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FORENSIC INVESTIGATION OF PAVEMENT FAILURE ON VASQUEZ BOULEVARD

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16. Abstract

Vasquez Boulevard between mileposts 291 and 297 in Commerce City was originally constructed in the 1940s with asphalt that didn't contain an anti-stripping agent. It is now part of US Highway 6 and has been designated as an over-weight and over-height relief route for the I-25 corridor. The boulevard has become a main trucking route for a heavily industrialized area.

There was a major rehabilitation project in 2001 on this stretch of road with 2" milling and 2" stone matrix asphalt (SMA) paving. Parts of this pavement started rutting less than a year after construction. An investigation of the pavement failure determined that the causes were excessive and repeated loading of over-weight and over-height trucks; exposure of milled surface that didn't contain an anti-stripping agent to traffic and weather; inexperience with SMA paving materials, testing, and construction; and highly variable mix gradation and AC content quality levels.

Recommendations for future SMA projects include training personnel to understand the complexities of SMA; establishing rigorous methods of calculating ESALs; adding fibers to reduce draindown and increase film thickness; using material transfer vehicles to minimize segregation and improve smoothness; and specifying the Superpave Gyratory Compactor for design and verification testing.

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Forensic Investigation of Pavement Failure on Vasquez Boulevard

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EXECUTIVE SUMMARY

Vasquez Boulevard between mileposts 291 and 297 was originally constructed in the 1940s with asphalt containing no anti-stripping agents. It was rehabilitated several times where the major distress was rutting. There was a rehabilitation project in 2001on this stretch of road which consisted of 2" milling and 2" Stone Mastic Asphalt (SMA) paving. Parts of this pavement started rutting less than a year after construction. An investigation was performed to analyze the cause of the failure.

The investigation consisted of reviewing pavement design, condition data videos, and project test results; extracting cores and analyzing them; interviewing project personnel; examining traffic volume and loading; and studying similar occurrences nationwide. The pavement design was found to be adequate for the information available at the time of the design. However, the CDOT database ESAL counts were later found to be inconsistent with actual site conditions. This road, designated as an alternate route for over-weight and over-height vehicles for I-25, carried over-weight and over-height truck traffic that was not considered in the design calculations.

The core samples showed inconsistencies in the construction practices with regard to the mix delivered to the site varying in composition with respect to the gradation, asphalt content and voids in the mix. In spite of the inconsistencies, the SMA layer did not show any significant distresses. The cores indicated that the SMA layer was stable and old hot mix asphalt (HMA) showed severe stripping and disintegration, indicating failure of the bottom layers.

It was learned that during construction, the milled surface was exposed to prolonged and unusual weather conditions. There was approximately 7.5 inches of precipitation during the months of planing and paving and the temperature varied between 30 and 100 degrees. This coupled with the SMA layer acting as a moisture sealant accelerated the baser asphalt failure. Similar occurrences in Georgia and Virginia also showed moisture trapped in the bottom layers leading to the failure of the pavement.

Based on the investigation, the pavement failure was a result of :

- Excessive and repeated loading of over-weight and over-height trucks which was not accounted for in the design;
- Exposure of milled surface that did not contain anti-stripping agent to traffic and weather. This exposure left the layer susceptible to weather elements. Consequently moisture was entrapped prior to the SMA overlay placement;.
- Inexperience with SMA paving materials, testing, and construction; and
- Highly variable mix gradation and AC content quality levels.

The recommendations of this study are:

- Reduce milled surface exposure time;
- Use Lottman test to establish limits for existing HMA layers prior to SMA overlay
- Train agency and Contractor personnel prior to construction;
- Establish rigorous methods of calculating ESALs, specifically for over-weight and over-height vehicle traffic;
- Perform in-house mixture design acceptance testing;
- Set minimum limits for binder content in design and verify during construction;
- Add fibers to reduce draindown and increase film thickness;
- Use a material transfer vehicle to minimize segregation and improve smoothness; and
- Apply AASHTO procedures by specifying the Superpave Gyratory Compactor for design and verification testing.

BACKGROUND

Pavement and Construction History

Vasquez Boulevard is located in Commerce City, Colorado near Denver. It was constructed as part of the first highway system and designated as US Highway 6. In the past 30 years, Vasquez Boulevard has become a main trucking route for the heavily industrialized Commerce City. The roadway accommodates high volumes of truck traffic year round. In addition, this section of Vasquez Boulevard has been designated as an over-weight and over-height truck relief route for the Interstate 25 corridor.

The section of Vasquez Boulevard between mileposts 291.03 and 296.22 was originally constructed with asphalt between 1940 and 1956. At the time of construction, the standard asphalt mixture did not include lime as an anti-stripping agent. In 1987 and 1988, several sections of Vasquez Boulevard were rehabilitated with HBP leveling course, plant mixed seal coat, and overlays. During the years between rehabilitations, Colorado Department of Transportation (CDOT) maintenance personnel patched several areas of Vasquez Boulevard with full depth asphalt prior to the SMA rehabilitation project. Maintenance forces also milled the approaches and departures at some intersections to level out the severely and continually rutted pavement.

In spring of 2001, CDOT rehabilitated this stretch of Vasquez. The pavement rehabilitation consisted of milling two inches of the existing asphalt and replacing it with two inches of stone matrix asphalt (SMA). At several intersections, the asphalt was milled between four inches and eight inches and replaced with HMA S(100)(PG 64-22) on bottom lifts and HMA S(100)(PG 76-28) on the top lift. During construction, rutting on the milled pavement was a problem in some areas but was repaired as soon as it was observed.

During construction, CDOT noticed high oil content in the delivered SMA mix resulting in bleeding problems in areas of the new pavement. In some areas, the oil content of the SMA exceeded 7%. Areas where bleeding or draindown was apparent were replaced, but not all of the high oil content SMA was removed. Gradation and densities were tested in accordance with frequencies required in the contract during the project and found to be within specifications.

Rehabilitation of Failed Asphalt

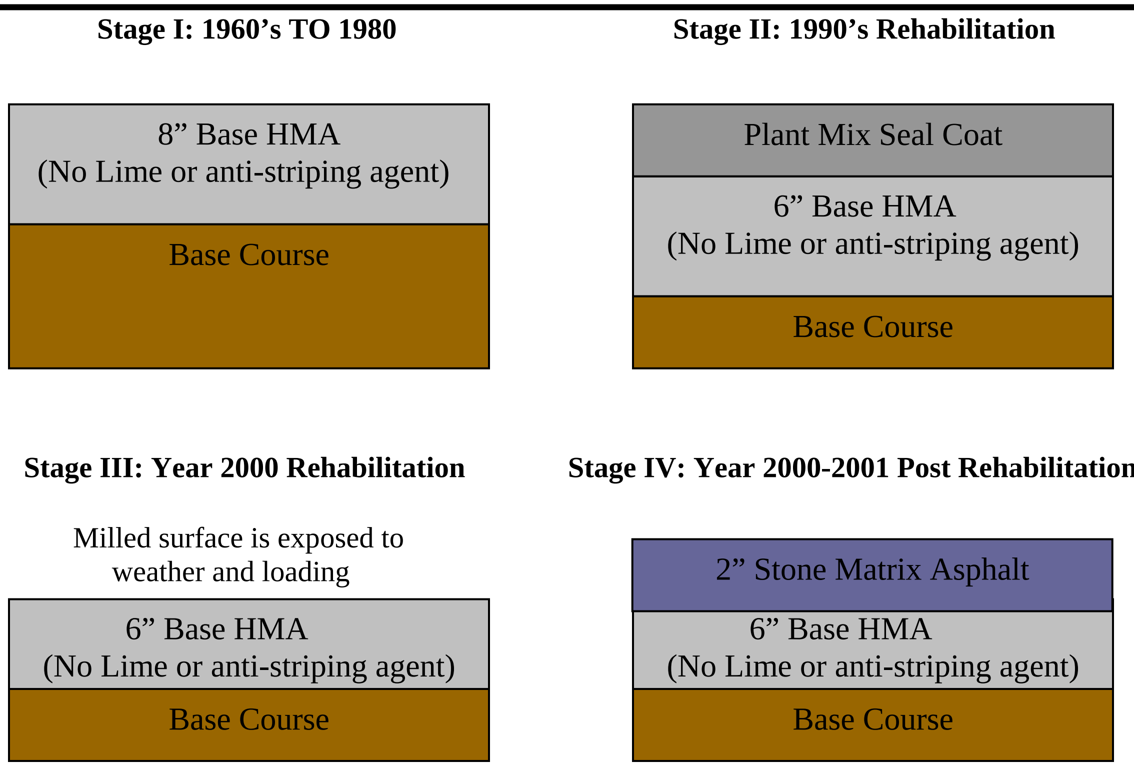
Within a year of construction completion, noticeable ruts measuring between ¼ inch and three inches indicated pavement failure in several areas of the project site. During October and November of 2002, CDOT performed remediation work replacing seventeen areas where asphalt failures were most evident. Neat line milling was performed to remove the old asphalt and up to three inches of roadbase. After the remaining roadbase was compacted with a steel drum roller, grading G-mix HMA (asphalt with 100% aggregate passing 1.5” sieve) was placed on the bottom (8 inches thick) and grading S-mix HMA (3/4” maximum nominal size aggregate) was used for the top lift (2 inches thick). As of November 2004, the areas that were repaired are still in good condition. In addition to the repairs, CDOT plans to reconstruct the roadway in the future.

Investigation

In the summer of 2002, CDOT launched an investigation to determine the cause of the premature SMA overlaid pavement failure. The investigation consisted of reviewing the 2001 project pavement design, extraction and examination of core samples from rutted sections of Vasquez Boulevard, visual observation of base course condition, reviewing prior years' pavement condition survey videos, and analyzing lab test results from the cores. The investigation also included review of similar failures in other parts of the United States.

The following sections provide the research and analysis information about the investigation.

Figure 1: Pavement History



Stage I: HMA without anti-stripping agent or lime treatment placed in 1960’s

Stage II: Plant Mix Seal Coat placed onto base HMA/ Plant Mix Seal Coat acts as water seal to moisture that seeps into lower asphalt layers.

Stage III: During rehabilitation, the base HMA is exposed to excessive loading, heat, and precipitation.

Stage IV: Two inches of SMA is placed upon the moisture damaged base HMA layers.

VASQUEZ BOULEVARD PROJECT PAVEMENT DESIGN REVIEW

The design data collected by CDOT Region 6 personnel included core samples, historical pavement records, Average Daily Traffic (ADT) measurements, and Equivalent Single Axle Load (ESAL) information. ESAL data was calculated from ADT data obtained from the Division of Transportation Development within CDOT and multiplied by a traffic equivalence factor at a given terminal serviceability index. The ESAL information provides for current traffic counts and future traffic projections. Since traffic calculations and records indicate an ADT of 17,939 for 1998, the new asphalt design should withstand 2,543,000 equivalent single axle loads (ESALs) over its ten year design life. The designer uses ESAL data and percentages of truck traffic that will likely be present during a designated time period to design the pavement. The ESAL information that was obtained did not match field conditions. This is due to the fact that Vasquez Boulevard is a relief route for Interstate 25 truck traffic, close proximity to interstate highways, and being an arterial in a major industrial area.

Initial core samples, seen in Appendix A, showed existing full depth asphalt thickness on the project site to range from five and three quarters inches to eleven and one half inches. Concrete was only present in the northbound section between mileposts 293.5 to 294.1 where samples consisted of two inches of SMA and eight inches of PCCP. The core samples showed that the existing HMA layers were porous and had slight stripping. Distress evaluation surveys found low to severe alligator cracking, depressions, potholes, corrugation at intersections, transverse and longitudinal cracking, and rutting in the northbound and southbound lanes. The pavement inspection reports for this project are in Appendix B.

A preliminary flexible pavement design performed by the CDOT Region 6 Materials Unit called for a two inch mill of the existing HMA and a two inch SMA (PG-76-28) overlay. The design also planned more extensive milling at three intersections. At the 56th Avenue intersection, eight inches of HMA would be replaced with eight inches of HMA (PG 76-28). At the 60th and 72nd Avenue intersections, four inches of existing HMA pavement would be removed with deep retro-milling and refilled with four inches of HMA (PG 76-28). The flexible pavement was designed for a ten year life and 2,453,000 equivalent single axle loads. During the pavement design phase, CDOT was working with the Colorado Asphalt Pavement Association (CAPA) to produce a design guideline for HMA intersections. Reza Akhavan, the Region 6 Materials Engineer was a member of that joint cooperation task force. The design strategy used to rehabilitate the intersections was ultimately adopted by the task group and published by CAPA.

The design strategy used by Region 6 consisted of coring the existing HMA, cutting the sample into 2 inch pucks and determining the total remaining voids. This effort enabled the pavement designer to identify the effective depth of existing low voids asphalt.

Prior to paving, the Contractor submitted a recommended mix design of three quarter inch SMA aggregate mix and a three eighths inch HMA for approval and subsequent production. The Job Mix Formulas (CDOT Form #43) issued by the Colorado Department of

Transportation defined the specified gradation, asphalt content, and admixture dosage for Vasquez Boulevard.

The three quarter inch aggregate design specified that the mix would have 3.7% voids with a +/-1.2% tolerance and an asphalt content of 6.2% with a +/- 0.3% with a PG 76-28 grade of asphalt binder. It also specified a bulk specific gravity of fine aggregate of 2.677, a bulk specific gravity of combined aggregate of 2.65, and a maximum specific gravity at % of A.C. of 2.432. The maximum specific gravity was later revised to 2.455 after verification tests were performed.

The three eighths inch aggregate design specified that the mix would have 3.8% voids with a +/-1.2% tolerance and an asphalt content of 6.7% with a +/- 0.3 with a PG 76-28 grade of the asphalt binder. It also specified a bulk specific gravity of fine aggregate of 2.659, a bulk specific gravity of combined aggregate of 2.653, and a maximum specific gravity at % of A.C. of 2.440. Both mixes contained 1% lime as an anti-stripping agent and a minimum angularity of 45.0%. The job mix formula form #43 for each design are in Appendix B.

The pavement design had to comply with both Superpave specifications and CDOT project specifications 401, 403, 503, 701 and 703, which outline the design and construction of Hot Bituminous Pavement, stone matrix asphalt, and Superpave binders.

Table 1: Pavement Design Criteria

US6/Vasquez, I 70 to I76, Pavement Design Criteria, September 15, 2000			
Roadway	Design Parameters	Flexible Overlay FWD Design	Patching
	Design life (years)	10	20
	18 k ESAL	2,243,000	8,538,000
	Initial Serviceability	4.5	4.5
	Terminal Serviceability	2.5	2.5
	% Reliability	80	95
	Overall Standard Deviation	0.44	0.44
	R-Value Design	31	10
	Soil Resilient Modulus (psi)	7,240	3,562
	Structural Coefficient	0.44	0.44
	Effective Pavement Modulus (psi)	133,149	--
	Drainage Coefficient	1	1
	Total Required Str. Number (inch)	3.65	6.12
	Overlay Str. Number (inch)	0.43	--
	Pavement Thickness (inch)	--	14”
	Overlay Thickness (inch)	2”	--
	Milling Thickness (inch)	2”	--
	HBP Grading	SMA(PG 76-28))	
	Top Lift	--	S(100)(PG76-28)
	Bottom Lifts	--	S(100)(PG64-22)
	Lift Thickness (Bottom to Top)(inch)	--	3-3-3-3-2

This information summarizes the pavement design report that is in Appendix B.

The pavement design review for the 2001Vasquez Boulevard rehabilitation project concluded that the design was sound except for the underestimation of the ESALs that were present in the field.

VASQUEZ BOULEVARD CORE SAMPLE TESTING AND ANALYSIS

Coring/Asphalt Testing

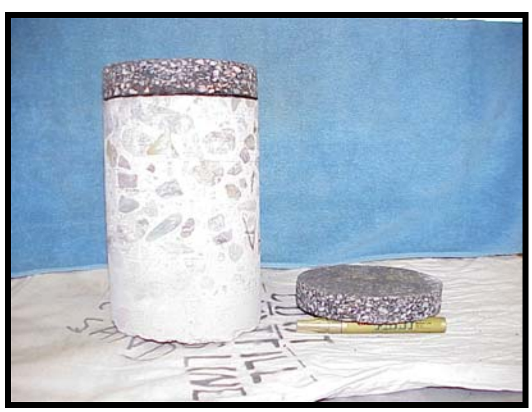
During the investigation, core samples were gathered from all lanes on northbound and southbound Vasquez Boulevard. Thirty-one core samples were collected for physical inspection of the SMA and HMA asphalt layers and to test the SMA asphalt against the SMA design submitted by the contractor.

Asphalt testing performed on the core samples included the Bulk Specific Gravity Test, Maximum Specific Gravity, Asphalt Content by Ignition Method, Sieve Analysis, Lottman Test, and the Compaction of Bituminous Material by the Superpave Compactor test. These tests were performed using Colorado procedures.

Visual Examination of Core Samples

The thirty-one core samples from US 6/Vasquez were measured and physically inspected before destructive testing was performed. In most cases, the new layer of SMA was in good condition with few fines and good stone-on-stone contact. The SMA aggregate was in good condition. Several core samples were found to have interconnected voids throughout the SMA; however, in several core samples, the HMA layers underneath the SMA showed moderate to severe asphalt stripping. Core samples showing the most severe stripping damage included samples 1C, 2CC, 2E, 2D, AND 6A. Samples 1C and 2CC had disintegrated during coring and fractured into several pieces. Core sample 6A had stripped out into an hour glass shape and very little aggregate could be seen on the surface of the HMA. Hour glass failures are indicative of moisture damage propagating into the base layer of asphalt. All cores showed some signs of degradation except for core 4A. Core 4A consisted of two inches of new SMA placed on eight inches of older PCCP. Coring site four was observed to have no rutting or shoving problems. The PCCP layer was also in good condition and showed very few signs of wear and tear.

Figure 2: Core sample 4A SMA over PCCP



When compared to pictures of core samples taken from I-75 near Atlanta, Georgia by GDOT, investigators noticed several similarities in the lower HMA layers. Both states' samples provided visual evidence that the SMA was in good condition but the HMA without anti-stripping agent suffered severe stripping damage. The core samples from Georgia showed a more advanced state of moisture damage conditions. Pictures of samples from both Vasquez Boulevard and I-75 in Georgia can be seen in Appendices A and C respectively.

During the remediation of problem areas along Vasquez Boulevard, it was observed that newer SMA asphalt was very malleable to the touch and could be picked apart from old HMA quite easily. The SMA and the top few inches of HMA asphalt were saturated with moisture during removal. Frost had formed between the HMA and SMA layers, indicating that moisture could have seeped through and become trapped within interconnected voids. A cross section of the removed pavement showed that rutting in the top layers of the asphalt had not pushed into the roadbase but had stressed the top few inches of HMA. The roadbase appeared to be in very good condition at the time of the repair. Images of this repair are in Appendix A.

Figure 3: Roadbase exposed during asphalt remediation

Sieve Analysis

A sieve analysis test was performed on the core samples from the Vasquez Boulevard project site to determine if the SMA placed in the field was comparable to the mix design submitted to the CDOT. Core sets 1, 3, 6, 7, 8, and 9 were used in the sieve tests. The following tables represent the results of sieve analysis.

Table 2: Sieve Analysis Results – Core Set 1

3/4" SMA Mix Cores:	1A,1B,1E	1C, 1D	
Size - In.	**% Passing**	**% Passing**	**Job Mix Formula**
3/4"	100	100	100
1/2"	89	99*	80-92
3/8"	73	83*	62-74
#4	34*	66*	22-32
#8	25	30*	15-25
#16	21	23	N/A
#30	18	19	10-18
#50	15	17	N/A
#100	13	13	N/A
#200	11.9*	10.7	6.7-10.7

* Out of Specification

Figure 4: Sieve Gradation Results – Core Set 1

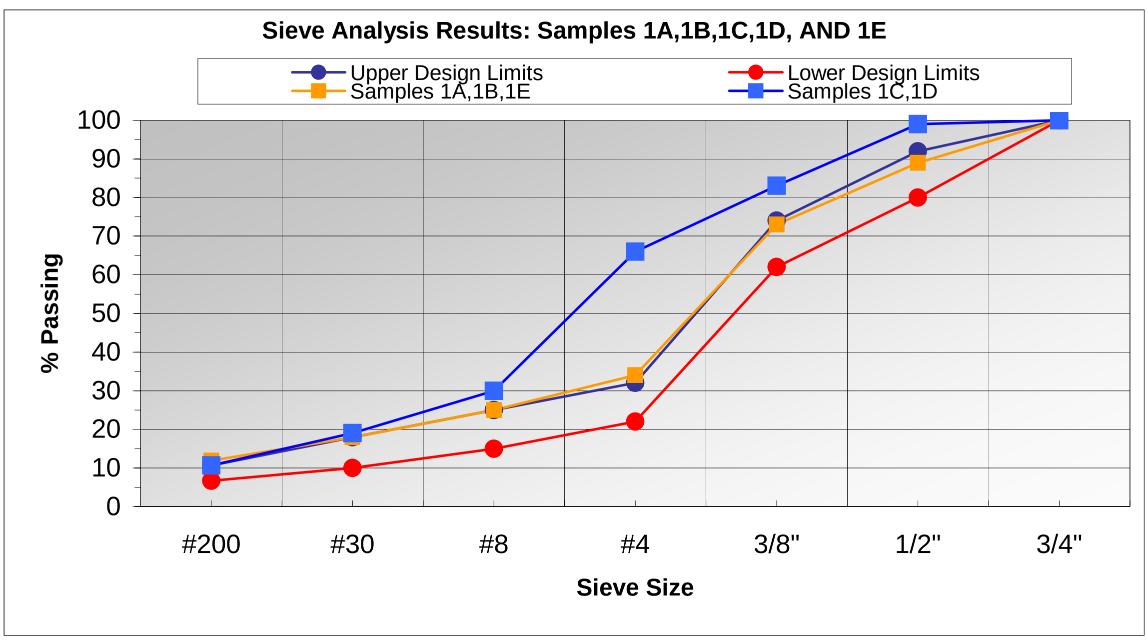


Table 3: Sieve Analysis Results – Core Set 3

3/4" SMA Mix Cores	3A	3B	
Size - In.	**% Passing**	**% Passing**	**Job Mix Formula**
3/4"	100	100	100
1/2"	89	89	80-92
3/8"	70	70	62-74
#4	30	30	22-32
#8	23	23	15-25
#16	19	19	N/A
#30	17	17	10-18
#50	15	15	N/A
#100	13	13	N/A
#200	11.6*	11.6*	6.7-10.7
* Out of Specification			

Figure 5: Sieve Gradation Results – Core Set 3

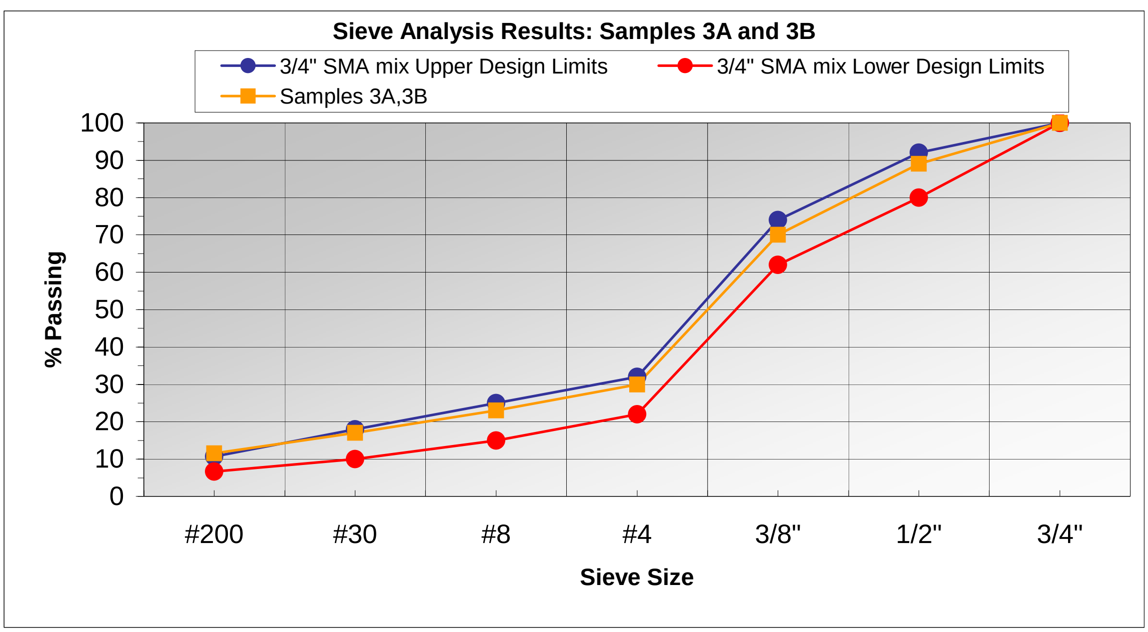


Table 4: Sieve Analysis Results – Core Set 6

3/8" SMA Mix Cores:	6A,6B	6AB	
Size - In.	**% Passing**	**% Passing**	**Job Mix Formula**
3/4"	100	100	100
1/2"	100	100	100
3/8"	100	100	90-100
#4	60*	60*	40-50
#8	34*	34*	21-31
#16	27	27	N/A
#30	23*	23*	12-20
#50	19	19	N/A
#100	15	15	N/A
#200	13.3*	13.3*	6.1-10.1
* Out of Specification			

Figure 6: Sieve Gradation Results – Core Set 6

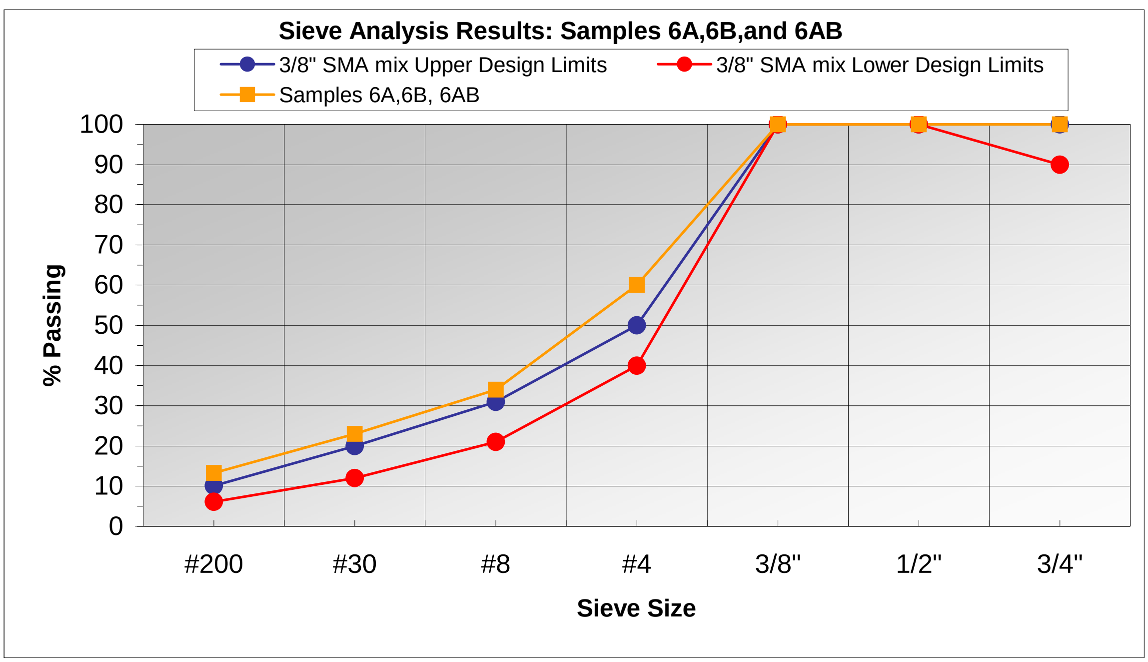


Table 5: Sieve Analysis Results – Core Set 7

3/4" SMA Mix Cores:	7A	7B	
Size - In.	**% Passing**	**% Passing**	**Job Mix Formula**
3/4"	100	100	100
1/2"	86	86	80-92
3/8"	71	71	62-74
#4	32	32	22-32
#8	25	25	15-25
#16	21	21	N/A
#30	18	18	10-18
#50	16	16	N/A
#100	13	13	N/A
#200	12.5*	12.5*	6.7-10.7

* Out of Specification

Figure 7: Sieve Gradation Results – Core Set 7

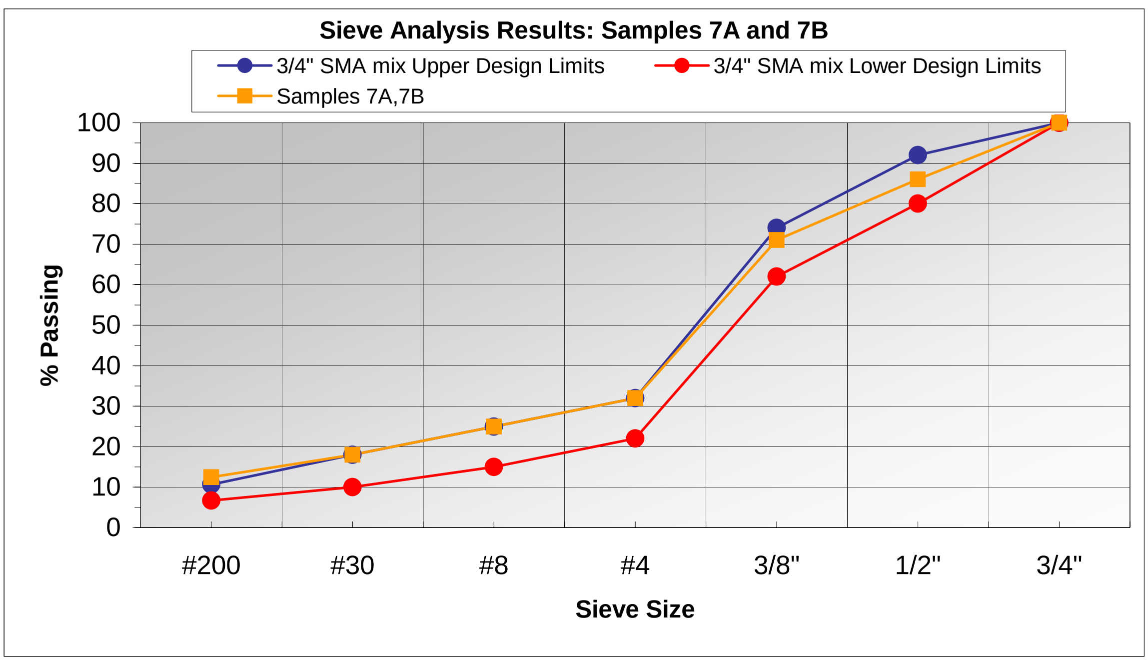


Table 6: Sieve Analysis Results – Core Set 8

3/4" SMA Mix Cores:	8A,8B	8C,8D	
Size - In.	**% Passing**	**% Passing**	**Job Mix Formula**
3/4"	100	100	100
1/2"	89	89	80-92
3/8"	73	73	62-74
#4	39*	40*	22-32
#8	30*	31*	15-25
#16	25	25	N/A
#30	21	20*	10-18
#50	17	16	N/A
#100	14	12	N/A
#200	11.5*	9.8	6.7-10.7
* Out of Specification			

Figure 8: Sieve Gradation Results – Core Set 8

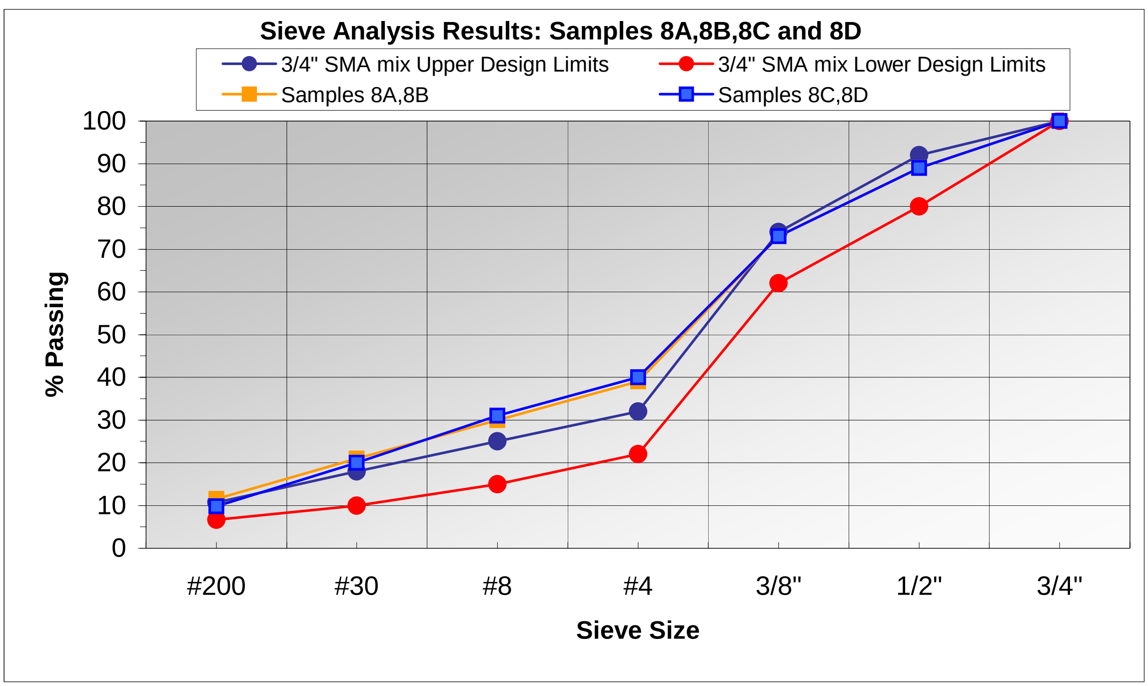
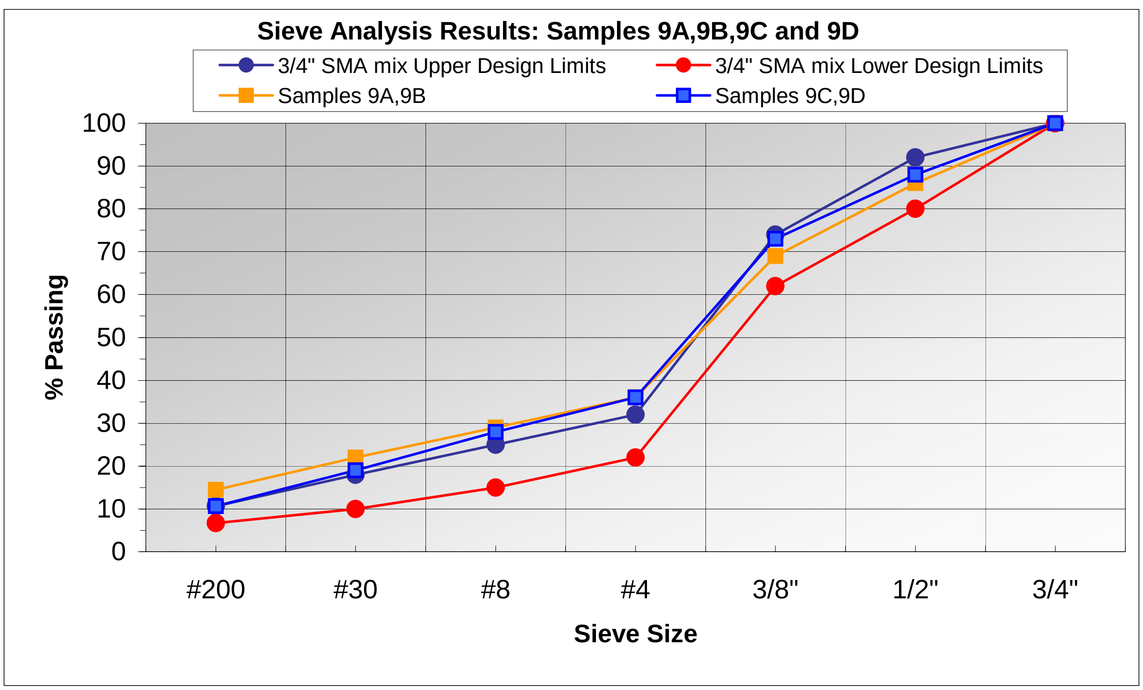


Table 7: Sieve Analysis Results – Core Set 9

3/4" SMA Mix Cores:	9A,9B	9C,9D	
Size - In.	**% Passing**	**% Passing**	**Job Mix Formula**
3/4"	100	100	100
1/2"	86	88	80-92
3/8"	69	73	62-74
#4	36*	36*	22-32
#8	29*	28*	15-25
#16	25	23	N/A
#30	22*	19*	10-18
#50	19	16	N/A
#100	17	13	N/A
#200	14.5*	10.7	6.7-10.7
* Out of Specification			

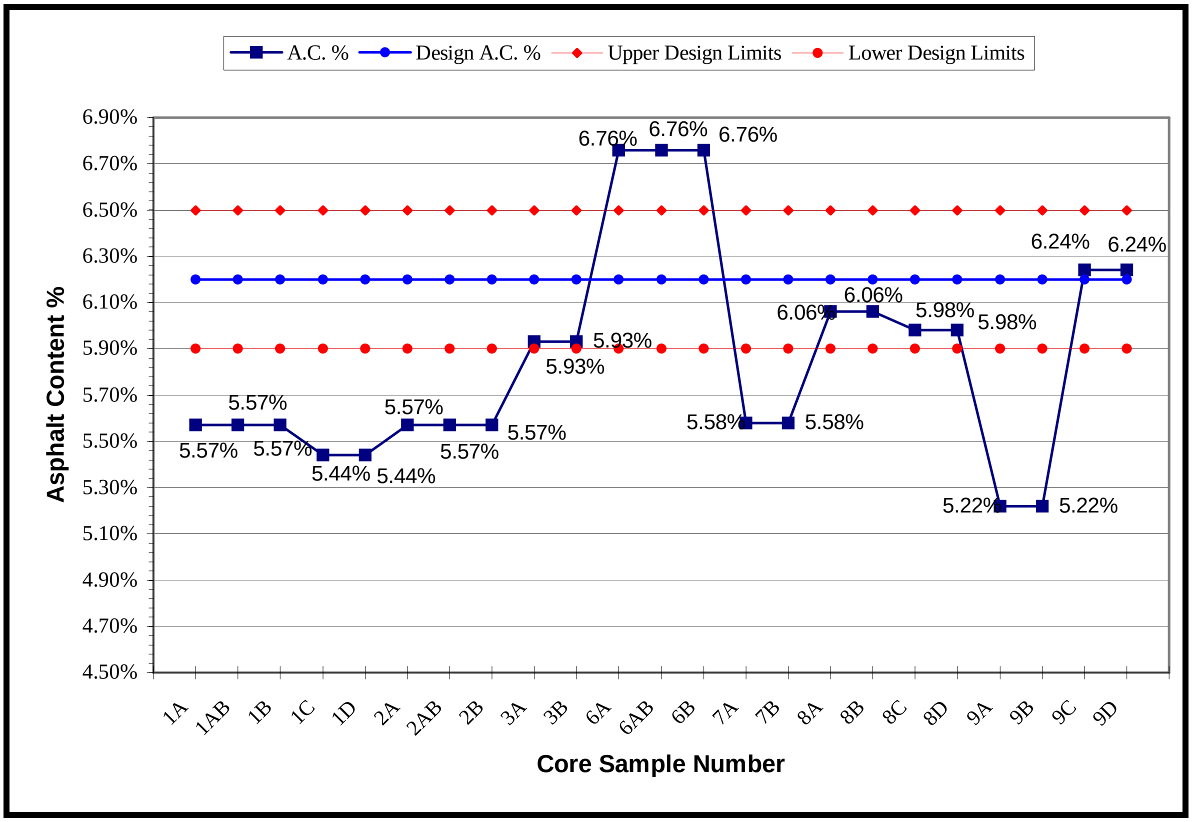
Figure 9: Sieve Gradation Results – Core Set 9



Asphalt Content of SMA Cores

Asphalt Content was measured in core samples from areas 1, 2, 3, 6, 7, 8, and 9. Results from these tests show that only 8 of the core samples tested had an asphalt content within the 6.20% +/-0.3 formula mix design specifications. 3 samples, 6A, 6AB, and 6B, exceeded the upper design limits for asphalt content. 12 samples, 1A, 1AB, 1B, 1C,AD, 2A, 2AB, 2B, 3A, 3B, 7A, 7B, 9A, and 9B did not meet the lower asphalt content tolerances.

Figure 10: Asphalt Content Testing Results



Asphalt Content Ranges from 5.22% to 6.76%

Lottman Testing

CDOT investigators performed Lottman tests on the intermediate HMA layers of the cores. Samples from core locations 1 and 6 were used during the tests. Samples from location 1 had a conditioned tensile strength of 42 PSI, a dry tensile strength of 66 PSI, and a percent tensile strength ratio of 63%. These samples had an average saturation of 97% with an average void content of 4.72%. Samples from location 6 had a conditioned tensile strength of 53 PSI, a dry tensile strength of 102 PSI, and a percent tensile strength ratio of 54 %. These samples had an average saturation of 92% and an average void content of 5.50%. These revealed that the

HMA mix would not withstand the freezing and thawing cycles that are prevalent in Colorado and would be more susceptible to stripping and rutting failures.

Voids

The new SMA asphalt layers had air void content between 3.50% and 8.30%, and the older HMA layers had air void content between 2.60% and 6.90%. Investigators could not determine a correlation between air voids and rutting areas because it was unclear whether the air voids were a product of poor densities or a result of shoving and rutting within the asphalt.

SIMILAR NATIONAL OCCURRENCES

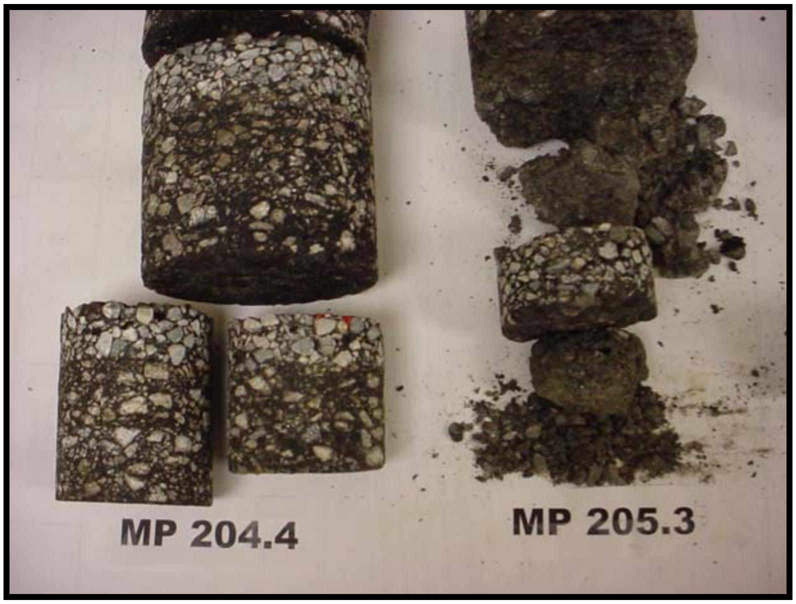
Similar asphalt failures have been reported in both Virginia and Georgia. In both states, a new SMA layer was placed on an older deteriorated HMA layer. The older HMA pavements were designed and placed before lime treatment of aggregate was identified and used as an anti-stripping agent to prevent moisture damage. Images of coring samples and pavement sections from these failures are shown in Appendix C.

In Georgia, 25 miles of I-75 south of Atlanta was rehabilitated with a two inch mill of existing asphalt and then overlaid with one and one half inches of SMA. The SMA performed well for eleven months after project completion, at which time quarter inch ruts became apparent. Less than two weeks later, ruts in some areas were nearly three inches deep. Later observations by GDOT revealed that the asphalt failure was not localized, but rather spread out over all twenty five miles of the rehabilitation as opposed to localized failure discovered in

After taking core samples of the asphalt, GDOT investigators found that the HMA had stripped out completely and in some areas could only be removed with a spoon. The old HMA layer was a pre-lime mix design and was placed in 1979. The HMA was between three inches to eight inches on top of a concrete base. Preliminary cores before the I-75 project showed that HMA layers were intact and did not indicate immediate failure. In areas where asphalt deterioration was the most severe, GDOT removed three and one half inches of the HMA layers replaced them with two inches of three quarter inch Superpave mix.

Only 2 to 3 months later, the three quarter inch Superpave asphalt began to show rutting failure, suggesting that pre-lime HMA layers left on the old concrete pavement were causing the rutting as they stripped out underneath the new pavement. It is important to note that Georgia and the east coast, on average, receives more precipitation than Colorado. This environment factor could accelerate the stripping conditions if old HMA was subjected to the same conditions. GDOT did have success with other projects wherein new full depth asphalt replaced all of the moisture-susceptible HMA on top of the old concrete pavements. GDOT is about to begin a reconstruction of the 23.8 mile segment of a failed roadway and will remove up to eight inches of the old moisture-susceptible-asphalt along with the recently placed SMA.

Figure 11: Core samples from I-75 south of Atlanta, Georgia



This picture shows the structural failure of the pre-lime Georgia HMA. The MP 205.3 core has nearly disintegrated.

On I-495 in Virginia, a similar failure in an SMA overlay occurred on I-495 where an old HMA layer had shown stripping during pre-construction design. The existing HMA layer was in place over a concrete pavement for approximately twenty five years and part of the surface mix was milled off during recent rehabilitation project. Two inches of SMA with a Novaphalt binder was placed over the existing HMA and a few test samples on the project failed to meet specifications during construction. Within six months, between two and three inches of rutting was found throughout the project limits. The Virginia Department of Transportation took core samples and performed falling head permeability tests (modified from the Florida procedure with a latex membrane) on a mixture of core samples from rutted and non-rutted areas. The cores were found to be impermeable and when broken, de-icing sand was found to have plugged up most of the voids in the mix.

A study on SMA failure on I-495 is ongoing but it is believed that adequate density was not achieved during construction and large amounts of moisture was able to penetrate into the base mix. The de-icing sand coupled with the SMA created a moisture seal that trapped water into the old mix accelerating and creating new moisture damage to the lower HMA layers.

POSSIBLE CAUSES OF FAILURE

From the findings and analyses of field observations, core sample testing, interviews, literature searches, and core inspections, CDOT investigators proposed various possible causes of failure.

The SMA used on the project site varies from the mix design formula submitted to the state. Asphalt that deviates from the specified design and requirements can result in premature failure when subjected to field conditions. Although samples of SMA from the field did show some inconsistencies and could have contributed to the failure of the SMA, the results of the investigation did not show that the failure of the SMA was influenced by them. However, these inconsistencies should be addressed in the future to prevent failure. During the investigation, the only distresses observed in the SMA were shoving and rutting in areas suspected of base HMA failure.

The SMA layer may have sealed moisture in the old HMA layers and accelerated the stripping that had occurred in the old asphalt. As old HMA layers strip out, the structural capacity of the lower HMA layers decreases and ultimately results in pavement consolidation. The SMA could have acted like a plant mix seal coat and provided no outlet for moisture trapped beneath it. CDOT no longer uses plant mix seal coat due its tendency to trap moisture and cause severe stripping damage in pavement. Weather records for Denver indicate that between April 28th, 2001 and July 31st, 2001, up to eight inches of rain and approximately seven inches of snow fell upon damaged areas. A summary of weather data can be referenced in Appendix D. Older HMA could have absorbed the large amount of precipitation that became trapped by the SMA overlay. Voids greater than 7% could have created areas of interconnecting voids and allowed moisture to seep in between the old and new asphalt layers. High VMA (voids in mineral asphalt) could have also contributed to shoving and rutting.

The loading on the pavement was much higher than the pavement was designed for. Unanticipated loading can further stress weak layers of asphalt and can contribute to accelerated failure if overweight loads are not taken into consideration during the design process. This can be attributed to higher volumes of traffic as well as suspected overweight trucks exceeding legal weight limits. New traffic counts could also impact calculations that would drastically increase the amount of ESALs that a pavement would have to withstand over its design life. A 24 hour traffic snapshot confirmed the large amounts of truck and automobile traffic that was attributed to the extreme loads subjected to the pavement.

Diesel contamination of either the SMA or old HMA layers could have also contributed to asphalt failure. Diesel was used in asphalt paving in the 50's and 60's and contaminated the HMA layers when they were placed. Diesel contamination could have also resulted from the SMA placement and then drained down into old HMA layers.

CONCLUSIONS

Several factors contributed to the failure of the asphalt on Vasquez Boulevard. The three main factors were heat, moisture, and load, coupled with inexperience working with SMA. Contributing to the failure was the foundation underneath the SMA lift. The old HMA placed forty years earlier was built without any lime treatment or anti-stripping agent. Aggregate in the old mix was rounded river rock that allows for increased stripping if moisture damage occurs.

Vasquez Boulevard has been designated as a relief route for over-weight and over-height truck traffic for the Interstate 25 corridor. This was unaccounted for during the design process. A previous distress video revealed that rutting had always been a major problem on Vasquez Boulevard, especially at the intersections.

During construction, asphalt was milled off the roadway to a depth of two inches, except for the intersections where HMA was milled and replaced to a depth of four to eight inches. Two months of milling were done before night paving operations began during which time more than nine inches of precipitation accumulated in the area. The milled pavement was exposed to excessive heat, precipitation, and traffic loading. It is our opinion that the runoff from this precipitation penetrated the old HMA lifts that were exposed and compounded the already existing moisture damage. The SMA created a moisture seal for the additional water and accelerated the existing moisture damage in the old mix.

In addition to environmental factors and unforeseen loading, construction inconsistencies with the practices and materials also contributed to the failure of the SMA. Contractor and staff inexperience with SMA, along with mix variations, low temperatures during night paving, and travel distance between the project site and the contractor's plant played a part in contributing to the failure of the pavement. Oil in the SMA was lowered during construction to prevent bleeding. The mix did not have fibers. Trucks that hauled the SMA did not have tarps over their trailers allowing the mix to cool off rapidly during transit form the plan at I-70 and Tower Road. Quality assurance was done by a consultant, providing limited oversight on the quality of the mix.

Several specifications and construction practices have been changed since the construction of this project in 2001. Region 6 now requires tarps on all trucks hauling SMA mix from the plant to the construction site. Density profiling and paver specifications have been added to check for segregation during construction. All SMA are required to contain fibers. Quality assurance is now being performed by CDOT with gyratory compactors.

The two areas that did not show signs of immediate failure were the intersections where HMA was removed and replaced and the area where SMA was placed over existing PCCP. The intersections that received increased structural foundations along with immediate paving after milling have not shown any failure since completion of the project. Areas where full depth patching was performed prior to the SMA rehabilitation to repair the failed SMA appear to be structurally stable and continue to hold up under heavy loads.

RECOMMENDATIONS

After completion of the Vasquez Boulevard investigation, CDOT investigators propose the following recommendations for projects using SMA mixes in the future:

1. Reduce time the milled surface is exposed to atmospheric conditions to reduce detrimental effects.

2. Initiate a research study to establish guidelines for testing and limits for tensile Strength Ratio (TSR) of the underlying HMA pavements.

3. Provide additional training for staff, contractors, and consultants to understand the complexities in paving with SMA mixes.

4. Establish rigorous methods of calculation to check ESAL numbers during the pavement design process. This is to provide a more accurate estimate of traffic loads for high volume roadways including roads designated as over-weight and over-height truck relief routes.

5. Evaluate the merits of volumetrics testing of produced SMA mixture for acceptance.

6. Set a minimum binder content in design and maintain that level during construction.

7. Require fiber in SMA in addition to polymer to minimize draindown.

8. Strongly encourage the utilization of material transfer vehicles to minimize segregation and increase uniformity of the placed mix.

9. Consider applying AASHTO procedures specifying the Superpave Gyratory Compactor for design and field produced mixture verification.

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APPENDIX A

Preliminary Project Core Samples Pictures

Figure 12: Coring samples 1 through 8 taken for 2001 rehabilitation

Figure 13: Coring samples 9 through 19 taken for 2001 rehabilitation

Investigation Core Samples and Coring Pictures

Figure 14: Core samples 1A, 1B, 1C, and 1D from coring site 1

Figure 15: Core samples 2A,2AB,2B,2C,2CC from coring site 2

Figure 16: Core sample 2D at shoulder from coring site 2

Figure 17: Core samples 2D and 2E from coring site 2

SMA only maintains its thickness to follow the contours of the failed HMA

Figure 18: Core samples 3A and 3b from coring site 3

Figure 19: Core sample 4A from coring site 4

No rutting was discovered in the SMA lifts over existing PCCP pavement

Figure 20: Core samples 5A and 5B from coring site 5

Figure 21: Core samples 6A and 6B from coring site 6

The hourglass failure is indicative of moisture damage in asphalt

Figure 22: Coring location 6 showing one to two inch ruts in the number 2 lane

Figure 23: Core samples 7A and 7B from coring site 7

Figure 24: Core samples 8A, 8B, 8C, and 8D, from coring site 8

Figure 25: Core samples 9A, 9B, 9C, and 9D, from coring site 9

Figure 26: Coring location 2 illustrating the shoving failure of the asphalt

Figure 27: Coring location 4 illustrating quarter inch ruts in the number 2 lane

Figure 28: Coring location 5 for investigation

One to two inch ruts in the number 2 lane where truck traffic was concentrated

Asphalt Patching/Repair Pictures

Figure 29: Failed SMA

Rutting and shoving evident during the remediation construction

Figure 30: Roadbase exposed during remediation

Figure 31: Asphalt removals during rehabilitation construction

APPENDIX B

2000 ESAL CALCULATION DATA

Future Traffic Volumes and ESALs for Highway

006H From R.P. 291 to R.P. 296

Route	Ref Point	End Ref Point	Length (Miles)	Annual Average Daily Traffic	Aadt Year	AADT Single Trucks	AADT Comb. Trucks	AADT 2011	AADT Single Trucks 2011	AADT Comb. Trucks 2011	18 KiP ESALs
006H	291.075	291.373	0.298	21,238	1998	1,091	713	22,618	1,162	759	1,886,000
006H	291.373	292.054	0.681	23,919	1998	1,172	764	25,474	1,248	814	2,028,000
006H	292.054	292.145	0.090	23,919	1998	1,172	764	25,474	1,248	814	2,028,000
006H	292.145	292.479	0.331	47,787	1998	2,312	1,595	50,893	2,462	1,699	4,169,000
006H	292.479	292.723	0.243	45,897	1998	2,331	1,514	48,880	2,483	1,612	4,018,000
006H	292.723	293.122	0.395	42,326	1998	2,886	1,061	45,077	3,074	1,130	3,393,000
006H	293.122	293.392	0.270	35,775	1998	2,400	1,073	40,426	2,712	1,212	3,300,000
006H	293.392	293.670	0.278	35,775	1998	2,400	1,073	40,426	2,712	1,212	3,300,000
006H	293.670	293.735	0.063	21,135	1998	1,365	953	29,378	1,897	1,325	2,915,000
006H	293.735	294.235	0.513	21,135	1998	1,365	953	29,378	1,897	1,325	2,915,000
006H	294.235	294.651	0.416	24,156	1998	1,386	724	35,147	2,017	1,053	2,518,000
006H	294.651	294.910	0.259	24,950	1998	1,372	718	41,168	2,264	1,185	2,738,000
006H	294.910	295.299	0.389	22,372	1998	1,313	545	32,551	1,910	793	2,061,000
006H	295.299	295.662	0.363	17,939	1998	1,153	586	33,097	2,127	1,081	2,428,000
006H	295.662	295.999	0.510	17,939	1998	1,153	586	33,097	2,127	1,081	2,428,000
		Average:		**27,675**				**35,070**			**2,743,206**
		Total:	**5.099**								

ESAL calculations based on the following:
Build Year: 2001
Design Life: 10
Number of Lanes: 4
Flexible Pavement

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Data Dictionary

Future Traffic Volumes and ESALs for Highway

006H From R.P. 291 to R.P. 296

Route	Ref Point	End Ref Point	Length (Miles)	Annual Average Daily Traffic	Aadt Year	AADT Single Trucks	AADT Comb. Trucks	AADT 2021	AADT Single Trucks 2021	AADT Comb. Trucks 2021	18 KIP ESALs
006H	291.075	291.373	0.298	21,238	1998	1,091	713	23,680	1,216	795	3,863,000
006H	291.373	292.054	0.681	23,919	1998	1,172	764	26,670	1,307	852	4,156,000
006H	292.054	292.145	0.090	23,919	1998	1,172	764	26,670	1,307	852	4,156,000
006H	292.145	292.479	0.331	47,787	1998	2,312	1,595	53,283	2,578	1,778	8,538,000
006H	292.479	292.723	0.243	45,897	1998	2,331	1,514	51,175	2,599	1,688	8,229,000
006H	292.723	293.122	0.395	42,326	1998	2,886	1,061	47,193	3,218	1,183	6,948,000
006H	293.122	293.392	0.270	35,775	1998	2,400	1,073	44,003	2,952	1,320	6,905,000
006H	293.392	293.670	0.278	35,775	1998	2,400	1,073	44,003	2,952	1,320	6,905,000
006H	293.670	293.735	0.063	21,135	1998	1,365	953	35,718	2,307	1,611	6,537,000
006H	293.735	294.235	0.513	21,135	1998	1,365	953	35,718	2,307	1,611	6,537,000
006H	294.235	294.651	0.416	24,156	1998	1,386	724	43,602	2,502	1,307	5,726,000
006H	294.651	294.910	0.259	24,950	1998	1,372	718	53,643	2,950	1,544	6,452,000
006H	294.910	295.299	0.389	22,372	1998	1,313	545	40,381	2,370	984	4,684,000
006H	295.299	295.662	0.363	17,939	1998	1,153	586	44,758	2,877	1,462	5,893,000
006H	295.662	295.999	0.510	17,939	1998	1,153	586	44,758	2,877	1,462	5,893,000
		Average:		**27,675**				**40,760**			**5,980,513**
		Total:	**5.099**								

ESAL calculations based on the following:
Build Year: 2001
Design Life: 20
Number of Lanes: 4
Flexible Pavement

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Data Dictionary

Future Traffic Volumes and ESALs for Highway

006H From R.P. 291 to R.P. 296

Route	Ref Point	End Ref Point	Length (Miles)	Annual Average Daily Traffic	Aadt Year	AADT Single Trucks	AADT Comb. Trucks	AADT 2021	AADT Single Trucks 2021	AADT Comb. Trucks 2021	18 KIP ESALs
006H	291.075	291.373	0.298	21,238	1998	1,091	713	23,680	1,216	795	5,509,000
006H	291.373	292.054	0.681	23,919	1998	1,172	764	26,670	1,307	852	5,920,000
006H	292.054	292.145	0.090	23,919	1998	1,172	764	26,670	1,307	852	5,920,000
006H	292.145	292.479	0.331	47,787	1998	2,312	1,595	53,283	2,578	1,778	12,204,000
006H	292.479	292.723	0.243	45,897	1998	2,331	1,514	51,175	2,599	1,688	11,724,000
006H	292.723	293.122	0.395	42,326	1998	2,886	1,061	47,193	3,218	1,183	9,556,000
006H	293.122	293.392	0.270	35,775	1998	2,400	1,073	44,003	2,952	1,320	9,635,000
006H	293.392	293.670	0.278	35,775	1998	2,400	1,073	44,003	2,952	1,320	9,635,000
006H	293.670	293.735	0.063	21,135	1998	1,365	953	35,718	2,307	1,611	9,392,000
006H	293.735	294.235	0.513	21,135	1998	1,365	953	35,718	2,307	1,611	9,392,000
006H	294.235	294.651	0.416	24,156	1998	1,386	724	43,602	2,502	1,307	8,055,000
006H	294.651	294.910	0.259	24,950	1998	1,372	718	53,643	2,950	1,544	9,070,000
006H	294.910	295.299	0.389	22,372	1998	1,313	545	40,381	2,370	984	6,485,000
006H	295.299	295.662	0.363	17,939	1998	1,153	586	44,758	2,877	1,462	8,295,000
006H	295.662	295.999	0.510	17,939	1998	1,153	586	44,758	2,877	1,462	8,295,000
		Average:		**27,675**				**40,760**			**8,437,549**
		Total:	**5.099**								

ESAL calculations based on the following:
Build Year: 2001
Design Life: 20
Number of Lanes: 4
Rigid Pavement

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Data Dictionary

Future Traffic Volumes and ESALs for Highway 006H From R.P. 291 to R.P. 296

Route	Ref Point	End Ref Point	Length (Miles)	Annual Average Daily Traffic	Aadt Year	AADT Single Trucks	AADT Comb. Trucks	AADT 2031	AADT Single Trucks 2031	AADT Comb. Trucks 2031	18 KIP ESALs
006H	291.075	291.373	0.298	21,238	1998	1,091	713	24,742	1,271	831	8,461,000
006H	291.373	292.054	0.681	23,919	1998	1,172	764	27,866	1,365	890	9,086,000
006H	292.054	292.145	0.090	23,919	1998	1,172	764	27,866	1,365	890	9,086,000
006H	292.145	292.479	0.331	47,787	1998	2,312	1,595	55,672	2,693	1,858	18,734,000
006H	292.479	292.723	0.243	45,897	1998	2,331	1,514	53,470	2,716	1,764	18,000,000
006H	292.723	293.122	0.395	42,326	1998	2,886	1,061	49,310	3,362	1,236	14,674,000
006H	293.122	293.392	0.270	35,775	1998	2,400	1,073	47,581	3,192	1,427	15,098,000
006H	293.392	293.670	0.278	35,775	1998	2,400	1,073	47,581	3,192	1,427	15,098,000
006H	293.670	293.735	0.063	21,135	1998	1,365	953	42,059	2,716	1,896	15,610,000
006H	293.735	294.235	0.513	21,135	1998	1,365	953	42,059	2,716	1,896	15,610,000
006H	294.235	294.651	0.416	24,156	1998	1,386	724	52,056	2,987	1,560	13,541,000
006H	294.651	294.910	0.259	24,950	1998	1,372	718	66,118	3,636	1,903	15,674,000
006H	294.910	295.299	0.389	22,372	1998	1,313	545	48,212	2,830	1,174	10,905,000
006H	295.299	295.662	0.363	17,939	1998	1,153	586	56,418	3,626	1,843	14,630,000
006H	295.662	295.999	0.510	17,939	1998	1,153	586	56,418	3,626	1,843	14,630,000
		Average:		**27,675**				**46,449**			**13,702,606**
		Total:	**5.099**								

ESAL calculations based on the following:
Build Year: 2001
Design Life: 30
Number of Lanes: 4
Rigid Pavement

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Data Dictionary

DESIGN ESALS FOR REGION 6 DESIGN PROJECTS

HIGHWAY	STREET NAME	BEGIN MILEPOINT	END MILEPOINT	10 YR ESAL ASPHALT	10 YR ESAL CONCRETE	20 YR ESAL ASPHALT	20 YR ESAL CONCRETE	30 YR ESAL ASPHALT	30 YR ESAL CONCRETE
006G	6TH AVE	280.91	283.86	2,726,000	3,526,000	5,585,000	7,222,000	8,575,000	11,089,000
006H	VASQUEZ BD	291.04	295.95	2,453,000	3,452,000	5,596,000	7,875,000	9,428,000	13,268,000
007D	160TH AVE	70	77.12	391,000	497,000	835,000	1,060,000	1,332,000	1,692,000
025A	I 25	216.78	218.6	8,968,000	13,094,000	19,154,000	27,965,000	30,557,000	44,614,000
025A	I 25	223.5	229.1	8,188,000	12,112,000	18,407,000	27,227,000	30,656,000	45,345,000
030A	HAMPDEN AVE	0	1.86	529,000	608,000	1,084,000	1,245,000	1,665,000	1,911,000
085C *	US 85	227	236	12,280,000	19,959,000	31,349,000	50,956,000	57,196,000	92,970,000
088A	FEDERAL BD	1.98	3.94	1,015,000	1,246,000	2,078,000	2,552,000	3,191,000	3,919,000
088A	BELLEVIEW AVE	13	14.7	824,000	1,006,000	1,688,000	2,061,000	2,592,000	3,164,000
095A	SHERIDAN BD	0	1.79	1,046,000	1,279,000	2,142,000	2,619,000	3,289,000	4,022,000
095A	SHERIDAN BD	6.9	9.89	976,000	1,189,000	1,998,000	2,435,000	3,068,000	3,739,000
095A	SHERIDAN BD	11.69	14.09	987,000	1,222,000	2,021,000	2,503,000	3,103,000	3,843,000
121A	WADSWORTH BD	21.9	23.85	1,728,000	2,403,000	3,691,000	5,132,000	5,888,000	8,188,000
121A	WADSWORTH BD	23.85	26.3	1,433,000	2,060,000	3,061,000	4,400,000	4,883,000	7,019,000
128A	120TH AVE	5.45	7.88	632,000	855,000	1,295,000	1,751,000	1,989,000	2,689,000
128B	120TH AVE	12	14	1,119,000	1,538,000	2,435,000	3,345,000	3,948,000	5,422,000
177A	UNIVERSITY BD	3.94	5.99	714,000	911,000	1,494,000	1,906,000	2,341,000	2,987,000
177A	UNIVERSITY BD	2	3.23	771,000	976,000	1,614,000	2,044,000	2,529,000	3,203,000
225A **4LN**	I 225	3	8	12,880,000	18,873,000	20,019,000	41,058,000	45,417,000	66,553,000
225A **6 LN**	I 225	3	8	8,586,000	12,582,000	18,679,000	27,372,000	30,278,000	44,369,000
285D	HAMPDEN AVE	263.18	263.87	1,118,000	1,410,000	2,340,000	2,951,000	3,667,000	4,625,000
287C	FEDERAL BD	282.68	285.75	839,000	1,006,000	1,792,000	2,148,000	2,860,000	3,426,000
391A	KIPLING ST	0.98	2.08	748,000	955,000	1,532,000	1,956,000	2,353,000	3,003,000

* **The values shown for this project are the same as those used for a prior project at the intersection of 104th Ave. & US 85. A special analysis was done to account for a significant number of loaded gravel trucks most of which headed southbound from several pits. You may not wish to use these values north of these pits. Unfortunately I don't know now the extent of these gravel operations. I am certainly willing to discuss this issue with you if necessary. In the meantime I also calculated a set of ESAL values that do not reflect the gravel operations. They are listed below in the same order as the table above.**

10 YR ESAL ASPHALT	10 YR ESAL CONCRETE	20 YR ESAL ASPHALT	20 YR ESAL CONCRETE	30 YR ESAL ASPHALT	30 YR ESAL CONCRETE
3,702,000	5,514,000	8,054,000	11,996,000	13,055,000	19,444,000

2000 PAVEMENT CONDITION EVALUATION

PROJECT NO.	STA 0062-014, 13349	LOCATION	US 6 / Vasquez, I-70 To I76
DIRECTION	Northbound	MP	291.08 (46th) to 291.30 (48th)
DATE	8/14/00	BY	DM
		TITLE	EPS TECH I

TRAFFIC

Existing	ESAL/YR
Design	ESAL

EXISTING PAVEMENT DATA

Subgrade (AASHTO)	Sand & Gravel
Base (type/thickness)	Roadbase/0-4"
Soil Strength (R/M_R)	N/A
Roadway Drainage Condition (good, fair, poor)	Fair
Shoulder Condition (good, fair, poor)	Fair

DISTRESS EVALUATION SURVEY

Type	***Severity***	***Approx. %***
Alligator Cracking	Low	10%
Bleeding	Low	10%
Block Cracking	Low	10%
Corrugation	Low	10%
Depression	Low	10%
Joint Reflection Cracking (from PCC Slab)	N/A	
Lane/Shoulder Joint Separation	Low	5%
Longitudinal Cracking	Low	10-20%
Transverse Cracking	Low	10-20%
Patch Deterioration	Low	10%
Polished Aggregate	Low	10%
Potholes	Low	10%
Raveling/Weathering	Low	10%
Rutting	Low, Severe @ 48th Inter. (1/2"-3/4")	
Slippage Cracking	N/A	
OTHER	Median curb is partially covered by previous overlays	

Figure 5-16 Pavement Condition Evaluation Checklist (Flexible)

PROJECT NO.	STA 0062-014, 13349	LOCATION	US 6 / Vasquez, I-70 To I76
DIRECTION	Northbound	MP	291.30(48th) To 291.95(52nd)
DATE	8/14/00	BY	DM
		TITLE	EPS TECH I

TRAFFIC

Existing	ESAL/YR
Design	ESAL

EXISTING PAVEMENT DATA

Subgrade (AASHTO)	Sand & Gravel
Base (type/thickness)	Roadbase/0-4"
Soil Strength (R/M_R)	N/A
Roadway Drainage Condition (good, fair, poor)	Fair
Shoulder Condition (good, fair, poor)	Fair

DISTRESS EVALUATION SURVEY

Type	*Severity*	*Approx. %*
Alligator Cracking	Severe	75%
Bleeding	Moderate	50%
Block Cracking	Severe	75%
Corrugation	Severe @ Intersections	50%
Depression	Moderate	20-30%
Joint Reflection Cracking (from PCC Slab)	N/A	
Lane/Shoulder Joint Separation	Low	10%
Longitudinal Cracking	Severe	75%
Transverse Cracking	Moderate	50%
Patch Deterioration	Moderate	50%
Polished Aggregate	Moderate	50%
Potholes	Moderate	50%
Raveling/Weathering	Low	10-20%
Rutting	Moderate, Severe @ 52nd Inter. (1/2-3/4")	
Slippage Cracking	N/A	
OTHER	Median curb is partially covered by previous overlays	

Figure 5-16 Pavement Condition Evaluation Checklist (Flexible)

PROJECT NO.	STA 0062-014, 13349	LOCATION	US 6 / Vasquez, I-70 To I76
DIRECTION	Northbound	MP	291.95(52nd) To 294.25(69th)
DATE	8/14/00	BY	DM
		TITLE	EPS TECH I

TRAFFIC

Existing	ESAL/YR
Design	ESAL

EXISTING PAVEMENT DATA

Subgrade (AASHTO)	Sand & Gravel
Base (type/thickness)	Roadbase/ 0-4"
Soil Strength (R/M_R)	N/A
Roadway Drainage Condition (good, fair, poor)	Fair
Shoulder Condition (good, fair, poor)	Fair

DISTRESS EVALUATION SURVEY

Type	***Severity***	***Approx. %***
Alligator Cracking	Moderate	30-50%
Bleeding	Low	15%
Block Cracking	Low	15%
Corrugation	Low, Severe @ 56th,60th,69th Intersection	
Depression	Low	10%
Joint Reflection Cracking (from PCC Slab)	Low @ MP 293.5 - 294.2	10%
Lane/Shoulder Joint Separation	Low	5-10%
Longitudinal Cracking	Moderate	30-50%
Transverse Cracking	Moderate	30-50%
Patch Deterioration	Low	10-20%
Polished Aggregate	Low	10-20%
Potholes	Moderate	30-50%
Raveling/Weathering	Low	10-20%
Rutting	Moderate, Severe @ 56th,60th,69th Intersection (2-3.5")	
Slippage Cracking	Low	

OTHER ***Note:*** There is a new overlay at the I 270 Bridge that extends approx. 0.25 miles. The median curb in the vicinity of MP 294.08 is deteriorated. There is a new 1" overlay, southbound only, at MP 293.7-293.15(approx.).

PROJECT NO.	STA 0062-014, 13349	LOCATION	US 6 / Vasquez, I-70 To I76
DIRECTION	Northbound	MP	294.25(69th) To 295.95(I76)
DATE	8/14/00	BY	DM
		TITLE	EPS TECH I

TRAFFIC

Existing	ESAL/YR
Design	ESAL

EXISTING PAVEMENT DATA

Subgrade (AASHTO)	Sand & Gravel
Base (type/thickness)	Roadbase/0-4"
Soil Strength (R/M_R)	N/A
Roadway Drainage Condition (good, fair, poor)	Fair
Shoulder Condition (good, fair, poor)	Fair

DISTRESS EVALUATION SURVEY

Type	***Severity***	***Approx. %***
Alligator Cracking	Moderate	30-50%
Bleeding	Low	10%
Block Cracking	Moderate	30-50%
Corrugation	Moderate	30-50%
Depression	Moderate	30-50%
Joint Reflection Cracking (from PCC Slab)	N/A	
Lane/Shoulder Joint Separation	Low	5-10%
Longitudinal Cracking	Moderate	30-50%
Transverse Cracking	Moderate	30-50%
Patch Deterioration	Low	15%
Polished Aggregate	Moderate	30-50%
Potholes	Moderate	30-50%
Raveling/Weathering	Moderate	30-50%
Rutting	Moderate, Severe @ 72nd,74th,77th, Intersection.(1/2-1")	
Slippage Cracking	Low	5-10%
OTHER		

Figure 5-16 Pavement Condition Evaluation Checklist (Flexible)

2000 DARwin PAVEMENT ANALYSIS

1993 AASHTO Pavement Design

DARWin Pavement Design and Analysis System

A Proprietary AASHTOWare
Computer Software Product
CDOT
2000 South Holly Street
Denver, CO
USA

Flexible Structural Design Module

STA 0062-014
US 6/Vasquez, I 70 to I 76
13349
Mainline US 6
Design Life (years): 20
Number of Lanes: 4
Date: 7/5/00

Flexible Structural Design

18-kip ESALs Over Initial Performance Period	8,538,000
Initial Serviceability	4.5
Terminal Serviceability	2.5
Reliability Level	95 %
Overall Standard Deviation	0.44
Roadbed Soil Resilient Modulus	3,562 psi
Stage Construction	1
Calculated Design Structural Number	6.12 in

Effective Roadbed Soil Resilient Modulus

Period	Description	Roadbed Resilient Modulus (psi)
1	Any Time	3,562

Calculated Effective Modulus 3,562 psi

Specified Layer Design

Layer	Material Description	Struct Coef. (Ai)	Drain Coef. (Mi)	Thickness (Di)(in)	Width (ft)	Calculated SN (in)
1	HBP Grading S	0.44	1	13.91	0	6.12
Total	-	-	-	13.91	-	6.12

USE 14 INCHES HBP
LIFTS 3-3-3-2-2

REGION 6 MATERIALS PRELIMINARY PROJECT RECOMMENDATIONS SUMMARY
FLEXIBLE OVERLAY ENGLISH DESIGN

Project: STA 0062-014

Location: US 6/Vasquez, I 70 to I 76

Subaccount: 13349

Date: September 15, 2000

Distribution List: Program Development Section/Schwab-Marusin
Staff Materials/Zamora
Maintenance/Jensen
File/13349

General Project Description: Overlay of US 6/ Vasquez from I 70 to I 76.

Pavement Design Criteria			
Roadway	Design Parameters	Flexible Overlay FWD Design	Patching/Widening
Mainline US 6/Vasquez	Design life (years) 18 k ESAL Initial Serviceability Terminal Serviceability % Reliability Overall Standard Deviation R-Value Design Soil Resilient Modulus (psi) Structural Coefficient Effective Pavement Modulus (psi) Drainage Coefficient Total Required Str. Number (inch) Overlay Str. Number (inch)	10 2,453,000 4.5 2.5 80 0.44 31 7,240 0.44 133,149 1 3.65 0.43	20 8,538,000 4.5 2.5 95 0.44 10 3562 0.44 -- 1 6.12 --
	Pavement Thickness (inch) Overlay Thickness (inch) Milling Thickness (inch) HBP Grading Lift Thickness (Bottom to Top)(inch)	-- 2" 2" ~~S(100)~~(PG 76-28) SMA	14" -- -- S(100)(PG 64-22) bot S(100)(PG 76-28) top 3-3-3-3-2

Approaches to intersection thickness:

Intersection	Mill and Replace
56th Ave.	8"
60th Ave. (Extend northbound approach at STA 137+10 thru curvature of roadway intersection)	4"
72nd Ave.	4"

Summary - page 1

1993 AASHTO Pavement Design

DARWin Pavement Design and Analysis System

A Proprietary AASHTOWare
Computer Software Product
CDOT
2000 South Holly Street
Denver, CO
USA

Overlay Design Module

STA 0062-014
US 6/Vasquez, I 70 to I 76
13349
Mainline US 6/Vasquez
Design Life (years): 10
Number of Lanes: 4
Date: 9/14/00

AC Overlay of AC Pavement

Structural Number for Future Traffic 3.65 in

Design Method	Effective Existing Structural Number (in)	Overlay Structural Number (in)
Component Analysis	2.88	0.77
Remaining Life	-	-
Non-Destructive Testing	3.22	0.43

Structural Number for Future Traffic

Future 18-kip ESALs Over Design Period	2,453,000
Initial Serviceability	4.5
Terminal Serviceability	2.5
Reliability Level	80 %
Overall Standard Deviation	0.44
Subgrade Resilient Modulus	7,240 psi R-31

Calculated Structural Number for Future Traffic 3.65 in

Effective Pavement Thickness - Component Analysis Method

Layer	Material Description	Structural Coefficient	Drainage Coefficient	Thickness (in)
1	Existing HBP	0.32	1	8
2	Existing Base	0.12	1	8

Milling Thickness 2 in

Calculated Results

Calculated Pavement Structural Number Before Milling 3.52 in
Calculated Effective Pavement Structural Number 2.88 in

Page 1

Effective Structural Number - Non-Destructive Testing

Total Pavement Thickness	16 in
Backcalculated Effective Pavement Modulus	133,149 psi
Milling Thickness	2 in
Effective Existing Pavement SN (SNEff)	3.22 in

Backcalculation - Imported Uniform

Total Pavement Thickness	16 in
Resilient Modulus Correction Factor, C	0.33
Existing AC Thickness	8 in
Base Type	Granular
Data Evaluation Basis	Mean

Calculated Results

Subgrade Resilient Modulus (MR)	7,240 psi
Effective Pavement Modulus (Ep)	133,149 psi
Dynamic k-value	- psi/in

Backcalculation - Imported Point by Point

Total Pavement Thickness	11 in
Resilient Modulus Correction Factor, C	0.33
Existing AC Thickness	11 in
Base Type	Granular
Data Evaluation Basis	Mean

Calculated Results*

Subgrade Resilient Modulus (MR)	- psi
Effective Pavement Modulus (Ep)	- psi
Dynamic k-value	- psi/in

*Note: These values are not represented by the inputs or an error occurred in calculation.

Specified Layer Design

Layer	Material Description	Struct Coef. (Ai)	Drain Coef. (Mi)	Thickness (Di)(in)	Width (ft)	Calculated SN (in)
1	New HBP	0.44	1	2	-	0.88
Total	-	-	-	2.00	-	0.88

Page 2

Colorado Department of Transportation
PRELIMINARY SOIL SURVEY
Date: 8/8/00

Note: If samples are submitted leave sieve analysis section blank

Form # 554 Report No. 974 Page 3 of 3
Project No. STA 0062-014 SA# 13349

NB Lane 2, MP 294.82								Air Voids
0 - 6.0"	16	HBP Core	Slight stripping and pourous at 2.5-6.0"					
6.0" - 10.0"		Aggregate Base Course						
10.0" -		Sand and Gravel						
NB Lane 2, MP 295.05		(72nd Ave. Intersection)						
0 - 9.0"	17A	HBP Core		17AA	2.4	2.411	2.439	1.15%
9.0 - 12.0"		Aggregate Base Course		17AB	2.2	2.382	2.419	1.53%
12.0" -		Sand & Gravel		17AC	3	2.403	2.469	2.67%
NB Lane 2, MP 295.05								
0 - 9.0"	17B	HBP Core		17BA	2.6	2.411	2.439	1.15%
9.0 - 12.0"		Aggregate Base Course		17BB	2.4	2.394	2.419	1.03%
12.0" -		Sand & Gravel		17BC	2.4	2.399	2.469	2.84%
SB Lane 2, MP 295.14								
0 - 7.50"	18	HBP Core	6.0"-7.5" is very sandy and poorly cemented mix. It appears to be a very low grade of HBP.					
7.50" -		Sand & Gravel						
NB Lane 2, MP 295.50								
0 - 6.50"	19	HBP Core						
6.50" -		Sand & Gravel						

2000 PRELIMINARY SOIL SURVEY

Colorado Department of Transportation
PRELIMINARY SOIL SURVEY

Form # 554 Report No. 974 Page 1 of 3

Date: 8/8/00 Note: If samples are submitted leave sieve analysis section blank

Project No. STA 0062-014 SA# 13349

Station and Log	Test No.	Description	Max. Size	Percent Passing 3"	1"	3/4"	3/8"	# 4	# 10	# 40	# 200	CORE #	Height In.	BULK Sp. Grav.	MAX Sp. Grav.	AIR VOIDS
Vasquez Blvd. I 70 - I 76		MP 291.04 - 295.95														
NB Lane 1, MP 290.97																
0 - 5.75"	1	HBP Core														
5.75"-10.0"		Aggregate Base Course														
10.0" -		Sand and Gravel														
SB Lane 2, MP 291.25																
0 - 8.50"	2	HBP Core	Slight stripping and pourous at 2.5-4.5"													
8.50 -		Sand and Gravel														
NB Lane 2, MP 291.47																
0 - 6.50	3	HBP Core	Slight stripping and pourous at 3.0-4.0", lower 2.0" crumbled													
6.50 - 10.5"		Aggregate Base Course														
10.50" -		Sand and Gravel														
SB Lane2, MP 291.65																
0 - 4.50"	4	HBP Core	Slight stripping and pourous at 2.5-3.5"													
4.50 - 10.50"		Aggregate Base Course														
10.50" -		Sand and Gravel														
NB Lane 2, MP 291.93		(52nd Ave. Intersection.)														
0 - 8.0"	5A	HBP Core	Slight stripping and pourous at 2.5-4.0"									5AA	1.8	2.388	2.438	2.05%
8.00" -		Sand and Gravel										5AB	1.6	2.344	2.436	3.78%
NB Lane 2, MP 291.93												5AC	2.6	2.339	2.431	3.78%
0 - 8.50"	5B	HBP Core	Slight stripping and pourous at 2.5-4.0"									5BA	1.9	2.381	2.438	2.34%
8.50" -		Sand and Gravel										5BB	1.8	2.339	2.436	3.98%
SB Lane 2, MP 292.04												5BC	2.3	2.362	2.431	2.84%
0 - 5.0"	6	HBP Core														
5.0" -		Sand and Gravel														
NB Lane 2, MP 291.91																
0 - 8.00"	7	HBP Core	Slight stripping and pourous at 1.5-4.0"													
8.0" -		Coarse Sand														

Colorado Department of Transportation
PRELIMINARY SOIL SURVEY
Date: 8/8/00

Note: If samples are submitted leave sieve analysis section blank

Form # 554 Report No. 974 Page 2 of 3
Project No. STA 0062-014 SA# 13349

Location / Depth	Sample	Description	Notes	ID				Air Voids
NB Lane 2, MP 292.46		(56th Ave Intersection)						
0 - 10.50"	8A	HBP Core		8AA	2.5	2.424	2.457	1.34%
10.5" -		Sand and Gravel		8AB	2.2	2.379	2.428	2.02%
NB Lane 2, MP 292.46				8AC	3	2.358	2.392	1.42%
0 - 10.50"	8B	HBP Core		8BA	2.4	2.427	2.457	1.22%
10.5" -		Sand and Gravel		8BB	2.4	2.381	2.428	1.94%
SB Lane 2, MP 292.97				8BC	3	2.358	2.392	1.42%
0 - 11.50"	9	HBP Core	**Note**: The botton portion sheared off at a depth of 7". There appeared to be a layer of dirt at this level.					
11.50" -		Sand and Gravel	There was no bonding between the layers of HBP.					
NB Lane 2, MP 293.07		(60th Ave. Intersection)						
0 - 7.50"	10A	HBP Core		10AA	2	2.396	2.446	2.04%
7.50" -		Sand and Gravel		10AB	1.7	2.419	2.464	1.83%
				10AC	1.7	2.413	2.482	2.78%
0 -7.50"	10B	HBP Core		10BA	1.9	2.407	2.446	1.59%
7.50" -		Sand and Gravel		10BB	2	2.413	2.464	2.07%
SB Lane 2, MP 293.51				10BC	2	2.387	2.482	3.83%
0 - 10.25"	11	HBP Core	Slight stripping and pourous at 5.0-8.0"					
10.25" -		Sand and Gravel						
NB Lane 2, MP 293.80								
0 -2.0"	12	HBP Core	0"-1.5" of 3/4" HBP, 1.5"-2.0" of what appears to be chip seal					
2.0" - 11.0"		**PCCP**						
11.0" -		Sand and Gravel						
SB Lane 2, MP 294.08								
0 - 10.5"	13	HBP Core						
10.5" -		Sand and Gravel						
NB Lane 2, MP 294.22		(69th Ave. Intersection)						
0 - 11.0"	14A	HBP Core	Slight stripping and pourous at 4.0-10.0"	14AA	2.1	2.41	2.449	1.59%
11.0" -		Sand and Gravel		14AB	2.6	2.364	2.44	3.11%
NB Lane 2, MP 294.22				14AC	3	2.318	2.409	3.78%
0 - 10.5"	14B	HBP Core	Slight stripping and pourous at 4.0-10.0"	14BA	2.3	2.424	2.449	1.02%
10.5" -		Sand and Gravel		14BB	2.3	2.365	2.44	3.07%
SB Lane 2, MP 294.49				14BC	2.8	2.307	2.409	4.23%
0 - 9.50"	15	HBP Core						
9.50" -		Sand and Gravel						

2001 JOB MIX FORMULA FORM 43s

Colorado Department of Transportation
JOB MIX FORMULA

Mix Design: 105878
Date: 5/21/2001

Region: 6
Project: STA 0062-014
Location: US 6/VASQUEZ, I70 TO I-76
S.A. 13349
From Project: N/A
From Project S.A.

This Job Mix Formula defines the specified gradation, asphalt content, and admixture dosage for the grading and project shown.

Contractor: Kiewit
Supplier: Kiewit
Plant: East

Item: 403 & Patching
Grading & Compaction: SMA (3/4"-50 Blow Marshall)
% RAP = 0
% Lime = 1%

Components
1 30% - 3/4" Rock - Meridian
2 46% - 1/2" Rock - Meridian
3 17% - 3/8" Fines - Co. Mat. Dust
4 6% - Limestone Dust - Pete Lien
5 1% - Lime
6
7

Remarks: **The in-place density shall be 93-97% of the max. specific gravity, as per the project revisions.**

Gradation (% Passing)

☑ Specification ☐ Voids Acceptenance

Sieve		Aggregate with RAP	Virgin Agg without Rap	Tolerance +/-
2"	(50.0mm)			
1.5"	(37.5 mm)			
1"	(25.0 mm)		100	100
3/4"	(19.0 mm)		100	90-100
1/2"	(12.5 mm)		86	6
3/8"	(9.5 mm)		68	6
# 4			27	5
# 8			20	5
# 16			16	
# 30			14	4
# 50			12	
# 100			11	
# 200			8.7	2.0

% A.C. = 6.2 +/- 0.3

Grade of A.C. PG 76-28

Source of A.C. Koch

Max.Specific Gravity at % A.C. 2.432

Bulk Sp. Gr. of combined agg: 2.65

Bulk Sp. Gr. of fine agg 2.677

Angularity T-304 45.0%

Stability for information.

Voids Data at N design		
Property	Target Value	Tolerance
Stability	2100 lbf.	1400 Min.
% Voids	3.7	+/- 1.2
% VMA	17.2	+/- 1.2

☑ New mix design with no change
☐ Staff Materials called and concurs with change or reapproval

Called: Tony Maestas Date: 5/21/01
Staff Materials Representative

Signed: ____________ Date:
Project Engineer

Signed: Reza Akhavan Date: 5/21/01
Regional Materials Engineer

Signed: ____________ Date:
Contractor's Representative

Distribution
Staff Materials
Region Materials Engineer
Project Engineer (2)
Contractor
CDOT Form # 43 revised 4-21-98

Colorado Department of Transportation
JOB MIX FORMULA

Mix Design: 105878-1
Date: 6/11/2001

Region: 6
Project: STA 0062-014
Location: US 6/VASQUEZ, I70 TO I-76
S.A. 13349
From Project: N/A
From Project S.A.

This Job Mix Formula defines the specified gradation, asphalt content, and admixture dosage for the grading and project shown.

Contractor: Kiewit
Supplier: Kiewit
Plant: East

Components
1 30% - 3/4" Rock - Meridian
2 46% - 1/2" Rock - Meridian
3 17% - 3/8" Fines - Co. Mat. Dust
4 6% - Limestone Dust - Pete Lien
5 1% - Lime
6
7

Item: 403 & Patching
Grading & Compaction: SMA (3/4"-50 Blow Marshall)
% RAP = 0 % Lime = 1%

Remarks: **Adjusted the max. specific gravity as per CP-56 and included gradation without limestone dust.**

Gradation (% Passing)

☑ Specification ☐ Voids Acceptenance

Sieve		Aggregate with limestone dust	Virgin Agg without limestone dust	Tolerance +/-
2"	(50.0mm)			
1.5"	(37.5 mm)			
1"	(25.0 mm)	100	100	100
3/4"	(19.0 mm)	100	100	90-100
1/2"	(12.5 mm)	86	85	6
3/8"	(9.5 mm)	68	66	6
# 4		27	23	5
# 8		20	15	5
# 16		16	11	
# 30		14	9	4
# 50		12	7	
# 100		11	5	
# 200		8.7	3.8	2.0

% A.C. = 6.2 +/- 0.3

Grade of A.C. PG 76-28

Source of A.C. Koch

Max Specific Gravity at % A.C. 2.455

Bulk Sp. Gr. of combined agg: 2.65

Bulk Sp. Gr. of fine agg 2.677

Angularity T-304 45.0%

Stability for information

Voids Data at N design		
Property	Target Value	Tolerance
Stability	2100 lbf.	1400 Min.
% Voids	3.7	+/- 1.2
% VMA	17.2	+/- 1.2

☐
☐ New mix design with no change
☑ Staff Materials called and concurs with change or reapproval

Called: Tony Maestas — Staff Materials Representative — Date: 6/11/01

Signed: ______ Project Engineer — Date:

Signed: R. Zocamda FOR Reza Akhavan — Regional Materials Engineer — Date: 6/11/01

Signed: ______ Contractor's Representative — Date:

Distribution
Staff Materials
Region Materials Engineer
Project Engineer (2)
Contractor
CDOT Form # 43 revised 4-21-98

Colorado Department of Transportation
JOB MIX FORMULA

Mix Design: 105877
Date: 5/21/2001

Region: 6
Project: STA 0062-014
Location: US 6/VASQUEZ, I70 TO I-76
S.A. 13349
From Project: N/A
From Project S.A.

This Job Mix Formula defines the specified gradation, asphalt content, and admixture dosage for the grading and project shown.

Contractor: Kiewit
Supplier: Kiewit
Plant: East

Item: 403 & Patching
Grading & Compaction: SMA (3/8" 50 Blow Marshall)
% RAP = 0
% Lime = 1%

Components

1. 65% - 3/8" Rock - Agg. Ind. Titan
2. 29% - 3/8" Fines - Co. Mat. Dust
3. 5% - Limestone Dust - Pete Lien
4. 1% - Lime
5.
6.
7.

Remarks: The in-place density shall be 93-97% of the max. specific gravity, as per the project revisions.

Gradation (% Passing)

☑ Specification ☐ Voids Acceptenance

Sieve		Aggregate ~~with RAP~~	Virgin Agg ~~without Rap~~	Tolerance +/-
2"	(50.0mm)		W/DUST	
1.5"	(37.5 mm)			
1"	(25.0 mm)		100	100
3/4"	(19.0 mm)		100	100
1/2"	(12.5 mm)		100	100
3/8"	(9.5 mm)		100	90-100
# 4			45	5
# 8			26	5
# 16			20	
# 30			16	4
# 50			13	
# 100			11	
# 200			8.1	2

% A.C. = 6.7 +/- 0.3

Grade of A.C. PG 76-28

Source of A.C. Koch

Max Specific Gravity at % A.C. 2.440

Bulk Sp. Gr. of combined agg: 2.653

Bulk Sp. Gr. of fine agg 2.659

Angularity T-304 45.0%

Stability for information

Voids Data at N design		
Property	Target Value	Tolerance
Stability	2800 lbf.	1400 Min.
% Voids	3.8	+/- 1.2
% VMA	17.2	+/- 1.2

☐
☑ New mix design with no change
☐ Staff Materials called and concurs with change or reapproval

Called: Tony Maestas — Staff Materials Representative — Date: 5/21/01

Signed: ____________ Project Engineer — Date:

Signed: Reza Akhavan — Regional Materials Engineer — Date: 5/21/01

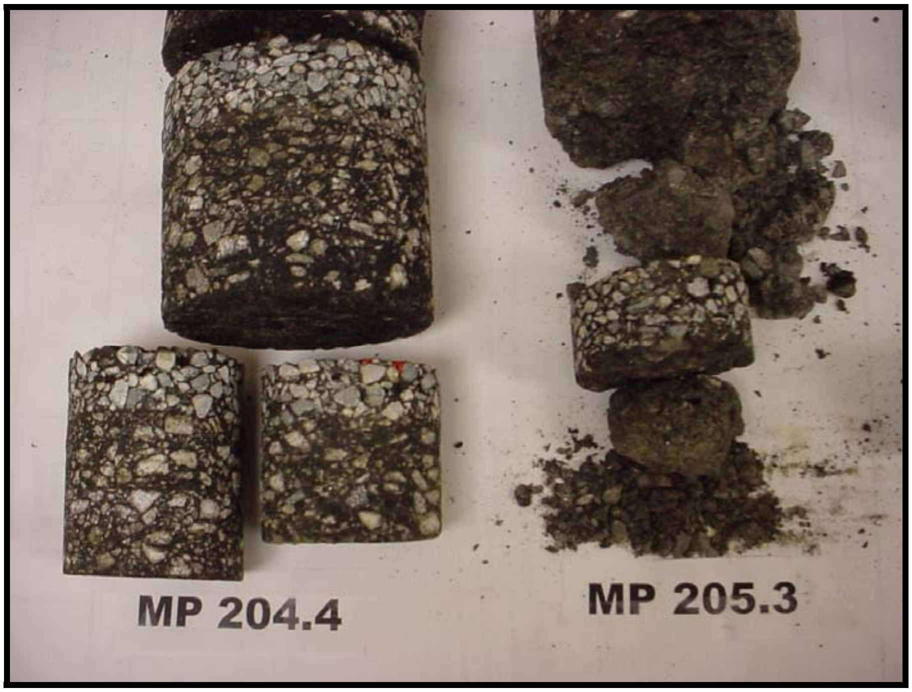
Signed: ____________ Contractor's Representative — Date:

Distribution
Staff Materials
Region Materials Engineer
Project Engineer (2)
Contractor
CDOT Form # 43 revised 4-21-98

APPENDIX C

Core Sample and Coring Pictures From I-75 near Atlanta, Georgia

Figure 32: Core Samples MP 204.4 and MP 205.3



Sample MP 205.3 Moisture Damage in Hot Mix Asphalt from I-75 in Georgia

Figure 33: Core Samples MP 206 and MP 207.2

Core samples showing moisture damage and pictures of rutting

Figure 34: Core Samples MP 208.1 and 209.1

Core samples showing stripping from moisture damage

Figure 35: Core Samples MP 210.1 and MP 211

Figure 36: Core Samples MP 212 and MP 213

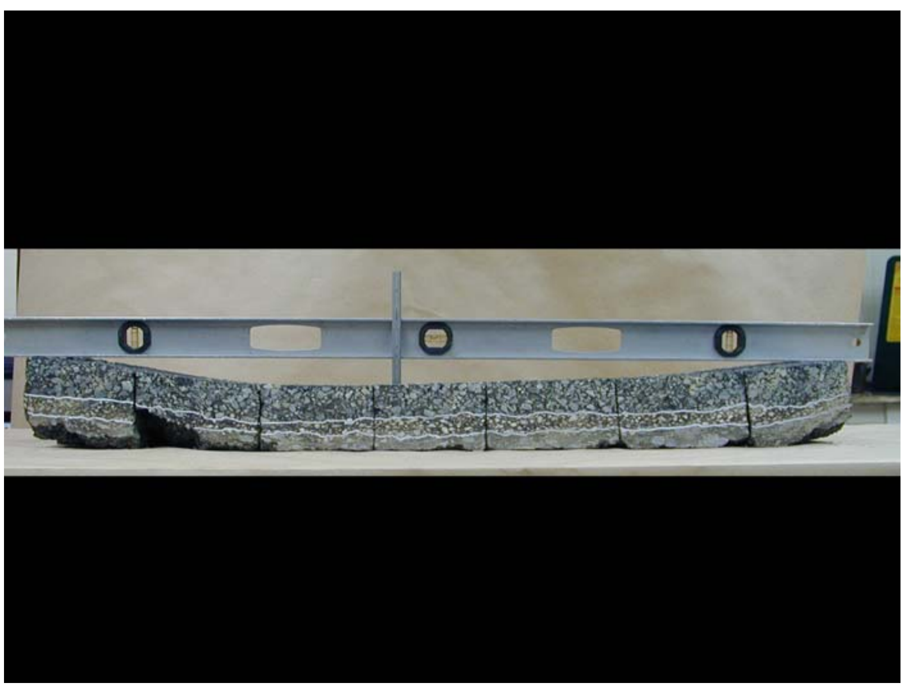
Figure 37: Core Samples MP 214 and MP 215

Figure 38: Core Sample MP 216

Samples of SMA failure from I-495 in Virginia

Figure 39: Core sample with evident striping and moisture damage

Figure 40: Cross section removed from I-495 showing 2”-3” ruts in SMA



APPENDIX D

2001 WEATHER SUMMARY

Table 8 : 2001 Weather Summary 8

Denver Weather Statistics for 2001						
	Temperature (Degrees Fahrenheit)				Precipitation	Snow Fall
MONTH	AVE MAX	AVE MIN	2001MONTH MA,X	2001 MONTH MIN	(Inches)	(Inches)
JAN	41.9	18.1	30.0	28.2	0.78	8.70
FEB	39.4	17.2	28.3	32.3	0.64	1.60
MAR	51.2	28.3	39.8	38.0	1.19	6.70
APR	62.9	36.2	49.6	46.8	1.28	11.70
MAY	69.7	44.4	57.1	55.9	3.74	7.20
JUN	84.2	54.5	69.4	67.0	1.53	0.00
JUL	90.7	62.7	76.7	72.1	4.75	0.00
AUG	87.2	59.4	73.3	69.8	0.71	0.00
SEP	81.5	52.0	66.8	61.0	0.99	0.00
OCT	66.0	36.9	51.5	50.2	0.08	1.00
NOV	54.0	27.7	40.9	37.6	0.72	4.20
DEC	43.5	19.9	31.7	29.6	0.14	2.90

*This information was obtained from www.crh.noaa.gov and is summarized for the purposes of this pavement investigation.

Table 9: April/May 2001 Planning/Paving Records Vs Weather Records

DATE	PLANNING	PAVING	PRECIPITATION	PRECIP. TYPE	PRECIP. AMOUNT (INCHES)	TEMP(HIGH) °F	TEMP(LOW) °F
4/28/2001	-	-	-	-	-	78	43
4/29/2001	YES**	-	-	-	-	79	46
4/30/2001	YES**	-	-	-	-	74	47
5/1/2001	YES**	YES**	-	-	-	84	49
5/2/2001	-	-	YES	Snow	0.22	49	32
5/3/2001	YES**	-	YES	Snow	0.21	36	32
5/4/2001	-	-	YES	Snow	0.81	40	32
5/5/2001	-	-	YES	Snow	0.85	46	38
5/6/2001	YES**	YES**	YES	Snow	0.01	58	40
5/7/2001	YES**	-	-	-	-	62	37
5/8/2001	YES**	YES**	-	-	-	74	47
5/9/2001	YES**	YES**	-	-	-	80	49
5/10/2001	YES	YES**	YES	Rain	0.02	78	53
5/11/2001	-	-	YES	Rain	Trace	71	46
5/12/2001	-	-	-	-	-	81	51
5/13/2001	YES	YES**	-	-	-	85	50
5/14/2001	YES	-	YES	Rain	0.14	81	52
5/15/2001	YES	-	-	-	-	84	54
5/16/2001	-	-	-	-	-	78	60
5/17/2001	-	-	YES	Rain	0.13	65	47
5/18/2001	-	-	YES	Rain	0.02	75	43
5/19/2001	-	-	YES	Rain	0.02	63	50
5/20/2001	YES	-	YES	Rain	0.05	72	31
5/21/2001	-	-	-	-	0	56	31
5/22/2001	YES	-	-	-	0	73	37
5/23/2001	YES	-	-	-	0	79	43
5/24/2001	YES	-	-	-	0	74	41
5/25/2001	-	-	-	-	0	71	39
5/26/2001	-	-	YES	Rain	Trace	76	47
5/27/2001	-	-	YES	Rain	0.1	79	52
5/28/2001	-	-	YES	Rain	1.2	80	47
5/29/2001	-	-	YES	Rain	Trace	74	52
5/30/2001	YES	-	YES	Rain	Trace	64	49
5/31/2001	YES	-	-	-	-	72	45
Totals					3.78		

** - Denotes milling and paving at the intersections only.

Table 10: June 2001 Planning/Paving Records Vs Weather Records

DATE	PLANNING	PAVING	PRECIPITATION	PRECIP. TYPE	PRECIP. AMOUNT (INCHES)	TEMP(HIGH) °F	TEMP(LOW) °F
6/1/2001	YES	-	-	-	-	79	50
6/2/2001	YES	-	-	-	-	89	50
6/3/2001	YES	-	YES	Rain	0.56	69	53
6/4/2001	YES	-	YES	Rain	0.03	66	47
6/5/2001	-	-	-	-	-	73	41
6/6/2001	-	-	-	-	-	80	49
6/7/2001	YES	-	YES	Rain	0.02	77	54
6/8/2001	-	-	-	-	-	86	53
6/9/2001	YES	-	YES	Rain	Trace	88	56
6/10/2001	-	-	-	-	-	93	62
6/11/2001	-	-	-	-	-	93	61
6/12/2001	-	-	-	-	-	90	54
6/13/2001	YES	-	YES	-	-	63	42
6/14/2001	-	-	-	-	-	65	41
6/15/2001	-	-	-	-	-	82	49
6/16/2001	-	-	-	-	-	88	48
6/17/2001	-	-	-	-	-	92	54
6/18/2001	YES	YES	-	-	-	91	60
6/19/2001	-	-	YES	Rain	0.01	72	54
6/20/2001	-	-	YES	Rain	0.23	79	51
6/21/2001	-	-	-	-	-	78	54
6/22/2001	-	-	-	-	-	89	57
6/23/2001	-	-	YES	Rain	Trace	94	58
6/24/2001	YES	YES	YES	Rain	Trace	92	63
6/25/2001	-	-	-	-	-	93	62
6/26/2001	-	-	-	-	-	92	62
6/27/2001	-	-	-	-	-	88	63
6/28/2001	-	-	-	-	-	92	59
6/29/2001	-	-	-	-	-	95	64
6/30/2001	-	-	-	-	-	98	63
Totals					0.85		

** - Denotes milling and paving at the intersections only.

Table 11: July 2001 Planning/Paving Records Vs Weather Records

DATE	PLANNING	PAVING	PRECIPITATION	PRECIP. TYPE	PRECIP. AMOUNT	Temp (High) °F	Temp(Low) °F
					(INCHES)	101	66
7/1/2001	-	-	YES	Rain	Trace	97	68
7/2/2001	-	-	-	-	-	94	63
7/3/2001	-	-	YES	Rain	0.94	96	60
7/4/2001	-	-	-	-	-	98	67
7/5/2001	-	-	YES	Rain	0.13	96	65
7/6/2001	-	-	YES	Rain	1.01	90	62
7/7/2001	-	-	YES	Rain	0.18	92	63
7/8/2001	-	-	YES	Rain	0.36	88	61
7/9/2001	-	-	-	-	-	87	62
7/10/2001	-	-	YES	Rain	Trace	89	60
7/11/2001	-	-	YES	Rain	0.13	85	63
7/12/2001	-	-	YES	Rain	Trace	85	61
7/13/2001	-	-	YES	Rain	0.07	83	59
7/14/2001	-	-	YES	Rain	Trace	85	58
7/15/2001	-	-	YES	Rain	0.04	91	61
7/16/2001	-	-	-	-	-	89	61
7/17/2001	-	YES	-	-	-	91	64
7/18/2001	-	-	YES	Rain	0.07	91	64
7/19/2001	-	-	-	-	-	94	61
7/20/2001	-	-	-	-	-	95	68
7/21/2001	-	-	-	-	-	96	69
7/22/2001	-	-	-	-	-	84	60
7/23/2001	-	-	YES	Rain	1.44	84	61
7/24/2001	-	-	YES	Rain	0.01	87	57
7/25/2001	-	-	-		-	80	61
7/26/2001	-	-	YES	Rain	0.02	86	59
7/27/2001	-	-	-	-	-	93	58
7/28/2001	-	-	-	-	-	98	69
7/29/2001	-	-	-	-	-	97	69
7/30/2001	-	-	YES	Rain	Trace	89	54
7/31/2001	-	-	YES	Rain	0.35		
Totals					4.75		

** - Denotes milling and paving at the intersections only.

Figure 41: Exposed Area of HMA Vs. Precipitation Accumulation