Report No. CDOT-DTD-R-2005-6
Final Report

DENSITY PROFILING OF ASPHALT PAVEMENTS

Scott Shuler

June 2005

COLORADO DEPARTMENT OF TRANSPORTATION
RESEARCH BRANCH

The contents of this report reflect the views of the author(s), who is (are) responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Colorado Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CDOT-DTD-R-2005-6		

4. Title and Subtitle	5. Report Date
DENSITY PROFILING OF ASPHALT PAVEMENTS	June 2005
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Scott Shuler	CDOT-DTD-R-2005-6

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Colorado State University Ft. Collins, CO 80523-1584	11. Contract or Grant No. OE HAA 04HQ0000271

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Colorado Department of Transportation - Research 4201 East Arkansas Ave. Denver, CO 80222	Final Report
	14. Sponsoring Agency Code 10.33

15. Supplementary Notes
Prepared in cooperation with the US Department of Transportation, Federal Highway Administration

16. Abstract:
Asphalt pavement density measurements were made using a conventional nuclear density gauge and a new electrical resistivity device called the "Pavement Quality Indicator." Five sets of density tests were made at each of nine sites during, or immediately following paving operations between July and September, 2004. Testing at each site attempted to capture differences in density caused by segregation under five distinct sets of circumstances. These included strip segregation along the centerline created by the auger gearbox of the paver, other visible segregation caused by practices such as truck dumping practices and hopper wing folding, transverse segregation caused by inherent design configurations of the paver including the slat conveyor system, screed extensions and stopping of the paver. Control sections were included where segregation was not visible during construction. Tests were conducted at random for each data set and replicated so that rigorous statistical analysis could be conducted. Results indicate that for the "strip" and "visible" data sets, an average decrease in density apparently occurs in the location of the segregation when all nine sites are included in the analysis. However, variability of the density data for all nine sites was very high. This variability is likely related to the differences in segregation occurring at each site. For example, some sites had noticeable segregation during construction while other sites had only minor segregation. To reduce this variability, further analysis of the data should be conducted after the sites are grouped according to the severity of the segregation present.

Implementation:
The results of this study indicate that further evaluation is needed to utilize non-destructive nuclear density measurements to identify sources of segregation in asphalt pavements. Additional work needed includes correlation between levels of segregation and density measurements.

17. Keywords	18. Distribution Statement
segregation, nuclear density testing, non-destructive testing	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	74	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

DENSITY PROFILING OF ASPHALT PAVEMENTS

by

Scott Shuler, Colorado State University

Report No. CDOT-DTD-R-2005-6

Sponsored by the
Colorado Department of Transportation
In Cooperation with the
U.S. Department of Transportation
Federal Highway Administration

June 2005

Colorado Department of Transportation
Research Branch
4201 E. Arkansas Ave.
Denver, CO 80222
(303) 757-9506

ACKNOWLEDGEMENTS

The Colorado Department of Transportation and the Federal Highway Administration provided funding for this study. Nuclear density testing was conducted by David Weld of the Research Branch with help from Andrew Creteau of CSU Construction Management. Donna Harmelink of CDOT Research was the original project manager providing much useful assistance in setting up the project and guiding the field data collection until her retirement from CDOT in June, 2004. Substantial support was also provided by Roberto DeDios who took over the project upon the departure of Donna Harmelink. Thank you all.

EXECUTIVE SUMMARY

Segregation of aggregates in asphalt pavements is a common workmanship deficiency. When segregation appears on the surface of the pavement, the texture of the paving mixture appears more open with larger voids in the segregated areas. The result of this differential in voids is often more infiltration of air and moisture into the pavement leading to premature raveling and potholes.

This study was conducted to determine if nuclear density tests can be used to identify segregation in asphalt pavements. The basis for this hypothesis is that the density of the asphalt pavement in the area of the segregation is lower than the surrounding pavement. If this is true, the nuclear density meter may be able to detect this lower density. Then, if the lower density of the affected pavement areas are statistically different than surrounding areas, a specification may be developed that utilizes the nuclear density meter to quantitatively detect segregation. This specification would provide a measuring tool for an inspector so that qualitative judgment and opinion are removed from the process for controlling paving quality with respect to segregation.

Asphalt pavement density measurements were made using a conventional nuclear density gauge and a new type of non-destructive density meter called the "Pavement Quality Indicator." Five sets of density tests were made at each of the nine sites during, or immediately following paving operations between July and September, 2004. Testing at each site attempted to capture differences in density caused by segregation under five distinct sets of circumstances. These included: strip segregation along the centerline created by the auger gearbox of the paver; other visible segregation caused by practices such as truck dumping practices and hopper wing folding; transverse segregation caused by inherent design configurations of the paver including the slat conveyor system and screed extensions; and stopping of the paver. Control sections were included where segregation was not visible during construction. Tests were conducted at random for each data set and replicated so that statistical analysis could be conducted. Results indicate that for the "strip" and "visible" data sets, an average decrease in density apparently occurs in the location of the segregation when all nine sites are included in the analysis. However, variability of the density data for all nine sites was high. This variability is likely related to the differences in segregation occurring at each site. For example, some sites had noticeable segregation during construction while other sites had only minor segregation which was difficult to detect visually.

Analysis of variance (ANOVA) of the data indicates that statistically significant differences exist in density for eight of nine locations of “strip” segregation, five of nine “visible” locations, six of nine “stop” locations and all nine of the “paver” data sets. In addition, four of the nine “control” data sets had statistically significant differences. Further analysis of the data should be conducted after the sites are grouped according to the severity of the segregation present. If after this re-analysis is conducted and the variability remains too high to develop a specification, a controlled field experiment should be constructed where segregation can be generated at differing levels and correlated to nuclear density measurements.

Implementation Statement

This research should be considered preliminary. No implementation is recommended at this time.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

Segregation of aggregates in asphalt pavements is a common workmanship deficiency. When segregation appears on the surface of the pavement the texture of the paving mixture appears more open with larger voids in the segregated areas. The result of this differential in voids is often more infiltration of air and moisture into the pavement leading to premature raveling and potholes. Current specifications (1) verify the presence of segregation by stating that "…when the percent passing the 4.75 mm (No. 4) sieve varies from the percent specified in the job-mix formula on the CDOT Form 43 by more than nine percent." A Special Provision to be utilized in 2003 extended this requirement to the No. 8 and No. 4 sieves for S and SX gradations. However, levels of segregation vary and since removal of a portion of the allegedly affected pavement area is required for verification, which slows construction and creates the potential for a discontinuous patch in the new pavement surface, many inspectors are reluctant to take this course of action. Therefore, only the most obvious severe segregation is likely to be removed and replaced. This means that low to moderate levels of segregation continue to occur and continue to cause premature asphalt pavement failures.

This study was conducted to determine if nuclear density tests can be used to identify segregation in asphalt pavements. The basis for this hypothesis assumes the density of the asphalt pavement in the area of the segregation is lower than the surrounding pavement. If this is true, the nuclear density meter may be able to detect this lower density. Then, if the lower density of the affected pavement areas are statistically different than surrounding areas, a specification may be developed that utilizes the nuclear density meter to quantitatively detect segregation. This specification would provide a measuring tool for an inspector so that qualitative judgment and opinion are removed from the process for controlling paving quality with respect to segregation. This study was conducted to determine if results obtained by Willoughby, et al in similar experiments linking temperature differential to segregation and pavement density could be utilized to develop a specification to measure segregation.

2.0 EXPERIMENT DESIGN

Five groups of pavement density data were collected to determine if non-destructive density tests could be utilized to measure density differences between segregated areas of asphalt pavements and non-segregated areas. Two types of non-destructive tests were conducted. These included a conventional nuclear gauge and a relatively new device manufactured by TransTech, Inc.[1] called the Pavement Quality Indicator (PQI). This device utilizes the dielectric constant of a material to predict density. The PQI gauge was included in the evaluation because it is lighter in weight, faster to operate, and does not require the special license or storage facilities as the conventional nuclear instrument. Early versions of this device did not provide density data well correlated to actual core densities or nuclear densities. However, improvements made to the device promised better performance and therefore this newer version was included since the possibility of obtaining additional data for identifying segregation was judged potentially beneficial.

Five groups of density tests were collected using each gauge as follows:

Strip - density measurements conducted along a diagonal through the centerline of the paving lane

Visible - density measurements conducted through the center of an area that is visibly segregated

Paver - density measurements conducted across the width of the paving lane edge-to-edge transverse to the direction of paving

Stop - density measurements taken parallel to the direction of paving before and after the paver temporarily stopped during paving

Control - density measurements taken parallel to the direction of paving in an area apparently without segregation

These density groups are shown in the schematics of Figure 1. Note that the width of paving is indicated as 0 to 12 feet on the vertical axis of the figures, but this varied, somewhat, for each project.

[1] Trans Tech Systems, Inc., 1594 State St., Schenectady, NY 12304 (518) 370-5558

Also, each point shown on the figures is the approximate location of the density tests since the “paver” tests were taken end-to-end across the width of paving.

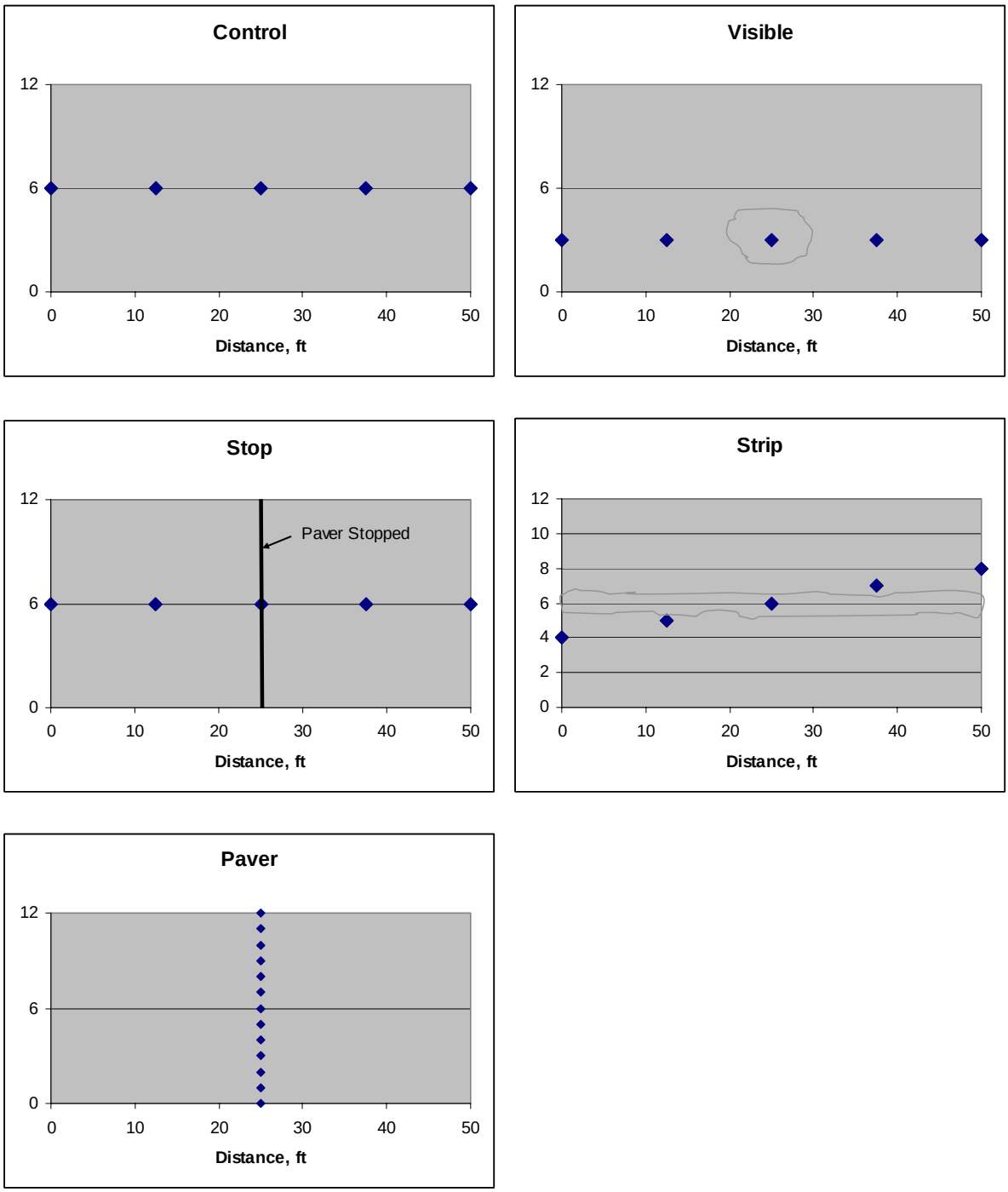


Figure 1. Density Groups Evaluated

Each point shown in Figure 1 was evaluated for insitu pavement density using the Troxler and TransTech devices. Each device was operated by a separate technician. Testing was conducted by marking each location, then randomly evaluating density with the non-destructive devices. Two replicate density tests were conducted by each operator. Each replicate for the Troxler device consisted of taking two readings at each spot marked on the pavement. This consisted of a total of four readings to obtain an average of the two replicate density readings. Each replicate for the TransTech device consisted of taking two sets of five readings at each spot marked on the pavement. This consisted of a total of twenty readings to obtain an average of the two replicate density readings. The resulting experiment can be analyzed by conventional analysis of variance (ANOVA) techniques to determine if a significant difference exists between the test locations evaluated for each density group. The model for the ANOVA is as follows:

$$y_{ij} = \mu + \tau_i + \varepsilon_{ij}$$

where,

y_{ij} = density readings, pcf
μ = the overall mean density, pcf
τ_i = the effect of density gauge location on the pavement
ε_{ij} = the random error component
i = 1, 2, … a is the number of gauge locations being tested
j = 2, is the number of replicates

3.0 PROJECT LOCATIONS

Nine asphalt pavement construction sites were evaluated in this study. These sites are shown in Table 1 in the order they were constructed and tested.

Table 1. Test Sites

Site No.	Project No.	Location	Contractor	Testing Date(s)
1	STA 0404-040	Colfax-Sheridan to Viaduct	Premier Paving	7/8&9/04
2	NH 0504-046	US50 OL-Troy to SH233	Lafarge	7/14/04
3	STA 0853-051	US85 Bus, 22nd St to 5th St.	Lafarge	7/29/04
4	NH 2873-123	US287 Loveland NB & SB	Coulson	8/2/04
5	STA 2571-008	SH257 US34 to Milliken	Aggregate Industries	8/3/04
6	STA 165A-010	SH165 OL and Intersections	Kirkland	9/1/04
7	STA 009A-023	SH9 Summit County Line N	A & S	9/28 & 10/5/04
8	STA 133A-028	SH 133, Paonia Dam N & S	Elam	10/6 &10/12/04
9	STU M055-016	Colfax –Peoria to Potomac	Brannan	11/5/04

4.0 MATERIALS

The grading of the asphalt concrete mixtures, gyratory compaction level, asphalt binder grade and percentage of asphalt in the mixtures as reported on the CDOT Form #43 for each project are shown in Table 2.

Table 2. Materials

Site No.	Location	Contractor	Grading/ Compaction	AC	AC, %	Gmm
1	Colfax-Sheridan	Premier Paving	S 100	76-28	5.1	2.508
2	US50	Lafarge	S 100	76-28	5.4	2.455
3	US85 Bus	Lafarge	S 100	64-28	5.4	2.447
4	US287 Loveland	Coulson	S 100	64-28	5.2	2.468
5	SH257	Aggregate Industries	S 75	64-28	5.2	2.440
6	SH165	Kirkland	S 75	58-28	5.8	2.431
7	SH9	A & S	SX 75	58-34	5.9	2.428
8	SH 133	Elam	SX 75	64-28	6.2	2.406
9	Colfax –Peoria	Brannan	S 100	64-22	5.4	2.513

5.0 PAVING EQUIPMENT

The paving equipment along with certain dimensions for each project is shown in Table 3.

Table 3. Paving Equipment

Site No.	Location	Paver	C/L to Slat C/L, in	Slat Width, in	Windrow Elevator	Breakdown	Inter-mediate	Finish
1	Colfax-Sheridan	B-K PF 5510	15	19	Yes	Hypac C766C	No	Hypac C766C
2	US50	Cat AP 1055B	16	30	Yes	Cat CB634D	Dynapac	Cat CB 534D
3	US85 Bus	Cat AP 1055B	16	26	No	Cat CB 634C	No	CB 534C
4	US287 Loveland	Cat AP 1055B	19	19	Lincoln 660H	Cat CB 634D	No	Cat CB 634C
5	SH257	B-K PF410	15	15	No	Cat 534C	No	Cat 534C
6	SH165	Cat AP 1055B	19	19	Na`	Cat CB 534C	Cat CB 534C	Hypac C766
7	SH9	CR CR551			CR MS-2	Hypac C784	Tampo	Cat CB 534B
8	SH 133	Cat AP1055B	16	25	Yes	Cat CB634D	Cat CB 634D	Hyster R6
9	Colfax – Peoria	N/A-Paving completed before tests						

6.0 TEST RESULTS

Each test conducted as part of this study appears in Appendix A. Appendix B is a summary of the ANOVA conducted for each data set. Appendix C includes graphs showing the averages of both the nuclear and PQI density test results for each density data set location on each project.

The data suggests that pavement density in areas where segregation occurred is lower than surrounding pavement areas where segregation did not occur. The following section describes these differences in detail.

7.0 ANALYSIS

The relative density of the pavement for each of the five density data sets is analyzed in the following section. Each density data set will be discussed separately.

7.1 Strip-Nuclear Tests

The strip density data set was analyzed to determine the average difference between the density of the pavement in the center of the segregation at test position no. 3 and the density in adjacent areas of pavement where segregation should have been lower or non-existent. Analysis was conducted by evaluating the difference between the density at Test No. 3 and the average of the densities at test position nos. 2 and 4. The results shown in Figure 2 suggest that in the area of the centerline strip segregation the density is 1.6 pounds per cubic foot (pcf) less than the adjacent pavement. However, there is much variability in this data with a standard deviation of 1.9 pcf

7.2 Visible-Nuclear Tests

“Visible” density data sets were analyzed by comparing the density at test position no. 3, in the center of the visible segregation, to the highest density recorded in the data set. The average difference for all sites shown in Figure 3 is 3.4 pcf less at Test No. 3 than for the highest

density recorded in the set of five tests. However, again, the variability between sites is high at 3.2 pcf.

	#3-(#2+#4)/2
Colfax and Sheridan	-0.3
SH50	1.3
US 85 Business	-1.9
US287	-5.6
SH257-Milliken	-2.8
SH165	-0.5
SH9	-2.3
SH133	-1.0
Colfax-Peoria	-1.2
Avg =	-1.6
Stdev =	1.9

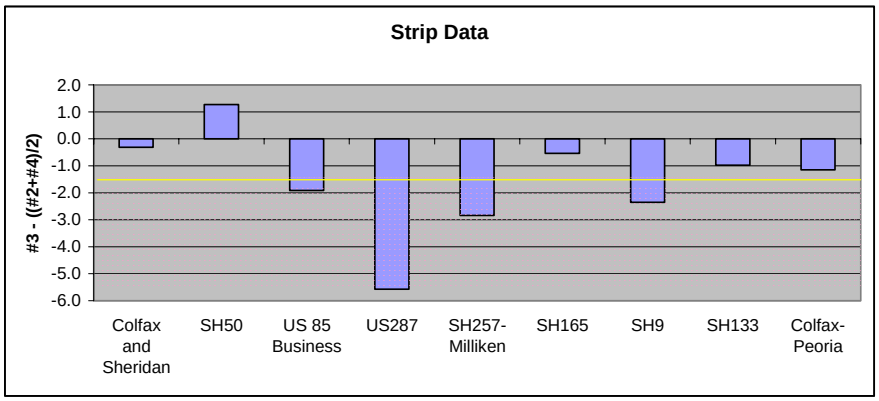


Figure 2. Average of "Strip" Density Data for All Sites

	#3-Hi
Colfax at Sheridan	-4.7
Hwy 50	-2.7
US 85 Business	-2.5
US 287	-0.2
SH 257-Milliken	-9.7
SH 165	0.4
SH 9	-6.4
SH 133	-1.1
Colfax-Peoria to Potomac	-3.3
Avg =	-3.4
Stdev =	3.2

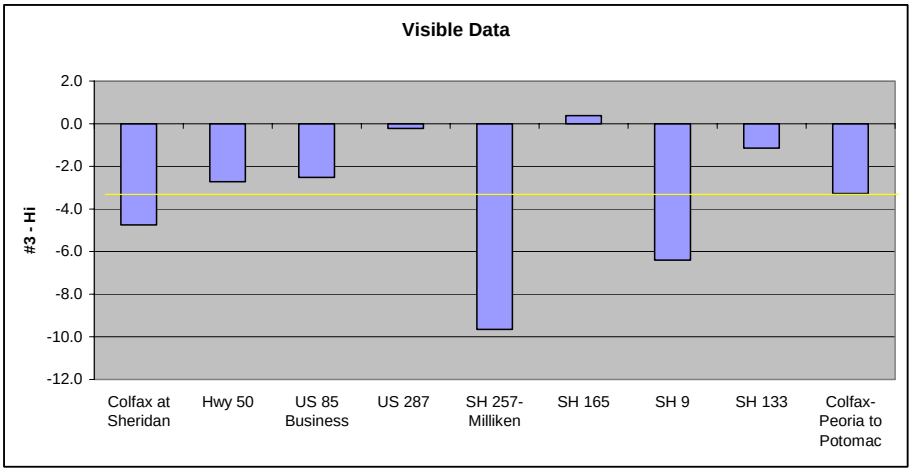


Figure 3. Average of "Visible" Density Data for All Sites

7.3 Control-Nuclear Tests

The control density data sets were analyzed by comparing the difference in density of the lowest and highest density values for each site. The results shown in Figure 4 indicate the average difference for the control sections is 1.4 pcf with a standard deviation of 2.2 pcf.

	Lo - Hi
Colfax at Sheridan	-1.3
Hwy 50	-1.1
US 85 Business	-3.5
US 287	-6.0
SH 257-Milliken	-0.8
SH 165	-1.0
SH 9	0.6
SH 133	1.1
Colfax-Peoria to Potomac	-0.3
Avg =	-1.4
Stdev =	2.2

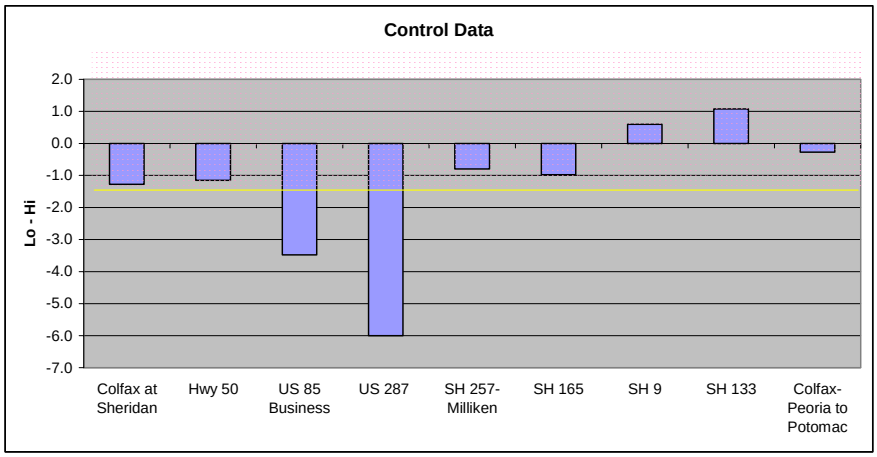


Figure 4. Average of "Control" Density Data for All Sites

7.4 Stop-Nuclear Tests

The stop density data sets were evaluated by comparing the density of the pavement where the paver stopped to the highest density recorded for that set. The results shown in Figure 5 suggest that a 2.4 pcf difference exists for the average of all sites with a standard deviation of 1.8 pcf.

	Stop - Hi
Colfax at Sheridan	0.0
Hwy 50	-3.3
US 85 Business	-5.9
US 287	-1.5
SH 257-Milliken	-2.0
SH 165	-2.1
SH 9	-3.3
SH 133	-1.0
Colfax-Peoria to Potomac	na
Avg =	-2.4
Stdev =	1.8

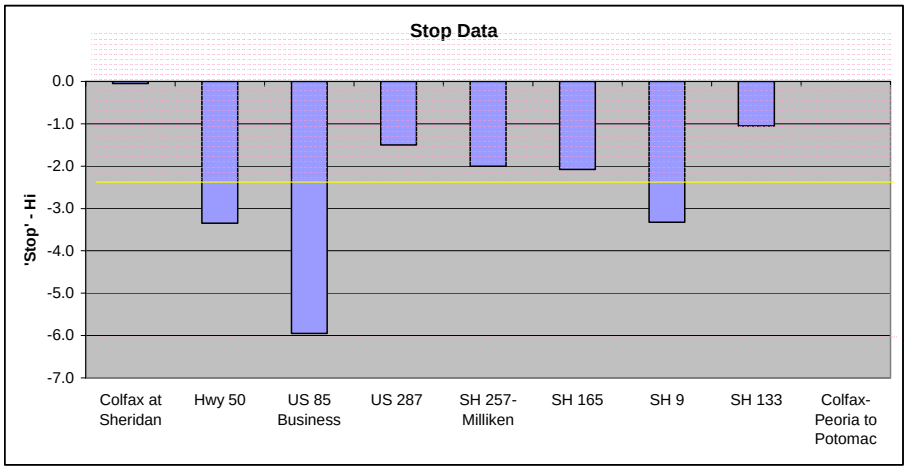


Figure 5. Average of "Stop" Density Data for All Sites

7.5 Paver-Nuclear Tests

The paver density data sets were evaluated after removing a portion of the test results from the analysis. The tests removed prior to analysis were located 24 inches from the edge of the paver width. These tests were removed from the analysis because of noticeably lower densities within these zones, possibly due to an apparent difficulty in achieving compaction at the edge of the paving width. The results shown in Figure 6 indicate a differential of 5.4 pcf across the paving width with a standard deviation of 2.1 pcf.

	Lo - Hi
Colfax at Sheridan	-7.2
Hwy 50	-8.4
US 85 Business	-5.8
US 287	-4.1
SH 257-Milliken	-8.2
SH 165	-4.4
SH 9	-3.3
SH 133	-3.3
Colfax-Peoria to Potomac	-3.7
Avg =	-5.4
Stdev =	2.1

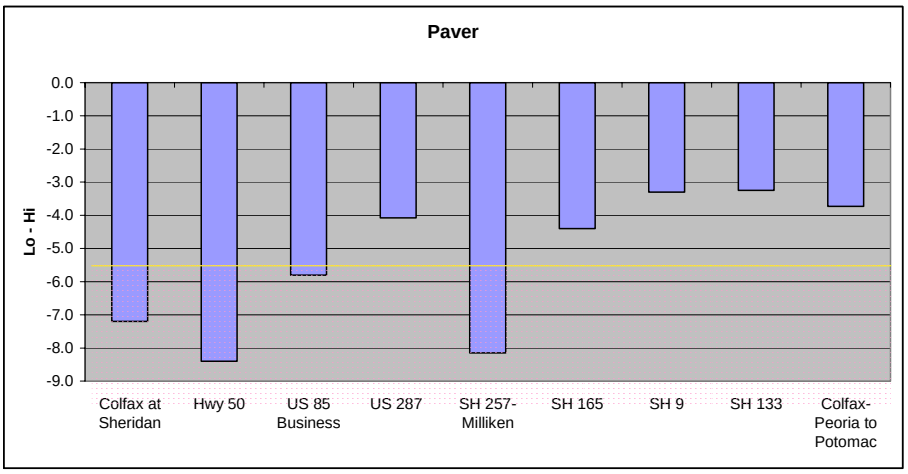


Figure 6. Average of "Paver" Density Data for All Sites

Appendix C shows the graphs of all the average test results recorded for both the nuclear and PQI density gauges for each project. The position of the paver centerline and position of the slat conveyors is superimposed on each graph for dimensions that were recorded. A difference in density due to the presence of the centerline gearbox is not apparent, however, a decrease in density is evident for certain projects at the outside edge of the slat conveyor, consistent with findings of Harmelink and Aschenbrener (3) regarding paver-created segregation.

7.6 Analysis of Variance

The variability discussed above is likely due to variations in conditions between sites such as testing error, materials, moisture content, construction methods and levels or degrees of segregation. Therefore, an analysis of variance (ANOVA) was conducted on each site for each density data set collected. The results appear in Appendix B and are summarized in Table 4.

The ANOVA was performed at an α level of 0.05. The results in Table 4 indicate whether a difference at the $\alpha = 0.05$ level exists for density values taken at the different gauge positions for each density data set. For example, there are five gauge positions for the "strip" data set. If there is not a significant difference in mean density values for these five gauge positions at $\alpha = 0.05$, a notation of "No" is shown in Table 4. This does not necessarily mean that there was no segregation; just that statistically, there is no difference between the densities recorded at the five gauge positions.

The "paver" ANOVA was conducted without using the three gauge readings at the edges of the paver width since there tended to be a significant reduction in density in these regions.

Table 4. Summary of ANOVA for Each Project ('Yes'-Significant Difference; 'No'-Not Significant)

	Density Data Set				
Project	**Strip**	**Visible**	**Stop**	**Paver**	**Control**
Colfax-Sheridan	Yes	Yes	Yes	Yes	Barely
SH 50	Yes	Yes	Yes	Yes	No
US 85 Bus	Yes	Yes	Yes	Yes	Yes
US 287	Yes	No	No	Yes	Yes
SH 257	Yes	Yes	Yes	Yes	No
SH 165	Yes	No	Yes	Yes	No
SH 9	Yes	Yes	No	Yes	Yes
SH 133	Yes	No	Yes	Yes	No
Colfax-Peoria	No	No	NA	Yes	No

To determine what the difference in density would be for segregated areas compared with non-segregated areas, the density in the No. 3 position for the "strip" and "visible" locations was compared with the average of the "control" density for projects where the ANOVA measured significance for the "strip" and/or "visible" tests and the "control" measured not significant. The results of this analysis are shown in Table 5.

Table 5. Density Differences for Statistically Significant Sites

Project	Strip	Visible	Control	Strip-Control	Visible-Control
SH 50	141.9	140.1	140.1	+1.8	0
SH 257	137.2	130.3	140.0	-2.8	-9.7
SH 165	142.0	No	141.8	+0.2	na
SH 133	140.4	No	143.0	-2.6	na

Table 5 indicates that for SH 50, the density on the centerline of the paver is 1.8 pcf higher than the control section and the area of visible segregation has a density equal to the control. The density in the area of the strip segregation on SH 165 is 0.2 pcf higher than the control. However, the strip segregation density on SH 257 is 2.8 pcf lower than the control and in the area of the visible segregation the density is 9.7 pcf lower than the control. SH 133 has 2.6 pcf lower density in the area of the strip segregation than the control.

7.7 Comparison of Nuclear and PQI Density Tests

Each of the five density data sets evaluated with the nuclear density gauge were also evaluated using the PQI density gauge. Readings were taken at random in the same location on the pavement as the nuclear gauge. A set of five readings were taken with the PQI gauge and the average recorded. A second set of five readings was taken and averaged producing the second replicate. The results of the average of the two replicates is presented below and compared with the nuclear density data. The PQI density gauge generally was less sensitive to changes in the asphalt pavement density than the nuclear gauge. Each of the density sets is presented in the next section.

7.7.1 Strip-PQI Tests

Except for projects SH133 and Colfax E there appears to be little correlation between the nuclear density tests and the PQI tests as shown in Figure 7 for the average values of the differences in density between gauge position #3 and the average of gauge positions #2 and #4. The regression analysis shown in Figure 8 confirms this.

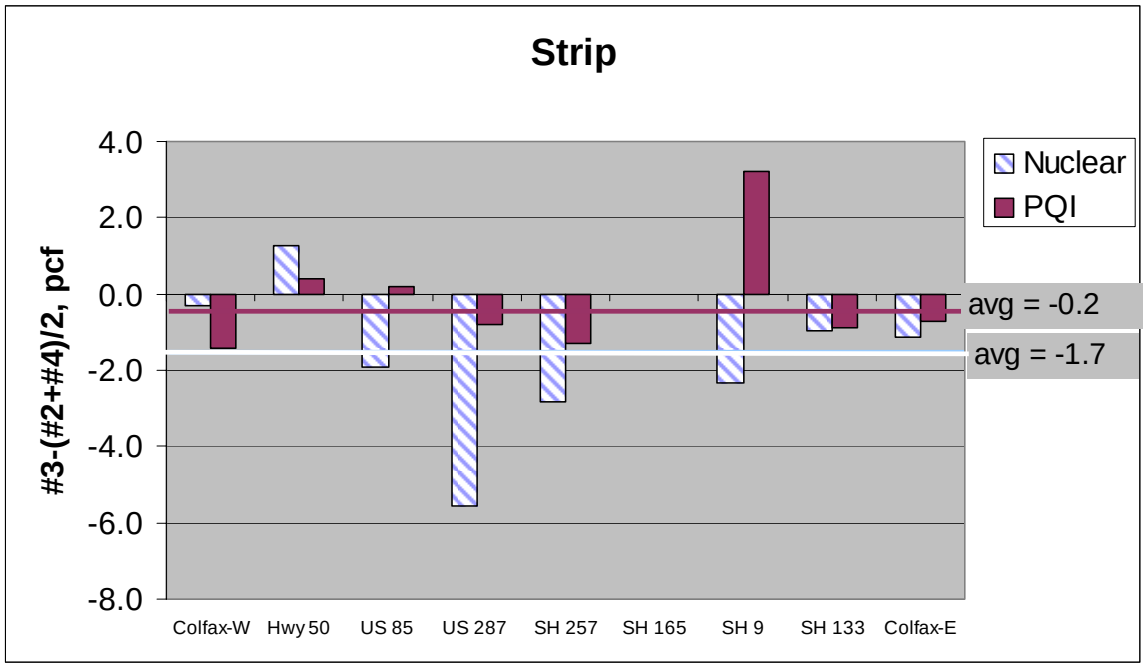


Figure 7- Nuclear and PQI Density Comparison for "Strip" Data

7.7.2-Visible-PQI Tests

Except for US287 there appears to be little correlation between the nuclear density tests and the PQI tests as shown in Figure 9 for the average values of the differences in density between gauge position #3 and the highest average density reading. The regression analysis shown in Figure 10 also confirms this.

7.7.3-Control-PQI Tests

The control density data sets were analyzed by comparing the difference in density of the lowest and highest density values for each site. Except for SH133 there appears to be little correlation between the nuclear density tests and the PQI tests as shown in Figure 11 for the average values of the differences in density between the lowest density and the highest density readings. The regression analysis shown in Figure 12 also confirms this.

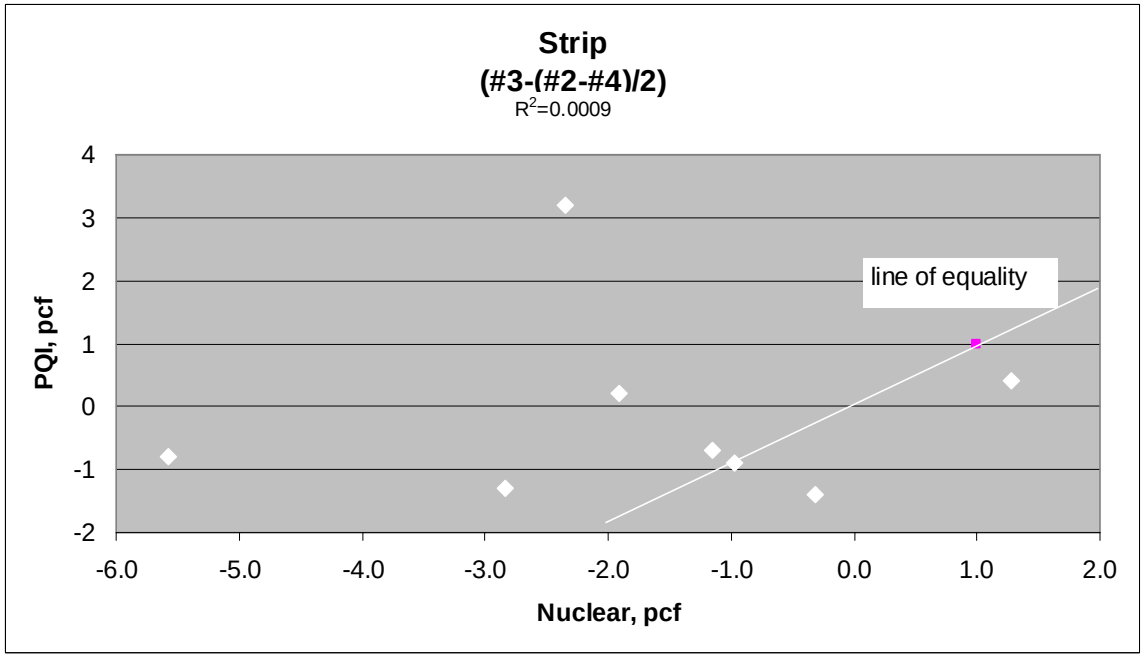


Figure 8 – Regression Analysis of Nuclear and PQI "Strip" Data

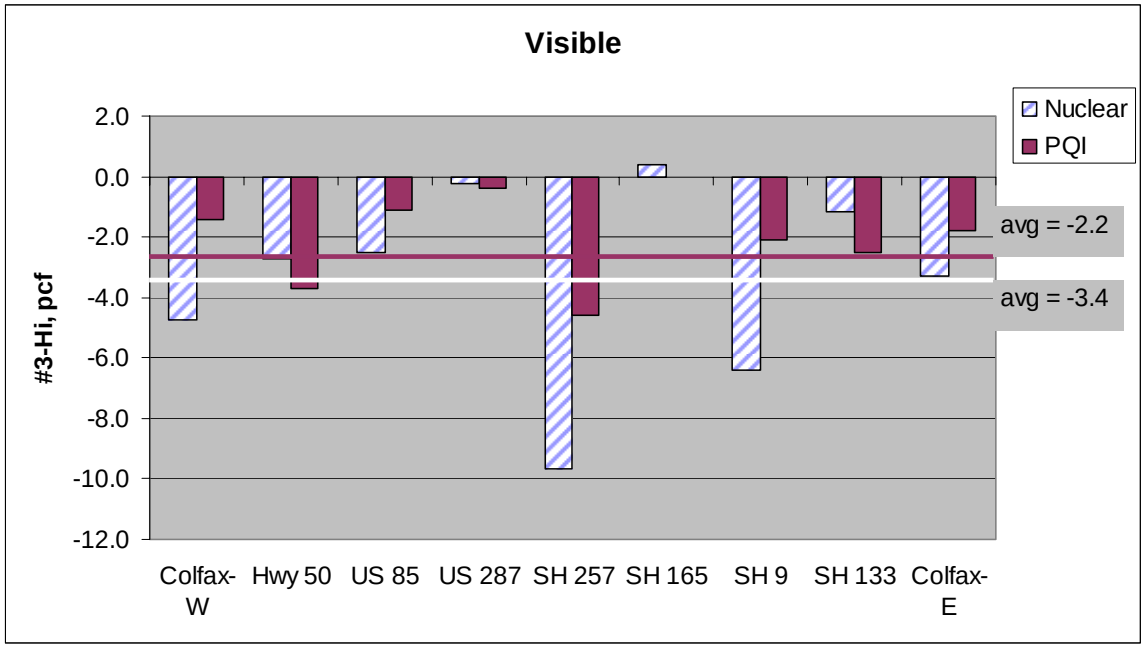


Figure 9- Nuclear and PQI Density Comparison for "Visible" Data

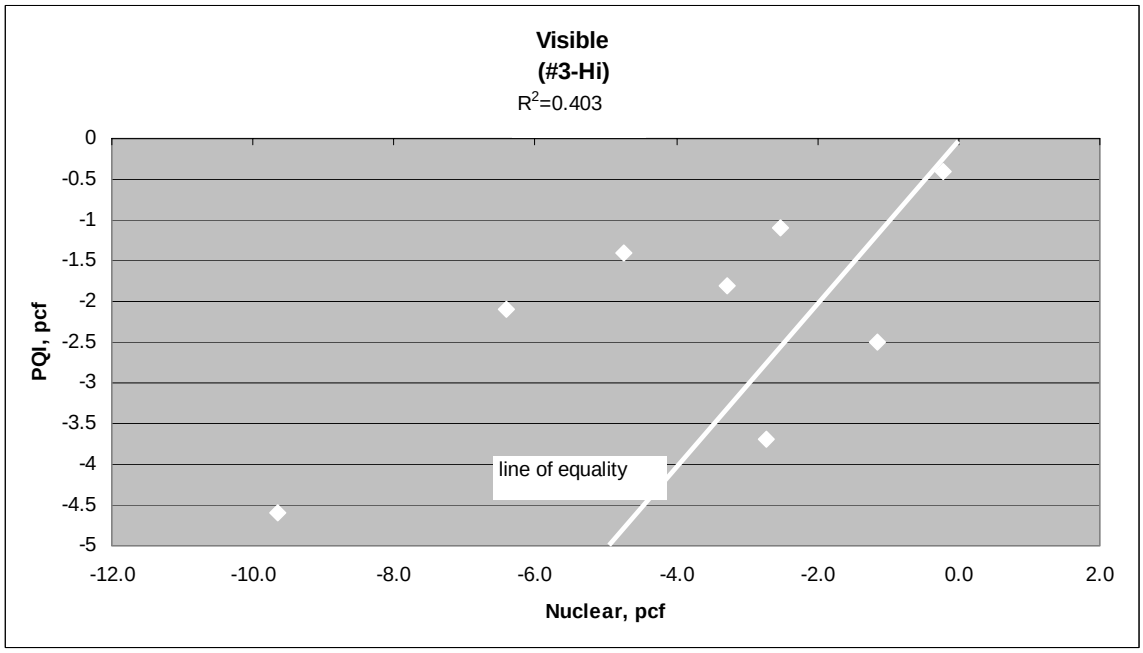


Figure 10 – Regression Analysis of Nuclear and PQI "Visible" Data

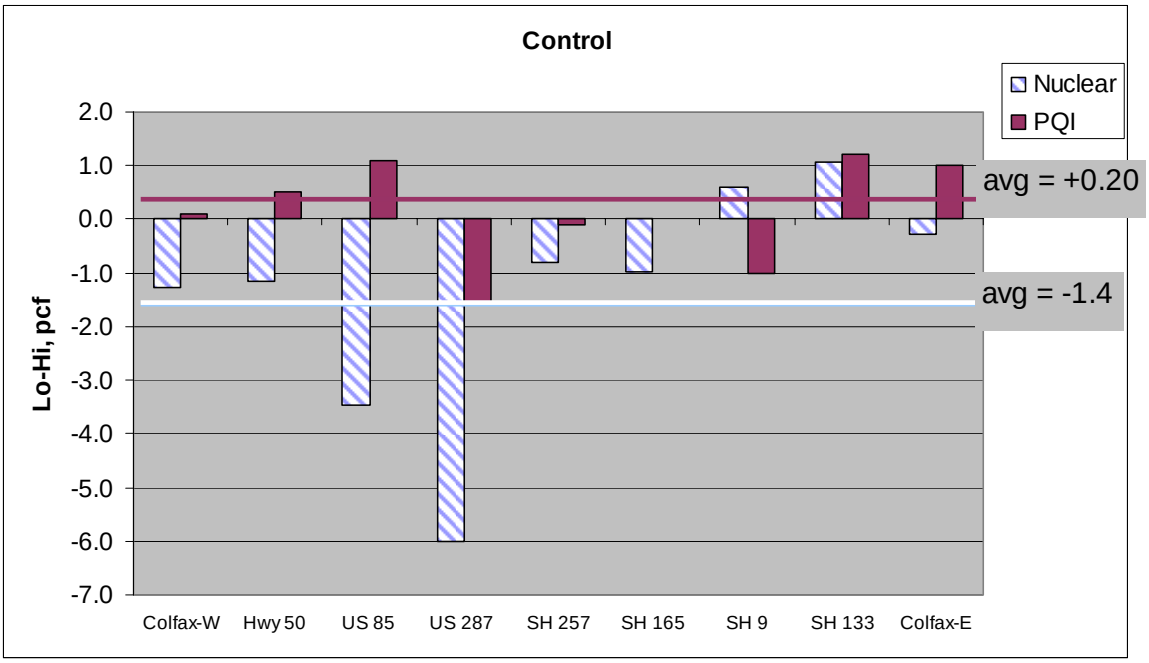


Figure 11- Nuclear and PQI Density Comparison for "Control" Data

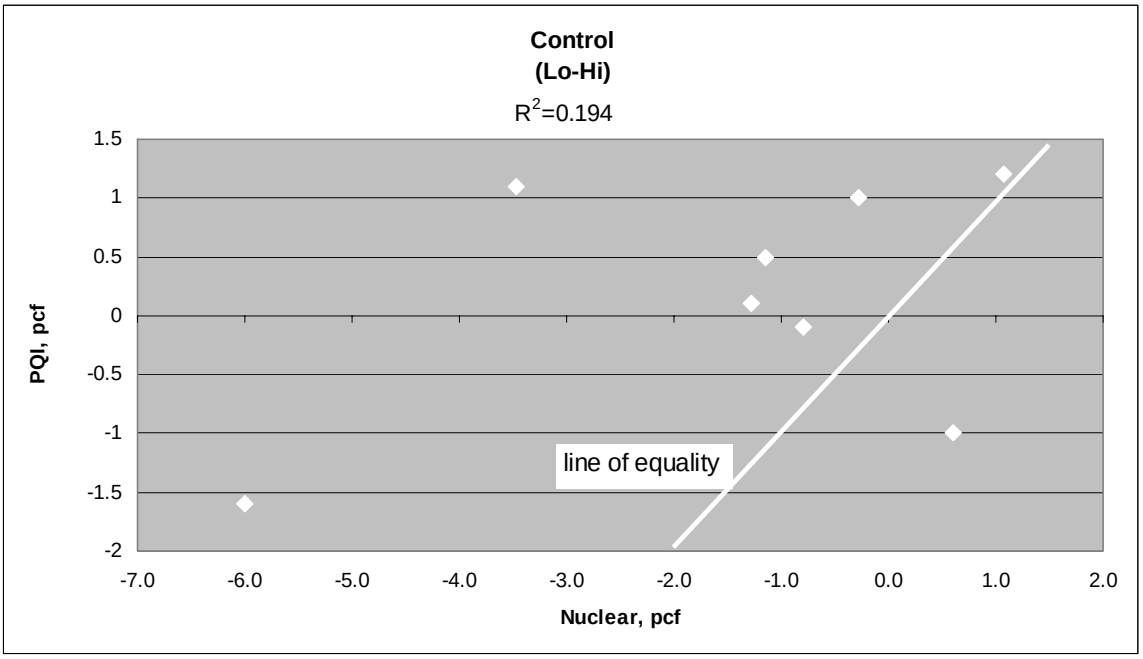


Figure 12 – Regression Analysis of Nuclear and PQI "Control" Data

Stop-PQI Tests

The stop density data sets were evaluated by comparing the density of the pavement where the paver stopped to the highest density recorded for that set of density readings. In this case, there appears to be reasonably good correlation between the nuclear test results and the PQI readings as shown in Figure 13. The regression analysis shown in Figure 14 indicates a good correlation between the two sets of data.

Paver-PQI Tests

The paver density data sets were evaluated after removing a portion of the test results from the analysis. The tests removed prior to analysis were located 24 inches from the edge of the paver width. These tests were removed from the analysis because of noticeably lower densities within these zones, possibly due to an apparent difficulty in achieving compaction at the edge of the paving width. Results shown in Figure 15 indicate reasonable agreement between nuclear and PQI for some sites and poor

agreement for other sites. The regression analysis in Figure 16 indicates a poor correlation between the two density testing devices.

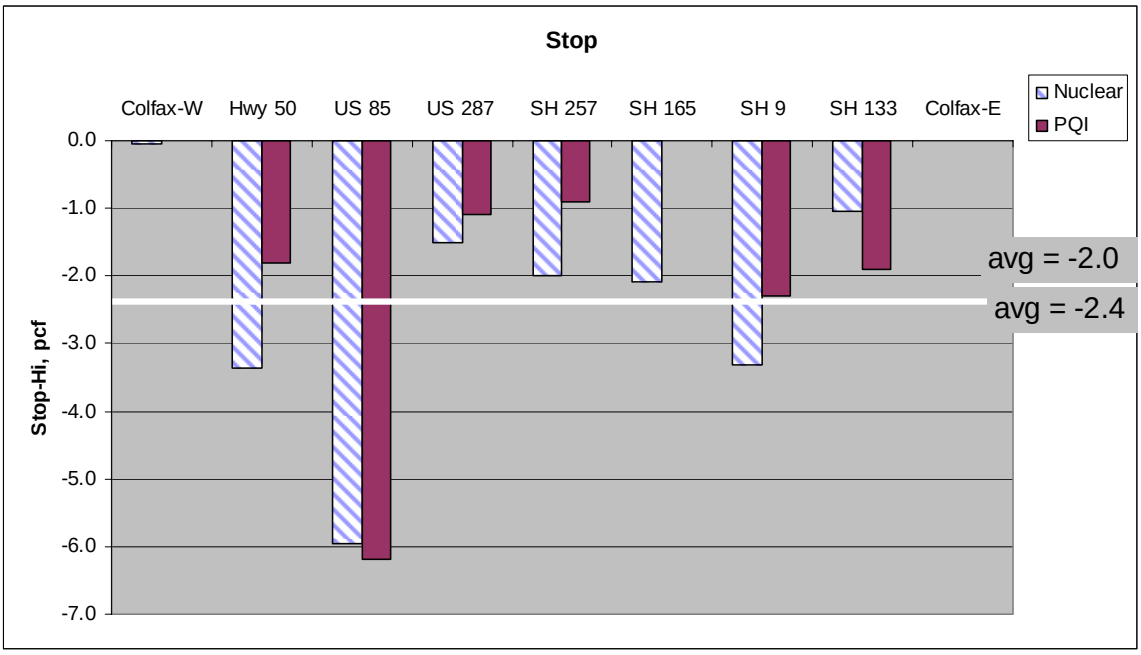


Figure 13- Nuclear and PQI Density Comparison for "Stop" Data

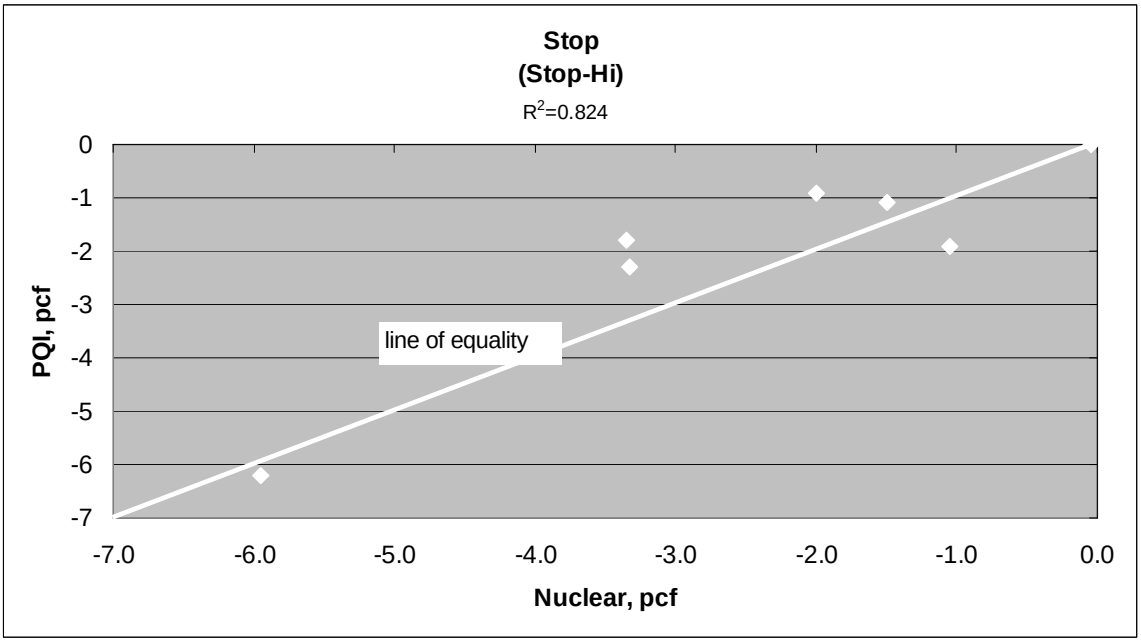


Figure 14 – Regression Analysis of Nuclear and PQI "Stop" Data

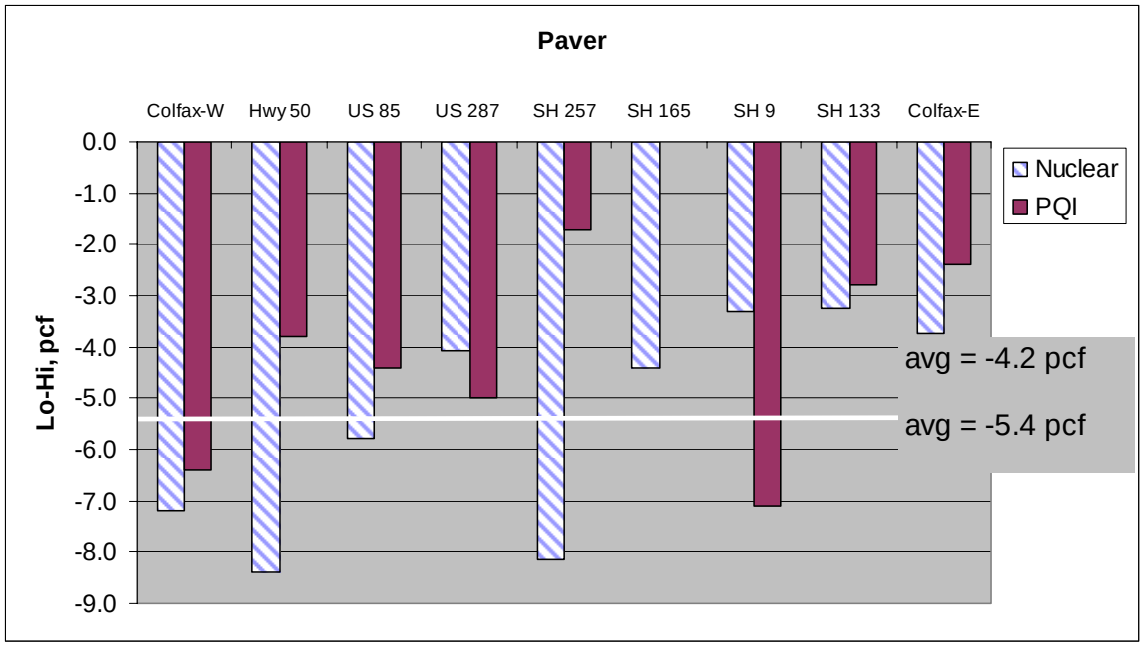


Figure 15- Nuclear and PQI Density Comparison for "Paver" Data

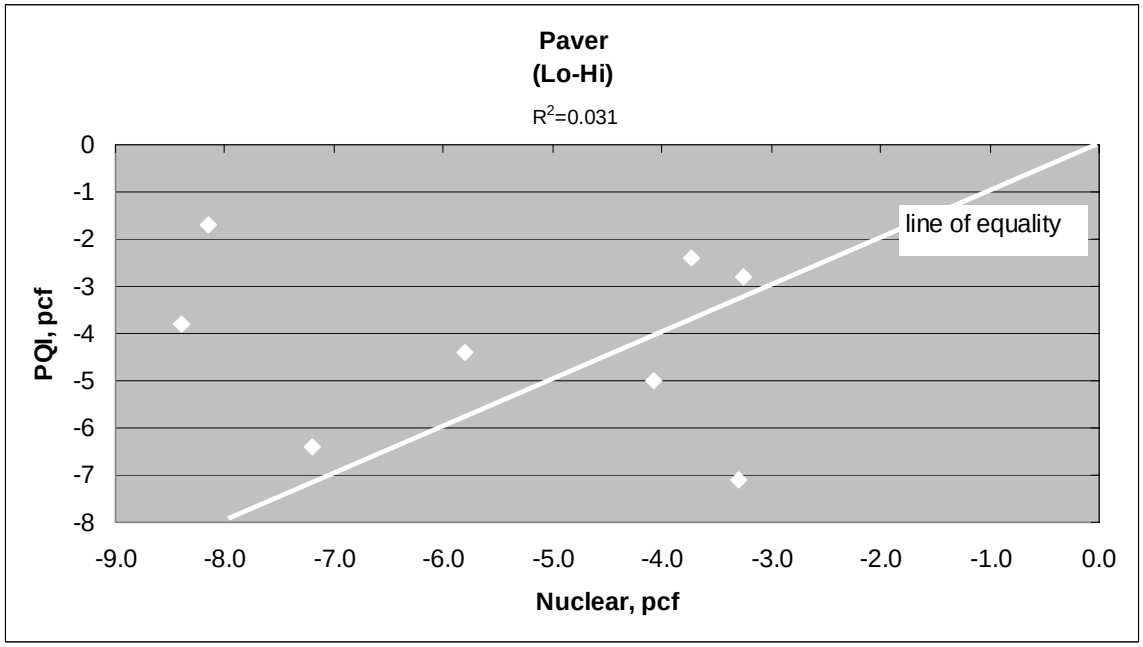


Figure 16 – Regression Analysis of Nuclear and PQI "Paver" Data

7.8 Effect of Segregation on Compaction

The average of the four density measurements obtained at each test position (1, 2, 3, 4 and 5) using the nuclear gauge was compared to the maximum theoretical density of the paving mixture reported from the mixture design and is shown in Figures 17, 18, and 19 for the Strip, Visible and Control data sets, respectively. This data is a transformation of the data presented in Appendix C and reinforces the relative effect of segregation on pavement construction quality. For example, in the areas of strip segregation SH287, US85, SH257, and SH9 appear to have less than the 92% relative compaction specified. For visible segregation, every project, except SH165 failed to reach 92% relative compaction in the area of the segregated mixture.

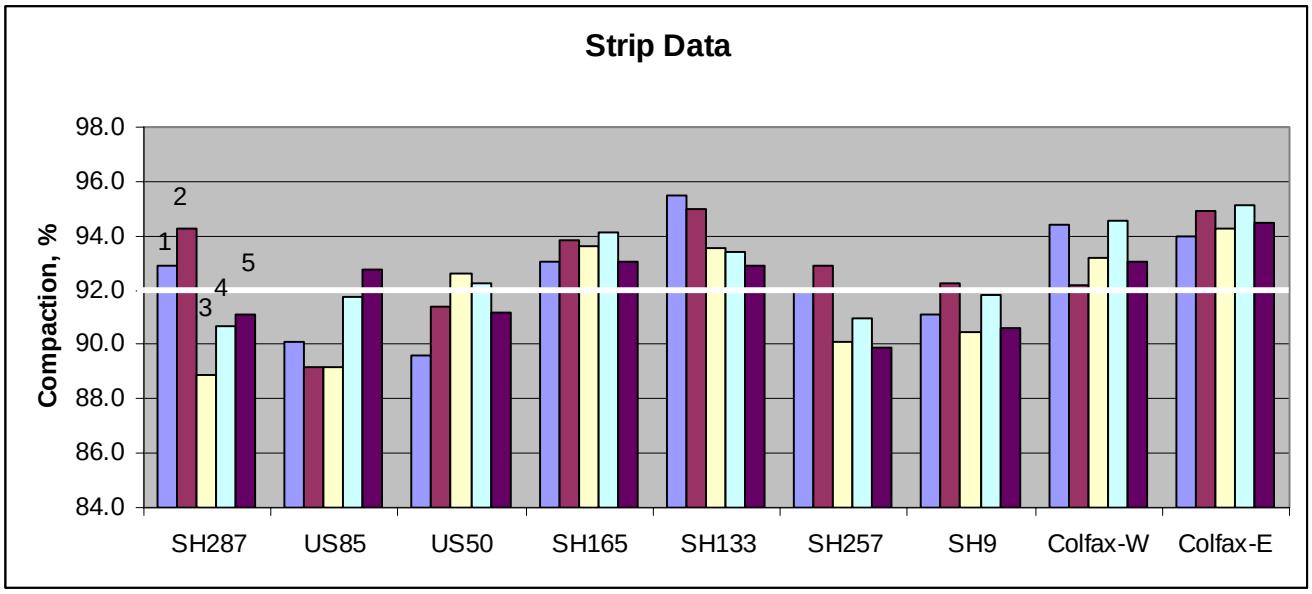


Figure 17 – Effect of Density Differences on Compaction for “Strip” Data Set

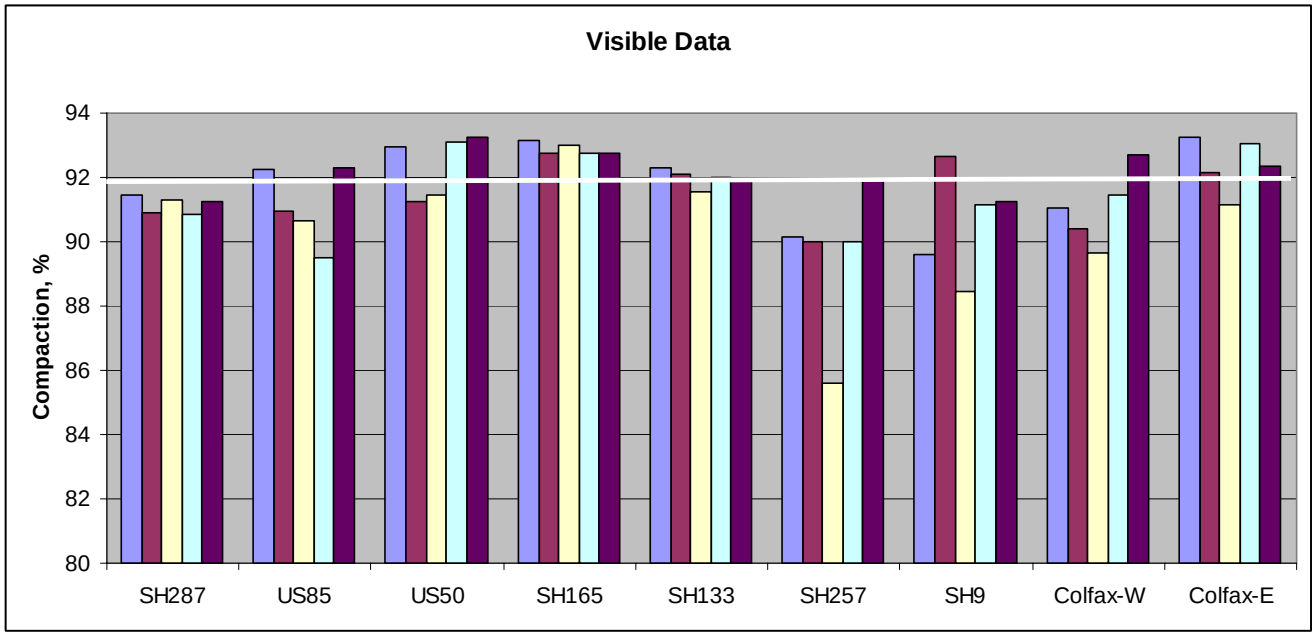


Figure 18 – Effect of Density Differences on Compaction for "Visible" Data Set

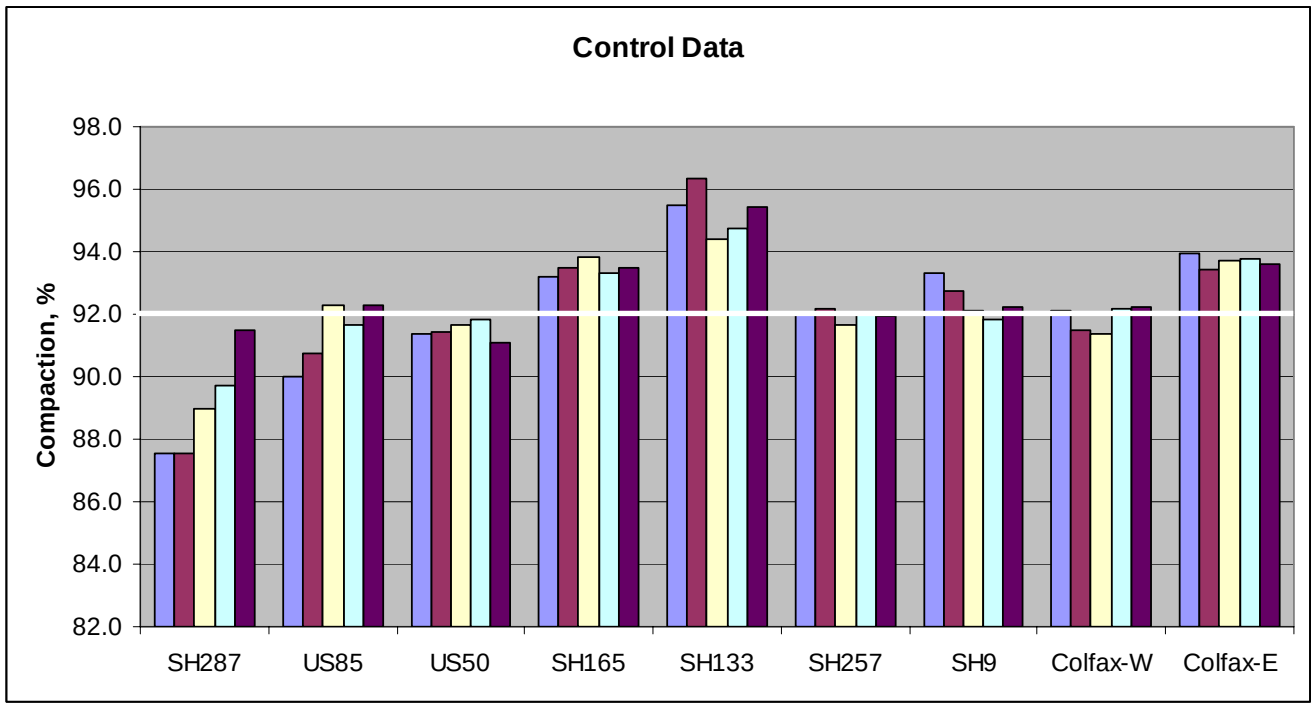


Figure 19 – Effect of Density Differences on Compaction for "Control" Data Set

8.0 CONCLUSIONS

1. The nuclear density gauge can detect differences in density due to mixture segregation.

2. Nine construction projects were tested using the nuclear gauge to detect segregation. Variability in density readings was high between sites and probably is due to differences in segregation between sites, as was expected.

3. A statistically significant difference in density was measured at all sites for the transverse "paver" density sets. The average difference in density was 5.4 pcf or approximately 3.8% of the pavement maximum unit weight.

4. A statistically significant difference in density was measured at eight of nine sites for the "strip" density sets. The average difference in density was 1.7 pcf or approximately 1.1% of the pavement maximum unit weight. Four of the nine sites had less than 92% compaction in the location of the strip segregation.

5. A statistically significant difference in density was measured at five of nine sites for the "visible" density sets. The average difference in density was 5.2 pcf or approximately 3.7% of the pavement maximum unit weight. Eight of the nine sites had less than 92% compaction in the location of the visible segregation.

6. A correlation between the nuclear density gauge and the PQI gauge was not apparent for the "strip," "visible," "control," or "paver" data sets. A relatively good relationship ($R^2 = 0.82$) was observed for the "stop" data set.

9.0 RECOMMENDATIONS

No effort was made to collect density data relative to the level of segregation observed and it is possible that in some cases, minimal or no segregation was present. Consequently, there is relatively high variability in the data relative to a correlation between presumed segregated areas and density differences.

The locations of the “strip” and “visible” segregation should be revisited. The level of segregation observed at each site should be recorded. The data should be re-analyzed to determine whether a correlation can be established between density differences and segregation.

A full-scale test pavement should be constructed with differing levels of segregation. Density tests should be conducted in the areas of segregation and compared with areas that are not segregated. A relationship should be developed between the levels of segregation and the density differences recorded.

REFERENCES

1. Colorado Department of Transportation Standard Specifications for Road and Bridge Construction, 1999.

2. Willoughby, Kim A., Mahoney, Joe P., Pierce, Linda M., Uhlmeyer, Jeff S., Anderson, Keith W., Read, Steven A., Muench, Stephen T., Thompson, Travis R., and Moore, Robyn, "Construction-Related Asphalt Concrete Pavement Temperature Differentials and the Corresponding Density Differentials", Washington State DOT, Report No. WA-RD 476.1, July 2001.

3. Harmelink, Donna, and Aschenbrener, Tim, "Extent of Top-Down Cracking in Colorado", Colorado DOT Report No. CDOT-DTD-R-2003-7, July 2003.

Appendix A - Nuclear Density Test Results

Colfax and Sheridan

Strip'	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#3-(#2+#4)/2	#3-avg
1	147.8	147.3	147.4	148.4	147.7		
2	143.2	144.8	144.9	144.1	144.3		
3	145.8	145.3	145.8	146.3	145.8		
4	148.0	149.3	146.3	148.3	148.0		
5	146.0	146.0	145.4	145.0	145.6		
					146.3	-0.3	-0.2

SH50

Strip'	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#3-(#2+#4)/2	#3-avg
1	137.4	135.8	139.3	136.5	137.3		
2	139.6	139.6	139.3	141.4	140.0		
3	141.0	142.8	142.3	141.6	141.9		
4	141.0	141.6	141.1	141.6	141.3		
5	138.4	139.3	139.8	141.0	139.6		
					140.0	1.3	0.8

US 85 Business

Strip'	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#3-(#2+#4)/2	#3-avg
1	138.6	137.8	137.9	136.1	137.6		
2	135.6	134.8	136.2	137.9	136.1		
3	137.4	137.9	135.3	134.1	136.2		
4	139.5	139.6	140.3	140.8	140.1		
5	142.1	141.3	141.1	142.1	141.7		
					138.3	-1.9	-1.3

US287

Strip'	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#3-(#2+#4)/2	#3-avg
1	139.8	145.2	143.7	143.4	143.0		
2	144.9	145.5	144.1	146.4	145.2		
3	136.8	137.2	136.5	137.0	136.9		
4	140.8	140.3	139.8	137.8	139.7		
5	140.2	141.1	140.0	139.8	140.3		
					141.0	-5.6	-3.7

SH257-Milliken

Strip'	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#3-(#2+#4)/2	#3-avg
1	139.4	140.5	138.5	141.5	140.0		
2	140.3	141.4	141.3	142.7	141.4		
3	136.9	136.9	137.1	137.7	137.2		
4	138.4	138.8	138.3	138.7	138.6		
5	136.5	137.4	136.7	136.7	136.8		
					138.8	-2.8	-1.9

SH165

Strip'	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#3-(#2+#4)/2	#3-avg
1	142.6	140.9	141.1	140.1	141.2		
2	141.4	142.7	142.0	143.1	142.3		
3	141.9	141.5	142.1	142.5	142.0		
4	142.2	143.6	142.5	142.8	142.8		
5	140.3	141.8	141.3	141.1	141.1		
					141.9	-0.5	-0.4

SH9

Strip'	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#3-(#2+#4)/2	#3-avg
1	137.6	137.0	139.2	138.2	138.0		
2	139.3	139.0	140.5	140.2	139.8		
3	136.9	137.6	136.7	137.2	137.1		
4	139.6	140.1	137.7	139.2	139.2		
5	137.7	136.9	138.0	136.7	137.3		
					138.3	-2.3	-1.6

SH133

Strip'	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#3-(#2+#4)/2	#3-avg
1	143.2	144.1	142.5	143.8	143.4		
2	142.7	142.7	142.4	142.6	142.6		
3	140.2	139.9	140.5	141.1	140.4		
4	140.3	140.6	140.2	139.7	140.2		
5	138.5	139.5	138.7	141.1	139.5		
					141.2	-1.0	-0.6

Colfax-Peoria

Strip'	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#3-(#2+#4)/2	#3-avg
1	146.4	147.2	146.4	149.4	147.4		
2	149.3	148.2	149.9	148.1	148.9		
3	148.1	147.0	147.9	148.5	147.9		
4	147.7	149.8	148.5	150.7	149.2		
5	147.2	148.4	148.8	148.3	148.2		
					148.3	-1.2	-0.8

Colfax at Sheridan

Control	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	Lo-Hi	Lo-Avg
1	144.2	143.7	144.4	144.3	144.2		
2	143.3	142.1	143.6	143.6	143.2		
3	142.9	143.4	142.5	143.3	143.0		
4	143.5	144.4	145.7	143.3	144.2		
5	143.6	144.1	145.4	144.1	144.3		
					143.8	-1.3	-0.7

Hwy 50

Control De	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	Lo-Hi	Lo-Avg
1	139.7	140.3	140.5	139.5	140.0		
2	139.7	140.0	140.7	139.7	140.0		
3	139.8	140.6	140.7	140.4	140.4		
4	139.8	140.8	141.5	140.7	140.7		
5	140.9	138.3	139.8	139.2	139.6		
					140.1	-1.1	-0.6

US 85 Business

Control De	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	Lo-Hi	Lo-Avg
1	137.4	137.7	137.7	136.9	137.4		
2	139.2	138.8	138.3	138.0	138.6		
3	141.4	140.3	140.3	141.5	140.9		
4	140.1	138.9	140.8	140.1	140.0		
5	141.5	139.8	140.2	142.1	140.9		
					139.6	-3.5	-2.1

US 287

Control De	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	Lo-Hi	Lo-Avg
1	135.3	134.1	135.4	134.6	134.9		
2	136.1	135.1	135.3	132.9	134.9		
3	138.1	135.9	137.1	137.0	137.0		
4	141.1	140.1	137.3	134.2	138.2		
5	140.2	140.3	140.9	142.0	140.9		
					137.2	-6.0	-2.3

SH 257-Milliken

Control De	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	Lo-Hi	Lo-Avg
1	141.7	139.0	140.0	139.8	140.1		
2	139.8	139.6	141.1	141.0	140.4		
3	139.9	140.9	138.4	139.1	139.6		
4	139.4	139.5	140.3	141.0	140.1		
5	141.4	138.4	140.4	139.8	140.0		
					140.0	-0.8	-0.4

SH 165

Control De	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	Lo-Hi	Lo-Avg
1	141.7	141.2	142.2	140.3	141.4		
2	141.8	142.3	143.2	140.1	141.9		
3	142.2	142.2	143.0	141.9	142.3		
4	142.0	140.4	141.9	141.9	141.6		
5	141.3	141.5	143.2	141.4	141.9		
					141.8	-1.0	0.1

SH 9

Control	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	Lo-Hi	Lo-Avg
1	141.0	141.7	0.0	0.0	141.4		
2	140.5	140.6	0.0	0.0	140.6		
3	139.6	139.5	0.0	0.0	139.6		
4	139.5	138.8	0.0	0.0	139.2		
5	139.7	139.8	0.0	0.0	139.8		
					140.1	0.6	-0.3

SH 133

Control De	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	Lo-Hi	Lo-Avg
1	143.0	143.1	143.7	143.7	143.4		
2	144.3	144.9	144.1	145.3	144.7		
3	141.9	138.9	142.5	143.5	141.7		
4	143.9	141.2	143.4	140.3	142.2		
5	144.0	144.0	143.7	141.4	143.3		
					143.0	1.1	0.2

Colfax-Peoria to Potomac

Control	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	Lo-Hi	Lo-Avg
1	148.2	145.9	147.5	147.5	147.3		
2	146.7	145.2	146.3	147.9	146.5		
3	146.9	147.0	147.0	147.0	147.0		
4	147.2	146.9	146.5	147.5	147.0		
5	147.1	147.2	146.2	146.5	146.8		
					146.9	-0.3	-0.2

Colfax at Sheridan

Visible	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#3-Hi	#3-avg
1	142.5	143.3	142.6	141.7	142.5		
2	140.1	140.4	144.9	140.6	141.5		
3	139.6	140.5	139.4	141.7	140.3		
4	142.6	142.7	144.0	143.3	143.2		
5	143.4	145.5	144.9	146.4	145.1		
					142.5	-4.7	-2.2

Hwy 50

Visible De	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#3-Hi	#3-avg
1	143.1	142.6	141.7	142.1	142.4		
2	138.3	139.9	140.7	140.1	139.8		
3	137.3	141.5	138.8	142.9	140.1		
4	142.3	141.7	142.4	144.2	142.7		
5	141.4	143.0	143.3	143.7	142.9		
					141.6	-2.7	-1.4

US 85 Business

Visible De	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#3-Hi	#3-avg
1	140.4	140.3	142.2	140.5	140.9		
2	136.4	135.1	141.8	142.1	138.9		
3	138.7	138.0	138.2	138.7	138.4		
4	135.8	135.9	137.9	137.1	136.7		
5	140.3	140.0	142.2	141.2	140.9		
					139.1	-2.5	-0.7

US 287

Visible De	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#3-Hi	#3-avg
1	141.7	141.4	139.5	140.8	140.9		
2	140.1	140.6	139.8	139.6	140.0		
3	140.9	140.7	139.5	141.4	140.6		
4	140.7	139.8	139.3	139.8	139.9		
5	141.1	140.9	139.6	140.6	140.6		
					140.4	-0.2	0.2

SH 257-Milliken

Visible De	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#3-Hi	#3-avg
1	135.8	139.6	135.5	138.0	137.2		
2	137.8	135.8	138.0	136.4	137.0		
3	129.8	128.5	130.3	132.7	130.3		
4	135.4	138.3	136.9	137.4	137.0		
5	139.7	140.3	139.8	140.1	140.0		
					136.3	-9.7	-6.0

SH 165

Visible De	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#3-Hi	#3-avg
1	140.7	139.1	144.3	141.0	141.3		
2	140.4	140.4	141.8	140.1	140.7		
3	140.5	141.6	140.7	141.5	141.1		
4	140.4	140.1	140.3	141.9	140.7		
5	142.9	139.9	139.5	140.5	140.7		
					140.9	0.4	0.2

SH 9

Visible	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#3-Hi	#3-avg
1	135.6	137.0	134.6	135.8	135.8		
2	139.7	141.0	139.7	141.2	140.4		
3	133.7	134.0	132.9	135.4	134.0		
4	138.8	138.3	136.9	138.5	138.1		
5	137.6	137.6	138.9	138.8	138.2		
					137.3	-6.4	-3.3

SH 133

Visible De	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#3-Hi	#3-avg
1	139.2	138.5	138.4	138.2	138.6		
2	135.6	139.5	139.2	138.8	138.3		
3	136.9	136.8	137.4	138.6	137.4		
4	138.5	138.7	137.8	137.5	138.1		
5	138.4	139.5	137.3	137.0	138.1		
					138.1	-1.1	-0.7

Colfax-Peoria to Potomac

Visible	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#3-Hi	#3-avg
1	147.1	145.9	146.7	145.1	146.2		
2	145.4	143.6	146.0	143.0	144.5		
3	140.0	143.2	140.8	147.7	142.9		
4	147.2	144.4	146.3	145.8	145.9		
5	142.5	144.1	144.7	148.0	144.8		
					144.9	-3.3	-1.9

Colfax at Sheridan

Stop	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#3-Hi	#3-avg
1	145.5	144.5	0.0	0.0	145.0		
2	146.0	145.8	0.0	0.0	145.9		
3	145.9	145.8	0.0	0.0	145.9		
4	145.4	144.6	0.0	0.0	145.0		
5	144.1	144.1	0.0	0.0	144.1		
6	0.0	0.0	0.0	0.0	0.0		
7	0.0	0.0	0.0	0.0	0.0		
8	0.0	0.0	0.0	0.0	0.0		
9	0.0	0.0	0.0	0.0	0.0		
10	0.0	0.0	0.0	0.0	0.0		
11	0.0	0.0	0.0	0.0	0.0		
					145.2	0.0	0.7

Hwy 50

Stop Dens	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#5-Hi	#5-avg
1	143.8	143.2	143.9	144.0	143.7		
2	143.7	143.6	142.2	142.3	143.0		
3	143.3	142.6	143.8	143.2	143.2		
4	139.9	141.8	143.8	141.0	141.6		
5	140.3	140.8	139.8	140.6	140.4		
6	140.2	139.6	138.3	140.8	139.7		
7	139.2	139.6	139.3	139.0	139.3		
8	139.6	139.2	140.1	140.4	139.8		
9	138.4	139.6	139.3	139.9	139.3		
10	139.5	138.5	139.9	141.1	139.8		
11	139.9	141.6	141.5	142.2	141.3		
					141.0	-3.3	-0.6

US 85 Business

Stop Dens	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#5-Hi	#5-avg
1	136.1	137.9	136.4	136.0	136.6		
2	137.9	137.1	135.0	134.0	136.0		
3	129.1	129.8	136.3	136.0	132.8		
4	131.1	131.3	136.3	134.1	133.2		
5	134.1	134.2	133.0	133.0	133.6		
6	133.6	133.9	135.1	134.0	134.2		
7	136.7	136.8	137.3	137.0	137.0		
8	134.5	135.0	135.2	135.0	134.9		
9	139.5	138.9	139.9	139.8	139.5		
10	139.3	138.1	139.5	139.0	139.0		
11	132.4	131.8	135.5	135.0	133.7		
					135.5	-5.9	-1.9

US 287

Stop Dens	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#5-Hi	#5-avg
1	144.8	143.9	141.7	142.0	143.1		
2	143.3	142.9	141.6	141.5	142.3		
3	144.2	142.5	142.6	141.9	142.8		
4	141.6	140.3	142.6	144.7	142.3		
5	141.4	140.9	143.7	141.4	141.9		
6	141.5	144.3	141.6	143.5	142.7		
7	143.3	143.2	143.0	143.9	143.4		
8	139.1	144.0	142.4	141.5	141.8		
9	142.2	143.1	142.3	143.1	142.7		
10	141.3	142.6	145.0	141.1	142.5		
11	140.9	141.4	145.0	143.7	142.8		
					142.6	-1.5	-0.7

SH 257-Milliken

Stop Dens	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#5-Hi	#5-avg
1	140.6	139.6	141.0	139.3	140.1		
2	140.6	139.5	140.1	139.7	140.0		
3	141.4	140.1	140.2	139.8	140.4		
4	141.2	140.0	140.2	141.3	140.7		
5	139.8	140.9	140.2	140.5	140.4		
6	140.1	139.9	141.3	139.0	140.1		
7	139.0	137.8	138.6	137.0	138.1		
8	139.5	138.2	140.4	138.8	139.2		
9	140.5	138.2	140.0	137.4	139.0		
10	139.1	139.4	139.3	138.1	139.0		
11	142.3	141.7	142.8	142.6	142.4		
					139.9	-2.0	0.4

SH 165

Stop Dens	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#5-Hi	#5-avg
1	143.0	142.8	140.5	141.0	141.8		
2	143.9	143.9	141.0	142.1	142.7		
3	143.9	142.2	141.6	140.1	142.0		
4	139.5	141.1	141.6	140.1	140.6		
5	141.1	139.0	140.9	140.4	140.4		
6	139.5	140.2	138.9	139.3	139.5		
7	134.2	138.5	139.6	138.4	137.7		
8	139.6	141.0	138.5	140.1	139.8		
9	133.2	140.7	140.0	140.0	138.5		
10	141.5	141.5	139.8	141.9	141.2		
11	143.2	141.9	142.5	142.1	142.4		
					140.6	-2.1	-0.2

SH 9

Stop	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#5-Hi	#5-avg
1	140.7	141.1	140.6	141.8	141.1		
2	140.7	140.1	141.4	140.4	140.7		
3	141.0	139.5	139.8	139.6	140.0		
4	139.0	138.0	139.8	140.0	139.2		
5	140.2	133.8	140.7	144.8	139.9		
6	139.8	144.0	141.7	141.4	141.7		
7	142.2	141.7	142.1	142.8	142.2		
8	142.3	140.8	143.3	139.8	141.6		
9	146.7	142.5	141.6	142.0	143.2		
10	146.3	140.5	141.0	141.5	142.3		
11	142.9	140.8	141.7	140.1	141.4		
					141.2	-3.3	-1.3

SH 133

Stop Dens	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#5-Hi	#5-avg
1	145.2	144.1	144.6	143.9	144.5		
2	143.9	144.9	144.1	143.8	144.2		
3	144.0	144.5	144.6	144.2	144.3		
4	144.7	144.2	144.6	143.8	144.3		
5	144.5	143.3	142.7	143.1	143.4		
6	143.5	143.5	144.4	141.9	143.3		
7	143.5	142.9	143.2	143.2	143.2		
8	142.6	142.7	142.5	141.0	142.2		
9	142.3	143.1	142.0	140.8	142.1		
10	140.5	142.7	141.6	140.6	141.4		
11	141.5	140.9	140.6	142.6	141.4		
					143.1	-1.0	0.3

Colfax-Peoria to Potomac

Stop	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	#5-Hi	#5-avg
1	0.0	0.0	0.0	0.0	0.0		
2	0.0	0.0	0.0	0.0	0.0		
3	0.0	0.0	0.0	0.0	0.0		
4	0.0	0.0	0.0	0.0	0.0		
5	0.0	0.0	0.0	0.0	0.0		
6	0.0	0.0	0.0	0.0	0.0		
7	0.0	0.0	0.0	0.0	0.0		
8	0.0	0.0	0.0	0.0	0.0		
9	0.0	0.0	0.0	0.0	0.0		
10	0.0	0.0	0.0	0.0	0.0		
11	0.0	0.0	0.0	0.0	0.0		
					0.0	0.0	0.0

Colfax at Sheridan

Paver	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	Lo-Hi	Lo-Avg
1	129.2	130.8	130.2	129.9	130.0		
2	137.3	133.7	133.7	134.1	134.7		
3	143.5	138.2	138.0	136.5	139.1		
4	139.7	143.7	138.0	137.5	139.7		
5	148.7	146.2	146.1	143.7	146.2		
6	146.2	148.1	145.0	145.7	146.3		
7	148.9	156.5	145.8	145.6	149.2		
8	144.3	143.3	144.3	142.9	143.7		
9	143.9	144.0	143.3	142.2	143.4		
10	148.8	144.1	143.3	142.2	144.6		
11	143.2	144.9	144.0	145.0	144.3		
12	145.7	145.3	146.8	145.0	145.7		
13	144.6	146.0	145.4	146.0	145.5		
14	146.3	147.9	145.1	148.4	146.9		
15	144.6	140.3	143.0	142.8	142.7		
16	142.8	143.0	NA	NA	142.9		
17	142.2	139.7	142.1	142.7	141.7		
					145.0	-7.2	-5.3

Hwy 50

Paver Den	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	Lo-Hi	Lo-Avg
1	140.5	139.5	138.9	138.1	139.3		
2	141.1	138.8	141.8	142.8	141.1		
3	141.1	140.6	141.5	140.7	141.0		
4	142.5	139.4	141.5	139.8	140.8		
5	143.6	142.9	142.6	143.1	143.1		
6	140.0	142.2	141.2	141.9	141.3		
7	133.7	135.1	135.2	134.6	134.7		
8	138.9	139.3	140.1	139.1	139.4		
9	139.6	138.3	139.1	138.6	138.9		
10	139.5	140.2	141.0	139.3	140.0		
11	139.2	140.5	141.3	138.6	139.9		
12	139.5	139.7	140.3	139.6	139.8		
13	139.9	141.7	140.3	141.0	140.7		
14	139.7	139.9	141.2	139.5	140.1		
15	143.4	140.0	142.5	141.9	142.0		
16	145.2	142.2	144.2	143.8	143.9		
					139.8	-8.4	-5.2

US 85 Business

Paver Den	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	Lo-Hi	Lo-Avg
1	130.5	133.4	130.9	130.1	131.2		
2	135.8	134.4	135.2	134.8	135.1		
3	137.0	137.2	136.8	136.5	136.9		
4	138.1	135.3	136.8	136.3	136.6		
5	136.3	135.6	139.1	136.2	136.8		
6	137.3	136.1	137.0	136.1	136.6		
7	134.5	135.9	135.6	134.9	135.2		
8	137.0	135.9	137.0	136.9	136.7		
9	139.5	139.3	137.1	138.6	138.6		
10	136.1	135.1	136.4	135.8	135.9		
11	138.2	137.1	137.6	136.9	137.5		
12	134.1	137.3	137.1	137.0	136.4		
13	134.1	134.5	135.3	136.4	135.1		
14	134.2	135.4	136.9	133.8	135.1		
15	135.2	135.9	134.9	134.1	135.0		
16	135.1	136.3	134.7	134.7	135.2		
17	135.4	134.6	135.8	135.4	135.3		
18	137.8	137.0	136.0		136.9		
19	140.0	139.1	139.8	139.6	139.6		
20	141.2	139.8	140.4	141.9	140.8		
21	134.6	133.8	140.0	139.2	136.9		
22	139.9	138.0	139.5	139.0	139.1		
23	138.1	138.3	137.2	137.4	137.8		
24	139.5	140.0	140.6	138.9	139.8		
25	143.3	141.3	138.9	140.2	140.9		
26	144.8	143.9	144.0	143.7	144.1		
					136.9	-5.8	-1.8

US 287

Paver Den	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	Lo-Hi	Lo-Avg
1	137.3	139.4	136.5	139.8	138.3		
2	142.7	142.6	140.9	143.3	142.4		
3	145.2	143.9	143.3	144.6	144.3		
4	144.6	144.7	143.3	144.2	144.2		
5	146.0	144.7	144.9	143.7	144.8		
6	143.3	142.4	144.4	143.9	143.5		
7	143.5	142.5	143.3	143.2	143.1		
8	144.1	144.7	144.9	145.0	144.7		
9	143.2	141.1	145.3	143.2	143.2		
10	144.0	145.2	144.9	144.9	144.8		
11	146.9	145.5	145.0	145.6	145.8		
12	145.4	143.9	147.4	144.1	145.2		
13	143.7	143.4	144.2	143.3	143.7		
14	141.1	142.2	142.2	141.2	141.7		
15	143.3	142.6	142.4	143.7	143.0		
16	142.1	144.1	143.2	143.8	143.3		
17	145.0	143.7	144.9	143.9	144.4		
18	0.0	0.0	0.0	0.0	0.0		
19	0.0	0.0	0.0	0.0	0.0		
20	0.0	0.0	0.0	0.0	0.0		
21	0.0	0.0	0.0	0.0	0.0		
22	0.0	0.0	0.0	0.0	0.0		
23	0.0	0.0	0.0	0.0	0.0		
24	0.0	0.0	0.0	0.0	0.0		
25	0.0	0.0	0.0	0.0	0.0		
26	0.0	0.0	0.0	0.0	0.0		
					144.1	-4.1	-2.4

SH 257-Milliken

Paver Den	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	Lo-Hi	Lo-Avg
1	141.2	140.2	0.0	0.0	140.7		
2	140.4	140.2	0.0	0.0	140.3		
3	139.5	140.6	0.0	0.0	140.1		
4	146.0	140.5	0.0	0.0	143.3		
5	139.8	140.6	0.0	0.0	140.2		
6	142.5	139.2	0.0	0.0	140.9		
7	143.2	141.5	0.0	0.0	142.4		
8	139.5	142.5	0.0	0.0	141.0		
9	139.8	140.4	0.0	0.0	140.1		
10	139.8	140.0	0.0	0.0	139.9		
11	140.1	141.1	0.0	0.0	140.6		
12	140.2	142.4	0.0	0.0	141.3		
13	139.8	140.0	0.0	0.0	139.9		
14	138.7	138.0	0.0	0.0	138.4		
15	146.1	146.9	0.0	0.0	146.5		
16	139.2	138.9	0.0	0.0	139.1		
17	141.0	140.2	0.0	0.0	140.6		
18	140.7	140.1	0.0	0.0	140.4		
19	139.2	140.1	0.0	0.0	139.7		
20	141.2	142.5	0.0	0.0	141.9		
21	140.0	142.5	0.0	0.0	141.3		
22	141.1	140.6	0.0	0.0	140.9		
23	139.2	139.9	0.0	0.0	139.6		
24	139.9	139.2	0.0	0.0	139.6		
25	138.4	138.4	0.0	0.0	138.4		
26	133.3	135.6	0.0	0.0	134.5		
					140.9	-8.2	-2.5

SH 165

Paver Den	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	Lo-Hi	Lo-Avg
1	134.1	135.7	136.1	136.6	135.6		
2	136.0	134.6	135.5	135.1	135.3		
3	136.7	137.2	136.6	137.5	137.0		
4	137.9	138.9	136.6	140.0	138.4		
5	141.7	141.0	141.0	140.0	140.9		
6	140.9	141.4	141.5	141.5	141.3		
7	142.6	142.6	141.6	142.6	142.4		
8	141.7	141.0	142.8	142.3	142.0		
9	142.2	142.2	142.6	142.1	142.3		
10	141.6	142.6	142.0	143.7	142.5		
11	140.9	141.3	143.2	143.5	142.2		
12	142.4	141.8	142.8	142.4	142.4		
13	143.2	141.0	142.8	142.6	142.4		
14	141.0	141.6	143.4	142.0	142.0		
15	140.0	140.8	141.4	141.7	141.0		
16	139.5	141.5	142.5	141.5	141.3		
17	141.9	141.3	140.1	142.0	141.3		
18	139.6	140.7	138.4	140.1	139.7		
19	138.7	140.6	139.1	138.7	139.3		
20	137.6	138.6	137.5	138.6	138.1		
21	140.4	141.5	138.5	138.3	139.7		
22	136.4	137.6	138.1	136.1	137.1		
23	136.4	136.0	136.1	135.4	136.0		
24	129.3	133.4	132.5	134.4	132.4		
					141.1	-4.4	-3.0

SH 9

Paver	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	Lo-Hi	Lo-Avg
1	133.9	136.5	134.2	136.8	135.4		
2	130.3	138.3	140.9	140.0	137.4		
3	139.4	136.7	138.2	139.5	138.5		
4	139.1	141.0	138.2	139.6	139.5		
5	139.8	140.2	139.6	139.7	139.8		
6	139.4	140.3	141.1	140.9	140.4		
7	139.1	138.3	140.4	139.5	139.3		
8	139.1	139.6	138.1	139.4	139.1		
9	138.3	137.9	138.6	137.9	138.2		
10	138.1	139.9	138.9	140.2	139.3		
11	137.6	139.9	137.6	139.7	138.7		
12	139.8	139.3	139.0	138.7	139.2		
13	137.3	139.7	138.8	140.0	139.0		
14	139.6	139.4	137.5	134.4	137.7		
15	136.3	137.9	135.7	138.6	137.1		
16	137.7	136.3	136.0	139.7	137.4		
17	136.2	133.1	136.3	134.9	135.1		
18	128.9	127.7	129.6	126.1	128.1		
19	120.6	123.9	120.8	127.5	123.2		
					138.8	-3.3	-1.7

SH 133

Paver Den	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	Lo-Hi	Lo-Avg
1	137.7	137.5	134.1	134.3	135.9		
2	137.0	135.7	137.6	136.2	136.6		
3	135.2	136.9	138.9	139.4	137.6		
4	139.7	138.6	138.9	137.5	138.7		
5	138.8	138.9	138.3	139.5	138.9		
6	140.7	138.7	139.8	138.8	139.5		
7	139.4	140.8	138.3	136.5	138.8		
8	140.8	141.5	137.7	138.1	139.5		
9	141.0	141.7	140.6	139.2	140.6		
10	140.9	140.1	140.8	139.4	140.3		
11	140.9	139.6	141.1	140.4	140.5		
12	141.6	142.7	138.4	140.7	140.9		
13	139.8	142.4	141.8	140.3	141.1		
14	140.7	142.4	136.5	139.8	139.9		
15	142.5	141.6	140.4	143.2	141.9		
16	142.1	141.1	142.7	136.6	140.6		
17	141.3	142.2	141.3	140.6	141.4		
18	140.9	141.1	139.7	140.3	140.5		
19	139.8	139.8	139.4	138.9	139.5		
20	135.1	135.6	135.0	135.0	135.2		
21	133.1	134.1	134.6	131.8	133.4		
22	127.2	132.9	131.4	131.6	130.8		
23	139.4	146.8	0.0	0.0	71.6		
					139.4	-3.3	-0.7

Colfax-Peoria to Potomac

Paver	Replicate 1		Replicate 2				
Position	Reading 1	Reading 2	Reading 3	Reading 4	Avg	Lo-Hi	Lo-Avg
1	139.6	139.9	138.6	139.7	139.5		
2	141.9	142.7	139.9	141.8	141.6		
3	144.7	146.4	145.4	144.0	145.1		
4	145.5	146.0	145.4	147.0	146.0		
5	146.6	147.2	147.0	147.7	147.1		
6	147.6	148.6	148.5	146.5	147.8		
7	147.5	147.6	146.5	147.9	147.4		
8	146.7	145.3	146.0	145.7	145.9		
9	146.3	145.2	146.6	145.0	145.8		
10	145.4	145.2	143.9	145.1	144.9		
11	139.9	145.5	145.9	145.0	144.1		
12	145.8	147.6	146.9	149.8	147.5		
13	148.5	147.7	148.5	146.2	147.7		
14	147.3	146.8	140.7	147.3	145.5		
15	145.8	140.7	145.3	145.9	144.4		
16	145.2	142.8	144.4	144.2	144.2		
17	142.2	139.7	142.1	142.7	141.7		
					146.3	-3.7	-2.3

Appendix B – ANOVA Nuclear Density Tests

Colfax and Sheridan
Strip'
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	590.9	147.725	0.249167
2	4	577	144.25	0.616667
3	4	583.2	145.8	0.166667
4	4	591.9	147.975	1.555833
5	4	582.4	145.6	0.24

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	39.097	4	9.77425	17.27917	1.73E-05	3.055568	Yes
Within Groups	8.485	15	0.565667				
Total	47.582	19					

SH50
Strip'
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	549	137.25	2.296667
2	4	559.9	139.975	0.9225
3	4	567.7	141.925	0.6225
4	4	565.3	141.325	0.1025
5	4	558.5	139.625	1.175833

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	52.652	4	13.163	12.85449	9.69E-05	3.055568	Yes
Within Groups	15.36	15	1.024				
Total	68.012	19					

US 85 Business
Strip'
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	550.4	137.6	1.126667
2	4	544.5	136.125	1.729167
3	4	544.7	136.175	3.1825
4	4	560.2	140.05	0.376667
5	4	566.6	141.65	0.276667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	96.077	4	24.01925	17.94714	1.38E-05	3.055568	Yes
Within Groups	20.075	15	1.338333				
Total	116.152	19					

US287
Strip'
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	572.1	143.025	5.2425
2	4	580.9	145.225	0.9425
3	4	547.5	136.875	0.089167
4	4	558.7	139.675	1.729167
5	4	561.1	140.275	0.329167

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	164.988	4	41.247	24.75068	1.86E-06	3.055568	Yes
Within Groups	24.9975	15	1.6665				
Total	189.9855	19					

SH257-Milliken
Strip'
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	559.9	139.975	1.7025
2	4	565.7	141.425	0.969167
3	4	548.6	137.15	0.143333
4	4	554.2	138.55	0.056667
5	4	547.3	136.825	0.155833

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	59.823	4	14.95575	24.69983	1.89E-06	3.055568	Yes
Within Groups	9.0825	15	0.6055				
Total	68.9055	19					

SH165
Strip'
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	564.7	141.175	1.089167
2	4	569.2	142.3	0.566667
3	4	568	142	0.173333
4	4	571.1	142.775	0.3625
5	4	564.5	141.125	0.389167

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	8.235	4	2.05875	3.988537	0.021253	3.055568	Yes
Within Groups	7.7425	15	0.516167				
Total	15.9775	19					

SH9
Strip'
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	552	138	0.88
2	4	559	139.75	0.51
3	4	548.4	137.1	0.153333
4	4	556.6	139.15	1.07
5	4	549.3	137.325	0.389167

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	21.198	4	5.2995	8.825146	0.000717	3.055568	Yes
Within Groups	9.0075	15	0.6005				
Total	30.2055	19					

SH133
Strip'
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	573.6	143.4	0.5
2	4	570.4	142.6	0.02
3	4	561.7	140.425	0.2625
4	4	560.8	140.2	0.14
5	4	557.8	139.45	1.396667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	45.848	4	11.462	24.71146	1.88E-06	3.055568	Yes
Within Groups	6.9575	15	0.463833				
Total	52.8055	19					

Colfax-Peoria
Strip'
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	589.4	147.35	2.01
2	4	595.5	148.875	0.7625
3	4	591.5	147.875	0.4025
4	4	596.7	149.175	1.7825
5	4	592.7	148.175	0.469167

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	8.778	4	2.1945	2.021959	0.142855	3.055568	No
Within Groups	16.28	15	1.085333				
Total	25.058	19					

Colfax at Sheridan
Control
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	576.6	144.15	0.096667
2	4	572.6	143.15	0.51
3	4	572.1	143.025	0.169167
4	4	576.9	144.225	1.195833
5	4	577.2	144.3	0.593333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	6.287	4	1.57175	3.06384	0.049603	3.055568	Barely
Within Groups	7.695	15	0.513				
Total	13.982	19					

Hwy 50
Control Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	560	140	0.226667
2	4	560.1	140.025	0.2225
3	4	561.5	140.375	0.1625
4	4	562.8	140.7	0.486667
5	4	558.2	139.55	1.19

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	2.997	4	0.74925	1.637109	0.216688	3.055568	No
Within Groups	6.865	15	0.457667				
Total	9.862	19					

US 85 Business
Control Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	549.7	137.425	0.1425
2	4	554.3	138.575	0.2825
3	4	563.5	140.875	0.4425
4	4	559.9	139.975	0.6225
5	4	563.6	140.9	1.166667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	36.9	4	9.225	17.36198	1.69E-05	3.055568	Yes
Within Groups	7.97	15	0.531333				
Total	44.87	19					

US 287
Control Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	539.4	134.85	0.376667
2	4	539.4	134.85	1.876667
3	4	548.1	137.025	0.809167
4	4	552.7	138.175	9.609167
5	4	563.4	140.85	0.683333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	101.345	4	25.33625	9.48568	0.000497	3.055568	Yes
Within Groups	40.065	15	2.671				
Total	141.41	19					

SH 257-Milliken
Control Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	560.5	140.125	1.289167
2	4	561.5	140.375	0.615833
3	4	558.3	139.575	1.155833
4	4	560.2	140.05	0.563333
5	4	560	140	1.573333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	1.345	4	0.33625	0.323473	0.857857	3.055568	No
Within Groups	15.5925	15	1.0395				
Total	16.9375	19					

SH 165
Control Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	565.4	141.35	0.656667
2	4	567.4	141.85	1.696667
3	4	569.3	142.325	0.2225
4	4	566.2	141.55	0.59
5	4	567.4	141.85	0.816667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	2.178	4	0.5445	0.683616	0.614161	3.055568	No
Within Groups	11.9475	15	0.7965				
Total	14.1255	19					

SH 9
Control
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	2	282.7	141.35	0.245
2	2	281.1	140.55	0.005
3	2	279.1	139.55	0.005
4	2	278.3	139.15	0.245
5	2	279.5	139.75	0.005

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	6.176	4	1.544	15.28713	0.005201	5.192168	Yes
Within Groups	0.505	5	0.101				
Total	6.681	9					

SH 133
Control Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	573.5	143.375	0.1425
2	4	578.6	144.65	0.303333
3	4	566.8	141.7	3.92
4	4	568.8	142.2	2.98
5	4	573.1	143.275	1.5825

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	21.043	4	5.26075	2.946099	0.055593	3.055568	No
Within Groups	26.785	15	1.785667				
Total	47.828	19					

Colfax-Peoria to Potomac
Control
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	589.1	147.275	0.949167
2	4	586.1	146.525	1.2425
3	4	587.9	146.975	0.0025
4	4	588.1	147.025	0.1825
5	4	587	146.75	0.23

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	1.298	4	0.3245	0.622442	0.653559	3.055568	No
Within Groups	7.82	15	0.521333				
Total	9.118	19					

Colfax at Sheridan
Visible
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	570.1	142.525	0.429167
2	4	566	141.5	5.18
3	4	561.2	140.3	1.1
4	4	572.6	143.15	0.416667
5	4	580.2	145.05	1.59

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	51.062	4	12.7655	7.323167	0.001772	3.055568	Yes
Within Groups	26.1475	15	1.743167				
Total	77.2095	19					

Hwy 50
Visible Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	569.5	142.375	0.369167
2	4	559	139.75	1.05
3	4	560.5	140.125	6.4425
4	4	570.6	142.65	1.163333
5	4	571.4	142.85	1.016667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	35.405	4	8.85125	4.407261	0.014864	3.055568	Yes
Within Groups	30.125	15	2.008333				
Total	65.53	19					

US 85 Business
Visible Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	563.4	140.85	0.816667
2	4	555.4	138.85	13.11
3	4	553.6	138.4	0.126667
4	4	546.7	136.675	1.015833
5	4	563.7	140.925	0.9825

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	51.273	4	12.81825	3.99281	0.021174	3.055568	Yes
Within Groups	48.155	15	3.210333				
Total	99.428	19					

US 287
Visible Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	563.4	140.85	0.95
2	4	560.1	140.025	0.189167
3	4	562.5	140.625	0.649167
4	4	559.6	139.9	0.34
5	4	562.2	140.55	0.443333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	2.663	4	0.66575	1.294394	0.316387	3.055568	No
Within Groups	7.715	15	0.514333				
Total	10.378	19					

SH 257-Milliken
Visible Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	548.9	137.225	3.749167
2	4	548	137	1.146667
3	4	521.3	130.325	3.0825
4	4	548	137	1.473333
5	4	559.9	139.975	0.075833

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	204.167	4	51.04175	26.78654	1.12E-06	3.055568	Yes
Within Groups	28.5825	15	1.9055				
Total	232.7495	19					

SH 165
Visible Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	565.1	141.275	4.7625
2	4	562.7	140.675	0.5825
3	4	564.3	141.075	0.309167
4	4	562.7	140.675	0.6825
5	4	562.8	140.7	2.32

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	1.242	4	0.3105	0.179342	0.945561	3.055568	No
Within Groups	25.97	15	1.731333				
Total	27.212	19					

SH 9
Visible
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	543	135.75	0.97
2	4	561.6	140.4	0.66
3	4	536	134	1.086667
4	4	552.5	138.125	0.709167
5	4	552.9	138.225	0.5225

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	97.755	4	24.43875	30.94818	4.35E-07	3.055568	Yes
Within Groups	11.845	15	0.789667				
Total	109.6	19					

SH 133
Visible Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	554.3	138.575	0.189167
2	4	553.1	138.275	3.2625
3	4	549.7	137.425	0.6825
4	4	552.5	138.125	0.3225
5	4	552.2	138.05	1.296667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	2.858	4	0.7145	0.620944	0.654542	3.055568	No
Within Groups	17.26	15	1.150667				
Total	20.118	19					

Colfax-Peoria to Potomac
Visible
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	584.8	146.2	0.786667
2	4	578	144.5	2.04
3	4	571.7	142.925	11.9825
4	4	583.7	145.925	1.369167
5	4	579.3	144.825	5.3425

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	27.215	4	6.80375	1.580736	0.230529	3.055568	No
Within Groups	64.5625	15	4.304167				
Total	91.7775	19					

Colfax at Sheridan
Stop
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	2	290	145	0.5
2	2	291.8	145.9	0.02
3	2	291.7	145.85	0.005
4	2	290	145	0.32
5	2	288.2	144.1	0

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	4.396	4	1.099	6.502959	0.032325	5.192168	Yes
Within Groups	0.845	5	0.169				
Total	5.241	9					

Hwy 50
Stop Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	574.9	143.725	0.129167
2	4	571.8	142.95	0.656667
3	4	572.9	143.225	0.2425
4	4	566.5	141.625	2.709167
5	4	561.5	140.375	0.189167
6	4	558.9	139.725	1.1425
7	4	557.1	139.275	0.0625
8	4	559.3	139.825	0.2825
9	4	557.2	139.3	0.42
10	4	559	139.75	1.156667
11	4	565.2	141.3	0.966667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	109.9355	10	10.99355	15.19686	1.15E-09	2.132504	Yes
Within Groups	23.8725	33	0.723409				
Total	133.808	43					

US 85 Business
Stop Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	546.4	136.6	0.78
2	4	544	136	3.273333
3	4	531.2	132.8	15.06
4	4	532.8	133.2	6.146667
5	4	534.3	133.575	0.4425
6	4	536.6	134.15	0.43
7	4	547.8	136.95	0.07
8	4	539.7	134.925	0.089167
9	4	558.1	139.525	0.2025
10	4	555.9	138.975	0.3825
11	4	534.7	133.675	3.409167

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	214.4268	10	21.44268	7.788113	2.99E-06	2.132504	Yes
Within Groups	90.8575	33	2.753258				
Total	305.2843	43					

US 287
Stop Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	572.4	143.1	2.233333
2	4	569.3	142.325	0.829167
3	4	571.2	142.8	0.966667
4	4	569.2	142.3	3.446667
5	4	567.4	141.85	1.576667
6	4	570.9	142.725	1.949167
7	4	573.4	143.35	0.15
8	4	567	141.75	4.19
9	4	570.7	142.675	0.2425
10	4	570	142.5	3.22
11	4	571	142.75	3.736667

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	9.345455	10	0.934545	0.456061	0.906006	2.132504	No
Within Groups	67.6225	33	2.049167				
Total	76.96795	43					

SH 257-Milliken
Stop Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	560.5	140.125	0.649167
2	4	559.9	139.975	0.235833
3	4	561.5	140.375	0.495833
4	4	562.7	140.675	0.449167
5	4	561.4	140.35	0.216667
6	4	560.3	140.075	0.895833
7	4	552.4	138.1	0.786667
8	4	556.9	139.225	0.895833
9	4	556.1	139.025	2.149167
10	4	555.9	138.975	0.355833
11	4	569.4	142.35	0.23

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	49.69545	10	4.969545	7.42731	4.9E-06	2.132504	Yes
Within Groups	22.08	33	0.669091				
Total	71.77545	43					

SH 165
Stop Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	567.3	141.825	1.589167
2	4	570.9	142.725	2.0425
3	4	567.8	141.95	2.47
4	4	562.3	140.575	0.9025
5	4	561.4	140.35	0.896667
6	4	557.9	139.475	0.295833
7	4	550.7	137.675	5.6625
8	4	559.2	139.8	1.086667
9	4	553.9	138.475	12.47583
10	4	564.7	141.175	0.875833
11	4	569.7	142.425	0.329167

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	106.1518	10	10.61518	4.078959	0.001044	2.132504	Yes
Within Groups	85.88	33	2.602424				
Total	192.0318	43					

SH 9
Stop
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	564.2	141.05	0.296667
2	4	562.6	140.65	0.31
3	4	559.9	139.975	0.4825
4	4	556.8	139.2	0.826667
5	4	559.5	139.875	20.64917
6	4	566.9	141.725	2.995833
7	4	568.8	142.2	0.206667
8	4	566.2	141.55	2.416667
9	4	572.8	143.2	5.58
10	4	569.3	142.325	7.189167
11	4	565.5	141.375	1.4625

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	57.10045	10	5.710045	1.480827	0.190565	2.132504	No
Within Groups	127.2475	33	3.855985				
Total	184.348	43					

SH 133
Stop Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
1	4	577.8	144.45	0.336667
2	4	576.7	144.175	0.249167
3	4	577.3	144.325	0.075833
4	4	577.3	144.325	0.169167
5	4	573.6	143.4	0.6
6	4	573.3	143.325	1.0825
7	4	572.8	143.2	0.06
8	4	568.8	142.2	0.646667
9	4	568.2	142.05	0.91
10	4	565.4	141.35	1.056667
11	4	565.6	141.4	0.78

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	55.97636	10	5.597636	10.31966	1.33E-07	2.132504	Yes
Within Groups	17.9	33	0.542424				
Total	73.87636	43					

Colfax - Peoria
Stop Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*

Stop Densities Not Available

Testing Conducted After Paving was Completed

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups							
Within Groups							
Total							

Colfax at Sheridan
Paver
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
4	4	558.9	139.725	7.909167
5	4	584.7	146.175	4.169167
6	4	585	146.25	1.763333
7	4	596.8	149.2	25.96667
8	4	574.8	143.7	0.506667
9	4	573.4	143.35	0.683333
10	4	578.4	144.6	8.446667
11	4	577.1	144.275	0.715833
12	4	582.8	145.7	0.62
13	4	582	145.5	0.44
14	4	587.7	146.925	2.2825

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	231.7518	10	23.17518	4.764694	0.000306	2.132502	Yes
Within Groups	160.51	33	4.863939				
Total	392.2618	43					

ANOVA

Hwy 50
Paver Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
4	4	563.2	140.8	2.113333
5	4	572.2	143.05	0.176667
6	4	565.3	141.325	0.955833
7	4	538.6	134.65	0.47
8	4	557.4	139.35	0.276667
9	4	555.6	138.9	0.326667
10	4	560	140	0.593333
11	4	559.6	139.9	1.5
12	4	559.1	139.775	0.129167
13	4	562.9	140.725	0.629167

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	169.2273	9	18.80303	26.22154	7.49E-12	2.210697	Yes
Within Groups	21.5125	30	0.717083				
Total	190.7398	39					

US 85 Business
Paver Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
4	4	546.5	136.625	1.355833
5	4	547.2	136.8	2.446667
6	4	546.5	136.625	0.3825
7	4	540.9	135.225	0.409167
8	4	546.8	136.7	0.286667
9	4	554.5	138.625	1.1825
10	4	543.4	135.85	0.31
11	4	549.8	137.45	0.336667
12	4	545.5	136.375	2.315833
13	4	540.3	135.075	1.029167
14	4	540.3	135.075	1.9425
15	4	540.1	135.025	0.555833
16	4	540.8	135.2	0.573333
17	4	541.2	135.3	0.253333
18	3	410.8	136.9333	0.813333
19	4	558.5	139.625	0.149167
20	4	563.3	140.825	0.8425
21	4	547.6	136.9	9.933333
22	4	556.4	139.1	0.673333
23	4	551	137.75	0.283333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	206.565	19	10.87184	8.286074	1.51E-10	1.765581	Yes
Within Groups	77.41167	59	1.312062				
Total	283.9767	78					

US 287
Paver Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
4	4	576.8	144.2	0.406667
5	4	579.3	144.825	0.889167
6	4	574	143.5	0.74
7	4	572.5	143.125	0.189167
8	4	578.7	144.675	0.1625
9	4	572.8	143.2	2.94
10	4	579	144.75	0.27
11	4	583	145.75	0.656667
12	4	580.8	145.2	2.593333
13	4	574.6	143.65	0.163333
14	4	566.7	141.675	0.369167

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	53.59	10	5.359	6.284542	2.58E-05	2.132502	Yes
Within Groups	28.14	33	0.852727				
Total	81.73	43					

SH 257-Milliken
Paver Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
4	2	286.5	143.25	15.125
5	2	280.4	140.2	0.32
6	2	281.7	140.85	5.445
7	2	284.7	142.35	1.445
8	2	282	141	4.5
9	2	280.2	140.1	0.18
10	2	279.8	139.9	0.02
11	2	281.2	140.6	0.5
12	2	282.6	141.3	2.42
13	2	279.8	139.9	0.02
14	2	276.7	138.35	0.245
15	2	293	146.5	0.32
16	2	278.1	139.05	0.045
17	2	281.2	140.6	0.32
18	2	280.8	140.4	0.18
19	2	279.3	139.65	0.405
20	2	283.7	141.85	0.845
21	2	282.5	141.25	3.125
22	2	281.7	140.85	0.125
23	2	279.1	139.55	0.245

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	114.085	19	6.004474	3.351646	0.004964	2.137007	Yes
Within Groups	35.83	20	1.7915				
Total	149.915	39					

SH 165
Paver Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
4	4	553.4	138.35	2.096667
5	4	563.7	140.925	0.489167
6	4	565.3	141.325	0.0825
7	4	569.4	142.35	0.25
8	4	567.8	141.95	0.603333
9	4	569.1	142.275	0.049167
10	4	569.9	142.475	0.835833
11	4	568.9	142.225	1.729167
12	4	569.4	142.35	0.17
13	4	569.6	142.4	0.933333
14	4	568	142	1.04
15	4	563.9	140.975	0.5625
16	4	565	141.25	1.583333
17	4	565.3	141.325	0.7625
18	4	558.8	139.7	0.953333
19	4	557.1	139.275	0.815833
20	4	552.3	138.075	0.369167
21	4	558.7	139.675	2.375833

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	140.175	17	8.245588	9.452537	9.3E-11	1.81554	Yes
Within Groups	47.105	54	0.872315				
Total	187.28	71					

SH 9
Paver
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
4	4	557.9	139.475	1.369167
5	4	559.3	139.825	0.069167
6	4	561.7	140.425	0.5825
7	4	557.3	139.325	0.7625
8	4	556.2	139.05	0.443333
9	4	552.7	138.175	0.115833
10	4	557.1	139.275	0.9225
11	4	554.8	138.7	1.62
12	4	556.8	139.2	0.22
13	4	555.8	138.95	1.47
14	4	550.9	137.725	5.809167
15	4	548.5	137.125	1.829167
16	4	549.7	137.425	2.849167

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	44.55923	12	3.713269	2.672526	0.010137	2.010182	Yes
Within Groups	54.1875	39	1.389423				
Total	98.74673	51					

SH 133
Paver Densities
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
4	4	554.7	138.675	0.829167
5	4	555.5	138.875	0.2425
6	4	558	139.5	0.886667
7	4	555	138.75	3.296667
8	4	558.1	139.525	3.629167
9	4	562.5	140.625	1.109167
10	4	561.2	140.3	0.486667
11	4	562	140.5	0.446667
12	4	563.4	140.85	3.336667
13	4	564.3	141.075	1.5025
14	4	559.4	139.85	6.15
15	4	567.7	141.925	1.4625
16	4	562.5	140.625	7.635833
17	4	565.4	141.35	0.43
18	4	562	140.5	0.4
19	4	557.9	139.475	0.1825
20	4	540.7	135.175	0.0825

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	148.2788	16	9.267426	4.906582	6.55E-06	1.846157	Yes
Within Groups	96.3275	51	1.888775				
Total	244.6063	67					

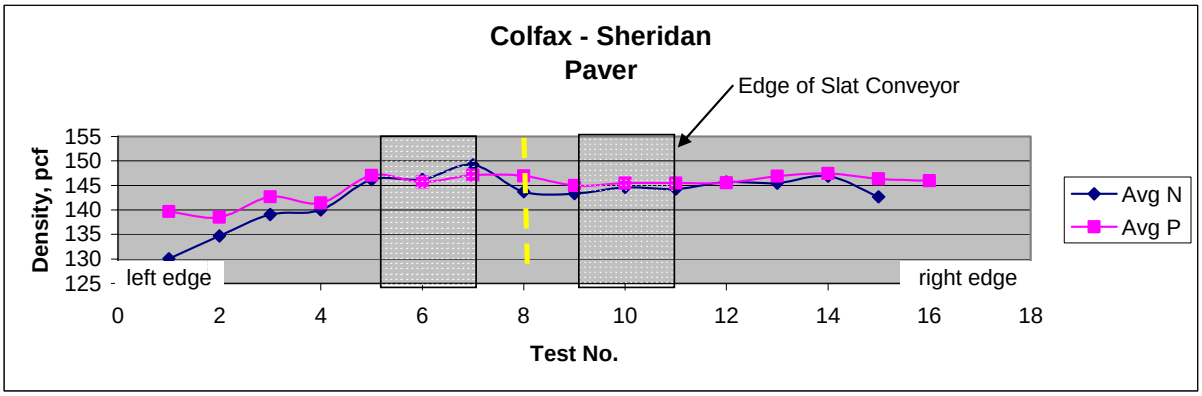
Colfax-Peoria to Potomac
Paver
SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
4	4	583.9	145.975	0.535833
5	4	588.5	147.125	0.209167
6	4	591.2	147.8	0.953333
7	4	589.5	147.375	0.369167
8	4	583.7	145.925	0.349167
9	4	583.1	145.775	0.629167
10	4	579.6	144.9	0.46
11	4	576.3	144.075	7.8825
12	4	590.1	147.525	2.849167
13	4	590.9	147.725	1.175833
14	4	582.1	145.525	10.4025

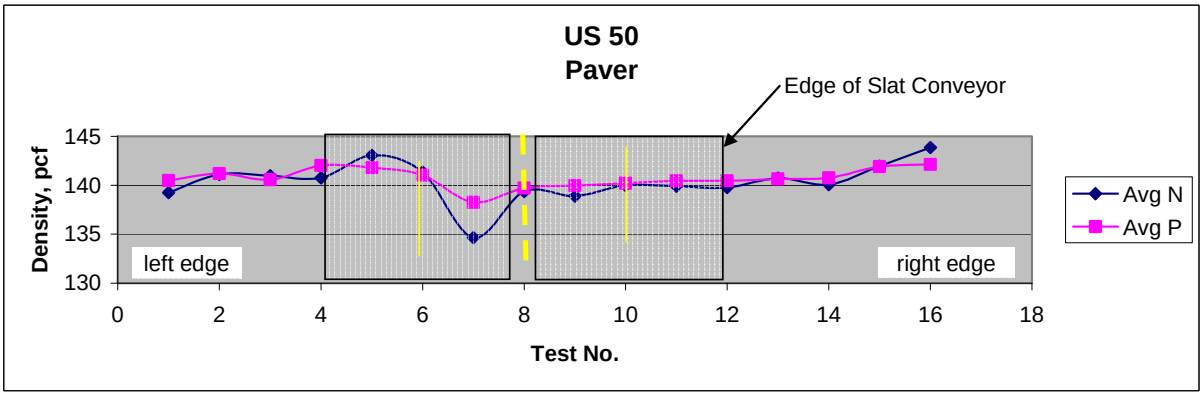
ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	*Signif ?*
Between Groups	62.53682	10	6.253682	2.664663	0.016591	2.132502	Yes
Within Groups	77.4475	33	2.346894				
Total	139.9843	43					

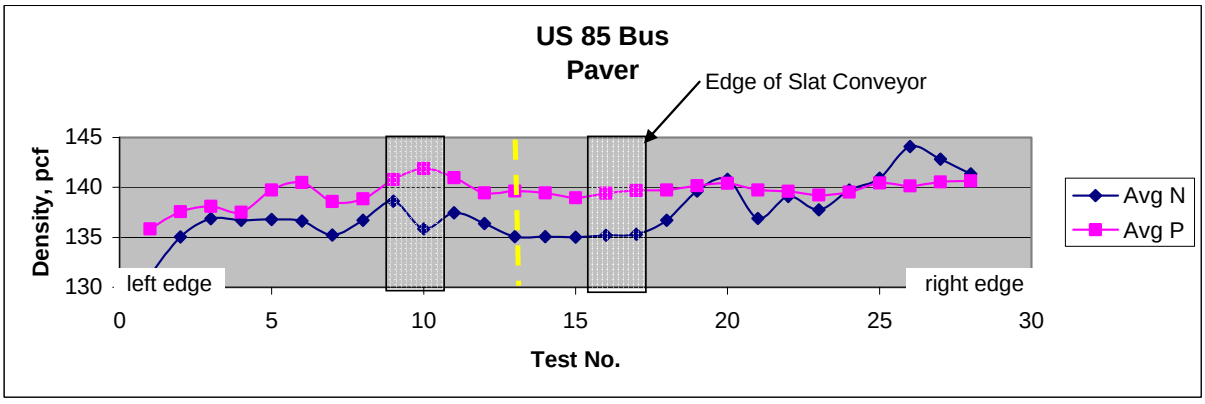
Appendix C – Averages of Test Results



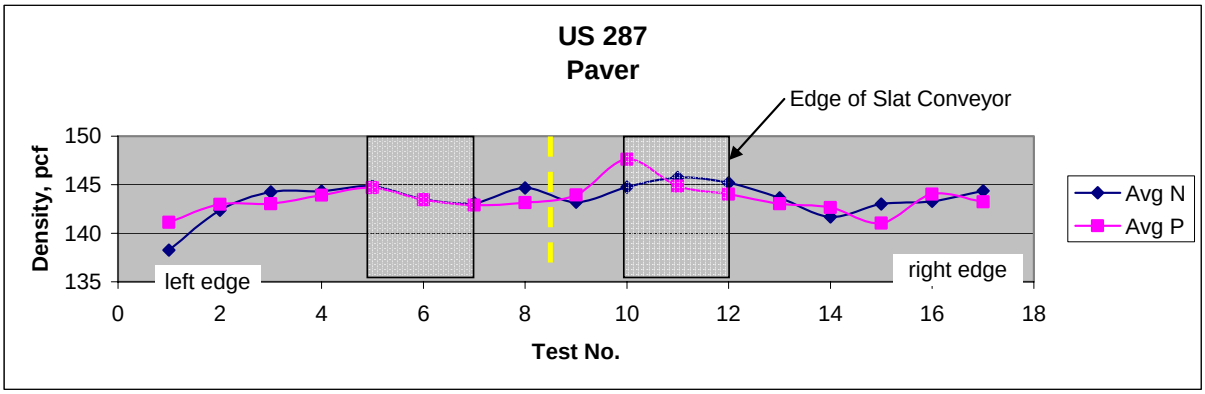
Signif



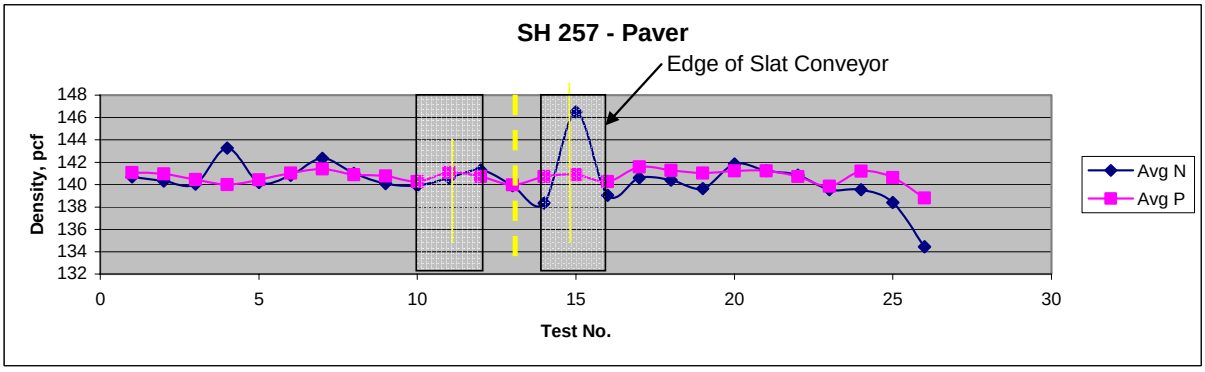
Signif



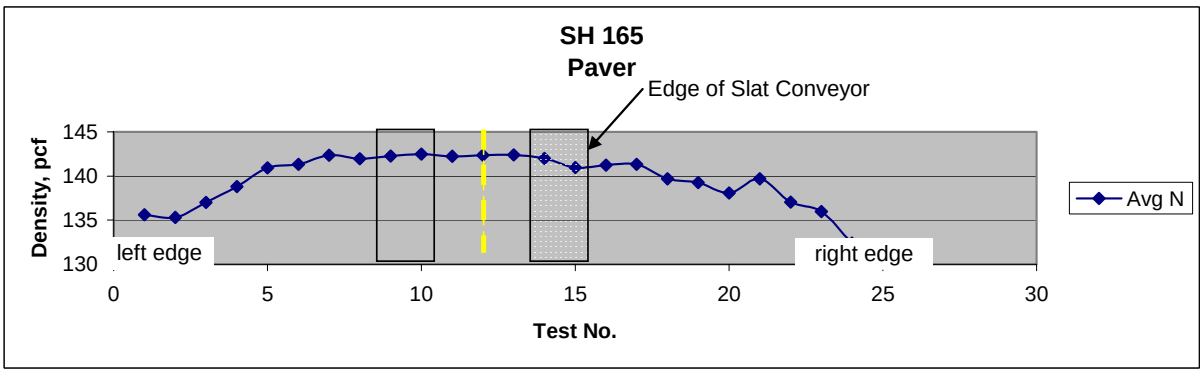
Signif



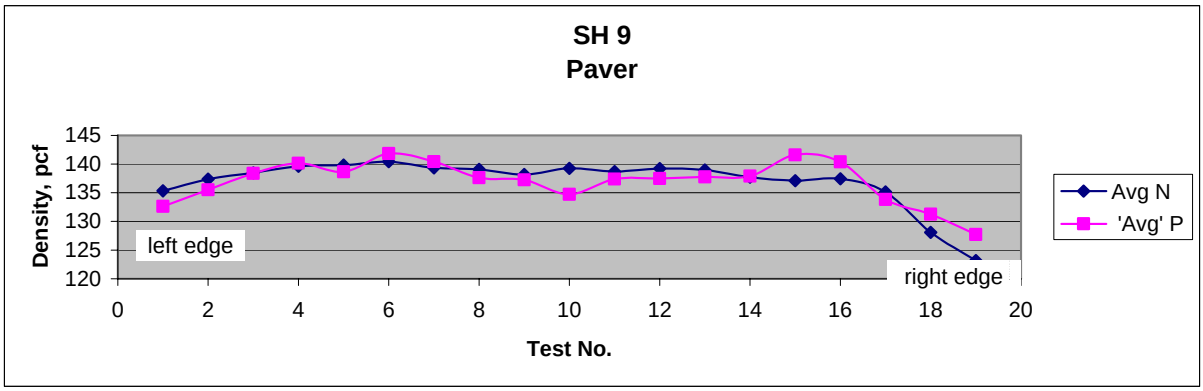
Signif



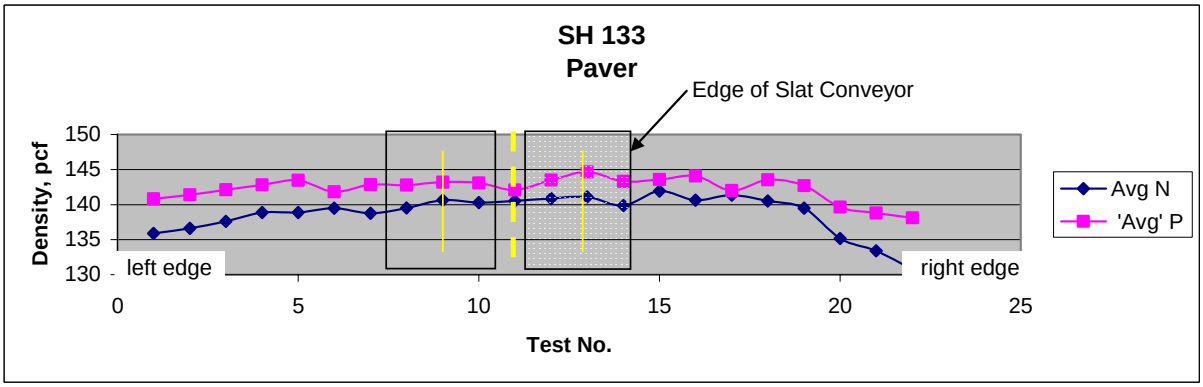
Signif



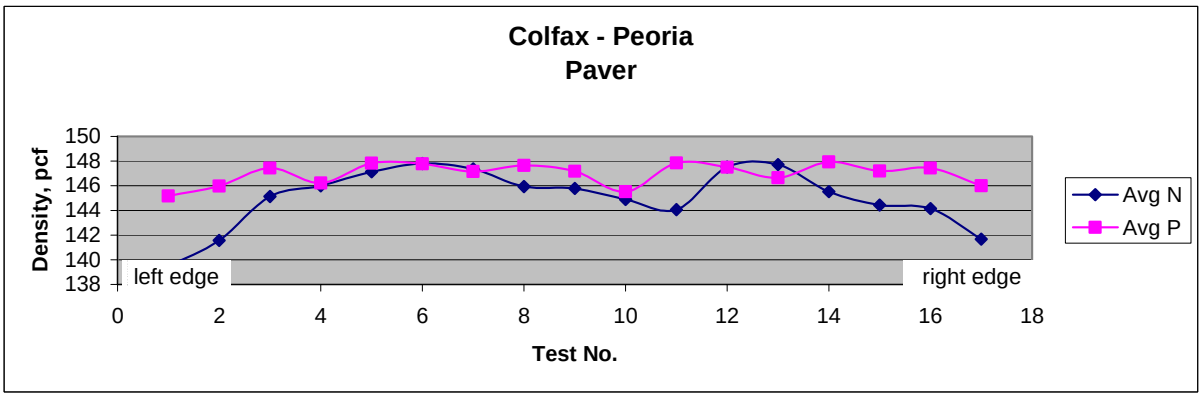
Signif



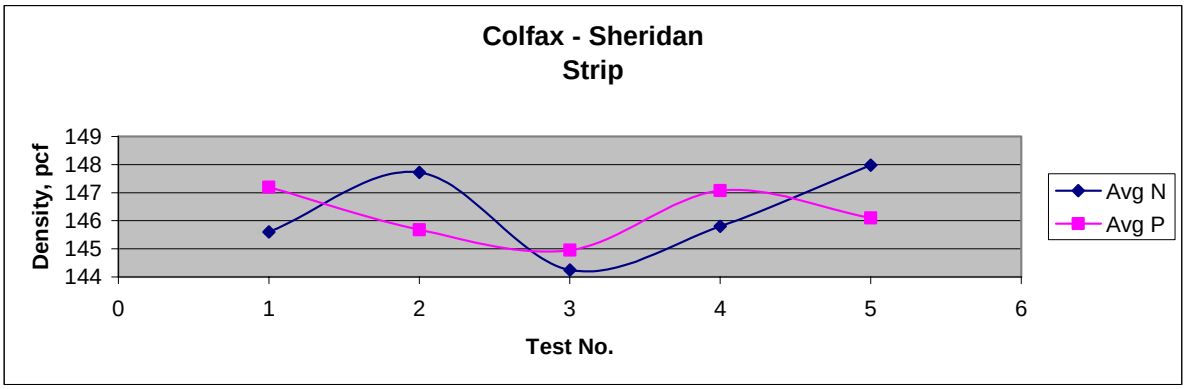
Signif



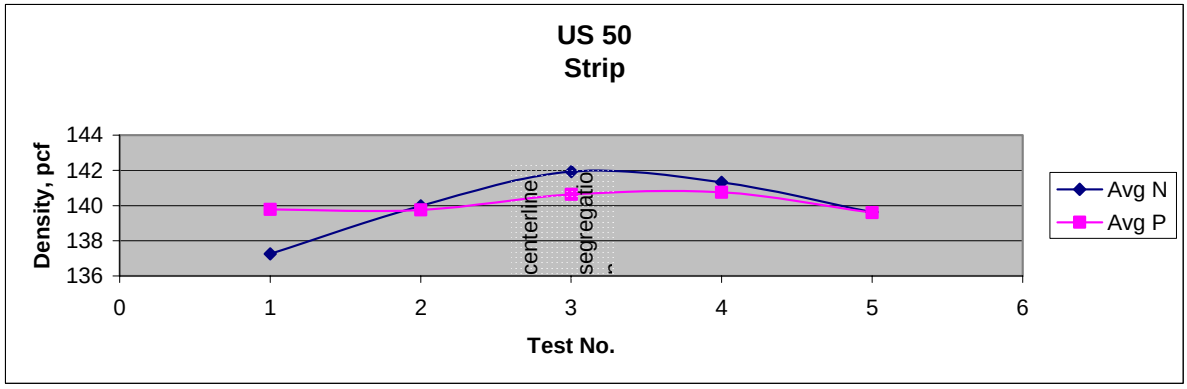
Signif



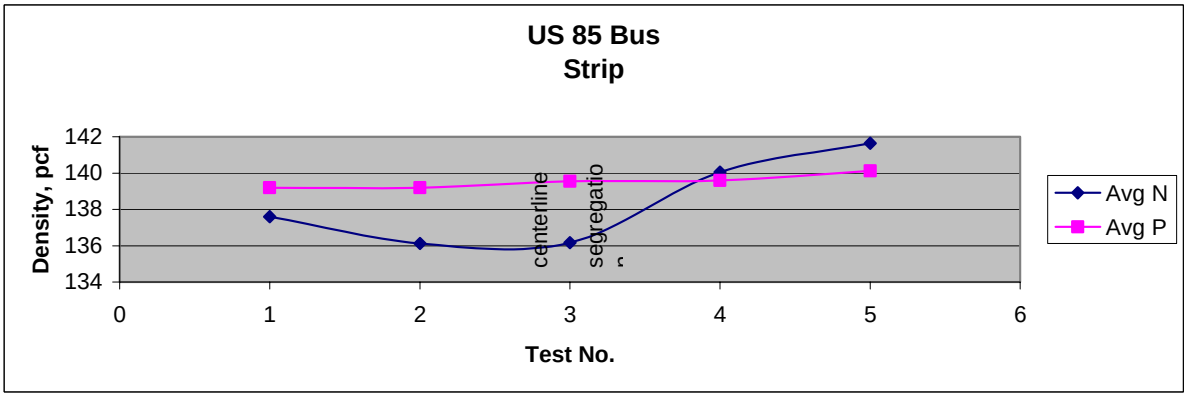
Signif



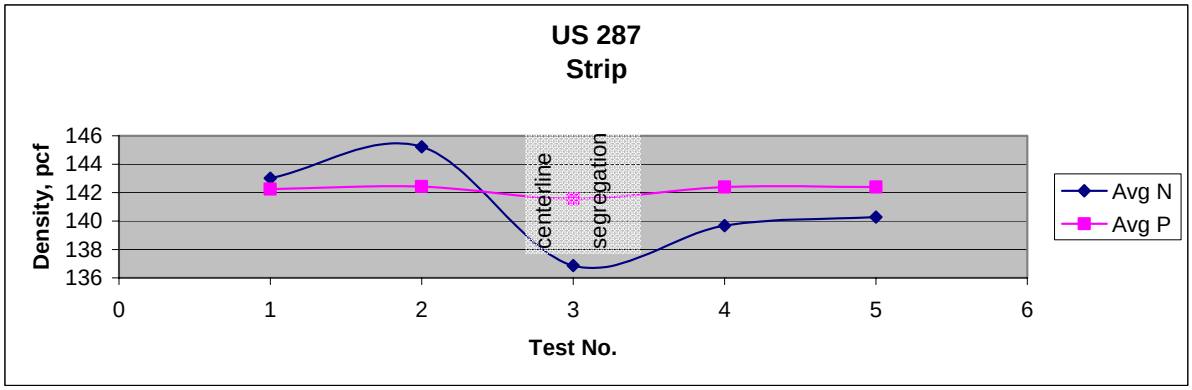
Signif



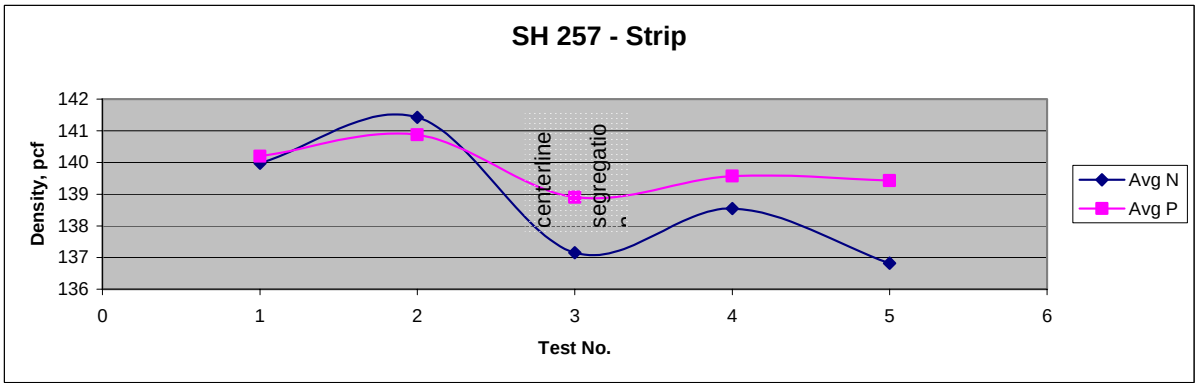
Signif



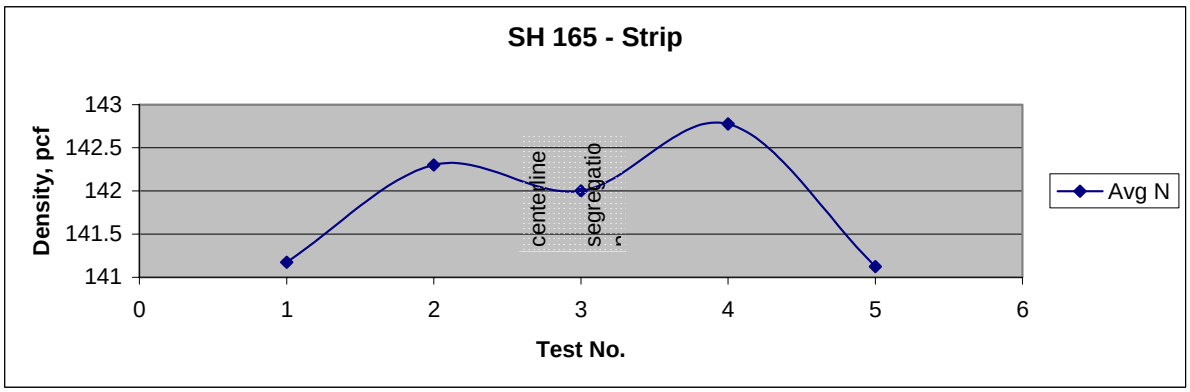
Signif



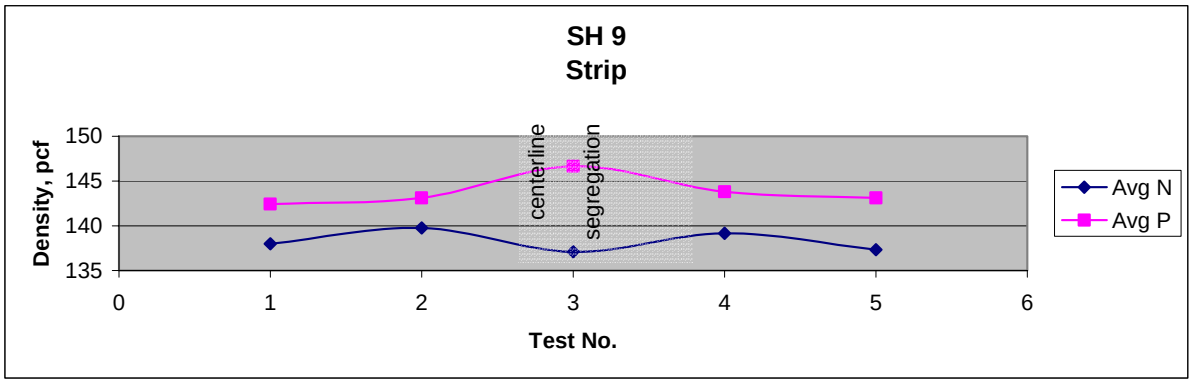
Signif



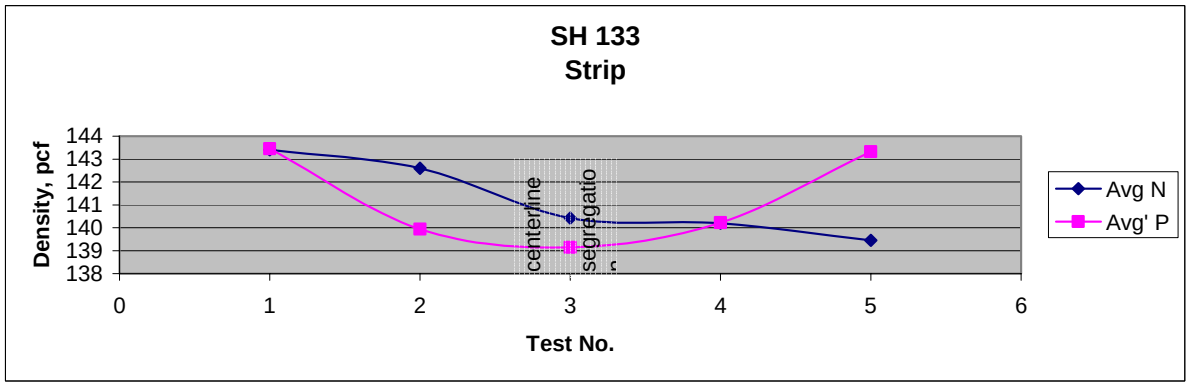
Signif



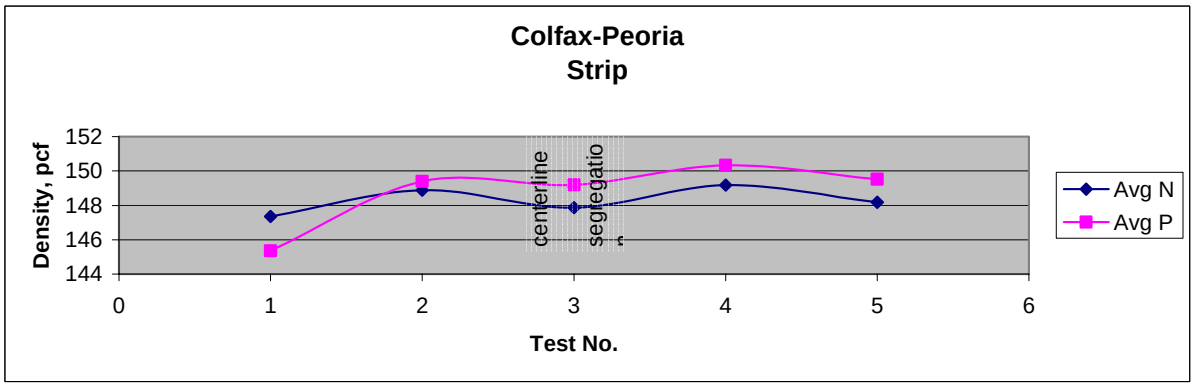
Signif



Signif

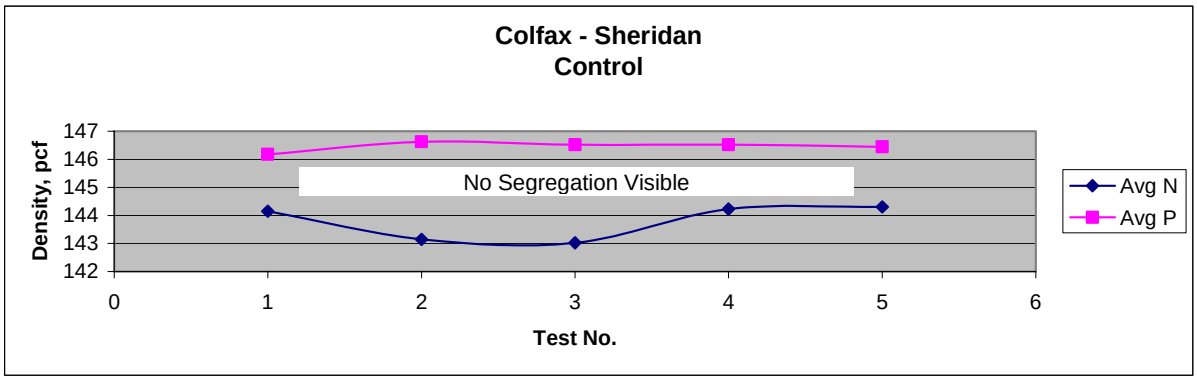


Signif

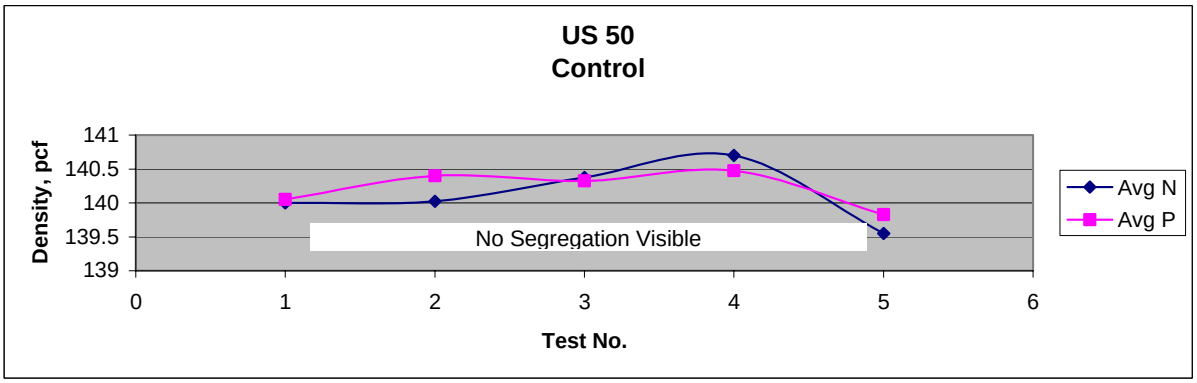


Not Signif

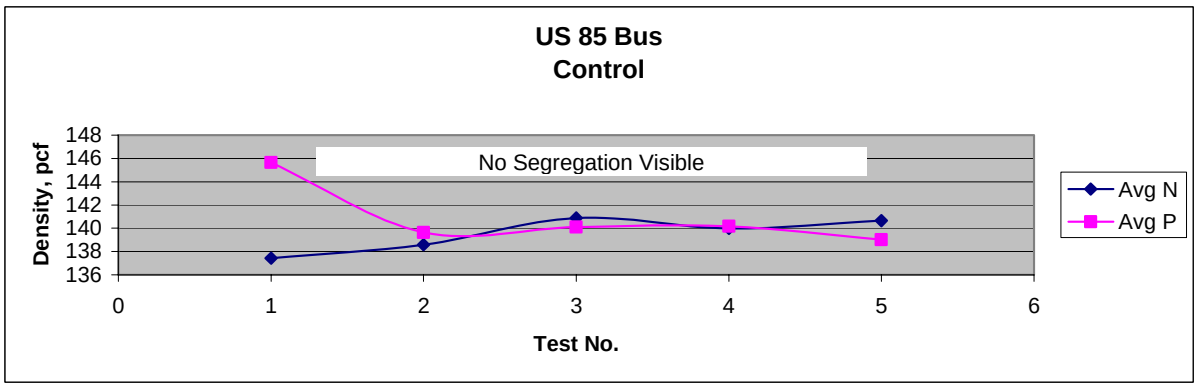
Cc



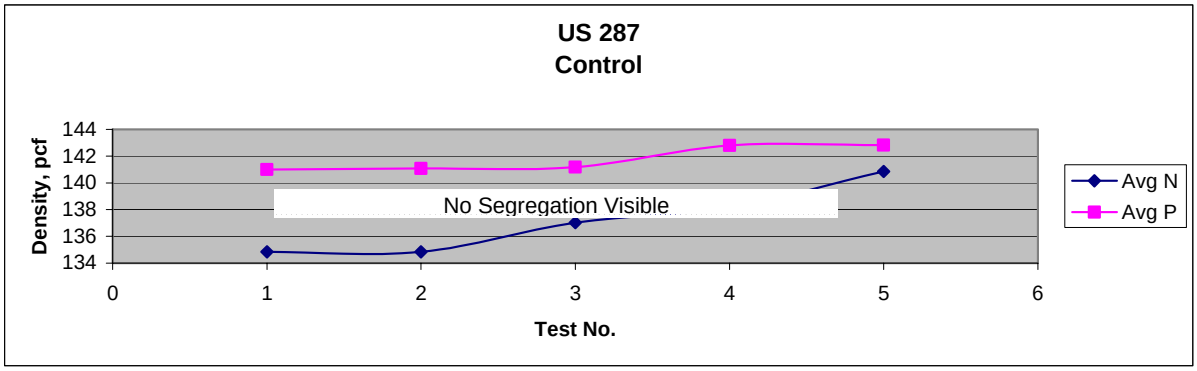
Signif @ 0.0496



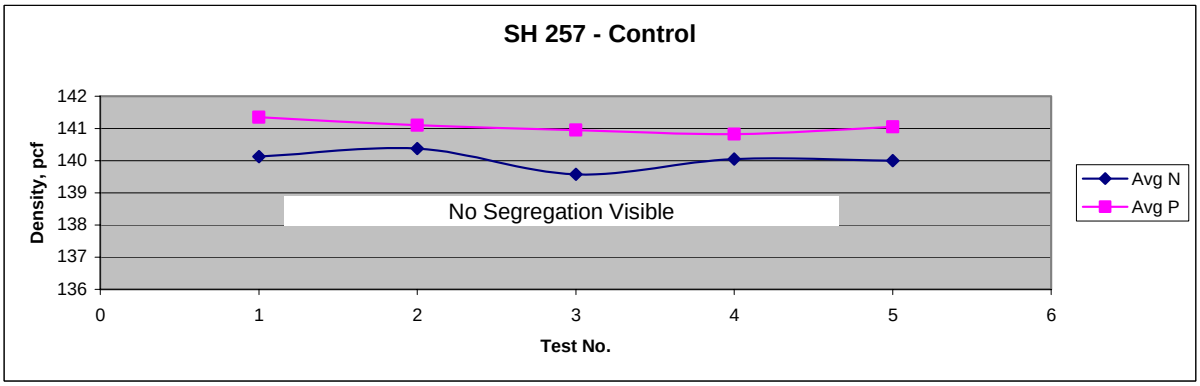
Not Signif



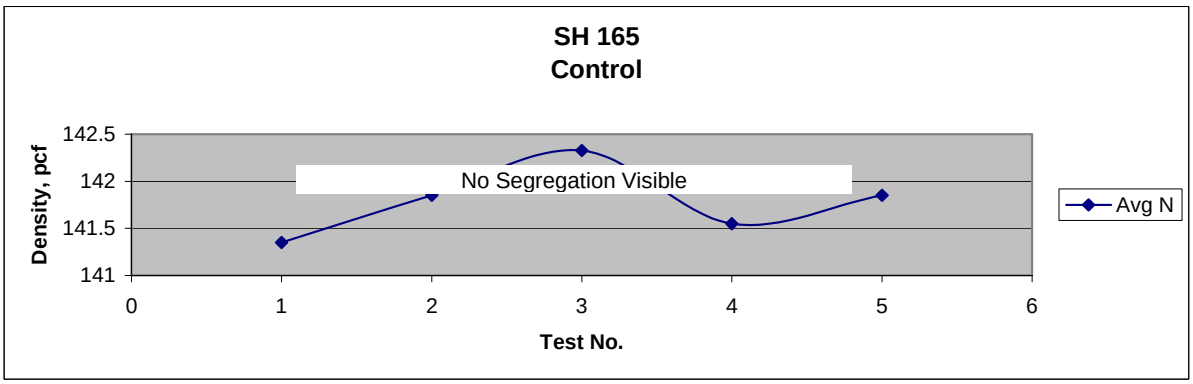
Signif



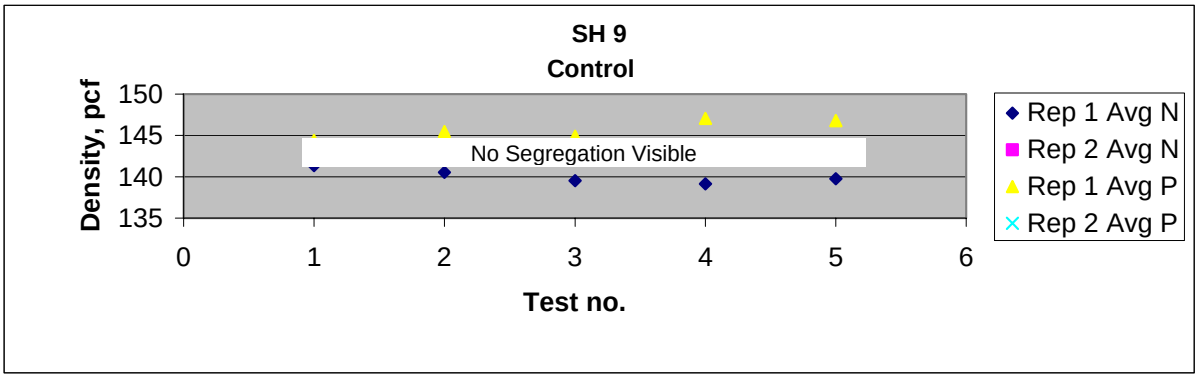
Signif



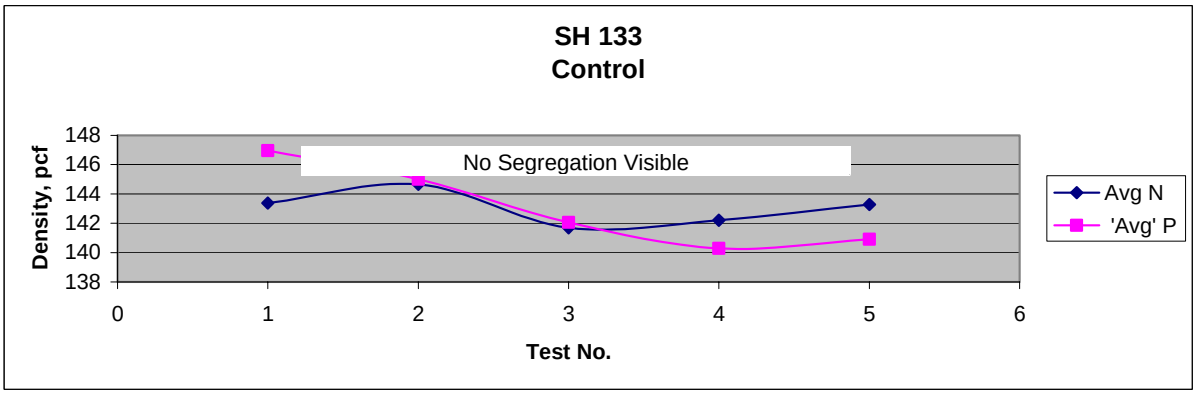
Not Signif



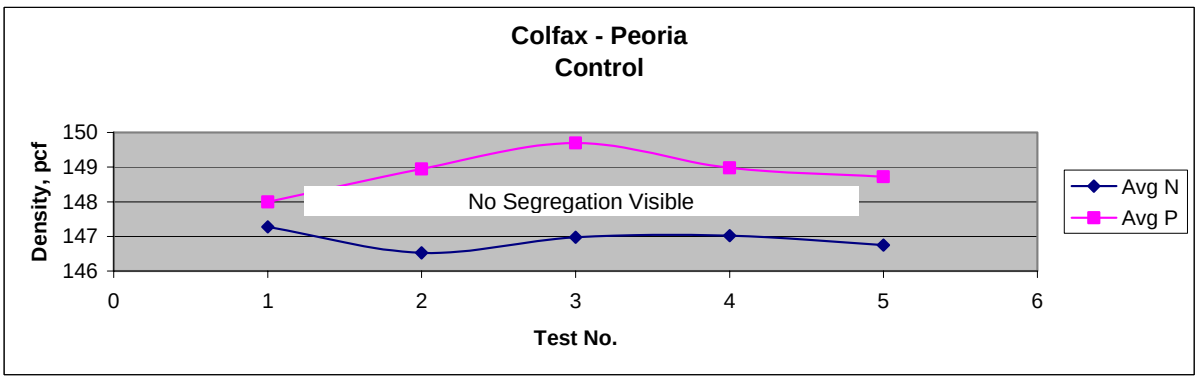
Not Signif



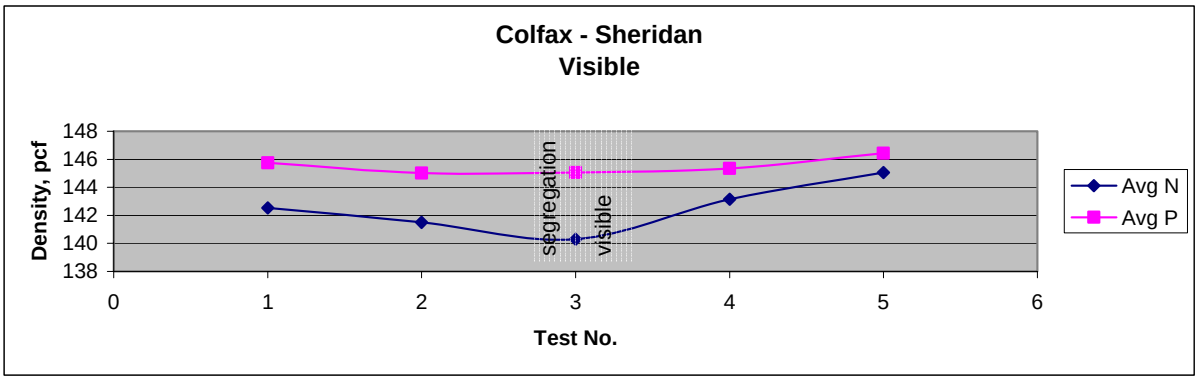
Signif



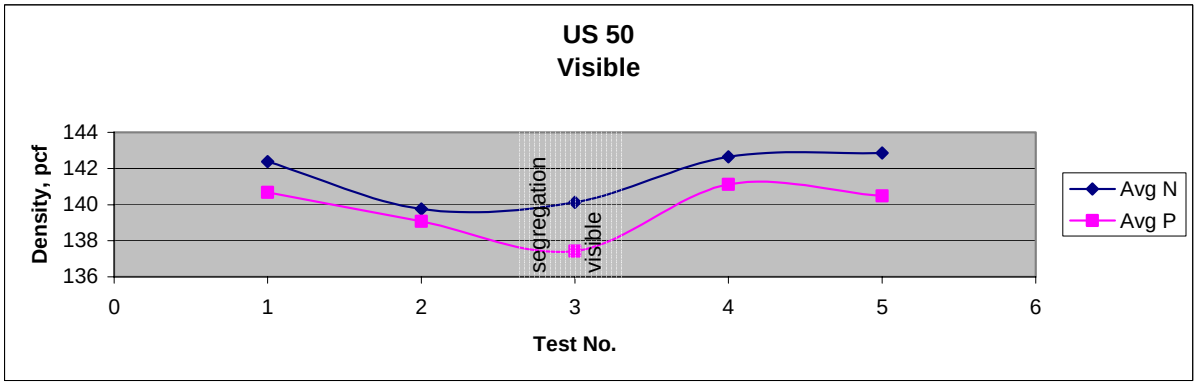
Not Signif @ 0.055



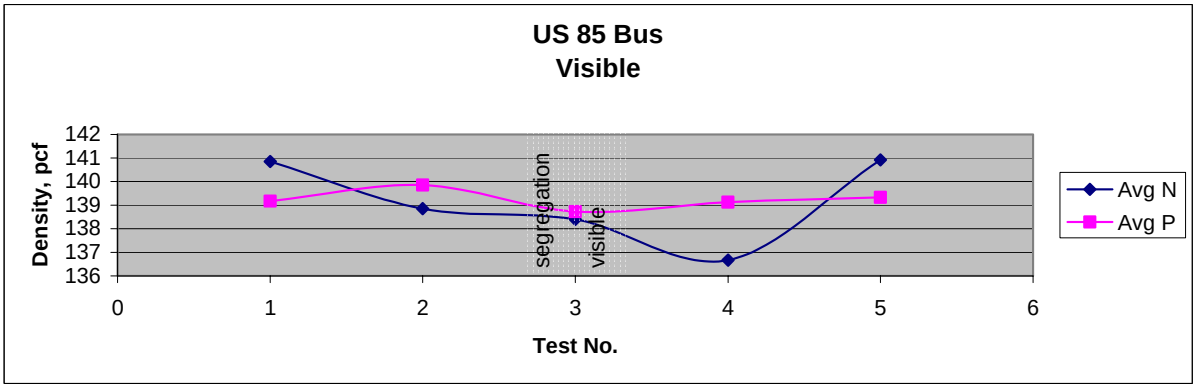
Not Signif



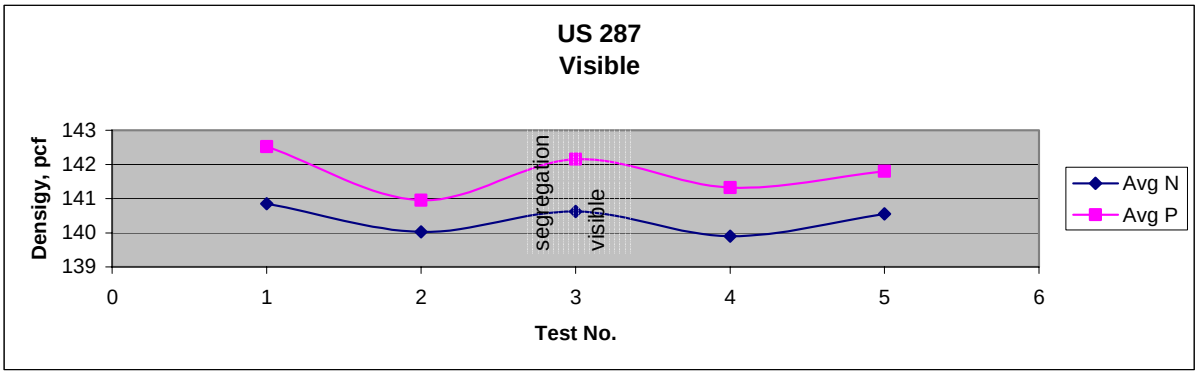
Signif



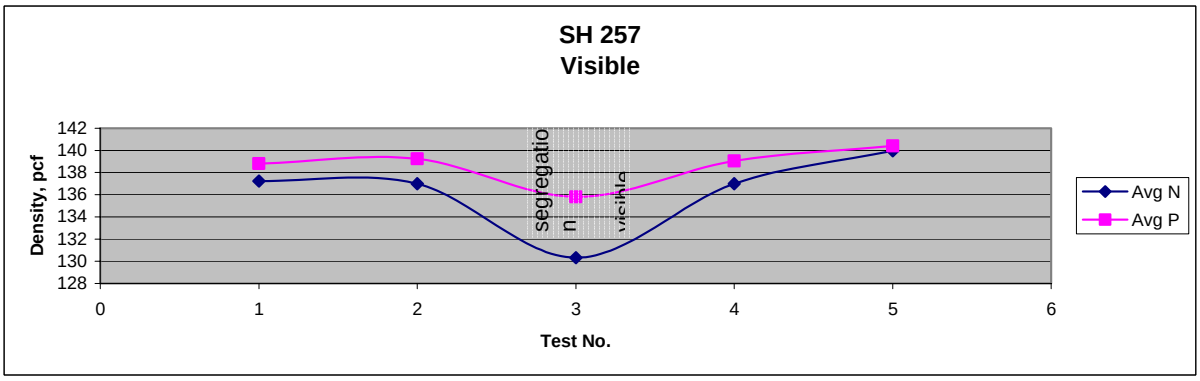
Signif



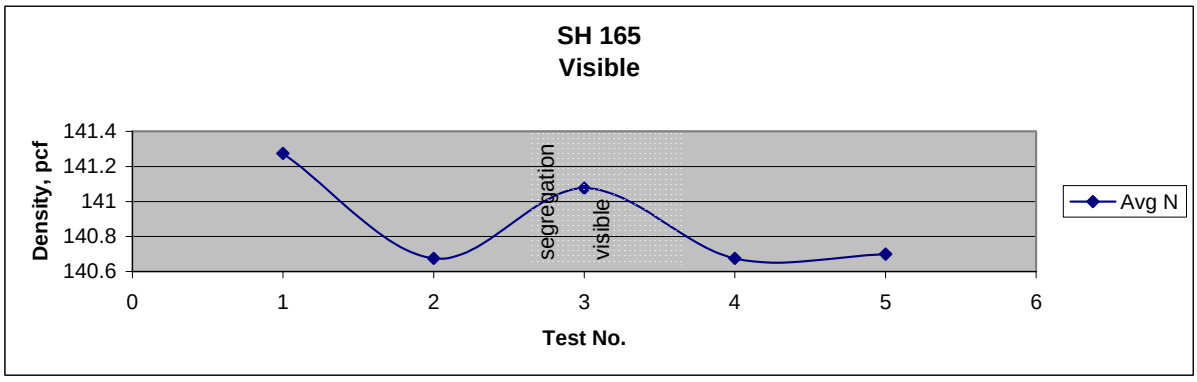
Signif



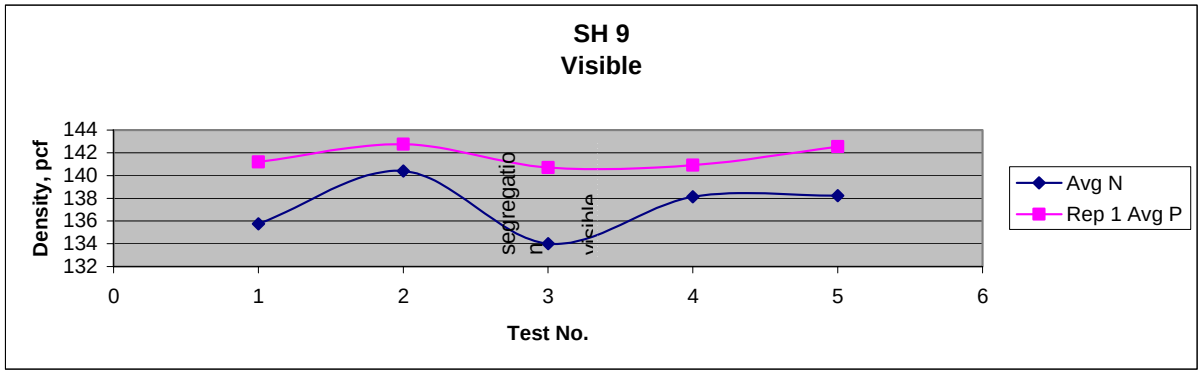
Not Signif



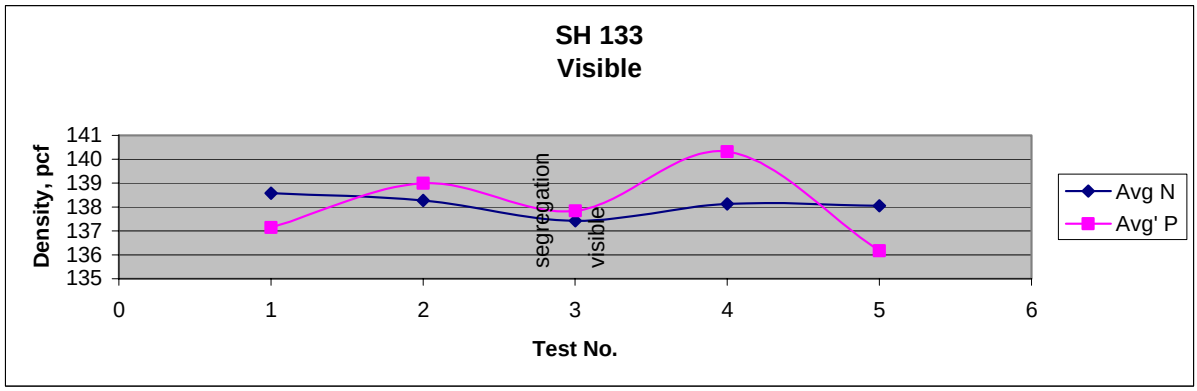
Signif



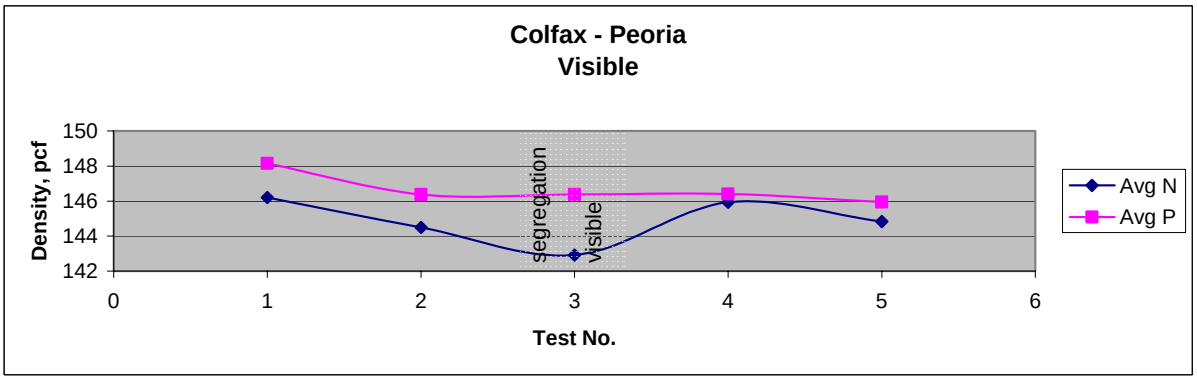
Not Signif



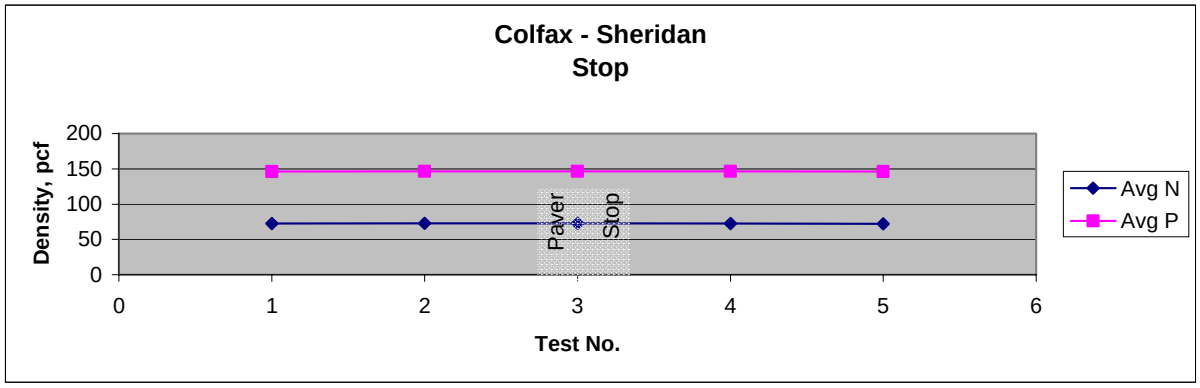
Signif



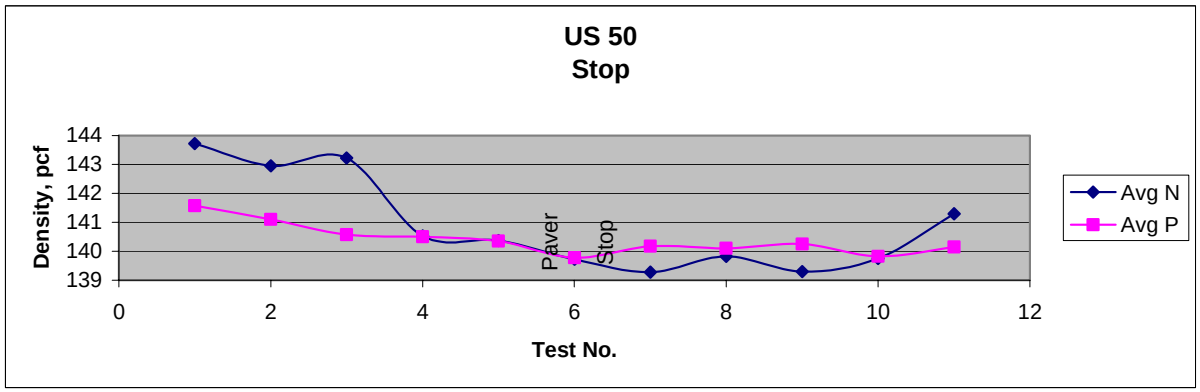
Not Signif



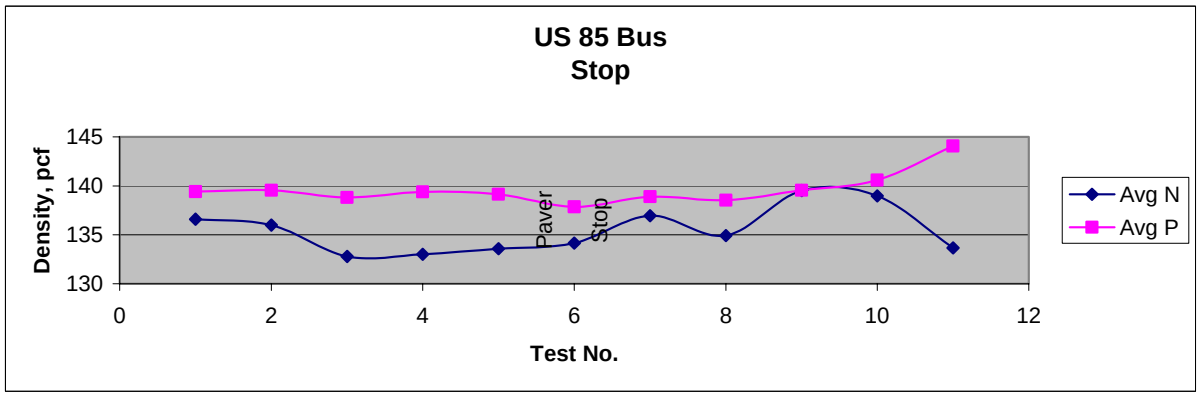
Not Signif



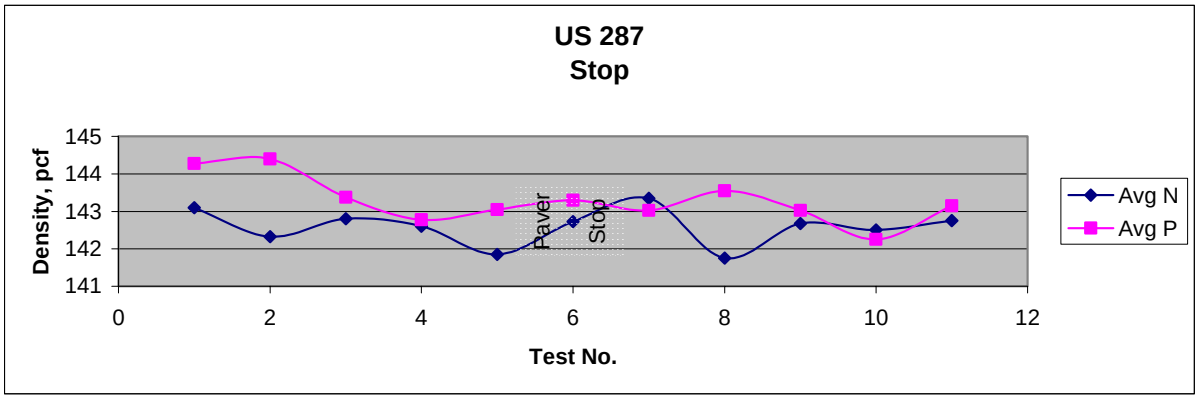
Signif



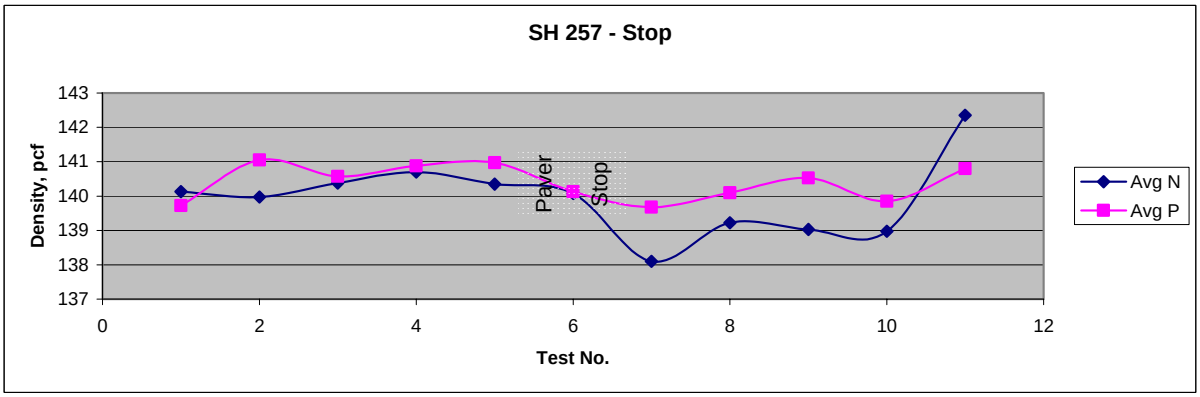
Signif



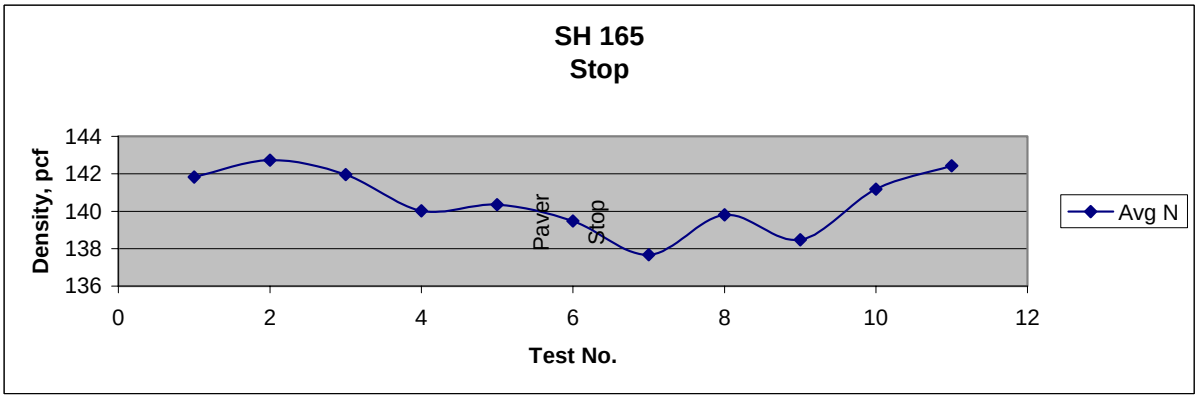
Signif



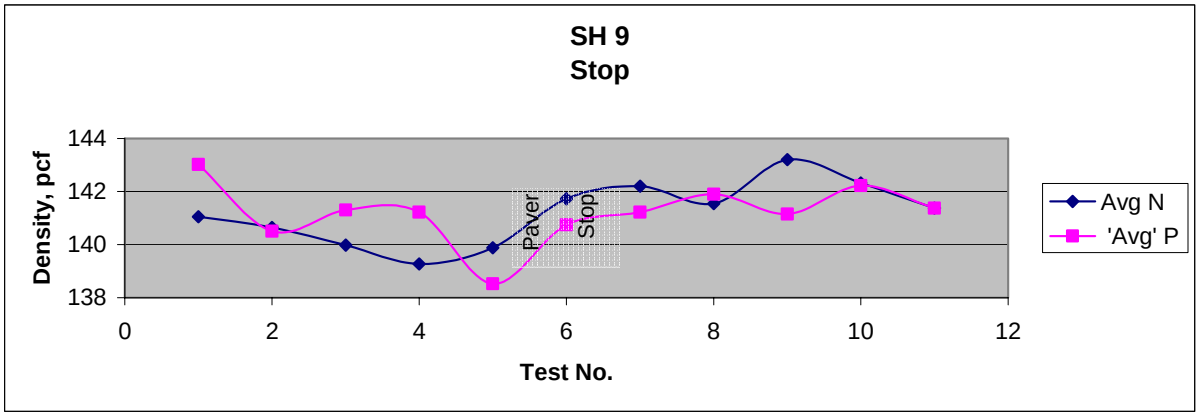
Not Signif



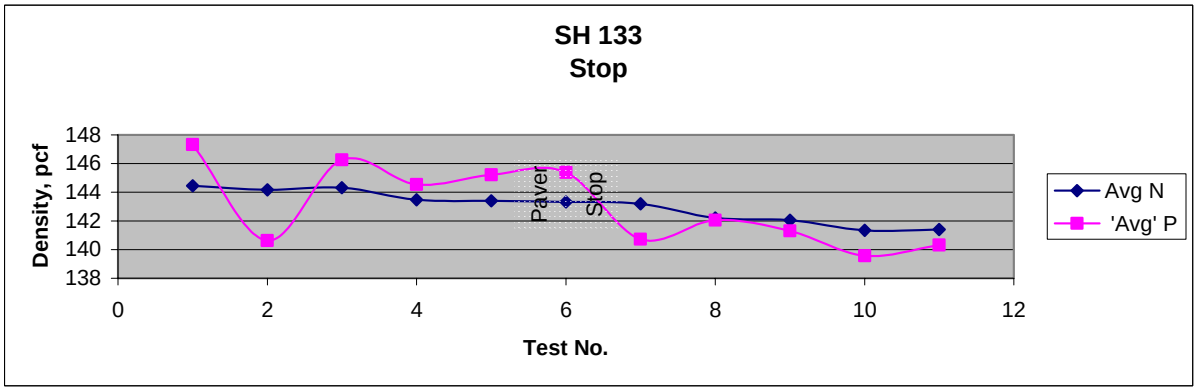
Signif



Signif



Not Signif



Signif