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CDOT and Colorado Paving Industry's Action Plan to Address Recently Documented Issue with Compaction Angle when Using the Troxler Gyratory with Four-Inch Molds

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The CDOT Materials Advisory Committee unanimously approved this Plan on April 19th, 2002.

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Problem Statement

In February 2002 the Colorado Department of Transportation (CDOT) and the asphalt industry in Colorado were informed by Troxler Electronic Laboratories, Inc., that the factory-induced angle of compaction in all Troxler Model 4140 compactors using four-inch molds was actually at 1.20 degrees instead of the specified target angle of 1.25 degrees. The angle difference is due to incorrect height constant applied by Troxler at the factory prior to shipping each compactor.

Attachment 1 contains the detailed problem description as presented by Troxler on February 19, 2002. In summary, the actual angle of compaction in Troxler 4140s is 0.05 degrees below the national Superpave specification. Gyratory compactors from other manufacturers and the Troxler 4141s are currently applying the specification angle of 1.25 degrees externally. This paper describes the impacts from this angle difference and the plan of action developed by CDOT and Industry in Colorado.

Background

National research and local experience led to the current state of gyratory use nationally and in Colorado. Colorado, like most state DOTs, developed its Superpave system based on current deficiencies in the national specification and on experience with local materials and conditions.

National Use of Gyratory Compactors

Nearly 2500 Superpave gyratory compactors are in use in the United States today. With the exception of Colorado, all Superpave states use six-inch specimen molds for laboratory compaction. All devices are currently required to be calibrated for angle by external measurement of the mold during operation. Method of external angle measurement is unique to each device manufacturer. FHWA field evaluations between 1994 and 2000 showed statistically significant differences in the volumetric results of compacted samples from different device manufacturers. The likely cause was determined to be variation in the internal angle. The FHWA has developed a Dynamic Angle Verification kit (DAV) and is currently conducting research on the actual angle applied to the sample inside the mold (internal angle).[(1)]

Preliminary results from the DAV research, as presented at the February 2002 Superpave Mixture Expert Task Group meeting (ETG), indicate that each type of gyratory induces a unique internal angle during mix compaction. This was as suspected during the original FHWA field evaluations and there is a current effort to change the Superpave specification to require DAV calibration to an internal angle of 1.16 degrees for all compactors.

However, in addition to angle differences between different types of compactors, the data also indicate that each compactor shows significant internal angle sensitivity to the stiffness of the mix being compacted. The implications of this angle variability within each machine are not yet fully understood. However, angle differences as great as 0.16 degrees have been reported. Internal angle variation appears to be a function of the mix type (stiffness), compactor type, and history of machine maintenance and calibration. Current suggestions from the FHWA researchers indicate that a day-long recalibration

with a DAV before each new mix type may eliminate internal angle variability. This is not possible in most labs in Colorado.

In addition to the national efforts to ensure equal compactive effort for all gyratory compactors, there is also an effort to reevaluate the Superpave design gyration levels. National Cooperative Highway Research Program project 9-9(1) (NCHRP 9-9) was started due to national concern that the existing table of gyratory compaction levels may set design compaction levels that are too high. The state of Virginia, as an example, has recently modified its design gyration levels to be lower than the national Superpave levels. NCHRP 9-9 is likely to be completed in 2003.

Colorado's Use of Gyratory Compactors

Colorado's Superpave specifications call for four-inch compacted specimens. This modification from the national standard was based on deficiencies in the current national standard and our experience with local materials and conditions. Below are several motivations for specification of four-inch samples:

- No national test for Moisture Susceptibility with 6" sample.
- No national shear strength test for Superpave mix with 6" sample.
- 4" molds allow for reduced sample size and support high frequency QC/QA sampling done on CDOT projects.

The original Lottman studies were conducted using four-inch samples and significant additional research has been conducted in Colorado to document test repeatability and the tie between the test results and the performance of the pavement after construction.[2] [3] The national Superpave effort did not include the development of a simple test to evaluate the anticipated performance of the finished pavement. CDOT has historic success in using the Hveem Stability test (Colorado Procedure – L5106) to screen for mix with rutting potential. There are current national efforts to develop a national Superpave test for moisture susceptibility (NCHRP 9-34) and a simple mix performance test (NCHRP 9-29). NCHRP 9-34 has yet to begin and 9-29 is expected to complete research and recommendations by April 2003. Several years typically pass before any research recommendations are fully implemented in national AASHTO test procedures and specifications. CDOT values the data from its current procedures. The tests help to ensure acceptance of high quality material. Until national Superpave tests are developed and evaluated for their value in Colorado, CDOT will continue to use its current specifications.

The quality of asphalt pavements in Colorado has improved with the advent of our Superpave specifications. Significant past problems with premature rutting have been virtually eliminated. Experience with our Superpave mixes has been that they are slightly drier and much stiffer than our past mixes. This results in reduced rutting and is due in part to the focus of Superpave on volumetric mix conditions and required aggregate angularity requirements. Experience gained statewide and on I-25, where a forensic investigation showed premature cracking, indicates that our current Superpave mixes typically contain adequate asphalt binder, but that further changes to procedure that

reduce binder content should be avoided. Our current system typically produces rut resistant durable asphalt pavements.

Developing A Solution to the Compaction Angle Problem

Initial Response: CDOT coordinated a meeting with Troxler, CDOT Region Materials Engineers and Colorado Industry to provide Troxler an opportunity to fully describe the gyratory angle problem. The meeting was conducted on February 19, 2002 and was attended by attended by four CDOT, seven Industry, and two local agency representatives. The group discussed impacts of the Troxler angle issue and potential plans of action to address the mix designs and construction projects for 2002 and beyond.

Most design and acceptance of Superpave mix has been done on the Troxler 4140 in Colorado. These mixes were compacted using an external angle of 1.20 degrees (when it was believe to be 1.25 degrees). The group discussed that increasing the angle by 0.05 degrees to actually be 1.25 on future mixes will result in roughly on percent drop in mix air voids. In order to meet voids requirements, the mixes would typically be 0.1 to 0.3 percent lower in percent asphalt content. Drier mixes would result.

Pine users at the meeting did not find recurring problems when running QC using a Pine. The CDOT requirement for compactor correction at the start of each job was suggested as the reason for this.

It was agreed that, given the current success with Superpave in Colorado and the understanding that our future mixes should not be designed any lower in percent asphalt content, the external compaction angle on ALL compactors should be set by specification to be 1.20 degrees. The users of non-Troxler equipment did not expect difficulty in setting their machines to 1.20 degrees. This will make a consistent effort to design and produce Superpave mixtures in the same manner as the majority of the mix produced in Colorado since the start of Superpave.

It was also agreed that during the 2002 season, data should be collected on project material compacted at both 1.20 and 1.25 degrees. This data should be used to establish action for the 2003 season.

Data Gathering:

The CDOT Asphalt Program gathered data after the initial meeting to help support decisions to be made on the compaction angle.

Colorado performed comparison of sample compaction between four-inch and six-inch samples during round robin testing in 1996 and 1997. It was found that the four-inch samples contained 0.21% greater air voids than the six-inch samples. Designing a mix with a four-inch mold will produce mixes with slightly higher percent asphalt content than with a six-inch mold. Switching to six-inch molds is another way to effectively make Colorado mixes drier.

Information on the national use of compactors was gathered and is included in the *Background* section above. The national perspective on compaction angle and compactive effort are evident. It is clear that there is a national effort to better define and control the actual angle of compaction. The current specification requirement for 1.25 degrees externally does not consider the now evident variability in the actual angle applied to the sample inside the mold. The national trend is to change the current spec to require the lower internal angle of 1.16 degrees measure using a device such as DAV. This angle change is several years away. Future national improvements to angle specification will undoubtedly be influenced by the relatively new discovery that the internal angle is also variable within an individual machine based on mix type and machine condition. This, coupled with the national effort to revise the design gyration levels, makes the significance of a new documented difference in Colorado's specified gyratory angle relatively insignificant. The national efforts to address angle variability and compactive effort will result in significant changes to the national Superpave specifications. Our confidence in the quality we have gotten with our current Superpave specifications supports our continuing their use at this time.

One final note on internal angle: The developer of the DAV, Tom Brovold, believes that the angle variation problems experience within six-inch molds is not present within four-inch molds. He attributes the lack of problem in the four-inch machines to the smaller sample mass and lower moment arm during compaction. There are currently no plans nor apparent need for developing an internal angle measuring device for the compactors using four-inch molds.

Round Robin 2002 results will be evaluated to gather information on compaction differences between machines in Colorado.

Colorado has a formal procedure in its specifications to require the correction of the Contractors' QC compactor to agree with the CDOT acceptance compactor. This is required at the start of each project during the compaction test section testing.

MAC Guidance:
CDOT's Materials Advisory Committee discussed the angle issue and provided guidance for the action plan at the March 13, 2002 meeting. The final plan below reflects the input of the MAC.

Angle Action Plan Finalization:
A joint meeting of Industry and CDOT was conducted on March 25, 2002, after direction from the MAC on the action plan. The final plan below reflects the input of the joint CDOT/Industry meeting.

Final Angle Action Plan Approval:
The MAC voted to formally approve the final action plan below. Unanimous MAC approval was given on April 19th, 2002.

Specific Action Plan to Address Compaction Angle

2002 CDOT Construction Season

1. The external compaction angle for all gyratory compactors using four-inch molds shall be set to 1.20 degrees. The external compaction angle for all gyratory compactors using six-inch molds shall be set to 1.25 degrees.

   Troxler Industries will visit all CDOT and Industry sites to formally set 4140s and 4141s to 1.20 degrees for four inch molds. Contact Bob Wilson, Troxler, at (303)969-0950.

   Users of other compactors will need to arrange assistance, if necessary, with the compactor manufacturer.

2. Issue a modified Project Special Provision Revision of Section 403, Hot Bituminous Pavement, to make angle requirements part of CDOT construction contracts. This will override CP-L 5115 until it is changed for 2003 season.
3. With assistance from Project Development Branch, issue Construction Bulletin by April 30, 2002, that summarizes the angle issue and the necessary Change Order for awarded projects to require proper compaction angle.
4. Notify local agencies and Industry via MGPEC and CAPA.
5. Gather data in Central Lab on 1.20 versus 1.25 degree compaction angle for 2002 construction season using the two Troxler 4140 compactors.
6. Collect make and model of all compactors used in the Round Robin 2002.

2003 CDOT Construction Season

1. Evaluate 2002 project data and Round Robin data by July 2002 and recommend action for 2003 season.
2. A joint CDOT/Industry meeting will be held and then MAC approval will be solicited for the final angle recommendation.
3. Contingent upon 2002 data , modify and issue CP-L 5115 by August 2002 to require the decided angle: 1.20 degrees or 1.25 degrees. An appendix to CP-L 5115 may also be added to summarize the angle issue and to detail the procedure to use when changing between four-inch and six-inch molds on the same compactor.
4. Establish the date after which all mix designs must be done according to the final established CDOT gyratory angle.
5. Monitor National efforts to develop internal angle device and calibration requirements

REFERENCES

(1) Tom Harman, John R. Bukowski, Francis Moutier, Gerald Huber, Robert McGennis, *The History and Future Challenges of Gyratory Compaction 1993 to 2001*, presented at the annual Transportation Research Board meeting in January 2002.

(2) Charles MacKean, Colorado Department of Transportation Report Number CDOT-DTD-R-93-4, Lottman Repeatability: *"Variability in the Indirect Tensile Stripping Test. Colorado Procedure L-5109 Within-Laboratory and Between-Laboratory Variations,"* published April 1994.

(3) Tim Aschenbrener, Colorado Department of Transportation Report Number CDOT-DTD-93-3, *"Investigation of the Modified Lottman Test to Predict the Stripping Performance of Pavements in Colorado,"* Published April 1993.

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Superpave
Gyratory Compactors in Colorado

February 2002

Since their introduction in the mid 1990's, Superpave gyratory Compactors have been used for the design of asphalt materials and asphalt mix designs. Original specifications in use today require an asphalt specimen to be compacted by applying a force of 600 Kpa to the mix while gyrating the mold at an angle of 1.25degrees. The specimen height is continuously monitored, providing information on the density of the mix through out the compaction cycle.

Troxler gyratory compactors use an innovative method to induce the mold angle. This process is called " Base- offset angle induction". The angle is induced by holding the top of the mold in a fixed position while displacing the base around an offset bearing.
By continuing to rotate the offset bearing, the induced angle is gyrated about the central axis of the compactor.

Angle verification is quick and easy. An electronic angle excursion indicator measures the induced angle as the compactor gyrates at constant pressure with HMA in the mold. Measuring the base excursion in millimeters and entering that number into the compactor controller unit determine the resulting angle. The system then calculates the actual angle based on a factory calibration.

Factory Calibration:

All 4140 series compactors are configured as 150mm machines per SHRP specifications. After assembly, the angle is set to 1.25 degrees. This is done initially by using a calibration device, "True Mold Angle Indicator, or TMA. Inside the TMA are two electronic angle excursion indicators. The exposed probe ends of the indicators are positioned to be in contact with the exterior surface of the compaction mold face.
The compactor is loaded with a "calibration mold" and the TMA attached to the chamber of the machine. As the material is being compacted excursion measurements are taken on the mold face. The data collected from the electronic indicators are converted to an "angle of compaction" using simple geometric calculations. Adjustments are made until the angle is 1.25 degrees.
Once the angle has been set with the TMA, the turntable base "assembly housing offset" is measured in millimeters. This is done with an electronic indicator similar to the one found in the "Performance Verification Kit, PVK" used to set and verify compactor angles. The offset measured in millimeters is used to calculate the "angle constants " for the compactor. Each compactor has a unique set of constants. (Example attached)
These "angle constants" allow the operator to set and verify angles on the machine with the digital indicator without having to use the "True Mold Angle " device. Both the TMA and the digital indicator routines should give comparable results.

ATTACHMENT 1 - Troxler Information – Feb. 19, 2002 Meeting

4140's in Colorado

Colorado is the only state where the compactors use 100mm specimens in volumetric mix design.
To convert a machine from 150mm to 100mm, the ram head must be changed out.
The operator enables the 100mm option from the control console. Then, the calibration routines of "pressure, height, and angle " are performed.
When the 100 mm option is enabled, the angle constants are adjusted for the smaller mold and sample size. This is necessary due to the decrease in specimen height from approximately 114mm down to 65mm, and because of the reduced shear loading on the gyratory frame. The 100mm angle is set using the digital indicator included with the " PVK" kit. The compactor interprets an excursion in mm and converts it to an angle. The angle is adjusted until 1.25 degrees is reached.
The machine is now set up for 100mm usage.

4141's in Colorado

The model 4141 was introduced in 1998 and adapted for 100mm molds in 1999.
Angles are set and fixed for the 4141 compactor to 1.25degrees. This angle is set through adjustment slots in the mold base turntable. The same type "TMA" device is used as for the 4140 series. A two-point measurement offset taken on the mold face is geometrically related to an angle in degrees.

Problem Identification:

In the fall 2001, 2- 4141 compactors were delivered to LaFarge in Denver, CO. The angles of these units were field set to 1.25 degrees. Voids analysis of material compacted by the two 4141's and the LaFarge lab 4140 disagreed. The angle of the lab 4140 was verified and calculated to be 1.25 degrees with the PVK kit digital indicator. Voids from specimens produced by the 4141's were lower than the lab 4140. Differences were about 1%. See attachment.

A request was made to have shipped out a calibration device "TMA" to check the angle on the 4140-lab gyro. The measured angle was 1.20 degrees. Note: The excursion calibration method showed 1.25 degrees. LaFarge wanted the "Baby" gyros to be adjusted down to 1.20 degrees to match the lab 4140.

Why does the TMA device show 1.20 degrees and excursion calibration 1.25 degrees? Is this an isolated case? It was arranged to have the Senior Field Service Technician for compactors accompany myself to look at 4140 series compactors in the Denver area. Twelve units were measured from January 22, 23 and 24, 2002. All had angles from 1.18 degrees to 1.22 degrees. Each had an excursion calibration of 1.25 degrees.
See attached.

The data was taken to the Engineering Dept. of Troxler Electronics for analysis. The problem was due to the angle calibration constants in the software. When the machines were converted from 150mm to 100mm molds, the software was not adjusted accordingly for sample heights from 114mm down to approximately 65mm. Height calibration constants are .0012 and should be down around .0001. The difference between .0012 and .0001 height constants is approximately 0.045 degrees.

Please see the three scanned data sheets attached below for reference.

ATTACHMENT 1 - Troxler Information – Feb. 19, 2002 Meeting

Troxler 1.pdf

Troxler 2.pdf

Troxler 3.pdf