IMPLEMENTING THE SUPERPAVE 5 ASPHALT MIXTURE DESIGN METHOD IN INDIANA

by

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ABSTRACT

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Recent research developments have indicated that asphalt mixture durability and pavement life can be increased by modifying the Superpave asphalt mixture design method to achieve an in-place density of 95%, 2% higher than the conventional density requirements of approximately 93% (7% air voids content). Doing so requires increasing the design air voids content to 5% from the conventional requirement of 4 percent. After successful laboratory testing of this modified mixture design method, known as Superpave 5, two controlled field trials and one full scale demonstration project, the Indiana Department of Transportation (INDOT) let 12 trial projects across the six INDOT districts based on the design method. The Purdue University research team was tasked with observing the implementation of the Superpave 5 mixture design method, documenting the construction and completing an in-depth analysis of the quality control and quality assurance (QC/QA) data obtained from the projects. QC/QA data for each construction project were examined using various statistical metrics to determine construction performance with respect to INDOT Superpave 5 specifications. The data indicate that, on average, the contractors achieved 5% laboratory air voids, which coincides with the Superpave 5 recommendation of 5% laboratory air voids. However, on average, the as-constructed in-place density of 93.8% is roughly 1% less than the INDOT Superpave 5 specification. The findings of this study will benefit the future implementation of this modified mixture design method.

INTRODUCTION

Density is one of the most important factors in determining asphalt pavement performance, both in the short and long term. Linden et al. (1989) demonstrated that each 1% increase in the air voids (1% decrease in density) of an asphalt pavement can result in a 10% loss in pavement life. Currently, the Indiana Department of Transportation's (INDOT) method of asphalt mixture design and construction of asphalt pavements targets 4% air voids (V_a) in the laboratory compacted specimens, as required by the conventional Superpave mixture design method. Motivated to increase in-place asphalt pavement densities, Hekmatfar et al. (2015) successfully modified the standard Superpave asphalt mixture design method to allow contractors to achieve higher in-place density without increasing the compactive effort. Known colloquially as "Superpave 5," this modified method selects the optimum binder content based on 5% laboratory air voids, rather than at 4% air voids, as does the standard method. Additionally, the number of design gyrations (N_{design}) needed to compact laboratory specimens are lowered in the Superpave 5 method. Finally, the required voids in the mineral aggregate (VMA) is raised by 1%, to account for the 1% higher air voids content and maintain the effective binder content (P_{be}). In the controlled laboratory study done by Hekmatfar et al. (2015), it was noted that the Superpave 5 mixture design method produced mixtures that could be compacted to 5% air voids (95% density) in the field without requiring additional compaction effort beyond that used for the standard mixtures.

The Superpave 5 mixture design method was successfully tested in the laboratory, two controlled field tests and one full-scale demonstration project (Montoya et al., 2016). As a result, INDOT let 12 additional projects (two each in of the six INDOT districts) based on the updated specification that included the Superpave 5 mixture design method. As part of these projects, INDOT contracted with Purdue University to observe the construction of at least one project in each district, document the construction and analyze the resulting data from all 12 projects.

Given the contract with INDOT, the objectives of this research were twofold. Firstly, analyze the construction data to determine if the specifications were met and if any additional adjustments are needed to the Superpave 5 mixture design method. Secondly, INDOT specifically asked that a literature review be completed concerning asphalt mixture lift thickness and its effect on asphalt pavement density, and recommendations made on the lift thicknesses used by INDOT.

LITERATURE REVIEW

Asphalt Mixture Design

Asphalt is one the most widely used construction materials throughout the world with 94% of the 2.7 million miles of United States (US) paved roads and highways being surfaced with some type of asphalt product (National Asphalt Pavement Association, 2019). Asphalt mixture design plays a crucial role in ensuring the best mechanical behavior and durability of these asphalt pavements as the behavior of these mixtures is affected by the properties of individual components and their interaction with each other in the system (McGennis, 1995).

The Marshall asphalt mixture design method has been widely used throughout the world since its development in the 1940's (Kandhal et al., 1985). The Marshall design method involves choosing an aggregate gradation and a compaction level, then making trial specimens to determine the optimum binder content for the chosen gradation. In most scenarios, the optimum binder content is chosen such that the mixture has 4% air voids when appropriately compacted in the laboratory (Asphalt Institute, 2014). Air void (V_a) are small pockets of air that occur between the coated aggregated particles in the final compacted mixture. Air voids are critical to constructed asphalt pavements as it allows additional compaction under traffic and provide adequate spaces in which small amounts of asphalt can flow under such compaction. In the current study, laboratory air void was determined as follows: $V_a = \left(\left[1 - \left(\frac{G_{mb}}{G_{mb}}\right)\right] * 100\right)$, where G_{mm} is the maximum theoretical specific gravity of the mixture and G_{mb} is the bulk specific gravity of the mixture (Colorado Asphalt Pavement Association, 2015).

Despite the Marshall mixture design method's popularity, it has been argued the method is empirical and therefore not entirely able to incorporate the full effects of variable environmental and loading conditions (Asi, 2007). The method does not incorporate the effects of component types and properties on the resulting pavement performance (Asi, 2007; Jitsangiam et al., 2013). It has also been noted that the Marshall laboratory compaction method (impact hammer) does not satisfactorily produce the densities observed in the field (Roberts et al., 2002). According to a study conducted in Thailand, continued use of the Marshall mixture design method for asphalt mixture design was believed to be responsible for premature pavement deterioration (Jitsangiam et al, 2013).

Over the years, due to a poor understanding of failure mechanisms, the success of the Marshall mixture design method was mainly attributed to thick, uneconomical pavement sections (Swami et al., 2004). Concerns about the Marshall mixture design method lead to the development of a new asphalt mixture design method in the US that incorporates performance-based asphalt binder specifications. Started in the 1980s, the Strategic Highway Research Program (SHRP), lead to the development of the SUPERPAVE (SUperior PERformance PAVEments) mixture design system (Brown et al., 2001; Roberts et al., 2002). Now most commonly written as "Superpave," the asphalt mixture design system consists of aggregate criteria and tests and the utilization of volumetrics based on specimens compacted in the Superpave gyratory compactor (SGC), the SGC having been developed as part of the SHRP work (Roberts et al., 2002; Asi, 2007; Jitsangiam et al., 2013).

With the Superpave mixture design method, the laboratory design air voids are chosen to be 4% and in-place, as constructed air voids to be around 7 to 8% (Hekmatfar et al., 2015; Jitsangiam et al., 2013). The method uses 6 inch diameter SGC-compacted specimens to evaluate the volumetric properties of a mixture (Anderson, 1993), as the SGC is able to produce laboratory specimens whose volumetric and engineering properties are sufficiently close to those of field specimens (Sousa et al., 1991; Asi, 2007; Jitsangiam et al., 2013). The Superpave mixture design method is thought to have enhanced asphalt mixture performance under severe conditions such as temperature fluctuations and variable environments (Roberts et al., 2002; Jitsangiam et al., 2013).

Currently, INDOT uses the Superpave mixture design method to design asphalt mixtures targeting 4% air voids content in laboratory compacted specimens and 93% in-place (7% air voids) density in the field compacted mixtures (INDOT, 2018). Density is technically defined as the weight of the material that occupies a unit volume of space. The present study uses percent density of the as-constructed pavement as the physical measurement of density expressed as a percentage of maximum theoretical specific gravity (G_{mm}) (Aschenbrener et al., 2017). However, even when the in-place density criterion is statistically met, it can result in lower than desired density in 10% of the pavement area. This can lead to decreased pavement service life due to premature asphalt aging and thereby durability loss (Hekmatfar et al., 2015). The literature indicates that increasing the pavement density can significantly increase pavement durability by substantially decreasing pavement aging.

Hekmatfar et al. (2015) conducted a study exploring the possibility of increasing initial asphalt pavement density by altering the Superpave mixture design method. By changing the design air voids from 4 to 5%, they demonstrated that initial in-place densities of 95% could be achieved, in contrast to the common 92-93%, without increasing the compaction effort. Thus, a slight change in the mixture design method increased asphalt pavement durability. The resulting modified mixture design method is colloquially referred to as "Superpave 5."

Compaction and Lift thickness

Compaction of asphalt mixtures is defined as the process by which the amount of air voids is reduced in a mixture through application of external forces, hence reorienting the particles into a denser arrangement. The degree of asphalt mixture compaction in a constructed pavement is one of the most important factors for ensuring asphalt pavement quality and durability (Aschenbrener et al., 2017; Tran et al., 2016). It is been suggested that approximately 10% of the pavement life is lost with a 1% increase in air voids (1% loss in density) (Linden, 1989). Additionally, according to Finn et al. (1980), laboratory investigations suggest that asphalt mixture fatigue life can be reduced by 35% or more for every 1% increase in air voids.

There are various compaction techniques available to achieve the desired density (air voids) in asphalt mixtures, both in the field and the laboratory. Previous studies have discussed numerous factors affecting the compactibility of asphalt mixtures and thus the constructed pavement. These are lift thickness, nominal maximum aggregate size (NMAS), aggregate gradation of the mixture and design compactive effort (Cooley et al., 2002; Asphalt Magazine, 2018). Among these, many researchers have noted that lift thickness can perhaps have the most significant influence on density and hence the degree of compaction in the pavement (Hainin et al., 2013; Cooley et al., 2002; Musselman et al., 1998). Lift thickness is defined as the thickness of compacted asphalt layers or "lifts," which are placed one over another to construct an asphalt pavement. The literature reports that lift thickness has a direct correlation to the compaction process during pavement construction, thereby affecting the final air-voids ratio of the completed pavement (Brown et al, 2004)

Hainin et al. (2013) evaluated 14 asphalt mixtures for lift thickness and permeability relationships. They concluded the heat retained in a mixture increases proportionately with the thickness of the layer being placed. This ultimately leads to an increase in the workability and compactibility of a mixture. Cooley, Brown and Maghsoodloo (2001) studied in-place critical field permeability and pavement density values for coarse-graded Superpave pavements. They used the data to recommend permeability values and critical in-place densities for the Superpave-designed mixtures. In-place permeability was measured using a special device developed by Cooley and Brown (2000) which could be used in the field. Their research concluded that permeability characteristics of the asphalt pavement is greatly affected by the asphalt mixture NMAS. They also stated that thinner pavements are likely to be more permeable.

Brown et al (2004) investigated the minimum ratio of lift thickness (t) to NMAS (t/NMAS) needed for desirable pavement density levels to be achievable and assessed the relationship between in-place air voids, lift thickness and permeability. It was found the relationship between lift thickness and air voids is essentially one of compactibility. If the lift thickness is too thin, asphalt mixture will not be sufficiently available during compaction and hence, the aggregate particles cannot slide past each other. Thinner lifts also tend to cool quickly, thereby making them harder to compact. Musselman et al. (1998) investigated Florida's early Superpave mixture design method implementation experience. They established that lift thickness should ideally be four times the NMAS for coarse-graded Superpave Mixtures. Their suggestions for coarse-graded Superpave mixture lift thicknesses were 1.5 inches for a 3/8-inch mixture, 2.0 inches for a ½-inch mixture, and 3.0 inches for a ¾-inch mixture.

In discussing Federal Aviation Administration asphalt specifications, the Washington Asphalt Pavement Association (WAPA, 2018) gave various recommendations for the minimum lift thickness required for asphalt pavement construction. Their determination was that minimum lift thickness should be between three to four times NMAS. Moreover, the association advises that maximum lift thickness should be less than six times NMAS to achieve desirable compaction. Scherocman and Walker (2018) also discussed various factors contributing to asphalt compaction. Properties of the asphalt mixture, type and density of the underlying base course material, thickness of the asphalt layers and the environmental conditions at the time of asphalt placement were cited as the most important factors in achieving density. It was stressed that thick lifts have higher compactibility than the thinner lifts, as thicker lifts increase the heat retention, ultimately leading to improved compaction. Concurring with the Musselman et al. (1998) findings, Scherocman and Walker also state that minimum lift thickness should be more than three times the NMAS for fine-graded mixtures. Similarly, for coarse-graded mixtures, the lift thickness should be four times the NMAS.

PROJECT OVERVIEW

A total of 12 projects, two in each of the six INDOT districts, were let to contracts by INDOT requiring the asphalt mixtures to be designed using the Superpave 5 mixture design method and the attendant pavement density specification met. One of the projects was mistakenly completed as a standard Superpave mixture, leaving only 11 projects in the experiment. The one remaining Superpave 5 project in the LaPorte District was completed early in the 2018 paving season, before the research team could visit the project. Additionally, two of the projects were not completed during the 2018 paving season. Thus, of the original 12 projects, the research team visited only five project sites and only nine projects were actually completed in 2018. The present study therefore contains data from nine of the 12 projects. Table 1 provides information about the 11 projects and shows which projects are included in this analysis. As seen in the table, most of the projects were overlays, with only three being pavement replacement projects. Figure 1 indicates the approximate location of each project.

Table 1: Superpave 5 project information

	Route	From	To	Work Type	Analysed in the current report?
LaPorte	SR 23	SR 10	SR 8	Asphalt Mixture Overlay, Preventive Maintenance	Yes
Fort Wayne	US 20	0.07 mi E of SR 127	0.58 mi E of SR 127	Pavement Replacement	No
	US 30	0.13 mi W of SR 13	0.06 mi E of SR 5	Asphalt Mixture Overlay, Minor Structural	Yes
Crawfordsville	SR 75	3.21 mi N of I-74	3.99 mi N of I-74	Pavement Replacement	No
	US 231	1.38 mi S of SR 32 S Jct	0.29 mi N of US 136	Asphalt Mixture Overlay, Preventive Maintenance	Yes
Greenfield	SR 135	0.52 mi S of US 31	US 31	Pavement Replacement	Yes
	US 31	1.55 mi S I-465	0.39 mi N I-465	Asphalt Mixture Overlay, Minor Structural	Yes
Seymour	US 231	E jct of SR 46	SR 46	Asphalt Mixture Overlay, Preventive Maintenance	Yes
	US 50	SR 350	SR 1	Asphalt Mixture Overlay, Preventive Maintenance	Yes
Vincennes	US 150	0.18 mi W of E Jct of SR 56	SR 66	Asphalt Mixture Overlay Minor Structural	Yes
	SR 62	1.96 mi E of W Jct of SR-69	1.34 mi W of E jct SR-69	Asphalt Mixture Overlay, Minor Structural	Yes

As part of the construction site visits, the research team interacted with contractor and INDOT personnel, made and recorded observations, sampled materials, and made arrangements to obtain the project quality control and quality assurance (QC/QA) data. Figure 2 shows photographs taken from the five site visits. Once the data was obtained, it was then analyzed for compliance with the Superpave 5 specifications.

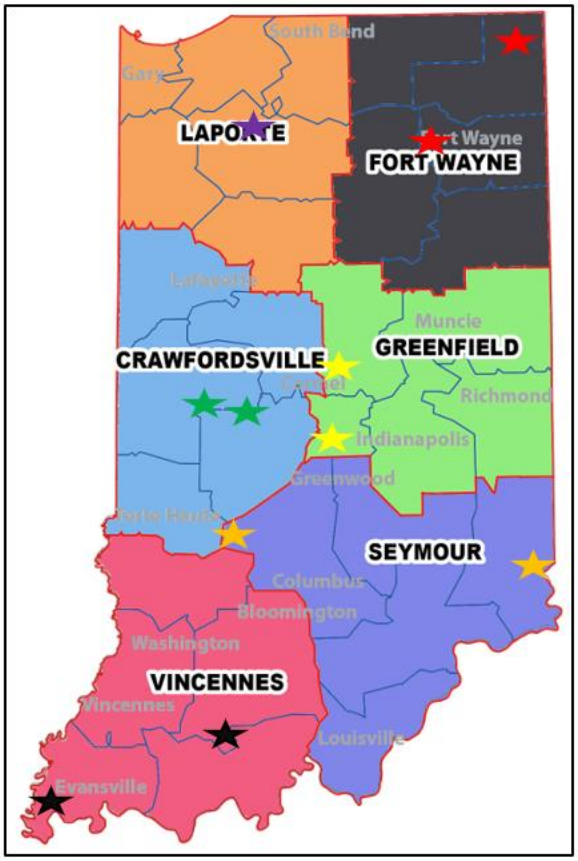


Figure 1: Superpave 5 projects locations

(a) Fort Wayne

(b) LaPorte

(c) Crawfordsville

(d) Greenfield

(e) Seymour

(f) Vincennes

Figure 2: Photographs from construction site visits

DATA ANALYSIS AND DISCUSSION

For each of the nine projects, the research team acquired the QC/QA data for analysis. These data are generated from asphalt mixture plate and core samples extracted from the roadway. Figure 3 shows the plate sampling in process. This process was completed according to INDOT standard methods and provided the asphalt mixture used to determine laboratory air voids. Once the constructed pavement lift had cooled sufficiently, cores were taken in accordance with INDOT standard procedures. All QC/QA work was completed by the contractor on INDOT personnel, not by the research team. The asphalt mixture properties obtained from the QC/QA data were aggregate gradation, fineness modulus, aggregate effective specific gravity (G_{se}), effective binder content (P_{be}), effective binder volume (V_{be}), laboratory air voids, laboratory VMA, pavement density, and the compaction procedures used.

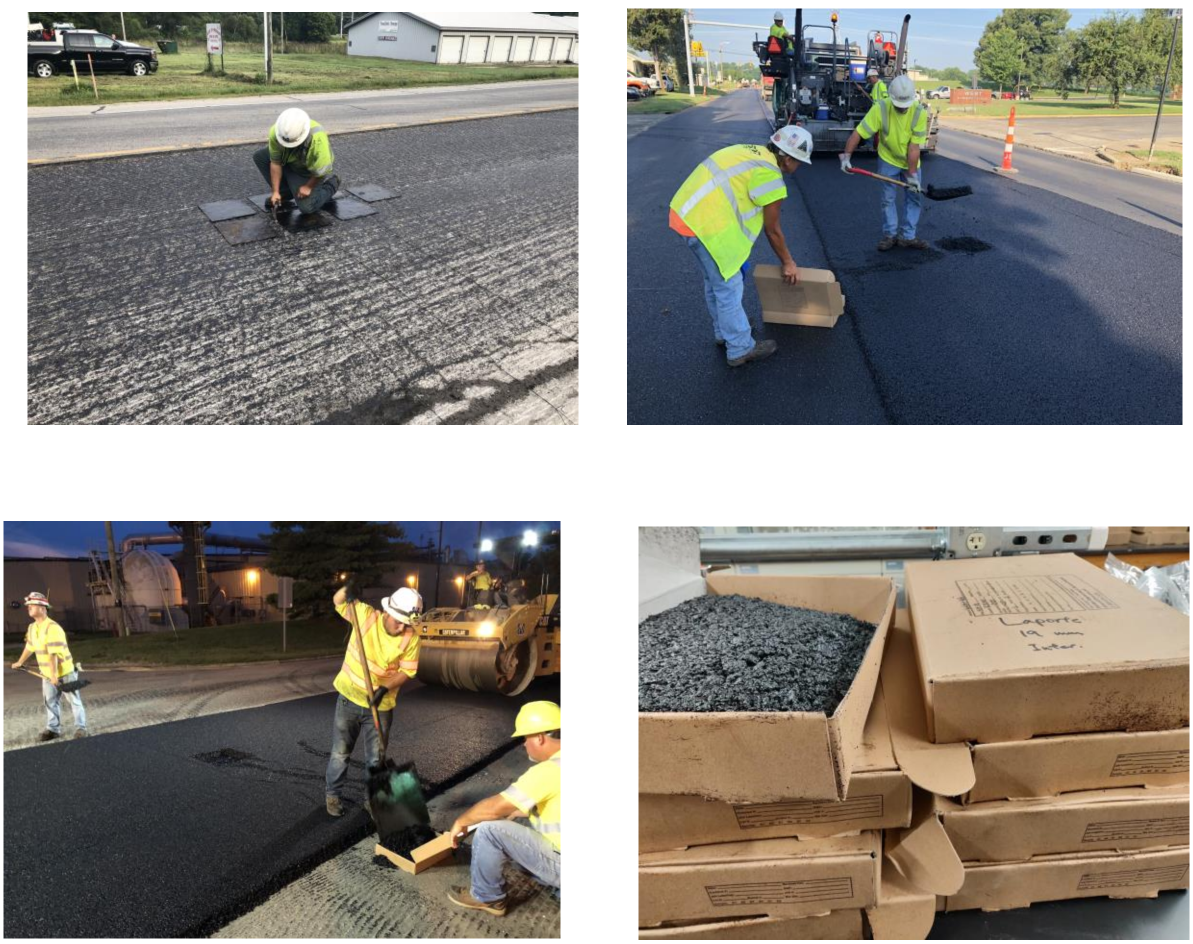


Figure 3: Sample collection at a Superpave 5 project site

A brief overview of the projects is given in Table 2. Information on quantity of asphalt (tons) placed was obtained from the Contract Information Book (CIB) available on the INDOT website. Asphalt mixture quantities which QC/QA data were available for the projects was obtained from Percent Within Limits (PWL) workbooks provided by INDOT. The data in Table 2 indicates the Fort Wayne project, RS 40253 produced the highest quantity of asphalt mixture, whereas the Crawfordsville project, RS 38668 had the lowest quantity. However, the Greenfield and Crawfordsville projects provided the largest amount of QC/QA data with respect to the quantity of asphalt mixture placed, with 12 and 30% respective differences between quantity of mixture placed and quantity of mixture for which data is available.

Table 2: Overview of the data received from Superpave 5 projects

Location	**Quantity of Asphalt Mixture placed (tons)**	**Quantity of Asphalt Mixture for which QC/QA data available (tons)**
Fort Wayne, RS 40253	49,192	24,940
Crawfordsville, RS 38668	6,150	4,321
LaPorte, RS 38629	16,500	2,711
Greenfield, R 30280	16,441	14,400
Vincennes, RS 39353	32,308	13,920
Vincennes, R 36648	7,185	7,100
Seymour, RS 39149	12,636	4,274
Seymour, RS 36176	3,180	1,979

To complete the primary objective of analyzing the construction data for compliance with Superpave 5 specifications, two main mixture properties were studied, laboratory air voids from the plate samples and pavement densities determined from field cores. Two sets of data were obtained for every test section, QC and QA. As two groups of data were sampled from every test section, it was necessary to investigate whether the difference between them was statistically significant or not. Hence, for every project, both laboratory air voids and in-place density QC and

QA data was t-tested assuming unequal variances, to determine whether the difference between them was statistically significant.

Table 3 shows the t-test results for eight of the projects. Seymour project RS 36176 was not t-tested due to lack of available data. The results show that on two projects, the laboratory air voids QC and QA data were statistically different. None of the projects showed a statistically significant difference between the QC and QA in-place density.

Table 3: t-test result summary

District	**Project number**	**Air voids data significantly different?**	**Density data significantly different?**
Fort Wayne	RS 40253	Yes	No
LaPorte	RS 38629	No	No
Crawfordsville	RS 38668	No	No
Seymour	RS 39149	No	No
Seymour	RS 36176	Not available	Not available
Vincennes	RS 39353	Yes	No
Vincennes	R 36648	No	No
Greenfield	R 30280	No	No

FORT WAYNE (RS 40253)

Overview

Project number RS 40253 in the Ft. Wayne district was an asphalt mixture overlay and minor structural work on US 30. The length of the project was 472 feet and involved 49,192 tons of mixture. The overall average laboratory air void was 5.4% while the overall average in-place density was 93.7 percent. Figure 4 is a plot of all the laboratory air voids and in-place density data and it shows that most of the air voids data are concentrated near the 5% line, as they should be, but most of the field densities are below the 95% line, indicating the mixture may have been somewhat under-compacted.

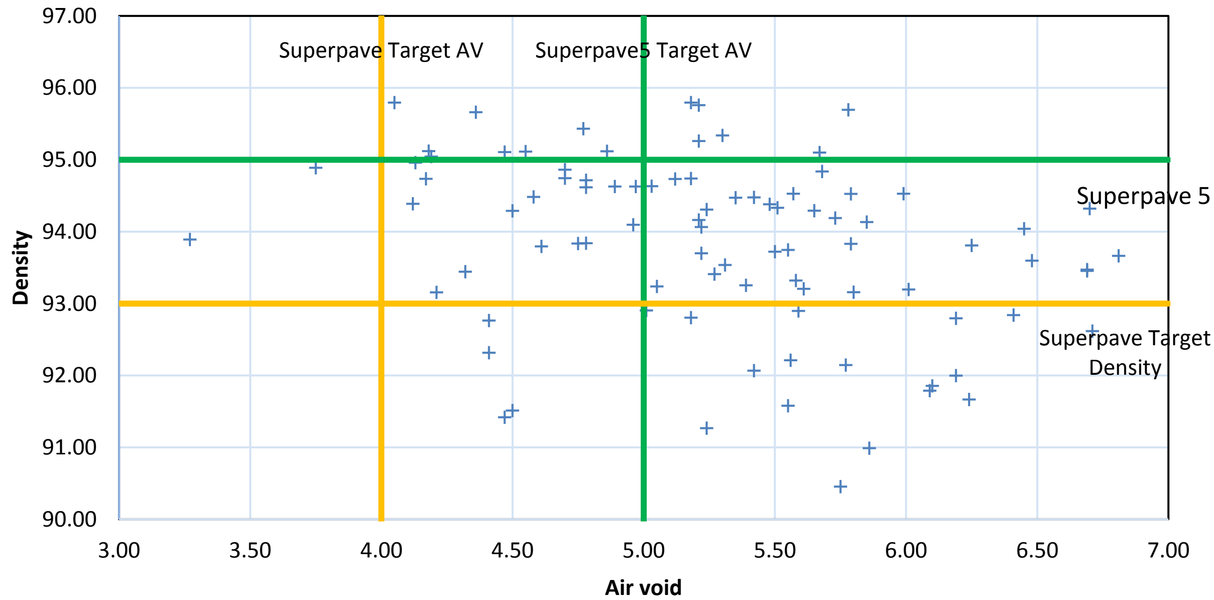


Figure 4: Volumetric data Summary for Project RS 40253

t-test analysis

The t-test was performed to determine if the QC and QA data are significantly different. From Table 4 it is observed that for α = 0.50 and assuming unequal variances, the t-test indicates the difference between QC and QA laboratory air voids is statistically significant as $t_{stat} > t_{critical}$. However, the data in Table 5 shows the QC and QA density data are not significantly different, again with α = 0.50 and unequal variances.

Table 4: t-test results for laboratory air void data (RS 40253)

T-test	**QA data**	**QC data**
Mean	5.5	5.2
Variance	0.6	0.4
t_{stat}	2.98	
$t_{critical,two-tail}$	1.98	

Table 5: t-test results for density data (RS 40253)

T-test	**QA data**	**QC data**
Mean	93.6	93.8
Variance	1.5	1.6
t_{stat}	-0.82	
$t_{critical,two-tail}$	1.98	

Volumetric analysis

Figure 5 is a box and whisker plot for the laboratory air voids data of the project. The lower and upper dimensions of the box represent the 25th and 75th percentile of the data, respectively. The line inside the box denotes the median value of the data (50th percentile). The QC plot shows that 50% of the data points lie within 5.0 ± 0.5%, with the median being close to 5.3 percent. The QA data plot has a higher estimate of median laboratory air voids at 5.5%, with more than 75% of the data points lying above the 5% air voids line. Thus, both the QC and QA data, though significantly different, indicate the laboratory air voids for the project are slightly higher than the Superpave 5 recommendation of 5 percent.

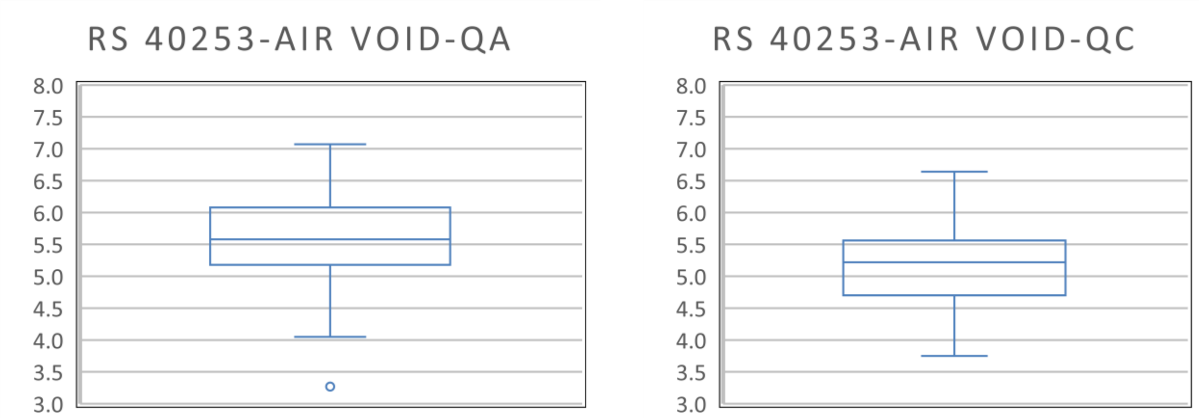


Figure 5: Box and whisker plot for laboratory air voids (RS 40253)

After studying QC and QA air voids individually through box and whisker plot, a Pareto chart was plotted to examine them together. It consists of a modified histogram with the bins arranged in the decreasing order of frequency. Afterwards, a Pareto line is plotted denoting the cumulative frequency of the distribution. Figure 6 shows the distribution of the air void data in uniformly spaced 0.5% bins. It is noted that approximately 55% of the data lies between 5 to 6% air voids, indicating that the project was successful in achieving laboratory air voids higher than the conventional Superpave mixture recommendation of 4 percent. Only 30% of all the air voids lie below the Superpave 5 air void recommendation of 5 percent.

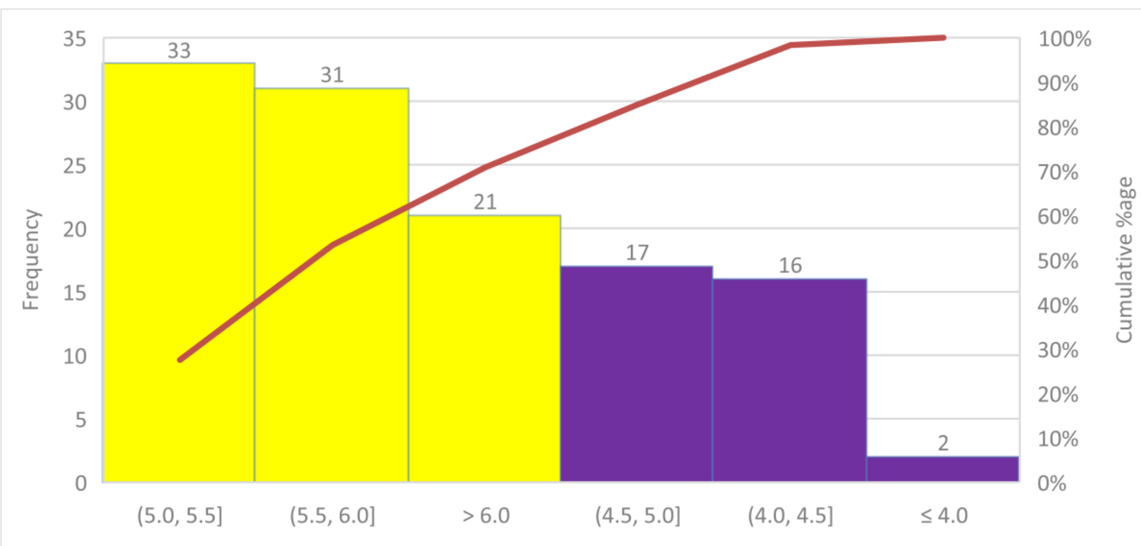


Figure 6: Laboratory air voids data Pareto chart, RS 40253 (QC and QA combined)

Figure 7 shows the box and whisker plot of the density data. Both the QA and QC box plots indicate that 75% of the respective data points lie below 95%, the target density for Superpave 5 mixtures. Moreover, the median of both the QC and QA data ranges are approximately 94%, indicating that the asphalt mixture was slightly under-compacted by about 1 percent.

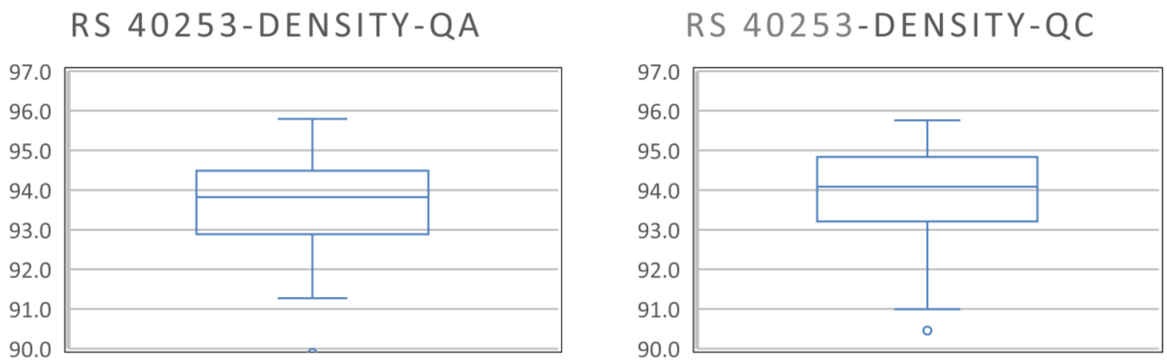


Figure 7: Box and whisker plot for density (RS 40253)

The Pareto chart in Figure 8 again indicates the under-compaction that occurred for the RS 40253 project. The figure shows about 85% of the density values are below the Superpave 5 density recommendation of 95%, with approximately 25% of densities values below 93 percent. Conversely, only 10% of densities values were reported to be equal to or higher than 95 percent.

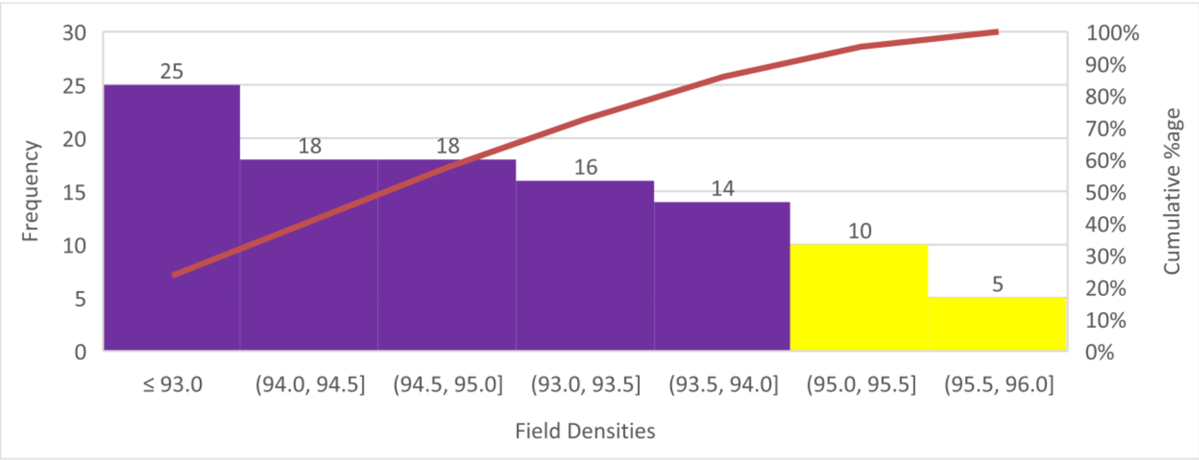


Figure 8: Density data Pareto chart for RS 40253 (QC and QA combined)

Lift thickness and Compaction

Table 6 shows the planned lift thickness data for the project. No as-built lift thickness data was supplied in either the QC or QA data set. The planned lift thickness data show that both the intermediate and surface mixtures have t/NMAS ratios between three and four, satisfying the recommended lift thicknesses indicated in the literature.

Table 6: Lift thickness data for RS 40253

Course	NMAS of mixture (inch)	Lift thickness of course, t (inches)	t/NMAS
Intermediate	3/4	2.5	3.3
Surface	3/8	1.5	4.0

The compaction method for the project was to apply seven vibratory passes with the breakdown roller followed by seven additional vibratory passes of the intermediate roller. The finish roller then applied seven oscillatory passed. Detailed information about the compaction process and the rollers is shown in Table 7. Figure 9 shows photographs taken during compaction.

Table 7: Compaction Methodology for RS 40253

	Breakdown	Intermediate	Finish
Number of Rollers	1	1	1
Vibratory Passes	7	7	0
Static Passes	0	0	7 (oscillation)
Operating Weight, lbs	37,000	37,000	28,175.1
Drum Width, in	84	84	78
Static Linear Load (front/rear), lbs/in	217 /224	217/224	179/181
Model	Dynapac CC7200	Dynapac CC722	HAMM HD 120

Figure 9: Compaction photographs for Project RS 40253

LAPORTE (RS 38629)

Overview

Project number RS 38629 in the LaPorte District was an asphalt mixture overlay and preventive maintenance work on SR 23. The length of the project was 400 feet and involved 16,500 tons of mixture. The overall average laboratory air voids was 4.9% while the overall average in-place density was 94.2 percent. Figure 10 is a plot of all the laboratory air voids and in-place density data and shows that nearly all the field densities are between the conventional Superpave and Superpave 5 criteria for densities, 93% and 95% respectively.

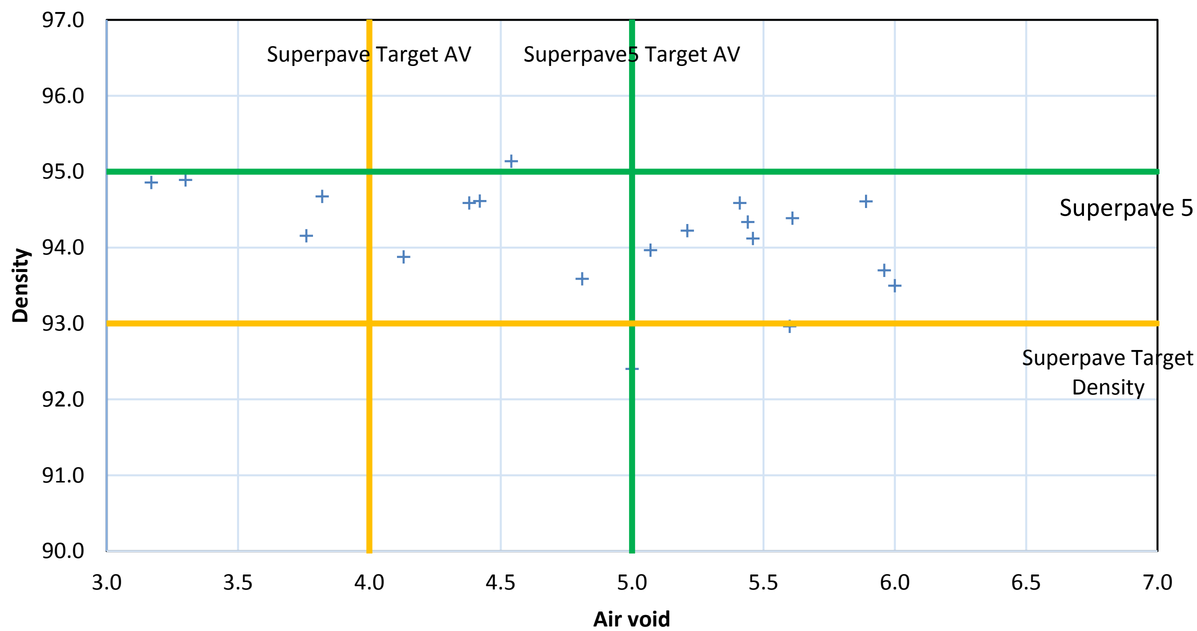


Figure 10: Volumetric data summary for project RS 38629

t-test analysis

The t-test was performed to determine if the QC and QA data are significantly different. From Table 8 it is observed that for α = 0.50 and assuming unequal variances, the t-test indicates that difference between QC and QA data are not statistically significant as $t_{stat} < t_{critical}$. The data in Table 9 shows the QC and QA density data are not significantly different, again with α = 0.50 and unequal variances.

Table 8: t-test results for laboratory air voids data (RS 38629)

T-test	**QA data**	**QC data**
Mean	4.9	4.8
Variance	0.8	0.8
t_{stat}	0.39	
$t_{critical,two-tail}$	2.10	

Table 9: t-test results for density data (RS 38629)

T-test	**QA data**	**QC data**
Mean	94.3	94.3
Variance	0.3	0.3
t_{stat}	0.00	
$t_{critical,two-tail}$	2.10	

Volumetric Analysis

Figure 11 is a box and whisker plot for the project laboratory air voids data in LaPorte. The medians of both QA and QC data is approximately 5%, which coincides with the target specification of Superpave 5. Moreover, in both the cases, more than 75% of the air voids lie above 4% mark, which is the conventional Superpave mixture design specification. Thus, both QC and QA data show the laboratory air voids for the RS 38629 to approximate the Superpave 5 recommendation of 5 percent.

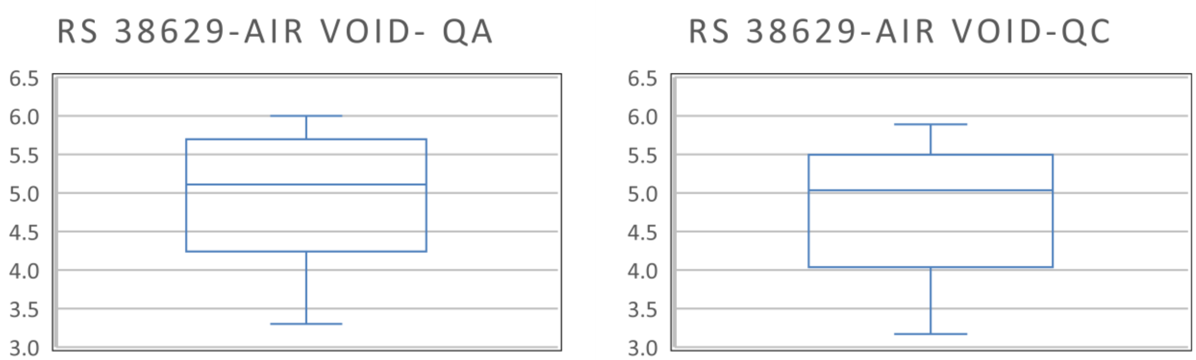


Figure 11**:** Box and whisker plot for laboratory air voids (RS 38629)

Figure 12 shows the distribution of laboratory air voids data in uniformly spaced 0.5% bins via the Pareto chart. It is noted that roughly 50% of the air voids lie in the range of 5 to 6 percent. Secondly, again a shift from the conventional Superpave design to Superpave 5 mixture design was noted as only 20% of the air voids are equal to or less than the 4% air voids mark.

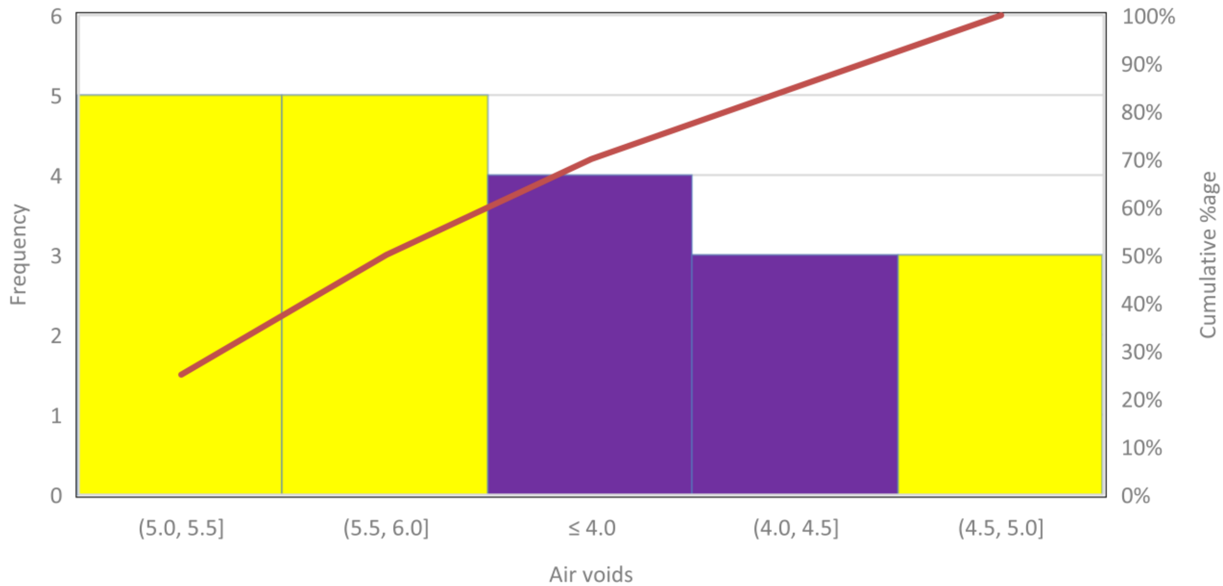


Figure 12: Laboratory air voids data Pareto chart, RS 38629 (QC and QA combined)

Figure 13 shows the box and whisker plot of the density data. The QA box plot shows the median of the data as 94.5%, whereas the QC box plot shows roughly 94% as the median data value. This project appears to be under-compacted with respect to the Superpave 5 specification, as most of the data points lie below the 95% mark for QC and QA cases. Not a single density was found to be equal to, or higher than 95% in the QC data. Moreover, with QC and QA combined average of 94.2%, this asphalt mixture appears to be under-compacted by about 1 percent.

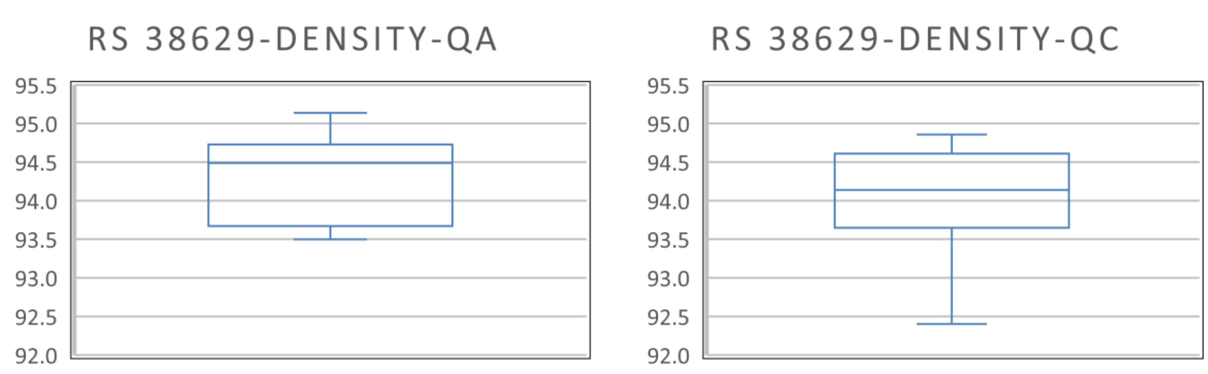


Figure 13: Box and whisker plot for density (RS 38629)

The under-compaction noted above is again highlighted by density Pareto chart in Figure 14. Most of the densities lie in the range 94.0-95.0 percent. More than 95% of the data lies below 95% density mark, the Superpave 5 specification for density.

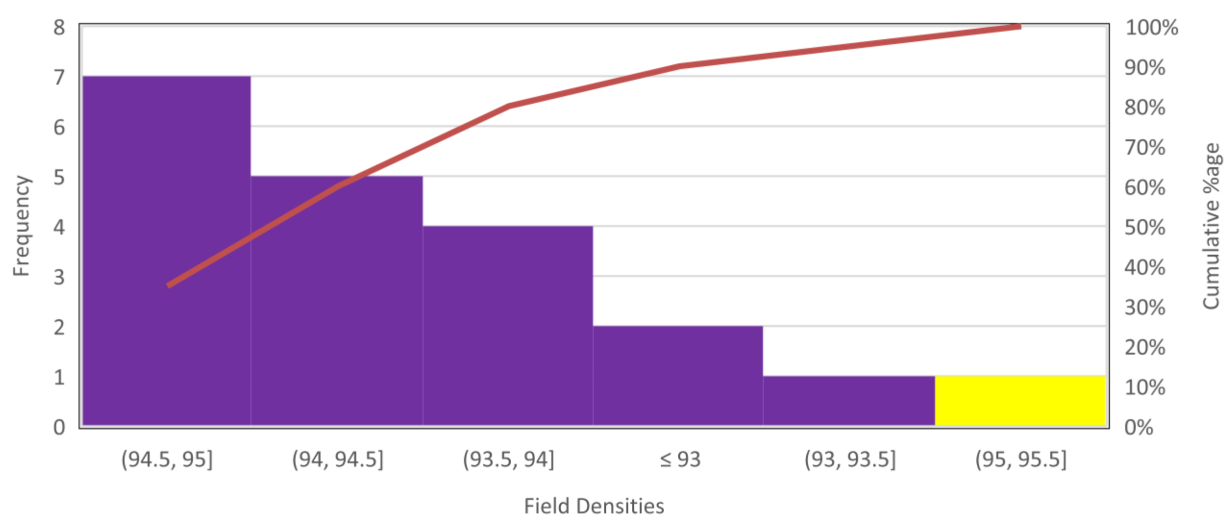


Figure 14: Density data Pareto chart for RS 38629 (QC and QA combined)

Lift thickness and Compaction

Table 10 shows the planned lift thickness data for the project. No as-built lift thickness data was supplied in either the QC or QA data set. The planned lift thickness data show that the surface mixtures have t/NMAS ratios between three and four, satisfying the recommended lift thicknesses indicated in the literature.

Table 10: Lift thickness data for RS 38629

Course	NMAS of mixture (inch)	Lift thickness of course, t (inches)	t/NMAS
Surface	½	1.5	3.0

The site visited in the LaPorte district by the research team was not being constructed according to the Superpave 5 specification. Therefore, compaction data is unavailable for the current project.

CRAWFORDSVILLE (RS 38668)

Overview

Project number RS 38668 in the Crawfordsville District was asphalt mixture overlay and preventive maintenance work on US 231. The length of the project was 292 feet and involved 6,150 tons of mixture. The overall average laboratory air voids was 4.7% while the overall average in-place density was 93.7 percent. Figure 15 is a plot of all the laboratory air voids and in-place density data and it shows that most of the densities lie between the conventional and modified Superpave specifications, leaning towards the former one. Moreover, air voids content is scattered from 3-6%, indicating that the project was not able to meet the Superpave 5 air voids content specification efficiently.

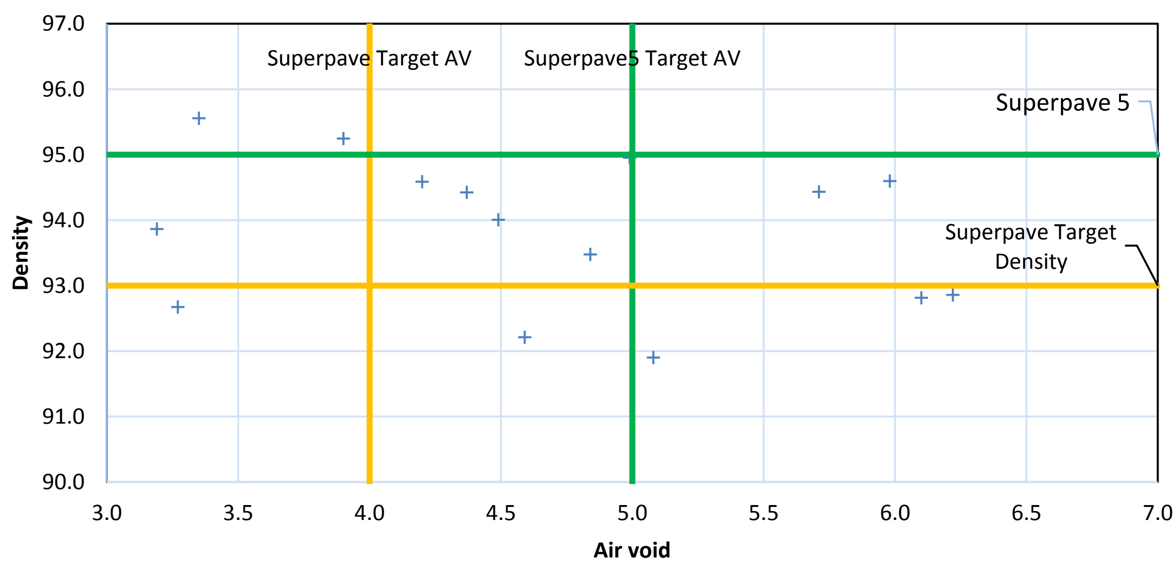


Figure 15: Volumetric data summary for Project no RS 38668

t-test analysis

The t-test was performed to determine if the QC and QA data are significantly different. From Table 11, it is observed that for $\alpha = 0.50$ and assuming unequal variances, the t-test indicates that QC and QA data are not significantly different from each other. Similarly, for density data, data in

Table 12 shows the QC and QA density data are not significantly different, again with α = 0.50 and unequal variances as $t_{stat} < t_{critical,two-tail}$.

Table 11: t-test results for laboratory air voids data (RS 38668)

T-test	**QA data**	**QC data**
Mean	4.3	5.0
Variance	0.7	1.1
t_{stat}	-1.51	
$t_{critical,two-tail}$	2.16	

Table 12 t-test results for density data (RS 38668)

T-test	**QA data**	**QC data**
Mean	94.1	93.8
Variance	1.4	1.2
t_{stat}	0.52	
$t_{critical,two-tail}$	2.14	

Volumetric Analysis

Figure 16 is a box and whisker plot for the project laboratory air voids data. The QA data indicates that more than 75% of the air voids lied below Superpave 5 specification of 5%, with the median of the data being 4.5 percent. However, the QC data reveals median of the air void to be 5%, in agreement with the Superpave 5 specification. Due to the limited amount of data, standard deviation of the data was high leading to bigger dimension boxes.

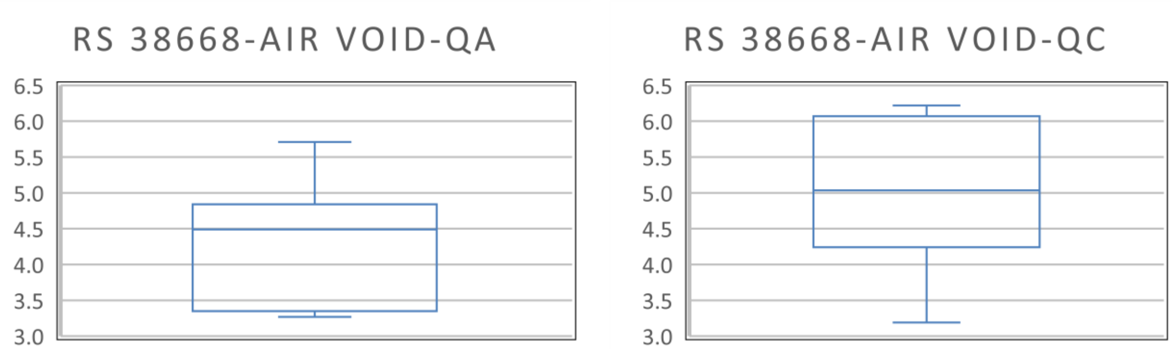


Figure 16: Box and whisker plot for laboratory air voids (RS 38668)

Figure 17 shows the combined QC and QA data for laboratory air voids through Pareto chart. Roughly 65% of the air voids are equal to or less than 5.0% air voids mark, indicating that project's air voids content leaned more towards the conventional air voids content specification of 4% rather than modified recommendation of 5 percent.

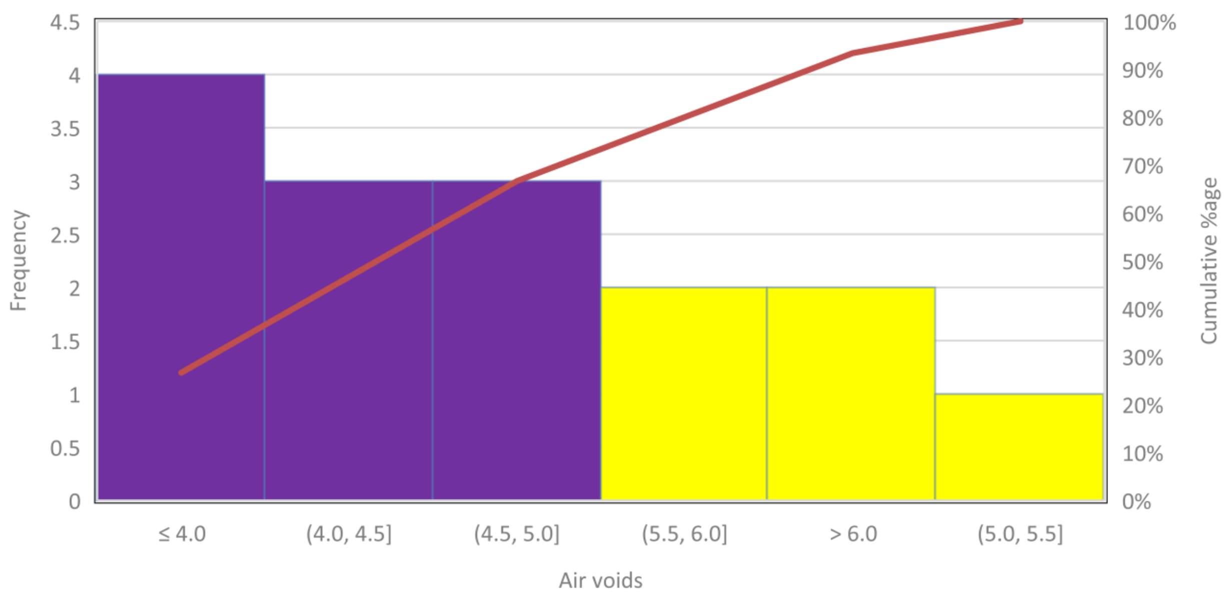


Figure 17: Laboratory air voids data Pareto chart, RS 38668(QC and QA combined)

Figure 18 shows the box and whisker plot of the density data which indicates median density for both sets of data is 94%, 1% less than the Superpave 5 recommendation. However, all the data points of QC densities lie below 95% mark, indicating under-compaction. As the number of observations in the current dataset was limited, the box plots are bigger than the previous locations suggesting a wider spread of data points.

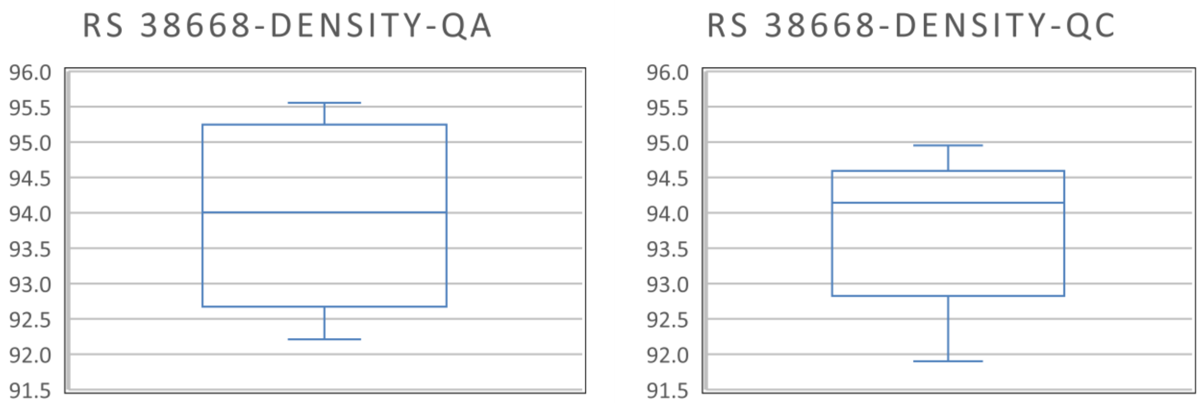


Figure 18: Box and whisker plot for density (RS 38668)

Figure 19 shows density data combining both QC and QA data. Majority of the densities are less than 93%, which is the density specification under conventional Superpave design. It can be concluded that the current project was under-compacted and failed to meet Superpave 5 density criteria.

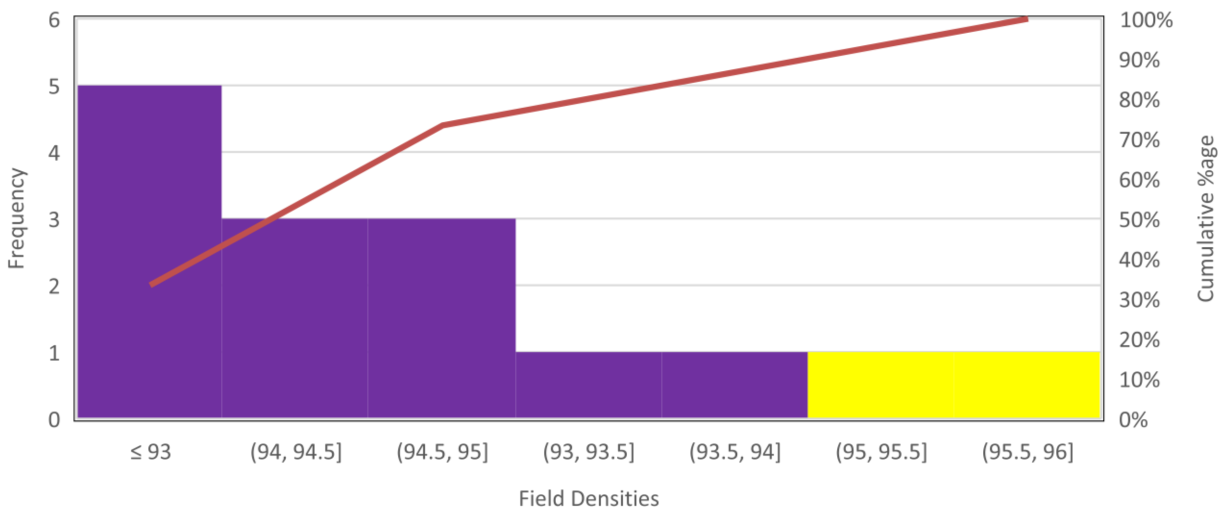


Figure 19: Density data Pareto chart for RS 38668 (QC and QA combined)

Lift thickness and Compaction

Table 13 shows the planned lift thickness data for the project. No as-built lift thickness data was supplied in either the QC or QA data set. The planned lift thickness data show that the surface mixture has t/NMAS ratios between three and four, satisfying the recommended lift thicknesses indicated in the literature.

Table 13: Lift thickness data for RS 38668

Course	NMAS of mixture (inch)	Lift thickness of course, t (inches)	t/NMAS
Surface	3/8	1.5	4.0

The compaction method for the project was to apply eleven vibratory passes with the breakdown roller followed by nine additional vibratory passes of the intermediate roller. The finish roller then applied seven oscillatory passes. Detailed information about the compaction process and the rollers is shown in Table 14. Figure 20 shows photographs taken during compaction.

Table 14: Compaction methodology for RS 38668

	Breakdown	Intermediate	Finish
Number of Rollers	1	1	1
Vibratory Passes	11	9	0
Static Passes	0	0 (oscillation)	7
Operating Weight, lbs	26,230	28,175.1	25,360
Drum Width, in	79	78	78
Static Linear Load (front/rear), lbs/in	166	179/181	170/155
Model	CAT CB54 XW	HAMM HD 120	Ingersoll-Rand DD-110 HF

Figure 20**:** Compaction photographs

SEYMOUR (RS 39149)

Overview

Project number RS 39149 in the Seymour District was an asphalt mixture overlay and preventive asphalt pavement maintenance work on US 231. The length of the project was 538 feet and involved 12,636 tons of mixture. The overall average laboratory air voids was 4.7% while the overall average in-place density was 93.7 percent. Figure 21 provides an overview of the volumetric data of the Superpave 5 project in Seymour. It is observed that most of the data points lie near or below the conventional Superpave specification for air voids and density. Furthermore, density was observed to be ranging from 90 - 97%, indicating high variability in the compaction effort. In the case for air voids too, values range between 3-7%, giving a ±2% variation to the Superpave 5 recommendation of 5 percent.

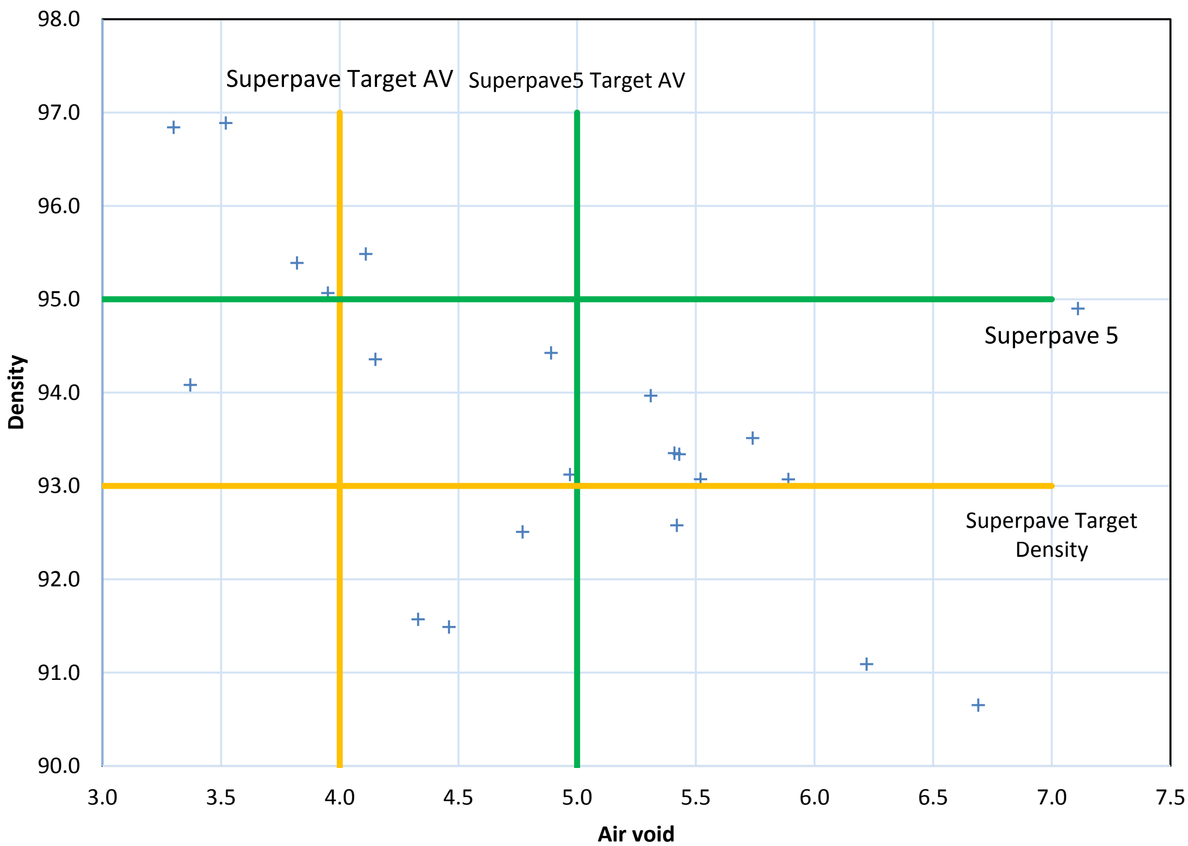


Figure 21: Volumetric data summary for Project no RS 39149

t-test analysis

The t-test was performed to determine if the QC and QA data are significantly different. From Table 15 it is observed that for α = 0.50 and assuming unequal variances, the t-test indicates the QC and QA laboratory air voids are not significantly different as $t_{stat} < t_{critical}$. The data in Table 16 shows the QC and QA density data are not significantly different, again with α = 0.50 and unequal variances.

Table 15: t-test results for laboratory air voids data (RS 39149)

T-test	QA data	QC data
Mean	4.6	4.9
Variance	1.6	1.4
t_{stat}	-0.66	
$t_{critical,two-tail}$	2.07	

Table 16: t-test results for density data (RS 39149)

T-test	QA data	QC data
Mean	93.5	93.9
Variance	2.7	2.7
t_{stat}	-0.46	
$t_{critical,two-tail}$	2.07	

Volumetric Analysis

Figure 22 is a box and whisker plot for the laboratory air voids data. The median air voids for both the data sets is approximately 5% coinciding with the Superpave 5 air voids recommendation. The QA air voids data ranges from 2.5-7% whereas the QC data ranges from 3.5-7 percent.

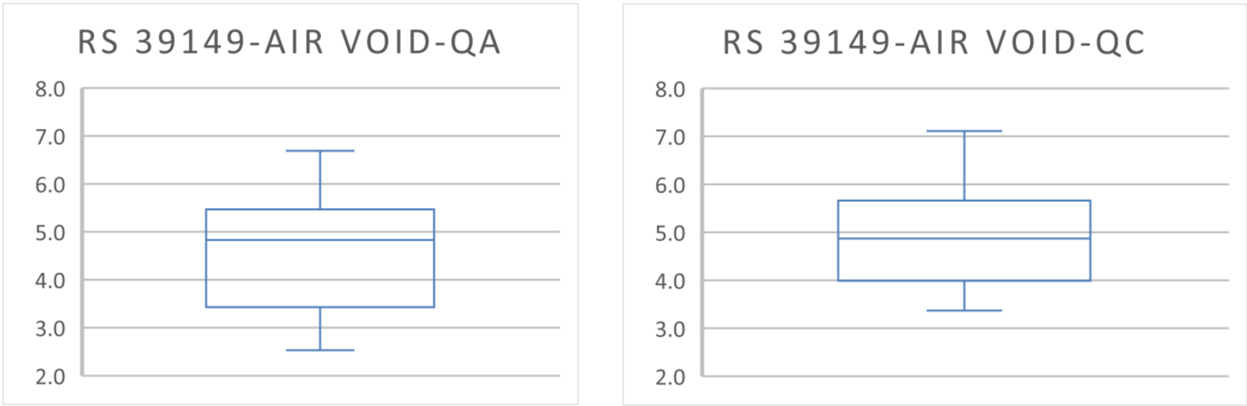


Figure 22: Box and whisker plot for laboratory air voids (RS 39149)

An overview of the air voids of the Superpave 5 project at Seymour is provided in Figure 23. From the Pareto chart, it is observed that roughly 50% of the data lies below 4.5% air voids, indicating that in general, air voids at the field was below Superpave 5 air voids specification of 5 percent.

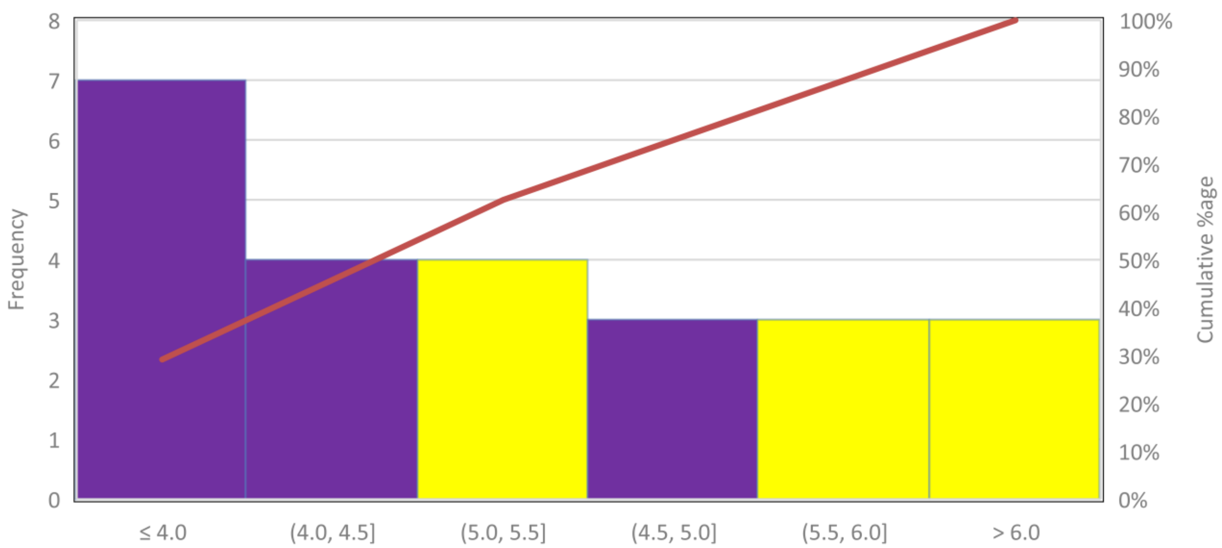


Figure 23: Laboratory air voids data Pareto chart, RS 39149 (QC and QA combined)

Figure 24 shows the box and whisker plot of the density data. In both the cases, 75% of the densities lie below Superpave 5 recommended density of 95 percent. Moreover, median field density achieved in case of QA database is 93.5% whereas its roughly 94% according to QC database, indicating lower compaction effort was applied than required to achieve 95% field density.

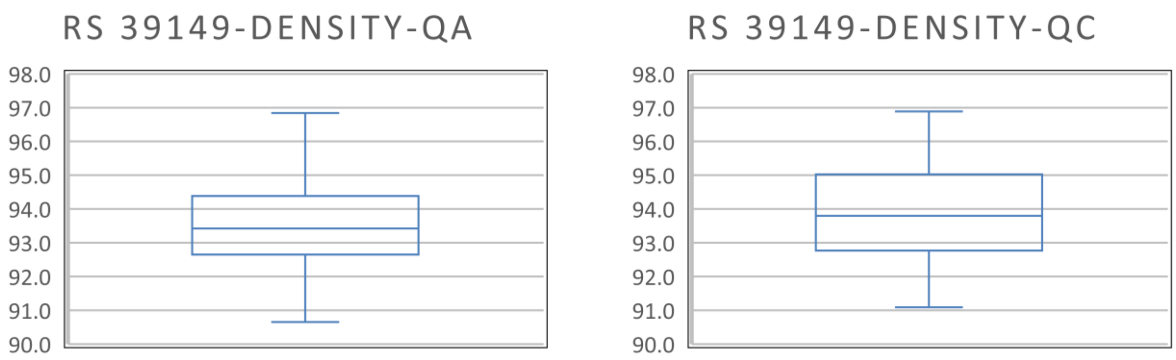


Figure 24: Box and whisker plot for density (RS 39149)

Pareto chart in Figure 25 gives a complete overview of the field densities. It is observed that as discussed previously, most of the densities are less than 94%, indicating inadequate compactive effort being applied. However, few density observations were noted in (96.5,97] region, which might be a result of anomalous over compaction being in few locations in the site.

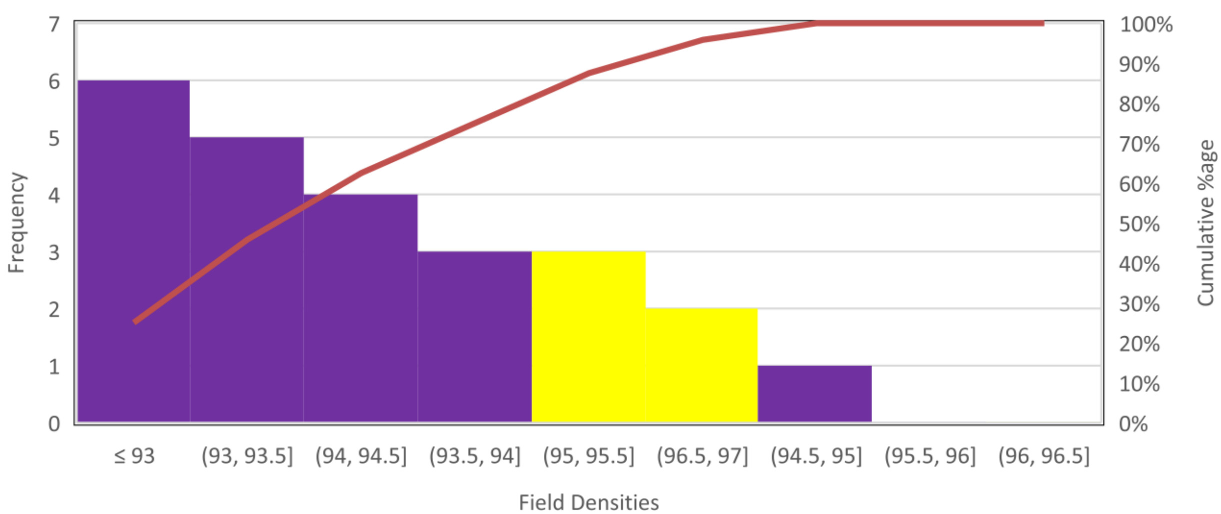


Figure 25: Density data Pareto chart for RS 39149 (QC and QA combined))

Lift thickness and Compaction

Table 17 shows the planned lift thickness data for the project. No as-built lift thickness data was supplied in either the QC or QA data set. The planned lift thickness data show that both the surface mixtures has t/NMAS ratios between three and four, satisfying the recommended lift thicknesses indicated in the literature.

Table 17: Lift thickness data for RS 39149

Course	NMAS of mixture (inch)	Lift thickness of course, t (inches)	t/NMAS
Surface	3/8	1.5	4.0

The compaction method for the project was to apply thirteen vibratory passes with the breakdown roller without involving any additional vibratory passes of the intermediate roller. The finish roller then applied nine static passes. Detailed information about the compaction process and the rollers is shown in Table 18. Figure 26 shows photographs taken during compaction.

Table 18: Compaction methodology for RS 39149

	Breakdown	Finish
Number of Rollers	2 (echelon)	1
Vibratory Passes	13	0
Static Passes	0	9
Operating Weight, lbs	26,230	26,230
Drum Width, in	79	79
Static Linear Load (front/rear), lbs/in	166	166
Model	CAT CB54 XW	CAT CB54 XW

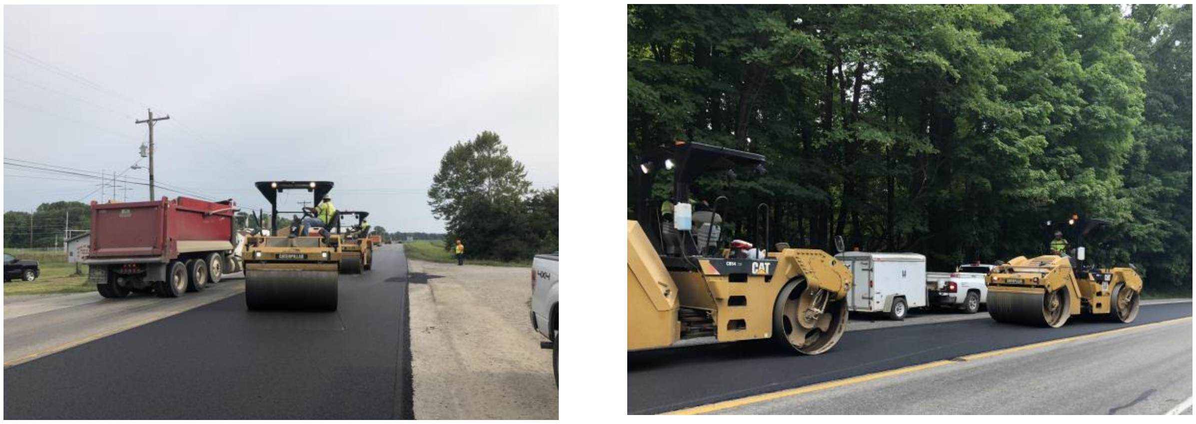


Figure 26: Compaction photographs for RS 39149

SEYMOUR (RS 36176)

Overview

Project number RS 36176 in the Seymour District was asphalt mixture overlay and preventive maintenance work on US 50. The length of the project was 593 feet and involved 3,180 tons of mixture. However, until the preparation of this report, surface layer had not been laid. Data for only intermediate and base layer was available. The average air voids achieve on the field for this project was 5.4% and the average field density was 91.5 percent.

Volumetric Analysis

From Figure 27, it is observed that unlike previous projects, very few data points are available for the current project in Seymour. Minimum density reported for the project was 85.7%, approximately 10% less than the Superpave 5 specification. Maximum density was reported to be 94.8% which is close to 95% density specification. Similarly, maximum air voids was found to be 7.3% which is 2.3% higher than the Superpave 5 specification. Rest of the air voids values lie between 4%-6% air voids mark, which is ±1% deviation from the Superpave 5 specification of 5% air voids.

As only 7 data points (QC and QA combined) were available for the current project, further data analysis was unfeasible. Therefore, based on the data available from laying the intermediate and base layer in this project, it can be concluded that the current project has failed to meet the Superpave 5 recommendation for modified mixture design.

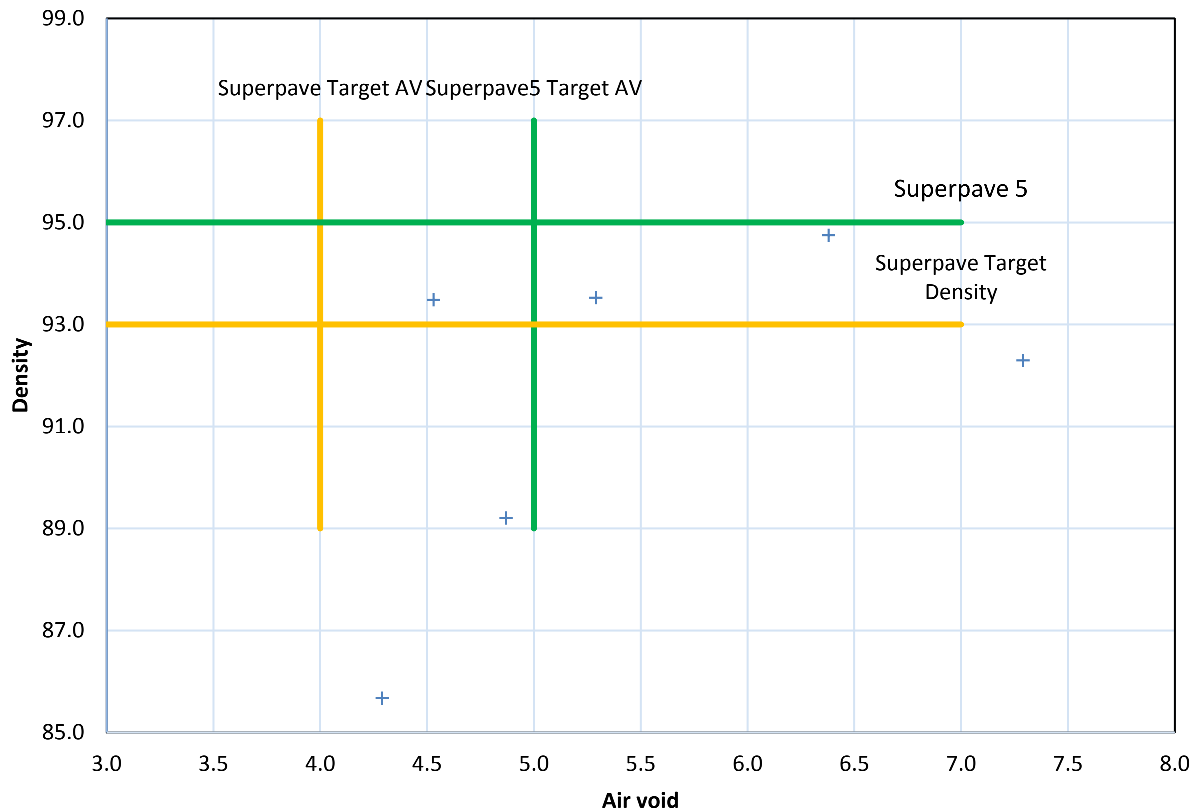


Figure 27: Volumetric Data Summary for RS 36176 Project

Lift thickness and Compaction

Table 19 shows planned lift thickness data of the project. It provided lift thickness of only the surface layer, lift thicknesses for the intermediate and base layer were unavailable for the current project. On the other hand, NMAS information for the surface layer of the project was unavailable with the researchers. Therefore, the study was not able to calculate t/NMAS ratio (Table 19) for either of the layers.

Table 19: Lift thickness data for RS 36176

Course	NMAS of mixture (inch)	Lift thickness of course, t (inches)	t/NMAS
Surface	-	1.5	-
Base	1.0	NA	-
Intermediate	3/4	NA	-

VINCENNES (RS 39353)

Overview

Project number RS 39353 in the Vincennes District was an asphalt mixture overlay and minor structural work on US 150. The length of the project was 1,372 feet and involved 32,308 tons of mixture. The overall average laboratory air voids was 5.0% while the overall average in-place density was 94.3 percent. Figure 28 represents an overview of laboratory air voids and field densities achieved. It can be observed that most of the data points are aggregated close to the Superpave 5 specification lines, indicating that the current project was more successful than the others in meeting Superpave 5 recommendations.

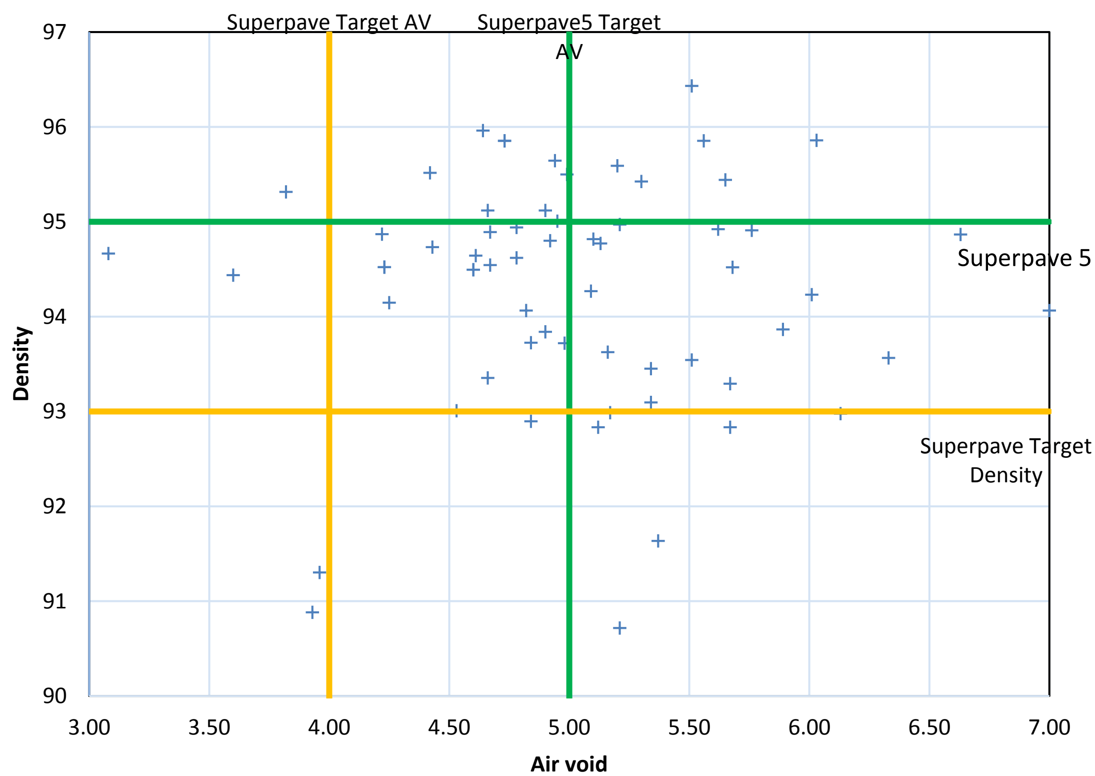


Figure 28**:** Volumetric data summary for Project RS 39353

t-test analysis

The t-test was performed to determine if the QC and QA data are significantly different. From Table 20 it is observed that for α = 0.50 and assuming unequal variances, the t-test indicates the QC and QA laboratory air voids are significantly different as $\mathrm{t_{stat}} > \mathrm{t_{critical}}$. The data in Table 21 shows the QC and QA density data are not significantly different, again with α = 0.50 and unequal variances as $-t_{critical,two-tail} < t_{stat} < t_{critical,two-tail}$.

Table 20: t-test results for laboratory air voids data (RS 39353)

T-test	**QA data**	**QC data**
Mean	5.3	4.7
Variance	0.5	0.5
t_{stat}	3.25	
$t_{critical,two-tail}$	2.00	

Table 21: t-test results for density data (RS 39353)

T-test	**QA data**	**QC data**
Mean	94.3	94.3
Variance	1.5	1.5
t_{stat}	0.07	
$t_{critical,two-tail}$	2.00	

Volumetric Analysis

Figure 29 is a box and whisker plot for the project laboratory air voids data for project no. 39353. It is observed that in case of QA data, median air voids is greater than 5% which is Superpave 5 specification for air voids, whereas it is close to 4.5% according to the QC database. However, in both the cases, Quality assurance air voids range from 3.5-6.5% whereas it ranges roughly from 4-6% in case of QC database. This represents a shift into higher air voids range from the conventional Superpave mixture design as recommended by the modified mixture design.

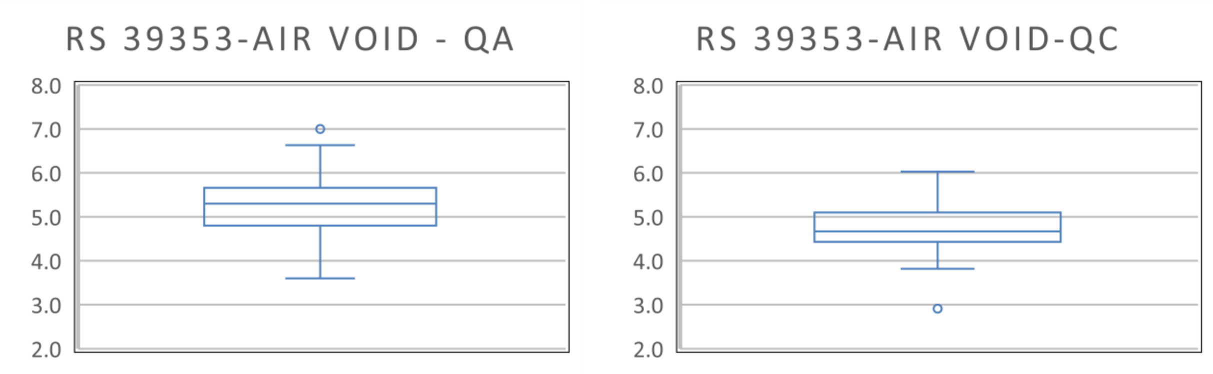


Figure 29: Box and whisker plot for laboratory air voids (RS 39353)

Figure 30 portrays the shift towards higher air voids range through Pareto chart. Roughly 60% of air voids lie in range 4.5-5.5% whereas most of the air voids lie above 5% mark. As the combined QC and QA average laboratory air voids was calculated to be 5%, it can be concluded that the current Vincennes project was able to meet the air voids specification of Superpave 5 satisfactorily.

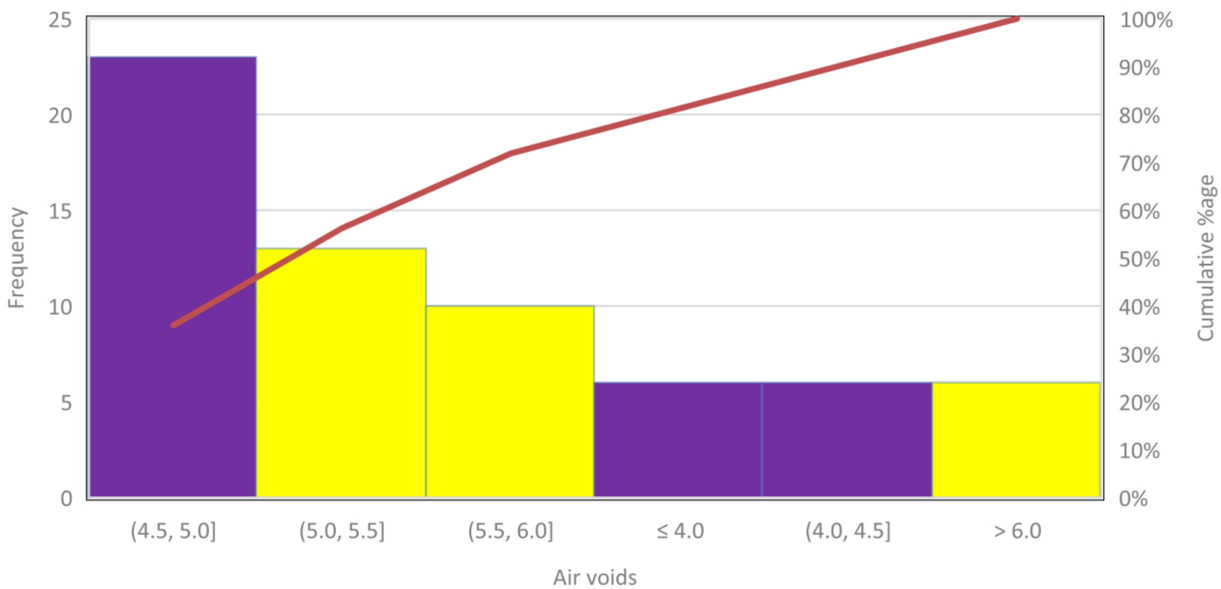


Figure 30: Laboratory air voids data Pareto chart, RS 39353 (QC and QA combined)

Figure 31 the box and whisker plot of the density data. It is observed that 75% of densities lie below the 95% density mark which is the Superpave 5 recommendation for field density to be achieved. Median air voids in both the cases was approximately same, roughly 94.5 percent. However, QA field density ranged from 92-97% whereas all the QC field densities lie between 93-96 percent.

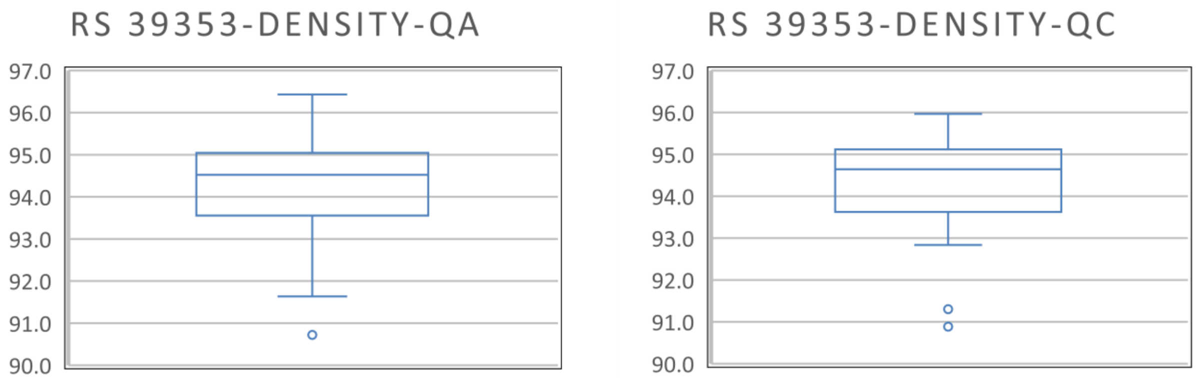


Figure 31: Box and whisker plot for density (RS 39353)

Figure 32 shows Pareto chart of the density data. More than 50% of the data lies below 95% mark, suggesting under-compaction has taken place in the field. However, greatest number of density field observations lie in (94.5,95] range, which is close to the 95% density recommendation by Superpave 5.

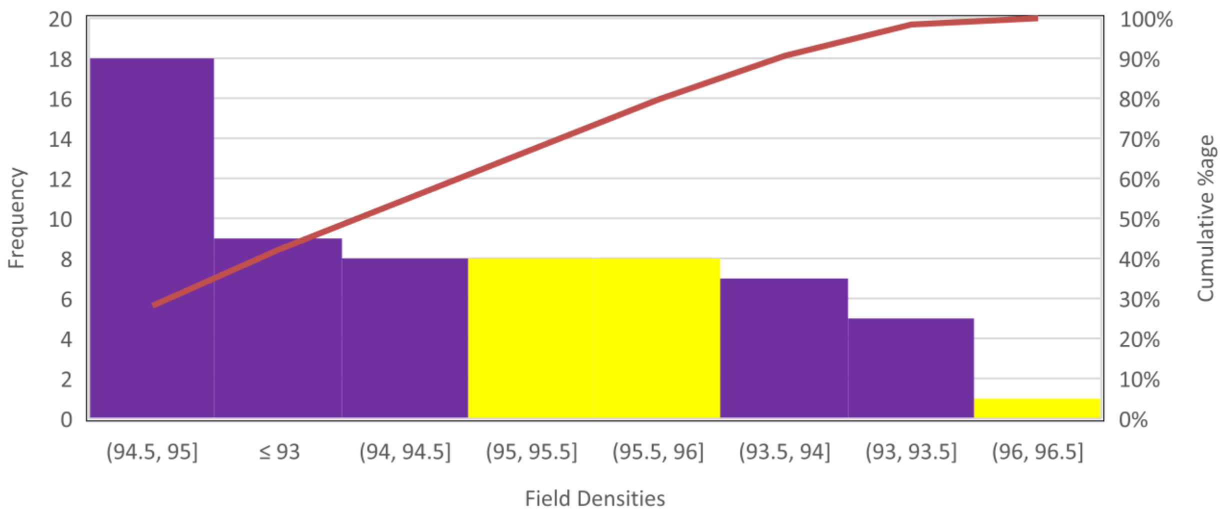


Figure 32: Density data Pareto chart for RS 39353 (QC and QA combined))

Lift thickness and Compaction

Table 22 shows the planned lift thickness data for the project. No as-built lift thickness data was supplied in either the QC or QA data set. The planned lift thickness data show that both the intermediate and surface mixtures have t/NMAS ratios between three and four, satisfying the recommended lift thicknesses indicated in the literature.

Table 22: Lift thickness data for RS 39353

Course	NMAS of mixture (inch)	Lift thickness of course, t (inches)	t/NMAS
Surface	3/8	1.5	4.0
Intermediate	3/4	2.5	3.3

The research team had visited R 36648 project in Vincennes district as a part of the project portfolio. Hence compaction data and methodology for the current project is unavailable.

VINCENNES (R 36648)

Overview

Project number R 36648 in the Vincennes District was asphalt mixture overlay and minor structural works on SR 62. The length of the project was 199 feet and involved 7,185 tons of mixture. The overall average laboratory air voids was 4.2% while the overall average in-place density was 93.7 percent. Figure 33 is a plot of all the laboratory air voids and in-place density data and it shows that almost all the data points lie to the left of 5% air voids mark, which is the Superpave 5 air voids specification. Moreover, most of the densities lie between the Superpave 5 recommendation (95%) and conventional Superpave recommendation (93%).

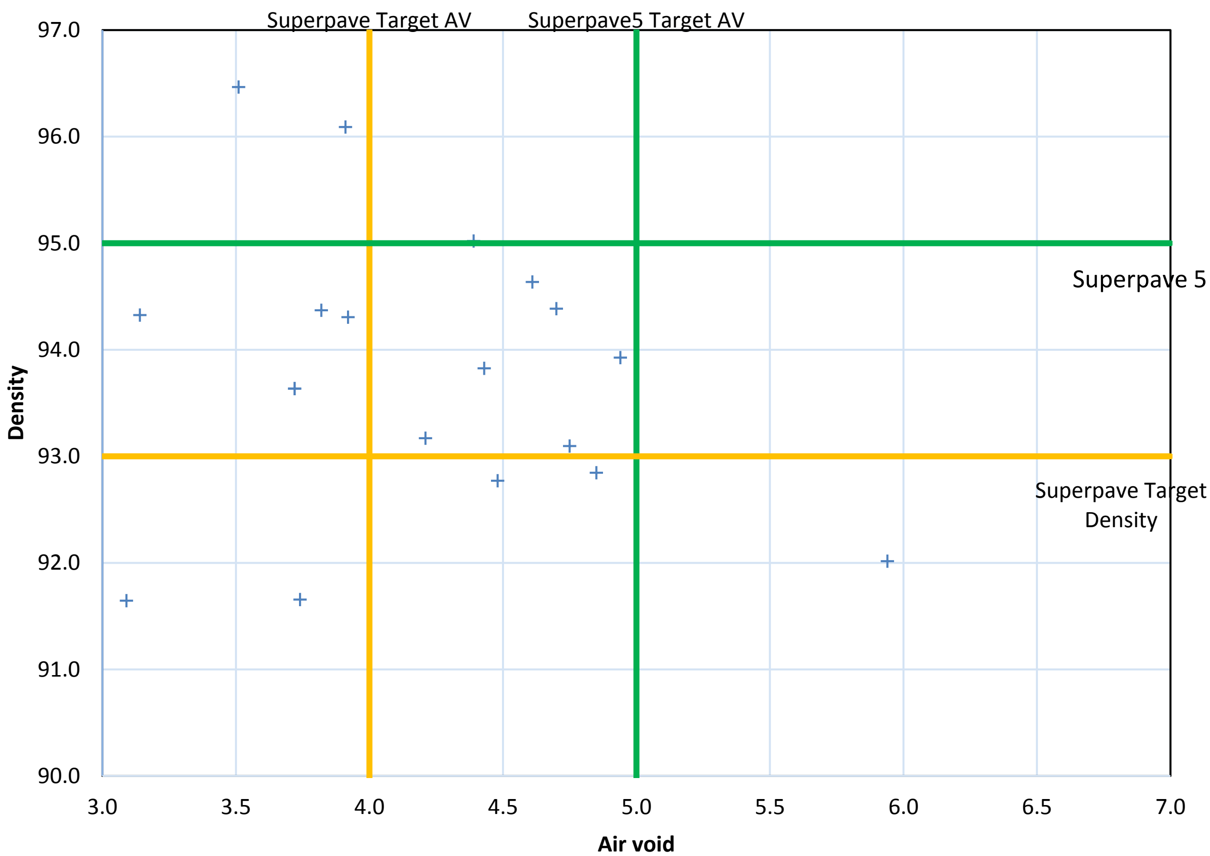


Figure 33: Volumetric Data Summary for Project R 36648

t-test analysis

The t-test was performed to determine if the QC and QA data are significantly different. From Table 23 it is observed that for α = 0.50 and assuming unequal variances, the t-test indicates the QC and QA laboratory air voids are not significantly different as $t_{stat} < t_{critical,two-tail}$. The data in Table 24 shows the QC and QA density data are not significantly different, again with α = 0.50 and unequal variances.

Table 23: t-test results for laboratory air voids data (R 36648)

T-test	QA data	QC data
Mean	4.6	3.9
Variance	0.9	1.1
t_{stat}	1.70	
$t_{critical,two-tail}$	2.10	

Table 24: t-test results for density data (R 36648)

T-test	QA data	QC data
Mean	93.5	93.9
Variance	1.6	2.0
t_{stat}	-0.65	
$t_{critical,two-tail}$	2.10	

Volumetric analysis

Figure 34 is a box and whisker plot for the project laboratory air voids data. Most of the data points from the QA data lie between 4 and 5% air voids mark, which are the conventional Superpave and Superpave 5 recommendation for air voids respectively. However, QC air voids data ranged from 2-6% air voids, indicating a higher variation.

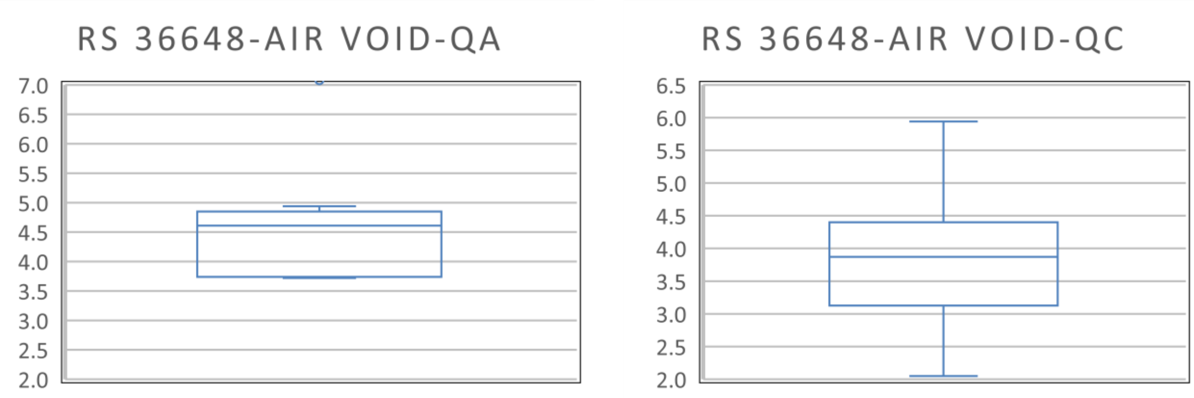


Figure 34: Box and whisker plot for laboratory air voids (R 36648)

Figure 35 is the Pareto chart displaying the air voids distribution for the project R 36648. The chart shoes that roughly all the air voids are less than 5% which is the Superpave 5 recommendation.

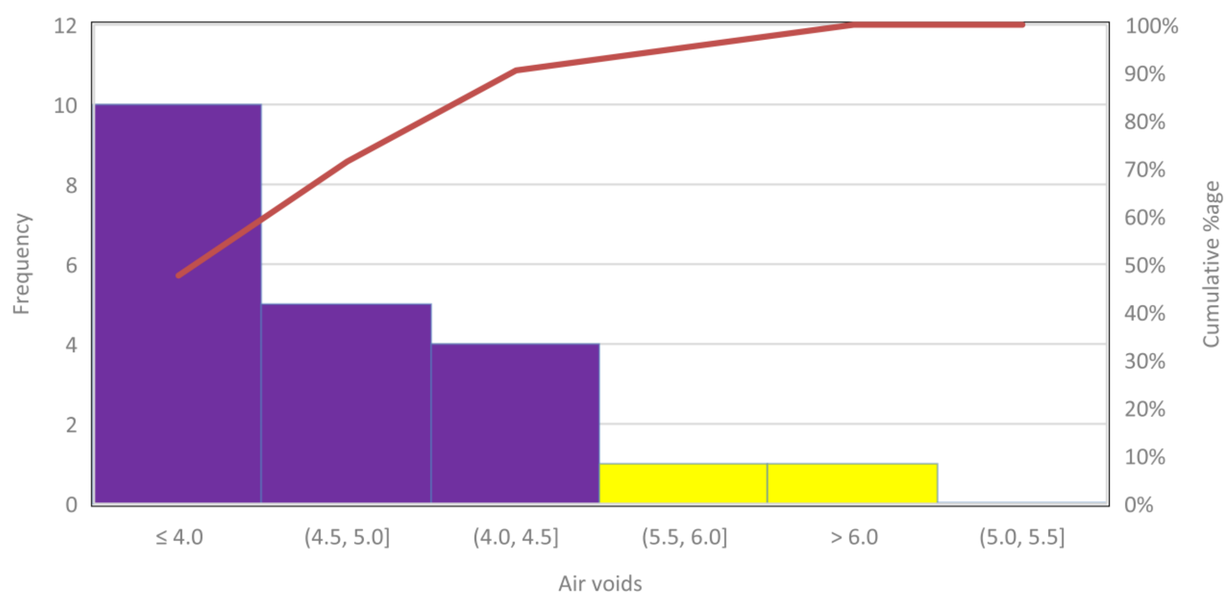


Figure 35: Laboratory air voids data Pareto chart, R 36648 (QC and QA combined)

Figure 36 represents field density data for the project R 36648. For both the QC and QA data, roughly 75% of densities lie below 95% density mark which is the Superpave 5 recommendation for density. Moreover, the median density achieved on the field is roughly 94%

according to both QC and QA data. Therefore, it can be concluded that project R 36648 in Vincennes was undercompacted by approx. 1% with respect to Superpave 5 recommendation.

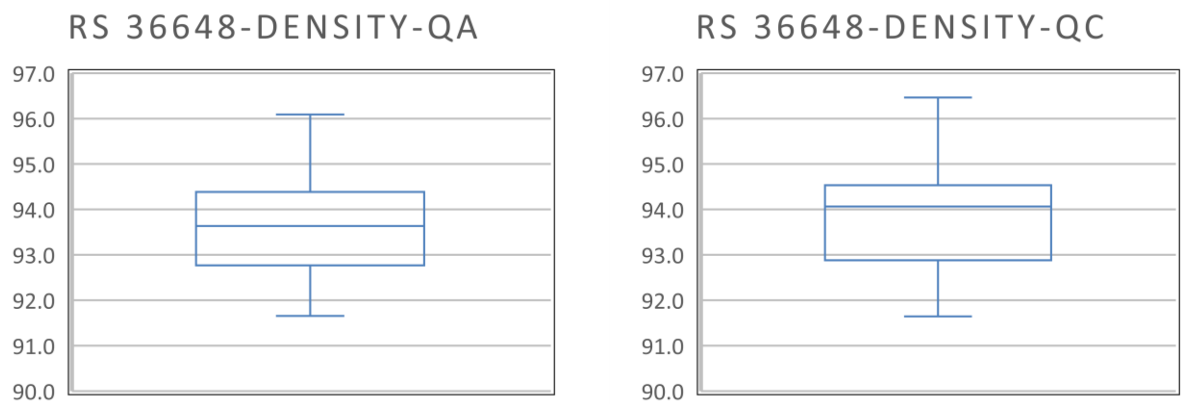


Figure 36: Box and whisker plot for density (R 36648)

Figure 37 represents the Pareto chart for the density data for project R 36648. Around 80% of the data lie below 95% density specification of Superpave 5. Consequently, only 3 observations lie above 95% density mark, highlighting the under-compaction in the current project.

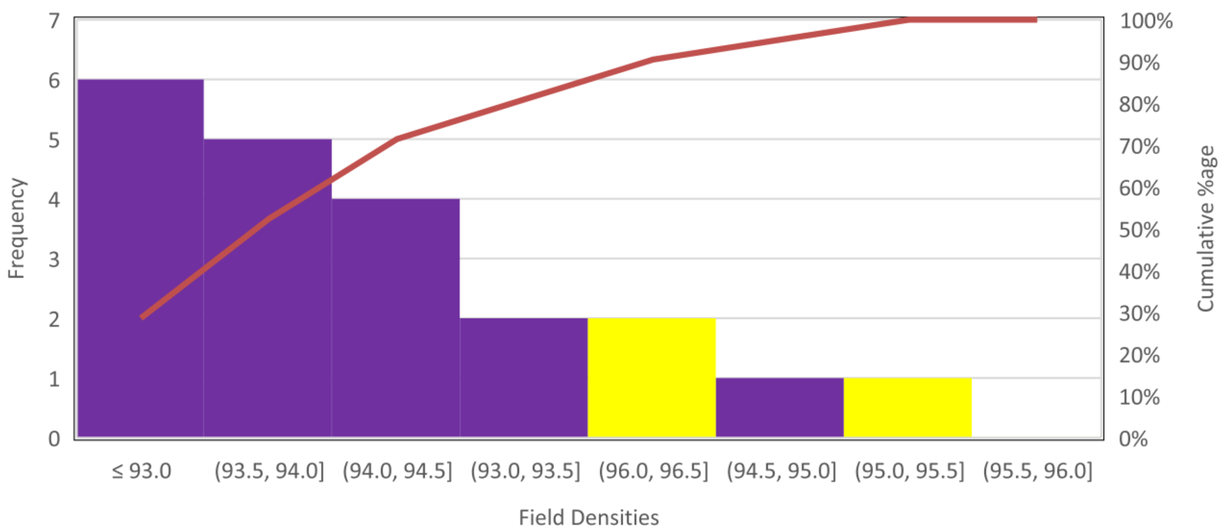


Figure 37: Density data Pareto chart for R 36648 (QC and QA combined)

Lift thickness and Compaction

Table 25 shows the planned lift thickness data for the project. No as-built lift thickness data was supplied in either the QC or QA data set. The planned lift thickness data show that both the intermediate and surface mixtures have t/NMAS ratios in the recommended range between three and four, satisfying the recommended lift thicknesses indicated in the literature.

Table 25: Lift thickness data for R 36648

Course	NMAS of mixture (inch)	Lift thickness of course, t (inches)	t/NMAS
Intermediate	½	2	4.0
Surface	½	2	4.0

The compaction method for the project was to apply seven vibratory passes with the breakdown roller. No intermediate rolling was involved in the compaction process. The finish roller then applied three vibratory passes and four static passes. Detailed information about the compaction process and the rollers is shown in Table 26. Figure 38 shows photographs taken during compaction.

Table 26: Compaction methodology for R 36648

	Breakdown	Finish
Number of Rollers	1	1
Vibratory Passes	7	3
Static Passes	0	4
Operating Weight, lbs	29,640	21,820
Drum Width, lbs	84	66
Model	Ingersoll-Rand DD-130 HF	Volvo DD90

Figure 38: Compaction photographs for R 36648

GREENFIELD (R 30280)

Overview

Project number R 30280 in the Greenfield District was a pavement replacement work undertaken on SR 135 and asphalt mixture overlay/minor structural work on US 31. The overall average laboratory air voids was 4.7% while the overall average in-place density was 93.3 percent. Figure 39 is a plot of all the laboratory air voids and in-place density data and it shows that most of the densities lie below the Superpave 5 target density, 95 percent. Similarly, most of the air voids also lie below the 5% air voids mark.

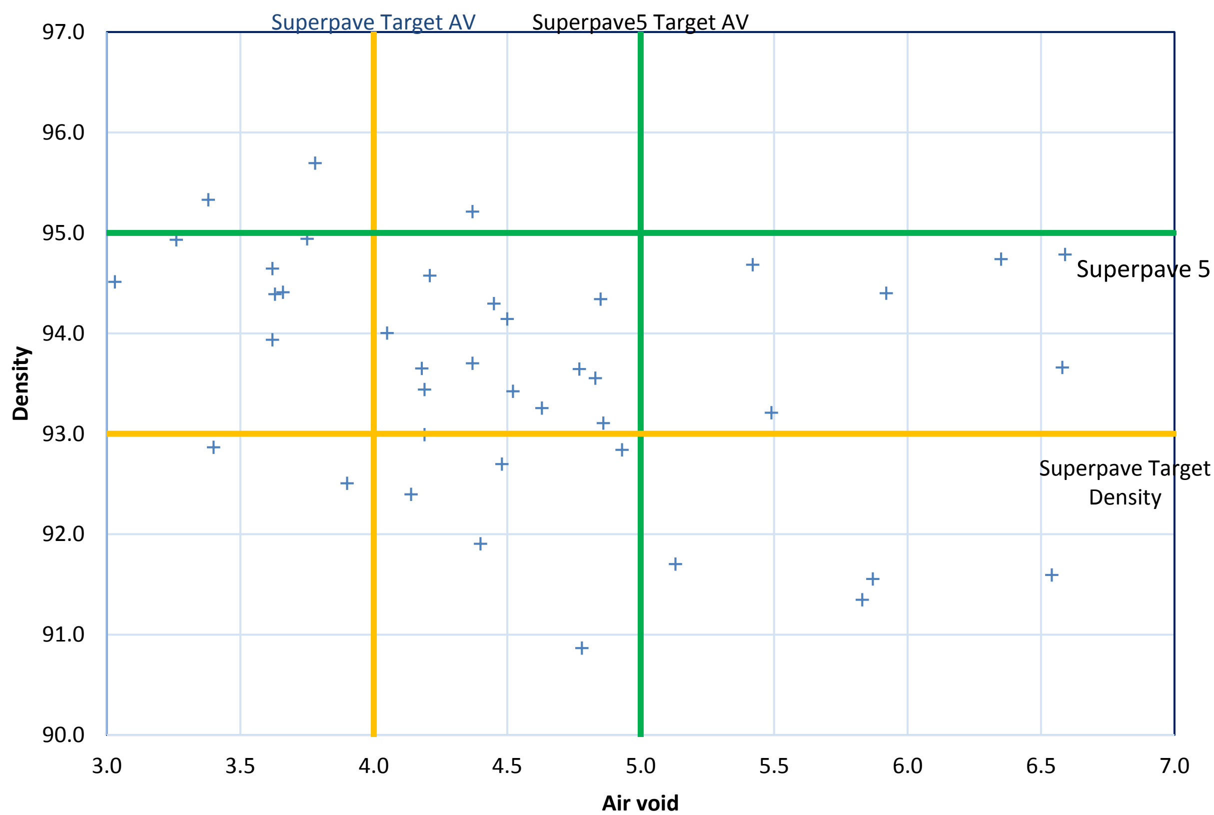


Figure 39: Volumetric data summary for the Project R 30280

t-test analysis

The t-test was performed to determine if the QC and QA data are significantly different. From Table 27 it is observed that for α = 0.50 and assuming unequal variances, the t-test indicates the QC and QA laboratory air voids are not significantly different as $t_{stat} < t_{critical,two-tail}$. The data in Table 28 shows the QC and QA density data are also not significantly different, again with α = 0.50 and unequal variances.

Table 27: t-test results for laboratory air voids data (R 30280)

T-test	**QA data**	**QC data**
Mean	4.4	4.6
Variance	0.9	1.4
t_{stat}	-0.8	
$t_{critical,two-tail}$	2.0	

Table 28: t-test results for density data (R 30280)

T-test	**QA data**	**QC data**
Mean	93.7	93.5
Variance	2.3	1.1
t_{stat}	0.5	
$t_{critical,two-tail}$	2.0	

Volumetric Analysis

Figure 40 shows the air voids for Greenfield project. Median air voids was evaluated to be approximately 4.5% for both the cases. QA data reports a wide range of laboratory air voids, from 2.5-6% whereas QC air voids range from 3-6.5 percent. However, in the case of QA database, 75% of the field voids lie below 5% air voids mark which is the Superpave 5 recommendation for air voids

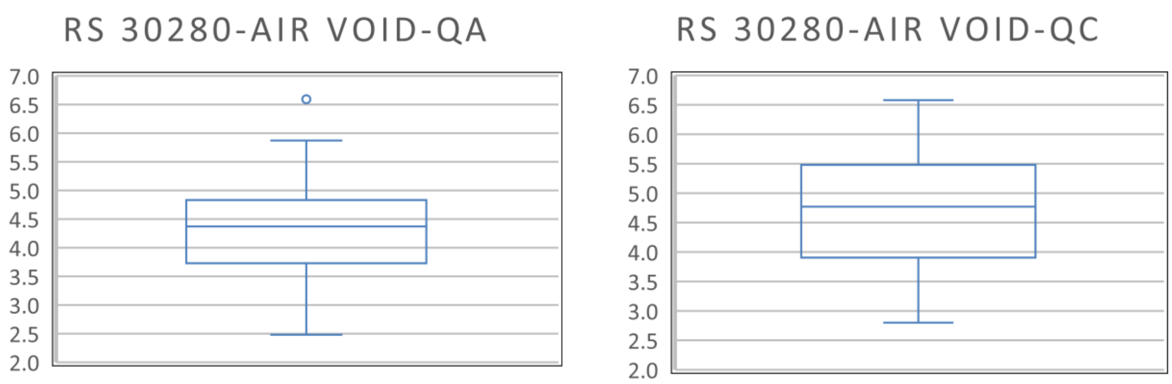


Figure 40: Box and whisker plot for laboratory air voids (R 30280)

After studying QC and QA air voids individually through box and whisker plot, Pareto chart was plotted to examine them together. As noted previously, majority of the air voids lie below Superpave 5 air voids recommendation of 5% (approximately 70%). The interval with largest number of air voids was ≤4.00% followed by (4.5,5.0], where 4% is the conventional Superpave recommendation for air voids for the asphalt mixture design.

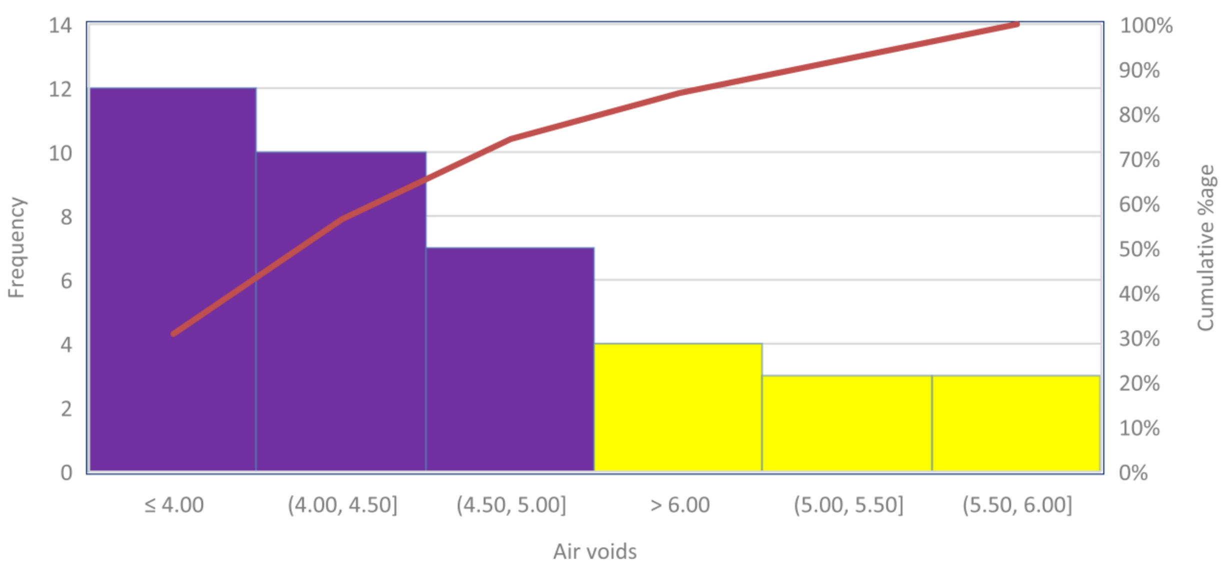


Figure 41: Laboratory air voids data Pareto chart, R 30280 (QC and QA combined)

Figure 42 shows the box and whisker diagram for density data. According to both sets of data, more than 80% of the field densities lie below 95% recommendation of Superpave 5, hence leading to the conclusion that the site was again under-compacted with respect to Superpave 5 specification. Both median field densities also lie close to 94% mark, 1% less than the Superpave 5 recommendation of field density.

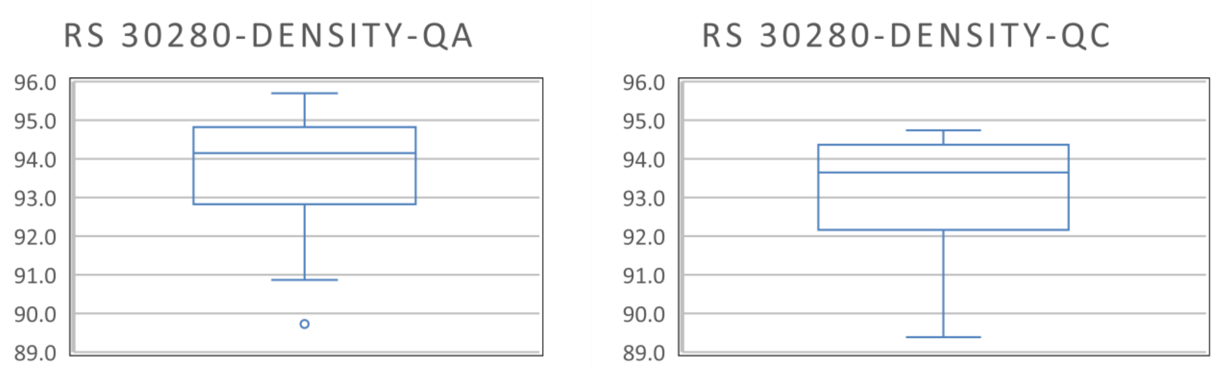


Figure 42: Box and whisker plot for density (R 30280)

Pareto chart for density given in Figure 43. Most of the densities lie in ≤93% range, followed by intervals less than 95% density. This highlights the under compaction which has occurred in the given location with respect to the Superpave 5 field density recommendation of 95 percent.

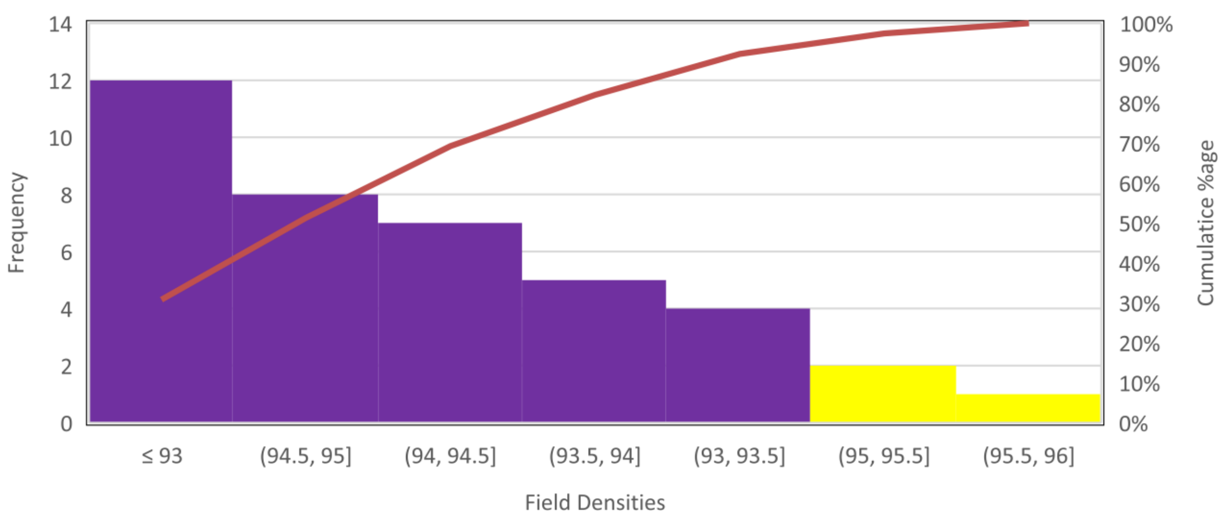


Figure 43: Density data Pareto chart for R 30280 (QC and QA combined)

Lift thickness and Compaction

Table 29 shows the planned lift thickness data for the project. No as-built lift thickness data was supplied in either the QC or QA data set. The planned lift thickness data show that both the intermediate and surface mixtures have t/NMAS ratios between three and four, satisfying the recommended lift thicknesses indicated in the literature. Although t/NMAS ratio for base layer was higher than the prescribed range, it was equal to maximum lift size (6 x NMAS) prescribed in literature to achieve desirable compaction.

Table 29: Lift thickness data for R 30280

Course	NMAS of mixture (inch)	Lift thickness of course, t (inches)	t/NMAS
Surface	3/8	1.5	4.0
Intermediate	3/4	2.5	3.3
Base	1	6	6.0

The compaction method for the project was to apply thirteen vibratory passes with the breakdown roller. There were no additional vibratory passes of the intermediate roller involved. The finish roller then applied eleven static passes. Detailed information about the compaction process and the rollers is shown in

Table 30. Figure 44 shows photographs taken during compaction.

	Breakdown	Finish
Number of Rollers	1	1
Vibratory Passes	13	0
Static Passes	0	11
Operating Weight, lbs	26,230	26,120 – 26,560
Drum Width, in	79	78.3
Static Linear Load (front/rear), lbs/in	166	
Model	CAT CB54 XW	BW 190 AD

Table 30: Compaction methodology for R 30280

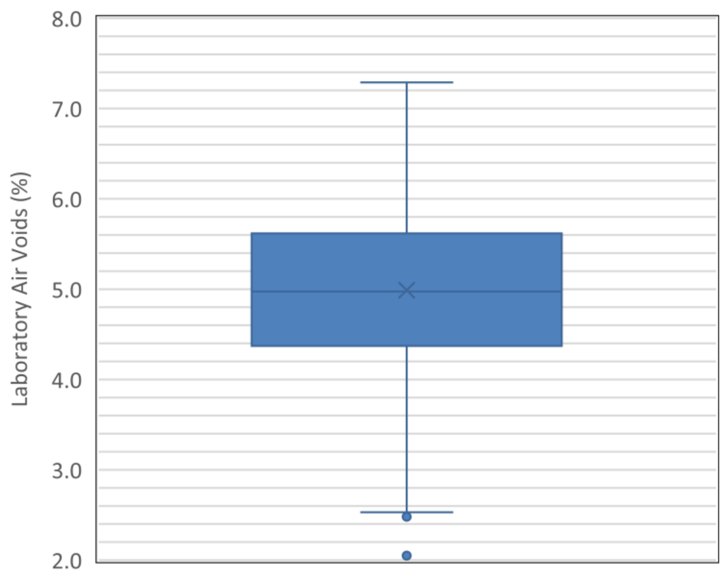
 

Figure 44: Compaction photographs for Project R 30280

COMBINED ANALYSIS

After examining each project individually, they were analysed together to get an overview of the air voids/densities and determine the success/failure of the practical application of the modified mixture design in the 9 pilot projects analysed. 380 data points were obtained, both QC and QA combined from all the projects.

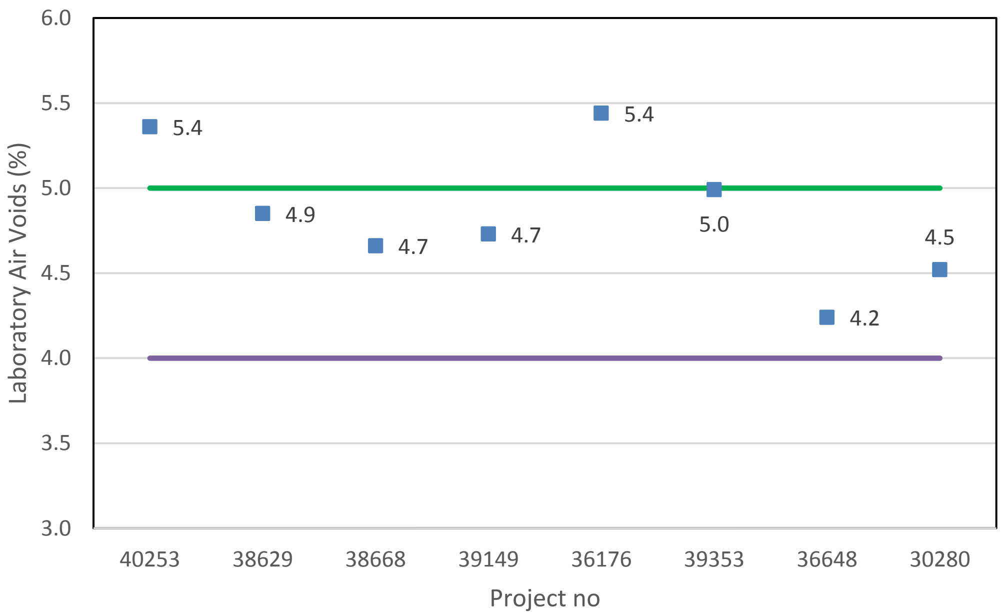
Figure 45 a and b summarize the air voids data (QC and QA combined) of the trial projects executed in Indiana according to Superpave 5 mixture design criteria. The air voids ranged between 2.5-7.5%, with the median and the average of the air voids being 5.0 percent; complying with the Superpave 5 target specification. Figure 45b shows that project no. RS 39353 was the most successful in achieving the target air voids. Project no. R 36648 was the farthest from achieving the target air voids (4.2%). As most of the air voids were in the range of 5±0.5%, it was found that the pilot projects were effective in achieving the Superpave 5 recommendation of 5% laboratory air voids.



(a)

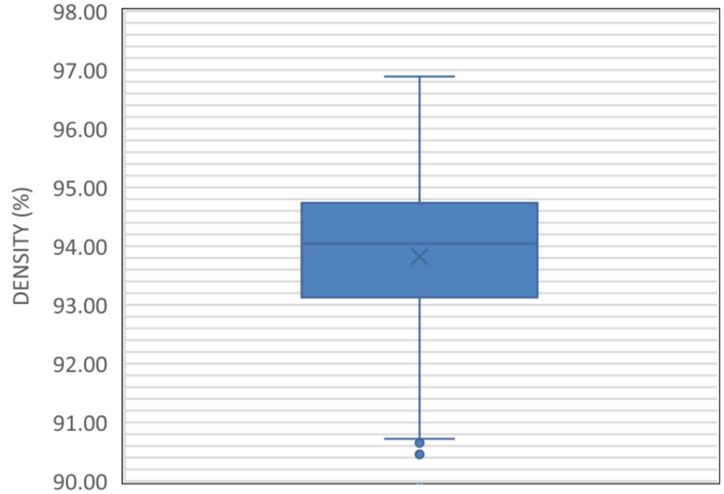
Figure 45: Laboratory air void summary from Superpave 5 projects

Figure 45 continued

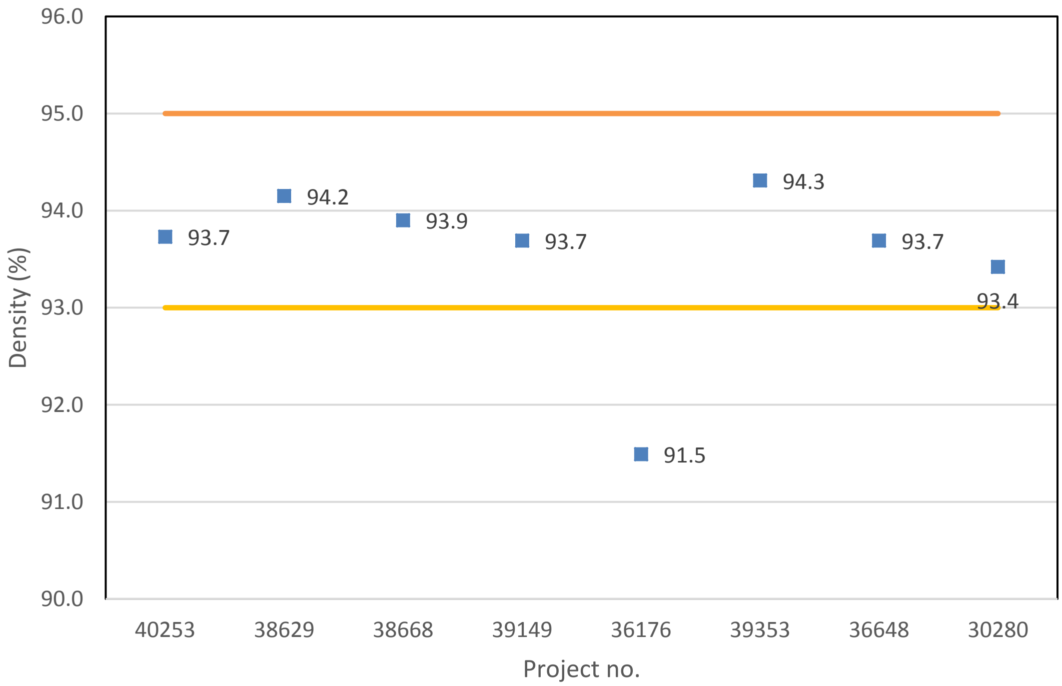


(b)

Figure 46 a and b denote summary of the in-field density data (QC and QA combined) of the trial projects executed in Indiana according to Superpave 5 mixture design criteria. The box and whisker plot show that the density ranges from 91-97% after compaction, nearly ±4% variability from 95% target. Figure 46b, portrays brief overview of the average densities achieved in each project. Project no. RS 36176 gave lowest density value of 91.5 percent within the limited amount of data available for it. On the other hand, apart from reporting perfect average air voids of 5%, asphalt mixture overlay and minor structural works project in Vincennes (RS 39353) also reported highest in-field density of 94.3% among all, which was closest to the target density of 95 percent. Most of the densities lied between 93% (conventional Superpave target) and 95% (Superpave 5 target), leaning towards former. The average density was calculated to be 93.8%, confirming that the trial projects constructed were considerably under-compacted with respect to Superpave 5 design criteria.



(a)



(b)

Figure 46: Field density summary from Superpave 5 projects

For project no. RS 38629 (Figure 11), the box plot for the QA laboratory air voids was found to be slightly higher than the box plot of the QC air voids, indicating air voids values for the QA data to be marginally greater than the QC data. However, Figure 13 shows the box plot of the in-field density QA data to be also higher than the box plot of the in-field density QC data, which is counter-intuitive. A similar anomaly was noted for project no. RS 39149. Figure 22 reports box plot range of the QC air voids data to be higher than the QA data range, yet the box plot range of the QC density data was also found to be marginally greater than QA data range (Figure 24). Likewise, for project no. RS 39353, the box plot for QA air voids data was quite higher than the box plot of QC air voids (Figure 29). However, the in-field density box plots for both the QC and QA data were approximately same (Figure 31). This highlights a bias in the QC and the QA data of the laboratory air voids and in-field density for the above-mentioned projects.

SUMMARY AND CONCLUSION

This project analyzed data from nine asphalt paving projects that used the Superpave 5 mixture design method. The main objective of the study was to analyze the construction data to determine if the specifications were met and if any additional adjustments are needed to the Superpave 5 mixture design method. Additionally, a literature review of asphalt mixture lift thickness and its effect on asphalt pavement density was completed, and recommendations made on the lift thicknesses used by INDOT. The research team visited five construction sites, observed the construction process and garnered feedback from the field engineers and contractor personnel about the modified mixture design procedure and any construction concerns. QC and QA data for the projects were supplied to the research team for each of the nine projects. Each set of project data was analyzed individually, then all the data combined and analyzed. Laboratory air voids and field density data were compared to Superpave 5 and conventional Superpave recommendations.

The average laboratory air voids achieved for all the trial projects combined was 5%, which is equal to the Superpave 5 recommendation. However, the in-place field density for all the trial projects combined was found to be 93.8 percent. Despite being established in the laboratory trials and demonstration project that initial in-place densities of 95% could be achieved without additional compaction effort beyond that used for conventional Superpave mixtures, the findings indicate that the Superpave 5 mixtures from the current projects, as a whole, were slightly under-compacted with respect to Superpave 5 recommendations. Therefore, some adjustments may be required in the usage of the Superpave 5 mixture design method. The study findings also indicate a possible bias in the QC and QA data, with the QC data often having lower laboratory air voids and higher in-place densities than the accompanying QA data. Furthermore, the t/NMAS ratio data for all the pavement layers constructed under the purview of this study show, that from a design standpoint, INDOT-specified lift thicknesses meet the requirements recommended in the literature.

RECOMMENDATIONS

While the in-place densities from the nine cited projects were slightly lower than expected for Superpave 5 mixtures, they were slightly higher than typical in-place densities for conventional Superpave mixtures. It is recommended that the field performance of the Superpave 5 mixtures from these projects be monitored over time to examine the impact of achieving the slightly higher densities. Additionally, an investigation exploring reasons for the under-compaction is recommended. If proper steps are taken to achieve desired density in the field, it is possible to reap the full benefits of the Superpave 5 mixture design method. Also, information about the as-built lift thicknesses of the constructed pavement layers should be collected and examined for compliance with the lift thicknesses, to ensure the under-compaction is not a result of inadequate lift thickness. Finally, it might be wise to complete laboratory performance-based testing of the Superpave 5 mixtures.

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