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OPTIMUM USE OF CDOT FRENCH AND HAMBURG DATA (FRENCH AND HAMBURG TESTS)

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16. Abstract
The Colorado Department of Transportation (CDOT) has been collecting data from the Hamburg Rutter and the French Rutter for over 20 years. No specifications have been written in that time for either the Hamburg Rutter or the French Rutter. This report looks at the state of practice within other states that own similar equipment. It addresses mixes being produced to pass the Hamburg Rutter being designed too dry. Tests that could be run along with the Hamburg Rutter are examined from a review of literature to determine if there is a suitable companion test for the Hamburg Rutter that would work to keep asphalt levels in the mix high enough to prevent cracking and fatigue.

Implementation
A companion test for the Hamburg Rutter may be purchased by CDOT. The equipment would need to be correlated to pavements of known performance. With this information and with 20 years of Hamburg Rutter and French Rutter data, specifications for the Hamburg Rutter and the new companion test could be written.

17. Keywords
Hamburg Rutter, French Rutter, Loaded Wheel Tracking Device (LWTD), Disk-Shaped Compact Tension (DC(T)), Indirect Tension (IDT), Semi-Circular Bend (SCB), Single-Edge Notched Beam (SENB)

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States that use Loaded Wheel Tracking Devices were asked to participate in a more in-depth survey so information could be gathered about their specifications and their thoughts about additional performance tests. A great debt and much gratitude are owed to Joe Peterson, James Trepanier, Chris Abadie, Matt Strizich, Ken Hobson, Robert Lee, and Howard Anderson.

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Thank you to the study panel members for their input and guidance: Bill Schiebel, Donna Harmelink, Mike Stanford, and Stephen Henry.

EXECUTIVE SUMMARY

The Colorado Department of Transportation (CDOT) has been collecting data from the Hamburg Rutter and the French Rutter for over 20 years. No specifications have been written in that time for either the Hamburg Rutter or the French Rutter. This is largely due to the need for a companion test to be developed so dry asphalt mixes would not be designed specifically for passing the Hamburg Rutter test. This report looks at the state of practice within other states that own similar equipment. Cracking tests that could be run with the Hamburg Rutter are examined from a review of literature to determine if there is a suitable companion test for the Hamburg Rutter that would work to keep asphalt levels in the mix high enough to prevent cracking and fatigue.

Mixes sometimes fail the Hamburg Rutter without reaching a stripping inflection point. CDOT data is reviewed to see if mixtures that fail in creep slope, without reaching the stripping inflection point, could work well for Colorado roadways.

Some states specify use of the Hamburg Rutter for mix designs while other states have a Hamburg Rutter specification for both design and production. Five years of Colorado Hamburg Rutter results were reviewed to ensure that all Colorado mixes can pass the Hamburg Rutter, not just in laboratory design conditions, but also when the mixes are plant produced.

Implementation Plan

Implementation will depend on Colorado’s commitment to performance testing. Testing of all 100 gyration mixes for information only could continue with no changes. Currently, CDOT is working on a statement that expresses their plan to move forward with a Hamburg Rutter specification. The specification could be for the design phase or for both design and production phases. Whichever is chosen, the issue of reproducibility will have to first be addressed. A CDOT representative is on an AASHTO committee that is working on the Hamburg Rutter procedure. Reproducibility has not yet been determined for the procedure. If a companion test for the Hamburg Rutter is selected for CDOT specification, the same reproducibility question will have to be addressed.

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1.0 INTRODUCTION

Tim Aschenbrener and Dwight Bower of the Colorado Department of Transportation (CDOT) joined nineteen officials from the American Association of State Highway and Transportation Officials (AASHTO), Federal Highway Administration (FHWA), National Asphalt Pavement Association (NAPA), Strategic Highway Research Program (SHRP), Asphalt Institute (AI), and Transportation Research Board (TRB) on a tour of six European countries in 1990. They learned about performance-related testing of hot mix asphalt (HMA) in the six countries that were visited (Report on the 1990 European Asphalt Study Tour, June 1991). Following the tour, CDOT and the Turner-Fairbank Highway Research center (TFHRC) received a mixer, compactor, French Rutter, and Hamburg Rutter to study performance-related test equipment. The Hamburg Rutter is often referred to as a Loaded Wheel Tracking Device (LWTD) and will be referred to as such throughout the rest of this paper. The equipment arrived in 1991 and numerous studies were performed by Aschenbrener over the next few years. When Aschenbrener left the EuroLab to work in the Flexible Pavement Unit in CDOT's Central Lab, the EuroLab continued testing project samples for information that could aid in improving HMA and in the possible development of acceptance specifications using performance-related test equipment.

As of 2013, CDOT has not implemented performance-based specifications using the LWTD and/or the French Rutter. Due to budget constraints, the EuroLab is not performing testing during the construction season of 2013. This study looks at the feasibility of closing the EuroLab or of possibly using EuroLab testing for design and/or production specifications.

2.0 DOT SURVEYS

At the end of May 2013, CDOT Materials and Geotechnical Manager, Bill Schiebel, sent a survey to all fifty state Departments of Transportation (DOT) asking if they used mix performance tests, such as the LWTD, the Asphalt Mixture Performance test (AMPT), or the Universal Test Machine (UTM). Twenty-eight states responded to the survey. Seventeen of those states use some type of performance test. Of those seventeen states, ten use the Asphalt Pavement Analyzer (APA), and seven states are currently using the LWTD in some phase of their specifications. Two states hope to start using the LWTD soon. One state utilized the University of Idaho to gather data using the AMPT for pavement design, which has an environmental chamber for testing to be done at low temperatures. Also being considered or used by some states as companion tests to the LWTD, are the Semi-Circular Bend (SCB) test, the Disk-Shaped Compact Tension (DCT) test, and the Overlay Test (OT).

The ten states that use the APA were not contacted for further information. In the early 1990s when CDOT's EuroLab began testing with new European performance test equipment, testing was done with the Georgia Rutter. The APA is an improved version of the old Georgia Rutter. Comparison testing between the French Rutter and the Georgia Rutter showed R^2= 0.54, which is a poor correlation. The French Rutter showed good correlation to pavements of known field performance (Aschenbrener, 1992). Due to space limitations, the Georgia Rutter was given to the FHWA in Denver. Therefore, states utilizing the APA as their performance test were not further interviewed. Another reason for the lack of interest in the APA is because plastic flow rutting is not a current problem on Colorado roadways. In fact, CDOT mixes may be too dry and are showing signs of raveling and cracking and not of plastic flow rutting. In addition, if information is needed about plastic flow rutting, the French rutter, which is a good predictor of plastic flow rutting, can be utilized by CDOT.

Because of the LWTD's predictive ability, states using a LWTD were further surveyed. Aschenbrener found excellent correlation between stripping performance in the field and the stripping inflection point found with the LWTD (Aschenbrener, Terrel, and Zamora, 1994). The following questions yielded useful information for CDOT as they decide what to do with the European Lab.

Do you believe your roads are better with the requirement of passing LWTD testing?

All seven states believe their roads have improved since implementing LWTD specifications.

Do you require the LWTD for mix designs, acceptance, or both?

Two states use the LWTD for the design phase and five states use the LWTD for both design and production.

Are there any drawbacks to using the LWTD requirement?

Several states found drawbacks that need to be overcome:

- Adding reclaimed asphalt product (RAP) or recycled asphalt shingles (RAS) can stiffen a mix and help it to pass the LWTD. There is fear that this stiffening will cause the pavements to crack prematurely.
- The LWTD test may fail a mix that can perform adequately on the roadway.
- Mixtures that are too low in asphalt content may still pass the LWTD if the aggregate structure is there.
- Coarser mixes are being produced.
- Softer mixes tend to do better with two Superpave gyratory compactor samples being tested in the LWTD than the same sample would do when the linear kneading compactor was used to compact the sample.

What other tests are required with the LWTD test for mix designs and/or production?

None of the seven states use just the LWTD as a true performance test. All seven states still require mix volumetrics. Some of the states still require the Lottman test for stripping. One state uses the SCB, and sand equivalent (SE) test. One state is looking at using the AMPT in the future to determine the flow number. Two states are working toward specifying the OT to be used as a companion test to the LWTD.

CDOT has wondered if we should "pass" a sample if the maximum rut depth is exceeded slightly but the sample never hit the stripping inflection point (SIP). What consideration has your DOT given to such an idea?

All seven states fail any sample that exceeds the maximum rut depth, even if the SIP has not been reached. One state did discuss this idea in the past with CDOT and can see where it might work to prevent mixes from becoming overly dry to pass the LWTD test. There was a suggestion of requiring a rut depth range, with no SIP reached, to ensure the mix isn't overly dry.

Have you had success with 50 and 75 gyration mixes passing?

Some states don't use 50 or 75 gyration mixes and some states use other gyrations, such as 60, 65, or 85. Some states have no problem with the lower gyration mixes passing the LWTD. One state recognized that the lower gyration mixes tend to use "softer" performance grade (PG) asphalts and, therefore, require a lower number of wheel passes to pass their LWTD test.

Are there any tests you have dropped or would be comfortable dropping with the inclusion of LWTD specifications?

Some states would or have already dropped Lottman testing. Other states continue using the Lottman test for extra stripping comfort. Several states would like to find a companion test to run with the LWTD, such as the OT, SCB, or DCT, to ensure mixes aren't overly dry. If that happened, some states would be content to use true performance testing and drop all other testing.

Are there any tests that you would NEVER drop, even if the LWTD test is required?

States were unanimous that, currently, Hamburg testing alone isn't enough to ensure good roadways. Volumetrics were very important to all states and would continue to be used in absence of a companion test to prevent dry, cracking mixes.

Do you apply incentives or disincentives for passing/failing LWTD tests?

One of the five states that use the LWTD specification for production samples gives a $1.50 bonus for every ton that passes the LWTD. The bonus will gradually be lowered and will eventually go to an incentive/disincentive system. CDOT used this same approach when new specifications for VMA were introduced.

Is your DOT using "warm" asphalt mixes? If so, how do they perform with the LWTD testing? Do you have specification changes that can accommodate warm mixes?

Most states test their Warm Mix Asphalt (WMA) as they do their normal mixes. Two states added an extra 2 hours to the oven cure time. None of the states see a reason not to use LWTD testing with WMA.

What testing are you doing to catch mixes that may do poorly in cracking and/or fatigue?

Several states recommend a performance test for cracking. Some ideas are the OT, DCT, and SCB. It's hoped that something will come out of the AMPT that could be helpful. Other suggestions that were made to limit cracking and fatigue are:

- **Increase VMA**. CDOT has long used VMA + 1, so this is not a new idea to Colorado. It may, however, behoove Colorado to investigate VMA + 1.5 or VMA + 2. Having a Stabilometer Test and a French Rutting Test, CDOT has tools available to ensure plastic flow rutting is prevented if the VMA was increased.

- **Drop Superpave Gyrations**. A number of states have dropped their gyrations below CDOT's standard 75 and 100 gyration mixes. A reduction in the number of gyrations, without a change in aggregate gradation, increases the binder content of the mix design. One state has dropped 100 gyration mixes and another state has dropped 50 gyration mixes. Gyrations used by the seven states are 50, 65, 70, 75, 80, 90, and 100. CDOT did a study in 2002 (Harmelink and Aschenbrener, 2002) that monitored in-place air voids that were designed with the Superpave gyratory compactor. CDOT found that in-place air voids in the roadways were not, even with traffic compaction, getting down to design voids. At that time, CDOT wrote a specification to allow Region Materials Engineers (RME) to adjust the air voids of mix designs after the designs were submitted. This method allowed the voids to be adjusted downward, with the same aggregate gradation, in an attempt to add asphalt binder to the mixes and to achieve lower in-place air voids. By allowing CDOT RMEs to adjust the binder content, Contractors were not able to lower the void content themselves, which could be done inexpensively by increasing the fines of the mix. Preliminary results from a study monitoring pavement air voids indicate that a reasonable number of gyrations are currently being used by CDOT.

- **Chipseal**. One state interviewed automatically chipseals after one year to prevent raveling. CDOT's Region 4 routinely chipseals after 3 or 4 years and has had good success with maintaining their highways.

- **Confirm Gsb**. Because the bulk specific gravity often varies throughout a stockpile, Gsb will often vary throughout production. Gsb is used to calculate VMA, which is used to maintain voids and asphalt content. If an incorrect Gsb is used to calculate VMA, the VMA calculation will be incorrect. CDOT uses a running average of Gsb values, which helps to eliminate Gsb values that are extremely high or low. CDOT could consider specific gravity retesting if the maximum specific gravity value of a mix, which is regularly checked during production, changes greatly.

Have you ever considered a "true" performance specification, such as accepting mix based solely on LWTD results?

No interviewed state feels it's possible to have a performance specification based solely on LWTD testing. Several of the states are looking at using their LWTD in conjunction with another test that can prevent mixes from being designed overly dry to pass the LWTD specification. Research has found that dry mixes can pass the LWTD (Stuart and Izzo, 1995). Dry mixes can increase cracking and fatigue problems. One state doesn't see strict performance testing ever happening because it would be too complicated.

2.1 States' Specifications

The seven states that specify the LWTD have different approaches to setting their specifications. Some states vary the number of passes run for different PG grades while other states vary the temperature for different PG grades. The specifications are as follows:

California	PG58-XX	½"	@10,000 passes	@ 50^0 C
	PG64-XX	½"	@10,000 passes	@ 55^0 C
	PG70+	½"	@10,000 passes	@ 60^0 C

The DOT is considering dropping the temperature to 50^0 C for the PG64-XX binders and to 55^0 C for the PG70+ binders.

Illinois	PG58-XX	12.5mm	@7,500 passes	@ 50^0 C
	PG64-XX	12.5mm	@15,000 passes	@ 50^0 C
	PG70-XX	12.5mm	@20,000 passes	@ 50^0 C

Louisiana	PG76-22	6mm	@20,000 passes	@ 50^0 C

Montana	PG58-XX	13mm	Design 15,000 passes @ 44^0 C
			Production 10,000 passes @ 44^0 C
	PG64-XX	13mm	Design 15,000 passes @ 50^0 C
			Production 10,000 passes @ 50^0 C
	PG70-XX	13mm	Design 15,000 passes @ 56^0 C
			Production 10,000 passes @ 56^0 C
Oklahoma	PG64-XX	12.5mm	@ 10,000 passes @ 50^0 C
	PG70-XX	12.5mm	@15,000 passes @ 50^0 C
	PG76-XX	12.5mm	@20,000 passes @ 50^0 C
Texas	PG64-XX	12.5mm	@ 10,000 passes @ 50^0 C
	PG70-XX	12.5mm	@15,000 passes @ 50^0 C
	PG76-XX	12.5mm	@20,000 passes @ 50^0 C
Utah	PG58-XX	10mm	@20,000 passes @ 46^0 C
	PG64-XX	10mm	@20,000 passes @ 50^0 C
	PG70-XX	10mm	@20,000 passes @ 54^0 C

CDOT sets their test temperature by the PG high temperature. For information only, CDOT's tolerances are:

Colorado	PG58-XX	4mm	@10,000 passes @ 45^0 C
	PG64-XX	4mm	@10,000 passes @ 50^0 C
	PG70-XX	4mm	@10,000 passes @ 55^0 C
	PG76-XX	4mm	@10,000 passes @ 60^0 C

CDOT originally tested to 20,000 passes and allowed a maximum rut depth of 10mm. Aschenbrener determined that running 10,000 passes and allowing a maximum rut depth of 4 mm would yield approximately equal pass/fail test results (Aschenbrener, Terrel, and Zamora, 1994). In the 2000s, CDOT went to a 10,000 pass test so more testing could be accomplished throughout the construction season. With two LWTDs in the HQ laboratory and with tests running to 10,000 passes, if samples are allowed to run overnight, up to six samples a day could be tested.

3.0 PERFORMANCE TESTS

All seven states that were interviewed believe that the LWTD alone is not enough to use as a performance test. A mixture can pass the LWTD while being dry, as reducing the asphalt cement content stiffens the mix, which can make it perform well in the LWTD (Texas DOT Technical Advisory, August 16, 2006). However, dry mixes are not expected to do as well on cracking or fatigue tests (Walubita et al, 2010). Therefore, the LWTD needs to be combined with other testing to be effective as a predictor of overall pavement performance. A number of tests are now in use or are in development that could provide a balanced mix design approach when using a LWTD. The tests that the seven states are investigating for future use are described below.

3.1 Overlay Test

One state is hoping to develop true performance specifications through using the LWTD paired with the OT or another crack test. The OT Standard Procedure they are using is Tex-248-F. From an interview it is known that testing is underway to improve the repeatability of the OT, which is currently a problem.

The OT is a repeated load test that simulates the opening and closing of cracks. The test is run at 77^0 F. The OT machine has a fixed side and a side that moves horizontally. An asphalt sample is epoxied to each side of the machine and a constant maximum displacement of 0.025 inches is applied to stress the sample. Each cycle takes 10 seconds to apply the displacement and to return to its initial position. A maximum of 1200 cycles would be run if the sample didn't prematurely fail.

Figure 3.1 Overlay Test

The 150 mm asphalt samples can be produced from road cores or from laboratory produced samples.

Colorado experiences many freeze-thaw cycles each year. A test that is run at 77^0 F may not be strenuous enough to meet CDOT's needs. Also, variability is still a concern. Therefore, the OT is not recommended for CDOT use.

3.2 Fracture Energy Tests

Fracture energy (FE) is the amount of energy required to create a new surface in a material due to cracking. Asphalt material has the ability to carry load even after a peak load is reached. The peak load can be found with tensile strength testing. However, softening behavior occurs past the peak load. In asphalt, the softening occurs in an area called the fracture process zone (FPZ). Strength tests have a focus on measuring the propagation of a crack. Fracture tests also measure the energy needed to initiate a crack (Dave et al, 2011.)

The Bending Beam Rheometer (BBR) and the Direct Tension (DT) test don't work well with polymer modified binders because they don't take into account the effects of physical hardening. In fact, the BBR was developed by testing on unmodified binders. FE testing appears to be able to model polymer modified binders (Rosales). FE tests more accurately determine the strength of polymer modified materials. Fracture mechanics is a technique which identities the cause of premature failure of materials due to built-in flaws, such as micro-cracks, under a load much smaller than the design load (Ponniah et al).

Work by Chiangmai (2010) shows that FE is increased by using more highly modified binders or by increasing the asphalt cement content of a mix. When mix is placed in the field, the compaction of the mix is critical to preventing fatigue cracking (Santucci et al, 1969). Higher asphalt contents help to achieve compaction in the field.

Several asphalt tests have been developed to determine a material's FE. They are discussed below.

3.2.1 Single-Edge Notched Beam Test

The Single-Edge Notched Beam (SENB) test is a low temperature test that applies a load to an asphalt rectangular beam with a notch on the bottom. A force is applied to the top of the beam to the point of fracture while a constant rate of strain is held. In contrast, asphalt binder is tested in the BBR where a constant force is applied to the beam and the strain is allowed to change over time. With the SENB test, the energy that is used to propagate a crack through the material is measured (Rosales).

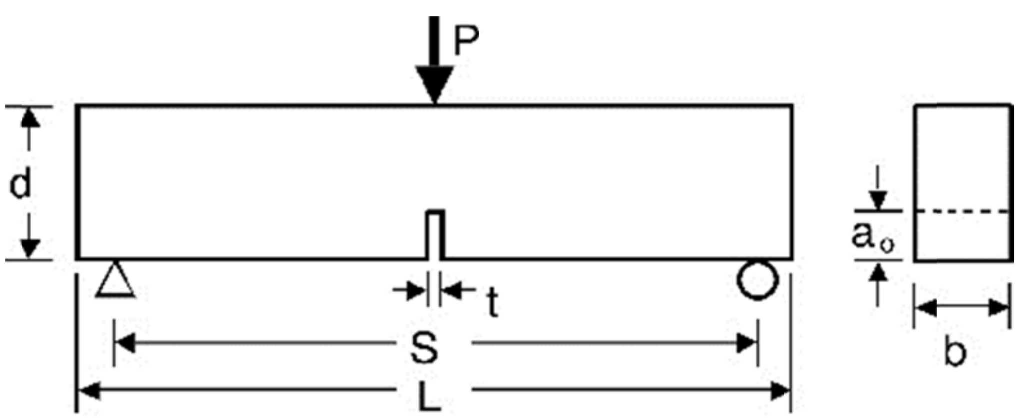

Figure 3.2 SENB Drawing

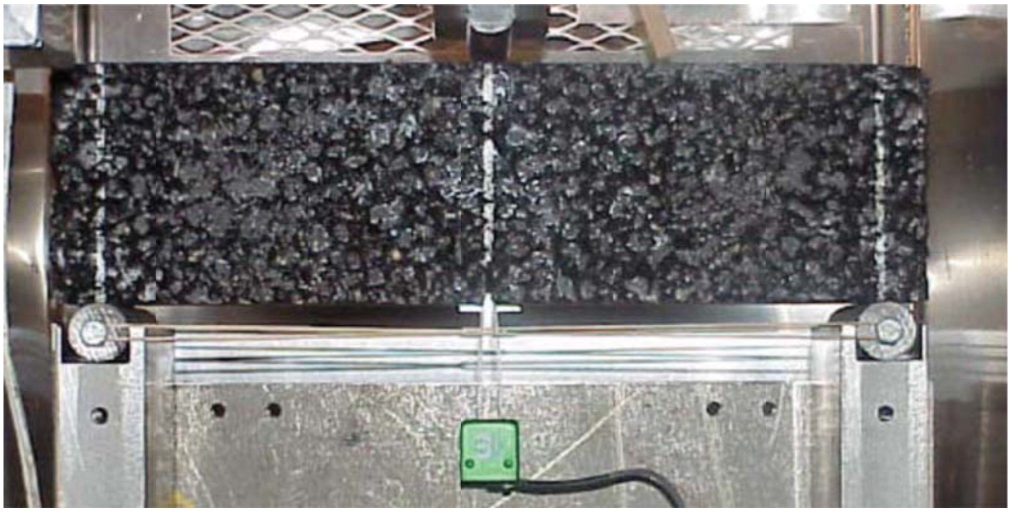

Figure 3.3 SENB Test

While this test is simple and provides information about a mixture's FE, the rectangular shape is a drawback as extra material must be prepared or cored from the roadway to create the sample.

3.2.2 Disk-Shaped Compact Tension Test

The DCT test also finds the FE of an asphalt mixture by modeling crack initiation and propagation. This test was developed because the SENB test was not a round geometry that would be easy to make in a laboratory or to core in the field. The procedure is standardized as ASTM D7313.

Figure 3.4 DCT Test

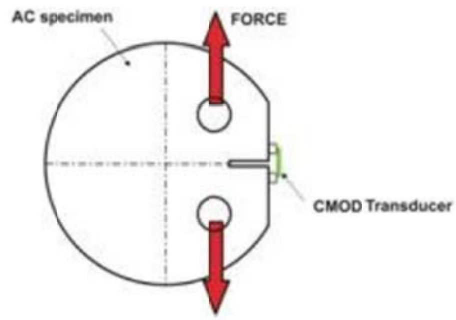

Figure 3.5 DCT Drawing

The DCT is a performance-type test that can be used to examine a mixture's susceptibility to various forms of cracking. The testing is done in an environmental chamber at 10^0 C warmer than the PG low temperature grade. The sample is bolted into the test jig through the holes that are drilled into the sample. A notch is also sawed into the sample and is where cracking is expected to initiate. A load is applied that pulls directly up and down on the sample. A crack will initiate and propagate through the sample (Wagoner et al, 2005).

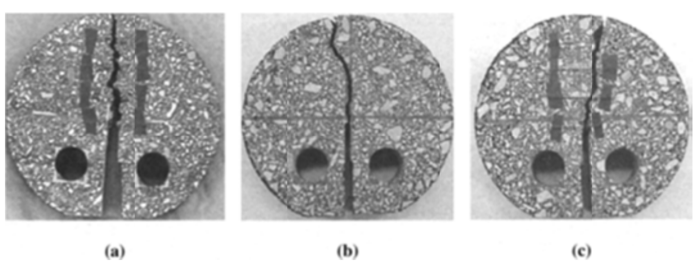

Figure 3.6 Crack Types

Three types of cracking may occur as the sample is placed in tension. In Figure 3.6, (a) shows a Type I crack. The crack initiates at the notch and propagates straight out from the notch. In (b), the crack initially goes straight out from the crack but deviates from the straight path. This is a Type II crack and is the most common type of crack. The least common type of crack is shown in (c). The initial cracking is at an angle. This is a Type III crack. Wagoner et al (2005) have demonstrated that there is no correlation between the type of crack and the FE. They also found that the Coefficient of Variance (COV) is within acceptable limits.

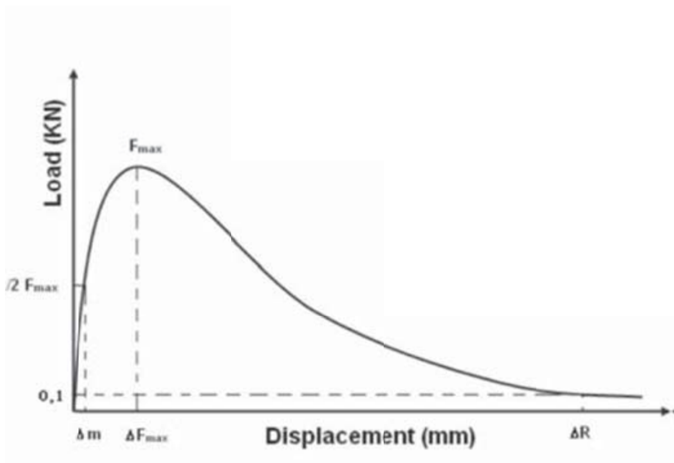

Figure 3.7 DCT Plot

Figure 3.7 is a typical DCT FE plot. It shows the load in kN vs. the displacement in mm. The FE is the energy under the graph divided by the fracture area and is expressed in Joules per meter squared (J/m^2). The displacement may also be called the Crack Mouth Opening Displacement (CMOD) (Chiangmai, 2010).

3.2.3 Semi-Circular Bend Test

The SCB test also finds the FE of an asphalt mixture. AASHTO procedure TP 105-13 covers the current test procedure. Like the DCT, the SCB is a performance test that examines an asphalt mixture's susceptibility to various types of cracking. The SCB is also run at 10^0 C warmer than the PG low temperature grade. The plot of the SCB test is similar to Figure 3.7 with load vs.

displacement. Also like the DCT, the SCB test sample has a notch sawn into it. The SCB sample has a geometric advantage in that a single field core can be cut in half to provide two samples for testing.

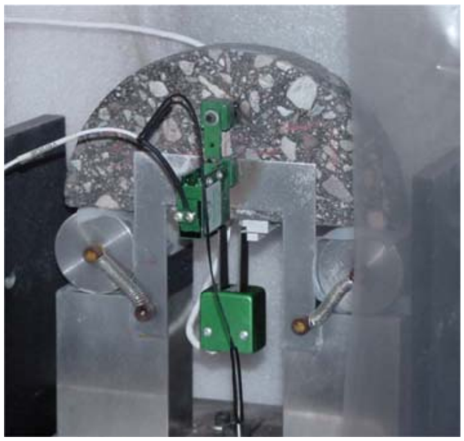

Figure 3.8 SCB Test

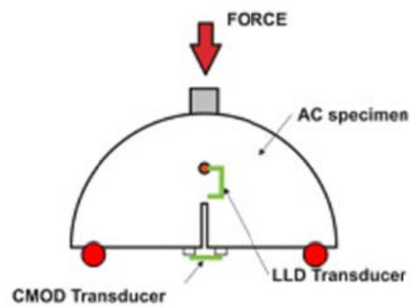

Figure 3.9 SCB Drawing

3.2.4 Indirect Tension Test

The IDT is another test that finds an asphalt mixture's FE using AASHTO T-322. The IDT evaluates the thermal cracking susceptibility of asphalt mixtures. The test applies a load to a cylindrical asphalt sample through its axis. A range of test temperatures are used depending on the binder grade. For CDOT's binders, the range would primarily run from -20° C, -10° C, and 0° C. The deformations that result are used to determine the viscoelastic material properties. These measurements are used in models to predict pavement performance. Values from the IDT are used to make predictions about thermal and fatigue cracking of the asphalt mix. Again, the test plot looks like the DCT test plot with load (kN) vs. load line displacement (mm).

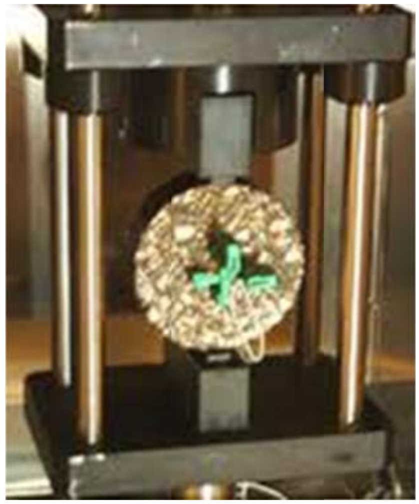

Figure 3.10 IDT Test

3.3 Comparison of Fracture Energy Tests

Minnesota University did testing on the IDT, SCB, and the DCT. An important finding of the comparison of the three types of tests was that only the DCT was little affected by air void content changes. The SCB test showed a decrease in FE when the air voids went up. Strangely, the IDT showed an increase in FE with an increase in air voids.

The DCT also had comparable results between lab and field samples. The SCB field samples produced lower FE values than did the laboratory prepared samples. The IDT showed poor correlation between field and lab samples (Marastteanu, 2012).

The geometry of FE testing is a consideration. The SENB test is performed on a rectangular sample that is not easily obtained from the field. The IDT, SCB, and DCT tests are performed on round samples that are easily produced in the lab or easily cored in the field. Also, the geometry of the DCT test sample creates a larger fracture zone than is found in the SCB test sample. The larger fracture zone helps to decrease the variability of the testing (Wagoner et al, 2005).

The DCT is recommended for use to find a mixture's FE. With the air voids having little effect on FE, and because the field cores correlate well to laboratory, the DCT is an excellent test to use to find the FE of asphalt materials.

Table 3.3.1 Comparison of Fracture Energy Tests

FE Test	Sample Geometry	FE Unaffected By Air Void Changes?	Lab and Field Results Comparable?
IDT	Fair	No	No
SCB	Good	No	No
DCT	Good	Yes	Yes

4.0 CREEP SLOPE FAILURES

CDOT personnel have wondered if the LWTD is so severe that it fails material that could perform well on the roadway. One way to lessen the severity of the test without tampering with the SIP, changing the test temperatures, or lowering the number of test passes is to consider if creep slope failures could be viewed as passing. Several surveyed states use the creep slope as a predictor of plastic flow rutting. Aschenbrener showed there was a poor correlation between the French rutter and the LWTD creep slope. Aschenbrener also showed a strong correlation between French Rutter failures and plastic flow rutting in the field (Aschenbrener, 1993). Therefore, we should not assume that a failure of a LWTD in creep slope would lead to rutting in the field.

Five years of LWTD test data was reviewed. Test reports from 2007, 2008, 2009, 2010, and 2012 were reviewed. Test results from 2011 were not found. Tests that failed while in creep slope, without hitting a SIP, were compared to stability tests of the same mix. Of the 22 non-Stone Mastic Asphalt (SMA) samples that failed in creep slope, zero of the samples had failing stability tests. In fact, the stability tests were at least 18% above the minimum stability specification. Note that SMA samples rarely have stability testing done and are not expected to pass minimum requirements if stability testing is done. Stability testing is CDOT's test for predicting plastic flow rutting. If requested by project personnel, French Rutter testing may also be done. The French Rutter values below are highlighted in yellow if they are failing.

Table 4.1 Stability Values

Year	Project Code	Location	Mix	Binder Grade	Creep Depth Failures (4mm max)	French Rut (5mm max)	Stability Test, Average Values (28 min)
2007	16028	083A, El Paso CL N	SX75	64-22	5.08	3.18	34
	16012	025A, Larkspur	S100	64-22	4.38	.94 – 2.96	39
	14086	050B, MP 352-356	SX100	64-28	5.10	4.38	36
	15095	050B, Holly	SX100	64-22	4.15	6.13	35
	15671	SH 109, La Junta	SX100	64-22	4.05 & 5.06	4.68 & 6.55	34
	15570	050B, Pueblo	SX100	64-22	4.50		36
	14890	285 at C470	S100	64-22	4.44	2.50	40
	15179	070A at SH58 Ramps	S100	64-22	4.20	3.67	40
	15364	6th Ave, 19th to Colfax	S100	64-22	6.17	1.92	41
2008	16420	050A, MP 313	SX100	64-28	5.39	2.00	37
	16569	050B, MP 338	SX100	64-22	5.03	3.96	36
	16453	070A, Vail West	SMA50	64-28	4.46	1.68	
	15914	076A, Sedgewick to SL	SX100	64-22	4.49		
	16050	085C, Weld County	SX100	64-28	4.89,5.15,4.04	2.21	35
	16145	034A, Weld County	SX100		4.94		35
	13579	270 at intersection with 36 and 76	SMA	76-28	4.31	2.46	
2009	13141	096, 4th St. Bridge	SX100	64-22	4.75	2.15	36
2010	17316	070A, EJ Tunnel to Bakersville	SMA100	64-28	4.46	1.68	
2012	17987	050A, Rocky Ford	SX100	64-22	4.56	1.87 - 3.86	37
	18021	069 Widening S of Westcliff	SX75	58-28	6.65	3.18 - 3.37	32
	18025		SMA	76-28	4.67		
	18262		SMA	76-28	4.15		
	18478		SMA100	76-28	4.37		

With good to very good stabilities, it's expected that the samples that failed in creep slope without hitting a SIP would be able to perform without plastic flow rutting occurring.

Does failing while in creep slope predict other HMA distresses? CDOT's primary problems with current pavements are cracking, fatigue, and raveling. The CDOT Pavement Management Program's (PMP) pavement surveys do not pick-up raveling, however, data was obtained pertaining to other distresses.

There are a number of reasons why the data from the PMP alone cannot be used to say that mixes that failed in the creep slope perform as well as or better than other mixes, even though the data looks good.

- The sample of projects that failed while in creep slope, without hitting a SIP, is very small. Looking at five years of data, 25 projects failed while in creep slope. Of these 25 creep slope failures, only 19 could be found in CDOT files to determine the location of the project.

- Within the project limits, there is no way to determine where the material that was tested in the LWTD was placed. A sample of mix represents 10,000 tons of mixture.

- There could be stripping at the bottom of the HMA layer that doesn't yet show on pavement surveys.

- Fatigue cracking occurs from the bottom up. Therefore, fatigue cracking could be occurring without yet having presented for visualization on the top of the HMA layer.

- There could be a loss of the base or subgrade causing any fatigue cracking that is visible.

- Poor field compaction of the HMA could be the root cause of HMA distresses.

Despite these cautions listed above, data was reviewed to determine if creep slope failures of mix in the LWTD could be related to poor pavement performance.

Unofficially, CDOT index calculations can be labeled good, fair, or poor based on their values from 0-100. Good would be a score of 85-100. Fair would be a score of 65-84. Poor would be a score of 50-64.

Table 4.2 CDOT Index Calculations

						Index Calculations 0 - 100							
Hwy	Dir	BMP	Emp	Length	Year	Rut		Fatg		Tran		Long	
006G	1	272.6	275.15	2.55	2007	92	Good	99	Good	95	Good	91	Good
006G	2	272.6	275.15	2.55	2007	91	Good	99	Good	96	Good	97	Good
025A	1	171.2	175.2	4	2007	97	Good	100	Good	99	Good	96	Good
025A	2	171.2	175.2	4	2007	98	Good	100	Good	100	Good	100	Good
034A	1	125.86	130.86	5	2008	100	Good	100	Good	99	Good	100	Good
034A	1	130.86	133.5	2.644	2008	100	Good	100	Good	98	Good	100	Good
034A	1	133.5	136	2.5	2007	100	Good	100	Good	100	Good	100	Good
034A	2	128	133	5	2008	100	Good	100	Good	100	Good	100	Good
034A	2	133	133.5	0.5	2008	100	Good	100	Good	100	Good	100	Good
034A	2	133.5	134.5	1	2007	100	Good	100	Good	100	Good	100	Good
036B	1	56.473	57.3	0.827	2012	100	Good	100	Good	100	Good	100	Good
036B	2	56.473	57.3	0.827	2012	100	Good	100	Good	100	Good	100	Good
050A	1	312.8	314.6	1.8	2012	100	Good	100	Good	100	Good	100	Good
050A	2	312.8	314.6	1.8	2012	100	Good	100	Good	100	Good	100	Good
050B	1	335.5	336	0.5	2008	100	Good	97	Good	87	Good	96	Good
050B	1	338	341	3	2008	99	Good	100	Good	99	Good	100	Good
050B	1	359.45	360.15	0.7	2012	100	Good	100	Good	100	Good	100	Good
050B	1	360.15	365.15	5	2012	100	Good	100	Good	100	Good	100	Good
050B	1	365.15	367	1.85	2012	100	Good	100	Good	100	Good	100	Good
050B	2	359.1	360.15	1.05	2012	100	Good	100	Good	100	Good	100	Good
050B	2	360.15	365.15	5	2012	100	Good	100	Good	100	Good	100	Good
050B	2	365.15	367.2	2.05	2012	100	Good	100	Good	100	Good	100	Good
070A	1	171.1	176.1	5	2008	85	Good	100	Good	99	Good	99	Good
070A	1	176.1	180	3.9	2008	90	Good	100	Good	100	Good	100	Good
070A	1	213.6	215	1.4	2010	52	Poor	100	Good	100	Good	100	Good
070A	1	215	220	5	2010	79	Fair	100	Good	99	Good	98	Good
070A	1	220	221	1	2010	68	Fair	99	Good	97	Good	96	Good
070A	1	264.3	265.5	1.2	2008	91	Good	100	Good	96	Good	93	Good
070A	2	171.1	176.1	5	2008	80	Fair	99	Good	98	Good	99	Good
070A	2	176.1	180	3.9	2008	80	Fair	100	Good	99	Good	100	Good
070A	2	213.6	215	1.4	2010	68	Fair	99	Good	100	Good	98	Good
070A	2	215	220	5	2010	84	Fair	99	Good	97	Good	94	Good
070A	2	220	221	1	2010	82	Fair	100	Good	99	Good	90	Good
070A	2	261.7	264.3	2.6	2010	100	Good	100	Good	100	Good	100	Good
070A	2	264.3	265.5	1.2	2008	97	Good	100	Good	95	Good	100	Good
070A	2	265.5	267.4	1.9	2010	98	Good	100	Good	99	Good	99	Good

						Index Calculations 0 - 100							
Hwy	Dir	BMP	Emp	Length	Year	Rut		Fatg		Tran		Long	
076A	1	3	5.55	2.55	2012	100	Good	100	Good	100	Good	100	Good
076A	1	6.9	7.4	0.5	2002	93	Good	90	Good	93	Good	92	Good
076A	1	7.4	7.9	0.5	2012	100	Good	100	Good	100	Good	100	Good
076A	2	3	5.55	2.55	2012	100	Good	100	Good	100	Good	100	Good
076A	2	7.4	7.9	0.5	2012	100	Good	100	Good	100	Good	100	Good
076A	2	168.5	173.5	5	2008	100	Good			100	Good	99	Good
076A	2	173.5	175.25	1.75	2008	100	Good			100	Good	100	Good
076A	2	175.25	180.25	5	2008	100	Good			100	Good	100	Good
076A	2	180.25	184.1	3.85	2008	100	Good			100	Good	100	Good
083A	1	33.2	38.2	5	2008	100	Good	100	Good	99	Good	100	Good
083A	1	38.2	41.2	3	2008	100	Good	100	Good	96	Good	100	Good
085C	1	254.011	259.011	5	2008	100	Good	100	Good	95	Good	100	Good
085C	1	259.011	261.694	2.683	2008	100	Good	100	Good	96	Good	100	Good
089A	1	0	4.78	4.78	2007	100	Good	100	Good	94	Good	97	Good
089A	1	8.96	13.96	5	2007	100	Good	100	Good	94	Good	97	Good
089A	1	13.96	18.96	5	2007	100	Good	100	Good	93	Good	95	Good
089A	1	18.96	23.96	5	2007	100	Good	100	Good	96	Good	99	Good
089A	1	23.96	28.96	5	2007	100	Good	100	Good	98	Good	100	Good
089A	1	28.96	34.3	5.34	2007	100	Good	100	Good	96	Good	99	Good
096A	1	51	55.12	4.12	2007	100	Good	100	Good	92	Good	100	Good
096A	2	51.5	55.12	3.62	2007	99	Good	100	Good	89	Good	99	Good
109A	1	31	36	5	2007	100	Good	100	Good	96	Good	100	Good
109A	1	36	41	5	2007	100	Good	100	Good	96	Good	100	Good
109A	1	41	46	5	2007	100	Good	100	Good	98	Good	97	Good
109A	1	46	51	5	2007	100	Good	100	Good	97	Good	96	Good
109A	1	51	54.7	3.7	2007	100	Good	99	Good	94	Good	92	Good
109A	1	54.7	56.07	1.37	2007	100	Good	93	Good	76	Good	95	Good
109A	1	56.07	56.99	0.92	2008	94	Good	90	Good	81	Fair	98	Good

A quick glance at Table 4.2 shows that nearly all tenth mile sections of roadway are in good condition, despite LWTD testing failing some of the material in creep slope. Also of note, the fair and poor ratings in rutting on I-70 are in mountainous parts of I-70. CDOT has found in the past that rutting in mountainous portions of I-70 is likely due to mechanical rutting from tire chains and studded tires. The rutting is highly unlikely, at the temperatures at high elevation, to be from plastic flow rutting. Therefore, it is possible for engineers to use discretion when looking at asphalt mix that failed while in creep slope and not automatically fail mixes that exceeded the maximum rut depth while in creep slope.

5.0 LWTD FOR DESIGN OR PRODUCTION

In the review of five years of data, it was found that all but one of Colorado's aggregate sources had passed the LWTD at least once. Aggregates from the Muddy Pass aggregate source, which was used once in the five years reviewed, did not show a passing LWTD test. The Muddy Pass mix was a 75 gyration mix that had scores of 6.38, 4.21, 4.25, and 4.34 mm. With nearly all aggregates able to pass the LWTD, CDOT can feel secure that Contractor aggregate sources, with proper handling and design, can pass the LWTD and be used in CDOT mixes.

Beyond the design phase, several factors affect the way the mix will perform in the LWTD. For example, if the lime is not properly added to the mix in production, a sample may fail the LWTD. Also, if aggregate is coated in fines, there is little chance the mix material will pass the LWTD. Because these issues also affect the way the material will perform in the field, it would be very useful to test the material in the LWTD during production.

Aschenbrener showed the influence of the combination of binder with aggregate in passing the LWTD. Some aggregates, for reasons unknown, have better adhesion between the aggregate and a binder than they do with other binders (Aschenbrener, 1994). Specifying the LWTD for design or production can encourage Contractors to use a binder that works well with their aggregates.

Four of the seven states that specify the LWTD for production have dropped their Lottman Test requirement. Because both the LWTD and the Lottman Test find the stripping potential of a mix, dropping the Lottman test seems like a reasonable approach to take if the LWTD were used for production.

6.0 CONCLUSIONS AND RECOMMENDATIONS

1. **Write a specification for the LWTD to be used on CDOT projects.** States interviewed that utilize LWTD specifications for design and/or production unanimously believe their roads are better because of these specifications. However, some states have noticed that their mixes are being designed dryer to meet maximum rut depth specifications for LWTD testing. This can lead to increased cracking and fatigue on roads. Therefore, LWTD testing alone isn't sufficient to produce good designs and asphalt mixtures for roadways. The LWTD testing would still need to be done in addition to current volumetric testing, which allows RMEs to adjust the binder content through adjusting the voids, to prevent mixes from becoming overly dry. CDOT could specify LWTD testing for design and/or production. If the LWTD were used for production, Lottman testing in the Flexible Pavement Unit could be discontinued. In addition, if LWTD production testing were done, suppliers might work harder to ensure that the addition of lime was properly handled.

2. **Write a specification for the DCT test.** If CDOT does begin using the LWTD for design and/or production, they should consider a companion test that would prevent asphalt mixes from becoming too dry. A test that finds a sample's FE could be used as a suitable companion test. Of the FE tests that numerous studies have looked at, the DCT appears to be the most useful for CDOT. The DCT shows little variability as void contents change, and field sample test results are similar to test results from lab produced mix. ASTM D7313-07a "Standard Test Method for Determining Fracture Energy of Asphalt Aggregate Mixtures Using the Disk-Shaped Compact Tension Geometry" has the with-in lab repeatability standard deviation already established. The between-lab reproducibility is currently being determined. Because CDOT already has an environmental test chamber in the UTM 25, the cost of the DCT jig and associated equipment would be just over $7200. The itemization of the costs is in Appendix A.

3. **CDOT should consider passing LWTD samples that fail in creep slope without ever hitting their SIP.** Reviewed pavement data overwhelmingly showed "good" ratings in

rutting, fatigue, longitudinal and transverse cracking on projects that had mixture fail while in creep slope without hitting the SIP. It's likely that mixes exceeding the maximum rut depth in creep slope without hitting the SIP will perform well on the roadway and Engineers could use their judgment in allowing the mix to be used.

4. **Round robin testing should continue with other states that use the LWTD.** Reproducibility should be established if a LWTD procedure is to be implemented. CDOT annually participates in LWTD round robins. Any labs that may perform testing on Colorado material should be included in the round robins. The round robin results may be used to establish reproducibility.

5. **Use the LWTD to test the performance of new materials and to verify current mixes used on projects.** The LWTD is an extremely valuable tool for verifying the expected performance of mixes that might contain new materials, such as asphalt shingles or tire rubber. As the asphalt industry moves toward using these materials, CDOT may be more inclined to allow their use if the LWTD were used to thoroughly test the mixtures. CDOT could ultimately benefit if addition of these materials resulted in lower costs.

6. **Continue to use the French Rutter to study asphalt rutting problems.** The French Rutter provides very useful information for RMEs if a rutting problem occurs on a project. The information can be used to solve field disputes. For example, when a Contractor disputed removing and replacing rutting material, French Rutter testing showed a lower existing lift, not the newly placed asphalt lift, was the rutting lift.

7.0 FUTURE RESEARCH

1. **Determine if using Superpave gyratory samples in the LWTD gives comparable results to samples produced in the linear kneading compactor that CDOT currently uses to compact samples.** If the LWTD were specified for design and/or production, making samples with the Superpave gyratory compactor would save the cost of Contractors or test labs having to purchase a linear kneading compactor. CDOT has numerous samples collected in the EuroLab that are not being tested due to a shortage of personnel. Those samples could be tested when the construction season is ended and personnel are available. The results could show if CDOT might need to adjust their 4mm maximum rut depth if gyratory compactor samples are used instead of linear kneading compactor samples.

2. **Determine the FE of current CDOT asphalt roadways.** If an FE test apparatus is purchased, run cores from existing roadways of known performance in the test apparatus to determine a correlating FE. This will verify the predictive ability of the FE apparatus and will help to determine appropriate specification values if a specification is written.

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APPENDIX A: INVOICE FOR COST OF DISC-SHAPED COMPACT TENSION JIG AND ACCESSORIES

CPN / InstroTek, Inc.
5052 Commercial Circle
Concord, CA 94520
925.363.9770 (t)
925.363.9385 (f)

Quote

Estimate #:	12367
Date:	8/16/2013
Terms:	Net 30
Contact:	Maurice Arbelaez
Delivery:	4-6 weeks

MA

Customer:

Jilbehr, Inc.
Kim Gilbert
3825 Depew St.
Wheat Ridge, CO 80212

Item	Qty	Description	Rate	Total
IPC-Misc parts	1.0	0002-3100 Disk Shaped Compact Tension - Jig Asy	2,800.00	**2,800.00T**
IPC-Service	1.0	0002-3835 ILC for clip gauge and calibration	950.00	**950.00**
Shipping	1.0	Shipping Charges to Australia & Back	650.00	**650.00T**
Misc.	1.0	Epsilon-0020-250T-ST COD Gaugue Length:0.2 Meas Range: -0.05" to +0.25" -40C to 100C Temp Range	1,650.00	**1,650.00**
Misc.	1.0	3541 Bolt on knife edges	80.00	**80.00**
Misc.	32.0	Gauge Points	32.00	**1,024.00**
Shipping	1.0	Shipping Charges	55.00	**55.00T**

Subtotal	$7,209.00
Sales Tax (0.0%)	$0.00