In-Place Voids Monitoring of Hot Mix Asphalt Pavements

by

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16. Abstract

In 1995, the Colorado Department of Transportation implemented the Superpave gyratory mix design to select the optimum asphalt content of a mixture. The optimum asphalt content was not the same as what the department had historically used. The purpose of this study was to gather data to validate the number of gyrations that should be used with the Superpave mix design. Based on the data gathered from the 25 evaluation sections, the optimal number of design gyrations for the Field Mixed/Lab Compacted material is too high. Mixes appear to be too stiff for the traffic and environmental conditions.

Implementation

Based on the results from this study, two options are recommended to improve design mixes for Colorado's traffic and environmental conditions:

1. Lower the number of gyrations
2. Adjust the target mix design air void content

Additional research is recommended to track the adjustments that are made to ensure the desired outcome is achieved.

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1.0 PURPOSE

The Colorado Department of Transportation (CDOT) implemented the Superpave gyratory mix design to select the optimum asphalt content of a mixture. The optimum asphalt content was not the same as what the department had historically used. The purpose of this study was to gather data to validate the number of design gyrations that should be used with the Superpave gyratory for mix designs in Colorado.

In order to achieve this objective, 22 field projects were monitored (primarily for the in-place air voids) over a 5 to 6 year period. The projects were selected to take into consideration the variability of traffic levels throughout the state. Further, the unique ranges of environment, temperature, and altitude were a factor in selecting projects.

The outcome of the research was intended to validate the current level of the number of design gyrations used to select the optimum asphalt content and / or recommend a new set of values for the number of design gyrations.

2.0 BACKGROUND

The Colorado Department of Transportation (CDOT) has used a number of asphalt mix design methods over the last 50 years. In 1949, the Colorado Department of Highways (now CDOT) began using the Marshall mix design method. The Department used this method up to the early 1960s.

In the early 1960s, the department began using the California kneading compactor to compact asphalt specimens for use in the Hveem Mix Design procedure. At first this mix design method produced abnormally low asphalt contents. To address this problem the compactive effort with the kneading compactor was reduced. Further adjustments were made to the asphalt content to compensate for altitude. This procedure worked well until the early 1970s.

In the early 1970s, rutting began to reoccur. This was attributed to the increase in truck tire pressures, heavier loads, radial tires and inconsistent asphalt sources. The same compactive effort was being used for all mix designs, whether it was for low volume, high altitude, or for the highest trafficked intersection in the state. This practice was considered successful until the population growth of the late 1970s, which resulted in a significant increase in traffic levels. Rutting became much more prevalent.

In the mid to late 1980s, CDOT took several steps to address rutting caused by increased traffic. First, a minimum Hveem stability of 37 was established for mixes on high volume roads, and a minimum number of fractured faces was required on the large aggregate (70% shall have at least two mechanically induced fractured faces). To address durability, a minimum asphalt content was also required depending on aggregate size. Several problems arose from the minimum asphalt content. It encouraged the use of fine mixes, and also the use of absorptive aggregates. These requirements were later replaced with the adoption of a minimum VMA (voids in mineral aggregates).

In the late 1980s, high stability pavement design was tried, which involved the use of a high stability lower lift with a plant mixed seal coat (PMSC) as a wearing surface. While this pavement design worked in many areas, there were also several catastrophic pavement failures caused from moisture damage in the HMA below the PMSC. The use of the plant mixed seal coats was stopped. The risk and cost of pavement failures was too high.

In 1991, CDOT replaced the California kneading compactor with the Texas gyratory compactor, based on the results of several national research studies that indicated that laboratory compacted specimens with the gyratory better simulated the in-place field compaction effort. While Colorado was one of the few states using the Texas gyratory, the Strategic Highway Research Program (SHRP) was in the process of evaluating the gyratory as the method of compaction.

Using the Texas gyratory, the design asphalt content was reduced substantially from the design asphalt content using the California kneading compactor. The leaner mixes helped increase the stability, which in turn reduced the rutting problems. However, the leaner mixes led to an increase in segregation, raveling, and cracking. Changes were quickly made. By 1993, all mixes were being designed with the Texas gyratory, but adjustments to the compactive effort were made based on environment and traffic loadings. Varying the end-point stress for individual mixes led to higher, and more appropriate, asphalt contents for asphalt mixtures placed in locations with lower traffic and colder climates.

In 1993, a research study was initiated to determine optimum asphalt content using varying laboratory compactive efforts that corresponded to the various traffic and environmental conditions in Colorado. Report No. CDOT-DTD-R-93-23[1] documents the recommended variable end-point stresses for the Texas gyratory to obtain the optimum asphalt content along with the traffic and environmental categories to assist designers on the appropriate selection of the specified end-point stress.

In 1994, as a follow up to the above-mentioned research, additional research was initiated which is the basis for this report. The purpose of this research was to validate the laboratory compactive effort to ensure that the appropriate asphalt content was determined in the design. A high traffic area in high temperatures and a low traffic area in cold temperatures need different asphalt mix designs. Using the various traffic and climatic zones, projects were selected to monitor the change in air voids in the pavements over time. These air voids were compared to the air voids from laboratory compacted samples.

Pavement design, mix design, and performance are related, in particular in their relationship with air voids. Monitoring the change in air voids over time, in asphalt pavements, and comparing the field's in-place voids (actual performance) to the laboratory compacted air voids (expected performance), will help the engineer design the mix at the optimal asphalt content. The results of this research will allow for adjustments in the mix design process for future projects accordingly.

3.0 DEVELOPMENT OF RESEARCH

At the time this research was initiated, Colorado was using the Texas gyratory for developing mix designs. All the mixes under this study were designed using the Texas gyratory. However, additional mix was taken during production from each project and tested in a Superpave gyratory compactor manufactured by Pine Instruments. The mix designs also met the Superpave criteria.

Recommendations from Report No. CDOT-DTD-R-93-23[1] provided the project selection criteria for this report. This report recommended dividing the state into four high temperature categories and five traffic categories. The temperature recommendations, which are based on highest 7-day average maximum temperatures, are shown in Table B.

If the project is a 20-year design, the design lane 18k ESALS will be for 20 years. The total 18k ESAL value for the roadway is then calculated from the 18k ESAL value for the design lane.

Table A. Colorado Traffic Recommendations Used for This Study

Traffic Category	Total 18-kip ESALs	CDOT Network (%)
Low	$< 3 \times 10^5$	21.8
Medium	3×10^5 to 10^6	34.4
High	10^6 to 3×10^6	16.1
Very High	3×10^6 to 10^7	21.3
Very Very High	$> 10^7$	6.4

ESAL – Equivalent 18-kip Single Axle Load

In the current CDOT Pavement Design Manual[6], Table A has been modified. The low category has a lower limit of 10^5 and a category of $<10^5$ has been added. This increases the number of traffic levels from 5 to 6. CDOT's current Superpave gyratory mix design criteria can be found in Appendix A (not available in electronic format).

Table B. Colorado Temperature Regions

High Temperature Region	*Highest 7-Day Average Maximum Air Temperature	CDOT Network (%)
Hot (SE and West)	>36 ^{0}C, (> 97^{0}F)	14.7
Moderate (Denver, Plains, and West)	32 to 36^{0}C, (90 to 97^{0}F)	57.2
Cool (Mountains)	27 to 31^{0}C, (81 to 88^{0}F)	13.9
Very Cool (High Mountains)	< 27^{0}C, (< 81^{0}F)	14.2

* The highest temperature is calculated as the average of the highest air temperatures for the hottest seven consecutive days. A summary of the average highest 7-day air temperatures taken in each Colorado county can be found in Appendix A A copy of the SHRP database with 153 weather stations in Colorado can also be found in Appendix A.

The recommended end-point stresses to be used with the Texas gyratory mix design methodology for various traffic and environmental zones are shown in Table C. The equivalent number of design gyrations for the Superpave mix design methodology is also shown in Table C.

Since Colorado began using Superpave criteria, several adjustments have been made. For this research, the projects were constructed with mixes that were designed using the criteria in Table C, D and E. CDOT uses four-inch Superpave Gyratory compactor samples.

Table C. Mix Design Compactive Levels

Traffic	High Temperature			
	Very Cool	Cool	Moderate	Hot
Low	25 [68]	25 [68]	25 [68]	50 [76]
Medium	25 [68]	25 [68]	50 [76]	75 [86]
High	25 [68]	50 [76]	75 [86]	100 [96]
Very High	50 [76]	75 [86]	100 [96]	125 [109]
Very Very High			125 [109]	

The first number in the table is the end-point stress for the Texas gyratory measured in psi. psi = 6.895 kPa. The value shown in brackets is the equivalent number of design gyrations for Superpave mix design.

Varying the end-point stress (EPS) on the Texas gyratory allows the design asphalt content to be adjusted for various traffic and environmental conditions. Adjusting the compactive effort alone would not be sufficient to resist rutting and ensure durability, so additional criteria were set. Minimum Hveem stability and VMA values were required to ensure that sufficiently angular materials were produced for the high and very high traffic categories. Table D shows the VMA requirements. Table E shows the minimum Hveem stability values and voids filled with asphalt (VFA) for the different end-point stresses.

Table D. VMA Criteria

Minimum VMA Specification[2]			
Nominal Maximum Size[1] (mm) in	Design Air Voids		
	3.0%	4.0%	5.0%
37.5 (1-1/2)	10.0	11.0	12.0
25.0 (1)	11.0	12.0	13.0
19.0 (3/4)	12.0	13.0	14.0
12.5 (1/2)	13.0	14.0	15.0
9.5 (3/8)	14.0	15.0	16.0

[1]The Nominal Maximum Size is defined as one size larger than the first sieve to retain more than 10%.

[2] Interpolate specified VMA values for design air voids between those listed.

Table E. Recommended Hveem Stability and VFA Criteria for Varying End-Point Stresses

End Point Stress KPa (psi)	Minimum Stability	VFA (%)
860 (125)	42	65-75
690 (100)	42	65-75
520 (75)	39	65-78
340 (50)	33	65-80
170 (25)	26	70-80

Since this study was initiated, these values have been adjusted and the current specified values can be found in Appendix A. All of CDOT's current Superpave design criteria can be found in Appendix A.

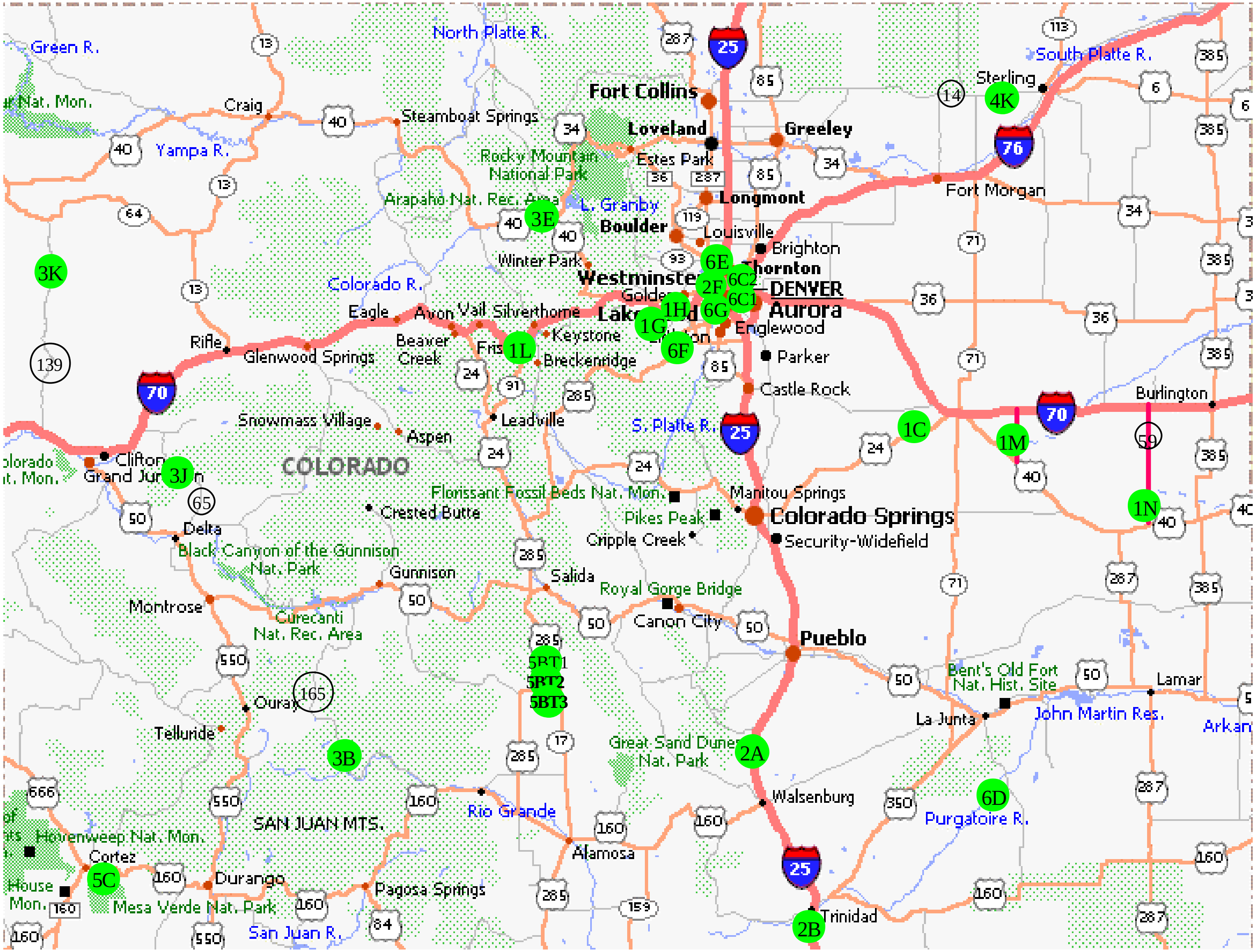
4.0 PROJECT SELECTION

Twenty-two projects were selected for evaluation under this study. Figure 1 shows the location of the projects with respect to Colorado. The projects were selected to try and cover the different temperature and traffic combinations in Colorado. Table F provides a list of the projects, their locations, the ESALs and temperature that were used to determine the "Recommended" EPS.

This study evaluated different compactive efforts. However, it was conducted on full volumetric mix designs according to CDOT Standard Specifications for Road and Bridge Construction[2]. This included Lottman (moisture damage), Hveem Stability (shear strength), VMA/VFA (minimum asphalt content), aggregate properties (Superpave consensus/source properties) and aggregate gradation (Superpave).

For some projects, the "Recommended" EPS was adjusted by the Region Materials Engineer (RME) based on engineering judgment. If the RME made an adjustment, the change is reflected in the column heading "Design EPS."

Figure 1.Locations of Projects in Colorado



1G Mt. Evans
1L Berthoud Pass
1M Hugo
3B Slumgullion Pass
1B Vail Pass
1C Limon
1N Kit Carson
3E Rabbit Ears Pass
3J Cedaredge
6G Broadway & Bellview
1H Bergan Park
3K Rangely
2B Raton Pass
5BT1 Saguache
5BT2 Saguache
5BT3 Saguache
6C1 Federal & Evans
6C2 Federal & Evans
2A Colorado City
2F Fowler
4K Sterling
5C Cortez
6D Sheridan
6F C470 Morrison
6E s/o US 36

Table F. Project Specifics

	Project No./ Location	Surface Treatment	Design ESALs	Temp	Design EPS (Ndesign)	Recommended EPS (Ndesign)	Date Paved
1B	MC 0702-195 I-70 Vail Pass MP 180 – MP 195	CX, 1-1/5" overlay, no pre-overlay work Conoco AC10	2,787,000 (High)	19°C (Cool Per Region)	50 (76)	50 (76)	1994
1C	C 0243-044 SH 24 Limon MP 359 – MP 375	C, 2.5" lift	73,000 (Low)	33°C (Moderate)	50 (76)	25 (68)	1995
1G	PHF 005A-001 SH 5 MT Evans MP 0 – MP 14.9	CX, one 2" lift some patching and grade work Sinclair AC5	1,330,000 (High)	19°C (Very Cool)	25 (68)	25 (68)	1994
1H	STA 0741-008 SH 74 Evergreen MP 0.5 - MP 3.5	C, three 2" lift HBP, Leveling Course AC10	1,547,660 (High)	30°C (Cool)	75 (86)	50 (76)	1996
1L	MC R100-002 SH 40 Berthoud Pass MP 235.9 – MP 249.3	CX, One 2" lift, No pre overlay work Conoco AC10	650,0 (Medium)	19°C (Very Cool)	25 (68)	25 (68)	1993
1M	FC NH(CX)CY 040-5(31) County Road 109 Hugo MP 3.0	C, 1.25" lift Diamond Shamrock AC20	60,000 (Low)	37°C (Hot)	25 (68)	50 (76)	1994
1N	FC NH(CX)CY 040-5(13) SH 59 Kit Carson MP 0.0 - MP 15.0	C, 2.25" lift Diamond Shamrock AC20	60,000 (Low)	37°C (Hot)	50 (76)	50 (76)	1994
2A	STA 0251-131 I-25 Colorado City MP 70.0 - MP 80.0	4" Cold Recycle, 2" HBP Gr C, 2" HBP Gr CX(P) Koch AC20P, Type 1D	5,245,000 (Very High)	39°C (Hot)	100 (96)	125 (109)	1994
2B	STA 0251-133 I-25, State Line MP 0.0 - MP 7.6	2" Milling, 2 – 4.5" HBP Gr C, 2"HBP Gr CX (R) Conoco AC20R	4,596,733 (Very High)	31°C (Cool)	75 (86)	75 (86)	1994
2F	C 0504-024 SH 50 Fowler MP 351.3 – 361.1	1" Heater Scarify 2" HBP Gr CX Conoco AC20	1,228,000 (High)	39°C (Hot)	100 (96)	100 (96)	1994
3B	PFH 149A-015 Hwy 149 Slumgullion Pass MP 55 – MP 62	CX, One 2" lift No surface preparation	65,000 (Low)	26°C (Very Cold)	25 (68)	25 (68)	1995

CX is a ½ inch nominal maximum size mix; C is a ¾ inch nominal maximum size mix

Table F. Project Specifics (Continued)

	Project No./ Location	Surface Treatment	Design ESALs	Temp	Design EPS (Ndesign)	Recommended EPS (Ndesign)	Date Paved
3E	MC 0402-040, Hwy 40 Rabbit Ears Pass MP 148 – MP155	CX, One 2" lift, Crack Filling by maintenance Sinclair AC20R	489,000 (Medium)	29°C (Cool)	50 (76)	25 (68)	1994
3J	C 065A-014 Hwy 65 Cedaredge MP 0-MP 10	CX, One 2" lift No surface preparation Koch AC20R	424, 000 (Medium)	33°C (Moderate)	50(76)	50 (76)	1994
3K	PLH 139A-022 Hwy 139 Rangely MP 61.6 – 64.6	New Construction, CX Three 2" lifts - 6" Class 6 6" Class 3, Top AC20R, Bottom AC20P	1,388,00 (High)	35°C (Moderate)	75 (86)	75 (86)	1995
4K	STA 0142-025 SH 14 Sterling MP 227.6-MP 233.4	GrC, 3" – 3.75" HBP Sinclair AC20	(Medium)	(Hot)	100 (96)	75 (86)	1994
5B	NH 2852-005 Hwy 285 Saguache MP 87.6 – MP 100.3	4" Cold Recycle, 2-2" lifts HBP (1) and (2) Koch 52-40 (3) Sinclair AC10	1,352,000 (High)	29°C (Cool)	75 (86)	50 (76)	1994
5C	NH(CX)160-1(31) Hwy 160 Cortez MP 40.5 – MP 49.0	Gr C, Cold Recycling, Two 2" lifts Chevron AC10	1,700,000 (High)	33°C (Moderate)	100 (96)	75 (86)	1995
6C	C0881-006 SH 88 Federal Blvd Bear Creek to Jewell	C, Planing, Fabric as needed, One 2" lift Sinclair AC10	1,004,000 (High)	33°C (Moderate)	75 (86)	75 (86)	1994
6D	CX 11-0285-32 Hwy 285 Hampden Raleigh to Platte	Planing, One 2" lift Frontier AC10	2,795,000 (High)	33°C (Moderate)	100 (96)	75 (86)	1994
6E	C0253-117 I-25, US 36 To 84th Ave	GrC, Planing in lane 2 Fabric, 4.25" HBP Placed in 2 lifts Sincalir AC10	9,574,000 (Very High)	33°C (Moderate)	125 (109)	100 (96)	1994
6F	CX 11-0285-30 SH 285 Hampden C470 to SH 8	C, planning, One 2" lift Sinclair AC10	1,338,000 (High)	33°C (Moderate)	100 (96)	75 (86)	1994
6G	CX 10-0075-29 Hwy 75 Broadway Hampden to Broadway	C,Minor treatment, 2" lift HBP Sinclair AC10	931,000 (Medium)	33°C (Moderate)	50 (76)	50 (76)	1994

Table G shows each project in its corresponding box on the matrix for the number of design gyrations on the Superpave gyratory. The large color boxes correspond to the recommended number of design gyrations (based on traffic and environment). The arrows under the individual project indicate (by direction) if the recommended number of design gyrations was reduced (↓) or increased (↑) by the RME.

Table G. Superpave Design Gyrations for Projects Used in Study

Traffic	Temperature			
	Very Cool	Cool	Moderate	Hot
Low	3B		1C ↑	1N, 1M ↓
Medium	1L	3E ↑	3J, 6G	4K ↑
High	1G	1H, 5BT(1,2,3) ↑ ↑	3K, 6C1, 6C2 6F 5C, 6D ↑ ↑ ↑	2F
Very High	1B	2B	6E ↑	2A ↓
Very, Very High				

Legends
68
76
86
96
109

- Project 1M, the recommended N-design based on traffic and temperature was 76. The project was designed at 68.

- Project 1C, the recommended N-design based on traffic and temperature was 68. The project was designed at 76.

- Project 3E, the recommended N-design based on traffic and temperature was 68. The project was designed at 76.

- Project 1H, the recommended N-design based on traffic and temperature was 76. The project was designed at 86.

- Projects 5BT1, 5BT2 and 5BT3, the recommended N-designs based on traffic and temperature were 76. The projects were designed at 86.

- Project 2A, the recommended N-design based on traffic and temperature was 109. The project was designed at 96.

- Project 4K, the recommended N-design based on traffic and temperature was 86. The project was designed at 96.

- Project 5C, the recommended N-design based on traffic and temperature was 86. The project was designed at 96.

- Project 6D, the recommended N-design based on traffic and temperature was 86. The project was designed at 96.

- Project 6F, the recommended N-design based on traffic and temperature was 86. The project was designed at 96.

- Project 6E, the recommended N-design based on traffic and temperature was 96. The project was designed at 109.

Adjustments were made to the number of revolutions on eleven of the projects. These adjustments, made by the RMEs, are 8 to 13 revolutions different from the original Superpave recommendations. In most cases (all but one) the number of revolutions was increased. According to studies completed by the Asphalt Institute for the Federal Highway Administration[3] and the National Center for Asphalt Technology for the National Cooperative Highway Research Program[4], a separation of 20 and 30 gyrations respectively must be realized before a significant difference can be observed. The adjustment of 8 to 13 revolutions on these projects is insignificant.

5.0 TESTING PLAN

5.1 During Construction

During construction, loose mix was obtained from behind the paver. Six cans (approximately 2.5 gallons each) of loose mix were obtained. CDOT's standard tests were performed on the mix. These tests included extraction (AASHTO T164-B), gradation (AASHTO T30), Hveem stability (Colorado Procedure – Laboratory 5109), Lottman (Colorado Procedure – Laboratory 5109), and Rice with dry back (AASHTO T209). Samples were compacted using the Texas gyratory: 3 samples at the design EPS, 3 samples at the design EPS minus 25 psi, and 3 samples at the design EPS plus 25 psi. The voids at each design EPS were averaged.

Samples were also compacted using the Superpave gyratory: 3 samples at the number of design gyrations, 3 samples at one level below the number of design gyrations, and 3 samples at one level above the number of design gyrations. The air voids from the 3 samples at each gyration level were averaged. The averaged value is the value used for data analysis.

The terminology for the mix that was sampled behind the paver and compacted in the laboratory is: Field Mixed / Laboratory Compacted (FMLC).

Further, each mix was tested in the French Rutter at the design temperature and at the design temperature minus 5^{o}C. One can of mix was saved for possible future Superpave Shear Tester (SST) testing. However, CDOT never acquired an SST device and this testing was not done and the mix is no longer available.

5.2 After Construction

Immediately after construction, air voids were measured in the pavement. Nuclear density measurements were taken in 3 to 5 locations on each project. In addition, cores were taken.

Fifteen cores were taken from each project. Five cores were taken in the left wheel path of the design lane. The wheel path for the initial cores was determined by using the wheel path definition in Section 101, "Definitions and Terms" in the 1999 CDOT Standard Specifications for Road and Bridge Construction[2]. The wheel path is defined as follows: "the center of each wheel path is located 3 feet (900 mm) from the center of the lane; each wheel path is 2 feet (600 mm) wide." Five cores were taken just to the left of the wheel path and five cores just to the right of the wheel path. Figure 2 shows the configuration of the 15 cores with respect to the shoulder striping. Testing on the cores from each of the three locations (wheel path, left of wheel path and right of wheel path) was done independently and the value of the air voids from each location was calculated.

The air voids from the cores were measured on the top lift of each core. The top lift was removed for testing. The bulk specific gravity was determined using T166. Two Rices with dry back according to AASHTO T 209 were determined. The air voids were then calculated.

The terminology for the mix that was obtained from cores in the compacted pavement is: Field Mixed / Field Compacted (FMFC).

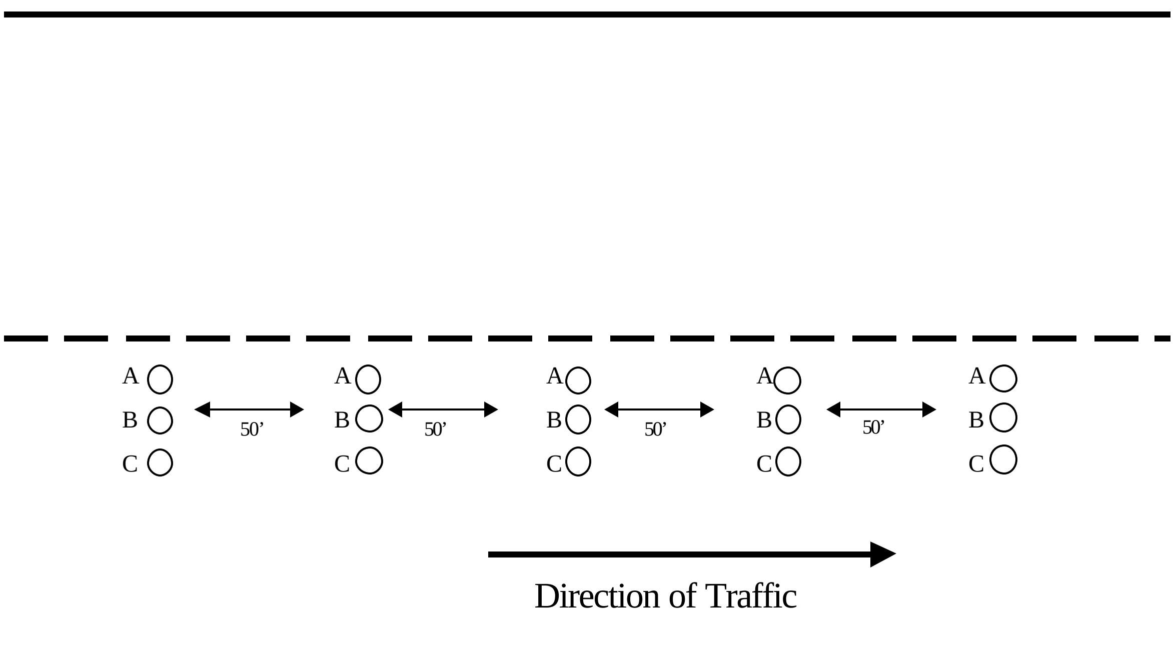
Rut measurements were taken in each wheel path. A total of 10 measurements were taken in each wheel path. These measurements were used to establish a baseline for future rut measurements.

5.3 Post-Construction Evaluations

In the first year following construction, the core location that best defined the wheel path was identified from the cores taken immediately following construction. The core that best defined the wheel path was the core location that had the lowest average void content. Generally, the core location that had the lowest average void content was the center set of cores whose location was determined using the wheel path definition in the 1999 Standard Specifications for Road and Bridge Construction[2]. For subsequent years, this location was where the cores were annually taken from the pavement. Five cores were taken from the pavement each year and air voids were determined as defined in the "After Construction" section. The air voids from the five cores were averaged and recorded as the in-place air void value for each individual project.

Rut measurements were taken every 50 feet in both the right and left wheel path of the driving lane in a 500-foot established evaluation section.

Figure 2. Core Locations



6.0 DATA ANALYSIS

The goals of the data analysis are listed below.

- Identify the number of years the Field Mixed / Field Compacted (FMFC) material takes to reach final densification under traffic.
- Measure the pavement performance after 5 to 6 years.
- Using the number of design gyrations required at the time this study was initiated, determine how well the air voids of the Field mixed / Laboratory compacted (FMLC) material matched the FMFC material.
- Based on the data gathered from the 25 test sites (22 projects), determine the optimal number of design gyrations for the FMLC material to match the FMFC material.

There were 25 sites from 22 projects that were evaluated. Twenty-one of the 25 data points were used for analysis. Four of the data points were not included because projects 3B and 1G were ruled as outliers with very high (12.1%, site 3B) and very low (0.5%, site 1G) FMLC voids. Site 1L did not have any initial Superpave data as it was included in the study after construction was complete.

6.1 Years Until FMFC Reaches Final Densification

The initial compaction (FMFC) for all but three of the 25 evaluation sections was within the specification range of 92 to 96%. The average density of the 22 evaluation sections was 94.7% with a standard deviation of 1.6.

The in-place field voids (FMFC) after 3 years, 4 years, 5 years and 6 years were compared to the air voids obtained from the Superpave gyratory, Field Mixed / Lab Compacted (FMLC) for each corresponding project. The FMLC air voids were determined from the number of gyrations that would have been recommended based on the high temperature and traffic for each project. (Table C)

Figure 3 represents the in-place field air voids (FMFC) after 3 years, Figure 4 represents the in-place field voids after 4 years, Figure 5 represents the in-place field voids after 5 years, and Figure 6 represents the average of the in-place field voids from years 3, 4, 5 and 6.

The comparison of FMFC in-place field voids after 6 years to the FMLC is not shown, as the data is limited. Not all projects were in-place for 6 years.

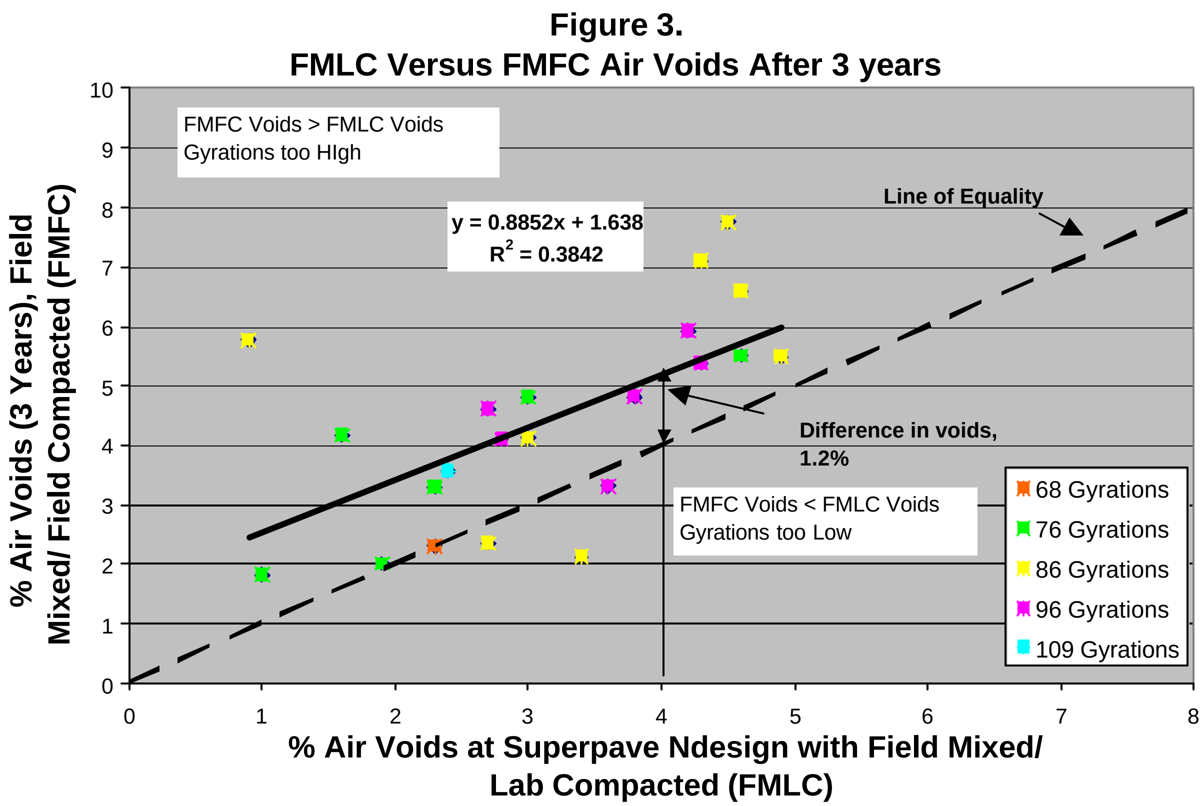


Figure 4.
FMLC Versus FMFC Air Voids After 4 Years

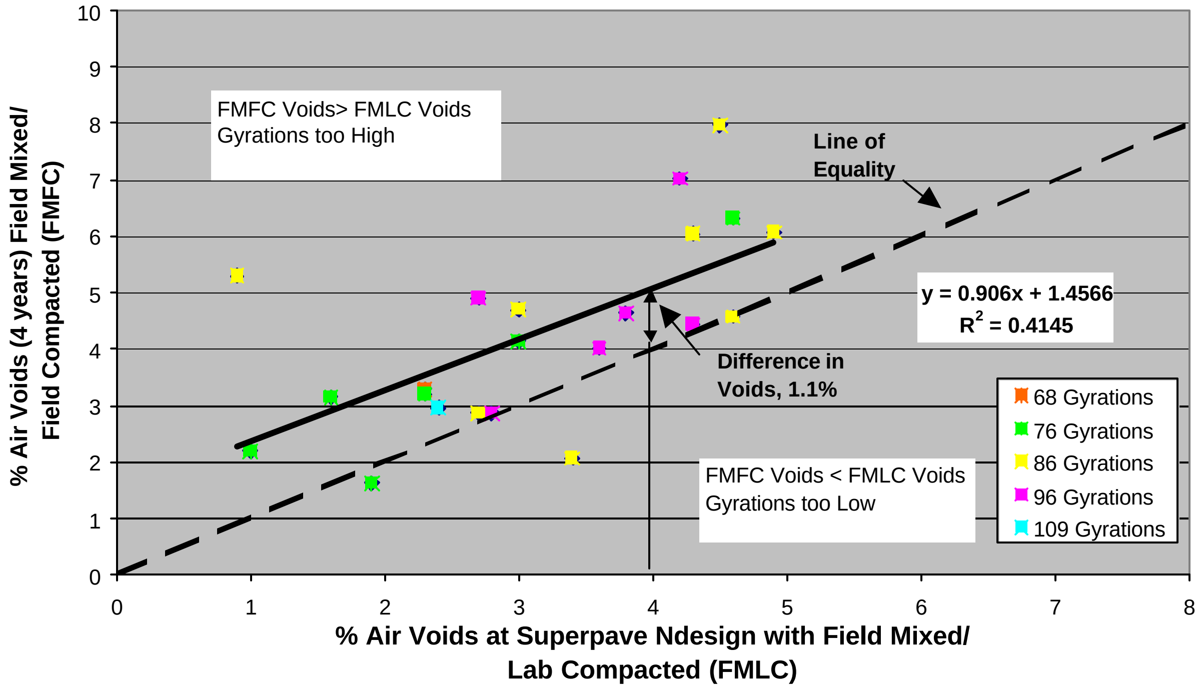


Figure 5.
FMLC Versus FMFC Air Voids After 5 Years

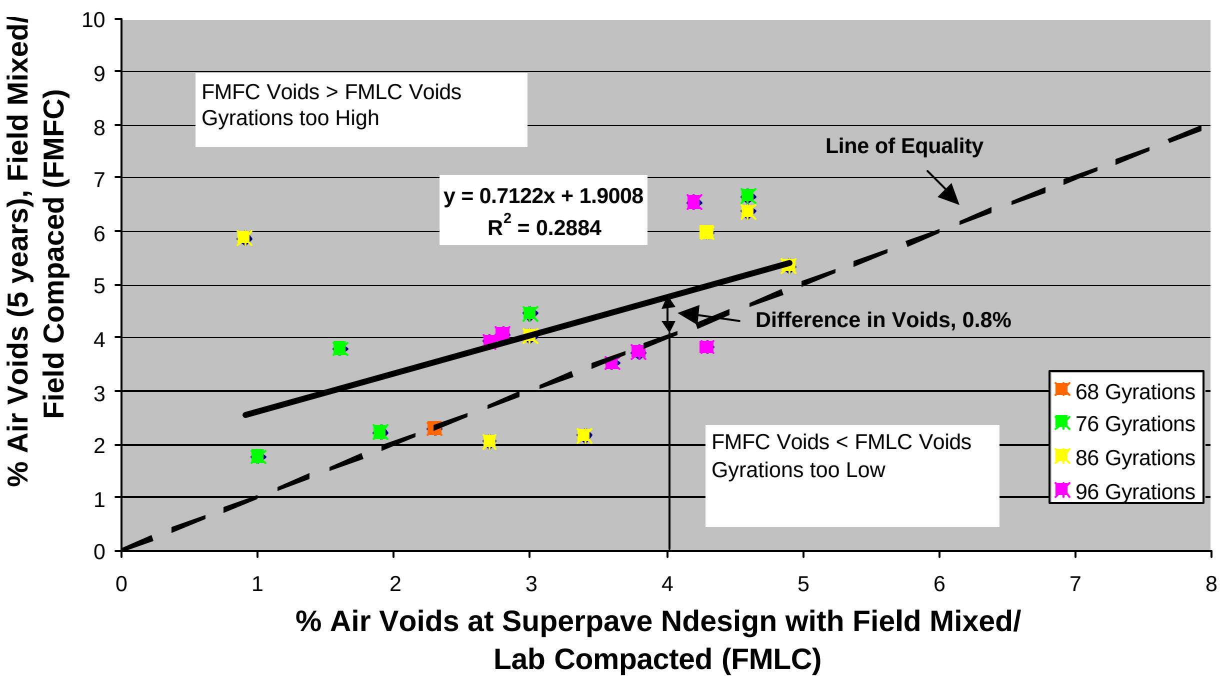
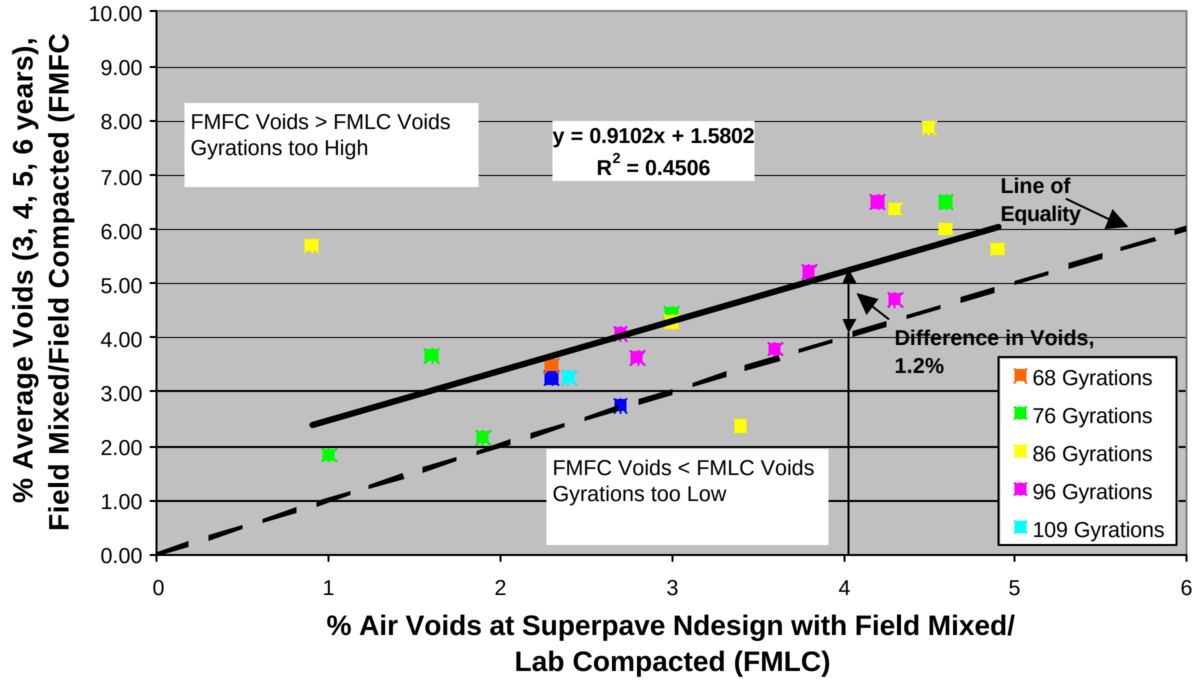


Figure 6.
FMLC Versus FMFC Average of In-Place Voids (year 3, 4 , 5 and 6)



With a perfect mix design methodology, the in-place voids (FMFC) after a certain length of time would match the Field Mixed/Lab Compacted voids (FMLC). This is represented with the line of equality on each of the graphs. It is apparent that this mix design methodology is not perfect because of the large amount of scatter, and because most of the data falls above the line of equality, there is a bias.

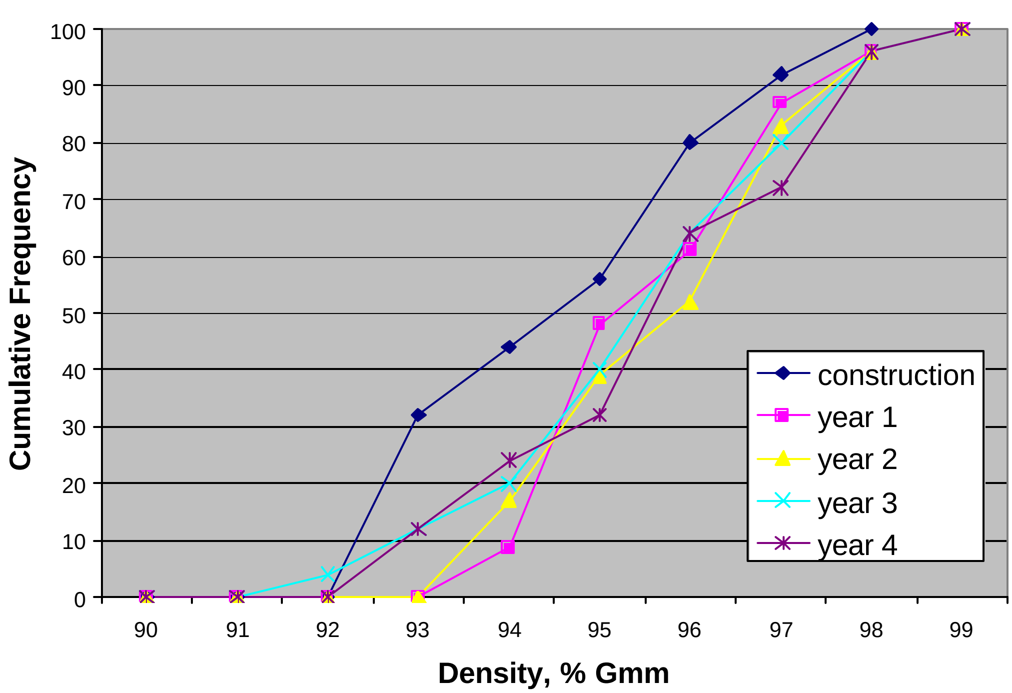
There have been a number of research studies that have evaluated the length of time for pavement densification to occur under traffic. Although the general consensus is that pavements reach their ultimate density after 2 to 3 years, the results have varied. Studies indicate that densification is reached as early at 2 years and some projects continue to densify up to 10 years.[5]

For this study, the overall in place voids measurements for 3, 4, 5, and 6 years did not change significantly. Therefore, for the projects in this study, it was assumed that the majority of the densification was achieved within the first 3 years.

The difference in percent voids between the line of equality at 4% voids and the actual best-fit line for the data is approximately 1.2%. This suggests that if one assumed that after 3 years a pavement should have achieved the final densification under traffic, these projects were designed at too high of compactive effort.

Figure 7 shows the cumulative frequency distributions of in-place densities from construction through year 4. This chart shows a definite increase in densification from construction to year one. Between year one and year two, additional densification occurs. Beyond year two densification begins to level off indicating that final densification was achieved between year two and three on the majority of the projects.

Figure 7. In-Place Densities



6.2 Description of the Surface Condition of the Pavements After 5 to 6 Years

Following construction, a 500-foot evaluation section was established at each evaluation location. Rut measurements were taken in the 500-foot evaluation section in the wheel paths each year. In addition, each year when the cores were obtained from the pavement the overall surface condition throughout the project was noted.

Other than rutting, no major distress was apparent on any of the projects at the conclusion of the study. In general loss of surface fines, raveling and periodic top down cracking was observed on many of the projects. These distressed are indicative of mixes designed at too high of compactive effort.

Rutting distress, according to the CDOT Pavement Design Manual[6], is considered to be of low severity at ¼ to ½ inch (6.25 to 12.5 mm), medium severity at ½ to 1 inch (12.5 to 25 mm) and high severity at > 1 inch (25mm). Table H shows the projects that, at the conclusion of the study, have measurable ruts. The maximum rutting on the 25 evaluation sections ranged from 0 to 17.1. Only three of the projects had low severity rutting and two of the projects had medium severity rutting.

Table H. Projects with Rut Depth Measurements Over 6 mm

Site Number	Maximum Rut in mm
1B	10.4
6C1	8.1
6C2	17.1
6D	7.7
6F	15.0

6.3 Comparison of FMFC Results with FMLC Using the Number of Gyrations Required at the Time of This Study

Assuming that a pavement will reach densification within three years of construction, Table I indicates if the number of design gyrations could have been reduced or increased based on the difference in the in-place voids (FMFC) after 3 years and the Ndesign voids (FMLC).

The criterion that was used to determine if the original number of Superpave design gyrations at Ndesign could have been reduced or increased was based on the difference between the in-place voids (FMFC) at three years and the Ndesign Superpave voids (FMLC).

When the difference between the 3-year in-place void (FMFC) and the Superpave Ndesign void (FMLC) was positive, the project was considered to have been designed at too high of a compactive effort.

When the difference between the 3-year in-place void (FMFC) and the Superpave Ndesign void (FMLC) was negative, the project was considered to have been designed at too low of a compactive effort.

Table I. Comparison of Current Design Gyrations to Actual Performance

Project	Recommended Ndesign (Actual Gyrations at Ndesign)	%Voids at Recommended Ndesign Gyrations (FMLC)	In-place Voids (FMFC) at 3 years minus Voids at Ndesign (FMLC)	Recommended Gyrations Based on Performance after 3 years	Estimated Gyrations Based on Performance after 3 years	Difference in Gyrations between Recommended Ndesign and Estimated Gyrations Based on Performance after 3 years
1G	68	0.5	2.8	<68	26	42
1L	68			<68		
1M	68 (76)	2.3	0	68	68	0
3B	68	12.05	-3.5	>68	>152	
1B	76	2.3	1.0	<76	56	20
1C	76 (68)	4.6	1.7	<76	54	22
1N	76	1.9	0.1	76	73	3
3E	76 (68)	1.6	2.6	<76	28	48
3J	76	3.0	1.8	<76	45	31
6G	76	1.0	0.8	<76	47	29
1H	86 (76)	4.5	3.3	<86	25	61
3K	86	0.9	4.9	<86	19	67
2B	86	4.6	2.0	<86	42	44
5BT1	86 (76)	4.9	0.6	<86	71	15
5BT2	86 (76)	4.3	2.8	<86	39	47
5BT3	86 (76)	3.0	1.1	<86	62	24
6C1	86	3.4	-1.3	>86	>134	
6C2	86	2.7	-.04	>86	88	-2
2A	96 (109)	4.3	1.1	<96	65	31
2F	96	2.7	1.9	<96	53	43
4K	96 (86)	3.8	1.0	<96	64	32
5C	96 (86)	4.2	1.7	<96	60	36
6D	96 (86)	2.8	1.3	<96	55	41
6F	96 (86)	3.6	-0.3	>96	116	-20
6E	109 (96)	2.4	1.2	<109	57	52

In the sixth column in this table are the estimated gyrations based on the difference in the design air voids and the in-place air voids after three years. Using the difference in air voids from the actual design air voids and the in-place air voids, the estimated gyrations were obtained from the gyration design curves. If the in-place air voids after three years were greater than the design air voids, the estimated number of gyrations would be lower than the design gyrations. If the in-place air voids after three years were less than the design air voids, the estimated design gyrations would need to be increased.

The seventh column in this table is the difference in the estimated design gyrations subtracted from the actual design gyrations obtained from the gyration design curve. The positive numbers in column seven indicate that the majority of these projects were designed at too high of a gyration level. The two negative numbers, indicate that these projects could have been designed at a higher gyration level.

The Colorado Department of Transportation began using the Superpave gyratory in 1995. CDOT began implementing Superpave projects in 1995 with three projects (binder specified only). Fourteen projects that specified the Superpave mixture and binder technology were placed in 1996 and nearly 95% of all CDOT projects in 1997 were constructed using Superpave mixture and binder technology. Currently, all CDOT projects are designed in accordance with Superpave mix and binder design requirements**.**

When Superpave was adopted by CDOT, the department used 5 levels of compactive effort. Using the mix design criteria that was in-place when these projects were designed, (Table I, In-place Voids (FMFC) at 3 years minus Voids at Ndesign (FMLC)), the FMFC voids after three years matched the FMLC voids on two of the 25 evaluation sections (8%), nineteen of the evaluation sections (76%) were designed at too high of a compactive effort, and four of the evaluation sections (16%) were designed at too low of a compactive effort.

6.4 Determination of the Optimal Number of Design Gyrations Based on These Sites

With a perfect mix design methodology, the in-place voids (FMFC) after 3 years would match the Field Mixed/Lab Compacted voids (FMLC). The majority of the evaluation sections shown in Figure 8 are above the “0.0 difference in voids” line. This suggests that the design gyrations used in this study were higher than necessary. Higher gyrations resulted in stiffer mixes. Regardless of the number of gyrations (68…..109), on the average, all of the FMFC are 1.2% higher than would have been predicted with the FMLC. This is shown on Figure 8 by the bold line “1.2 % difference in voids.”

There are several options available to adjust the Superpave design methodology for Colorado. These options include lowering the number of design gyrations or lowering the design air void content. As can be seen in Figure 9 with an 86-gyration design, a reduction of 30 gyrations would be necessary to obtain the 1.2% air voids. As the compactive level increases, the reduction in the number of gyrations to obtain the 1.2% air voids would increase. This large of a change in the number of gyrations may not be desirable.

Using the data from Table I, Figure 10, shows the actual design gyrations plotted against the predicted gyrations based on the field density of the projects after 3 year. This graph also indicates that the majority of the mixes used on these projects were designed at too high of compactive efforts. A design gyration of 100 is equal to a predicted gyration of 62 as shown with the bold blue line.

The seven sites with polymer-modified asphalt had an average of 2.3 percent difference in voids, while the 15 sites with unmodified asphalt had an average 0.82 percent difference in voids. This difference is worth noting and should be further investigated.

Figure 8. FMFC Air Voids After 3 Years Minus FMLC Air Voids During Construction

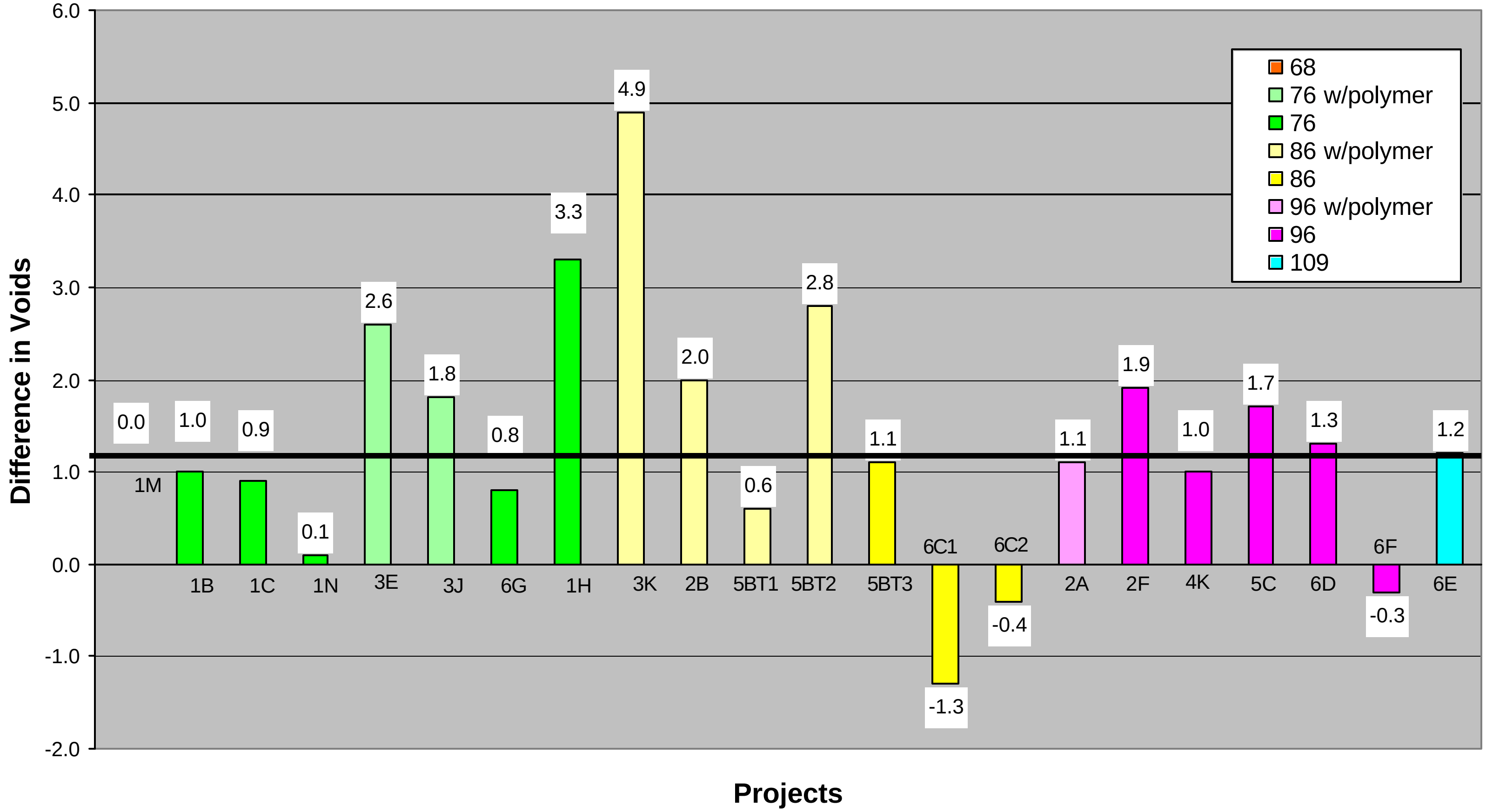


Figure 9.
Air Voids - Gyrations

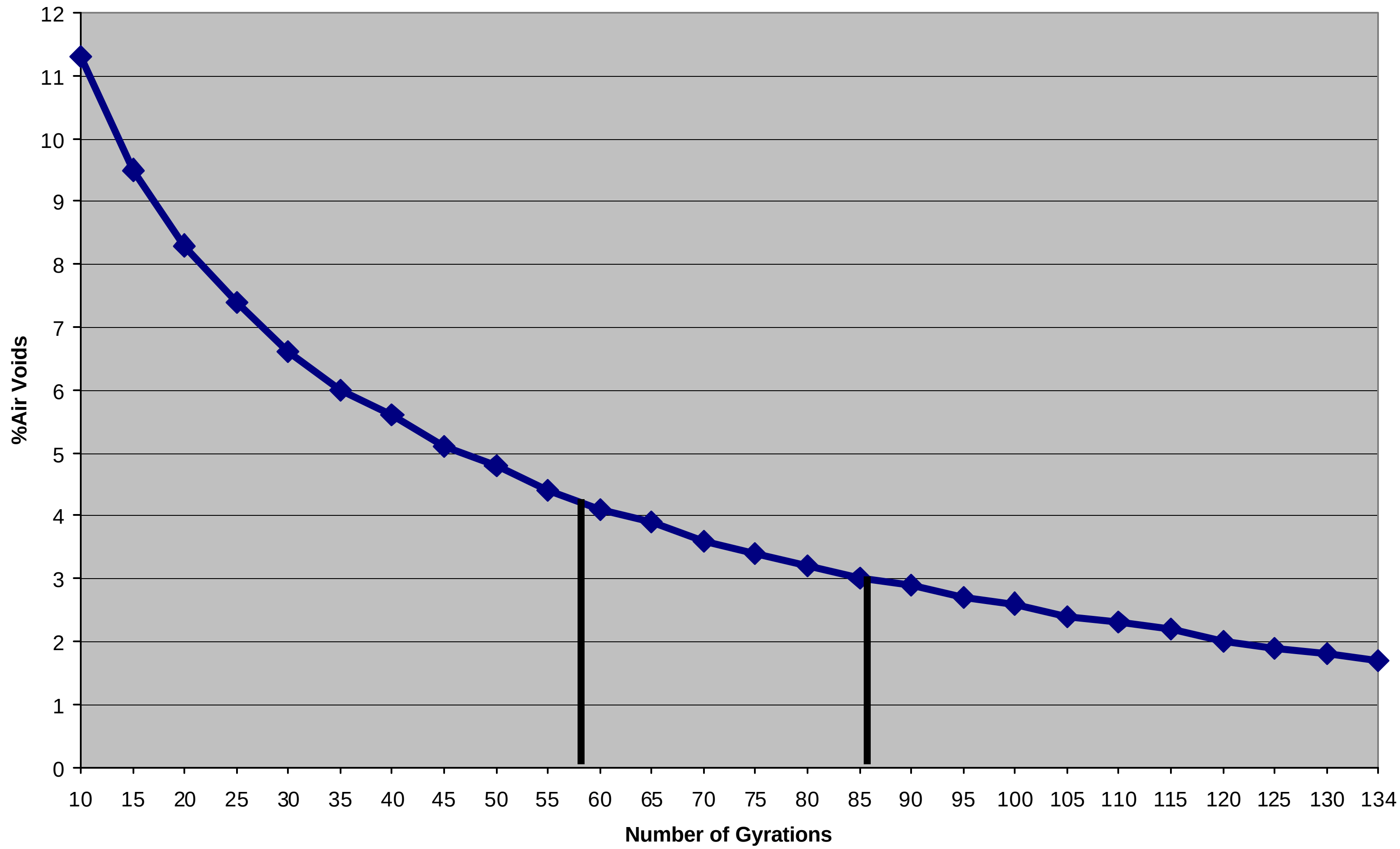
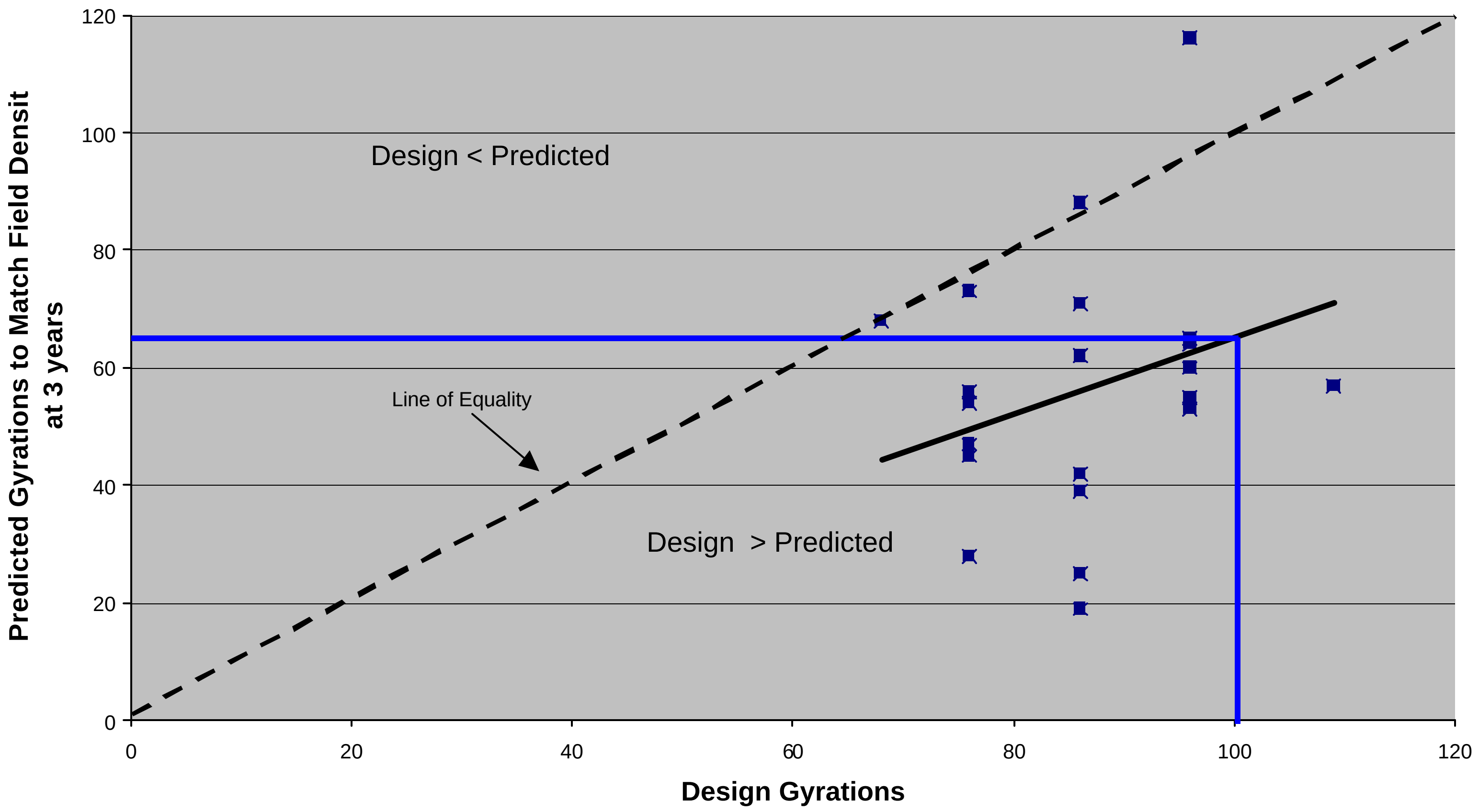


Figure 10. Design Versus Predicted Gyrations



7.0 CONCLUSIONS

The in-place void (FMFC) data indicates, through the trend lines in Figures 3, 4, 5 and 6, that mixes designed at the levels of compaction used in this study have not reached (FMLC) air voids after 6 years. The 6-year trend is that the pavement will never reach design air voids. A majority of the densification occurs during the first three years and the change in densification is not significant after three years.

Although loss of surface fines, raveling and periodic top-down cracking was observed on many of the project, the overall pavement performance at the conclusion of this study (in-place from 5 to 6 years) was not compromised. However, of the 25 evaluation sections, three had low severity rutting and two had medium severity rutting measured based on CDOT's Pavement Design Manual[6]. These distresses could reduce the service life of the pavement.

Based on Figure 7, the majority of the evaluation sections were high in air voids (FMFC) when comparing the difference in FMLC voids to the FMFC voids after 3 years. The average was 1.2%.

Based on the data gathered from the 25 evaluation sections, the optimal number of design gyrations for the FMLC material is too high. Currently, mixes appear to be designed to be too stiff for the traffic and environmental conditions. Less laboratory compactive effort is justified.

8.0 RECOMMENDATIONS

The mixes are being designed at too low of an asphalt content. The optimum asphalt content is too dry for the environmental and traffic considerations in Colorado. Options for adjustments include:

Option 1: Lower the number of design gyrations.

Option 2: Adjust the target mix design air void contents.

When modifications to the Superpave gyratory design procedures are made, the adjustments should better predict actual in-place voids after 3 years. Additional research should be conducted to track these changes to ensure the desired outcome is achieved.

The Central Materials Laboratory should review the Job Mix Formula (Form 43) for appropriateness of voids and asphalt content.

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