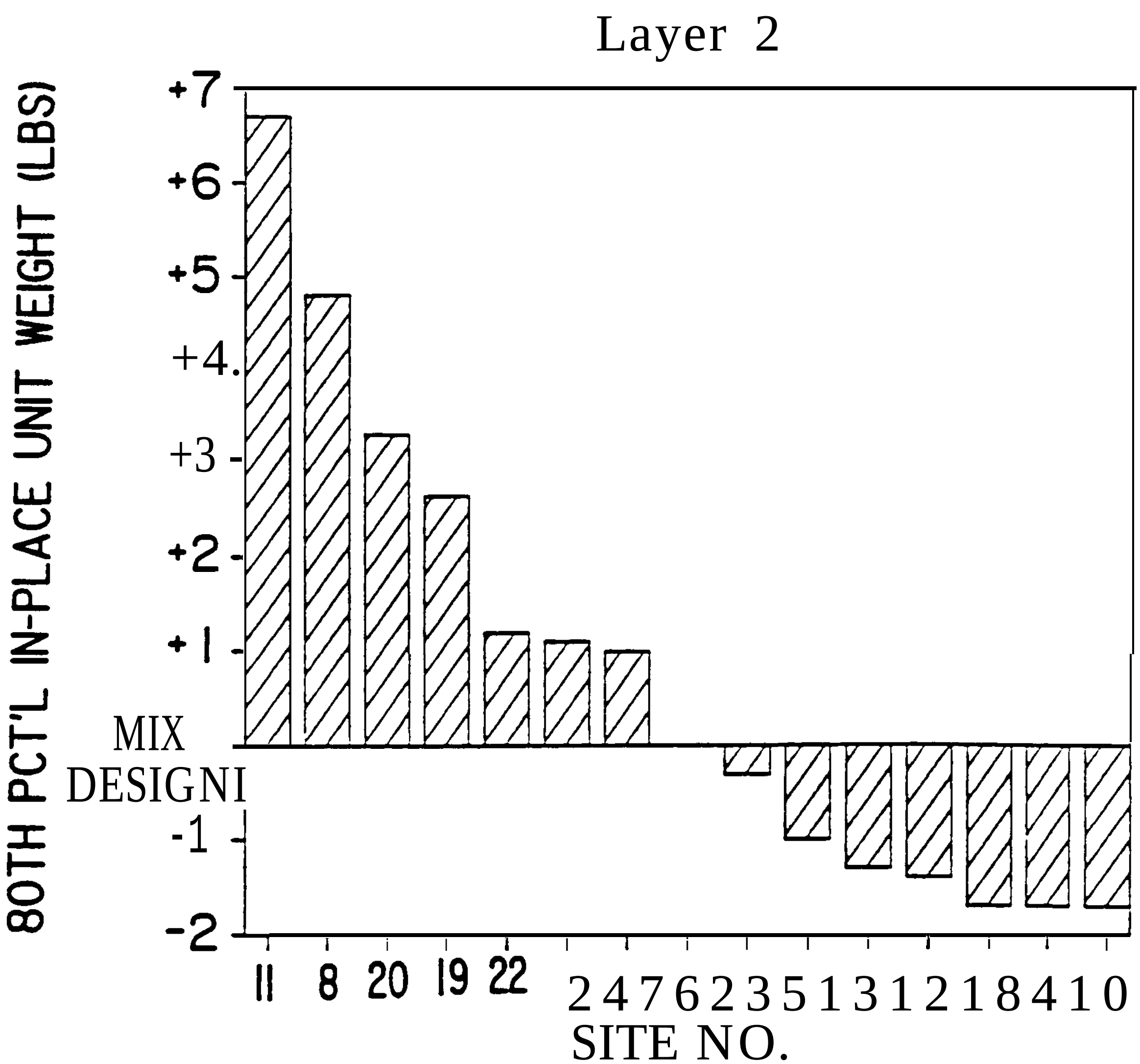

Figure 13. Comparison of 80th Percentile In-Place Unit Weights to Their Mix Design Unit Weights for Layer 2 Mixtures

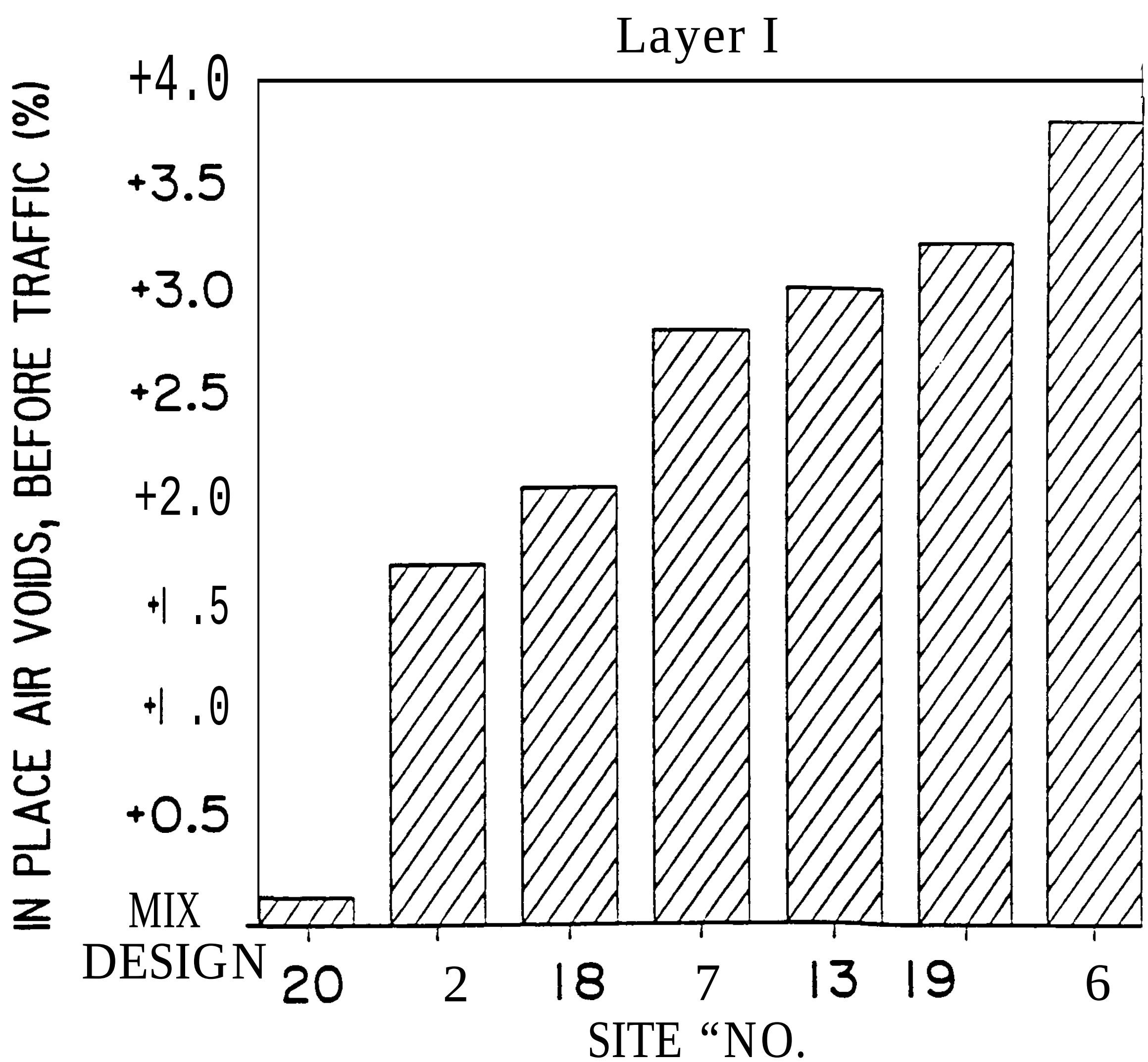

Figure 14. Comparison of Quality Control Air Void Contents Obtained Prior to Traffic to Their Mix Design Air Void Contents for Layer 1 Mixtures

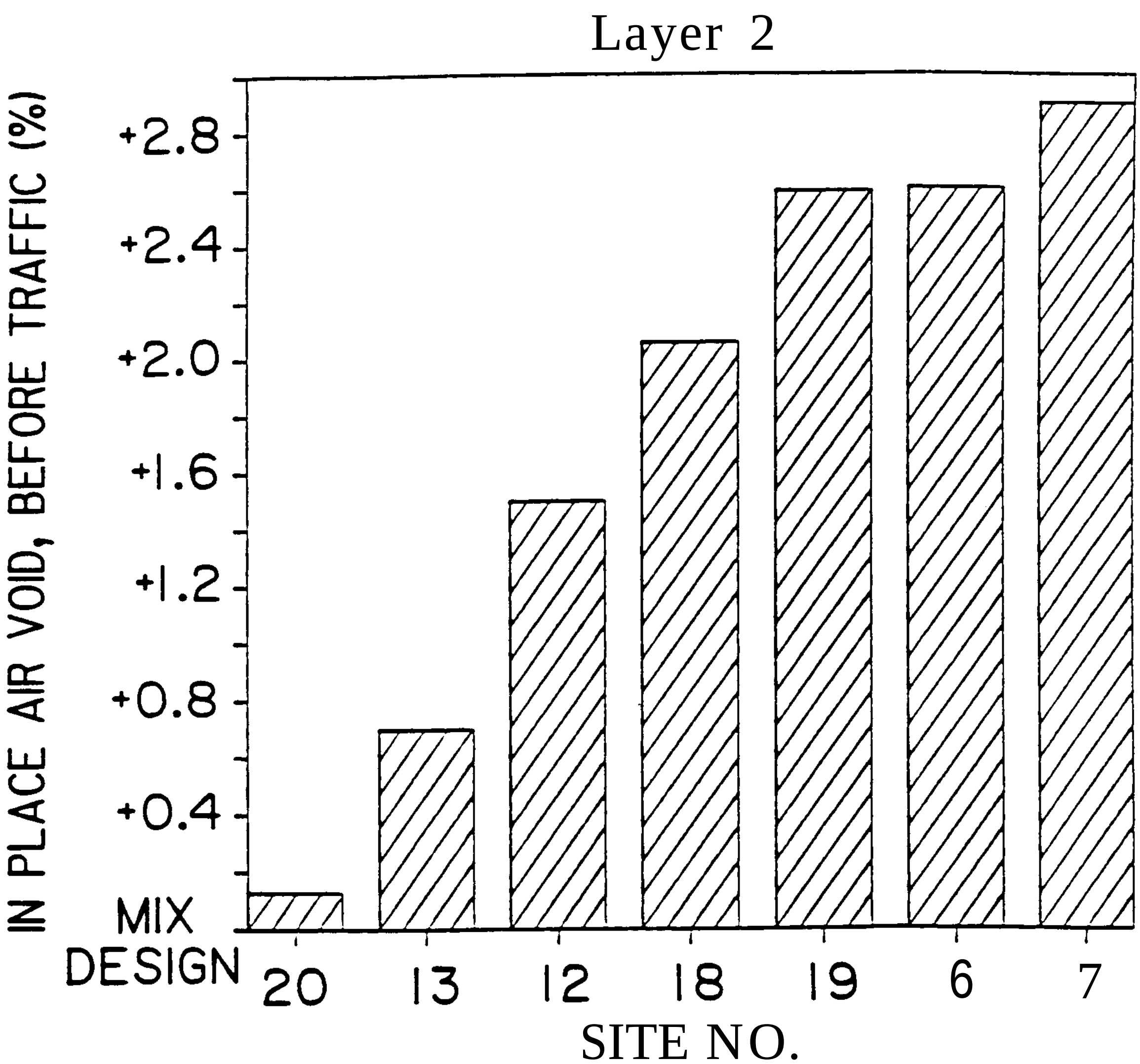

Figure 15. Comparison of Quality Control Air Void Contents Obtained Prior to Traffic to Their Mix' Design Air Void Contents for Layer 2 Mixtures

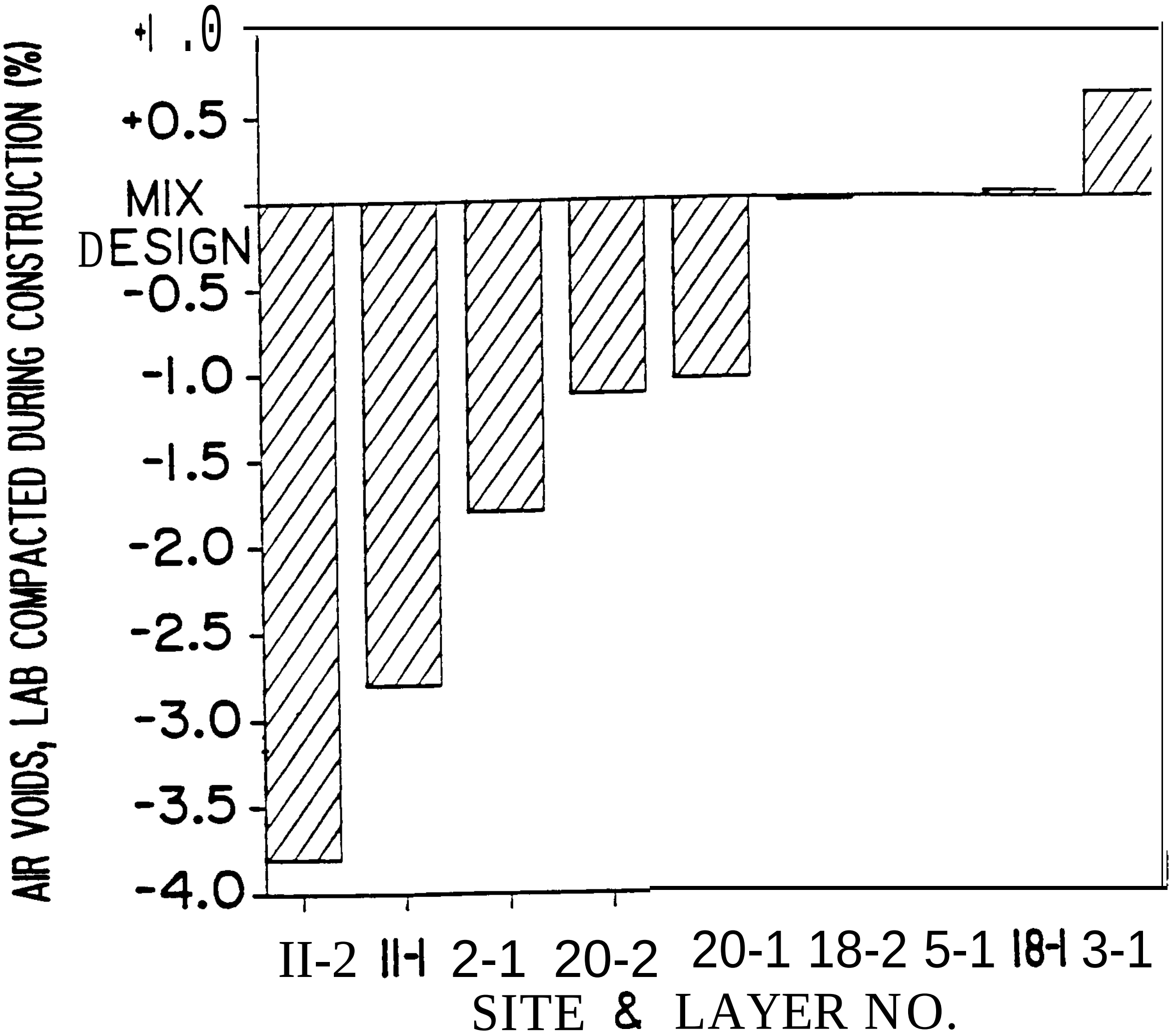

Figure 16. Comparison of Laboratory Compacted Air Void Contents to Their Mix Design Air Void Contents