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Final Report

I 70 GLENWOOD CANYON OVERLAY WITH TRINIDAD LAKE ASPHALT/STEEL SLAG HOT MIX ASPHALT

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September 2006

COLORADO DEPARTMENT OF TRANSPORTATION
RESEARCH BRANCH

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16. Abstract

In 2001, CDOT overlaid twelve miles of I 70 in Glenwood Canyon with a unique asphalt mix design that utilized a traditional Performance Graded Binder blended with Trinidad Lake Asphalt (TLA) and traditional aggregate blended with steel slag aggregate. This is the first project where CDOT has incorporated TLA in the mix design.

There are many natural deposits of asphalt found around the world; Trinidad Lake is the most famous and has the largest commercial deposit of natural asphalt in the world. This study was designed to evaluate the performance of a pavement containing Trinidad Lake Asphalt blended with a polymer modified asphalt (PG 76-28) in combination with a very hard and angular steel slag under Colorado weather and traffic conditions.

Two of three test sections experienced premature failure along the longitudinal construction joint and that failure appears to have been due to inadequate densities along the longitudinal joint rather than due to the mix design. The pavement performed well in all of Test Section 3, and in Test Sections 1 and 2 in areas away from the longitudinal joint.

Implementation:

The use of Trinidad Lake Asphalt and steel slag to enhance performance of HMA looks promising; however, further evaluation is warranted to address the poor joint performance and heavy smoke caused by the necessity for high mixing and placement temperatures.

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EXECUTIVE SUMMARY

Project NH 0702-217, constructed on I-70 in Glenwood Canyon in 2001, was the first use of Trinidad Lake Asphalt (TLA) in combination with steel slag by the Colorado Department of Transportation. To evaluate the performance of the TLA modified pavement, a three-year study was developed. By tracking rutting, cracking and general pavement condition through semi-annual site evaluations, researchers hoped to determine if the addition of TLA and steel slag aggregate could improve the performance of the pavement over traditional mix designs.

For this project the entire two inch thick hot mix asphalt (HMA) surface was planed to a depth of 1-1/2 inches and replaced with two inches of Trinidad Lake Asphalt / steel slag modified HMA. The job mix formula, which called for asphalt cement of 6.5% ±0.2% of the total mixture by weight, utilized Koch PG 76-28 binder modified with 25% TLA by weight of the binder. The aggregate was crushed, with 100% of the particles retained on the #4 sieve having 3 or more fractured faces, and this requirement included 25% steel furnace slag by weight. International Milling Service of Pueblo, Colorado supplied the slag. The mix design included requirements for high mix temperatures during production and placement, as well as a minimum Hveem stability of 55 and low mix permeability.

For this evaluation, three 1000-foot test sections were selected, two westbound and one eastbound. In the westbound lanes, Section 1 developed severe alligator cracking associated with the longitudinal joints, and Section 2 had longitudinal cracks at or adjacent to the centerline joint that extended completely through the test section. All of this distress was in the area of the longitudinal joint, not in the wheel path where damage from traffic normally occurs. The location of the longitudinal and alligator cracking lead to the conclusion that the compaction in the immediate area of the longitudinal construction joint was inadequate. The fact that the amount of cracking increased yearly indicated that the condition of the pavement in the area of the joint will continue to deteriorate. The cracking is evidently the result of low joint densities allowing moisture to penetrate and weaken the surface. An intense sealing effort may prolong the life of the failing joint; however, the danger of pop-outs developing into potholes may require replacement of the asphalt in the near future. The eastbound test section also developed longitudinal cracking along the construction joint in the first few months after construction. However, subsequent site visits did not find any additional cracking or deterioration of the pavement. The pavement in the eastbound test section is in excellent condition and shows no need of extensive maintenance.

IMPLEMENTATION STATEMENT

Because the vast majority of distress occurred in the area along the longitudinal construction joint, the researchers felt that the early failure of the pavement was due to inadequate construction joint densities caused by high mix stiffness during compaction and lack of mix resistance to repeated freeze-thaw stress. The relatively good condition of the surface away from the longitudinal joints and the good performance of the eastbound test section suggest that properly constructed the TLA/steel slag mix can perform well. Additional research is warranted to address poor joint performance and heavy smoke caused by the necessity for high mixing and placement temperatures.

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1.0 BACKGROUND

I 70 through Glenwood Canyon was completed in various stages over 15-20 years, and throughout that time, the pavement has experienced heavy traffic as well as severe weather conditions. Parts of the roadway in the canyon are never exposed to sunlight during the winter and portions receive a freeze-thaw cycle almost every day during the winter. With the many turns, the problem of pavement shoving by heavy trucks has often occurred. Since the completion of construction in the canyon, no uniform pavement has been applied to address the distresses that have occurred in various parts of the canyon. Depending on the section and its age, portions of the pavement have had distress from shoving, raveling, bleeding, or rutting. There are also isolated areas of stripping, polished aggregates, fatigue cracking, and longitudinal cracking.

Additionally, much of I 70 through the canyon is built on structures or post-tensioned slabs. Pavement permeability may be an issue, since moisture and salt need to be kept away from the concrete and steel structures immediately below the pavement.

In order to provide a long lasting, smooth, relatively impermeable pavement, a special pavement design was sought to prevent the recurrance of the many distresses already present. To accomplish this, the existing pavement was milled to remove the distressed surface layers and a new pavement was to be placed. The asphalt mix design for this type of pavement needed to be rutting and shoving resistant as well as having durable weather resistance and very low permeability.

To obtain a mix with these properties a consultant mix design was developed which contained Trinidad Lake Asphalt (TLA) blended with a locally available polymer modified asphalt and a steel slag blended with very angular local aggregate.

2.0 EXPERIMENTAL MATERIALS IN MIX

Pitch Lake in LaBrea, Trinidad was discovered by European explorers more than 400 years ago. One of its first recorded users was Sir Walter Raleigh who used the “pitch” to caulk his ships in March of 1595 and pronounced it “most excellent goode.” As a road surfacing material, the first documented usage of Trinidad Lake Asphalt (TLA) was in 1815 on the streets of Port-of-Spain, the capital city of the two-island nation of Trinidad and Tobago. Between 1871 and 1874, Pennsylvania Avenue, in Washington, D.C., was paved with TLA.

Figure 1. Pitch Lake in LaBrea,Trinidad

An emulsion, in its crude state, the natural asphalt is composed of soluble bitumen, mineral matter and other minor constituents, mainly water. Proponents of TLA list several properties they feel support their claims of excellence:

1. Ability to blend with most refinery bitumen
2. Exceptional adhesion as a binder
3. High mechanical stability in paving mixtures
4. Skid-resistant surface texture
5. Mat-gray surface that makes it excellent for night driving
6. Admirable and long service life
7. High resistance to cracking and deflection." (1)

A Transportation Research Information Services (TRIS) survey, along with contact with other states, revealed there has been mixed success when using Trinidad Lake Asphalt on projects. Salt Lake City had joint separation problems while an airport in Wendover has performed well.

The few other state experiences that were reported were also mixed as far as performance was concerned.

Lake Asphalt of Trinidad and Tobago (1978) Ltd., the company that mines and ships the emulsion to users worldwide, lists the following properties of Trinidad Lake Asphalt on their 2005 web site:

Table A. Physical Properties of Trinidad Lake Asphalt

Specific Gravity/density @ 25º C	1.39 – 1.44
Penetration 25oC, 5 seconds, 100 gm.	0-4
Softening Point (R&B)	93º – 99º C
Loss on heating for 5 hrs @ 163º C	2.0% max.
Solubility in Trichlorethylene	52 – 55%
Ash Mass	35 – 39%
Breakdown of bitumen/mineral mixture	
Soluble bitumen	53-55%
Maltenes	63-66%
Asphaltenes	33-37%
Acid Value	6.9%
Saponification value	40%
Fixed Carbon	10.8%
Mineral Matter	36-37%

Note: Close to 40% of the mineral matter is less than 1 micron in size and is very finely divided.

Research indicates that when TLA is added to the bituminous mixture as a modifier it increases mix stiffness and permanent deformation resistance, and provides increased stability, fatigue resistance, and low temperature performance. It also improves adhesion to the aggregate, aging resistance, durability and mix workability. TLA as a bituminous modifier has shown varying degrees of performance and has not been used a great deal in the United States. [(1)]

The second special component of this mix was steel slag. Steel slag aggregate is noted for hardness, durability, and angularity. The large aggregate is noted for producing pavements with excellent skid resistance and being an aggregate that maintains its angularity and does not polish under severe traffic conditions. The fine steel slag aggregate is also angular, with high fine aggregate angularity values and helps prevent shoving of an asphalt mix. The steel slag aggregate was supplied by International Milling Service of Pueblo, Colorado and Table 2 shows some of the physical properties of the steel slag aggregate.

Table B. Steel Slag Properties

	Typical Gradation	
Bulk Specific Gravity = 3.01	Sieve Size	% Passing
Los Angles Abrasion (AASHTO T90) = 18	1/2”	92
Absorption = 4.22%	3/8”	80
	#4	52
	#8	33
	#16	23
	#30	17
	#50	13
	#200	6.9

Figure 2 shows a close-up of the large steel slag aggregate, and Figure 3 shows the steel slag aggregate stockpile at the plant site.

Figure 2. Large Steel Slag Aggregate, Note Angularity and Rough Surface Texture

Figure 3. Steel Slag Aggregate Stockpile

The third experimental element was the asphalt mix design. This asphalt mix design was developed by the consultant, and is similar to mixes used on racetracks. While the gradation meets the Colorado Department of Transportation (CDOT) and Superpave specifications for a 100-gyration, nominal 1/2 –inch mix, the requirement for a minimum Hveem Stability of 55 is considerably higher that the normal CDOT requirement of 30. An additional requirement of mix permeability less than 1.0 X e^{-8} cm/sec. is also not a standard requirement. Permeability is normally not measured by on CDOT projects. Together these features were expected to provide a long-lasting mix that would withstand the rigorous conditions present on I 70 in Glenwood Canyon.

3.0 STUDY OBJECTIVES

Project NH 0702-217, on I-70 from mile point 118.7 to mile point 131.0 in Glenwood Canyon, was constructed in 2001. This project was the first use of TLA with steel slag aggregate by the Colorado Department of Transportation (CDOT).

The goal of this study was to evaluate the performance of the pavement over a three-year period. By tracking rutting, cracking and general pavement condition through semi-annual site evaluations, researchers hoped to determine if the TLA/steel slag combination could improve the performance of the pavement over traditional mix designs.

4.0 CONSTRUCTION

4.1 Mixing and Placement

I-70 through project NH 0702-217 was built with two inches of hot mix asphalt pavement (HMA). The HMA is continuous over numerous structures and a large portion rests on top of eight-inch post-tensioned concrete slabs. The reminder of the roadway is approximately 8 inches of HMA on an aggregate base. For this project the entire surface was planed to remove 1-1/2 inches of old HMA, which was replaced with two inches of Trinidad Lake Asphalt modified HMA.

The job mix formula called for an asphalt cement content of 6.5% ± 0.2% by weight of the total mixture and utilized a PG 76-28 binder modified with 25% TLA. The crushed aggregate, with

Figure 4. The Surface Was Planed to a Depth of 1-1/2 inch.

100% of the particles retained on the #4 sieve having 3 or more fractured faces, included 25% steel furnace slag by weight (See Job Mix formula in Appendix F). The asphalt mixing plant was located east of Glenwood Canyon near Dotsero, which made the haul distance less than 13 miles for most of the project. However, because all traffic was routed into one lane through the construction area, traffic volume slowed the haul trucks to the point that, at times, the paving operation was stopped completely, sometimes for as long as 20 minutes.

Belly-dump trailers carried just over 22 tons of mix per load and laid it in windrows in front of the paving operation. A Road-Tech SB 2500 Shuttle Buggy picked up the windrow and conveyed the mix to the 7-ton hopper of the Ingersoll Rand paver. Average temperatures for the asphalt were 350°F at the plant, 332°F in the windrows and 318°F directly behind the paver screed.

Behind the paver, the break down roller, an Ingersoll Rand DD-130, operated in vibrate mode for forward passes and static mode in reverse. (In accordance with CDOT Special Provisions, p. 46, all of the rollers were used in static mode only on the bridge decks through the project.) The average temperature after the first roller pass was 255°F; and 240°F after the final breakdown roller pass.

The intermediate roller, a Dynapac 501, also operated in vibrate mode for forward passes and static mode in reverse. Average temperature after the intermediate roller's first pass was 222°F; and 198°F after the final pass.

The finish roller, a Dynapac C522, ran in vibrate mode for both forward and reverse passes, except on the structures. The average temperature after the finish roller's first pass was 186°F, dropping to 165°F after the final pass.

CDOT specifications call for compaction to be obtained before the mixture cools to 230^{o} F if the hot mix asphalt contains a polymer modified binder such as PG 76-28. As can be seen above, the intermediate roller's first pass was in the approved temperature range to obtain final compaction, but the finish roller was operating at a lower temperature, either because the finish rolling was slow or the mix cooled faster than would be anticipated in a normal mix.

The high mixing and compaction temperatures were recommended for this mix by the TLA supplier because of the TLA modified PG 76-28, and the stiff mixture produced by the highly crushed aggregates. This mix was difficult to compact and was very stiff as noted by the design Hveem stability of 55. This mix design, while similar in gradation to a CDOT SX (1/2 inch dense graded mix), was more like a race track mix designed to prevent shoving as well as rutting, moisture intrusion, and adequate skid resistance. Several study panel members questioned whether joint density could be obtained using this mix.

4.2 Special Testing

To ensure that the desired properties of the TLA/steel slag mix were obtained during construction, a special Quality Assurance Plan (QAP) was developed by the Region 3 Materials Engineer, the CDOT Research Engineer, and the Asphalt Program Engineer from CDOT Staff Materials. A copy of the QAP appears as Appendix A and contains the QAP and copies of the Project Special Provisions that address all of the tests required for the TLA/steel slag mix. Some of the tests included in the QAP (beyond normal testing for voids, VMA, asphalt content, and density) were Hamburg Wheel Tracking Device, French Rut Test, and in-place mix permeability, as well as special fractured faces, absorption, deleterious materials, and angularity tests for the steel slag aggregate. Other unusual testing was also done to document that CDOT received the correct percentage of TLA mixed with the PG 76-28 polymer modified binder. The binder testing showed that the binder was mixed properly and uniformly for the duration of the project.

While the contractor had some problems with mix volumetrics because the mix was extremely sensitive to slight changes in gradation, the majority of the special tests were passing. For instance, permeability was required to be less than 1.0 X e^{-8} cm/sec, and measured values on the project were less than 1.0 X e^{-9} cm/sec.

Another special test was to determine if the mix would meet the low temperature requirements for Glenwood Canyon. The binder selection program LTPPBind lists the 98% reliability low temperature binder for this area as PG xx-28. During mix production, samples of project-produced mix were submitted to the Asphalt Institute for determination of low temperature cracking properties using Indirect Tensile Creep and strength testing to calculate the mix critical cracking temperatures. Based on the seven samples submitted, the critical mix cracking temperature ranged from -28^{o}C to -37^{o}C. This testing includes the SX mix with only PG 76-28 as well as the TLA/PG 76-28 blended binder. Appendix B contains the complete testing report supplied by the Asphalt Institute. The calculated critical temperatures for each sample met the low temperature requirements for this area.

Appendix C contains the summary of more conventional acceptance test data: asphalt content, density, and % passing the #4 sieve. As can be seen in Appendix C, the asphalt content was consistent near the target of 6.5%, and the density averaged 94%, the center of the density target range, 92-96%. Very few failing densities (<92%) were measured on the project. Unfortunately, joint density cores were not taken on the project, because CDOT did not require measurement of joint density for pay in 2001.

4.3 Cost Comparison

In order to compare the costs of the TLA/steel slag mix with more conventional mixes, the average cost-per-ton of polymer modified S and SX mixes (CDOT nominal 3/4" and ½" dense graded mixes respectively) for 2001 were obtained from the CDOT Cost Data Book. The average cost from 10 projects with more than 12,000 tons was $40.60 on a statewide basis. A more accurate cost would be to compare the TLA/steel slag mix with the SX(100) PG 76-28 mix which had 30,313 tons bid on this same project. The cost-per-ton of SX(100) PG 76-28 on this project was $44/ton and the TLA/steel slag mix was $62/ton. The percent difference was calculated using the following formula (High-Low)/Low = 41%. The TLA/steel slag mix was

41% higher in cost than a more conventional polymer modified mix that is often used as a surface course on the western slope of Colorado.

There are numerous reasons for the higher cost, such as TLA cost and special handling required at the plant, and the steel slag that was hauled from Pueblo, Colorado, a distance of approximately 230 miles. There are also the unknowns of an experimental mix, high mix temperatures, and the requirements for static rolling because of the many structures on I 70. All

Figure 5. There Is a paver Hidden in the Smoke Behind the Transfer Vehicle. High Mix Temperatures Were Required.

of these issues contributed to the higher cost of the TLA/steel slag mix. Figures 5, 6, and 7 show some of the possible reasons for the higher cost of the TLA/steel slag mix.

Figure 6. Trinidad Lake Asphalt Delivered to Project

Figure 7. Trinidad Lake Asphalt Ready to Blend in Asphalt Tank

To justify the cost of this special mix, it will need to perform 41% longer that the more common mix containing polymer modified asphalt. Cost comparison calculations and references appear in Appendix D.

Near the completion of the construction, a project open house was held. Following this open house, a project overview was written to update the Chief Engineer. This update contains numerous opinions from various project and staff personnel and appears as Appendix E.

5.0 TEST SECTION DESCRIPTIONS

Three 1000-foot test sections, two westbound and one eastbound, were established for this study. The sites were selected to represent typical pavement base conditions in the canyon.

Test Section 1 (Figure 8) is located from Mile Post (MP) 121.2 to MP 121.0 westbound. It included 430 feet on structure F08-AA and 140 feet on structure F07-AR, with the 430 feet in between being a retaining wall topped with a post-tensioned concrete slab.

Test Section 2 (Figure 9) is located from MP 122.2 to MP122.0 westbound and Test Section 3 (Figure 10) begins 1000 feet east of MP 128.0 and extends 1000 feet east. Both Sections 2 and 3 are located on post-tensioned slab on top of retaining walls with the post-tensioned slabs immediately under the pavement.

FIGURE 8 SECTION #1 MAP

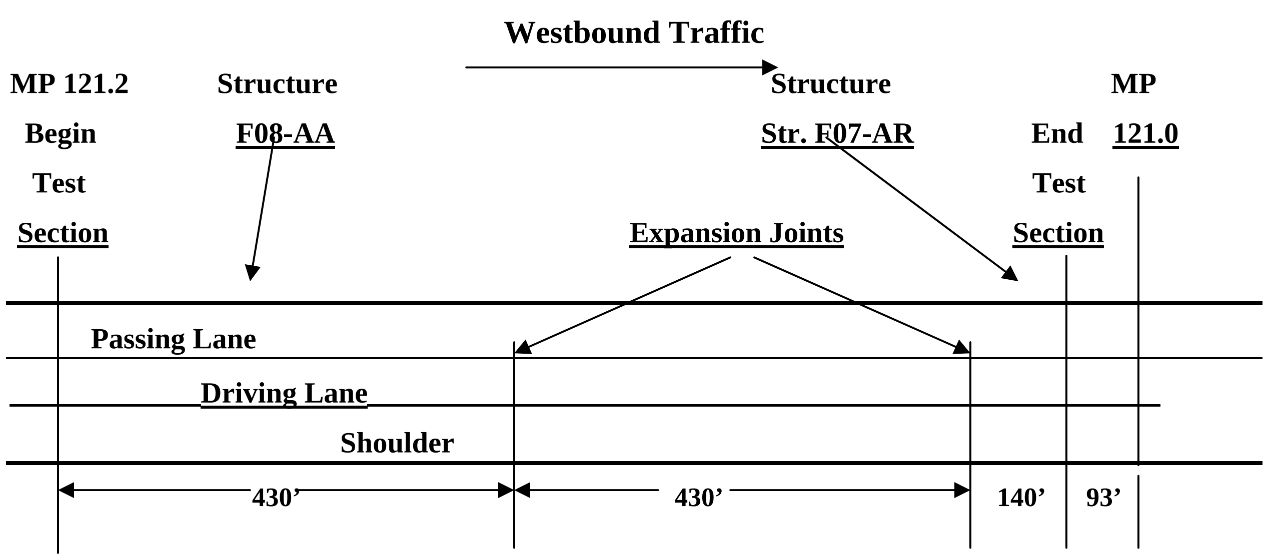


FIGURE 9 **TEST SECTION #2**

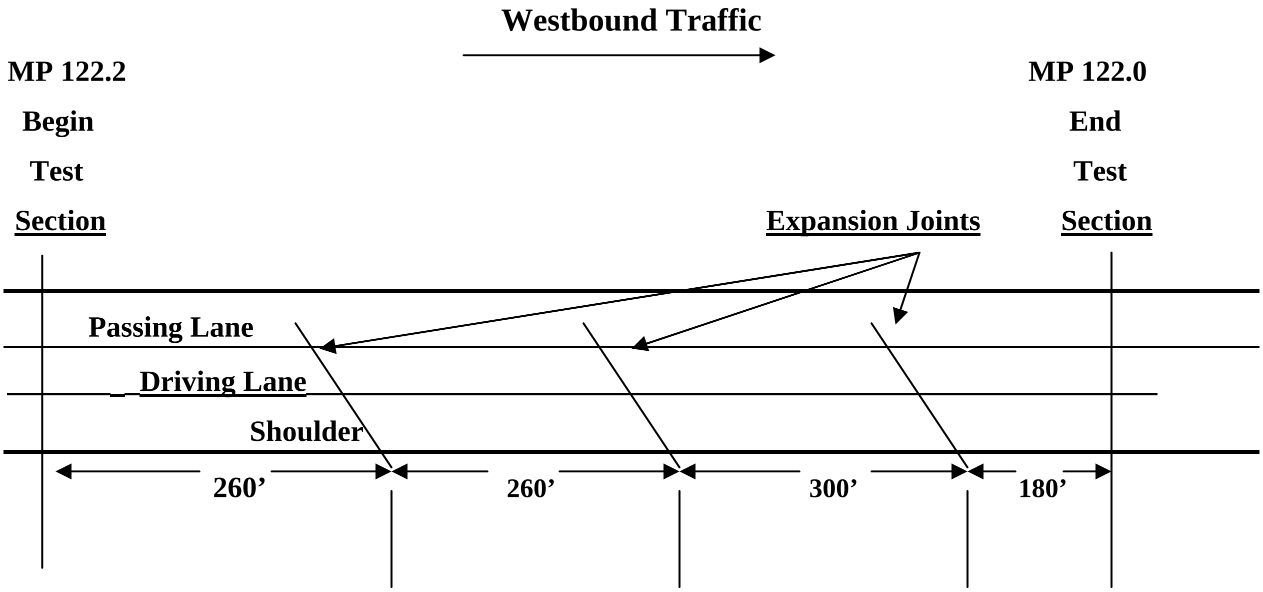
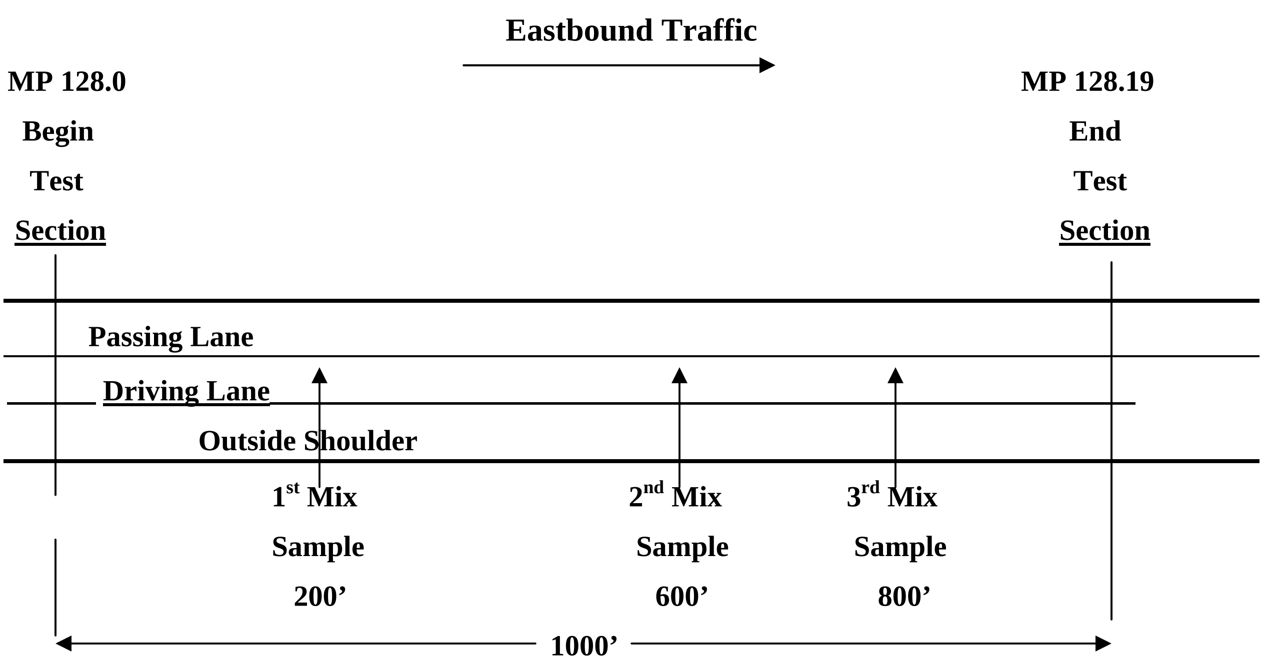
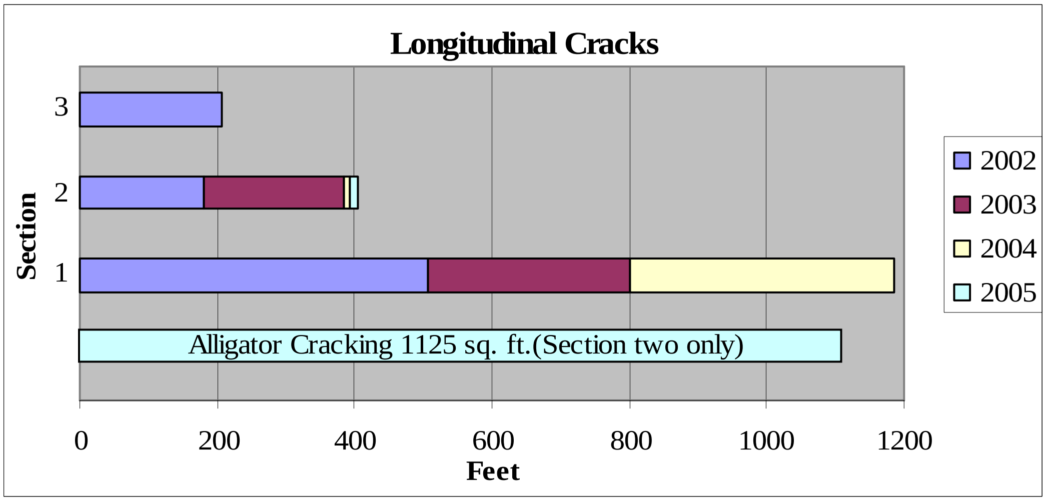


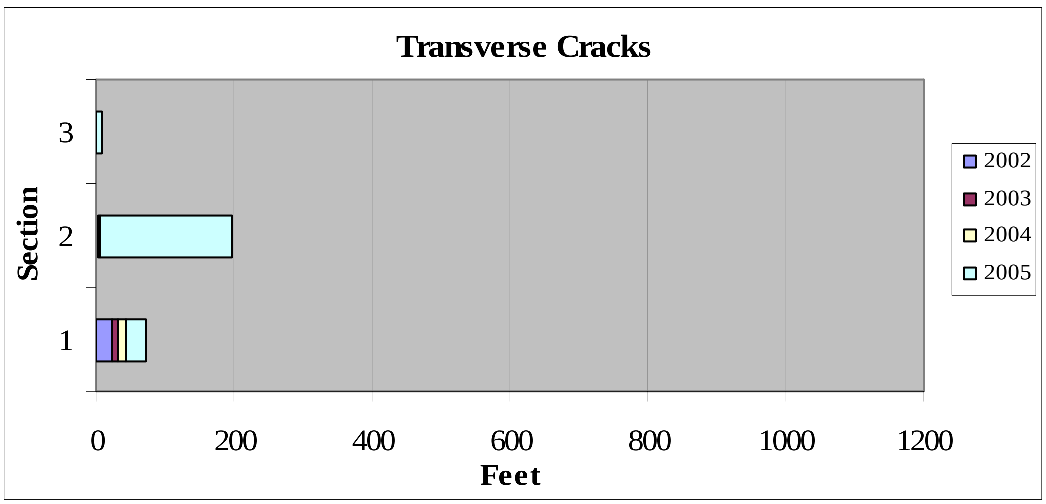
FIGURE 10 TEST SECTION #3



6.0 PAVEMENT TEST SECTION EVALUATIONS

The original work plan called for evaluations to be conducted in the spring and fall of each year from 2002 to 2004. Planned evaluations of all sections included crack mapping, visual observations of both lanes and shoulders, and rut depth measurements to be taken every 50' in the right and left wheel paths of the driving lane only.





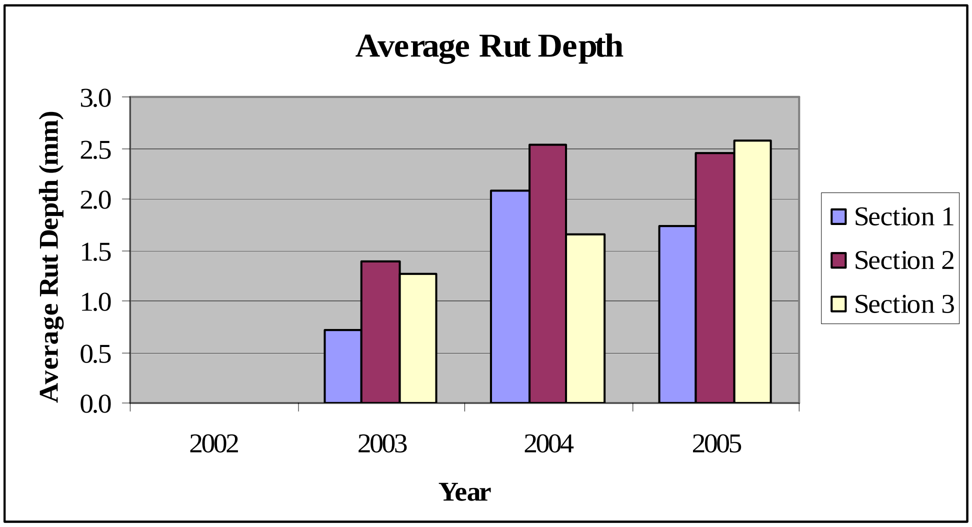


Figure 11. Test Section Evaluation Data

6.1 2002 Evaluation

During the first evaluation on September 20, 2002, the average rut depth, measured with a six-foot-long straightedge, was less than 1mm for all of the test sections.

As Figure 6 shows, there was nearly 200 feet of longitudinal cracking in Sections 2 and 3, and more than 500 feet in Section 1. In all three sections the longitudinal cracking was along the longitudinal paving joint and had been sealed by maintenance personnel prior to the evaluation. Only 23 feet of transverse cracking was seen. This was a crack at the end of the departure slab from structure F-08-AA in Section 1.

6.2 2003 Evaluation

On August 13, 2003 cracking was evident at the longitudinal construction joint along the skip stripe for more than 800 feet of Section 1. In Test Section 2 the longitudinal cracking had nearly doubled to almost 400 feet, while in Section 3 there was no new cracking at all. In many locations the longitudinal cracking was parallel to the longitudinal construction joint about 6 to 8 inches to the side; in some areas there was cracking on both sides of the joint.

Very small amounts of new transverse cracking were detected in Sections 1 and 2 – eight feet and four feet respectively.

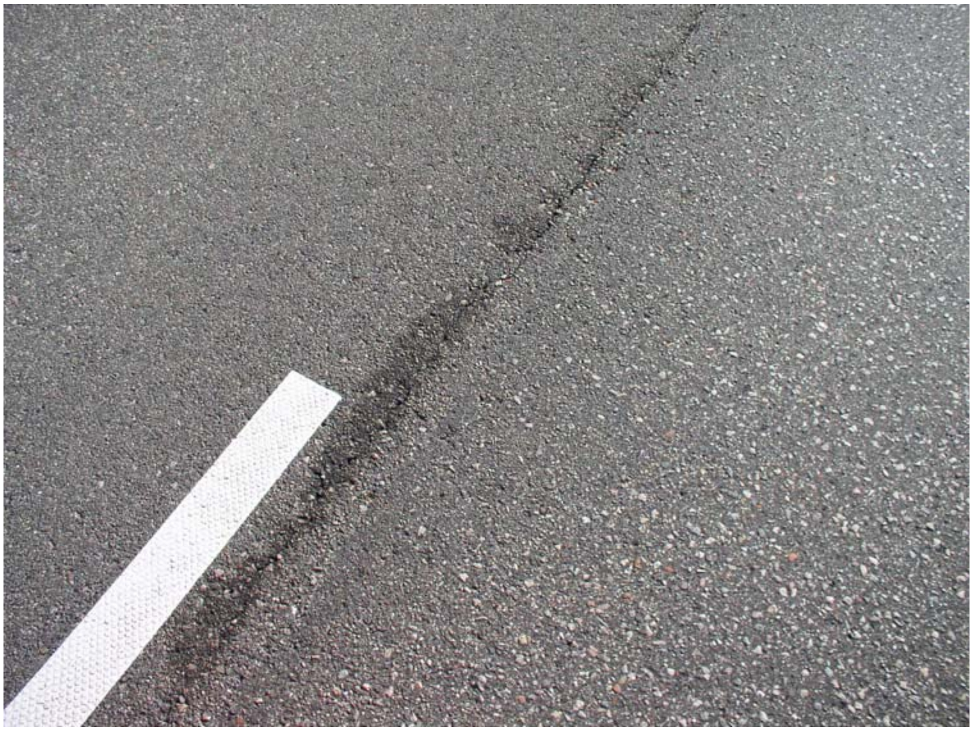


Figure 12. Early Deterioration of Longitudinal Joint, Note Moisture in Joint (2003)

Figure 13. Raveling at Longitudinal Joint

Rut measurements were taken in the driving lane. In both westbound test sections rutting was observed in the left wheel path. The average rut measurement for the west bound sections was 3.5mm (0.14 in.). The eastbound section's average rut depth was 3 mm (0.12 in.).

In Section 2, several small patches – about 10 to 30 square feet each - were scattered from about 300 feet to about 500 feet into the section in both lanes and on the right shoulder. The patches were repairs of holes that had been caused by rocks falling from the side of the canyon onto the highway.

6.3 2004 Evaluation

The evaluation conducted on October 28, 2004, showed minor increases in transverse cracking in the westbound test sections – 12 feet in Section 1 and 3 feet in Section 2 – and no new cracks at all in Section 3. Section 1 had 383 feet of new longitudinal cracks near the longitudinal construction joint similar to those seen in previous evaluations. Maintenance crews had sealed the longitudinal cracks along the construction joint sometime after the 2003 evaluation. The longitudinal cracks in Section 1 were beginning to progress into alligator cracking at several locations.

Rutting in both westbound sections increased to an average measurement of 2 mm (0.08 in.) in Section 1 and 3 mm (0.12 in.) in Section 2. The rutting in eastbound Section 3 also increased to 2 mm (0.08 in.).

6.4 2005 Evaluation

There was very little new longitudinal cracking in any of the sections in 2005. In Section 1, about 450 feet of longitudinal cracks had developed into alligator cracking. Nearly 200 feet of transverse cracking had appeared in Section 2; all of it in short cracks less than eight feet long.

The final evaluation was conducted on April 6, 2005. Rutting in the westbound lanes was almost unchanged from the 2004 evaluation; in the eastbound section it increased about 1 mm (0.04 in.). The slight decrease in the average rutting in the westbound Test Section 1 seen in the graph (Figure 10) may have been due to measurements taken by a different operator or a slight shift in the traffic pattern in the section.

Figure 14. Alligator Cracking Developed Along Both Sides of the Construction Joint in Test Section 2.

Test Section 2 had a considerable increase in transverse cracking in 2005. Although the graphs don't show it, the new transverse cracking in Section 2 is all short cracks from two to eight feet long. Nearly all of this new transverse cracking was located in the last 400 feet of the section.

In Test Section 1, beginning about 450 feet into the section and continuing without break for about 450 feet, the parallel longitudinal cracks along the longitudinal construction joint had developed into an area of severe alligator cracking. The alligator cracking was two to three feet wide, roughly centered on the longitudinal joint. Except for the area near the longitudinal construction joint, the pavement was in good condition in this test section.

Test Section 3 showed no increase in rutting and no increase in cracking and was in very good condition.

Figure 15. EB Section 3 in Excellent Condition (2005)

7.0 ANALYSIS

Since the severe alligator cracking in Section 1 and the longitudinal cracks that extend completely through Section 2 are all very close to the longitudinal construction joint, it is very likely that compaction along the longitudinal construction joint was inadequate and that the low joint densities allowed moisture to penetrate and weaken the surface. The intense sealing effort by maintenance forces may prolong the life of the failing pavement; however, the danger of pop-outs developing into potholes may also be the cause of many patches along the centerline.

In the first few months after construction the eastbound test section also developed a longitudinal crack along the longitudinal construction joint. However, subsequent site visits did not find any additional cracking or deterioration of the pavement. Test Section 3 is in excellent condition and shows no need of rehabilitation.

The vast majority of distress in the test sections occurred along the longitudinal construction joint and the distresses in the test sections are typical for the entire project. The relatively good condition of the surface away from the longitudinal joints led the researchers to believe that the early failure of the pavement was due to inadequate compaction along the joint in addition to mix sensitivity to freeze-thaw cycles along the joints, where higher air voids occur. The TLA manufacturer recommended very high temperatures to help obtain density. Density was very hard to obtain in the mat, and would have been even more so at the joint, with or without a joint density specification. Since the construction of this project, CDOT has adopted a density specification for longitudinal joints. The performance of the pavement at the joint on this project reinforces this specification change.

8.0 CONCLUSIONS

Much of the failure of the pavement in this study appeared to be construction-related. The very stiff mixture properties appear to have contributed to the construction-related difficulties. The performance of the pavement in areas away from the longitudinal joint was acceptable, and may indicate that properly constructed TLA/steel slag mix can perform well. Certainly better longitudinal joints need to be constructed. The longitudinal cracks developed parallel to the longitudinal joint at the centerline and then proceeded to become alligator cracking. The location of the joint close to the wheel path may have contributed to the rate of distress by providing the opportunity for lateral shoving by traffic and increased moisture penetration under traffic loading. A more flexible mix might have shoved under these conditions, but this TLA/steel slag mix simply cracked parallel to the weaker longitudinal joint.

No significant rutting was noted in the pavement, which supports the test results from the French Rut Tester and the Hamburg Wheel Tracking Device.

Evaluation of any future projects should include special attention to construction practices including asphalt density, particularly along the longitudinal construction joint. Also, selection of sites using a conventional pavement design without an experimental aggregate may provide better information to evaluate the performance of TLA alone. Since the construction of this project, CDOT has adopted the wider use of stone matrix asphalt (SMA) mixes, so any future TLA/slag evaluations should be compared to SMA as well as conventional polymer modified dense graded mixes.

The stiffness of the TLA/steel slag mix was high, which may have contributed to the low compaction near the longitudinal joint and the opening of the joint and cracking that followed.

Beyond the longitudinal joint problems, TLA/steel slag mix performed well. However, because of the lack of a control section with a standard dense graded mix, no conclusion could be drawn by comparing the performance of the TLA/steel slag mix with CDOT polymer modified mixes.

The results of this study reinforce the need for CDOT to strictly enforce joint density specifications.

9.0 RECOMMENDATIONS

Because this study was unable to identify superior performance of the TLA/steel slag mix to justify its higher cost, future use should be an experimental feature in conjunction with standard mix test sections built to allow performance comparisons. On future studies, conventional CDOT mix test sections should be included regardless of the modifier or mix feature being evaluated. Additionally, if the benefits of using only TLA or steel slag are to be determined, future studies should compare conventional CDOT mixes with asphalt mixes modified with only one product at a time.

10.0 REFERENCES

1. <http://www.trinidadlakeasphalt.com/asphalt4.htm> (1 Dec. 2004)

APPENDIX A

Appendix A

HBP Materials Quality Assurance Plan for
I70 - Glenwood Canyon Overlay
NH 0702-217
Subaccount No. 12238

David Eller – R3 Materials Engineer

Bill Schiebel – Asphalt Program Engineer

Donna Harmelink – HBP Research Engineer

April 10, 2001

Table of Contents

Introduction

This is a Quality Assurance Plan (QAP) for the Glenwood Canyon Overlay Project. This QAP details the standard and special high level materials testing and monitoring to be conducted in order to document the quality and performance of the unique HBP materials specified for use on the project. The activities, responsibilities and frequencies are described for the testing and monitoring of the project.

The Glenwood Canyon Overlay Project has elements related to soils, base course, concrete, hot bituminous pavement, asphalt cement, and other miscellaneous items that will all require materials testing and inspection. This QAP addresses the testing that is to be conducted for the HBP items - HBP (Grading SX)(100) (76-28) and HBP (Special) - that will be used for paving on this project. The plan will detail the testing requirements in the project plans for both of these HBP items as well as detail the additional CDOT testing beyond the construction contract requirements to document the quality of the HBP (Special) item. The plan for monitoring the pavement after construction is also described.

The HBP (Grading SX)(100) (76-28) will be used for the lower (bottom) lifts and ramp sections of the project, and is a standard CDOT specification that utilizes current Superpave methodology for asphalt design. This material was recommended by Region 3 Materials and incorporated into the plans under applicable CDOT Specifications at the time of advertisement.

The HBP (Special) is a unique mix design in that it utilizes a traditional Performance Graded Asphalt binder blended with Trinidad Lake Asphalt (TLA) and traditional aggregates blended with steel slag material. This mix was proposed by CTL Thompson, as a hired consultant to provide a recommendation for a High Performance Pavement to be used in Glenwood Canyon. A report of this design recommendation is available upon request. The specifications for this material are in general less tolerant and more specific than the standard CDOT HBP mixes. This specification is included in the appendix for reference. Additional testing and a performance-monitoring plan will be conducted by CDOT on this unique mix. Alternative materials may be recommended for use should testing indicate that the HBP (Special) mix is unacceptable before or during construction.

CTL/Thompson performed preliminary testing to establish mix design criteria, with the exception of European Lab testing, which was performed in the CDOT Materials and Geotechnical Branch's European Lab. This included Hamburg and French Rut Testing.

Preliminary Design of the proposed mix to be used in construction is currently being performed by Granite Construction. This is necessary to verify that specific crushing methods, aggregate resources, and binder materials will meet the specified design. CDOT has agreed to perform any necessary Hamburg and French rut testing verification.

Contract Requirements

Contract Testing and Inspection Responsibilities:

Quality Control (QC) Testing During Production:

Quality Control Testing for this project is required, and will be provided by the Contractor, or qualified Contractor Representative. QC testing is being performed to assure that the contractor is meeting and maintaining consistency in regards to all Project Standard Provisions and Project Special Provisions set forth in the Contract. QC Testing will be performed on both the HBP (Grading SX)(100), and the HBP (Special). This QC testing is to be performed as per the requirements set forth in ***Revision of Sections 105 and 106 Quality of Hot Bituminous Pavement included in appendix.***

Quality Acceptance (QA) Testing During Production:

Quality Acceptance Testing for this project is required, and will be provided by CTL Thompson and or CDOT staff. QA testing is performed to accept the material for payment, and to verify the QC testing that is being performed by the contractor. This verification between QA and QC is addressed in the 105/106 specification (paragraph c) as “Check Testing Program”. QA Testing will be performed on both the HBP (Grading SX)(100), and the HBP (Special). This QA testing is to be performed as per the requirements set forth in ***Revision of Sections 105 and 106 Quality of Hot Bituminous Pavement included in appendix. Also see the Frequency Guide Schedule for Minimum Materials Sampling located in the CDOT Field Materials Manual.***

Mix Verification Testing During Production:

Mix Verification Testing for this project is required, and will be provided by CDOT through Region 3 Materials. The Region 3 Portable Lab will be on site to perform this testing as well as routine verification testing with Staff Materials Lab. This testing will be performed throughout the project duration. This testing is referred to in the testing schedule as “Check Testing”, not to be confused with the QA/QC Check Testing Program. Region 3 Materials has identified Robert Somrak, recently retired Region 3 Materials Engineer, to be dedicated to this project part time to troubleshoot any Mix Design problems. CTL Thompson may also be utilized as engineering support in this Verification Testing, as a CDOT consultant. Mix Verification Testing will be performed in accordance with ***Revisions of Sections 105 and 106 Quality of Hot Bituminous Pavement (see appendix), and the Frequency Guide Schedule for Minimum Materials Sampling located in the CDOT Field Materials Manual.***

Independent Assurance Testing:

CDOT Region 3 Staff will perform Independent Assurance Testing, under the standard project requirements addressed in the Quality Assurance Program. The Hot Bituminous Pavement testing will fall under the Region 3 System Basis

Sampling and Testing, as in accordance with Federal Regulations 23 CFR. ***This testing will follow the Standard Frequency Schedule for Independent Assurance Evaluation in the CDOT Field Materials Manual.***

Contract Testing Activities:

The following two categories are **standard tests performed** on the majority of CDOT paving projects administered in Region 3. These tests and procedures are covered in the CDOT Materials Manual.

Quality Assurance testing of HBP - by CTL as a representative of CDOT
(Frequency: Per FMM Schedule)

Gradations
Fractured faces
Asphalt Content
Density
Specific Gravity
Longitudinal Joint Density as referenced in Appendix

Mix properties testing - done by CDOT Region and/or Materials and Geotechnical Branch
(Frequency: per FMM Schedule)

Voids
Voids in the Mineral Aggregate
Stability
Lottman
Asphalt Cement/Binder Properties – as per Item 411 (see revised table 702-2)

Testing Beyond the Contract Requirements

The following category of tests are specific to the Glenwood Canyon HBP (Special) mix and will be done as additional testing specific to this project. Region 3 has contracted with CTL Thompson for additional testing as described in **the scope of work and Task Order 1 included in the appendix**. Further testing in addition to this will also be conducted by CDOT and is described in this section of the QAP.

Additional tests conducted by CTL under Region 3 contract:

Percentage of TLA in Asphalt Cement – The percentage of TLA must be measured to assure that the required 25% is included. This will be done either by one or combination of both Copper Strip and Ash Burn Off Methods. 1/500 tons

Permeability of placed mix – There will be places on the bridge decks and cantilever decks that will not have a membrane to protect the concrete. The mix will be required to have near zero permeability to protect the decks from deterioration. 1/20,000 tons

Volumetrics – Voids and VMA will be monitored throughout the project as requested by the Region Materials Engineer. This is not an *acceptance criteria*, other than for mix design verification, but volumetrics will be monitored for use in establishing a comparison to other standard Superpave mixes. 1/5000 tons

Slag Gradations (1/5000 tons)

Additional Tests done by CDOT

Percentage of TLA in Asphalt Cement – The percentage of TLA must be measured to assure that the required 25% is included. This will be done by CDOT Region 3 Staff using one or combination of Copper Strip and Ash Burn Off Methods. 1/10000tons

High Level Mix and Binder Testing by CDOT Asphalt Program.
The Asphalt Program will coordinate the following testing to be conducted by the Asphalt Institute. Region 3 will provide CE Pool funding for a purchase order managed by the Asphalt Program.

Mixture Testing at 1/10,000 tons on HBP(Grading SX)(76-28) and HBP(Special) for total of 16 samples

- Low Temperature Indirect Tensile Testing for Creep
  -24, -18, and -12degrees C

Blended Binder Testing at 1/10,000 tons on PG 76-28 and PG 76-28 with TLA for total of 16 samples.

- BBR
  -12, -18, and -24 degrees C
- Direct Tension
  -12, -18, and -24 degrees C
- Results from the binder testing should be analyzed in the critical cracking temperature software

Analysis to determine critical cracking temperature of asphalt mixture. Low Temperature Modeling (*Rey Roque)* on BBR/IDT at 1/10,000 tons on HBP(Grading SX)(76-28) and HBP(Special) for total of 16 samples.

High Level Slag Testing by CDOT Asphalt Program. Central Lab and/or CTL under Region 3 contract will conduct the following tests on the slag component of the mix aggregate. Stockpile sampling will be as prescribed by CDOT:

Bulk of Slag in Rodded Container (verify during initial Mix Design Approval Testing). This test to be conducted by CTL

Slag Fine and Coarse Aggregate Absorption (verify during initial Mix Design Approval Testing). Done by Central Lab and CTL.

Slag Deleterious Materials Testing (verify during initial Mix Design Approval Testing). Done by Central Lab and CTL.

Plan for Monitoring the Glenwood Canyon Pavement

1. Identify three evaluation sections throughout the project. Each of the evaluation sections will be approximately 1000 feet in length. There will only be one mix used throughout the project so there will not be a control section. There will be one section in each of the following project areas: bridge deck, overlay on milled pavement, full reconstruction.

2. Once the three evaluation sections have been identified a pre-construction evaluation will be performed to document existing distress before and after milling. The evaluation will include: crack mapping, rut depth measurement and documenting any additional distresses.

3. Construction at the three evaluation sections will be documented. Documentation will include temperature of mix, rolling pattern, densities, construction technique of both longitudinal and construction joints etc. In addition independent samples of project produced mix will be obtained from the three evaluation sections. This mix will be tested in accordance with the contract testing requirements as listed above in the section "**Contract Testing Activities".** Independent longitudinal joint densities will also be taken according to the contract specifications in each test section.

4. Following construction an evaluation of the three sections will be made. This evaluation will establish the base line for the future evaluations.

5. The project will be evaluated in the spring and fall of each year for 3 years following construction. The evaluation in the spring will include documentation of cracking, smoothness and visual observations. In the fall the evaluation will include coring and rut depth measurements.

6. Following the three year evaluation a report will be completed that documents performance and makes recommendations.

Literature Search

Since the Colorado Department of Transportation has little experience with the use of Trinidad Lake Asphalt (TLA) a literature search and review on TLA was conducted to determine the state of the practice. The information was limited and is summarized below.

An e-mail request to the states asking for their experiences revealed the following:

> Georgia - They have only tested the material a few years ago. The TLA tested was very hard at room temperature and broke when dropped. The TLA failed the SHRP binder testing. The TLA also failed the Pen-Viscosity specification. The material was never approved for use by Georgia DOT.
>
> Utah - They currently have a test section with TLA in Region 1 near Ogden, Utah. Mike Rhodes of UDOT stated that the pavement is experimental but does appear to be performing well. It was placed on a 5 mile portion of highway. One lane contained the TLA and the other three lanes contained a PG 64-34. The pavement carries a large quantity of truck traffic.
>
> Nebraska Department of Roads has no experience with TLA.
>
> Nevada - The DOT constructed one project in 1995. The mix contained 75% AC-20 and 25% TLA. The project was constructed on a street in Las Vegas with high traffic volumes and is a major bus route. The project has developed extensive block cracking since construction. The department experienced problems during construction with some of the mineral matter in the TLA setting the asphalt storage tank. This caused pumping and mixing problems in the hot plant. We did not get the expected performance that the department was hoping for. With the increase in cost, and fair to poor performance, the department with proceed with polymer modified asphalts.

Other information collected on the use of TLA in the USA:

> The New York/New Jersey Port Authority used TLA for many years. They quit using it about 8 or 10 years ago. They quit because it was expensive and not performing. Pavements would last 4 to 5 years and fail from cracking. A specific example was the George Washington Bridge, 25% TLA was combined with 75% PG 64-22. The pavement cracked and fell apart. The specific cracking distress was transverse and fatigue. They were never able to get TLA to work. It was expensive. They quit using it.
>
> Granite constructed a TLA project at the Windover Airport a couple of years ago. There is no cracking and the materials are performing well. Paving was done in echelon.

The Transportation Research Information Service (TRIS) search revealed a number of research studies the majority of which were conducted in Europe. Unfortunately the reports were not readily available and the most of the abstracts documented the development of the testing procedure and not the long term performance. Below are brief summaries of the some of the research studies.

Trinidad Lake Asphalt in Road Pavements - presented at the 13th World Meeting of the International Road Federation
Author: Charles, R and Grimaldi, R
This paper shows that both user-producer and performance based specifications can be met with selected percentages of TLA modification through traditional blending procedures, and that its modulus and performance characterization facilitates the use of most design codes for new surfacing and overlays. Case studies are presented for Trinidad and Tobago airports and for the New York Metropolitan airports, tunnels and bridges.

Resurfacing of the AC Dover Viaduct with Hot Rolled Asphalt Containing Trinidad Lake Asphalt
Author: Walsh, Id
This project incorporated 50% TLA. Performance after 2 years is considered to have been goo. No cracking or crazing has occurred, texture depths remain high and rutting has reached a maximum of 1.8 mm downhill and 0.8 mm uphill.

The Economical Treatment of Highways with Natural Asphalt. Sino-British Highways and Urban Traffic Conference.
This report documents the use of what the author refers to one well-proven high performance binder, Trinidad Lake Asphalt. The paper states that TLA is specified for pavement construction for the following reasons:

1. It provides improvements in stability and skid resistance
2. It has a high temperature stability, long life, a high level of consistency, a high resistant to spalling, and a light color.

Case studies for this report are on projects in the USA, the United Kingdom, Trinidad, Japan and Hong Kong.

Laboratory Evaluation of Trinidad Lake Asphalt, Final Report
Authors: Paul, HR; Kemp, SF
In this study Trinidad Lake Asphalt in both an epure and a powder form was examined in the laboratory. Laboratory testing included: binder properties testing of combinations of Trinidad with three asphalt cements at three levels of addition; binder durability testing using the Thin Film Oven; Marshall optimization of mix design for a low stability dense graded mix, a high stability dense graded mix and sand mix each at three Trinidad addition levels; water susceptibility testing; and , fundamental property testing. In addition an economic analysis was performed. Results were:

1. Marshall stabilities were found to increase with increasing Trinidad Lake Asphalt content for all mix designs. 2. Modulus values and tensile stress at failure were increased with the use of Trinidad material while the tensile strain at failure was decreased. 3. Due to the mineral matter in the naturally occurring asphalt, viscosities were higher and penetration and ductilities were lower than values normally associated with conventional binders. Viscosity indices after thin film oven treatment, however demonstrated no unexpected hardening. An economic analysis on either a first cost or life cycle basis showed that a Trinidad mix would have to perform an additional two years beyond a conventional mix in order to achieve economical parity.

This report was done by the Louisiana Department of Transportation. It would be interesting to see if based on the laboratory testing if the department has used TLA in any pavements.

Appendices

Consultant Testing Scope and Task Order
Project Special Provision for binder
Project Special Provision for HBP(Special)
Standard Special Provision for Quality of HBP
Standard Special Provision for Longitudinal Joints
Longitudinal Joints Field Data Sheet

MATERIALS TESTING/ENGINEERING SUPPORT
SCOPE OF WORK

Scope Date: April 2001 to October 2002

Project Number: NH 0702-217

Project Location: I-70 through Glenwood Canyon

REGION TRANSPORTATION DIRECTOR
REGION 3

Active day-to-day administration of this contract will be delegated to

DAVID A. ELLER – REGION MATERIALS ENGINEER – 970-248-7239

RICH ORTON – GLENWOOD SPRINGS RESIDENT ENGINEER – 970- 945-8187

TONY ROSO – BUSINESS MANAGER – 970-248-7236

222 S 6TH ST RM 317 GRAND JUNCTION (Address)

WORK DURATION:

The time period for the work described in this scope is 575 calendar days. Work may be required: night or day; on weekends; on holidays; or on a split shift basis.

AUTHORIZATION TO PROCEED:

Work shall not commence until the written Notice to Proceed is received by the consultant, and shall be completed within the allotted time specified.

ROUTINE REPORTING AND BILLING:

The consultant shall provide the following on a routine basis:

- Coordination of all contract activities by the Consultant's Project Manager
- Periodic reports and billings required by CDOT Procedural Directive 400.2

PROJECT STANDARDS:

All sampling, testing and documentation shall be in accordance with the Colorado Department of Transportation (CDOT) Materials Manual. The applicable CDOT Materials Manual shall be the one currently in use when the construction project is advertised. If the required method is not described in the CDOT Materials Manual, the required work shall be completed in accordance with the current AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing (as revised and supplemented) or the ASTM Standards and Tentatives. Proposed work procedures shall be coordinated by the CDOT Project Engineer prior to the start of work.

LABOR, MATERIALS AND EQUIPMENT:

MATERIALS LAB FACILITY

The consultant shall furnish all personnel, materials and equipment required to perform the work. The consultant shall provide a field laboratory or laboratory facility within one hour travel time of the project. The only exception is for Permeability testing, which may be contracted to outside resources due to the uniqueness of the test.

The Lab Facility needs to meet all minimum equipment standards identified in M-620-2 Field Laboratory (Class 2). In addition, the following equipment shall be furnished by the consultant for this project in sufficient quantity to ensure performance of all work required in a timely manner:

1. A.C. Content gauge
2. Nuclear Moisture/Density gauge
3. Concrete air meter, slump cone, and other concrete testing equipment
4. Sieves for aggregates and soil gradations
5. Electronic Scales
6. Sample containers and small tools
7. Proctor equipment for soil curves and 1-point tests
8. Atterberg equipment
9. Sample drying equipment
10. Miscellaneous equipment for performing the required soils, concrete and asphalt field tests.
11. Concrete cylinder molds which conform to AASHTO requirements, except that PAPER MOLDS SHALL NOT BE USED, AND PLASTIC MOLDS SHALL NOT BE REUSED.
12. Concrete cylinder breaker for bridge or concrete paving projects.
13. Curing Tank with Recording Thermometer
14. Cell phone for each tester.
15. Computer and printer for each test lab (CDOT or Consultant).
16. Forced Air Convection Oven – 1500 Watts, blower, min. 4.8 cubic feet, vented, electronic control w/ digital temp.

16. Ignition furnace – As per CPL 5120
17. Superpave Gyratory – As per CPL 5115
18. Aparatus for Identification of TLA Percentage Testing. – ASTM D 5710, D 2172, D 1856, D 140
19. Permeability Test System and/or Capability to utilize outside Lab resources. – As per ASTM D 5084.

Personnel qualifications and staffing levels for the project shall be subject to the approval of the CDOT Project Engineer and Region Materials Engineer.

MATERIALS ENGINEERING SUPPORT

The consultant tester shall be under the direction of, and shall be reviewed, stamped and signed by the Professional Engineer registered in the state of Colorado. The only work to be stamped will be the summary sheets, i.e., (CDOT Forms 6,9,58,69,212,250, and 554). The Professional Engineer shall be available within 24 hours at the request of the project engineer to review work, resolve problems, and make decisions in a timely manner as requested by the CDOT Project Engineer. The Consultant Engineer must be experienced and competent in road and bridge construction materials testing and should have, or acquire prior to work, a distinct knowledge of the nature of construction of the Glenwood Canyon infrastructure and how it directly effects paving operations. This knowledge should include, but not limited to the following:

Subgrades and Subslabs for this project
Cantilever, Post Tensioned Slabs and Bridges
Rigid Bridge Decks and Tunnel Foundations
Complex Bridge Joint Systems
Existing Membrane System
The Consultant Engineer shall have experience with Hot Bituminous Pavement mix design proceedures, sampling, testing and interaction of the unique materials used in HBP (Special), including but not limited to the following:

Trinidad Lake Asphalt (TLA)
Steel Furnace Slag

MATERIALS TESTING

The materials testing technician(s) shall be permanently assigned to a project and shall be certified as defined by the requirements set forth in active year Colorado Procedure CP-10. Minimum requirements for certification are dependent on the item to be sampled and tested. The materials technician(s) responsible for sampling and testing on a particular project shall have all required certifications based on that specific materials testing schedule. A copy of all required certifications shall be provided to the CDOT Project Engineer. The materials testing technician(s) performing the tests must have a minimum of one year experience in each specialty field (soils, aggregates, asphalt paving, concrete, etc.) that is being tested.

The materials testing technician(s) shall be thoroughly familiar with CDOT forms and documentation requirements.

Personnel provided by the consultant who do not meet all of the specified requirements, or who fail to perform their work in an acceptable manner, shall be removed from the project when determined and directed by the CDOT Project Engineer.

GENERAL WORK DESCRIPTION:

The consultant shall be capable of performing any or all of the three elements defined:

- Materials Lab Facility – The consultant shall provide a furnished lab facility that can perform all field testing required on this project.

- Materials Engineering Support – The consultant shall provide Professional Engineering support for any materials related subject on this project as requested by the Project Engineer. This includes the potential for redesign of the HBP (Special) job mix formula.

- Materials Testing- The consultant shall sample, test and inspect those specified materials utilized in construction.

Other services may be requested in writing by the CDOT Project Engineer. Test results and inspection observations shall be documented by the consultant and approved by the CDOT Project Engineer in accordance with the references sited above in PROJECT STANDARDS.

PROJECT STAFFING AUTHORITY:

The CDOT Project Engineer is in direct charge of the work and is responsible for administration of the project contract as defined in the CDOT Standard Specifications. This includes approving and setting work hours for both project construction and the materials sampling and testing. Region 3 Materials will provide Independent Assurance Testing, Project Support, and all mix design verification testing as in accordance with CDOT Materials Manual.

INITIAL PROJECT MEETING:

The consultant, CDOT Project Engineer, Resident Engineer and Region Materials Engineering/Physical Science Technician shall meet to coordinate and schedule the required work. The consultant shall complete all work in accordance with their approved schedule.
SPECIFIC TESTING REQUIREMENTS:

The consultant shall sample, test, inspect and document all materials generated and produced on the project. This includes: materials delivered to the project that are listed in the Summary of Approximate Quantities in accordance with the SCHEDULE in the Field Materials Manual; materials that may be added to the project through contract modification; and altered material quantities whether increased or decreased. The consultant's Project Manager, field tester(s) and CDOT's Project Engineer shall be required to review project quantities on a monthly basis to ensure that sufficient tests have been performed for the material placed to date. The consultant shall also provide any other services as requested by the CDOT Project Engineer.

Additional Materials Testing that will be required that is not defined in the SCHEDULE is a follows:

- Permeability Testing (inc. Falling Head, Rising Tail Method) – Prior to mix production a correlation between voids and permeability will be establised for each mix design. This correlation shall be established by testing permeability on 5 variable points for lab mixed material with voids ranging between 3.5 % - 5.5%. This correlation shall be plotted for use in permeability verification of field produced material. Permeability Testing shall be performed at a rate of 1 test per day for the first 3 days of field production for Mix Verification. If permeability requirements are met, testing will then be performed at a rate of 1 test per 20,000 Tons on all mix produced – ASTM D 5084.
- Percent TLA / Asphalt Content – Performed on HBP (Special) for each Asphalt Content as per CDOT Testing Schedule – AASHTO
- Voids Testing – 1 per 5000 Tons of mix produced – In Accordance CDOT Materials Manual
- Voids in Mineral Aggregate - 1 per 5000 Tons of mix produced – In Accordance CDOT Materials Manual

Testing of materials that are specifically designated to be pre-inspected or pre-tested by this or any other Department of Transportation shall remain the responsibility of CDOT. The consultant shall document and transport samples of any and all materials to the CDOT Central Laboratory that are required to be tested by CDOT regardless of pre-inspection or pre-testing responsibilities. The items and test frequencies of Department tested materials shall be in accordance with the column titled "Central Laboratory" in the TESTING SCHEDULE as identified in the CDOT Field Materials Manual.

DOCUMENTATION:

Each of the consultant's field testers shall maintain a daily diary for each day the tester performs work on the project. They may use CDOT's Form 103, Project Diary, or a form approved by the CDOT Project Engineer. The contents of the diary shall be brief and accurate statements of progress and conditions encountered during the prosecution of the work. Editorial comments are not to be incorporated in the diaries or on any written correspondence applicable to the project. A copy of the daily diary shall be given to the CDOT Project Engineer within one working day of its date.

Test results, sample submittal and inspection documentation transmitted to CDOT's Region or Central Laboratory shall be recorded on appropriate CDOT Forms. The consultant may use CDOT worksheets or worksheets approved by the CDOT Project Engineer. CDOT Forms and worksheets are available through the Region Materials Engineering/Physical Science Technician.

The consultant shall furnish the CDOT Project Engineer with copies of all worksheets on a daily basis. The consultant shall also keep the CDOT Form 626 up to date at all times and provide copies of this form to the CDOT Project Engineer and the contractor within 12 hours for any material found to be non-specification.

The consultant shall coordinate the schedule for Independent Assurance Tests for the project in accordance with CDOT Form 379, with the Region Materials Engineering/Physical Science Technician.

STATUS OF PROJECT:

The consultant shall monitor the status of the project, and advise the CDOT Project Engineer of any potential for supplementing their contract. Failure to monitor project status and provide timely notification may result in discontinuing the consultant's services on the project until a supplemental agreement can be effected.

SUBMITTAL OF FINAL DOCUMENTATION:

Final documentation shall be submitted to the CDOT Project Engineer within 20 working days after project acceptance. A completed CDOT Form 250 shall be submitted to the CDOT Project Engineer 10 working days after the consultant has been notified of final quantities. Failure to submit final documentation as required may result in withholding any and all consultant payments received subsequent to project acceptance until this material is received.

STATE OF COLORADO

DEPARTMENT OF TRANSPORTATION
Region 3
222 South Sixth Street, Room 317
Grand Junction, Colorado 81501-2769
(970) 248-7239 FAX # (970) 248-7254

March 27, 2001
Project No.: NH 0702-217
Sub-Account: 12338
CMS ID#: ID 059-01

CTL/Thompson, Inc.
1971 West 12th Avenue
Denver, CO 80204

Attention: Mr. John Mechling / Mr. Scott Sounart

Re: Region Three Project Specific Contract Materials Engineering and Inspection, Proposal for Task Order No. 1 to provide Engineering Support for Mix Design Verification and Quality Assurance Testing for Region Materials and the Glenwood Springs Construction Residency.

We are requesting a cost proposal for Materials Engineering Support and Project Assurance Testing on the project identified above. All work shall be performed in accordance with the basic Scope of Work (Exhibit A) as supplemented by these task requirements.

The Contract Administrator for this Task Order will be:

Richard Orton, Resident Engineer
Region 3, Glenwood Springs Residency
202 Centennial Street
Glenwood Springs, Colorado 81601
Office: (970) 945-8187
Fax: (970) 945-6889

Active Day-to-Day administration and monitoring of this contract will be delegated to the following CDOT employee:

Thomas Metheny, Project Engineer
Region 3, Glenwood Springs Residency
202 Centennial Street
Glenwood Springs, Colorado 81601
Office: (970) 384-3389
Mobile: (970) 379-0833
Fax: (970) 945-6889

Authorization to Proceed

Work shall not commence until written Notice to Proceed is received by the Consultant, and shall be completed in the time specified.

Routine Billing & Reporting

The Consultant shall provide the following on a regular basis:

1.) Monthly billing formats, suitable to the CDOT Engineer, for all contract activities performed by the Consultant's Project Engineer, inspectors, office help and field Materials Testing Technician (MTT).
2.) Periodic reports and billings required by CDOT Procedural Directive 400.2.
3.) Weekly time cards for consultant personnel. These must be signed by the CDOT Resident Engineer or CDOT Project Engineer prior to billing.

Status of Contract

The Consultant shall monitor the fiscal status of the contract, and advise the CDOT Resident Engineer of any potential for supplementing their contract or negotiating an additional task order. Failure to monitor contract status and provide timely notification may result in discontinuation of the Consultant's services on the project until a supplemental agreement can be effected.

General Requirements

Region Materials Engineering Support:

- We will require an experienced materials engineer to advise on the HBP (Special) on this project. Your Senior Materials Advisor should be available to discuss all aspects of the mix design proposed for use on this project. This materials advisor should stay informed of all progress on the project, and must be available within 24-hour notice to troubleshoot or discuss any materials related problems on this project. This materials advisor should be a registered Professional Engineer is the State of Colorado, and will be ultimately responsible for certification of the testing on this project as per the requirements established in the Scope of Work. This advisor will work directly with the Region Three Materials engineer to prepare a CDOT Form #43 for the HBP (Special) material that will be used on this project. This materials advisor will also be available to discuss with the Materials Engineer and Resident Engineer all constructability and asphalt specification requirements for this project.

The Senior Materials Advisor will be needed from April 1, 2001 to October 1, 2001 for approximately **20 days total, average of 6 - 8 hours per day**. The Senior Materials Advisor will receive assignments and report directly to the Glenwood Springs Resident Engineer, Rich Orton.

Construction Materials Engineering Support:

- We will require a Staff Engineer or qualified technician to administer all testing for mix design verification, check testing, and quality assurance testing requirements that the consultant will conduct. This person must be LabCat Level C and Level E as per CP 10 Qualifications. This staff engineer will work directly with the Region Materials Engineer to evaluate and monitor the mix design volumetrics, QA/QC Testing reports, and all other materials related specifications on this project. Region Materials Personnel will conduct all standard Check Testing and Independent Assurance Testing requirements as described in the Field Materials Manual, but the staff engineer will be available to discuss any results and discrepancies. Your staff engineer should be available on a routine basis to observe and oversee all consultant testing performed on this project, as defined in the project special provisions, including all Quality Assurance Testing. The staff engineer will be responsible for accurate and timely notification to the project engineer of any deficiencies of project specifications. This Staff Engineer will conduct weekly reviews and summaries of all check testing including volumetric testing and other specialized testing that is required for the HBP (Special). These reviews shall be documented in a weekly progress report and submitted to the project engineer for verification at the end of each week of asphalt production. This documentation is in addition to, and separate from, all other QA/QC documentation requirements for this project.

The Staff Engineer will be needed from April 1, 2001 to October 1, 2001 for approximately **90 days total, average of 8 hours per day**. The Staff Engineer will receive assignments and report directly to the Project Engineer, Tom Metheny.

Construction Materials Testing Support:

- We will require a Field Technician to conduct all Quality Acceptance Testing on this project as per the CDOT Field Materials Manual, AASHTO Standard Specifications, ASTM Standards, and Project Specifications as described in the Scope of Work (exhibit A). Testing of materials that are specifically designated to be pre-inspected or pre-tested shall be performed by CDOT staff or the Consultant as requested by CDOT. The consultant shall document and transport samples of any and all materials that are required to be tested by CDOT to the CDOT Region or Central Laboratory regardless of pre-inspection or pre-testing responsibilities. The items and test frequencies of CDOT tested materials shall be in accordance with the column entitled "Central Laboratory" in the Schedule in the Field Materials Manual. The Engineer may require additional testing or other services for adequate Quality Control or Quality Assurance.

The Consultant Tester and CDOT Engineer shall review project quantities on a weekly basis to ensure that sufficient tests have been performed for all material placed to date on the project. The Consultant Tester and the Resident Head Tester shall meet on a regular basis throughout the duration of the project to address any questions or issues involving materials testing procedures, frequency, or documentation.

The Field Technician will be needed from April 1, 2001 to October 1, 2001 for approximately **120 days total, average of 8 -10 hours per day**. The Field Technician will receive assignments and report directly to the Project Engineer, Tom Metheny.

This proposal will be used to write a Task Order on your Project Specific Contract for Materials Engineering and Testing on this project.

If you have any questions about this request, please call David Eller at (970) 248-7239.

Sincerely,

David A. Eller
Region 3 Materials Engineer

COLORADO PROJECT NO. NH 0702-217 NOVEMBER 13, 2000
CONSTRUCTION SUBACCOUNT NO. 12238

REVISION OF SECTIONS 401 AND 403
HOT BITUMINOUS PAVEMENT (SPECIAL)

Section 401 of the Standard Specifications is hereby revised for this project as follows:

Subsection 401.01 is revised to include the following:

The second paragraph shall include the following:

This work also includes placement of one course of bituminous mixture as indicated on the plans.

Subsection 401.02 shall include the following:

(a) Mix Design. The top lift of all pavements shall be Hot Bituminous Pavement (Special) which shall be a mixture of aggregate, steel furnace slag, and polymer modified asphalt cement with 25 percent Trinidad Lake Asphalt (TLA). A mix design has been performed and a project mix is here-in provided using Koch PG 76-28, International Milling Service steel furnace slag, and Trinidad Lake Asphalt.

Any deviation from the HBP (Special) mix design shall require retesting of all properties in Table 401-1(a). Properties testing shall meet the minimum requirements of Table 401-1(a). Properties testing shall be subject to the Engineer's approval and shall be at Contractor's cost.

TABLE 401-1(a)
HBP (SPECIAL) MIX DESIGN PROPERTIES

PROPERTY	TEST METHOD	HBP (SPECIAL)
Air Voids at N (design), %	CPL 5115, 5102	3.5-4.5
Hveem Stability, minimum	CPL 5106	55
Aggregate retained on the No. 4 sieve with at least 3 mechanically induced fractured faces, % minimum	CP 45	100
Voids in the mineral aggregate (VMA), % minimum	CP 48	17.0
Hamburg Wheel Tracking Device, maximum impressions, mm	CPL 5112	3.7
French Rut Test, percentage of rutting after 30,000 cycles, max.	CPL 5114	2.0
Permeability, falling head, rising tail, hydraulic conductivity, cm/sec, max.	ASTM D 5804	$<1 \times 10^{-8}$

REVISION OF SECTIONS 401 AND 403
HOT BITUMINOUS PAVEMENT (SPECIAL)

Subsection 401.03 shall include the following:

Aggregates for HBP (Special) shall be uniform quality, composed of clean, hard, durable particles of 100 percent crushed gravel. Excess of fine material shall be wasted before crushing. The material shall not contain volcanic materials, clay balls, vegetable matter, or other deleterious substance. Aggregate shall have a maximum LA Abrasion (AASHTO T 96) of 25%. Aggregate shall have at least 100 percent of particles with three or more fractured faces.

Steel Furnace Slag. HBP (Special) shall include 25 percent steel furnace slag of the total aggregate blend by weight. Steel furnace slag shall contain a maximum of 2.5 percent sulfur content and meet the following gradation and limits in Table 401-1(b) such as supplied by International Milling Service in Pueblo, Colorado.

TABLE 401-1(b)
STEEL FURNACE SLAG RANGE

	Steel Furnace Slag	Job Mix
Sieve Size	Actual Grading	Tolerances (+/-) %
1-1/2"	-	-
1"	-	-
3/4"	100	0
½"	92	5
3/8"	80	4
#4	52	4
#8	33	3
#16	23	-
#30	17	3
#50	13	-
#200	6.9	2.0

REVISION OF SECTIONS 401 AND 403
HOT BITUMINOUS PAVEMENT (SPECIAL)

Steel furnace slag shall have a maximum LA Abrasion of 15, an aggregate specific gravity of at least 3.050, and stockpiles shall be free of foreign materials.

Gradation. The HBP gradation, including the steel furnace slag, shall be in accordance with mix design and shall be wholly within the control point gradation range set forth in Table 401-2(A).

TABLE 401-2(A)
GRADATION RANGE

Sieve Size	HBP (Special) Actual Grading	HBP (Special) Job Mix Tolerances
1-1/2"	-	-
1"	-	-
3/4"	100	0
½"	98	5
3/8"	92	5
#4	69	4
#8	51	4
#16	41	-
#30	30	2
#50	17	-
#200	6.8	2.0

The asphalt cement used for HBP (Special) shall be PG 76-28 per Table 702-2 grade modified with Trinidad Lake Asphalt (TLA). The asphalt cement shall be 7.2 percent of the total mixture by weight with a tolerance of +/- 0.2 percent. (The percentage of asphalt content shall be determined by ignition furnace, CPL-5120.) The Contractor shall provide to the Engineer complete laboratory test results of supplied asphalt cement along with "Certifications of Compliance".Trinidad Lake Asphalt (TLA). TLA shall be added at the rate of 25 percent by weight directly in-line with the base asphalt cement. The blending equipment and continual supervision of the blending of asphalt cement/TLA will be provided by the TLA supplier's representatives and conform to the requirements listed in Table 702-2 as revised for this project.

Subsection 401.07 shall include the following:

The HBP (Special) shall be placed with a minimum air and surface temperature of 50 degrees F., and only when weather conditions permit the pavement to be properly placed and finished as determined by the Engineer.

Subsection 401.10 shall include the following:

The paver shall be capable of operating at forward speeds consistent with uniform and continuous laying of the mixture. Stop and go operations of the paver will not be permitted. The screed or strike-off assembly shall produce the specified finished surface without tearing, shoving, or gouging of the mixture. Pavers shall be equipped with automatic screed controls with sensors capable of sensing grade from an outside reference line, and maintaining the screed at the specified longitudinal grade and transverse slope.

Subsection 401.15 shall include the following:

The minimum and maximum temperatures of the HBP (Special) mixture when discharged from the mixer shall be 330 and 360 degrees Fahrenheit.

Subsection 401.17 shall include the following:

For HBP (Special), the mixture immediately behind the screed shall be in the temperature range of 305° F to 320° F. Breakdown compaction shall be completed within this temperature range.

The HBP shall be compacted by rolling. The roller pattern shall consist of the following types and frequencies:

Breakdown:

Static steel wheel compactor (16 to 18 ton) shall perform two passes immediately behind paver in the mat temperature range of 305° F to 320° F.

Intermediate and finish:
Static steel wheel compactor (12 to 16 ton) shall perform intermediate and finish compacting. All roller marks shall be removed with the finish rolling.

<u>Vibratory compaction on bridge decks will not be permitted. Pneumatic compactors will not be permitted.</u>

This roller pattern procedure may be re-evaluated by the Contractor and Engineer throughout the paving operations, or during a test strip installation prior to commencement of paving.

The pavement shall be compacted to 93 to 96 percent of Maximum Theoretical Density as determined by AASHTO T-209, <u>including the supplemental procedure for porous aggregate</u>. Field density determinations will be made in accordance with CP 44 or 81. The Contractor shall cease production after three successive failing Maximum Theoretical Density tests. For all hot mix bituminous pavements, the Contractor shall core the pavement as required by the Engineer for field density tests in accordance with AASHTO T-230, or for field calibration of nuclear density equipment in accordance with ASTM D-2950. At a minimum, cores for nuclear density equipment calibration shall be taken at the beginning of placement of each pavement layer or change of mixture based on a new job mix formula. Density and thickness will be determined on these cores. Untested areas during placement will also require cores, at the Engineer's discretion, to be taken to verify compaction.

COLORADO PROJECT NO. NH 0702-217 NOVEMBER 13, 2000
CONSTRUCTION SUBACCOUNT NO. 12238

-6-

REVISION OF SECTIONS 401 AND 403
HOT BITUMINOUS PAVEMENT (SPECIAL)

Subsection 403.01 shall include the following:

This work consists of placing a special bituminous pavement mixture on bridge and cantilever decks or on prepared foundations in accordance with plan details. No hydrated lime will be required for HBP (Special).

Subsection 403.05 shall include the following:

Pay Item	Pay Unit
Hot Bituminous Pavement (Special)	Ton

REVISION OF SECTION 702
SUPERPAVE PERFORMANCE GRADED BINDERS

Section 702 of the Standard Specifications is hereby revised for this project as follows:

Table 702-2 is deleted and replaced with the following table:

TABLE 702-2
SUPERPAVE PERFORMANCE GRADED BINDERS

PROPERTY	REQUIREMENT FOR PG BINDER 76-28	AASHTO Test No.
Original Binder Properties		
Flash Point Temp., ^oC, minimum	230	T 48
Viscosity at 135 ^oC Pa.s, maximum	3	TP 48
Dynamic Shear, Temperature ^oC, where G*/Sin @ 10 rad/s ≥ 1.75 kPa	76	TP 5
RTFO Residue Properties		T 240
Mass Loss, percent maximum	1.00	T 240
Dynamic Shear, Temperature ^oC, where G*/Sin @ 10 rad/s ≥ 3.05 kPa	76	TP 5
PAV Residue Properties		
Aging Temperature 100 ^oC		PP 1
Dynamic Shear, Temperature ^oC, where G*/Sin @ 10 rad/s ≤ 5000 kPa	28	TP 5
Creep Stiffness, @ 60 s, Test Temp. in ^oC	-18	TP 1
S, maximum, MPa	180	TP 1
m-value, minimum	0.30	TP 1

APPENDIX B

Appendix B.1

From: Turner, Pam [PTurner@AsphaltInstitute.org]
Sent: Friday, May 03, 2002 9:10 AM
To: Schiebel, Bill
Subject: AI Low temperature testing for Glenwood
Attachments: reportcololtc.doc; Appendix.xls (below)
Dear Mr. Schiebel,
Attached is the report for low temperature evaluation of seven mixes labeled as follows:

Glenwood Canyon 4th 10K Sx special PG 76-28 (212) Glenwood Canyon 1st 10K Sx 100 (219) Glenwood Canyon 10K-5 403 Special (298) Glendwood Canyon 7-17 403 Special (299) Glenwood Canyon 7-30 403 Special (300) Glenwood Canyon 8-16 403 Special (301) Glenwood Canyon 8-22 403 Special (302)

Please do not hesitate to contact me if you have any questions or wish to discuss this data further. A hard copy of the report will be put in the mail early next week along with an invoice for the testing costs. Total cost for testing completed to date is $4,102.00.

Sincerely,
Pamela Turner
859-288-4986
pturner@asphaltinstitute.org
The following files (from the Asphalt Institute) are below: Reportcololtc.doc & Appendix.xls

Reportcolo.doc:

Background

The Asphalt Institute was asked by the Colorado DOT to evaluate the low temperature cracking properties of seven mixtures. The mixtures were received in three gallon cans and quartered to obtain mix to compact one to three Superpave Gyratory Compactor (SGC) specimens, depending on the amount of mix available. Specimens were compacted to a height of 75mm and approximately 7% air voids. Following compaction, the SGC specimens were aged for five days at 85°C to simulate in service aging of the mix, then cut to a height of 50 mm and tested using the Indirect Tensile Tester according to AASHTO TP9.

Indirect Tensile Creep and Strength

The Indirect Tensile Creep and Strength tests provide a measure of the low temperature cracking resistance of mixture specimens. {*1*} The test is run at cold temperatures, and is performed by applying a static creep load to a 50 mm tall by 150 mm diameter sample for 100 seconds (240 seconds was used for this research). Measurements of horizontal and vertical deformation are taken throughout the loading period and used to calculate the stiffness of the material over time. Creep testing is repeated at three temperatures. For this research, -12, -18, and -24 C were used. After the creep loading at all three temperatures is completed, the sample is again loaded at a rate of 12.5 mm/min until failure. Figure 1 shows the Indirect Tension Testing apparatus.

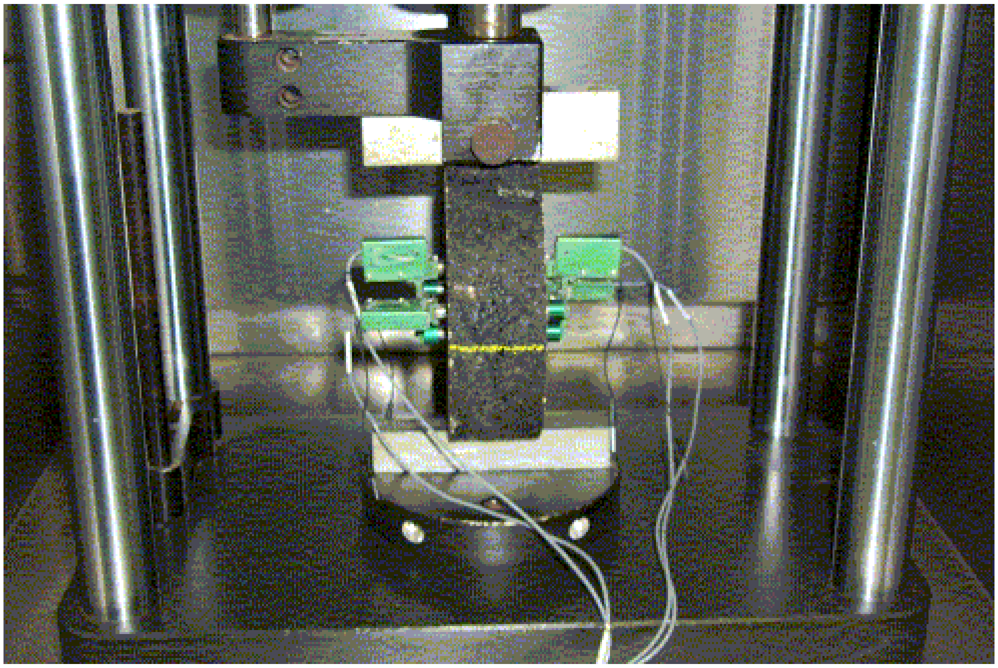


Figure 1: Indirect Tension Apparatus

The IDT results were also analyzed using a spreadsheet developed by Don Christensen that is a modification of the models developed by Roque and others during SHRP. This approach develops thermal stress curves for the materials based on the indirect tensile creep results and then determines a critical cracking temperature at which the thermal stress in the material exceeds the thermal strength of the material as determined by the indirect tensile strength test. This critical temperature is used only for comparison purposes and should not be used to predict actual pavement performance.

Results

TABLE 1 AND FIGURES 2 - 4 SHOW THE IDT STIFFNESS RESULTS FOR MIXES

Table 1: IDT Stiffness, MPa

			Stiffness, MPa		
ID	**Sample**	**Time, sec**	**-12°C**	**-18°C**	**-24°C**
212	Glenwood Canyon	15	12,429	15,930	20,403
	4th 10K	60	10,394	15,285	19,393
	Sx special PG 76-28	240	8,366	13,011	19,090
219	Glenwood Canyon	15	11,943	16,093	21,345
	1st 10K	60	10,301	13,056	18,688
	Sx 100	240	7,487	10,487	16,595
298	Glenwood Canyon	15	10,517	15,084	18,184
	10K-5	60	8,296	13,058	15,803
	403 Special	240	5,964	10,664	13,696
299	Glenwood Canyon	15	9,601	13,852	17,028
	7-17	60	7,444	12,181	15,405
	403 Special	240	5,343	9,720	13,709
300	Glenwood Canyon	15	13,510	19,057	21,789
	7-30	60	9,237	16,990	19,925
	403 Special	240	6,797	14,319	17,021
301	Glenwood Canyon	15	9,935	17,717	20,995
	8-16	60	8,035	14,843	18,144
	403 Special	240	5,298	11,942	15,002
302	Glenwood Canyon	15	7,756	14,834	18,047
	8-22	60	7,030	13,873	17,064
	403 Special	240	6,694	13,550	16,704

Values reported in Table 1 are the averages of one to three test results, depending on the amount of mix available. Complete test data is included in the appendix.

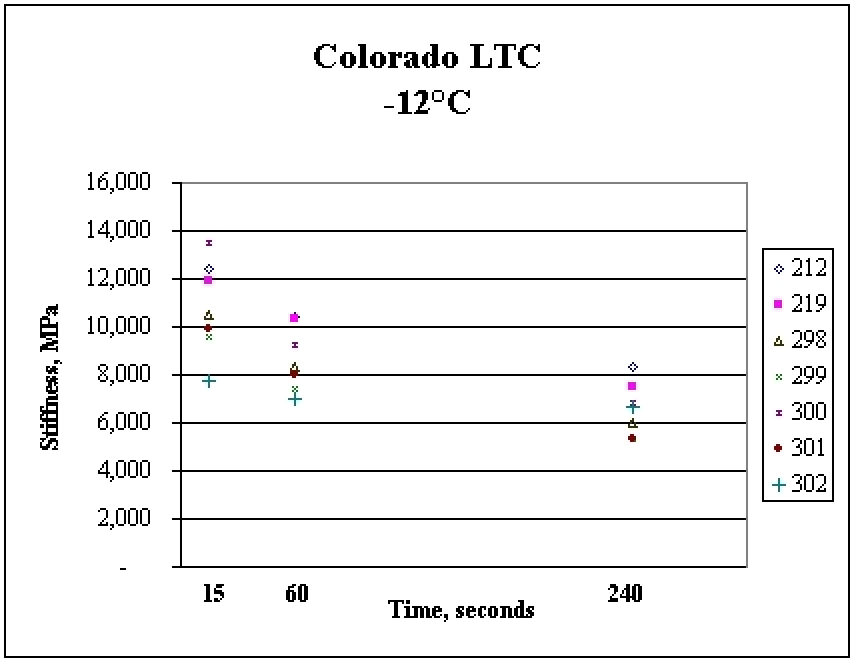


Figure 2: Stiffness vs Time, -12°C

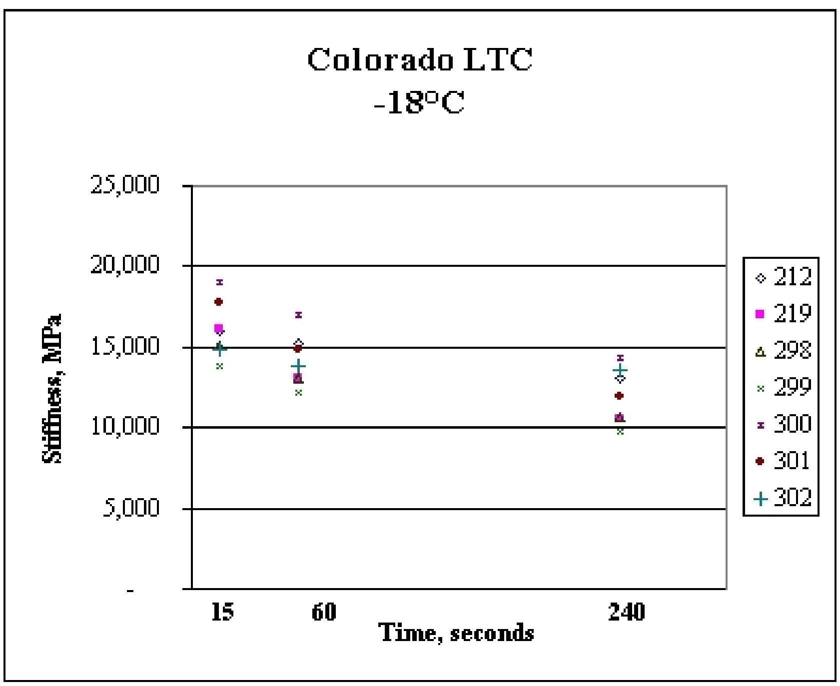


Figure 3: Stiffness vs Time, -18°C

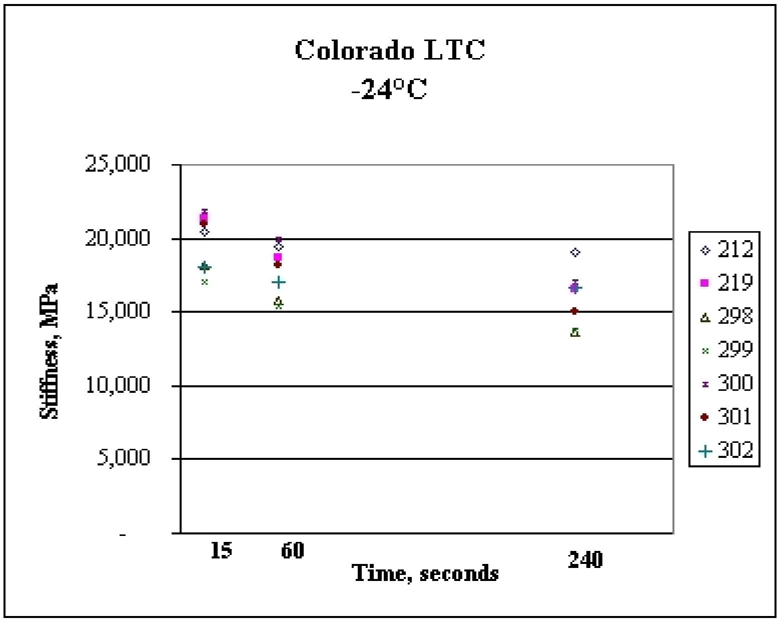


Figure 4: Stiffness vs Time, -24°C

The Stiffness values for these mixtures follow all expected trends. Stiffness values increase with decreasing temperature and decrease during the 240 second loading period. At –12°C, stiffness values at 60 seconds range from a high of 10,394 MPa for mixture 212 to a low of 7,030 MPa for mixture 302. Based on the similarity of the results, a Tukey (HSD) comparison of means was performed which showed that there was indeed no statistical difference in the stiffness values at 60 seconds for the seven mixtures. At –18°C, stiffness values at 60 seconds ranged from 16,990 MPa for mixture 300 to 12,181 MPa for mixture 299. At –24°C, stiffness values at 60 seconds ranged from 19,925 MPa for sample 300 to 15,405 MPa for sample 299. Again, a Tukey analysis showed no difference in the stiffness values for the mixtures at either temperature.

Table 2 shows the IDT strength results for the two mixtures.

Table 2: Ultimate Strength at -18C, kPa

ID	Sample	Ultimate Tensile Strength, kPa
212	Glenwood Canyon 4th 10K Sx special PG 76-28	5,338
219	Glenwood Canyon 1st 10K Sx 100	5,944
298	Glenwood Canyon 10K-5 403 Special	6,491
299	Glenwood Canyon 7-17 403 Special	6,525
300	Glenwood Canyon 7-30 403 Special	6,228
301	Glenwood Canyon 8-16 403 Special	6,389
302	Glenwood Canyon 8-22 403 Special	4,875

Again, a statistical analysis of the data shows no significant difference in the Tensile Strength values. Sample 302 showed a much lower tensile strength than the other mixtures, however since there was only enough mixture for sample 302 to make one test specimen, it is difficult to know whether or not this is an accurate value.

The IDT results were also analyzed using a spreadsheet developed by Don Christensen that is a modification of the models developed by Roque and others during SHRP. *{2}* This approach develops thermal stress curves for the materials based on the indirect tensile creep results and then determines a critical cracking temperature at which the thermal stress in the material exceeds the thermal strength of the material as determined by the indirect tensile strength test. This method is simply a way to provide a more understandable way to rank pavements, it should not in anyway be considered an actual measure of pavement performance. Table 3 shows the pavement critical cracking temperatures for the mixes.

Table 3: Christensen Analysis Results

ID	Sample	Pavement Tc, °C
212	Glenwood Canyon 4th 10K Sx special PG 76-28	-28
219	Glenwood Canyon 1st 10K Sx 100	-33
298	Glenwood Canyon 10K-5 403 Special	-33
299	Glenwood Canyon 7-17 403 Special	-36
300	Glenwood Canyon 7-30 403 Special	-33
301	Glenwood Canyon 8-16 403 Special	-30
302	Glenwood Canyon 8-22 403 Special	-37

As would be expected from the IDT stiffness and strength results, the pavement critical temperatures are very similar, with most of the mixtures between –28°C and –33°C. This would imply that the seven mixtures should exhibit similar low temperature behavior.

Conclusions

- At –12°C, mixture 212 exhibits the highest stiffness at 60 seconds. Mixture 302 shows the least stiffness.
- At –18°C, mixture 300 exhibits the highest stiffness at 60 seconds. Mixture 299 exhibits the lowest stiffness.
- At –24°C, mixture 300 exhibits the highest stiffness at 60 seconds. Mixture 299 exhibits the lowest stiffness.
- Based on the mean results at 60 seconds, statistical analysis shows that all of the mixtures have similar stiffness values.
- At –18°C, tensile strength values range from 6,525 kPa for mixture 299 to 4,875 kPa for mixture 302. Again, statistical analysis shows the tensile strengths for all of the mixtures to be statistically the same.
- Pavement critical temperatures for the mixtures range from –28°C to –37°C.

References

1. "Method for Determining the Creep compliance and Strength of Hot Mix Asphalt (HMA) Using the Indirect Tensile Test Device", American Association of State Highway and Transportation Officials, AASHTO Designation TP9-99, Gaithersburg, MD, 1998.
2. Christensen, D.W. "Analysis of Creep Data from Indirect Tension Test on Asphalt Concrete", Journal of the Association of Asphalt Paving Technologists, Volume 67, 1998.

Appendix.xls

212 - Glenwood Canyon, 4th 10K SX Special, PG 76-28

Time, sec	Replicate	G*, MPa -12	G*, MPa -18	G*, MPa -24	ITS, KPa -18	Pavement Tc °C
15	1	12,779	15,109			-28
	2	12,479	15,862	21,328	5,206	
	3	12,029	16,818	19,477	5,470	
	average	**12,429**	**15,930**	**20,403**	**5,338**	
60	1	10,067	16,035			
	2	11,229	13,900	20,401		
	3	9,886	15,919	18,385		
	average	**10,394**	**15,285**	**19,393**		
240	1	8,391				
	2	8,420	12,550	19,981		
	3	8,288	13,472	18,199		
	average	**8,366**	**13,011**	**19,090**		

219 - Glenwood Canyon, 1st 10K, SX100

Time, sec	Replicate	G*, MPa -12	G*, MPa -18	G*, MPa -24	ITS, KPa -18	Pavement Tc °C
15	1	12,023	16,749	25,244	5,697	-33
	2	11,862	15,436	17,445	6,191	
	3					
	average	**11,943**	**16,093**	**21,345**	**5,944**	

60	1	10,839	13,540	23,010		
	2	9,762	12,571	14,366		
	3					
	average	**10,301**	**13,056**	**18,688**		
240	1	7,871	10,976	21,637		
	2	7,102	9,998	11,553		
	3					
	average	**7,487**	**10,487**	**16,595**		

298 - Glenwood Canyon, 10K - 5, 403 Special

		G*, MPa			ITS, KPa	Pavement Tc
Time, sec	Replicate	-12	-18	-24	-18	°C
15	1	9,253	13,780	17,676	6,167	-33
	2	10,064	15,497	18,442	6,531	
	3	12,233	15,976	18,433	6,775	
	average	**10,517**	**15,084**	**18,184**	**6,491**	
60	1	6,642	12,262	15,578		
	2	7,843	13,195	15,902		
	3	10,402	13,717	15,930		
	average	**8,296**	**13,058**	**15,803**		
240	1	4,759	10,707	13,472		
	2	5,537	10,405	14,367		
	3	7,596	10,880	13,250		
	average	**5,964**	**10,664**	**13,696**		

299 - Glenwood Canyon, 403 Special, 7-17

Time, sec	Replicate	G*, MPa -12	G*, MPa -18	G*, MPa -24	ITS, KPa -18	Pavement Tc °C
15	1	9,601	13,852	17,028	6,256	-36
	2					
	3					
	average	**9,601**	**13,852**	**17,028**	**6,256**	
60	1	7,444	12,181	15,405		
	2					
	3					
	average	**7,444**	**12,181**	**15,405**		
240	1	5,343	9,720	137		
	2					
	3					
	average	**5,343**	**9,720**	**13,709**		

Appendix B.2

From: Turner, Pam [PTurner@AsphaltInstitute.org]
Sent: Wednesday, October 17, 2001 8:55 AM
To: Schiebel, Bill
Subject: Colorado LTC testing
Attachments: reportcololtc.doc (below)
Mr. Schiebel,
Attached are the low temperature test results for mixtures 212 and 219.

Please don't hesitate to contact me if you have any questions or wish to discuss this data further.

Pamela Turner
Asphalt Institute
859-288-4986
859-288-4999 (fax)

Reportcololtc

Background

The Asphalt Institute was asked by the Colorado DOT to evaluate the low temperature cracking properties of two mixtures. The mixtures (labeled 212 and 219) were received in three gallon cans and quartered to obtain mix to compact three Superpave Gyratory Compactor (SGC) specimens. Specimens were compacted to a height of 75mm and approximately 7% air voids. Following compaction, the SGC specimens were aged for five days at 85°C to simulate in service aging of the mix, then cut to a height of 50 mm and tested using the Indirect Tensile Tester according to AASHTO TP9.

Indirect Tensile Creep and Strength

The Indirect Tensile Creep and Strength tests provide a measure of the low temperature cracking resistance of mixture specimens. The test is run at cold temperatures, and is performed by applying a static creep load to a 50 mm tall by 150 mm diameter sample for 100 seconds (240 seconds was used for this research). Measurements of horizontal and vertical deformation are taken throughout the loading time and used to calculate the stiffness of the material over time. Creep testing is repeated at three temperatures. For this research, -12, -18, and -24 C were used. After the creep loading at all three temperatures is completed, the sample is again loaded at a rate of 12.5mm/min until failure. Figure 1 shows the Indirect Tension Testing apparatus.

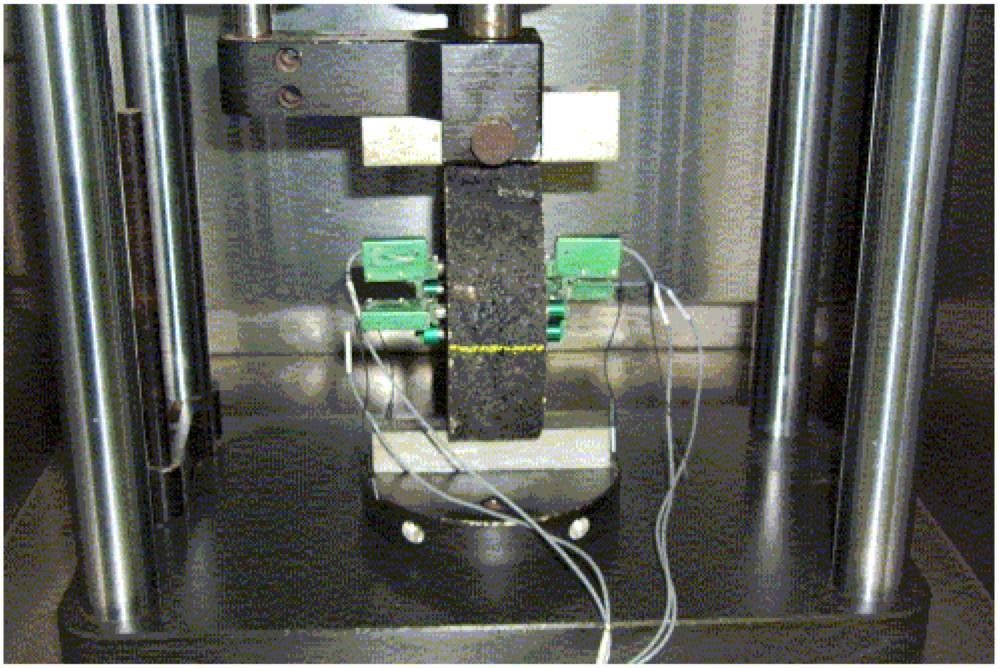


Figure 1: Indirect Tension Apparatus

The IDT results were also analysed using a spreadsheet developed by Don Christensen that is a modification of the models developed by Roque and others during SHRP. This approach develops thermal stress curves for the materials based on the indirect tensile creep results and then determines a critical cracking temperature at which the thermal stress in the material exceeds the thermal strength of the material as determined by the indirect tensile strength test. This critical temperature is used only for comparison purposes and should not be used to predict actual pavement performance.

Results

Table 1 and Figure 2 show the IDT stiffness results for the two sets of material.

Table 1: Stiffness, Mpa

Sample	Time, sec	Temperature, C -12	-18	-24
212	15	12,429	15,930	20,403
	60	10,394	15,285	19,393
	240	8,366	13,011	19,090
219	15	11,943	16,093	21,345
	60	10,301	13,056	18,688
	240	7,487	10,487	16,595

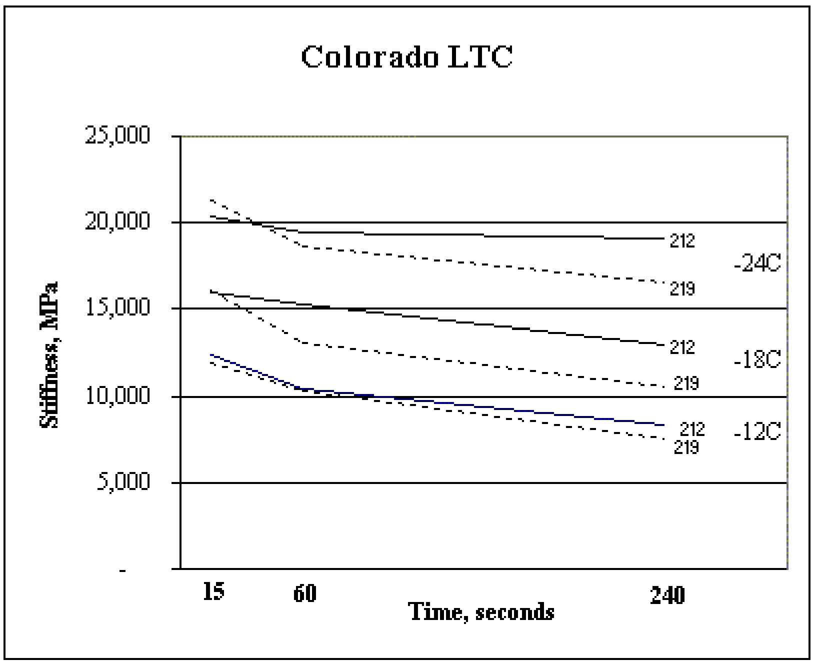


Figure 2: Stiffness vs Time

Table 2 shows the IDT strength results for the two mixtures.

Table 2: Ultimate Strength at -18C, kPa

Sample	Ultimate Tensile Strength, kPa
212	5,338
219	5,944

From Tables 1-2 and Figure 2, it can be seen that the test results follow the expected trends. Stiffness values increase with decreasing temperature and decrease over time. At 60 seconds, mixture 212 shows low temperature stiffness values that are slightly higher than mixture 219. Mixture 219 has a slightly higher ultimate tensile strength at -18C than does mixture 212. However, the results for the two materials are very close in value and a t-test analysis ($\alpha = 0.05$) shows that the two sets of results are statistically the same.

Using Don Christensen's spreadsheet, a critical pavement temperature of -28C is found for sample 212 and a critical pavement temperature of -33C is found for sample 219. This corresponds to the slightly higher stiffness values found for mixture 212.

Conclusions

- Mixture 212 appears to be slightly stiffer at low temperatures than mixture 219. Mixture 212 also has a slightly lower ultimate strength value at -18C. However, there is not enough difference in the two sets of results for them to be considered statistically different.
- According to the Christensen spreadsheet, mixture 219 has a critical pavement temperature that is 5 degrees colder than mixture 212.

APPENDIX C

Appendix C

Average Acceptance Test Properties for TLA in Glenwood Canyon

Date (AC Only)	**% AC**	Date (AC Only)	**% AC**	**Density**	**Density**	% Passing #4 Sieve
29-Jun	6.75	16-Jul	6.36	94.3	93.6	76
29-Jun	6.5	16-Jul	6.61	93.1	94	72
29-Jun	6.49	17-Jul	6.79	94.7	94.1	76
29-Jun	6.46	17-Jul	6.54	96	93.2	77
29-Jun	6.59	17-Jul	6.31	95.5	94.3	78
30-Jun	6.53	18-Jul	6.49	95.7	94	77
30-Jun	6.48	18-Jul	6.43	95.5	93.1	78
30-Jun	6.45	18-Jul	6.37	95.9	92.8	78
30-Jun	6.37	18-Jul	6.44	95.7	92.2	74
30-Jun	6.55	18-Jul	6.55	94	95.1	74
1-Jul	6.61	19-Jul	6.57	92.9	94.3	72
1-Jul	6.3	19-Jul	6.67	92.8	93.2	76
1-Jul	6.31	19-Jul	6.43	93.9	93.4	76
1-Jul	6.51	23-Jul	6.45	93.1	94.5	77
1-Jul	6.38	23-Jul	6.27	93.4	91.8	73
2-Jul	6.62	23-Jul	6.46	93.8	93.5	75
2-Jul	6.42	23-Jul	6.39	94.2	95	77
11-Jul	6.72	24-Jul	6.54	93.5	91.3	79
11-Jul	6.38	24-Jul	6.55	94.5	93.4	79
12-Jul	6.48	24-Jul	6.57	94.5	93.2	77
12-Jul	6.47	24-Jul	6.4	93.1	92.5	76
12-Jul	6.24	24-Jul	6.5	93.8	93.4	
12-Jul	6.4	25-Jul	6.49	93.6	94.8	
13-Jul	6.51	25-Jul	6.63	94.4	93	
13-Jul	6.38	27-Jul	6.74	93.4	93.3	
13-Jul	6.47	27-Jul	6.48	94	94.1	
		27-Jul	6.57	94.1	94.4	
		27-Jul	6.47	93.2		

	% AC	**Density**	**% Passing #4 Sieve**
Average	**6.48**	**94.2**	**76**
Std Dev	**0.1**	**0.97**	**2.1**

APPENDIX D

Appendix D

Cost Comparison Calculations of S or SX Mixes with PMA versus Trinidad Lake Asphalt / Steel Slag Mix

	Mix + AC		Mix	PMA	Mix In Place	
1	42	5	41	202.35	$53.14	
2	45	6	24.75	228	$38.43	
3	31.05	7	20.31	252.5	$35.46	
4	37.5	8	28.35	250	$43.35	
		9	24.5	253	$39.68	
		10	26	240	$40.40	
			used 6.0%AC to calc		$42.00	
			Total Ton Price		$45.00	
					$31.05	
					$37.50	
		Statewide	Average PMA Mix		$40.60	S & SX PMA Mixes
			Standard Deviation		$5.95	
		SX (100) PG 76-28 same Project			$44.00	
		HBP Special			$62.00	

On Project Comparison

Percent Difference = (High - Low)/Low = 0.41 => <u>41%</u> more for TLA Mix

Statewide Average PMA Comparison

Percent Difference = (High - Low)/Low = 0.53 => <u>53%</u> more for TLA Mix

Project List	Sub Acct	Proj No.	Mix	PG Grade	# tons	Region
1	13441	IM 0252-344	S(100)	PG 70-28	17597	2
2	13008	IM 0703-260	S(75)	PG 64028	22198	1
3	13147	NH 0342-035	S(100)	PG 64-28	20504	4
4	12019	NH 0470-088	S(100)	PG 76-28	52869	6
5	13498	IM 0703-275	S(75)	PG 58-34	25257	1
6	13109	STA 0141-013	SX(75)	PG 64-28	24044	3
7	13325	NH 0501-045	SX(100)	PG 76-28	59068	3
8	13106	STA 0641-011	SX(75)	PG 64-28	13879	3
9	13112	STA 0502-04	SX(75)	PG 64-28	13254	3
10	13108	STA 092A-015	SX(75)	PG 64-28	68223	3

APPENDIX E

Appendix E

Glenwood Canyon Overlay
Project NH0702-217 – SA#: 12238

Update to Chief Engineer, September 17, 2001

Overview

Project Open House was given in August by Region, CAPA, Contractor and Suppliers. The project paving is now complete and the crew is gone. Some perspectives of CDOT and Contractor are here:

- CDOT Program Engineer – Provided overview of design process at open house. Explained the Region desire for a rut resistant, impermeable HMA overlay. I have no summary of his opinion of the project construction.
- CDOT Project Engineer – The Contractor was very difficult to work with and did not communicate or respond appropriately. Contractor used a low caliber crew and a 20-year-old HMA plant. Contractor workmanship was poor, especially at the joints.
- CDOT Region Materials Engineer – JMF difficult to acquire. Sensitivity to production variability made mix production difficult. The CTL design did not predict this sensitivity. Contractor was unfamiliar with CDOT materials spec. practices and QC/QA requirements and took time to get up to speed. Contractor inexperience compounded by Region use of a unique consultant design that did not fit CDOT's existing framework for specifying, testing, and accepting HMA materials. Joint construction and handwork were very difficult. Materials testing and oversight were much higher on this project.
- Asphalt Program Engineer – This design of the HMA(Special) targeted a rut resistant low permeability mix and did not adequately consider mix production. Open joints will need sealing to maintain the design requirement for impermeable mat. The mix spec. requirements do not consider the existing CDOT materials framework and Colorado experience. Existing HMA developed by CDOT could have resulted in equal or better finished product. We hope to learn from the Canyon's increased testing and monitoring.
- Contractor – Granite couldn't wait to get off the job. Seemed satisfied with materials they produced but were unhappy with the price reductions. Contractor blames mix design for problems and was unprepared for this mix in this canyon.

Project Specific QAP

The QAP was developed and used on the project to provide increased testing and long term monitoring to document the quality and performance of the unique HMA materials specified. The Region provided the QAP schedule to all testers and the samples are coming in for high-level testing by Central Lab and the Asphalt Institute.

Current Status of QAP

Their has been some tester difficulty in submitting all samples required by the QAP. Missing samples were identified and requested from the project to complete all high level testing. Monitoring plan has been established. Performance monitoring sections were identified and sampled. Interim and final reports will summarize findings and make recommendations.

APPENDIX F

Appendix F

Colorado Department of Transportation
JOB MIX FORMULA

Region: 34
Project: NH 0702-217
Location: Glenwood Canyon Overlay
S.A.: 12238
From Project:
From Project S. A.:

Form 43 Serial #: 184
Mix Design: Granite-Special
Date: 5/18/2001

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

Contractor: Granite
Supplier: Granite
Plant: Gypsum

Item: 403 Test Section
Grading - Compaction: SP 100
% RAP: 0 % Lime: 0

Components

1: 10% 1/2" Rock
2: 50% Crushed Sand Type 3
3: 15% Crushed Sand Type 1
4: 25% Pueblo Slag
5:
6:
7:

Remarks: 25% TLA Conditional Approval for Test Section and Grand Ave. Bridge Only, Grad. Cold Feed

Gradation Pay Factor

Seive	Virgin Agg. w/o RAP %Passing	Aggregate with RAP %Passing	Tolerance +/-
2" (50mm)			-
1 1/2" (37.5mm)			6
1" (25mm)			6
3/4" (19.0mm)	100		100
1/2' (12.5mm)	100		5
3/8" (9.5mm)	89		5
#4	70		4
#8	50		4
#16	37		-
#30	28		2
#50	20		-
#100	14		-
#200	8.9		2.0

☑ Mix Design Based On Ndes

Hveem Stability @ Optimum %AC: 55

Percent AC: 6.5 +/-0.3

Grade of A.C.: PG 76-28

Source of A.C.: Koch +TLA

Max Specific Gravity at % A.C: 2.538

Bulk Sp. Gr. of Combined Agg.: 2.447

Bulk Sp. Gr. of Fine Agg.:

Angularity (CPL 5113):

☑ New mix design with no change

☐ Staff Materials called and concurs with change or reapproval

Stability for Information

Voids Data at N (Design)

Property	Target Value	Tolerance
Stability:	55	Minimum
% Voids:	3.6	+/- 1.2
% VMA:	16.5	+/- 1.2

Date:

Staff Materials Representative

Signed: ______ Date:

Project Engineer

Signed: Robert A. Somrak Date: 5/18/2001

Region Materials Engineer

Signed: ______ Date:

Contractor Representative

Distribution:
Staff Materials
Region Materials Engineer
Resident Engineer (2)
Contractor
CDOT FORM # 43 v1.00a