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Identifying Segregation in Asphalt Pavements Using Rapid, Non-Destructive Techniques

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Abstract
Asphalt pavement density measurements were made using a conventional nuclear density guage. 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 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 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 between the nine sites was high due to differences in segregation levels. For example, some sites had noticeable segregation during construction while other sites had only minor segregation. However, statistically significant differences in density were measured for all sites for the 'paver' transverse measurements, eight of nine sites for the 'strip' density sets and five of nine for the 'visible' data.

Keywords
Asphalt pavement segregation, quality control, pavement density, quality improvement

1. 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. 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) which utilizes the dielectric constant of a material to predict density. The five groups of density tests consisted of the following:

Strip	density measurements conducted along a diagonal to 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 Figure 1.

Each point shown in Figure 1 was evaluated for insitu pavement density using the nuclear 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:

$$y_{ij} = \square + \square_{i} + \square_{ij}$$

where,

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

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

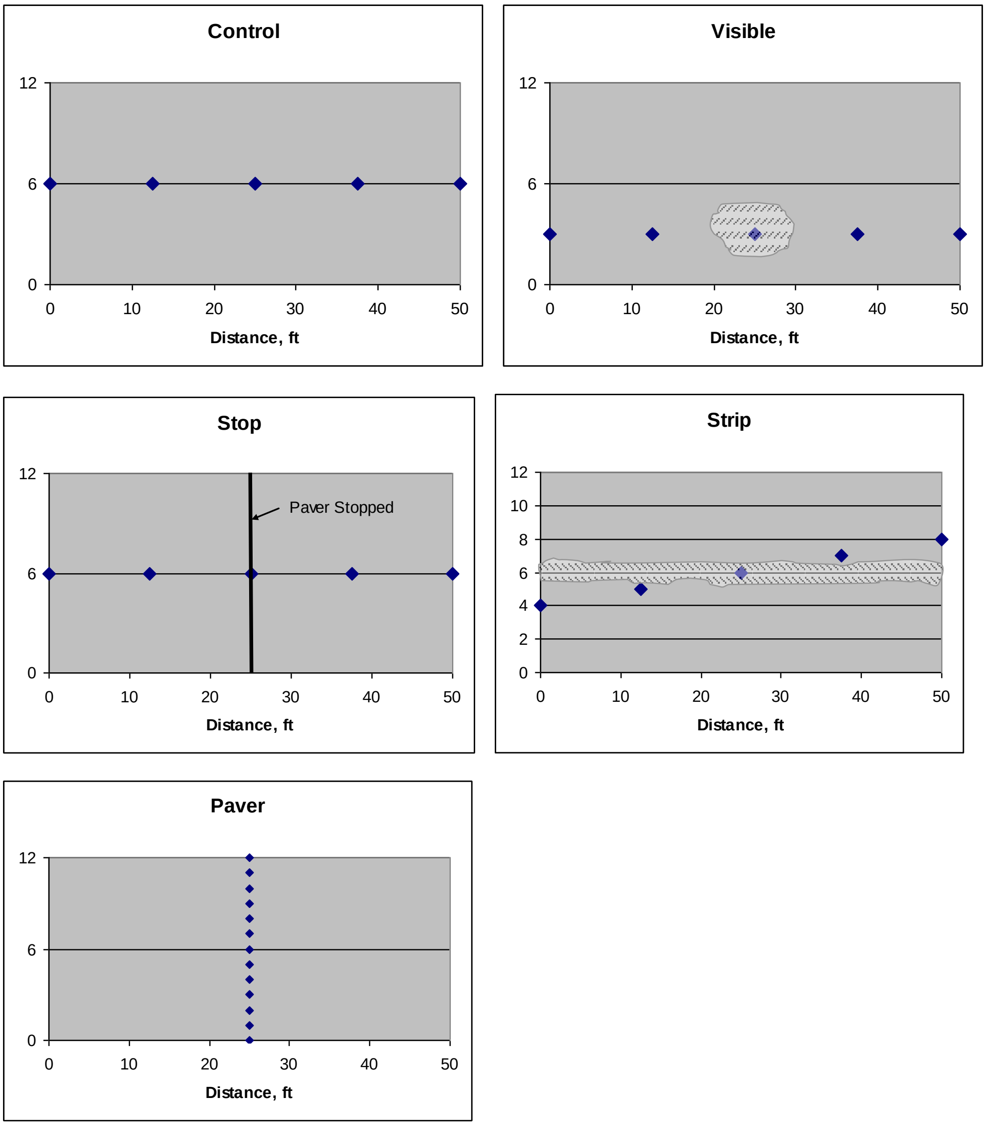

Figure 1. Density Groups Evaluated

3. 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

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

4. Materials

The grading of the asphalt concrete mixtures, gyratory compaction level, asphalt binder grade and percentage of asphalt in the mixtures for each project are shown in Table 2.

Table 2. Materials

No.	Location	Grading/ Compaction	Binder Grade	Binder, %
1	Colfax-Sheridan	S 100	76-28	5.1
2	US50	S 100	76-28	5.4
3	US85 Bus	S 100	64-28	5.4
4	US287 Loveland	S 100	64-28	5.2
5	SH257	S 75	64-28	5.2
6	SH165	S 75	58-28	5.8
7	SH9	SX 75	58-34	5.9
8	SH 133	SX 75	64-28	6.2
9	Colfax –Peoria	S 100	64-22	5.4

5. Results

The relative density of the pavement for each of the five density data sets is presented below:

5.1 Strip

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 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 Tests 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.

5.2 Visible

Visible density data sets were analyzed by comparing the density at Test 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

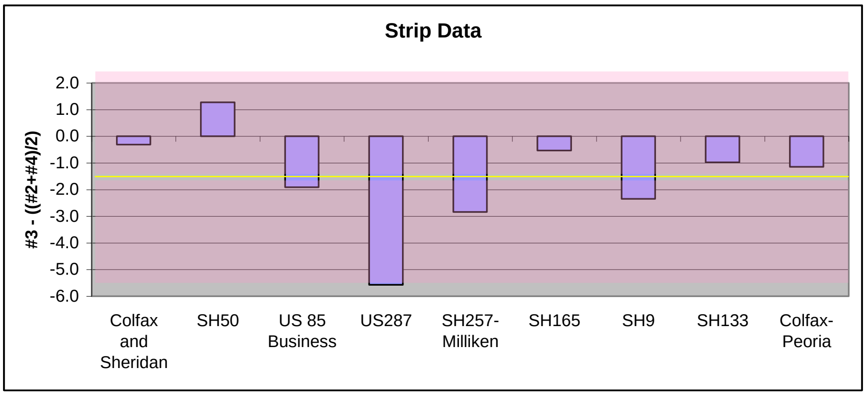

Figure 2. Average of 'Strip' Density Data for All Sites

	#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

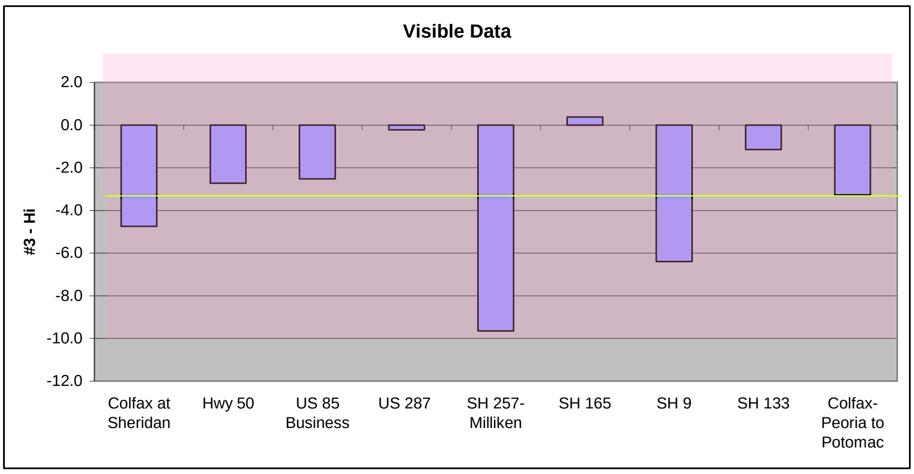

Figure 3. Average of 'Visible' Density Data for All Sites

5.3 Control

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

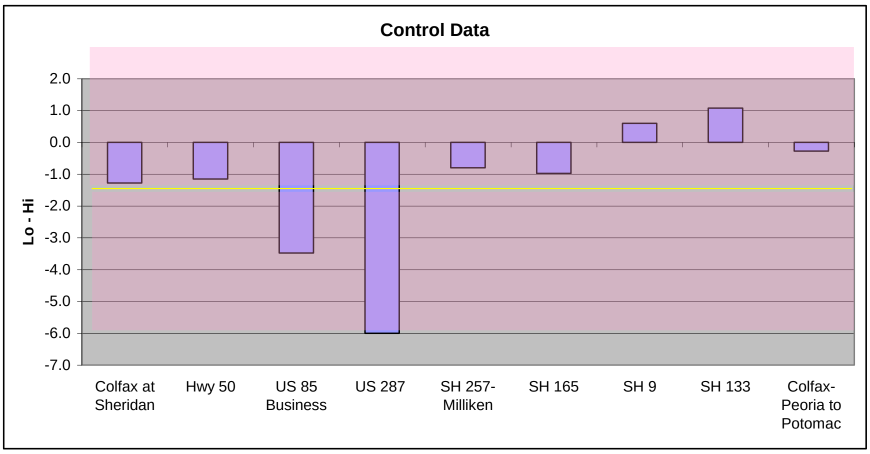

Figure 4. Average of 'Control' Density Data for All Sites

5.4 Stop

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

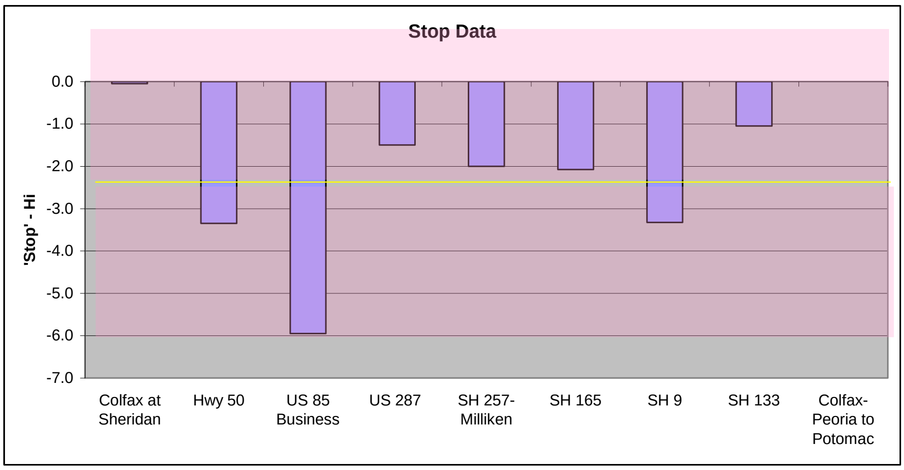

Figure 5. Average of 'Stop' Density Data for All Sites

5.5 Paver

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

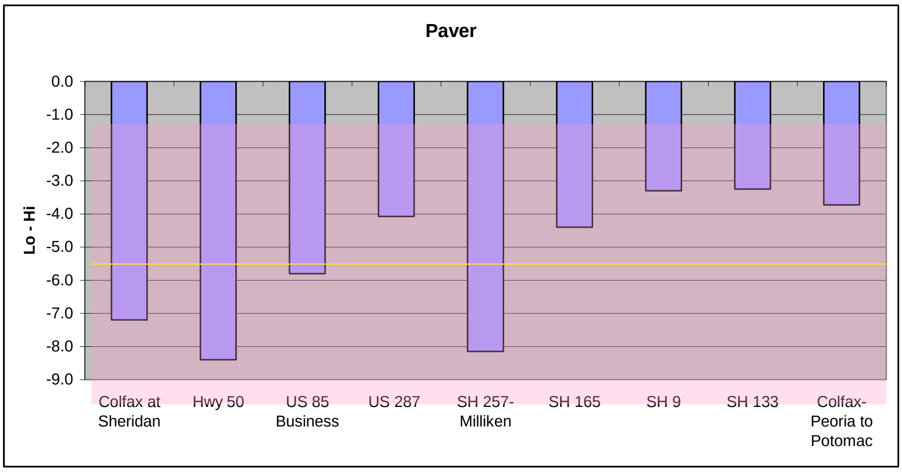

Figure 6. Average of 'Paver' Density Data for All Sites

The variability discussed above is likely due to variations in conditions between sites such as testing error, materials, moisture content, construction methods and segregation. Therefore, an analysis of variance (ANOVA) was conducted on each site for each density data set collected. The results are summarized in Table 4. The ANOVA was performed at an □ level of 0.05. The results in Table 4 indicate whether a difference at the □ = 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 □ = 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 density values 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

	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

* ‘Yes’ = Statistically significant at □=0.05

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 ‘visible’ tests and the ‘control’ measured not significant. The results of this analysis is 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

* Red shading = statistically significant at □=0.05. Green = no significant difference in readings

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 equal density 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.

6. Conclusions

1. The nuclear density gauge detects 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 appears to be 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.
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.

7. References

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

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.

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

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Keywords
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1. 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.

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2. 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.[2] called the Pavement Quality Indicator (PQI) which utilizes the dielectric constant of a material to predict density. The five groups of density tests consisted of the following:

Strip	density measurements conducted along a diagonal to 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 Figure 1.

Each point shown in Figure 1 was evaluated for insitu pavement density using the nuclear 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:

$$y_{ij} = \square + \square_i + \square_{ij}$$

where,

y_{ij} = density readings, pcf

□ = the overall mean density, pcf

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

$\square_i$ = the effect of density gauge location on the pavement
$\square_{ij}$ = the random error component
i = 1, 2, … a is the number of gauge locations being tested
j = 2, is the number of replicates

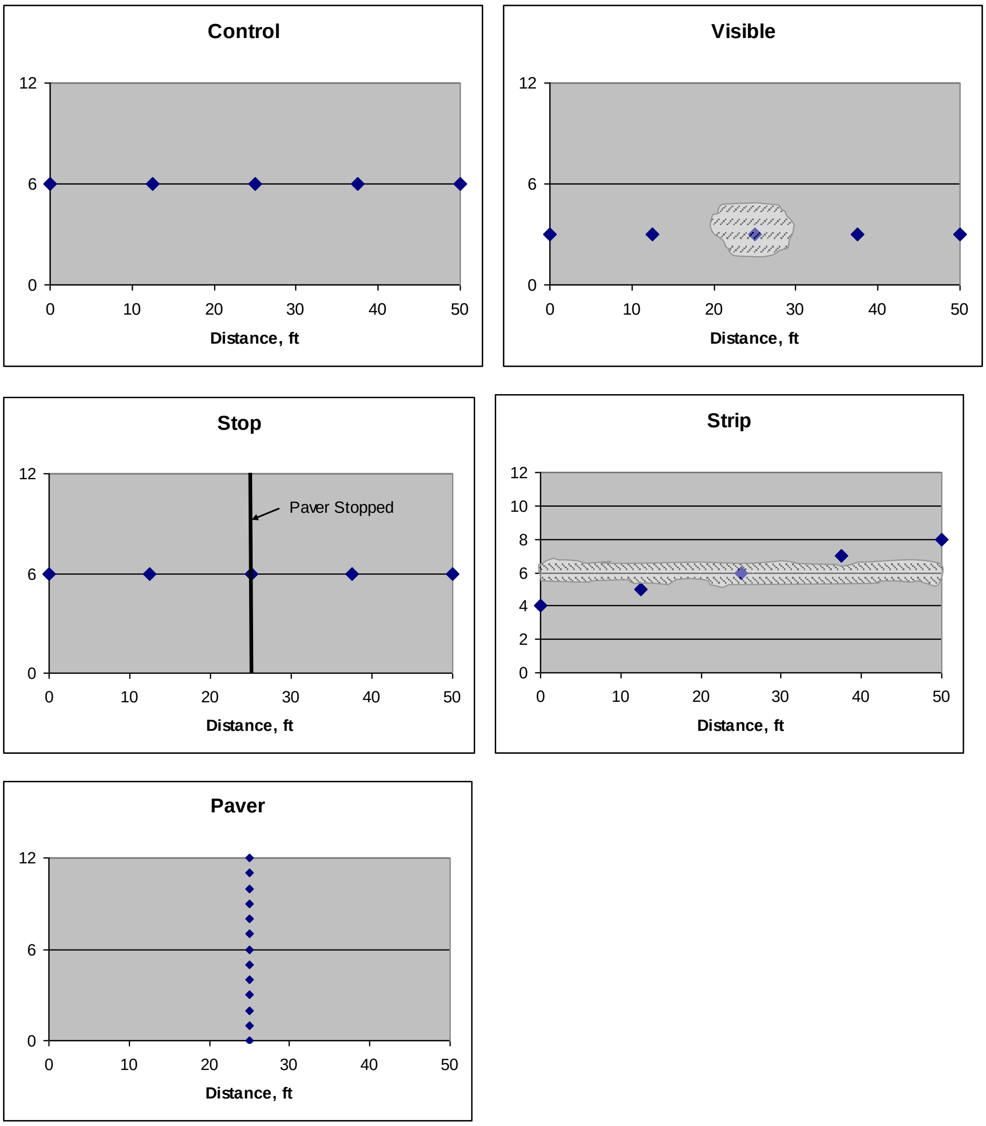

Figure 7. Density Groups Evaluated

3. 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

No.	Project No.	Location	Contractor	Testing Date(s)
1	STA 0404-040	Colfax-Sheridan to Viaduct	PP	7/8&9/04
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3	STA 0853-051	US85 Bus, 22nd St to 5th St.	L	7/29/04
4	NH 2873-123	US287 Loveland NB & SB	C	8/2/04
5	STA 2571-008	SH257 US34 to Milliken	AI	8/3/04
6	STA 165A-010	SH165 OL and Intersections	K	9/1/04
7	STA 009A-023	SH9 Summit County Line N	AS	9/28 & 10/5/04
8	STA 133A-028	SH 133, Paonia Dam N & S	E	10/6 &10/12/04
9	STU M055-016	Colfax –Peoria to Potomac	B	11/5/04

4. Materials

The grading of the asphalt concrete mixtures, gyratory compaction level, asphalt binder grade and percentage of asphalt in the mixtures for each project are shown in Table 2.

Table 2. Materials

No.	Location	Grading/ Compaction	Binder Grade	Binder, %
1	Colfax-Sheridan	S 100	76-28	5.1
2	US50	S 100	76-28	5.4
3	US85 Bus	S 100	64-28	5.4
4	US287 Loveland	S 100	64-28	5.2
5	SH257	S 75	64-28	5.2
6	SH165	S 75	58-28	5.8
7	SH9	SX 75	58-34	5.9
8	SH 133	SX 75	64-28	6.2
9	Colfax –Peoria	S 100	64-22	5.4

5. Results

The relative density of the pavement for each of the five density data sets is presented below:

5.1 Strip

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 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 Tests 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.

5.2 Visible

Visible density data sets were analyzed by comparing the density at Test 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

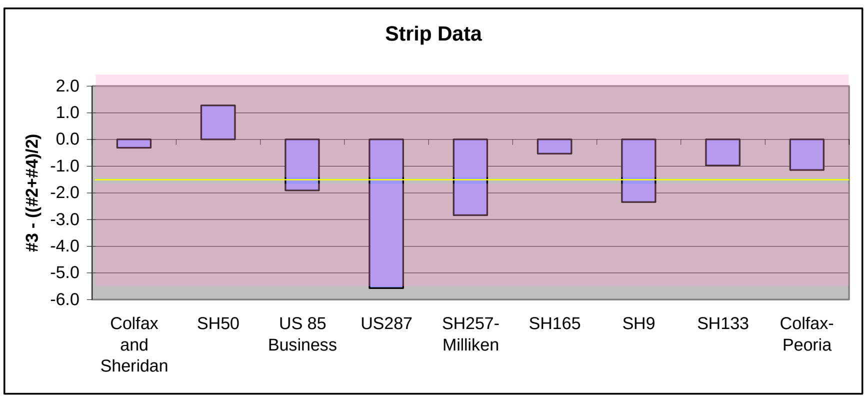

Figure 8. Average of 'Strip' Density Data for All Sites

	#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

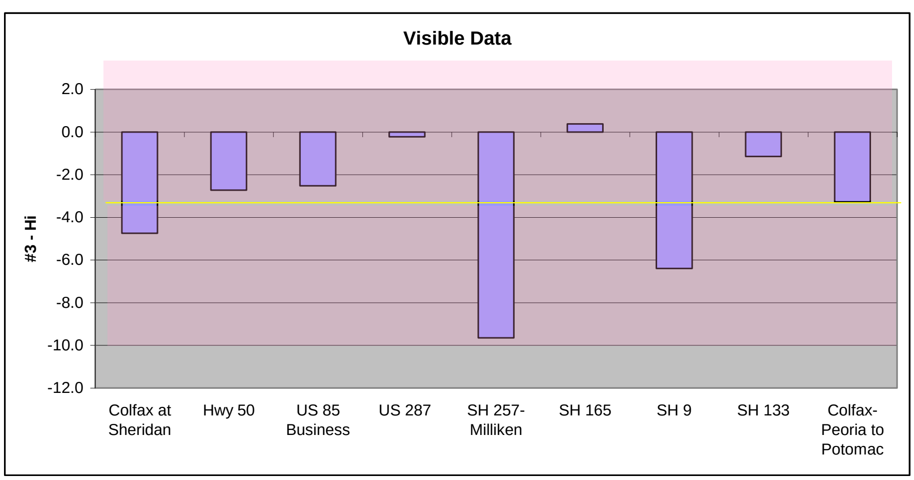

Figure 9. Average of 'Visible' Density Data for All Sites

5.3 Control

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

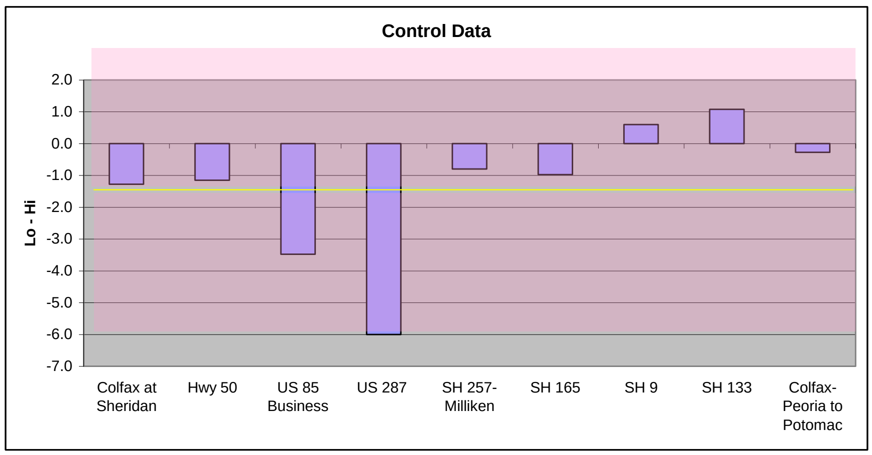

Figure 10. Average of 'Control' Density Data for All Sites

5.4 Stop

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

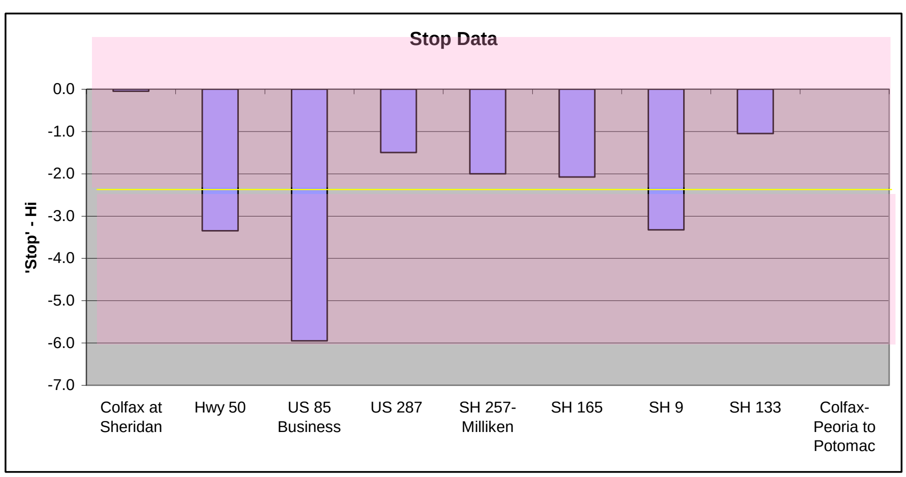

Figure 11. Average of 'Stop' Density Data for All Sites

5.5 Paver

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

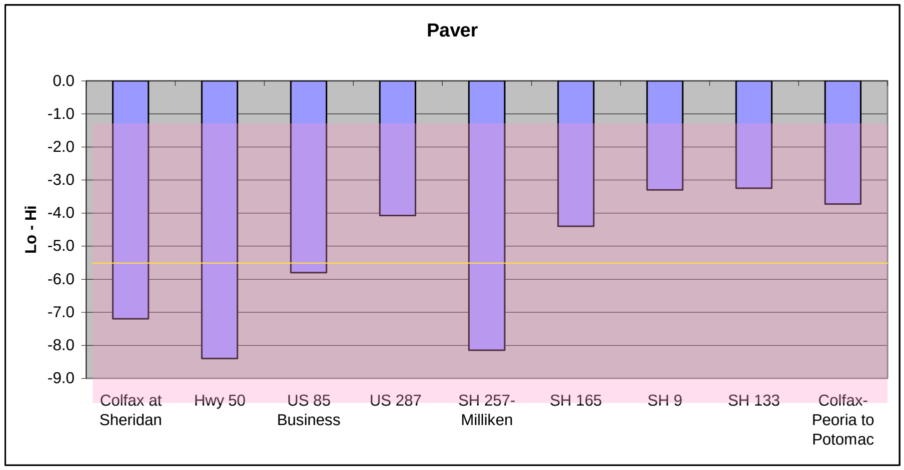

Figure 12. Average of 'Paver' Density Data for All Sites

The variability discussed above is likely due to variations in conditions between sites such as testing error, materials, moisture content, construction methods and segregation. Therefore, an analysis of variance (ANOVA) was conducted on each site for each density data set collected. The results 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 α = 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 α = 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 density values 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

	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

* ‘Yes’ = Statistically significant at α=0.05

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 ‘visible’ tests and the ‘control’ measured not significant. The results of this analysis is 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

* Red shading = statistically significant at α=0.05. Green = no significant difference in readings

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 equal density 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.

6. Conclusions

1. The nuclear density gauge detects 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 appears to be 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.

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.

7. References

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

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