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Demonstration of a Volumetric Acceptance Program for Hot Mix Asphalt in Colorado

FHWA Demonstration Project No. 74

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16. Abstract

The Colorado Department of Transportation is attempting to change it's method of acceptance of hot mix asphalt (HMA). Currently, HMA is accepted based upon asphalt content and gradation. It has been previously shown that the volumetric properties of HMA relate to field performance. Volumetric acceptance of HMA is planned within the next five years. The purpose of this report is to describe three pilot projects that used the specification.

Implementation:

Results from the pilot projects indicated the volumetric acceptance specification was reasonable and achievable. When contractors had control of their materials and processes, bonus payments were common. Recommendations to improve the specifications are included. Volumetric testing was performed around the state for information. Five changes to HMA during production were identified that could not be detected with gradation acceptance.

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Demonstration of a Volumetric Acceptance Program for Hot Mix Asphalt in Colorado

By Tim Aschenbrener

1.0 INTRODUCTION

Improved field management of asphalt mixes is an area that needs emphasis. Once a mix design meets the specifications for performance and has been approved, there are many places in the plant operation for material-related problems to develop: from stockpiling, cold feed bins, baghouse fines, to the mixture discharge. In Demonstration Project 74: Field Management of Asphalt Mixes, D'Angelo (1) has shown that volumetric properties provide the necessary information to make effective adjustments to the hot mix asphalt (HMA).

The void acceptance plan measures the effect of material changes on mix properties that, in turn, effects field performance. Accepting HMA with gradation does not provide any indication of the changes to mix properties. In some instances, small changes to gradation from baghouse fines can be detrimental to the HMA; volumetric acceptance will identify this problem and gradation acceptance will not.

Correlations of the rutting performance of HMA pavements and the volumetric properties of field produced material compacted in the laboratory have been performed by Aschenbrener (2). The correlation of volumetric properties with actual field performance was excellent. When field verification air voids were below 3%, there was a high probability the HMA pavements rutted. When field verification air voids were greater than 3%, the HMA pavements did not rut.

Additionally, volumetric acceptance does not require the use of chlorinated solvents; it is extractionless. Because of concerns for worker safety, environmental regulations are becoming more restrictive about the disposal and workers' exposure to chlorinated solvents. Volumetric acceptance is a way to ensure quality HMA is being produced and not expose workers to the solvents.

A 5-year implementation plan for using void acceptance has been developed by the Colorado Department of Transportation (CDOT). The plan is outlined below:

1992	Obtain, learn, and use the equipment.
1993	Construct 1 or 2 pilot projects with the CDOT performing both the quality control and acceptance.
1994	Construct 6 projects, one per Region with the CDOT performing both the quality control and acceptance. Additionally, construct 1 or 2 pilot projects and have the contractor perform the quality control and CDOT perform the quality acceptance.
1995	Construct 6 projects, one per Region with the CDOT performing the quality control and acceptance. Additionally, construct 1 project per Region and have the contractor perform quality control and CDOT perform the quality acceptance.
1996	Full implementation of volumetric acceptance with the contractor performing the quality control and the state performing the quality acceptance.

A great deal of training has been scheduled and performed by the CDOT to familiarize people with the void acceptance concept. To date, the training includes:

1-30-92	In-house training by D'Angelo on the use and implementation of void acceptance.
3-13-92	Development of a 5-year plan for implementing the voids acceptance concept.
8-10-92	A one month visit of the Demonstration 74 testing trailer to a Colorado project to demonstrate the void acceptance concept.
9-18-92	Close-out session of Demonstration 74 results.
2-16-93	Statewide training of void acceptance concept by D'Angelo.
8- 1-93	A one month visit of the Demonstration 74 testing trailer to a Colorado project to demonstrate the void acceptance concept.
9-14-93	Close-out session of Demonstration 74 results.

The purpose of this paper is to present the results of the 1993 portion of the void acceptance implementation plan. Results from three projects were analyzed and changes to the void acceptance specifications are recommended.

2.0 THE PROJECTS

2.1 Project Descriptions

During 1992, Region Material Engineers volunteered three projects for the demonstration. One project was actually awarded and constructed in 1993; it was on 6th Avenue. A project east of Alamosa exceeded the engineer's estimate so the project was re-bid without the void acceptance specification. The project south of Pueblo was awarded in July, but paving was postponed to 1994. A cold-recycling contractor could not be scheduled in 1993.

Two other projects were added "for information only": the Arapahoe Road project and I-70 at Silverthorne. These projects used the standard gradation acceptance specifications, but void acceptance properties were also tested for information. The three projects summarized in this report are shown in Table 1.

Table 1. Projects Analyzed with Void Acceptance Information.

Project Number	Project Location	Void Status
IM-NH-I(CX)-CX 070-2(176)	I-70, Silverthorne to Copper Mtn.	Info.
CX 10-0088-42	Arapahoe Road, Galena to Parker	Info.
CX 11-0006-17	6th Avenue, Knox Ct. to Wadsworth	Spec.

70,000 tons of HMA from 1992 were analyzed from the I-70 project. The overlay was 100mm (4 in.) thick. The Arapahoe Road project consisted of 26,000 tons of HMA placed 50mm (2 in.) thick. The 6th Avenue project consisted of 29,000 tons of HMA with a typical thickness of 50mm.

2.2 Pavement Management Techniques

The I-70 project utilized a fabric in areas severely cracked. The pavement under over-passes was milled. All cracks were sealed. The Arapahoe Road and 6th Avenue projects were milled 12mm (0.5 in.) below the bottom of the ruts. All cracks were filled.

2.3 Bid Prices

Since this was the first year for three pilot projects, it was anticipated that bid prices would be high. The risks associated with a new specification are not always clear. A summary of the overall project bid and the HMA bid price are summarized in Table 2 for projects with the void acceptance specification. Bid prices were lower than the engineer's estimate for the 6th Avenue project in Denver that has several commercial sources. Bid prices were higher than the engineer's estimate for projects likely to use portable plants.

Table 2. Bid Prices for Projects with the Void Acceptance Specification.

	Engineer's Est.	Low Bid	Diff.
6th Avenue:			
Project Cost	$3,497,388	$3,333,326	- 4.7%
Grading C (per ton)	$29.00	$29.00	0.0%
Alamosa:			
Project Cost	$1,673,414	$1,950,879	+16.6%
Grading C (per ton)	$23.00	$24.80	+ 7.8%
Pueblo:			
Project Cost	$5,459,717	$5,893,317	+ 7.9%
Grading C (per ton)	$23.00	$21.90	- 4.8%
Grading CX (Polymer)	$23.25	$28.20	+21.3%

The costs for each ton of HMA includes the asphalt cement, haul, and placement. The Grading CX on the Pueblo project had a polymer modified asphalt cement, and the engineer's estimate did not include the cost of the polymer.

2.4 Pre-Bid Conferences

A pre-bid conference was held for each project with the void acceptance specification. The purpose of the conference was to explain the new specification to potential bidders. The agenda used at each conference is in Appendix A. The conferences were considered successful because they 1) transmitted important information to the contractor, 2) allowed the contractors to ask important questions about a new specification, and 3) allowed the CDOT to modify portions of the specification prior to bidding based on contractor input.

2.4.1 Commonly Asked Questions

The standard deviations used to develop the tolerances were based on the analysis of six projects constructed in 1992. All six projects would have received bonuses with the void acceptance specification. A Grading CX used in small quantities on one of the projects was price reduced. As more data is collected and analyzed, the standard deviations used in the specification will be modified.

Samples will be taken at one location throughout the project. The location will be selected by the Engineer. When the contractors asked, they were informed where the point of acceptance would be.

When the void properties need a slight adjustment, the target asphalt cement content will be adjusted very quickly for the contractor. This will require a change to the Form 43, and the necessary parties required to approve the change will be readily available. Adjustments to the asphalt cement content will not be allowed to correct dramatically different void properties.

Results for two of the three daily samples will be available the same day. Results from the third sample will be available the following morning. Ultimately, the contractors will be responsible for their own day-to-day quality control. The contractors were encouraged to begin performing these tests or hiring a private laboratory.

The void acceptance specification will be applied to the HMA produced for overlays. Small quantities would not be accepted with void properties, such as patching or plant mixed bituminous base.

The asphalt cement will be paid as part of the HMA. This is the current policy of the CDOT and joint CDOT and contractor specification committee.

2.4.2 Modifications to the Specification

The mix design will require a minimum Hveem stability of 37. For project acceptance, the minimum Hveem stability required will be 35.

When calculating the pay factor for one or two sample lots, the equation in the specification had a parenthesis missing. The correct equation should be:

$$PF = 1.00 - [(T_L - T_O) / V]^2$$

When the number of samples is greater than or equal to 8, one of the constants in the equation was incorrect. The equation should be:

$$PF = 0.103228 + 1.739576(QL/100) - 0.792804(QL/100)^2$$

When the CDOT pays for the HMA, the composite pay factor will always be used. The composite pay factor is the sum of the weighted pay factors of each element. However, the continued production of material out of specification will not be tolerated. When the pay factor for any element is less than 75, the contractor shall take corrective action before being permitted to continue production.

3.0 CONSTRUCTION OPERATIONS

3.1 I-70 at Silverthorne

A brand new Bituma counter-flow, drum mixer with a production capacity of 410 tonnes per hour was used on the project. The fuel source was liquid propane. There were five cold feed bins. Lime was added with a weigh pod and vane feeder and mixed with damp aggregate in an approved pugmill. The lime silo had a 32-tonne storage capacity. A baghouse was used for emission control. The storage silo for the HMA had a 100-tonne capacity.

The HMA was delivered to the project with bottom-dump trucks and placed in the paver with an elevating loader. The round-trip haul time was 50 minutes. The paver was Blaw-Knox with a variable width screed and extended augers. Paving widths were 3.0-, 3.7, and 4.9m (10-, 12- and 16-feet). Three rollers were used to compact the HMA. The breakdown was a 11-tonne, dual-drum vibratory roller, and the intermediate was an 7-tonne, rubber-tired roller. A 12-tonne, dual-drum vibratory roller operated in the vibratory mode to provide additional compaction and operated statically for finish rolling.

Fig. 1. Construction of I-70 at Silverthorne.

3.2 Arapahoe Road

A CMI parallel-flow, drum mixer with a production capacity of 320 tonnes per hour was used on the project. The fuel source was natural gas. There were four cold feed bins. Lime was added with a weigh pod and vane feeder and mixed with damp aggregate in an approved pugmill. The lime silo had a 32-tonne storage capacity. A baghouse was used for emission control. The three storage silos for the HMA each had a 180-tonne capacity.

The HMA was delivered to the project with end-dump trucks, and the round-trip haul time was 75 minutes. Two pavers were used, one had a 3.7m (12-foot) width and the other had a 7.3m (24-foot) width with extended augers. Four rollers were used to compact the HMA. The breakdown was a dual-drum vibratory roller, and the intermediate was a rubber-tired roller. A dual-drum vibratory roller operated in the vibratory mode to provide additional compaction and operated statically for finish rolling.

Fig. 2. Construction on Arapahoe Road.

3.3 6th Avenue

A Bituma parallel-flow, drum mixer with a production capacity of 360 tonnes per hour was used on the project. The fuel source was natural gas. There were five cold feed bins. Lime was added with a weigh pod and vane feeder and mixed with damp aggregate in an approved pugmill. The lime silo had a 45-tonne storage capacity. A baghouse was used for emission control. The four storage silos for the HMA each had a 260-tonne capacity.

The HMA was delivered to the project with end-dump and live-bottom trucks. The round-trip haul time was approximately 60 minutes. The paver was Blaw-Knox with a variable width screed and extended augers. Paving widths were 4.9- and 5.5-m (16- and 18-feet). Three rollers were used to compact the HMA. The breakdown was a 14-tonne, dual-drum vibratory roller, and the intermediate was a 5-tonne, rubber-tired roller. A 11-tonne, dual-drum vibratory roller operated in the vibratory mode to provide additional compaction and operated statically for finish rolling.

Fig. 3. The Plant Used to Produce HMA for 6th Avenue.

4.0 MIX DESIGNS

Copies of the mix designs and gradations plotted on the 0.45 power chart are in Appendix B. All mix designs were performed with the Texas gyratory (ASTM D 4013). The Arapahoe Road project and 6th Avenue project were designed and controlled using the 690 kPa (100 psi) end point stress. The I-70 project used the 1030 kPa (150 psi) end point stress recommended in ASTM.

4.1 I-70 at Silverthorne

A Grading C, 19.0 mm (0.75 in.) top size aggregate, on the fine side of the maximum density line was used on the project. The aggregate was primarily from a commercial quarry. The 20% washed, natural fines in the HMA were very angular. The asphalt cement was Conoco AC-10. The optimum asphalt content was 5.2% at 2.4% air voids. The HMA was designed at low air voids because the 1030 kPa (150 psi) end point stress was believed to be too great a compactive effort for the traffic and environment. The VMA at optimum was 12.6%. The 12 mm (0.5 in.) nominal maximum aggregate had a minimum VMA of 12.5% specified.

4.2 Arapahoe Road

A Grading C on the fine side of the maximum density line was used on the project. The aggregate was primarily from a commercial quarry. A washed concrete sand was used as 20% of the aggregate blend. The asphalt cement was Sinclair AC-10. The optimum asphalt content was 4.7% at 4.0% air voids. The VMA was 13.6%. The 19.0 mm (0.75 in.) nominal maximum aggregate had a minimum VMA of 13.0% specified.

4.3 6th Avenue

A Grading C on the fine side of the maximum density line was used. The aggregate was from a commercial quarry. A washed concrete sand was used as 20% of the aggregate blend. The asphalt cement was Conoco AC-10. The optimum asphalt content was 4.8% at 4.0% air voids. The VMA was 14.4%. The 19.0 mm (0.75 in.) nominal maximum aggregate had a minimum VMA of 13.0% specified.

5.0 FIELD ACCEPTANCE RESULTS

5.1 The Void Acceptance Specification

The void acceptance specification used for this demonstration is in Appendix C. The specification is used to calculate the pay factor for the HMA based on test results of five elements shown in Table 3. Test results from each of the five elements are statistically analyzed and compared to their target value and specified tolerance.

The allowable tolerance is $\pm$ 2 standard deviations of acceptable variability from testing and production. The quality of the HMA, quality level (QL), is calculated as the percent of HMA that is statistically within the tolerance of each element. A pay factor is then computed for each element based on the QL. The pay factors of each element are then weighted according to importance to determine the composite pay factor. The five elements, their weighting, and the standard deviation used to develop the tolerances are listed in Table 3.

Table 3. The Five Elements Used in the Void Acceptance Specification.

Element	Weighting Factor	Standard Deviation
Relative Compaction (Field)	40	1.3
Air Voids	30	0.6
Voids in the Mineral Aggregate	20	0.6
Asphalt Content	5	0.15
Hveem Stability	5	3

When approximately 82% of the HMA is within the tolerances ($\pm$ 2 standard deviations), the contractor is paid the bid price for the HMA, a pay factor of 100. The four potential outcomes are:

1) QL > 82, a pay factor up to 105, a bonus situation,
2) QL = 82, a pay factor of 100, the bid price of the material,
3) QL < 82 and a pay factor > 75, the inferior material can be accepted at a reduced price,
4) QL < 82 and a pay factor < 75, the unacceptable material should be removed.

5.2 I-70 at Silverthorne

5.2.1 Gradation Acceptance Results

The specifications for accepting the HMA were based on gradation, asphalt content, and percent relative compaction on the roadway. The percent relative compaction was based on the maximum specific gravity of the HMA (AASHTO T 209). The project had QA/QC specifications so the contractor was performing the specification tests to control his quality. All of the material placed on the project met or exceeded the CDOT specifications, and the contractor was receiving a 3.1% bonus. A summary of the results is shown in Table 4.

Table 4. Summary of QA/QC Gradation Acceptance Results from the I-70 Project.

	Asphalt Content (%)	Percent Relative Compaction	Gradation	Composite
Specification	4.9-5.5	92-96	Variable	---
n	40	130	34	---
Pay Factor	103.9	102.6	103.3	103.1

5.2.2 Void Acceptance Results

A new mobile field trailer equipped to perform all the void acceptance testing was located at the plant site. Control charts for the void properties are shown in Figs. 4 through 7. The statistical data for each element is shown in Table 5. The contractor was receiving a pay factor of 102.4 as shown in Table 6.

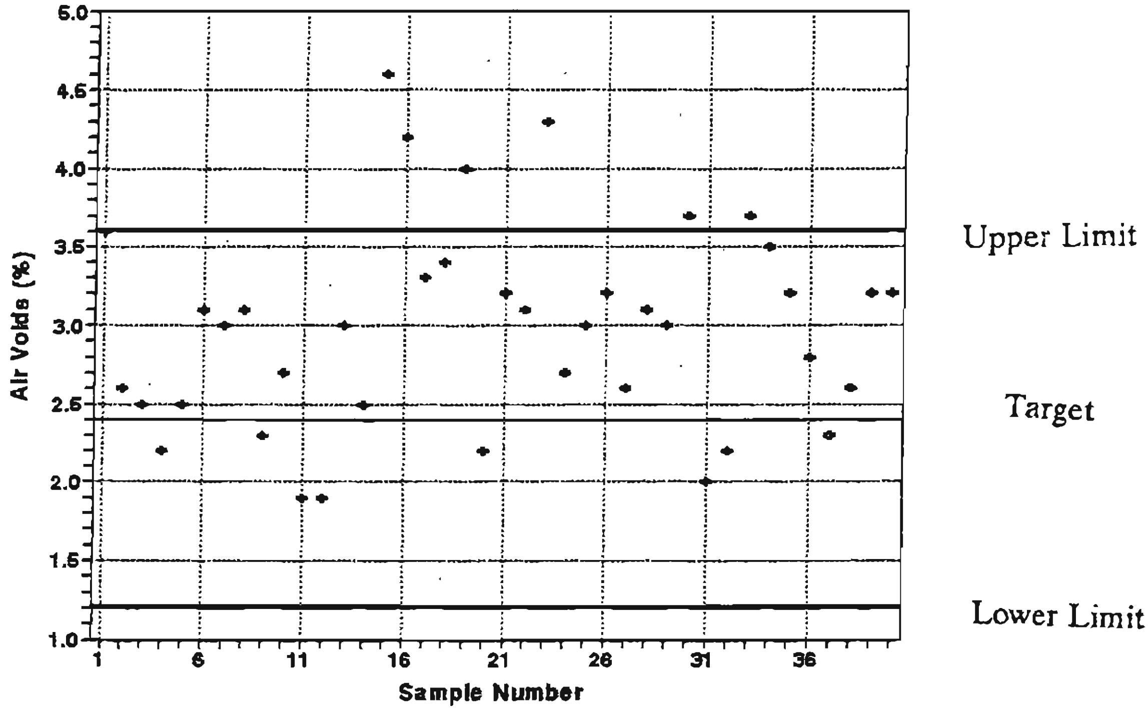


Fig. 4. Control Chart for Air Voids on I-70.

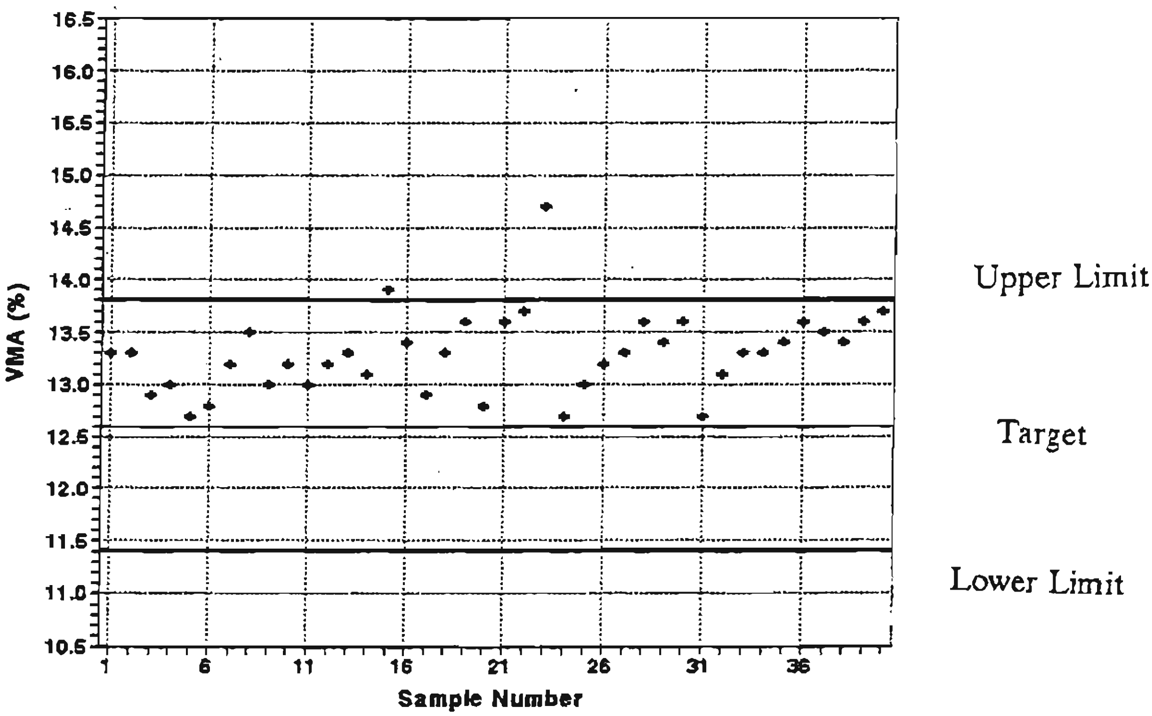


Fig. 5. Control Chart for VMA on I-70.

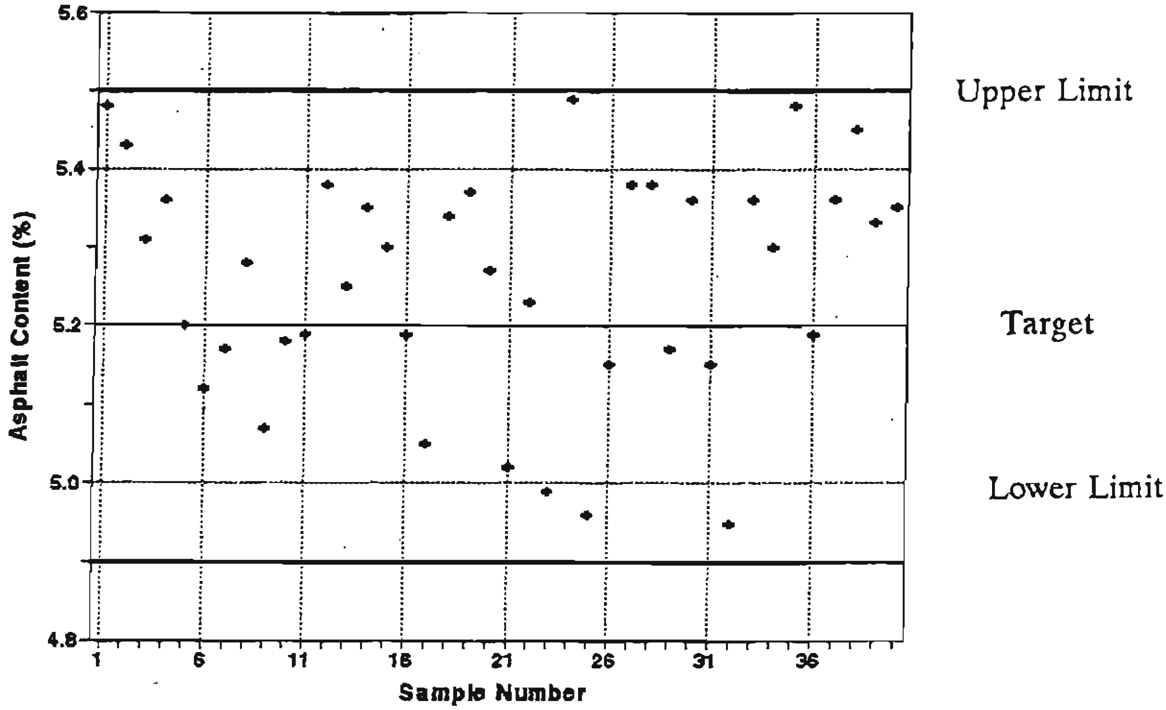


Fig. 6. Control Chart for Asphalt Content on I-70.

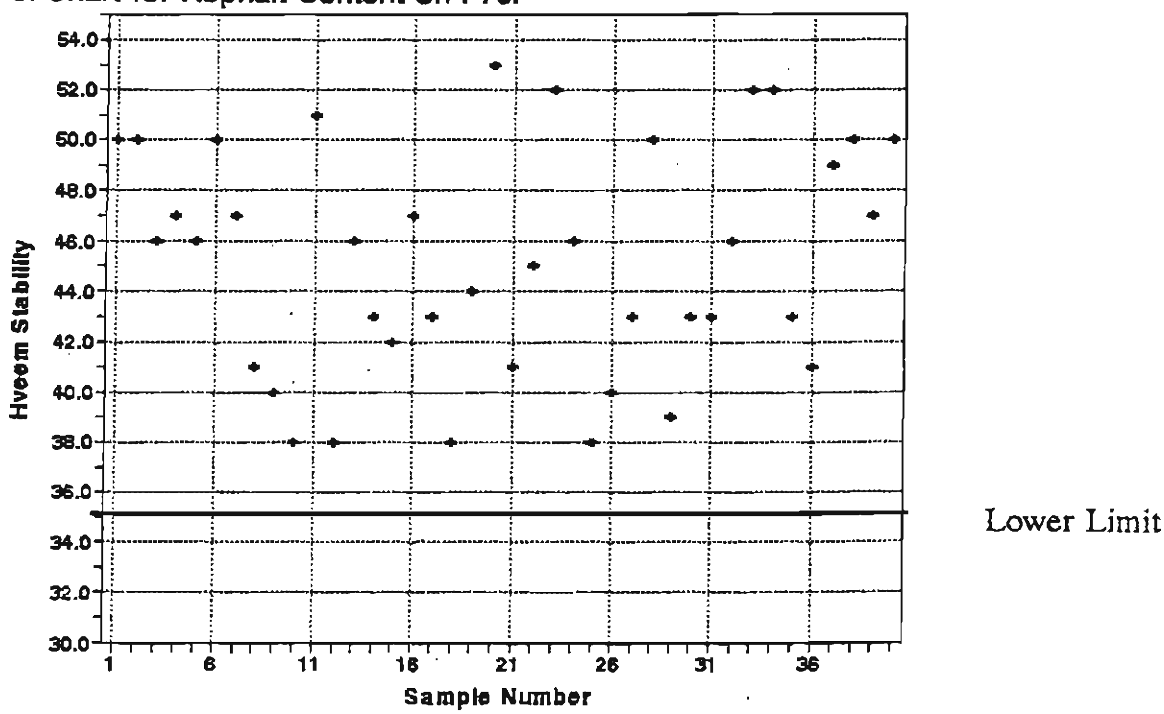


Fig. 7. Control Chart for Stability on I-70.

Table 5. Void Acceptance Testing Results on I-70 at Silverthorne.

	Design Target	Field Production		
		Average	S.D.	n
Relative Compaction (%)	92-96	93.3	0.96	130
Air Voids (%)	2.4	2.95	0.64	40
VMA (%)	12.6	13.3	0.37	40
Asphalt Content (%)	5.2	5.26	0.15	40
Stability	37	45.2	4.5	40

Table 6. Pay Factors Calculated for the I-70 Project from Void Testing.

Element	Pay Factors
Relative Compaction	102.6
Air Voids	100.6
VMA	103.7
Asphalt Content	103.9
Stability	104.9
Composite	102.4

5.2.3 European HMA Test Results

Several pieces of European testing equipment were obtained for demonstration. This equipment has been described previously by Aschenbrener and Stuart (3). The French rutting tester uses a hot air environment to measure the ability of the HMA to resist rutting from plastic flow. The Hamburg wheel-tracking device uses a hot water bath to measure the ability of the HMA to resist moisture damage.

Samples mixed in the laboratory and samples produced in the field were tested in the European equipment. The material produced for the project appears to match the material designed in the laboratory very closely.

Results from the French rutting tester are shown in Fig. 8. Both the lab and field prepared samples have significantly less than the 10% rutting depth specified at 30,000 cycles. The material appears to be resistant to rutting from plastic flow.

Results from the Hamburg wheel-tracking device are shown in Figs. 9 and 10. Unfortunately, the lab and field produced material appear to be very susceptible to moisture damage. The samples do not come close to passing the specification of less than 4 mm at 20,000 passes.

5.2.4 Discussion

For this project, the gradation acceptance specification had a pay factor of 103.1. and the void acceptance specification had a pay factor of 102.4. Both specifications provided the contractor with a comparable bonus.

Based on results from the Hamburg wheel-tracking device, the HMA was a very poor quality. The void acceptance specification is not a measure of the quality of the HMA, but a measure of how well the HMA produced from the plant matches the HMA designed. If an HMA is designed poorly, the void acceptance specification will ensure the material produced for the project is just as poor.

The scatter in the air void data appears to be high based on data in Fig. 4. The pay factor for the air void element was 100.6. When air void results are comparable to those shown in Fig. 4, the contractor will be paid his bid price for the HMA.

The testing and production variability measured in air voids, VMA, and stability were well within the standard deviation used to develop the void acceptance specification.

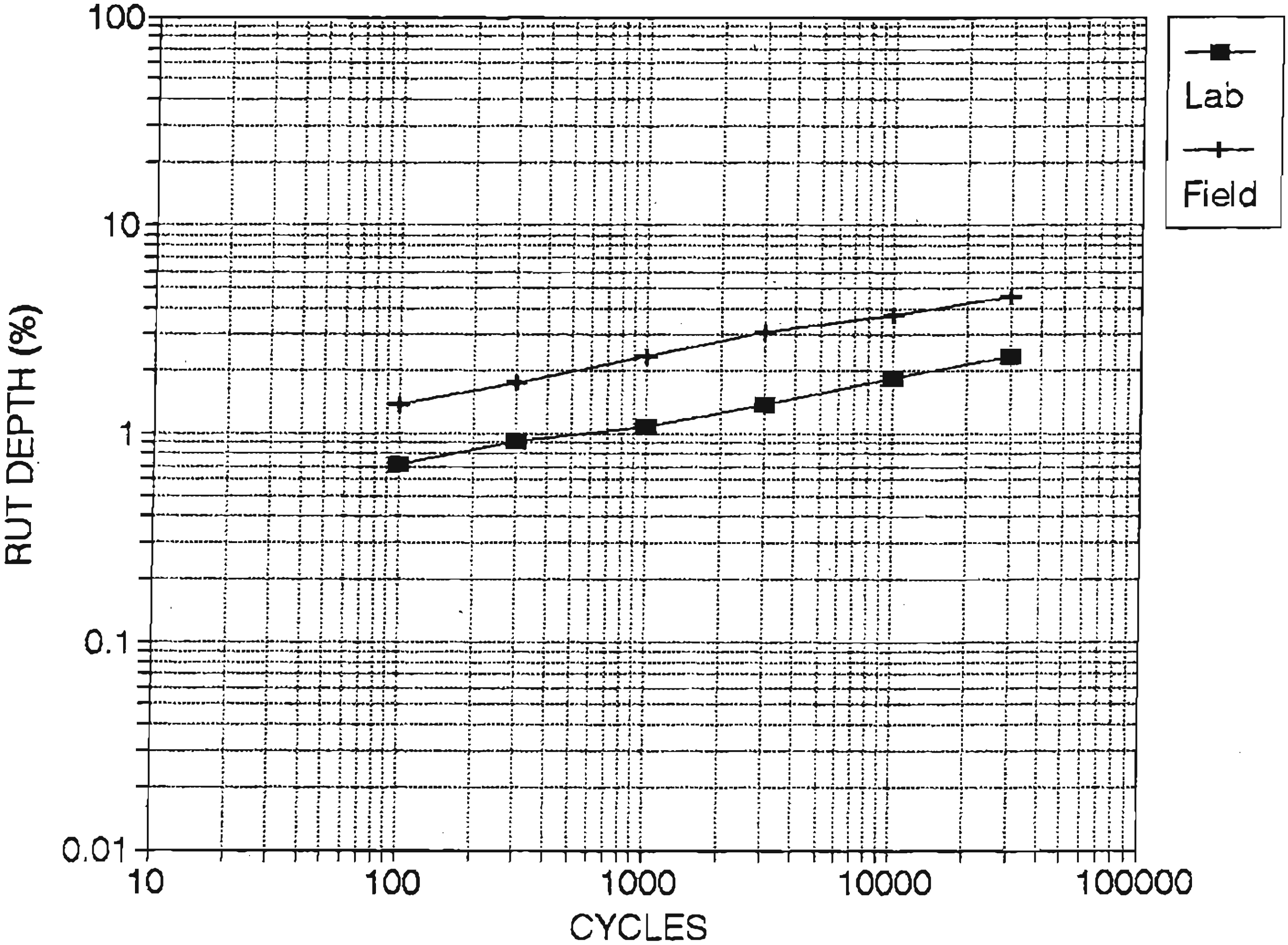
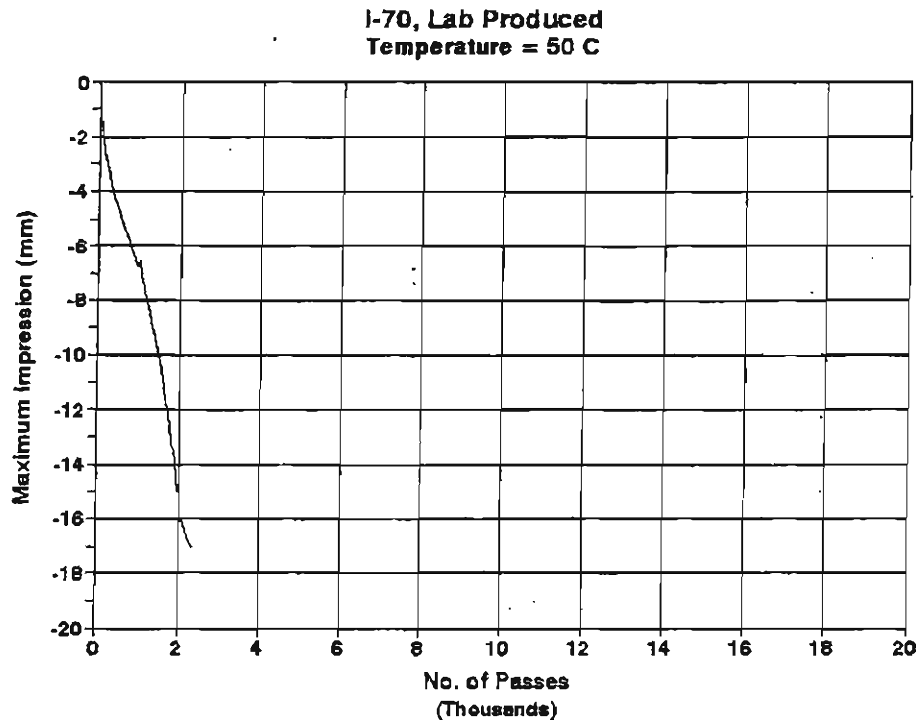


Fig. 8. Results of Lab and Field Produced HMA in the French Rutting Tester.



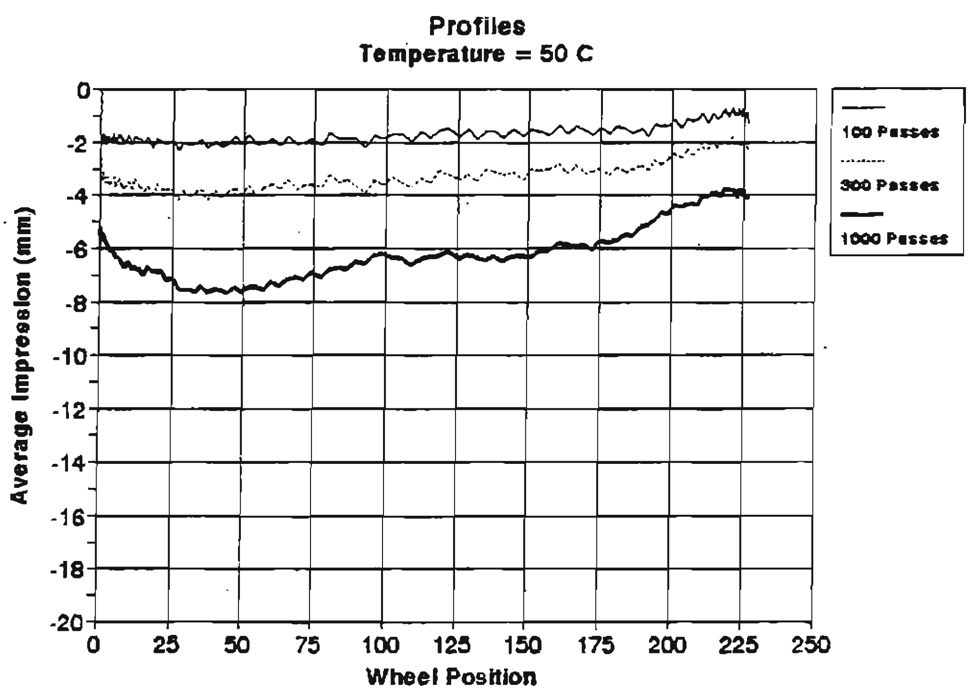
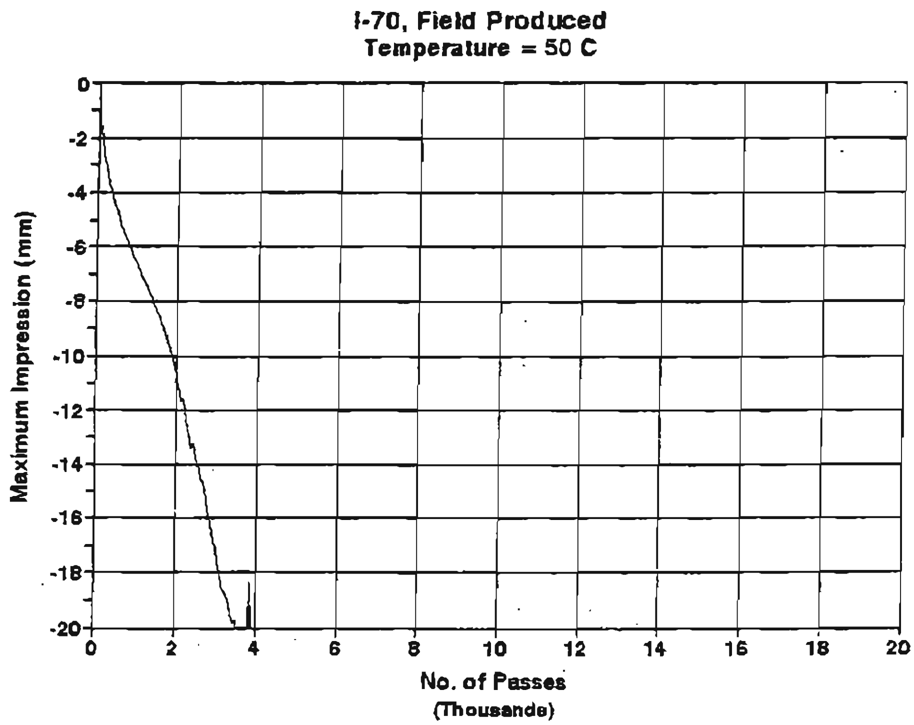


Fig. 9. Results of the Lab Produced HMA in the Hamburg Wheel-Tracking Device on I-70.



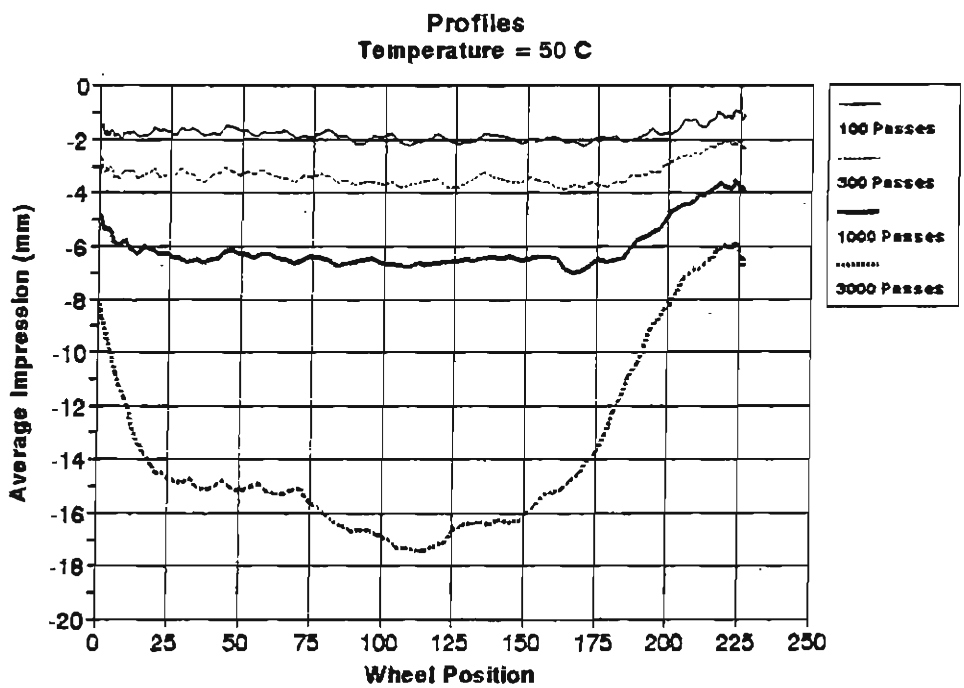


Fig. 10. Results of Field Produced HMA in the Hamburg Wheel-Tracking Device on I-70.

5.3 Arapahoe Road

5.3.1 Gradation Acceptance Results

The specifications for accepting the HMA were based on gradation, asphalt content, and percent relative compaction on the roadway. The percent relative compaction was based on the maximum specific gravity of the HMA (AASHTO T 209). The project had QA/QC specifications so the contractor was performing the specification tests to control his quality. A summary of the QA/QC results using gradation are shown in Table 7. Some problems with the gradation on the material passing the 4.75 mm (No. 4) were encountered during the first 16,000 tons. The gradation acceptance indicated the final 10,000 tons placed were better than the initial 16,000 tons since the problem on the 4.75 mm (No. 4) sieve disappeared.

Table 7. Summary of QA/QC Gradation Acceptance Results for Arapahoe Road.

	Asphalt Content (%)	Percent Relative Compaction	Gradation	Composite
Specification	4.3-5.1	92-96	Variable	---
n	14	54	16	---
Pay Factor	102.9	101.7	101.1	101.9

5.3.2 Void Acceptance Results

There were two distinctly different materials produced on this project. Control charts for air voids, VMA, and Hveem stability are shown in Figs. 11 to 14. The first 16,000 tons of HMA were represented by 14 tests. This material was very consistent and within 2 standard deviations of the target. Results are shown in Table 8.

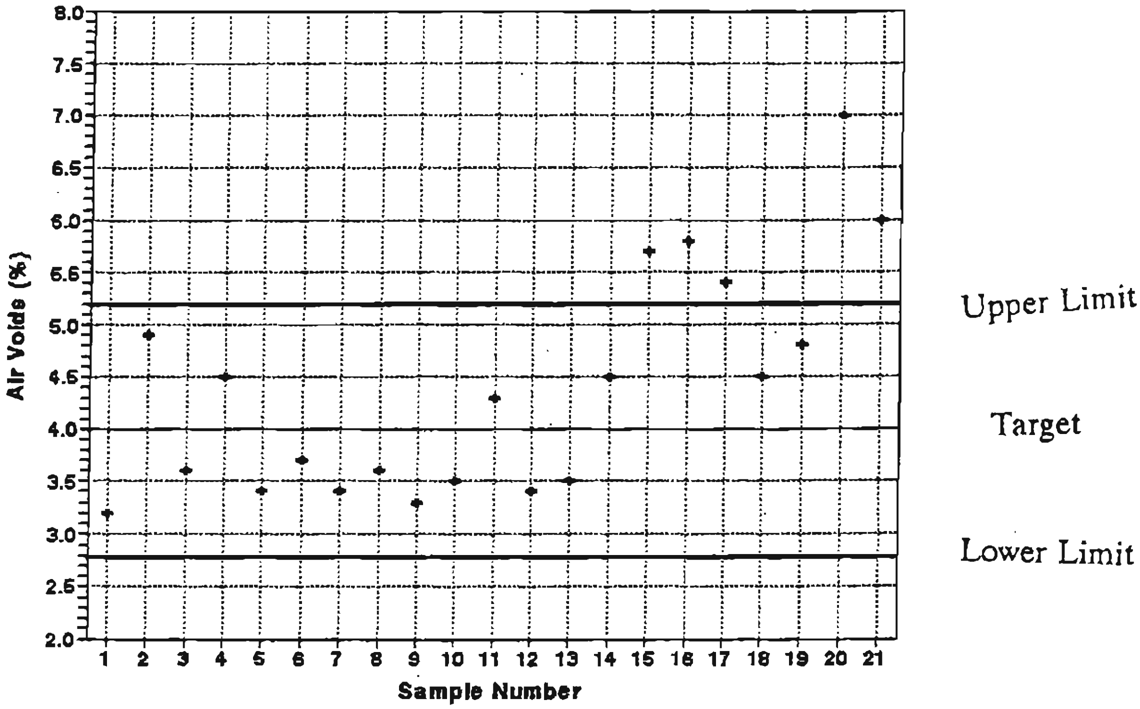


Fig. 11. Control Chart for Air Voids on Arapahoe Road.

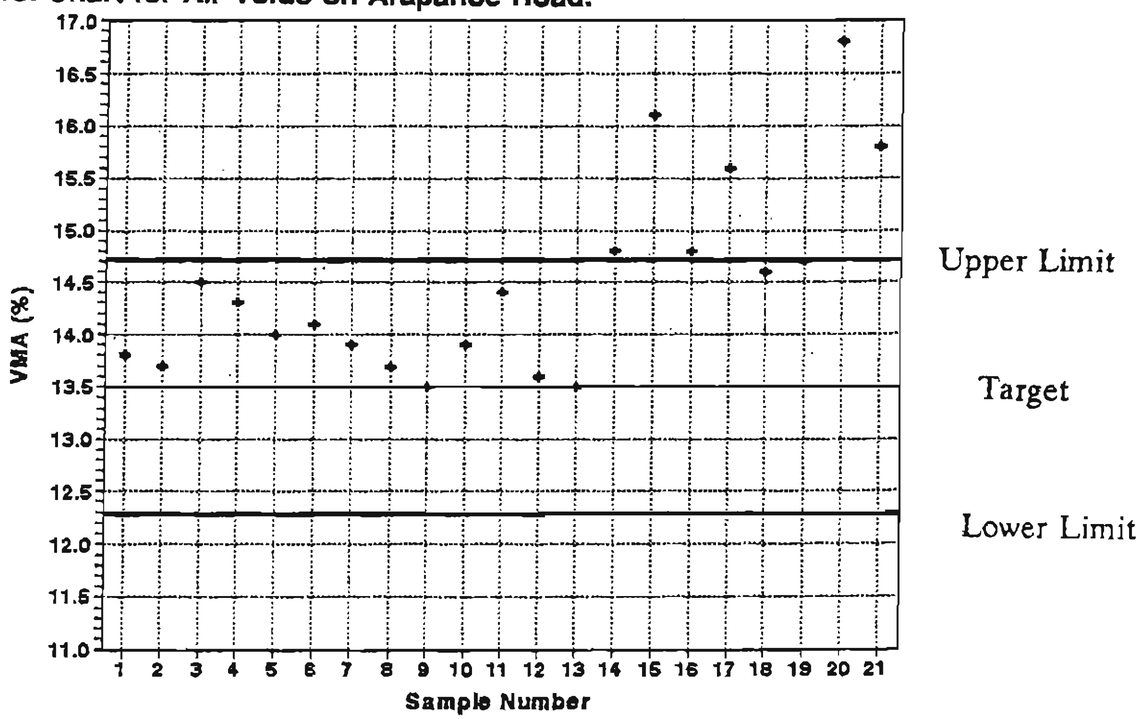


Fig. 12. Control Chart for VMA on Arapahoe Road.

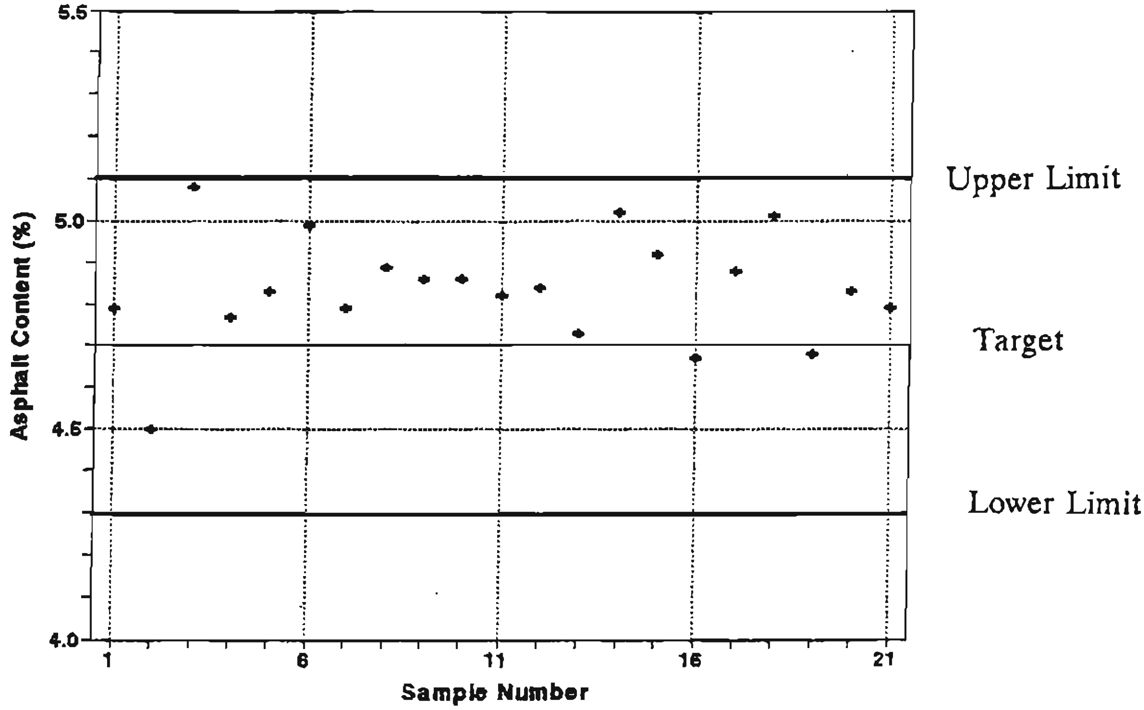


Fig. 13. Control Chart for Asphalt Content on Arapahoe Road.

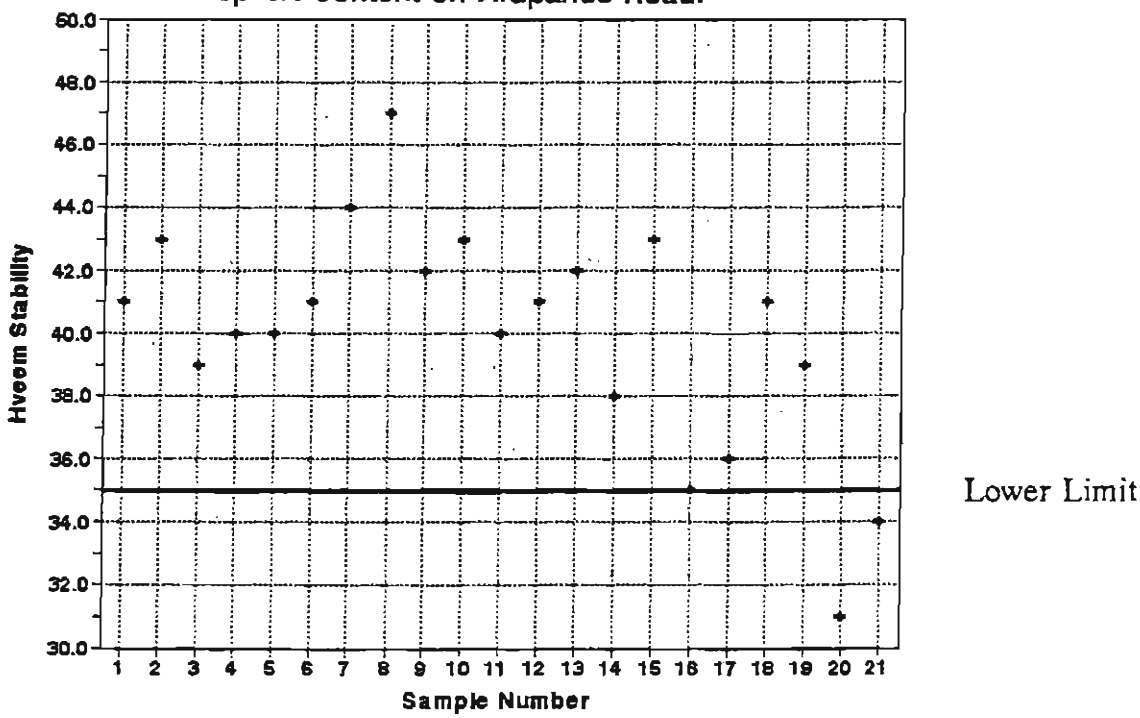


Fig. 14. Control Chart for Stability on Arapahoe Road.

Table 8. Void Acceptance Testing Results from the First 16,000 Tons on Arapahoe Road.

	Design Target	Field Production		
		Average	S.D.	n
Relative Compaction (%)	92-96	93.6	1.24	32
Air Voids (%)	4.0	3.77	0.54	14
VMA (%)	13.5	13.98	0.40	14
Asphalt Content (%)	4.7	4.84	0.14	14
Stability	37	41.5	2.3	14

The final 10,000 tons of HMA produced on this project were represented by the final 7 tests. The material did not resemble the original mix design or the first 16,000 tons of production. Results are shown in Table 9. This material was consistently outside the tolerances. The average air voids and VMA were not even within the tolerances.

Table 9. Void Acceptance Testing Results from the Final 10,000 Tons on Arapahoe Road.

	Design Target	Field Production		
		Average	S.D.	n
Relative Compaction	92-96	93.2	0.97	22
Air Voids	4.0	5.60	0.82	7
VMA	13.5	15.49	0.83	7
Asphalt Content	4.7	4.80	0.15	7
Stability	37	37	4.2	7

The pay factors calculated for the two drastically different HMAs are shown in Table 10. The pay factors appear to be representative of the material quality. During the excellent production for the first 16,000 tons, the contractor received a bonus. During the problematic final 10,000 tons, the material would have required removal if the void acceptance specification was in the contract.

Table 10. Pay Factors Calculated for the Arapahoe Road Project from Void Testing.

Element	Pay Factors	
	First 16,000 Tons	Final 10,000 Tons
Relative Compaction	102.3	102.7
Air Voids	104.6	59.5
VMA	104.6	39.8
Asphalt Content	104.7	105.0
Stability	105	92.3
Composite	103.7	76.7

An investigation was performed to determine the cause for the dramatically different materials. After much testing, it was unclear why the HMA changed. However, two contributing causes were identified. First, it was determined the supply of aggregate from the commercial source had changed. Dust coating on the coarse aggregates increased by 2%. The dust coating the coarse aggregates had a plasticity index of 4 to 6. Adding more P200 that was clay-like could have resulted in a change in the HMA that was detrimental.

The second change was related to the baghouse. The baghouse used on this project looses its "seal" after 50,000 tons of HMA is produced. The "seal" had to be replaced on Monday immediately following the end of the project. Most of the final 10,000 tons were placed on Saturday and Sunday. It is possible that an inconsistent quantity of baghouse fines was being introduced into the HMA on Saturday and Sunday. The baghouse operation could have been a contributing factor to the variations.

5.3.3 European HMA Test Results

Monitoring the field performance of the 2 dramatically different HMA mixtures will be interesting. There will likely be a noticeable difference in the next 5 years. The accelerated testing provided by the European equipment could provide an indication of the future pavement performance.

Samples of the different HMA were tested in the European testing equipment. Three sets of samples were tested: a mix design prepared in the lab, a field produced sample from the first 16,000 tons, and a field produced sample from the final 10,000 tons. All of the samples tested in the French rutting tester passed. Results are shown in Fig. 15.

The Hamburg wheel-tracking device indicated a dramatic difference. A mix was prepared in the lab and tested on the Hamburg wheel-tracking device (Fig. 16). The material produced early in the project had an 11 mm rut depth after 20,000 passes (Fig. 17) and matched the original mix design very closely. The material produced towards the end of the project had 20 mm rut depth after 10,000 passes (Fig. 18). Results from the Hamburg wheel-tracking device are consistent with the test results from the void acceptance program.

5.3.4 Discussion

For the first 16,000 tons of HMA produced, the gradation and void acceptance specifications produced similar results. For the final 10,000 tons of HMA produced, the gradation acceptance results indicated a higher quality material was being placed than the first 16,000 tons. Quite differently, the void acceptance specification indicated the final 10,000 tons of HMA should be removed and replaced.

The Hamburg wheel-tracking device can provide several years of pavement performance in a very short time. The Hamburg wheel-tracking device indicated the final 10,000 tons of HMA had a significantly lower quality than the first 16,000 tons. Results from the Hamburg wheel-tracking device indicate that the void acceptance specification may relate more closely to actual pavement performance than the gradation acceptance specification.

During the first 16,000 tons of production, the testing and production variability of air voids, VMA and stability were well within the standard deviation used to develop the void acceptance specification.

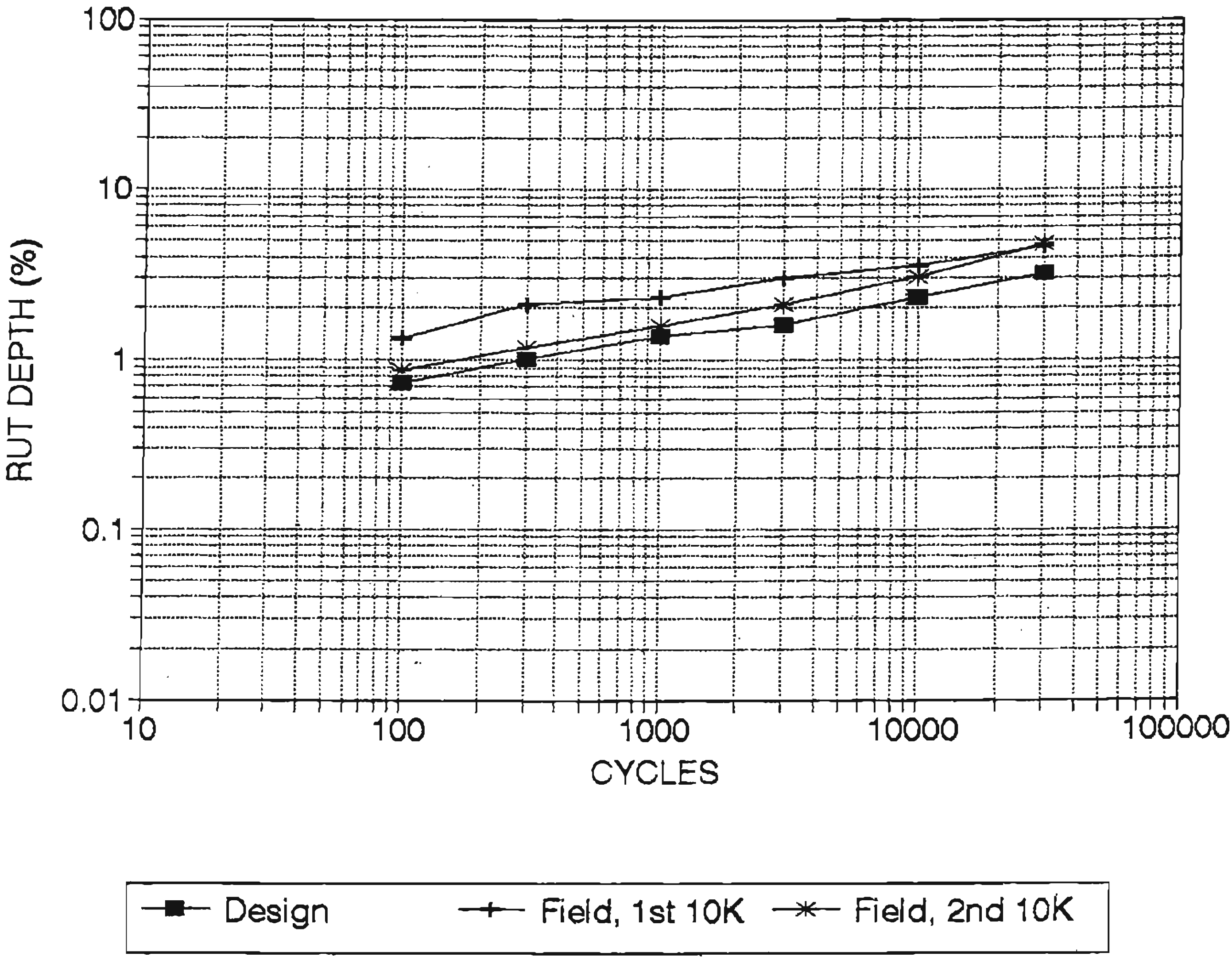
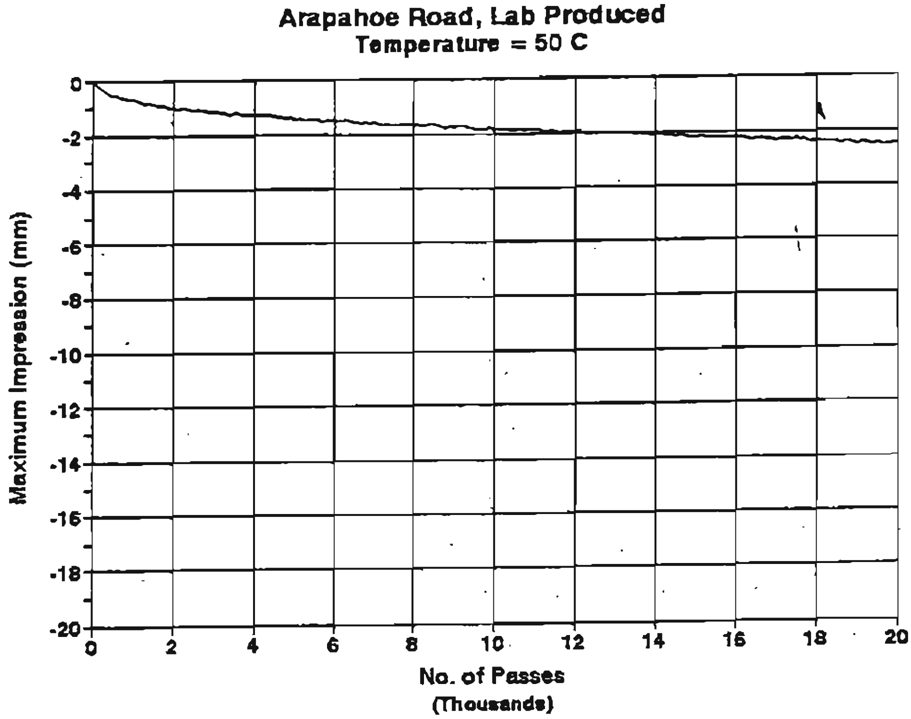


Fig. 15. Results of Lab and Field Produced HMA in the French Rutting Tester on Arapahoe Road.



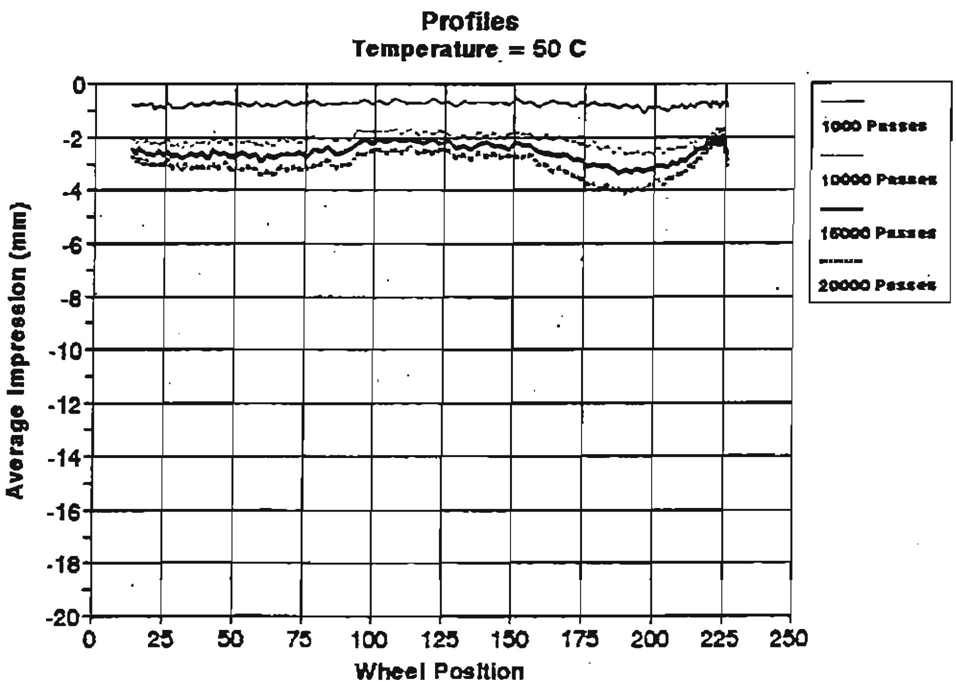
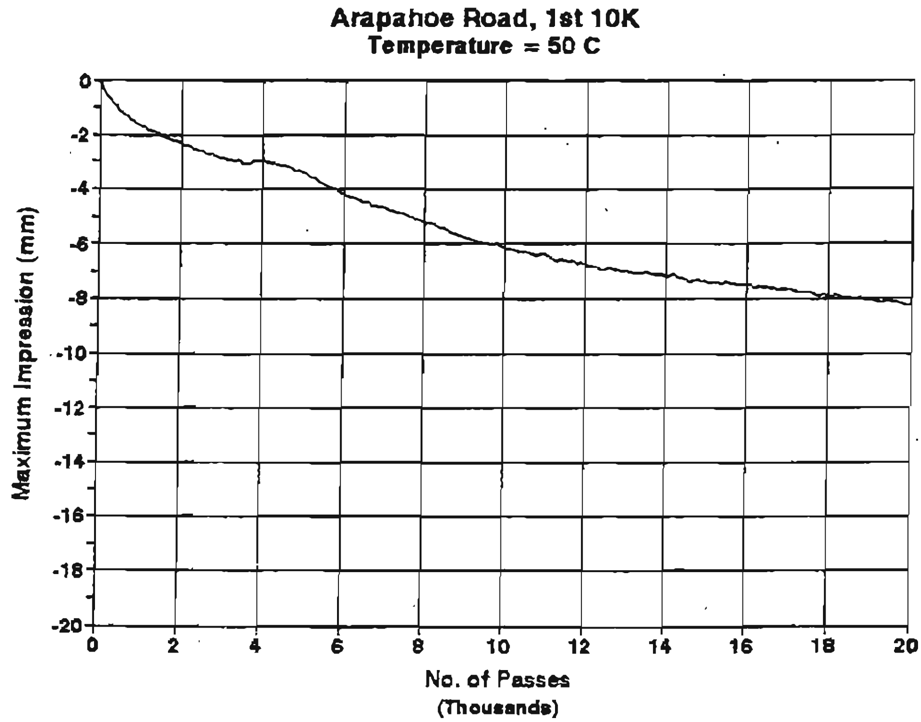


Fig. 16. Results of Lab Produced HMA in the Hamburg Wheel-Tracking Device on Arapahoe Road.



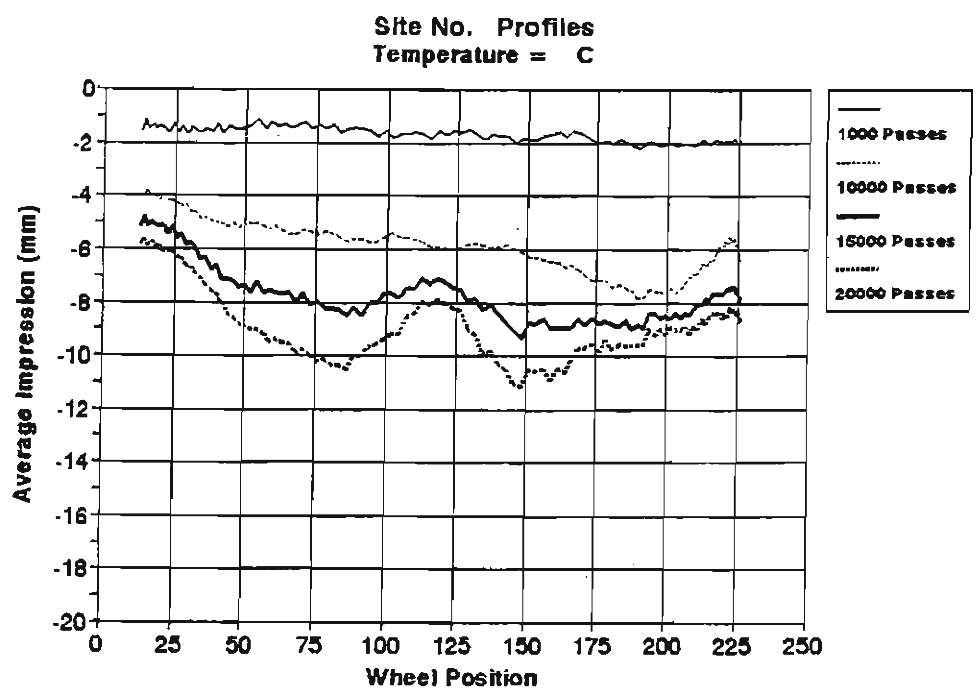
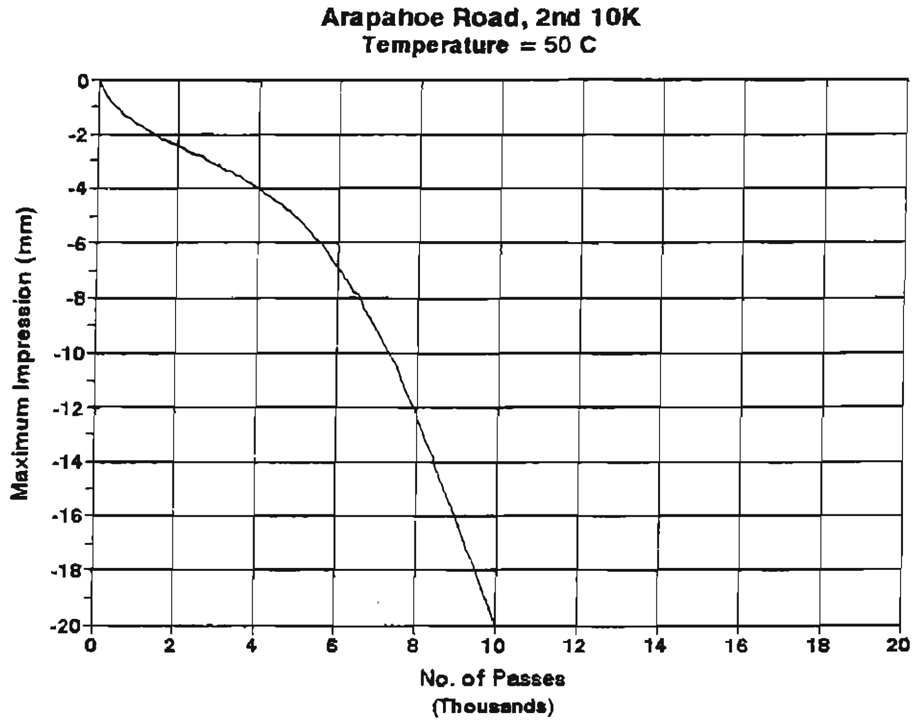


Fig. 17. Results of Field Produced HMA in the Hamburg Wheel-Tracking Device for the First 16,000 Tons on Arapahoe Road.



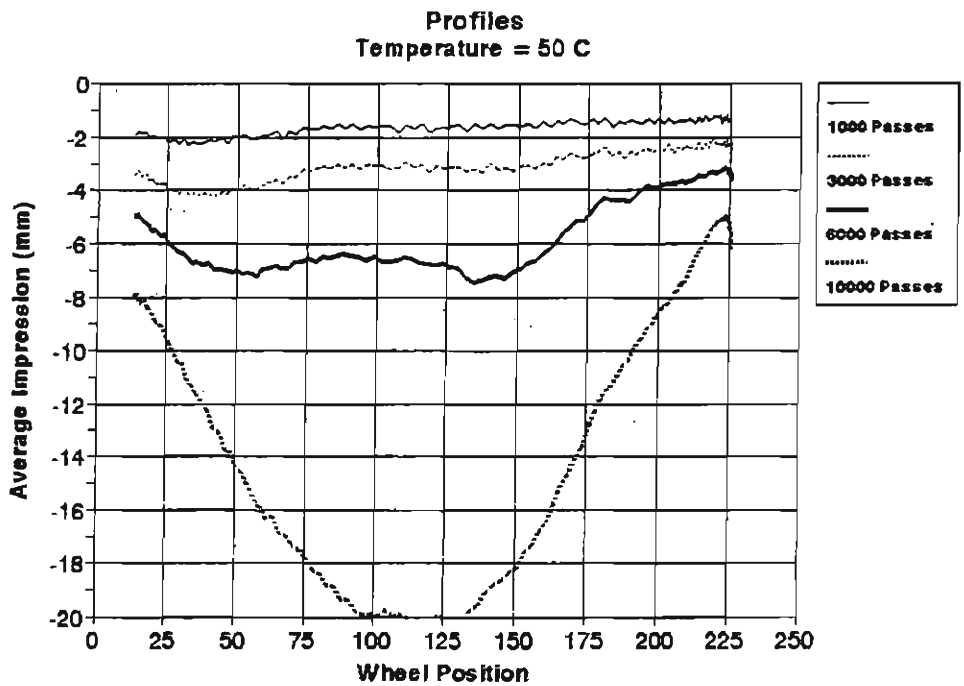


Fig. 18. Results of Field Produced HMA in the Hamburg Wheel-Tracking Device for the Final 10,000 Tons on Arapahoe Road.

5.4 6th Avenue

5.4.1 Void Acceptance Results

Control charts for the void properties are shown in Figs. 19 through 22. For tests 1 through 8 one set of target values were used. After test 8, the target values for air voids and VMA were lowered by 0.5%. This was necessary because the CDOT Region laboratory obtained results that were consistently lower than the CDOT Central and contractor laboratories.

The statistical summary for each element tested by the CDOT Region laboratory is shown in Tables 11 and 12. The pay factor received by the contractor was 101.9, as shown in Table 13. Additionally, the pay factor calculated using results from the CDOT Central laboratory and contractor's laboratory are shown in Table 13. The targets for air voids and VMA were not shifted to calculate the pay factor from the CDOT Central and contractor results.

Table 11. Void Acceptance Testing Results on 6th Avenue for the First 8 Tests.

	Design Target	Field Production		
		Average	S.D.	n
Relative Compaction (%)	92-96	93.3	0.5	12
Air Voids (%)	4.0	3.44	0.58	8
VMA (%)	14.2	13.71	0.49	8
Asphalt Content (%)	4.8	4.72	0.17	8
Stability	35	41.5	2.3	8

Table 12. Void Acceptance Testing Results on 6th Avenue for the Final 22 Tests.

	Design Target	Field Production		
		Average	S.D.	n
Relative Compaction (%)	92-96	93.2	0.6	39
Air Voids (%)	3.5	2.61	0.44	22
VMA (%)	13.7	12.87	0.33	22
Asphalt Content (%)	4.8	4.75	0.18	22
Stability	35	37.8	3.5	22

Table 13. Pay Factors Calculated for the 6th Avenue Project from Void Testing.

Element	Pay Factors		
	Region	Central	Contractor
Relative Compaction	104.6	104.6	104.6
Air Voids	97.1	102.1	102.6
VMA	101.4	104.5	99.3
Asphalt Content	102.9	103.0	103.0
Stability	92.8	105	104.5
Composite	101.0	103.8	102.9

There were statistically significant differences between results from the Region laboratory and the CDOT Central and contractor's laboratories. The largest differences were in the measured Hveem stabilities, and there were noticeable differences in the measured air voids. By "shifting" the target of the air voids and VMA by 0.5% for the Region laboratory, there were minimal differences in the resulting pay factors. However, it is not desirable to have a "shift" factor for each laboratory. Training and round robin testing should be performed to minimize the differences between laboratories.

5.4.2 European HMA Test Results

Samples mixed in the laboratory and produced in the field were tested in the French rutting tester and the Hamburg wheel-tracking device. Comparisons of the field and laboratory prepared samples were very similar in both devices. The field and lab produced material tested in the French rutting tester is shown in Fig. 23. The Hamburg wheel tracking results for the lab produced material is shown in Fig. 24, and the field produced material is shown in Fig. 25. The void acceptance testing on the project also indicated the field produced and laboratory prepared samples were very similar.

5.4.3 Discussion

The contractor made extraordinary efforts to validate the field produced HMA prior to placing it on the project. The plant produced HMA was tested 5 different times before it was sent to the project. The CDOT performed one of those checks two days prior to paving. Advanced planning was critical to the success of this project.

It is necessary to have an effective assurance testing program. During the first 4000 tons of paving, the Texas gyratory compactor went out of calibration because of a manufacturing defect. Fortunately, the assurance program identified the change in results so the Texas gyratory could be repaired. Unfortunately, there was a lot of confusion for the first 4,000 tons of paving. An adequate assurance testing program prevented the confusion from lasting longer.

Testing for volumetric properties throughout the project was performed by the CDOT Central and Region laboratories and the contractor. Results from the three different laboratories did not always provide statistically similar results. The variability of results is a problem that must be corrected before future projects use the specification.

The void acceptance specification was prepared for a standard deviation including production and testing variability of 0.6 for air voids and VMA. Regardless of the laboratory, the material produced for the 6th Avenue project was well within the standard deviation used to develop the specifications for air voids and VMA.

The material produced for the 6th Avenue project had standard deviations slightly higher than those used to develop the specifications for Hveem stability and asphalt content.

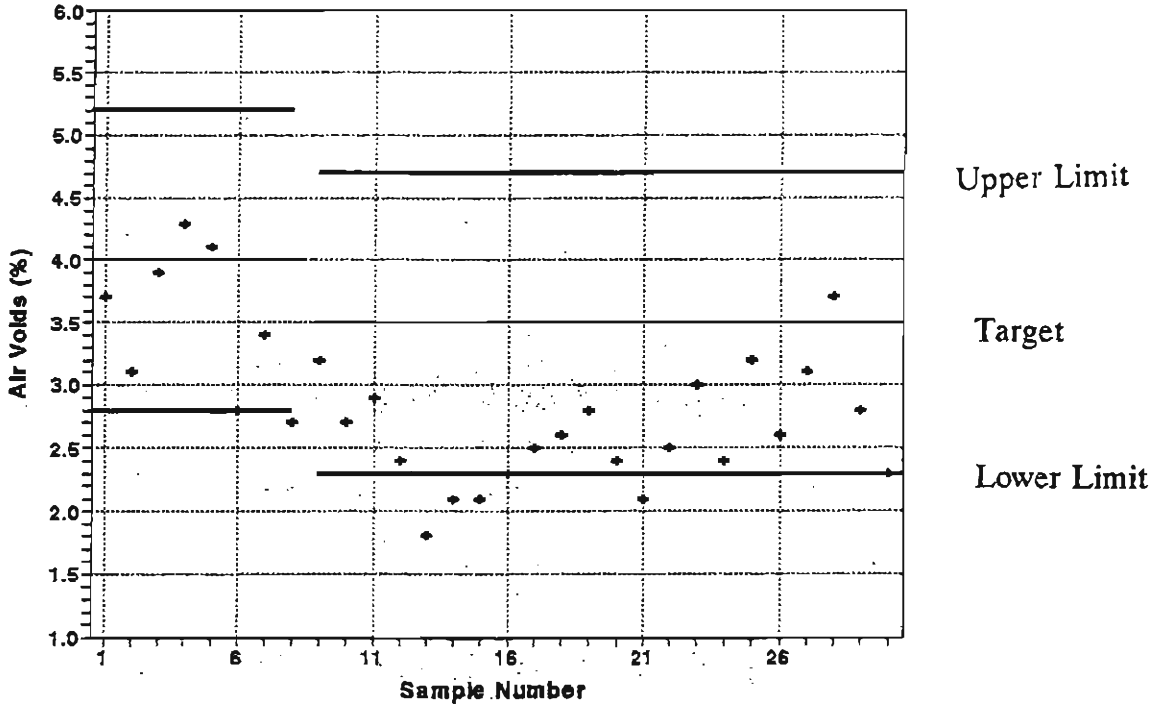


Fig. 19. Control Chart for Air Voids on 6th Avenue.

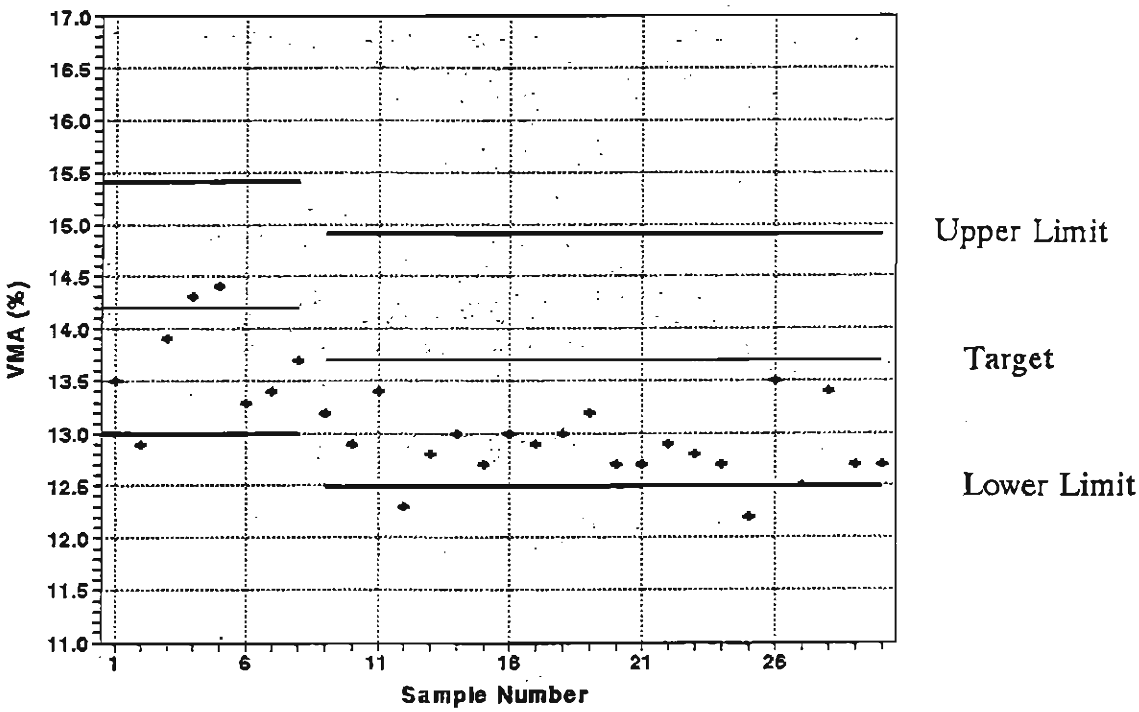


Fig. 20. Control Chart for VMA on 6th Avenue.

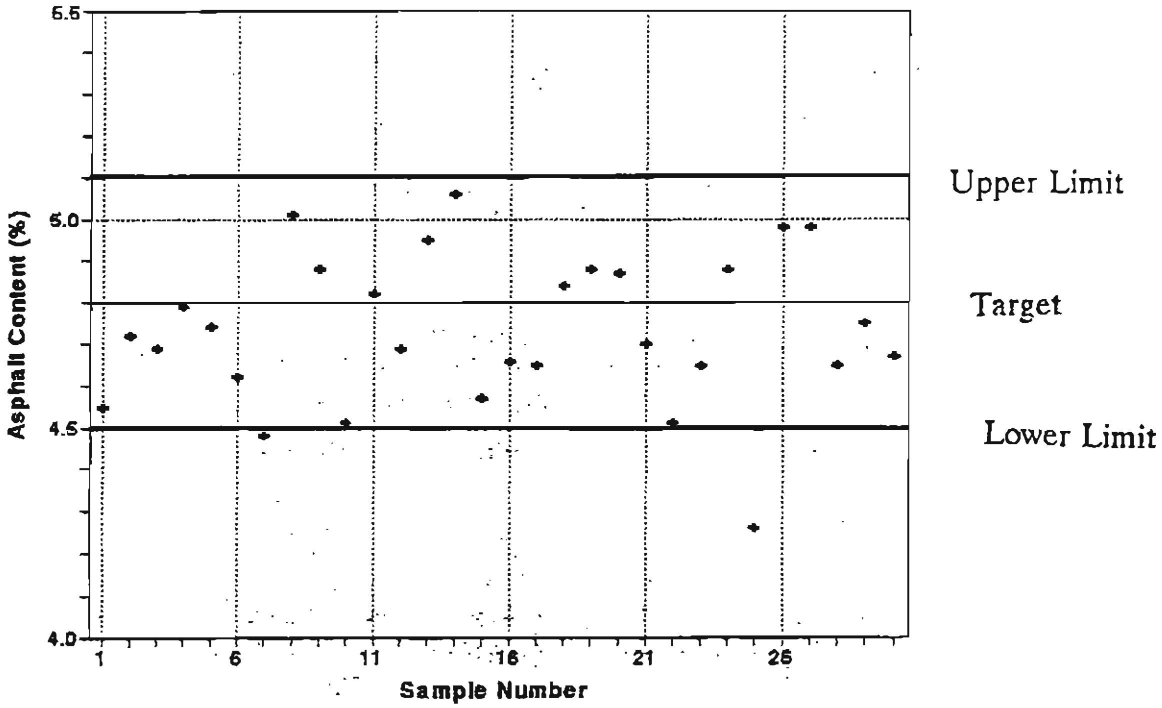


Fig. 21. Control Chart for Asphalt Content on 6th Avenue.

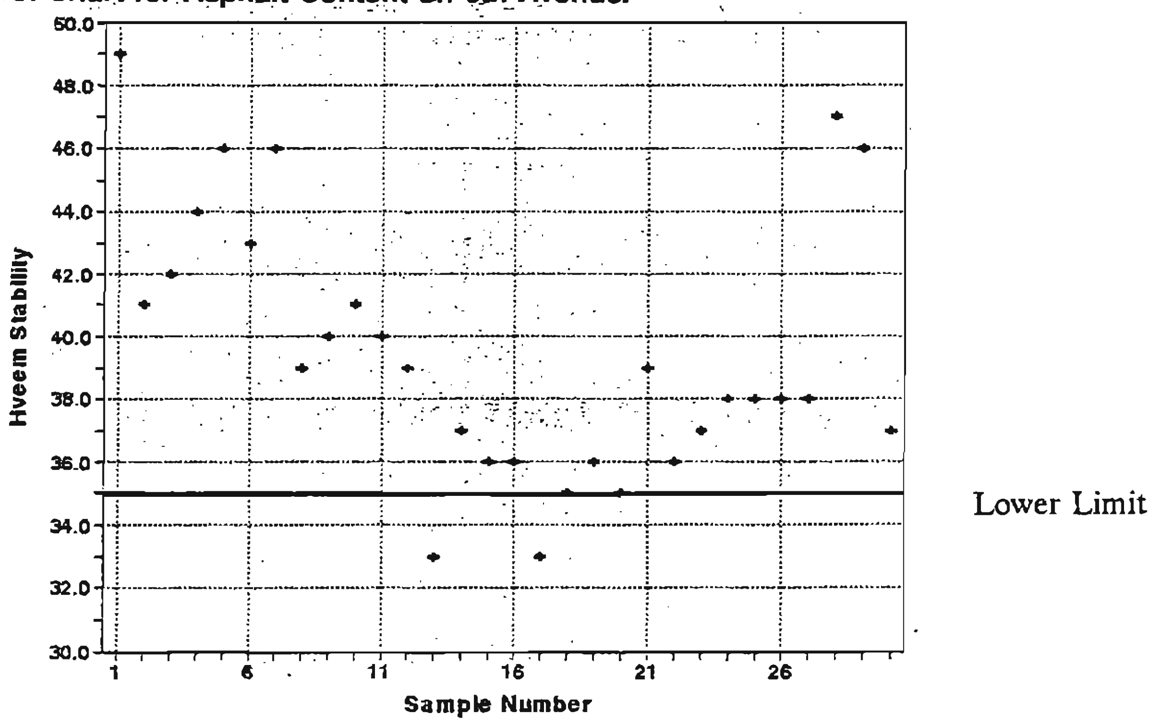


Fig. 22. Control Chart for Stability on 6th Avenue.

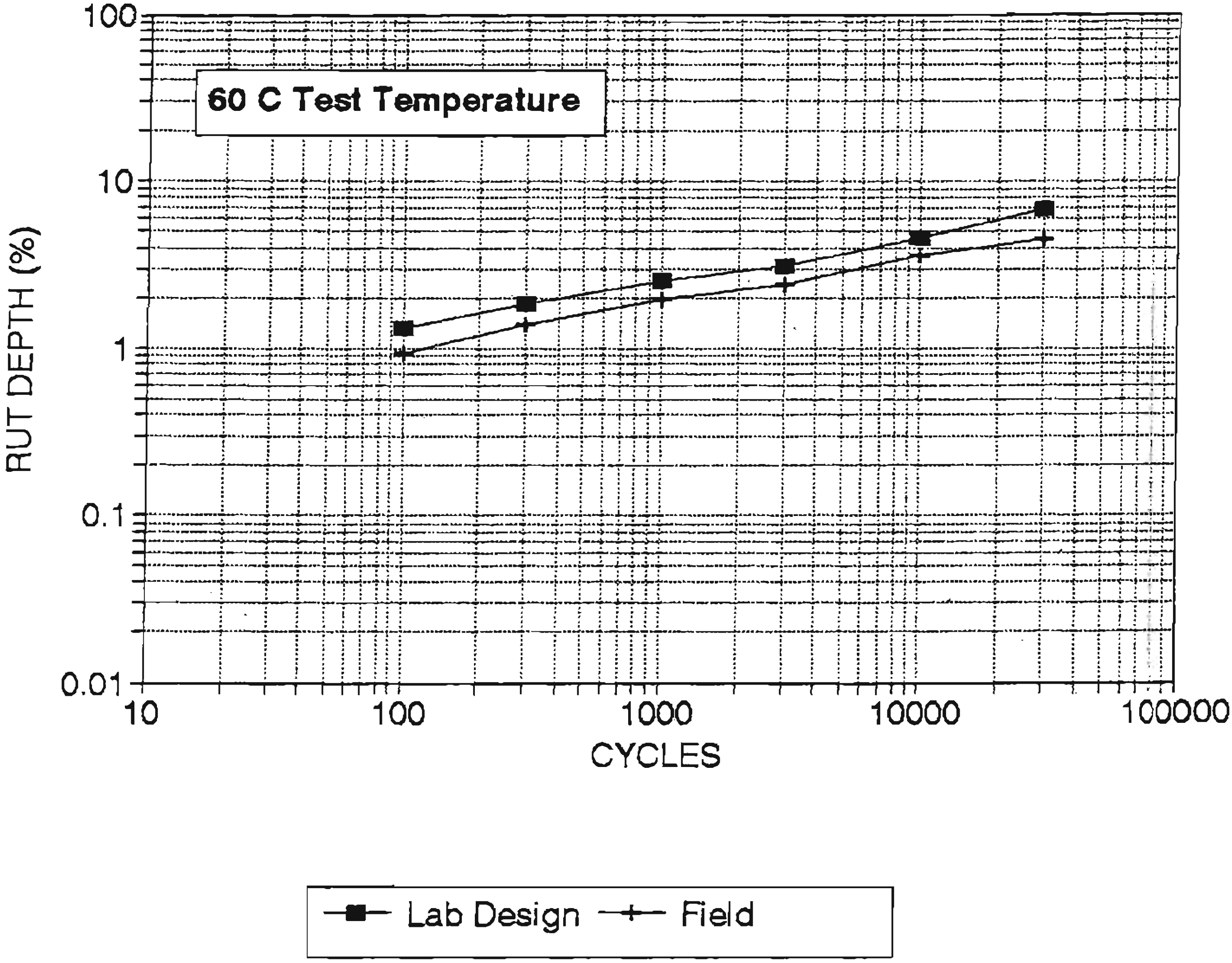
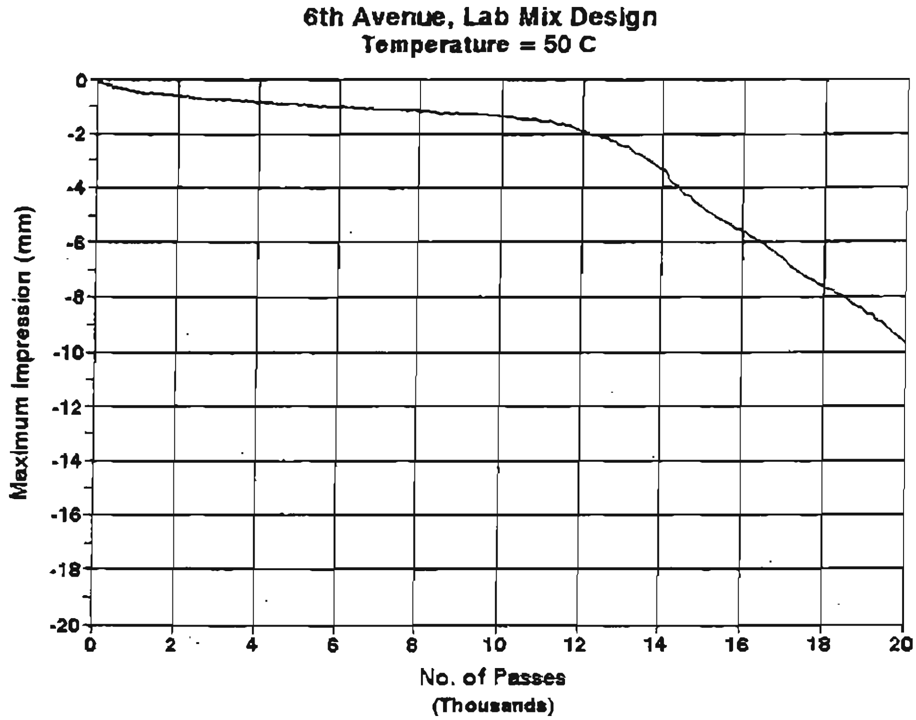


Fig. 23. Results of Lab and Field Produced HMA in the French Rutting Tester on 6th Avenue.



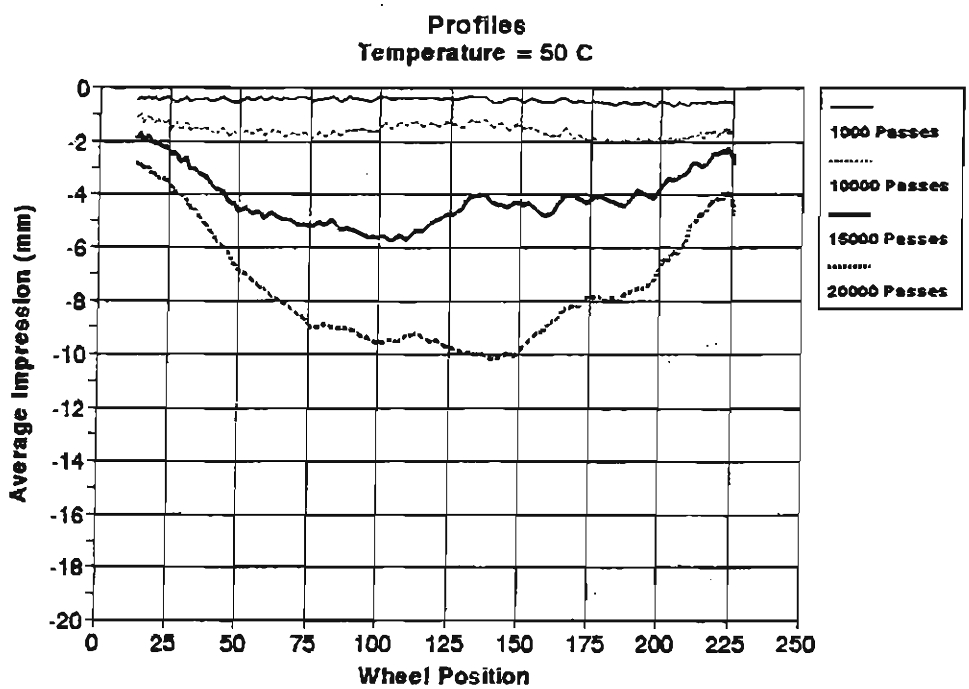
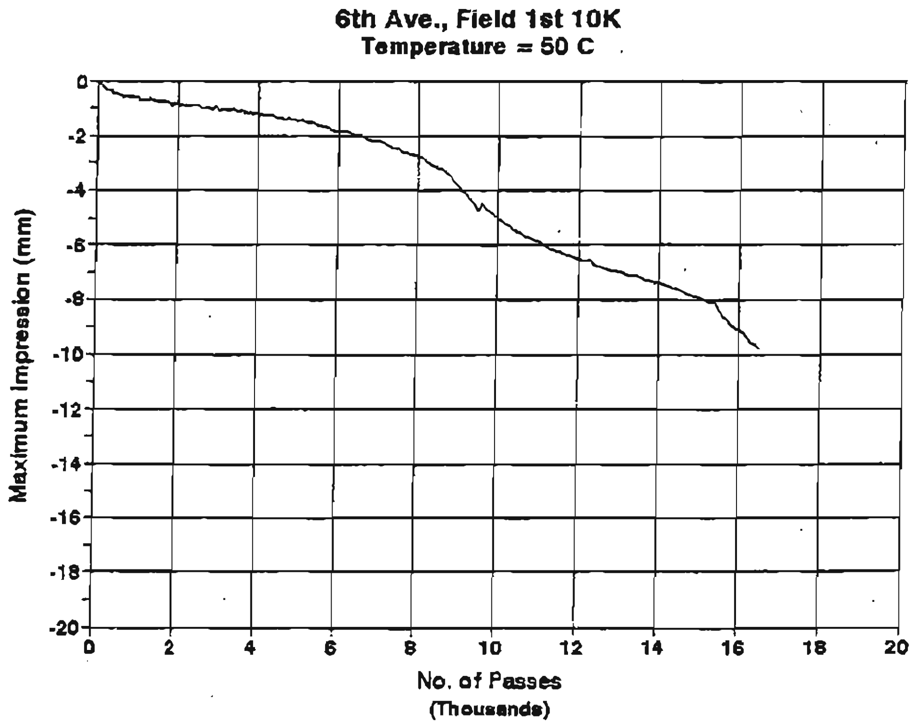


Fig. 24. Results of Lab Produced HMA in the Hamburg Wheel-Tracking Device on 6th Avenue.



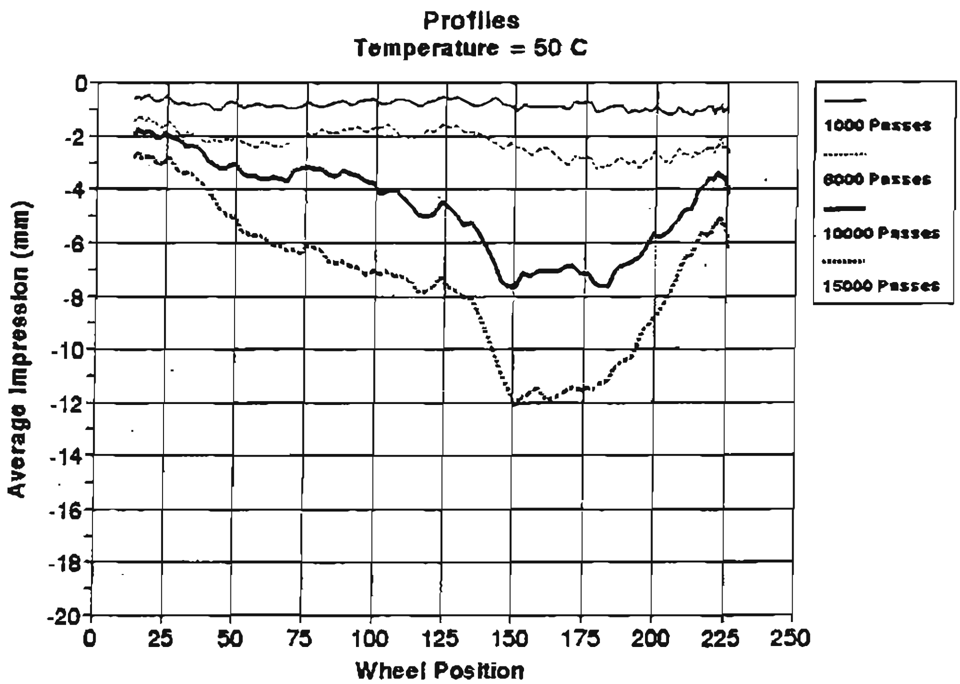


Fig. 25. Results of Field Produced HMA in the Hamburg Wheel-Tracking Device on 6th Avenue.

6.0 OTHER CASE HISTORIES

6.1 Aggregate Specific Gravity

On the Hampden Avenue project in Denver, problems developed with field compaction; it became very difficult to achieve the specified density. Aggregate gradation and asphalt contents indicated the HMA had incurred no change. Void testing was performed for information on the project, and indicated a change had occurred. The field verification air voids increased approximately 2%. Additional asphalt cement was added to the HMA.

Two weeks later the problem was identified. The aggregate was purchased from a commercial quarry. Since the different benches at the quarry have different properties, the quarry blends the blasted rock to provide a more uniform product. When no problems existed on the Hampden Avenue project, the blended rock was being delivered to the contractor. Problems developed on the project when the quarry was providing unblended rock to the project.

The aggregate change resulted in a lowered specific gravity of the aggregate. Since aggregate is added into the plant by weight, the increased volume was not identified. The increased volume resulted in a "drier" HMA. Since the gradation test is by weight, it did not identify the volumetric problem either. However, the field verification air void properties identified the "drier" HMA because of the change in air voids.

6.2 Natural Sands

On a project near Wray, the field verification air void properties lowered by approximately 2%. No changes in gradation or asphalt content were detected. The contractor inadvertently had increased the quantity of rounded natural sands and decreased the quantity of angular crushed sands into the HMA. Since the natural sands and crushed sands had a very similar gradation, the gradation testing indicated no change. However, the field verification air voids properly identified the change.

6.3 Absorptive Aggregates

On a project near Wolf Creek Pass, a highly absorptive aggregate was used. The aggregate absorbed 3.5% water. The nuclear asphalt content gauge indicated the contractor was producing HMA at the specified asphalt content. Although moisture corrections were performed as part of the nuclear asphalt content gauge procedure, not all of the moisture was removed from the highly absorptive aggregate, and the gauge reading was incorrect. There were problems achieving compaction on the project.

The field verification air voids indicated the HMA had air voids of 2.7% higher than the mix design. Additional asphalt cement was added to the HMA to fill the air voids. Compaction problems were reduced significantly.

6.4 Baghouse Fines

A project on I-70 at Copper Mountain was finished in the summer of 1993. The HMA placed was probably the most tested HMA ever in Colorado. Testing on laboratory prepared HMA indicated optimum asphalt content of 5.7% at 3.7% air voids. Air voids of laboratory compacted HMA less than 2.4% would be very susceptible to rutting.

When production started, the field verification air voids were 1.8% to 2.2%. The HMA had lost nearly 2% air voids. It was believed the change in air voids was related to the change in quantity of P200. Extraction testing identified an increase of 2% material passing the 75 micron sieve size (P200). The change in P200 likely came from a 1.3% increase in the stockpile (based on gradations from samples taken off the cold feed belt), and the baghouse fines were attributed for the other 0.7%. Testing on the French rutting tester and Hamburg wheel-tracking device indicated the mix was unacceptable. Three options were suggested.

Option 1: <u>Asphalt Content.</u> The optimum asphalt cement content could be reduced by 0.3%. Testing on the French rutting tester and Hamburg wheel-tracking device indicated the slight change would make the mix acceptable. This option was not considered desirable because a great deal of effort was made to increase the asphalt content of this HMA.

Option 2: Adjust Gradation. A change in 0.3% asphalt content would be approximately equivalent to a change in 0.8% P200. By increasing the blending percentages of the aggregates, the material passing the P200 entering the plant could be reduced. A washed natural sand that was very angular contained very little P200 and its proportion could be increased 10%. The crushed fines contained high quantities of P200 and its proportion could be reduced by 10%. This slight gradation adjustment would decrease the P200 entering the plant by [illegible]%.

Option 3: Baghouse Fines. The baghouse fines could be wasted. This option was not tried.

6.5 Asphalt Cement Viscosity

A second problem was identified on the Copper Mountain project. The asphalt cement used for the design was an AC-10 with an absolute viscosity of 900 poises at 60°C. The asphalt cement delivered to the project had a viscosity of 550 poises, approximately one grade softer. With the softer asphalt cement, the void properties of the field produced material were significantly lower than the laboratory design. It was discovered that the refinery was adding excessive quantities of liquid anti-stripping additive that resulted in the lower viscosities. The refinery corrected the problem. When the asphalt cement delivered to the project had a viscosity similar to the asphalt cement in the mix design, the void properties were similar to the mix design.

The problems on the Copper Mountain project were likely a combination of the higher P200 and lower viscosity than that used in the mix design.

7.0 VOID ACCEPTANCE SPECIFICATION REVIEW

7.1 Recommended Specification Modifications

The void acceptance specification should be applied on projects with large quantities of HMA. The specification should not apply to small quantities or patching.

The detailed random sampling plan used for each of the projects has worked very well. The sampling plan should be detailed in a Colorado Procedure for inclusion in the Materials Manual.

The standard deviations used to develop the specification appear reasonable. The standard deviation that includes within laboratory and production variability was achievable regardless of the laboratory performing the testing as shown in Table 14. However, there were some noticeable differences between laboratories in the targets, average values, calculated. It is necessary to continue training and round robin testing to improve the between-laboratory repeatability.

Table 14. Within-Laboratory and Production Variabilities (Standard Deviations).

Projects	Air Voids	VMA	Stab.
6, 1992 Projects	0.62	0.51	3.6
I-70 @ Silverthorne	0.64	0.37	4.5
Arapahoe Road	0.54	0.40	2.3
6th Avenue	0.44	0.33	3.4
Specification	0.6	0.6	3

For 1994, it is recommended that each Region should have a project that measures the void acceptance properties for <u>information</u>. A second alternative would be to use the void properties for acceptance but expand the tolerances to include the between laboratory variability. Results from these projects can be used to better assess the repeatability. For these projects, the Central laboratory should test one assurance sample per day. This will allow for a large data base to compare between laboratory results.

Provisions should be made to have "back-up" laboratory testers so one laboratory can perform the acceptance testing for an entire project. When laboratory equipment broke or operators went on vacation, the Central laboratory had to perform acceptance and assurance tests. This situation should never occur.

In the current program, three samples are selected randomly for each days production. The number of samples may have to be increased, particularly when a contractor is making adjustments to his mix. Testing four samples for each days production should be investigated.

The formulas in the specification need to be reviewed. The beta function in the specification may not be exactly the same as that used in the computer program to calculate the pay factor. Additionally, some of the formulas may still contain typographical errors. The computer program worked effectively but still caused new users difficulty. Some modifications should be made to the computer program to make it more forgiving to operator errors.

7.2 Time of Testing Analysis

The testers were interviewed to determine the testing time required for each of the projects. The testing time was controlled primarily by the temperature of the sample delivered to the laboratory. If the sample was delivered hot enough to split, testing could proceed immediately. If the sample had cooled, the sample had to be reheated for 2 hours before it could be split. In all cases the samples were delivered hot and split immediately. Samples were often placed in an insulated cooler during delivery. It should be emphasized that the delivery of a hot sample can save a significant amount of time.

Table 15. Total Time for Testing Volumetrics and Stability.

Task	Time	Comments
Split sample for testing	0:15	5 samples
Heat sample for compacting	0:45	3 samples to 121°C
Compact 3 samples	0:20	ASTM D 4013
Allow samples to cool	0:30	
Bulk specific gravity of compacted samples	0:20	AASHTO T 166
Heat samples for stability	2:00	3 samples to 60°C
Perform Stability	0:20	AASHTO T 246
Maximum specific gravity of mix (AASHTO T 209)	0:00	Performed while allowing samples to cool or reheat
Totals	4:30	

Table 16. Total Additional Time for Testing Moisture Susceptibility (AASHTO T 283).

Task	Time	Comments
Split sample	0:10	6 additional samples
Compact 6 samples	0:25	ASTM D 4013
Bulk specific gravity of compacted sample	0:40	AASHTO T 166
Vacuum saturation	0:20	Placing sample in freezer and hot water bath is negligible
Tensile strengths	0:25	
Totals	2:00	Results require 2 days

7.2.1 Total Testing Time

The tests performed include volumetrics, stability, and moisture susceptibility. A break down of the total time required to test one sample for volumetrics and stability Is shown in Table 15. If volumetrics are the only test performed, 2 hours and 10 minutes are required. Volumetrics and stability results require 4 hours and 30 minutes of total time. The additional time required to test for moisture susceptibility is 2 hours as shown in Table 16. AASHTO T 283 is performed approximately once per week of production.

7.2.2 Time in Motion

If samples are uniformly spaced throughout the day, three samples can be tested for volumetrics and stability in 8 hours and four samples can be tested in 10 hours. However, random sampling does not often allow for uniformly spaced samples. Random sampling will permit the testing of 3 samples in 10 to 12 hours. These times are assuming two laboratory technicians.

8.0 CONCLUSIONS

The conclusions in this study were based upon the construction of three projects in Colorado using void properties to accept asphalt mixtures.

1) The void and gradation acceptance specifications can sometimes provide the same results. This occurred on the I-70 project. However, as observed on the Arapahoe Road project, the void and gradation specifications can sometimes provide quite different results. Based on testing with European equipment, the void specification related more to actual pavement performance than the gradation specification.

2) Meeting the void acceptance specification does not ensure the HMA is a high quality material, only that the HMA produced in the field matches the HMA designed. On the I-70 project the HMA designed had a very low quality and the HMA produced matched the design very closely. Mix design specifications to ensure a quality HMA are needed.

3) The standard deviations used to develop the specification tolerances are reasonable. Testing and production variability were well within the tolerances for most of the HMA produced on these projects. Differences between laboratories in the measured stabilities and air voids occurred on one of the projects. Additional training and round robin testing needs to be performed to improve the between-laboratory variability.

9.0 IMPLEMENTATION

The void acceptance specification can identify changes in an HMA during production that can be detrimental to the performance of a pavement; gradation acceptance cannot identify many of these changes. The use of a void acceptance specification can improve the quality of the HMA pavements placed in Colorado.

Although the specification itself appeared reasonable for contractors to achieve and CDOT construction personnel to administer, there were the problems encountered with the differences in test results between laboratories on the 6th Avenue project. There is a need to improve the between-laboratory repeatability. It is recommended to use the void acceptance specification on one project per Region in 1994 for either 1) information only, or 2) as a specification with wider tolerances (for example, tolerances set at 2.5 standard deviations). The data generated from these projects can be used to better understand the between-laboratory variability. Additional training of operators and round robin testing is needed.

10.0 REFERENCES

1. D'Angelo, J.A. and T. Ferragut (1991), "Summary of Simulation Studies from Demonstration Project No. 74: Field Management of Asphalt Mixes," Journal of the Association of Asphalt Paving Technologists, Volume 60, pp. 287-309.

2. Aschenbrener, T. (1992), "Investigation of the Rutting Performance of Pavements in Colorado," Colorado Department of Transportation, CDOT-DTD-R-92-12, 63 pages.

3. Aschenbrener, T. and K.D. Stuart (1992), "Description of the Demonstration of European Testing Equipment for Hot Mix Asphalt Pavement," Colorado Department of Transportation, CDOT-DTD-R-92-10, 23 pages.

APPENDIX A

PRE-BID MEETING AGENDA

4-5-93

Demonstration of A Volumetric Acceptance Program for Hot Mix Asphalt in Colorado

I. Introduction
   A. Demonstration Project 74
   B. Correlation with field performance
   C. Extractionless acceptance
   D. 5-Year implementation plan
   E. Training to date

II. Projects
   A. Project numbers, names, and locations
   B. Pavement management techniques
   C. Overlay thickness and tonnage
   D. Mandatory pre-bid conference
   E. Bid costs of HMA

III. Contractor Operation
   A. Plant type, fuel source, production rating
   B. Baghouse/wet scrubber
   C. Storage silo
   D. Transport trucks/haul time
   E. Paver type/rollers

IV. Mix Designs
   A. Specifications (Appendix A)
   B. Design method (private lab, plant produced)
   C. Aggregate source
   D. Gradation
   E. Optimum AC, VMA, stability, Lottman
   F. French, Hamburg, Georgia wheel-tracking tests

V. Field Acceptance
   A. Specifications (Appendix B)
   B. Region lab/trailer
   C. Test results
   D. "Go as is", "Go with change", "Redesign"
   E. Mix adjustments
   F. Incentive/Disincentive
   G. French, Hamburg, Georgia wheel-tracking tests

VI. Field Acceptance Specification Review
   A. Post construction meeting
   B. Recommended specification modifications
   C. Time of testing analysis (real time, time-in-motion)

VII. Conclusions

VIII. Future Research
   A. Monitor pavement performance to see if mix design specifications need revision

APPENDIX B

MIX DESIGN INFORMATION

[illegible]

Division of Transportation
State of Colorado
Form DOH 429   Flex 1.98

Date Received 7 /16/92

Project No: IMNHICX-CX70-2(176)
Location: Copper Mtn. to Silverthorne
District # 1   Subaccount: 89003
Lab # 513x-516x
Field Sample # 62612

LABORATORY DESIGN for HOT BITUMINOUS PAVEMENT - CONSTRUCTION

Item 403   Grading SF   Conoco AC-10
Pit name: Alpine Rock & LG Eve   Contractor/Supplier: Asphalt Paving

SIEVE ANALYSIS: T11 & T27, sampled by CP30

Test No.->	513x	554x	515x	516x	Hyd	As Used		Job Mix
% used-->	17.0	20.0	42.0	20.0	1.0			
1 1/2	100	100	100	100	100	100	1 1/2	
1	100	100	100	100	100	100	1	
3/4	100	100	100	100	100	100	3/4	100
5/8	100	100	100	100	100	100	5/8	
1/2	42	100	100	100	100	90	1/2	89
3/8	3	83	100	100	100	80	3/8	80
4	1	7	95	98	100	62	4	62
8	0	2	69	79	100	46	8	46
16	0	2	50	55	100	33	16	
30	0	2	37	30	100	23	30	23
50	0	2	26	11	100	15	50	
100	0	1	17	4	98	9	100	
200	0.0	1.2	10.7	1.5	97.0	6.0	200	6

%AC in aggr.

Combined Aggregate: Bulk SpG: 2.622   Sand Equivalency: 75.0

Ret .10

TEST RESULTS				
Percent bitumen	4.5	5.0	5.5	6.0
Max Sp. Gr. T209	2.507	2.487	2.467	2.447
Bulk Sp. Gr. T166	2.388	2.416	2.422	2.408
% Voids CPL 5105	4.7	2.8	1.8	1.6
Stability CPL 5105	53	51	44	26
Modulus CPL 5110				
Strength coefficient	0.44	0.44	0.44	0.44
VMA (effective)	15.3	14.7	14.9	15.8
VMA (bulk)	13.0	12.5	12.7	13.7
% of bulk VMA filled	63	76	85	87
Dust / AC ratio	1.28	1.14	1.03	0.94

IMMERSION-COMPRESSION   CPL 5104
% bitumen
PSI Wet
PSI Dry
% Absorption
% Swell
% Ret. Strength
% Additive used
Asphalt additive type

LOTTMAN	CPL 5109
4.6	% bitumen
39	Wet D.T.St
41	Dry D.T.St
7.31	% Voids
62	% Saturation
96	% T.S.Ret.
	% Additive

Optimum asphalt content   5.0
Stability at Optimum A.C.   51
Lab Max. SpG at Optimum 2.487
% Voids at Optimum A.C. 2.84
Asphalt film thickness at Optimum A.C.: 9.1 microns

B1   Bob LaForce   757-9724

Date Reported 8/6/92

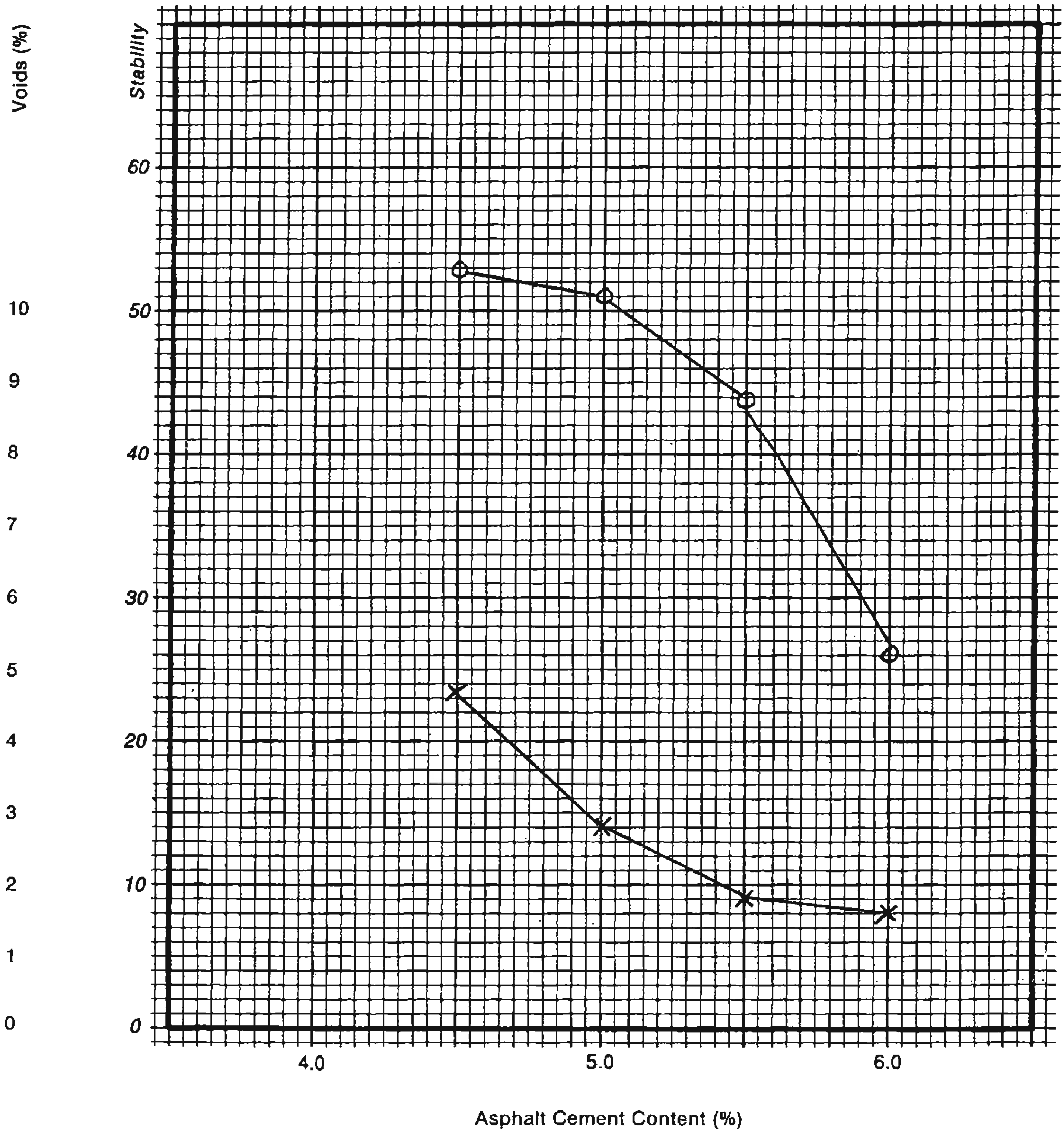
COLORADO DEPARTMENT OF HIGHWAYS

ASPHALT MIX DESIGN GRAPH

Project No. IMNHICX-CX 70-2 (176)

Location I-70, Silverthorne to Copper Mountain

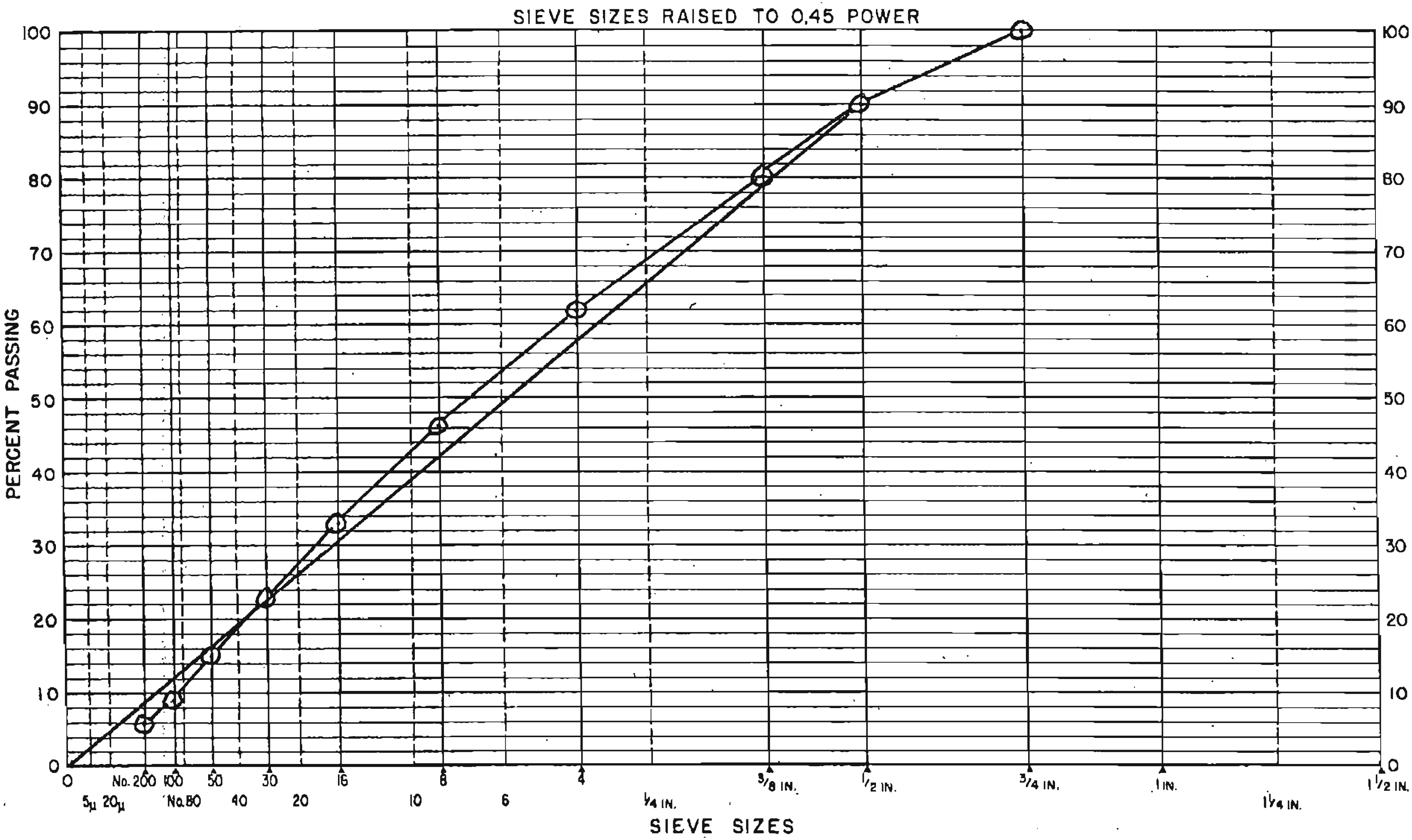
Field Sheet No. 62612



CDOH form #1094
3/91

COLORADO DEPARTMENT OF TRANSPORTATION

GRADATION CHART



REMARKS:

Alpine Rock / LG Everist

FS # 62612

Division of Transportation
State of Colorado
Form DOH 429 Flex 1.98

Project No: CY 11-0121-79
Location: SH 121 @ Ken caryl, Belleview
District # 6 Subaccount: 93128
Lab # 107x-110y

Date Received

Field Sample # 63358 (combination 2)

LABORATORY DESIGN for HOT BITUMINOUS PAVEMENT - CONSTRUCTION

Item 403 Grading C Sinclair AC-20 15% RAP 30-100
Pit name: MPM/KWC Contractor/Supplier: Kiewit

SIEVE ANALYSIS: T11 & T27, sampled by CP30

Test No.->	107x	108x	109x	110y	Hyd	As Used		Job Mix
% used-->	29.0	35.0	20.0	15.0	1.0			
1 1/2	100	100	100	100	100	100	1 1/2	
1	100	100	100	100	100	100	1	
3/4	100	100	100	100	100	100	3/4	100
5/8	100	100	100	100	100	100	5/8	
1/2	58	100	100	97	100	87	1/2	87
3/8	33	100	100	84	100	78	3/8	78
4	2	80	100	68	100	60	4	60
8	1	59	83	57	100	47	8	47
16	1	43	56	45	100	34	16	
30	1	32	36	39	100	25	30	25
50	1	24	21	24	100	17	50	
100	1	16	9	14	98	11	100	
200	0.2	10.8	2.9	8.0	97.0	6.6	200	6.6
%AC in aggr.	0.00	0.00	0.00	4.90	0.00	0.74		

Combined Aggregate: Bulk SpG: 2.677 Sand Equivalency:

TEST RESULTS

Percent bitumen	4.5	5.0	5.5	6.0
Max Sp. Gr. T209	2.534	2.513	2.493	2.472
Bulk Sp. Gr. T166	2.420	2.436	2.437	2.436
% Voids CPL 5105	4.5	3.1	2.2	1.5
Stability CPL 5105	51	44	30	20
Modulus CPL 5110				
Strength coefficient	0.44	0.44	0.44	0.44
VMA (effective)	15.2	15.0	15.4	15.8
VMA (bulk)	13.7	13.5	14.0	14.4
% of bulk VMA filled	67	77	83	89
Dust / AC ratio	1.40	1.25	1.13	1.03

IMMERSION-COMPRESSION CPL 5104
% bitumen
PSI Wet
PSI Dry
% Absorption
% Swell
% Ret. Strength
% Additive used
Asphalt additive type

LOTTMAN CPL 5109
% bitumen
Wet D.T.St
Dry D.T.St
% Voids
% Saturation
% T.S.Ret.
% Additive

Optimum asphalt content
Stability at Optimum A.C.
Asphalt film thickness at Optimum A.C.: microns

Lab Max. SpG at Optimum
% Voids at Optimum A.C.

Date Reported 5/17/93

Bob LaForce 757-9724
Flexible Pavement Engineer

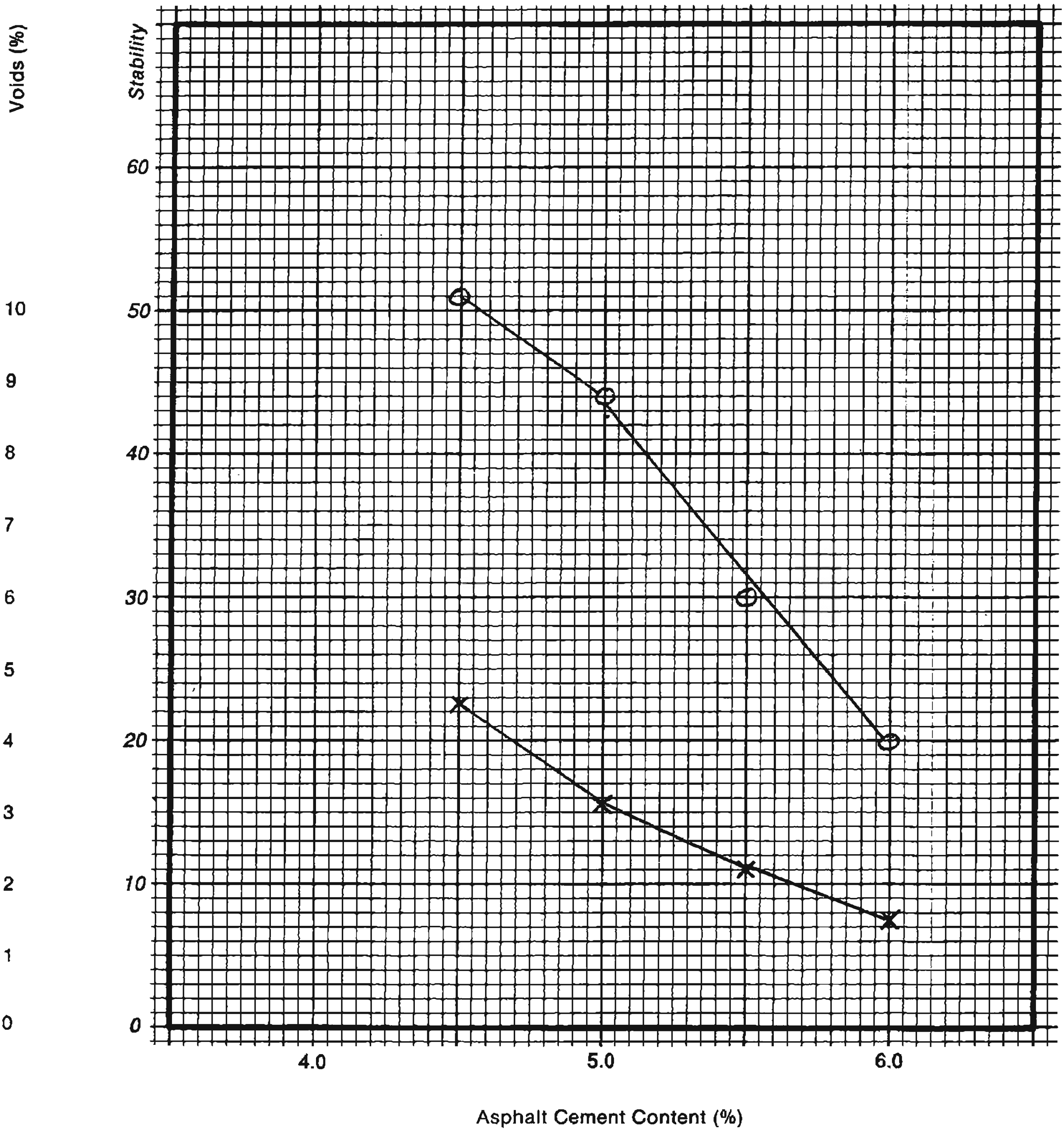
COLORADO DEPARTMENT OF HIGHWAYS

ASPHALT MIX DESIGN GRAPH

Project No. CX 10-0088-42

Location Arapahoe Road, Galena to Parker

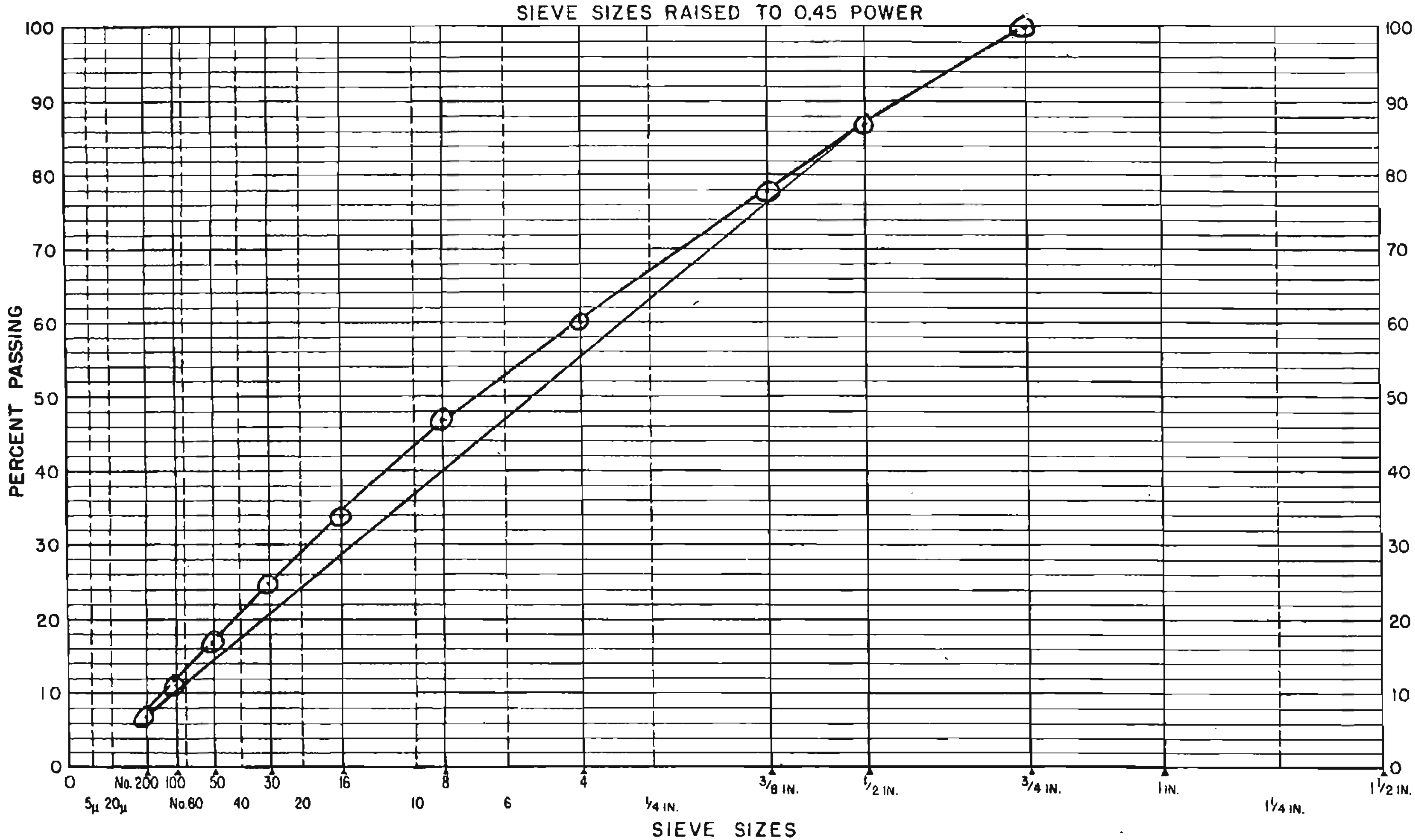
Field Sheet No. 63358



CDOH form #1094
3/91

COLORADO DEPARTMENT OF TRANSPORTATION

GRADATION CHART



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REMARKS:

CX 10-0088-42

Spec. Agg

F.S. 63358

Division of Transportation
State of Colorado
Form DOH 429   Flex 1.99

Date Received 07/16/93

Project No: CX 11-0006-17
Location: 6th Ave.,Wadsworth to Federal
District # 6   Subaccount: 93092
Lab # 553x-555x
Field Sample # 63367

LABORATORY DESIGN for HOT BITUMINOUS PAVEMENT - CONSTRUCTION

Item 403   Grading C   Conoco AC-10 (30-100-1500 PSI)
Pit name: MPM/Crane   Contractor/Supplier: Western Paving

SIEVE ANALYSIS: T11 & T27, sampled by CP30

Test No.->	553x	554x	555x	Hyd	As Used		Job Mix
% used-->	31.0	48.0	20.0	1.0			
1 1/2	100	100	100	100	100	1 1/2	
1	100	100	100	100	100	1	
3/4	99	100	100	100	100	3/4	100
5/8	76	100	100	100	93	5/8	
1/2	53	100	100	100	85	1/2	85
3/8	20	100	100	100	75	3/8	75
4	2	85	100	100	62	4	62
8	1	62	96	100	50	8	50
16	1	43	61	100	34	16	
30	1	32	33	100	23	30	23
50	1	23	14	100	15	50	
100	1	16	6	98	10	100	
200	0.6	11.1	2.8	97.0	7.0	200	7.0

%AC in aggr.
Combined Aggregate: Bulk SpG: 2.675   Sand Equivalency:

TEST RESULTS

Percent bitumen		4.5	5.0	5.5	6.0
Max Sp. Gr.	T209	2.523	2.503	2.482	2.462
Bulk Sp. Gr.	T166	2.388	2.417	2.420	2.421
% Voids	CPL 5105	5.4	3.4	2.5	1.7
Stability	CPL 5105	46	43	38	33
Modulus	CPL 5110				
Strength coefficient		0.44	0.44	0.44	0.44
VMA (effective)		15.9	15.3	15.5	15.9
VMA (bulk)		14.7	14.2	14.5	14.9
% of bulk VMA filled		63	75	82	88
Dust / AC ratio		1.50	1.34	1.21	1.11

IMMERSION-COMPRESSION CPL 5104		LOTTMAN	CPL 5109
% bitumen		4.8	% bitumen
PSI Wet		35	Wet D.T.St
PSI Dry		41	Dry D.T.St
% Absorption		7.17	% Voids
% Swell		56	% Saturation
% Ret. Strength		85	% T.S.Ret.
% Additive used		0.0	% Additive
Asphalt additive type			

Optimum asphalt content   4.8
Stability at Optimum A.C.   44
Lab Max. SpG at Optimum 2.511
% Voids at Optimum A.C. 4.00
Asphalt film thickness at Optimum A.C.: 7.3 microns

Date Reported 7/29/93

Bob Laforce   757-9724
Flexible Pavement Engineer

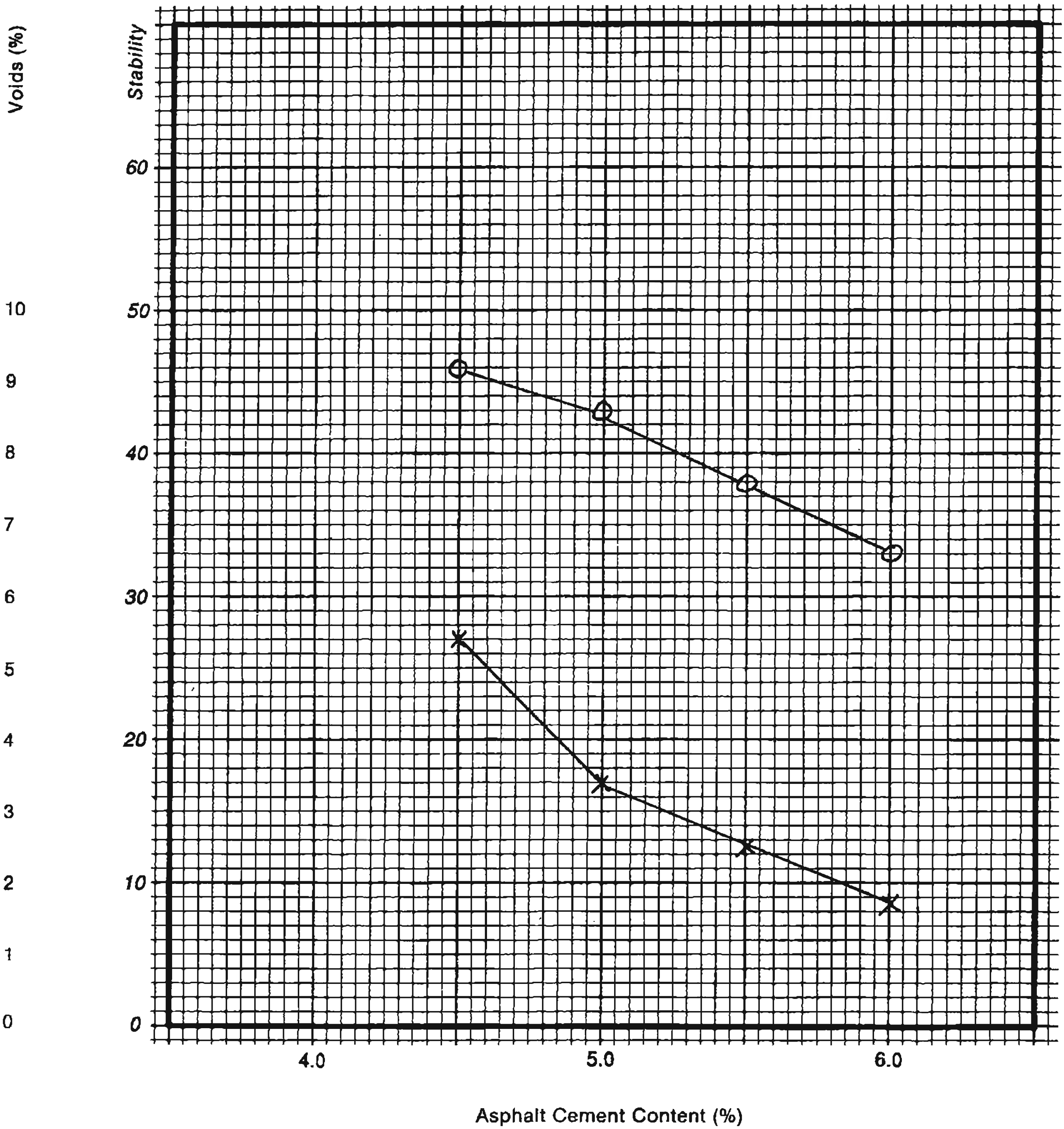
COLORADO DEPARTMENT OF HIGHWAYS

ASPHALT MIX DESIGN GRAPH

Project No. CX 11-0006-17

Location 6th Avenue, Wadsworth to Federal

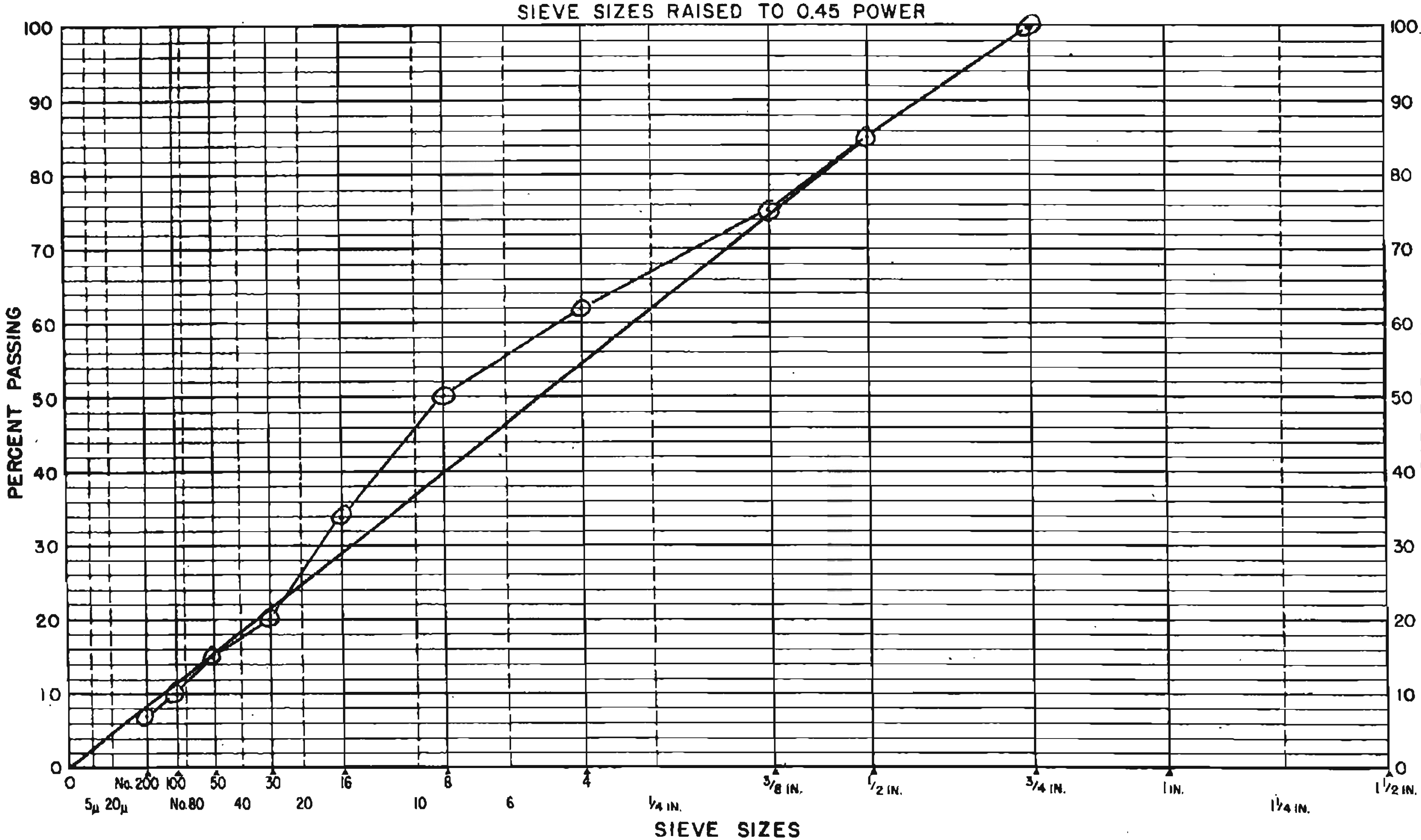
Field Sheet No. 63367



CDOH form #1094
3/91

COLORADO DEPARTMENT OF HIGHWAYS

GRADATION CHART



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REMARKS:

MPM Spec. Agg / Crane

FS # 63367

APPENDIX C

VOID ACCEPTANCE SPECIFICATION

REVISION OF SECTION 105
CONTROL OF WORK

Section 105 of the Standard Specifications is hereby revised for this project as follows:

Subsection 105.03 shall include the following:

Conformity to the Contract of all Hot Bituminous Pavement, Item 403, will be determined in accordance with the following:

All work performed and all materials furnished shall conform to the lines, grades, cross sections, dimensions, and material requirements, including tolerances, shown in the Contract.

For those items of work where working tolerances are not specified, the Contractor shall perform the work in a manner consistent with reasonable and customary manufacturing and construction practices.

When the Engineer finds the materials or work furnished, work performed, or the finished product are not in conformity with the Contract and has resulted in an inferior or unsatisfactory product, the work or material shall be removed and replaced or otherwise corrected at the expense of the Contractor.

Materials will be sampled and tested by the Division in accordance with Section 106 and with the applicable procedures contained in the Division's Field Materials Manual. The approximate maximum quantity represented by each sample will be as set forth in Section 106, Table 106-1. Additional samples may be selected and tested at the Engineer's discretion.

Evaluation of materials for pay factors (PF) will be done on a lot basis. Lots will consist of a consecutive series of random samples, one from each sublot, for those items and elements listed in Section 106, Table 106-1. All materials produced will be assigned to a lot. Each lot will have a pay factor computed in accordance with the requirements of this Section. Test results determined to have sampling or testing errors will not be used.

Whenever two consecutive test results for an element are outside the tolerances, the Engineer shall create an experimental one-sample lot of each individual test. Each test shall be individually evaluated in accordance with the following:

(1) A PF shall be computed for each test.
(2) If the PF for the test is less than 0.75, the test shall constitute a lot and the material represented by the test shall be handled in accordance with subsection (f) of this specification.
(3) If the PF for the test is 0.75 or greater, the test shall not constitute a lot, and the test shall be placed in the appropriate lot.

REVISION OF SECTION 105
CONTROL OF WORK

The Engineer shall establish a new lot when there are major changes in materials, a change in the job-mix formula, extended suspension of production or as otherwise deemed necessary. New lots may be established following the close of the pay estimate period.

Providing none of the above conditions exist, a lot may consist of any number of consecutive samples.

If there are less than three samples in a lot, the material will be evaluated as one-sample lots in accordance with the procedure below.

When it is necessary to represent a quantity by one or two tests, lots will be established represented by one test each, as determined by the Engineer. If the value of the test is within the specification limits, the lot will be assigned a pay factor (PF) of 1.00.

If the value of the test is above the maximum specified limit, then

$$PF = 1.00 - (T_o - T_u)^2/V$$

If the value of the test is below the minimum specified limit, then

$$PF = 1.00 - (T_L - T_o)^2/V$$

Where: PF = pay factor
V = V factor from table 105-3
T_o = the individual test value
T_L, T_u = lower and upper specification limits, respectively

(a) Each lot of materials or work represented by three or more tests will be evaluated for a PF by the following procedure:

Determine the arithmetic mean (X) of the several test results for each element of the sample being evaluated:

$$\bar{X} = \frac{\Sigma X}{n}$$

Where: Σ = summation of
X = individual test value to X_n
n = total number of test values

Compute the element standard deviation (s):

$$s = \sqrt{\frac{\Sigma(X - \bar{X})^2}{n - 1}}$$

REVISION OF SECTION 105
CONTROL OF WORK

Compute the quality level (QL) and PF as follows:

$$QL = 100 - (p_L + p_u)100$$

where:

p_L = fraction defective at the lower specification limit
p_u = fraction defective at the upper specification limit

The fraction defective is obtained by numerically integrating the beta distribution function:

$$p = \int_{x=o}^{x = Max[0,1/2 - Q\sqrt{n} /2(n-1)]} \beta(a,b,x)\ dx$$

where:

p = fraction defective of the population
$\beta(a,b,x)$ = beta distribution function = n/2 - 1
n = sample size
Q = quality index, $(\bar{X} - T_L)/s$ or $(T_u - \bar{X})/s$

$\bar{X}$ = sample mean
s = sample standard deviation
T_L, T_u = lower and upper specification limits
x = integration variable

Compute PF by the following formulae:

1. When n = 3 and QL < 68, then

   $$PF = 0.410702 + 1.157738\ (QL/100) - 0.423928\ (QL/100)^2$$

2. When n = 3 and QL $\geq$ 68, then

   $$PF = 0.572303 + 0.953058\ (QL/100) - 0.475399\ (QL/100)^2$$

3. When n = 4, then

   $$PF = 0.264319 + 1.566711\ (QL/100) - 0.781846\ (QL/100)^2$$

4. When n = 5, then

   $$PF = 0.232740 + 1.557903\ (QL/100) - 0.739563\ (QL/100)^2$$

5. When n = 6, then

$$PF = 0.161687 + 1.679072\ (QL/100) - 0.790861\ (QL/100)^2$$

6. When n = 7, then

$$PF = 0.121571 + 1.727903\ (QL/100) - 0.798947\ (QL/100)^2$$

7. When $n \geq 8$, then

$$PF = 0.102049 + 1.72804\ (QL/100) - 0.792804\ (QL/100)^2$$

(b) In lieu of using the formulas under (a) above, reasonable approximations of QL and PF can be made by the following procedures (for payment purposes the above formulas will be used):

1. Compute the upper quality index (Q_u):

$$Q_u = \frac{T_u - \bar{X}}{s}$$

Determine P_u (percent within the upper specification limit which corresponds to a given Q_u) from Table 105-1. If T_u is not specified, P_u will be 100.

2. Compute the lower quality index (Q_L):

$$Q_L = \frac{\bar{X} - T_L}{s}$$

Determine P_L (percent within the lower specification limit which corresponds to a given Q_L) from Table 105-1. If T_L is not specified, P_L will be 100.

3. Determine the Quality Level (QL, the total percent within specification limits):

$$QL = (P_u + P_L) - 100$$

Using QL, determine PF from Table 105-2.

(c) A pay factor will be determined for each lot of material or work. For pay period estimates, or for any interim time period, each individual element will have the average pay factor (PF_A) for all the lots of the period, weighted by the quantities represented by each lot, computed as follows:

$$PF_A = \frac{[M_1(PF_1) + M_2(PF_2) + \ldots\ldots M_j(PF_j)]}{\Sigma M}$$

Where: M_j = Quantity of item represented by the lot.

PF_j = The lot pay factor.

ΣM = Sum of Quantities, M_1 to M_j (the total quantity for the period).

(d) When there is more than one element for the item, determine the composite pay factor (PF_C) for the time period as follows (ΣM used to compute each element PF_A must be numerically the same):

$$PF_C = \frac{[W_1(PF_{A1}) + W_2(PF_{A2}) + \ldots\ldots W_j(PF_{Aj})]}{\Sigma W}$$

Where: W = element factor from Table 105-3.

PF_{Aj} = element average pay factor.

ΣW = sum of the element factors.

(e) Numbers in the above calculations will be carried to significant figures and rounded according to AASHTO Standard Recommended Practice R-11.

(f) When PF for any element in the lot is between 0.75 and 1.05, the finished product will be accepted at the appropriate pay factor. If PF for any element in the lot is less than 0.75, the Engineer may: (1) require complete removal and replacement with specification material at no additional cost to the Division; or (2) document the basis for acceptance by Contract Modification Order (CMO) and permit the Contractor to leave the material in place, if the finished product is found to be capable of performing the intended purpose and the value of the finished product is not affected. If the material remains in place, the CMO will make an appropriate price adjustment such that PF will not be greater than 0.75. The final PF for the lot will be used in the applicable formulas when computing the average and composite pay factors.

The Contractor will not have the option of accepting a price reduction in lieu of producing specification material. Continued production of non-specification material will not be permitted. All costs related to redesign of the asphalt mix and subsequent delays shall be borne by the Contractor. Material which is obviously defective may be isolated and rejected without regard to sampling sequence or location within a lot.

TABLE 105-1
QUALITY LEVEL ANALYSIS BY THE STANDARD DEVIATION METHOD

P_U or P_L %	Upper Quality Index Q_u or Lower Quality Index Q_L														
	n= 3	n= 4	n= 5	n= 6	n= 7	n= 8	n= 9	n=10 to n=11	n=12 to n=14	n=15 to n=18	n=19 to n=25	n=26 to n=37	n=38 to n=69	n=70 to n=200	n=201 to n=x
100	1.16	1.50	1.79	2.03	2.23	2.39	2.53	2.65	2.83	3.03	3.20	3.38	3.54	3.70	3.83
99		1.47	1.67	1.80	1.89	1.95	2.00	2.04	2.09	2.14	2.18	2.22	2.26	2.29	2.31
98	1.15	1.44	1.60	1.70	1.76	1.81	1.84	1.86	1.91	1.93	1.96	1.99	2.01	2.03	2.05
97		1.41	1.54	1.62	1.67	1.70	1.72	1.74	1.77	1.79	1.81	1.83	1.85	1.86	1.87
96	1.14	1.38	1.49	1.55	1.59	1.61	1.63	1.65	1.67	1.68	1.70	1.71	1.73	1.74	1.75
95		1.35	1.44	1.49	1.52	1.54	1.55	1.56	1.58	1.59	1.61	1.62	1.63	1.63	1.64
94	1.13	1.32	1.39	1.43	1.46	1.47	1.48	1.49	1.50	1.51	1.52	1.53	1.54	1.55	1.55
93		1.29	1.35	1.38	1.40	1.41	1.42	1.43	1.44	1.44	1.45	1.46	1.46	1.47	1.47
92	1.12	1.26	1.31	1.33	1.35	1.36	1.36	1.36	1.37	1.37	1.39	1.39	1.40	1.40	1.40
91	1.11	1.23	1.27	1.29	1.30	1.30	1.31	1.31	1.32	1.32	1.33	1.33	1.33	1.34	1.34
90	1.10	1.20	1.23	1.24	1.25	1.25	1.26	1.26	1.26	1.27	1.27	1.27	1.28	1.28	1.28
89	1.09	1.17	1.19	1.20	1.20	1.21	1.21	1.21	1.21	1.22	1.22	1.22	1.22	1.22	1.23
88	1.07	1.14	1.15	1.16	1.16	1.16	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17
87	1.06	1.11	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.13	1.13
86	1.04	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
85	1.03	1.05	1.05	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04
84	1.01	1.02	1.01	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.99
83	1.00	0.99	0.98	0.97	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.95	0.95	0.95
82	0.97	0.96	0.95	0.94	0.93	0.93	0.93	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
81	0.96	0.93	0.91	0.90	0.90	0.89	0.89	0.89	0.89	0.88	0.88	0.88	0.88	0.88	0.88
80	0.93	0.90	0.88	0.87	0.86	0.86	0.86	0.85	0.85	0.85	0.85	0.84	0.84	0.84	0.84
79	0.91	0.87	0.85	0.84	0.83	0.82	0.82	0.82	0.82	0.81	0.81	0.81	0.81	0.81	0.81
78	0.89	0.84	0.82	0.80	0.80	0.79	0.79	0.79	0.78	0.78	0.78	0.78	0.77	0.77	0.77
77	0.87	0.81	0.78	0.77	0.76	0.76	0.76	0.75	0.75	0.75	0.75	0.74	0.74	0.74	0.74
76	0.84	0.78	0.75	0.74	0.73	0.73	0.72	0.72	0.72	0.71	0.71	0.71	0.71	0.71	0.71

TABLE 105-1 (CONT.)

QUALITY LEVEL ANALYSIS BY THE STANDARD DEVIATION METHOD

P_U or P_L %	Upper Quality Index Q_u or Lower Quality Index Q_L														
	n= 3	n= 4	n= 5	n= 6	n= 7	n= 8	n= 9	n=10 TO n=11	n=12 TO n=14	n=15 TO n=18	n=19 TO n=25	n=26 TO n=37	n=38 TO n=69	n=70 TO n=200	n=201 TO n=X
75	0.82	0.75	0.72	0.71	0.70	0.70	0.69	0.69	0.69	0.68	0.68	0.68	0.68	0.68	0.67
74	0.79	0.72	0.69	0.68	0.67	0.66	0.66	0.66	0.66	0.65	0.65	0.65	0.65	0.64	0.64
73	0.76	0.69	0.66	0.65	0.64	0.63	0.63	0.63	0.62	0.62	0.62	0.62	0.62	0.61	0.61
72	0.74	0.66	0.63	0.62	0.61	0.60	0.60	0.60	0.59	0.59	0.59	0.59	0.59	0.58	0.58
71	0.71	0.63	0.60	0.59	0.58	0.57	0.57	0.57	0.57	0.56	0.56	0.56	0.56	0.55	0.55
70	0.68	0.60	0.57	0.56	0.55	0.55	0.54	0.54	0.54	0.53	0.53	0.53	0.53	0.53	0.52
69	0.65	0.57	0.54	0.53	0.52	0.52	0.51	0.51	0.51	0.50	0.50	0.50	0.50	0.50	0.50
68	0.62	0.54	0.51	0.50	0.49	0.49	0.48	0.48	0.48	0.48	0.47	0.47	0.47	0.47	0.47
67	0.59	0.51	0.47	0.47	0.46	0.46	0.46	0.45	0.45	0.45	0.45	0.44	0.44	0.44	0.44
66	0.56	0.48	0.45	0.44	0.44	0.43	0.43	0.43	0.42	0.42	0.42	0.42	0.41	0.41	0.41
65	0.52	0.45	0.43	0.41	0.41	0.40	0.40	0.40	0.40	0.39	0.39	0.39	0.39	0.39	0.39
64	0.49	0.42	0.40	0.39	0.38	0.38	0.37	0.37	0.37	0.36	0.36	0.36	0.36	0.36	0.36
63	0.46	0.39	0.37	0.36	0.35	0.35	0.35	0.34	0.34	0.34	0.34	0.34	0.33	0.33	0.33
62	0.43	0.36	0.34	0.33	0.32	0.32	0.32	0.32	0.31	0.31	0.31	0.31	0.31	0.31	0.31
61	0.39	0.33	0.31	0.30	0.30	0.29	0.29	0.29	0.29	0.29	0.28	0.28	0.28	0.28	0.28
60	0.36	0.30	0.28	0.27	0.27	0.27	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.25	0.25
59	0.32	0.27	0.25	0.25	0.24	0.24	0.24	0.24	0.23	0.23	0.23	0.23	0.23	0.23	0.23
58	0.29	0.24	0.23	0.22	0.21	0.21	0.21	0.21	0.21	0.21	0.20	0.20	0.20	0.20	0.20
57	0.25	0.21	0.20	0.19	0.19	0.19	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
56	0.22	0.18	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.15	0.15	0.15	0.15	0.15	0.15
55	0.18	0.15	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
54	0.14	0.12	0.11	0.11	0.11	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
53	0.11	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
52	0.07	0.06	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
51	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE 105-2
Pay Factors

Pay Factor	Required Quality Level for a given sample size (n) and given Pay Factor					
	n= 3	n= 4	n= 5	n= 6	n= 7	n = 8 TO n = X
1.05	100	100	100	100	100	100
1.04	90	91	92	93	93	93
1.03	80	85	87	88	89	90
1.02	75	80	83	85	86	87
1.01	71	77	80	82	84	85
1.00	68	74	78	80	81	82
0.99	66	72	75	77	79	80
0.98	64	70	73	75	77	78
0.97	62	68	71	74	75	77
0.96	60	66	69	72	73	75
0.95	59	64	68	70	72	73
0.94	57	63	66	68	70	72
0.93	56	61	65	67	69	70
0.92	55	60	63	65	67	69
0.91	53	58	62	64	66	67
0.90	52	57	60	63	64	66
0.89	51	55	59	61	63	64
0.88	50	54	57	60	62	63
0.87	48	53	56	58	60	62
0.86	47	51	55	57	59	60
0.85	46	50	53	56	58	59
0.84	45	49	52	55	56	58
0.83	44	48	51	53	55	57
0.82	42	46	50	52	54	55
0.81	41	45	48	51	53	54
0.80	40	44	47	50	52	53
0.79	38	43	46	48	50	52
0.78	37	41	45	47	49	51
0.77	36	40	43	46	48	50
0.76	34	39	42	45	47	48
0.75	33	38	41	44	46	47

REVISION OF SECTION 105
CONTROL OF WORK

TABLE 105-3
"W' Factors for Various Elements

Hot Bituminous Pavement		
Element	V factor	W factor
Asphalt Content	0.2	5
Stability	3	5
Voids in Mineral Aggregate (VMA)	0.6	20
Air Voids (AV)	0.6	30
Field Compaction	1.3	40

REVISION OF SECTION 106
CONTROL OF MATERIAL

Section 106 of the Standard Specifications is hereby revised for this project as follows:

Subsection 106.03 shall include the following:

All Hot Bituminous Pavement, Item 403, shall be tested in accordance with the following program of acceptance and assurance testing:

(a) **Acceptance Testing.** The Colorado Department of Transportation (CDOT) shall be responsible for acceptance testing on all items in the Contract listed in Table 105-3.

1. **Frequency of Tests.** Acceptance tests will be taken at the frequency specified in Table 106-1.

2. **Point of Sampling.** The material for acceptance testing shall be sampled by the Contractor using approved procedures. The location where material samples will be taken shall be determined by the Engineer.

(b) **Assurance Testing.** Except for Asphalt Content and Percent Relative Compaction, the CDOT Staff Materials Laboratory shall be responsible for assurance testing. Check tests for Stability, Voids in the Mineral Aggregate (VMA), and Air Voids (AV) shall become Independent Assurance Tests.

All materials being used are subject to inspection and testing at any time prior to, during, or after incorporation into the work.

1. **Frequency of Tests.** Assurance sampling and testing procedures will be in accordance with the Schedule for Minimum Materials Sampling, Testing and Inspection in the CDOT Field Materials Manual.

REVISION OF SECTION 106
CONTROL OF MATERIAL

TABLE 106-1
TESTING SCHEDULE FOR HOT BITUMINOUS PAVEMENT

ACCEPTANCE TESTS

TEST		TESTING FREQUNCY	
		> 1,500 TONS/DAY	< 1,500 TONS/DAY
CP-42	Determining Asphalt Content for Bituminous Pavements	3 Tests Per Day	1/500 Tons
CP-44 CP-81	Determining Field % Relative Compaction of Bituminous Pavement Mixtures	1/500 Tons	1/500 Tons
AASHTO T-166	Bulk Specific Gravity of Bituminous Paving Mixtures	3 Tests Per Day	1/500 Tons
AASHTO T-209	Maximum Specific Gravity of Bituminous Paving Mixtures	3 Tests Per Day	1/500 Tons
CPL-5105	Resistance to Deformation and Cohesion of Bituminous Mixtures by Means of Hveem	3 Tests Per Day	1/500 Tons
CPL 5105	Percent Air Voids in Laboratory Compacted Bituminous Paving Mixtures	3 Tests Per Day	1/500 Tons

TESTS FOR INFORMATION ONLY

CPL 5109	Tensile Strength Retained Ratio (Lottman)	1 test for every 4 days production	1 Test for every 4 days production
AASHTO T-11 & T-27	Sieve Analysis for Fine and Coarse Aggregate	1 Test Per Day	1 Test Per Day

Testing shall be performed using the Texas Gyratory (ASTM D 4103). The results for each test, using laboratory compacted samples, shall be the average of three compacted specimens.

REVISION OF SECTIONS 401 AND 703
COMPOSITION OF MIXTURES

Sections 401 and 703 of the Standard Specifications are hereby revised for this project as follows:

In subsection 401.02, second paragraph, delete items (1) and (2) and replace with the following:

(1) A proposed job-mix gradation for each mixture required by the Contract which shall be wholly within the Master Range Table, Table 703-3 or 703-6. The weight of lime shall be included in the total weight of the material passing the No. 200 sieve.

(2) The aggregate source, percentage of each element used in producing the final mix, the gradation of each element, and the proposed job-mix formula (JMF) gradation. The gradation used by the Division shall be based on the Contractors JMF. Before the design is performed, adjustments to the gradation of each element as determined by the Division shall be made only on the aggregates retained on the No. 4 sieve or larger.

In subsection 401.02, Table 401-1, delete the tolerances for Hot Bituminous Pavement - Item 403 , and replace with the following:

Hot Bituminous Pavement - Item 403

Stability	37, minimum
Voids in the Mineral Aggregate (VMA)	±1.2%
Air Voids	±1.2%

In subsection 401.02 delete the tenth paragraph.

In subsection 703.04 delete Table 703-3 and replace with the following:

TABLE 703-3
Master Range Table for Hot Bituminous Pavement

Sieve Size	Percent by Weight Passing Square Mesh Sieves			
	Grading G	Grading C	Grading CX	Grading F
1-1/2"	100			
1"	-----			100
3/4"	63-85	100		-----
1/2"	46-78	70-95	100	-----
3/8"	-----	60-88	74-95	-----
#4	22-54	44-72	50-78	-----
#8	13-47	30-62	32-64	45-85
#30	4-26	12-38	12-38	-----
#200	1-7	3-7	3-7	7-13

REVISION OF SECTION 403
HOT BITUMINOUS PAVEMENT

Section 403 of the Standard Specifications is hereby revised for this project as follows:

Subsection 403.02 shall include the following:

The design mix for hot bituminous pavement shall conform to the following:

TABLE 403-1

PROPERTY	TEST METHOD	VALUE FOR GRADING		
		C	CX	Patching
Air Voids, percent	CPL 5105A	3-5	3-5	3-5
Stability, minimum	CPL 5105A	37	37	37
Aggregate retained on the No. 4 sieve with at least 2 mechanically induced fractured faces, % minimum	CP 45	70	70	70
Accelerated Moisture Susceptibility Tensile Strength Ratio (Lottman), minimum	CPL 5109	80	80	80
Minimum dry split tensile strength, psi	CPL 5109	30	30	30
Grade of Asphalt Cement		PM-Type 1D	AC-10	AC-10
Voids in the mineral aggregate (VMA), % minimum	CP 48	See TABLE 403-2		
Voids filled with asphalt (VFA), %	AI MS-2	65-76	65-76	65-76

AI MS-2 = Asphalt Institute Manual Series 2
CPL 5105A = End point stress shall be 100 psi

Note: Design criteria for Grading C and Grading CX mixes should be approached with caution to avoid mixes that produce a maximum density plot. As a minimum, contractors are advised to develop mixes 2-3% above or below the maximum density line.

TABLE 403-2
Minimum Voids in the Mineral Aggregate (VMA)

		VMA, Percent Min.		
Air Voids(%)		3	4	5
	1 1\2	10	11	12
Nom.	1	11	12	13
Size	3/4	12	13	14
(in)**	1/2	13	14	15
	3/8	14	15	16
	#4	16	17	18

** The nominal size is defined as one sieve larger than the first sieve to retain more than 10%

REVISION OF SECTION 403
HOT BITUMINOUS PAVEMENT

The Contractor shall prepare a quality control plan outlining the steps taken to minimize segregation of HBP. This plan shall be submitted to the Engineer and approved prior to beginning the paving operations. When the Engineer determines that segregation is unacceptable, the paving shall stop and the cause of segregation corrected before paving operations will be allowed to resume.

The hot bituminous pavement shall not contain more than 15 percent reclaimed asphalt pavement.

Hot bituminous pavement for patching shall conform to the gradation requirements for Hot Bituminous Pavement (Grading ___).

A minimum of one percent hydrated lime by weight of the combined aggregate shall be added to the aggregate for all hot bituminous pavement.

Subsection 403.03 shall include the following:

Areas to be patched shall be excavated and squared to a neat line, leaving the sides of the excavation vertical. Prior to placement of the patch the exposed sides of the existing pavement shall be thoroughly coated with Emulsified Asphalt (slow-setting). Hot bituminous pavement shall then be placed and compacted in succeeding layers not to exceed three inches in depth.

Subsection 403.05 shall include the following:

Aggregate, asphalt cement, asphalt recycling agent, additives, hydrated lime, and all other work necessary to complete each hot bituminous pavement item will not be paid for separately but shall be included in the unit price bid.

Excavation, preparation, and tack coat of areas to be patched will not be measured and paid for separately, but shall be included in the work.