State of Florida

Department of Transportation

EVALUATION OF HIGH RAP ASPHALT MIXTURE PERFORMANCE IN FLORIDA

FDOT Office
State Materials Office

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ABSTRACT

This study examined the long term performance and life span of high RAP (≥ 30%) mixture designs used on higher tonnage (>5000 tons) projects. Pavement performance was compared between mixtures containing high RAP percentages and mixtures containing no RAP from the time period 1991-1999.

All of the pavements analyzed contained a lower structural layer that contained RAP and an upper layer that contained either an open graded or dense-graded non-RAP friction course.

Several databases were consulted to obtain the necessary information regarding tonnage, mixture designs, percent RAP, project information, traffic volumes, pavement performance, and life-span.

A trend showing decreased age to deficiency as the percent RAP increases was evident when examining the data without accounting for the volume of traffic. When accounting for traffic volume and isolating projects ≥ 5000 tons, there is a trend showing decreasing performance with increasing amounts of RAP. However, in the range analyzed (30-50 %RAP) all mixtures containing RAP performed better than the mixtures containing no RAP.

When considering the type of non-RAP friction course placed over the RAP mixtures, as the amount of RAP increased, pavement performance decreased at the same rate regardless of the type of friction course. Although this trend may be correct, the implication that RAP mixtures overlaid with an open graded friction course have a longer life-span than RAP mixtures overlaid with a dense-graded friction course may not be correctly reflected in this data set.

INTRODUCTION

The use of Reclaimed Asphalt Pavement (RAP) has received significant attention nationally in the last few years. In 2007, the Federal Highway Administration (FHWA) created the RAP Expert Task Group (ETG) to advance the use of recycled materials (1). In cooperation with the American Association of State Highway and Transportation Officials (AASHTO), the RAP ETG conducts a survey every 2 years. In 2007, the reported national average RAP content being used in asphalt pavements was 12 percent, increasing only to about 15 percent by 2010 (2). In 2009, 23 states claimed experience with high RAP mixtures and many of the states continued to increase the amount of RAP permitted within their asphalt mixtures. Even though by 2011, more than 40 states allowed greater than 30 percent RAP use in their asphalt mixtures, only 11states reported actually using more than 25 percent RAP consistently.

In the past, the use of RAP has demonstrated a performance quality comparable to that of non-RAP hot mix asphalt (HMA) (3-11). With the increase in raw material prices and for environmental reasons, there is a demand to use more recycled materials. The use of more RAP in asphalt pavements is a potential cost savings and an environmentally friendly technique to address these issues. However, despite the success rate of these mixtures, the perception that mixtures containing these recycled materials have inferior performance still persists (3).

The innovation by Robert Mendenhall to the use of RAP in asphalt pavements in the 1970's, was the start to a worldwide acceptance asphalt recycling (14). The Florida Department of Transportation (FDOT) had its first RAP project in 1977, where it was used to construct an asphalt base (14). Through industry's continued interest and national improvement of the process (15) the FDOT started using RAP routinely in 1980.

Due to its seemingly favorable history, long-term performance of RAP pavements has not been well documented over the years (4). However, the Strategic Highway Research Program performed a 20 year study which monitored in-service pavements across North America. Now managed by the FHWA, the Long Term Pavement Performance (LTPP) program contains a large amount of performance data for 18 pavements in the U.S. and Canada. Several researchers have accessed this data to study different aspects of RAP performance (3, 5, 7-9). Hong, et al. was able to access data for five Texas sections using 35% RAP, which were monitored over a 16 year period (8). Similarly CALTRANS was able to analyze 47 RAP sections using 15 % RAP in several different environmental zones across the state (9). All reports have shown the RAP mixtures' performance to be equal to or not statistically different than the non-RAP asphalt mixtures.

Performance of mixtures containing 10-25% RAP that were paired with non-RAP control sections as well as several other non-paired projects from Georgia were evaluated by NCAT in 1995 showing no statistical differences between the non-RAP mixtures and the RAP mixtures within the first 2.5 years of service (10). Al-Qadi, et al. along with the Illinois Center for Transportation conducted a similar analysis of data from Illinois examining RAP contents from 10-50% (11). Visual inspection over 3 years of service showed no significant difference.

A experiment was conducted at the NCAT Test Track in 2006 to evaluate high percentage (≥25%) RAP surface mixtures for constructability and performance (16). Four test sections containing 45% RAP were compared to control sections containing no RAP or 20% RAP. Constructability issues appeared in the 45% RAP sections and appeared to be binder influenced. Even with an additive to aid compaction, the 45% RAP and PG 76-22 binder section required the most compaction effort. With respect to performance, all the sections performed favorably in both the laboratory and field in terms of rutting and cracking.

Initially, RAP was used in the pavement base and underlying structural layers. Unfortunately, long-term performance is typically based on the pavement surface condition and visual observation of the, then non-RAP, friction courses (4). Today, nearly all of FDOT's structural and dense-graded friction course mixtures contain RAP. The only mixtures where RAP is currently not permissible are open-graded friction course mixtures.

In 2010, FDOT placed 4,340,909 tons of hot mix asphalt of which 3,481,909 tons contained RAP material. For those mixtures containing RAP the average RAP content was 20%. In Florida, the Marshall mixture design method was used to design asphalt mixtures until the late 1990's, when the FDOT switched to the Superpave mixture design method. Due to the limited long-term performance data of the Superpave mixtures, this study focused on Marshall designed mixtures constructed from 1991-1999. Projects constructed prior to 1991 were excluded from this analysis due to the poor quality of available construction data. A follow-up study will be conducted on Superpave designed mixtures.

The purpose of this study is to examine the long term performance and life span of high RAP ($\geq$ 30%) mixture designs used on higher tonnage (>5000 tons) projects. The reason for only including RAP mixtures with $\geq$30% RAP is to ascertain the affects of RAP on the performance (cracking, ride, and rutting) of asphalt pavements. Smaller percentages of RAP have been assumed not to affect pavement performance significantly.

Pavement performance will be compared between mixtures containing high RAP percentages and mixtures containing no RAP from the same time period (1991-1999). The mixtures containing no RAP will serve as the baseline for pavement performance for which the high RAP mixtures will be compared.

DATABASES

Multiple databases were referenced in order to compile the construction and performance data for each mixture design and project. FDOT maintains extensive mixture design records, including test results used for the approval of the mixture for use on DOT projects, changes or revisions to the design, and the history of a design (design transfers). The mixture designs also provide general information about the material used, such as, the source of the aggregate or RAP material, the blend percentages for each component, specific gravities of each material and the type and amount of asphalt binder (Figure A1).

Construction reports were referenced to confirm the use of hot mix asphalt and the mixture design used for each project. During the timeframe of these projects, FDOT limited the use of RAP to the structural course. Even though the friction courses, both dense-graded and open-graded, did not contain RAP, they were also identified from the construction reports for later reference (Figure A2 and A3).

Once the project Financial Identification Number (FIN) was identified, the Financial Project Management database provided much of the basic contract document information, such as the location of the project (District, county, state road, and milepost limits), the important dates of execution (contract executed, under construction, and construction complete dates), the Contractor, and the type of work being performed (Figure A4).

FDOT's Pavement Management Office maintains a large database of projects with associated mixture designs and tonnage. Only mixture designs with $\geq$ 5000 tons were selected for further investigation to assure that projects of substantial size were analyzed (Figure A2). The Pavement Condition Survey (PCS) data was queried within the original project limits to determine the life span of the pavement. Since cracking is the number one distress for Department maintained asphalt pavements, the first year of a deficient crack rating was the criterion used to determine the life span of the constructed pavement (Figure A5 and A6). The majority of the pavements used in this analysis have already been resurfaced; therefore the history of each current pavement limits was reviewed. This task proved to be challenging since the resurfacing limits for each project change from resurfacing to resurfacing due to the variable performance of each section of the pavement.

Additional information from the PCS data included estimated future work (work program), the date and work mix of previous construction, percent trucks and Average Annual Daily Traffic (AADT) of each roadway selection (Figure A7).

DATA COLLECTION

Two methodologies were used to analyze the data: 1) Mix Design Search and 2) Tonnage Search.

Mix Design Search Methodology

This approach was basic in nature. A list of Marshall Mixture Designs with high RAP and their corresponding projects were identified. From this list, the District, dates of construction and performance data were collected. This approach is shown in Figure 1.

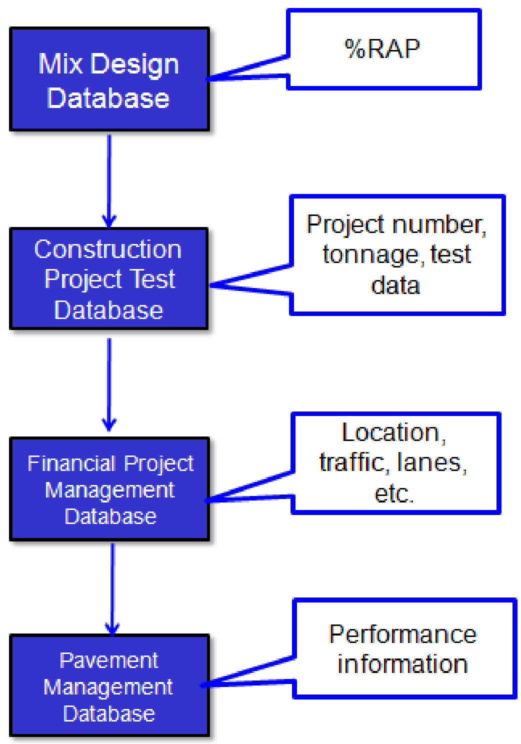

Figure 1 - Mix Design Search Methodology

Tonnage Search Methodology

The initial data search indentified the importance of many items missing in the data sets. Therefore, the data collection methodology was revised to include tonnage, non-RAP mixtures, the associated friction course for each mixture, and the percent of the AADT that was truck traffic (AADTT). A minimum tonnage requirement of 5000 tons of produced hot mix asphalt was the first criterion used for the selection of mixture designs. If the mixture design was used on multiple projects, the project with the highest tonnage for that mixture design was selected. A similar search and analysis of non-RAP mixtures was used for a baseline comparison of life span and performance. Additionally, the friction course data on each project was analyzed to determine if there was a correlation between the performance of the underlying RAP mixture and its corresponding friction course type (open graded or dense-graded). This approach is shown in Figure 2.

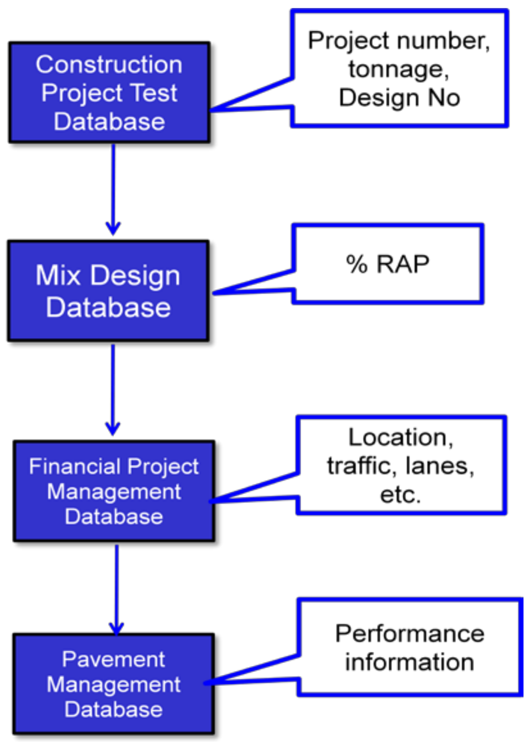

Figure 2 - Tonnage Search Methodology

DATA ANALYSIS

All of the pavements analyzed contained a lower structural layer that contained RAP and an upper layer that contained a non-RAP friction course. The reported crack rating in the PCS database is based on visual inspection of the surface layer. The depths of the cracks are unknown, as is the origination of the cracks (top-down or bottom-up). Therefore, it is not possible to isolate the performance of the underlying RAP structural layer. As a result, performance of the structural layer containing RAP is inferred based on the performance of the entire pavement structure.

Using the data collected in the mix design search methodology, the age was determined for each project. The data for various categories of percent RAP (30, 35, 40, and 45%) and the average age for each percentage were plotted and are shown in Figure 3. This data is not filtered based on size of project (tonnage) or traffic volume.

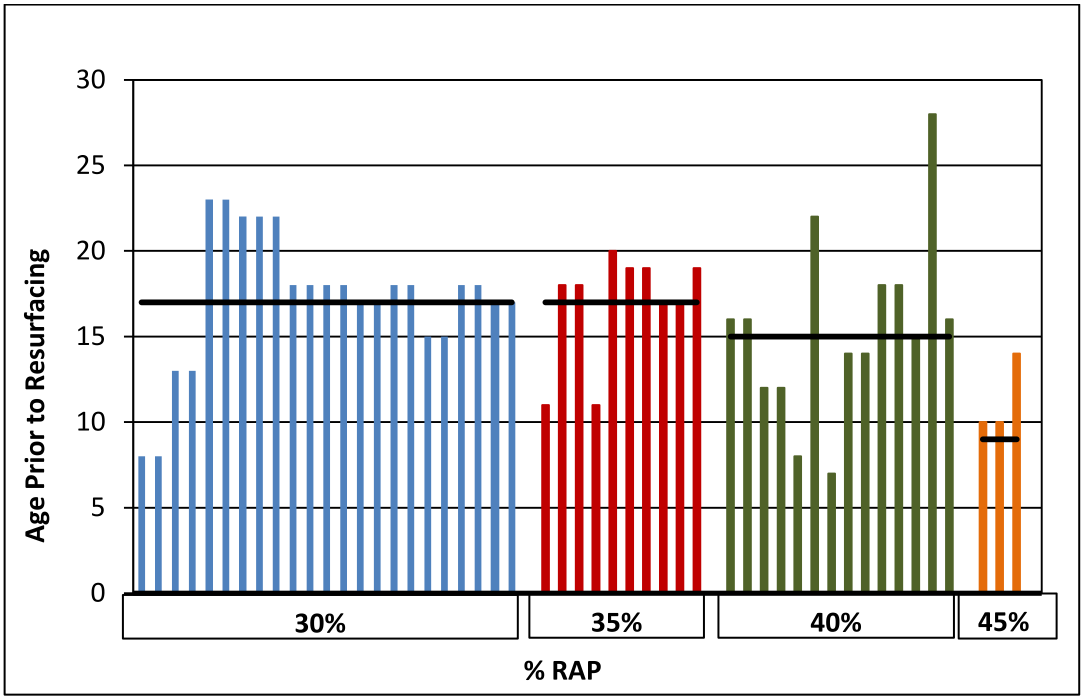

Figure 3 - Age Prior to Resurfacing vs. Percent RAP

Figure 3 identifies a trend showing decreased age to deficiency as the percent RAP increases. However, the data shown in Figure 3 does not account for the volume of traffic each pavement was exposed to.

To ascertain the affects of truck traffic, the age was normalized by truck traffic [AADTT * Age (yrs) * 365(days/yr)] and plotted against the percent RAP as shown in Figure 4. Projects included in this analysis had an added criterion of ≥ 5000 tons of produced hot mix asphalt.

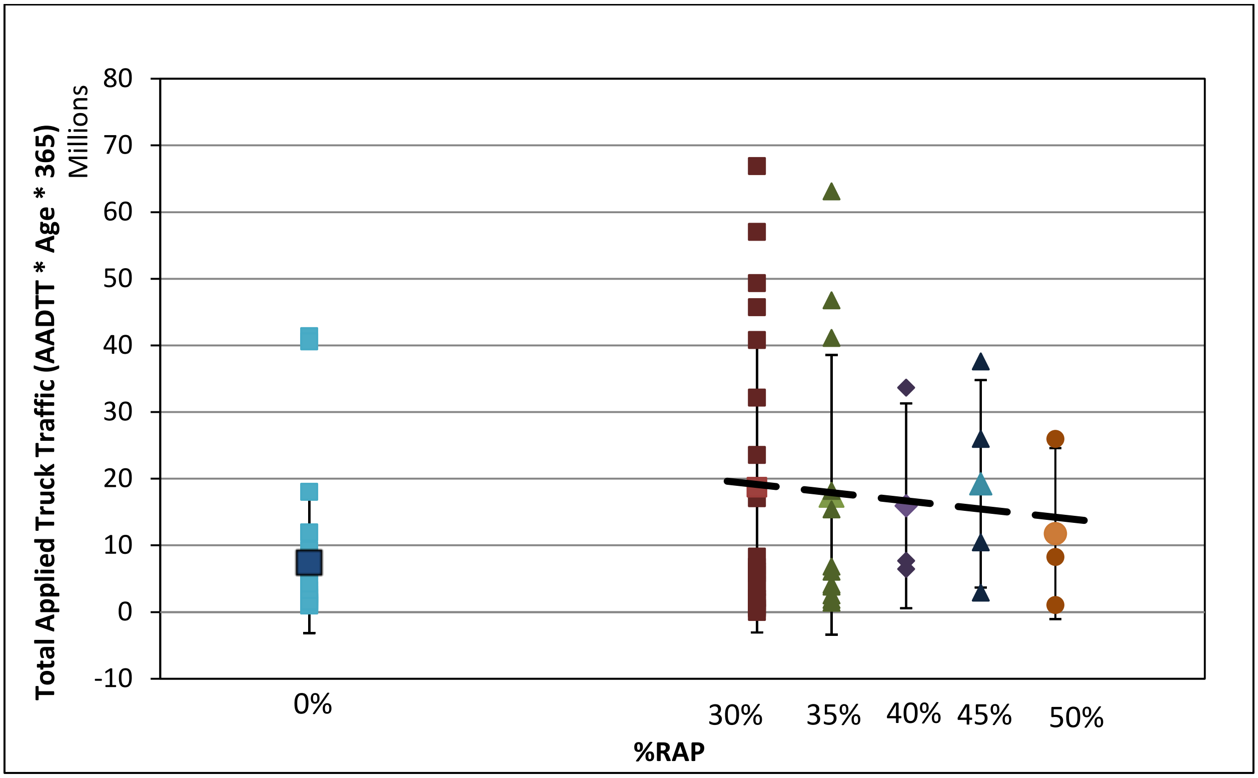

Figure 4 – Total Truck Traffic vs. Percent RAP

Two points of interest are identified in Figure 4. There is a trend showing decreasing performance with increasing amounts of RAP. However, in the range analyzed (30-50 %RAP) all mixtures containing RAP performed better than the mixtures containing no RAP.

Relationship between Friction Course Type and Percent RAP in Structural Course

Friction course types analyzed were open graded and dense-graded mixtures. Within each type, the following mixture designations existed.

Open graded: FC-2 with ground tire rubber (GTR)

Dense-graded: FC-3 with GTR

Other friction course types not analyzed due to lack of data points include FC-1, FC-2 with latex additive and FC-3 with latex additive.

The age of pavement vs. percent RAP for pavement with open graded friction courses is shown in Figure 5.

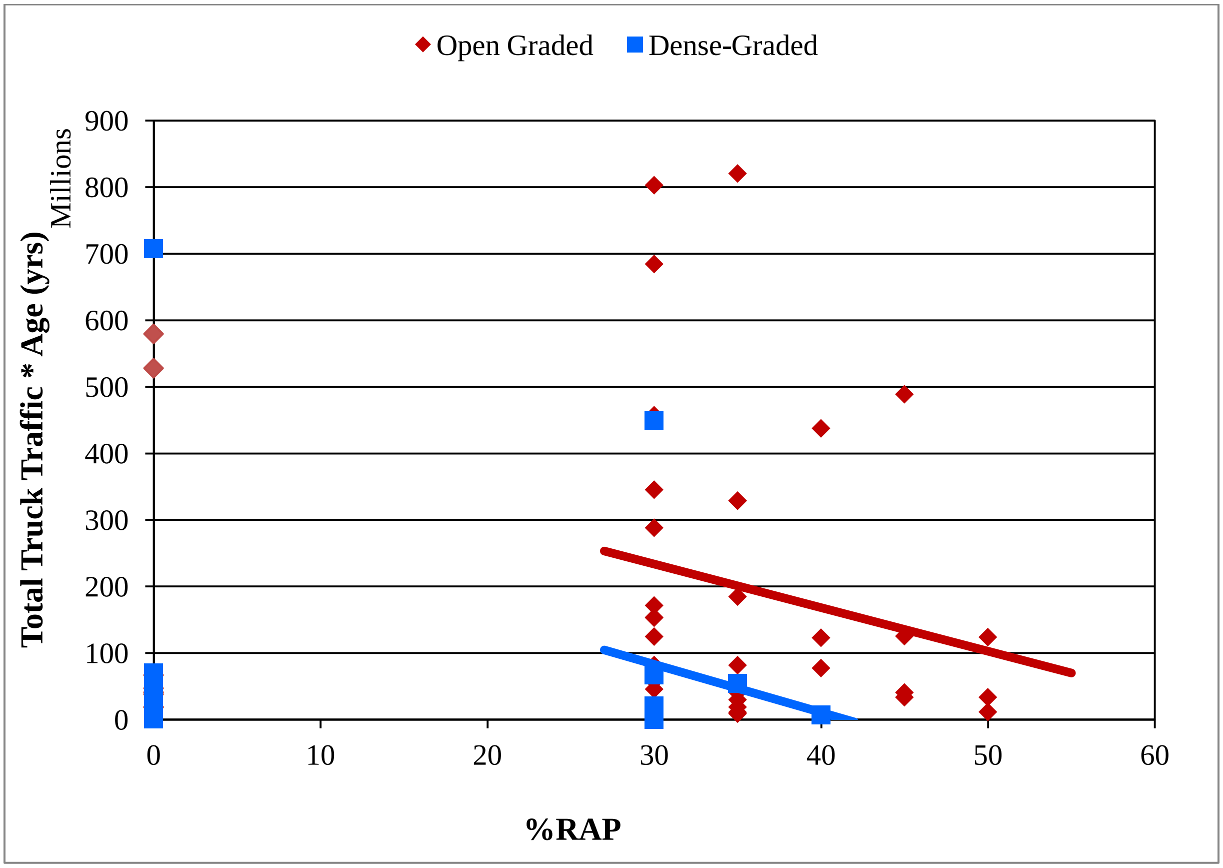

Figure 5 – Total truck traffic * age (yrs) vs. percent RAP filtered by their corresponding friction course.

Data presented in Figure 5 indicates RAP mixtures overlaid with non-RAP open graded friction course mixtures decrease in performance with increasing percentages of RAP at the same rate as RAP mixtures overlaid with non-RAP dense-graded friction course mixtures.

Additionally, the data indicates that RAP mixtures overlaid with non-RAP open graded friction course mixtures have a longer loading capacity than RAP mixtures overlaid with non-RAP dense-graded friction course mixtures.

The average age in which the open graded friction courses become deficient is 11.2 years. This is in close agreement with our Pavement Management Office's reported performance of Florida's open graded friction courses in general. However, for dense-graded friction courses, the average age to deficiency was 10.7 years. This does not agree with reported performance, which typically averages 14 years before becoming deficient. The trend of the decreased performance with increased amounts of RAP may be correct, but due to the lack of sufficient data points for the dense-graded friction course mixtures, the relationship between the open graded and dense-graded friction course performance may not be correctly reflected in this data set.

CONCLUSIONS

The following conclusions were derived from the findings of this analysis:

1. A trend showing decreased age to deficiency as the percent RAP increases was evident when examining the data without accounting for the volume of traffic.
2. When accounting for traffic volume, there is a trend showing decreasing performance with increasing amounts of RAP. However, in the range analyzed (30-50 %RAP) all mixtures containing RAP performed better than the mixtures containing no RAP.
3. When considering the type of non-RAP friction course (open graded or dense-graded) placed over the RAP mixtures, as the amount of RAP increased, pavement performance

decreased at the same rate regardless of the type of friction course.   Additionally, the data indicates that RAP mixtures overlaid with open graded friction course mixtures have longer life-spans than RAP mixtures overlaid with dense-graded friction course mixtures. Although the trend of the decreased performance with increased amounts of RAP may be correct; the implication that RAP mixtures overlaid with an open graded friction course have a longer life-span than RAP mixtures overlaid with a dense-graded friction course may not be correctly reflected in this data set.

RECOMMENDATIONS

Based on the results of this analysis, the following recommendations are made:

1. Since this study analyzed data for mixtures designed with the Marshall Mix Design System, it is recommended to perform a similar study using mixtures designed with the Superpave Mix Design System.
2. A study involving RAP mixtures in the surface course should be undertaken to more directly determine the relationship between percent RAP and pavement performance.
3. A follow-up study should include a more detailed monitoring of the pavement performance in addition to the annual PCS rating for the pavement’s life-span.

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APPENDIX A

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Contract No. ________ Project No. ________________ Type Mix S-I Recycle Date 07 / 18 / 96

Road No. SR-500 (US-17/92/441) County Orange District 5 Phone No. (407) 656-9255

Contractor Name & Plant Location ________________ Fax No. ________

Intended Use of Mix ________ Submitted By ________ E-Mail ________

Q.C. Tech. ________ ________

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. Crushed R. A. P.		RAP Material	Stockpile	07 / 10 / 96
2. S-1-A Stone	42	Aggeregate Company	87-555	07 / 10 / 96
3. FC-3 Stone	55	Aggeregate Company	87-555	07 / 10 / 96
4. Medium Screenings	21	Aggeregate Company	87-555	07 / 10 / 96
5. Local Sand		Aggeregate Company	11-200	07 / 10 / 96
6.				

PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

	Blend	35%	15%	16%	28%	6%		JOB MIX	GRADATION		
	Number	1	2	3	4	5	6	FORMULA	DESIGN RANGE		
S	1" 25.0mm										
I	3/4" 19.0mm	100	100	100	100	100		100		100	
E	1/2" 12.5mm	99	73	100	100	100		96	88	-	98
V	3/8" 9.5mm	96	40	90	100	100		88	75	-	93
E	No. 4 4.75mm	79	4	39	100	100		68	47	-	75
	No. 10 2.0mm	63	3	3	86	100		53	31	-	53
S	No. 40 425µm	42	2	3	45	99		34	19	-	35
I	No. 80 180µm	21	2	2	18	35		15	7	-	21
Z	No. 200 75µm	11.0	1.0	2.0	5.0	1.0		6.0	2	-	6
E	Sp. Gr.	2.585	2.335	2.339	2.471	2.626		2.474			

MATERIALS DIVISION USE ONLY

No. 200 increased due to expected aggregate breakdown during production.

Figure A1. Marshall Mixture Design

Mix Design used in: District 1
From : 01Jan1993
To : 31Dec1993

MIX DESIGN #	# of PROJECTS	TONS PLACED	FROM DATE	TO DATE
QA-825522	1	468.94	01JUL1993	01JUL1993
QA-88-3876	1	162.84	09DEC1993	09DEC1993
QA-904570	1	682.03	12JUL1993	27JUL1993
QA-92-5169	1	7.13	25FEB1993	25FEB1993
QA-92-5522	1	1020.12	20JAN1993	20JAN1993
QA-92-5526	1	277.15	02SEP1993	03SEP1993
QA-92-5527	1	840.95	08SEP1993	09SEP1993
QA-925169	1	321.25	23FEB1993	23FEB1993
QA-925522	1	4024.8	28JUN1993	27JUL1993
QA-925526	1	84.31	18APR1993	18APR1993
QA-93-5806	1	52.12	02SEP1993	07SEP1993
QA-93-5979	1	58.78	01SEP1993	10SEP1993
QA-93-92-5527	1	1010.1	07SEP1993	07SEP1993
QA-935806	1	2782.27	07JUN1993	08JUN1993
QA-935923	1	4158.78	08JUN1993	11JUN1993
QA5527	1	850.85	14APR1993	14APR1993
QA88-3876	1	162.84	09DEC1993	09DEC1993

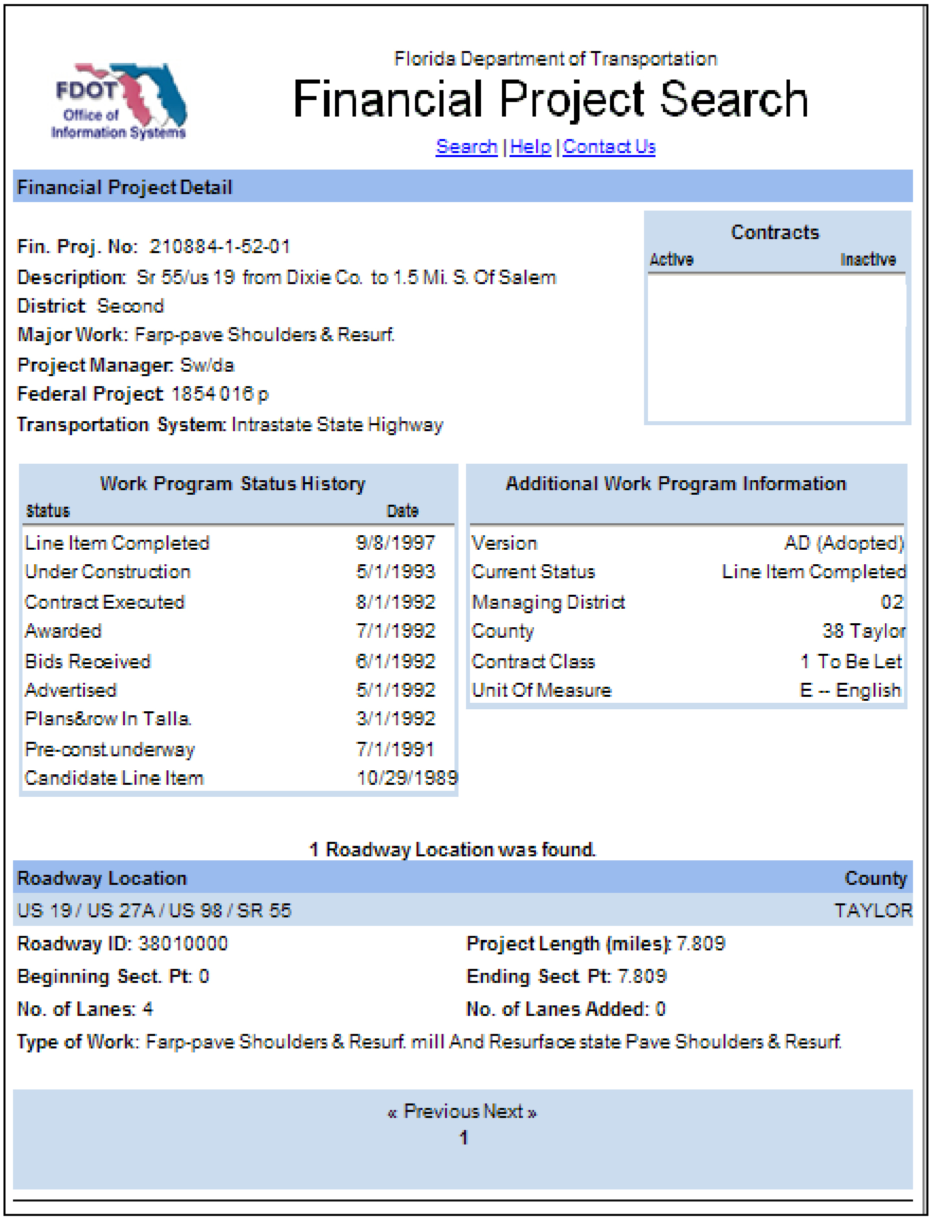
Figure A2. Mix Designs and Associated Tonnage Produced as Displayed Through the Pavement Management Database

Search results for Mix Design Number: QA92-5522

****Click the red MATL. link to view test results****

MATL.	JOB	TONS PLACED	MIX DESIGN NUMBER	REPORT	SAMPLE	SAMPLE DATE	SOURCE
120A	197494 -1 -52 -01	108.0900	QA92-5522	28402	L3012	02/04/1993	N/A
120A	197494 -1 -52 -01	42.6600	QA92-5522	28402	S3013	02/05/1993	N/A

Figure A3. Construction Reports Correlating to Hot Mix Asphalt Production (Material 120A) and the Associated Project ID, Tons Placed and Mix Design



Florida Department of Transportation

Financial Project Search

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Financial Project Detail

Fin. Proj. No: 210884-1-52-01
Description: Sr 55/us 19 from Dixie Co. to 1.5 Mi. S. Of Salem
District: Second
Major Work: Farp-pave Shoulders & Resurf.
Project Manager: Sw/da
Federal Project: 1854 016 p
Transportation System: Intrastate State Highway

Contracts

Active	Inactive

Work Program Status History

Status	Date
Line Item Completed	9/8/1997
Under Construction	5/1/1993
Contract Executed	8/1/1992
Awarded	7/1/1992
Bids Received	6/1/1992
Advertised	5/1/1992
Plans&row In Talla.	3/1/1992
Pre-const underway	7/1/1991
Candidate Line Item	10/29/1989

Additional Work Program Information

Version	AD (Adopted)
Current Status	Line Item Completed
Managing District	02
County	38 Taylor
Contract Class	1 To Be Let
Unit Of Measure	E -- English

1 Roadway Location was found.

Roadway Location	County
US 19 / US 27A / US 98 / SR 55	TAYLOR

Roadway ID: 38010000 **Project Length (miles):** 7.809
Beginning Sect. Pt: 0 **Ending Sect. Pt:** 7.809
No. of Lanes: 4 **No. of Lanes Added:** 0
Type of Work: Farp-pave Shoulders & Resurf. mill And Resurface state Pave Shoulders & Resurf.

« Previous Next »
1

Figure A4. Financial Project Information Search

Pavement Condition Survey

For Levy County

Other Conditions: Critical Value=6.4, Section= 050, Subset= 000

Click on the Begin Mile Point to plot the history and forecast years of crack, ride and rut ratings distribution for a roadway segment.
Click on the Roadway ID to plot the current year of crack, ride and rut ratings distribution for an entire roadway.

Roadway Segment							Tentatively Planned Project							PCS Survey Information				
SR	US	Begin Mile Point (History Link)	End Mile Point	Rdwy Side	Posted Speed	AADT	Item Segment	Begin Mile Point	End Mile Point	Rdwy Side	Fiscal Year	Work Mix	Current Pvmt age In Yrs	Cracking 2009	Ride 2009	Rutting 2009	Lane Miles
55	19	0.000	9.831	L	65	5800	2103762	0.000	9.831	C	2007	0012	34				19.662
55	19	0.000	9.831	R	65	5800	2103762	0.000	9.831	C	2007	0012	34				19.662
55	19	9.831	24.026	L	65	3700	2103764	9.831	24.026	C	2009	0012	15	3.5	7.7	9.0	28.390
55	19	9.831	24.026	R	65	3700	2103764	9.831	24.026	C	2009	0012	15	4.5	7.7	9.0	28.390
55	19	24.026	35.060	L	65	2900	2103763	24.026	35.028	C	2010	0012	15	4.5	7.6	7.0	22.068
55	19	24.026	35.060	R	65	2900	2103763	24.026	35.028	C	2010	0012	15	7.0	8.3	7.0	22.068
55	19	35.060	35.637	L	45	3700	2103768	35.028	36.547	C	2009	0012	15	4.5	7.2	9.0	1.154
55	19	35.060	35.637	R	45	3700	2103768	35.028	36.547	C	2009	0012	15	5.0	7.6	8.0	1.154
55	19	35.637	36.137	C	30	7500	2103768	35.028	36.547	C	2009	0012	15	5.0	6.4	8.0	2.000
55	19	36.137	36.547	L	35	10500	2103768	35.028	36.547	C	2009	0012	15	6.5	7.4	9.0	0.820
55	19	36.137	36.547	R	35	10500	2103768	35.028	36.547	C	2009	0012	15	6.5	6.5	9.0	0.820

Download Report Table to Excel

Figure A5. Pavement Condition Survey Database

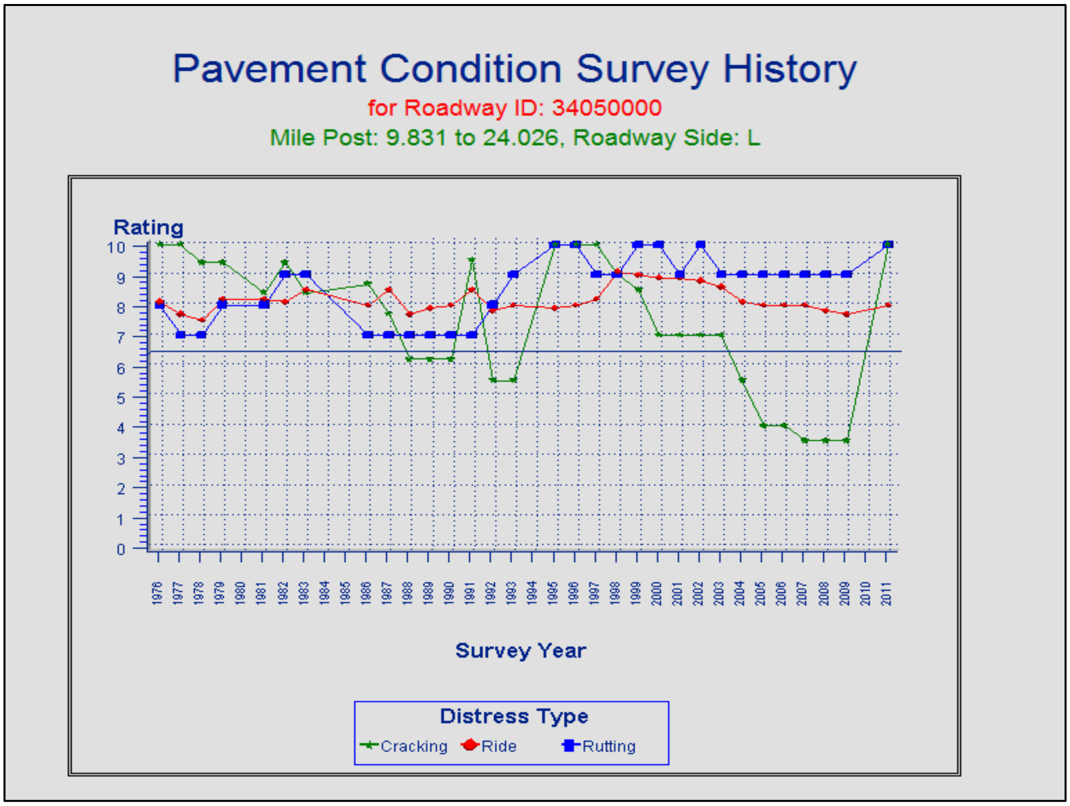
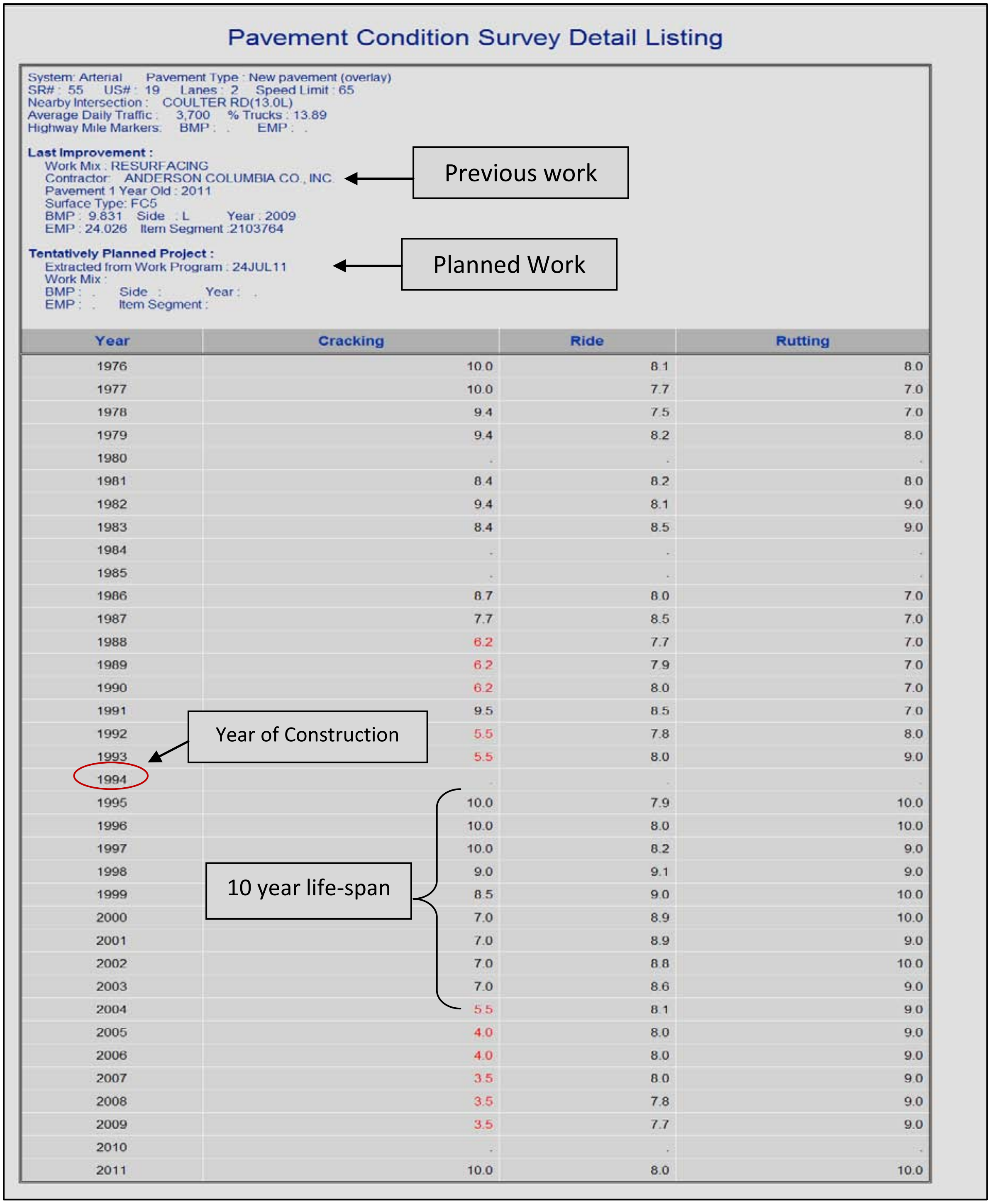


Figure A6a. Pavement Condition Survey Data – graphical representation of the pavement performance for a segment of the roadway



Pavement Condition Survey Detail Listing

System: Arterial Pavement Type : New pavement (overlay)
SR# : 55 US# : 19 Lanes : 2 Speed Limit : 65
Nearby Intersection : COULTER RD(13.0L)
Average Daily Traffic : 3,700 % Trucks : 13.89
Highway Mile Markers: BMP : . EMP : .

Last Improvement :
Work Mix : RESURFACING
Contractor: ANDERSON COLUMBIA CO., INC.
Pavement 1 Year Old : 2011
Surface Type: FC5
BMP : 9.831 Side : L Year : 2009
EMP : 24.026 Item Segment :2103764

Tentatively Planned Project :
Extracted from Work Program : 24JUL11
Work Mix :
BMP : . Side : Year : .
EMP : . Item Segment :

Year	Cracking	Ride	Rutting
1976	10.0	8.1	8.0
1977	10.0	7.7	7.0
1978	9.4	7.5	7.0
1979	9.4	8.2	8.0
1980	.	.	.
1981	8.4	8.2	8.0
1982	9.4	8.1	9.0
1983	8.4	8.5	9.0
1984	.	.	.
1985	.	.	.
1986	8.7	8.0	7.0
1987	7.7	8.5	7.0
1988	6.2	7.7	7.0
1989	6.2	7.9	7.0
1990	6.2	8.0	7.0
1991	9.5	8.5	7.0
1992	5.5	7.8	8.0
1993	5.5	8.0	9.0
1994	.	.	.
1995	10.0	7.9	10.0
1996	10.0	8.0	10.0
1997	10.0	8.2	9.0
1998	9.0	9.1	9.0
1999	8.5	9.0	10.0
2000	7.0	8.9	10.0
2001	7.0	8.9	9.0
2002	7.0	8.8	10.0
2003	7.0	8.6	9.0
2004	5.5	8.1	9.0
2005	4.0	8.0	9.0
2006	4.0	8.0	9.0
2007	3.5	8.0	9.0
2008	3.5	7.8	9.0
2009	3.5	7.7	9.0
2010	.	.	.
2011	10.0	8.0	10.0

Figure A6b. Pavement Condition Survey Data – Table of Survey Ratings for a segment of the pavement of interest