

On the Variability of Results from the Hamburg Wheel Tracker Device

James Allen Cox, LS F.ASCE
Utah Valley University
Orem, Utah

Kevin M. VanFrank, P.E
Utah Department of Transportation
Salt Lake City, Utah

Pedro Romero, Ph.D., P.E., M. ASCE
University of Utah
Salt Lake City, Utah

The Hamburg Wheel Tracker Device has been used for over thirty years to evaluate the performance of asphalt pavements in terms of rutting susceptibility and moisture damage (*Public Roads, 1998*). This paper focuses on using Linear Kneading Compactors and Hamburg Wheel-Tracker devices to make and test specimens of asphalt binder and aggregates from one source to determine any bias and typical errors related to the materials testing procedures used by various state testing laboratories. The objective is to determine whether the existing procedures can produce consistent and repeatable results, which can then be used in design and eventually in field acceptance tests. This report will provide a recommended procedure and precision statement for verifying the test specimen preparation and testing. In order to have consistent designs it is necessary to insure laboratories are performing at the same level.

Key Words: Uniformity, Repeatability**,** Procedure, Statistically Compatible, Bias

Introduction

The Hamburg Wheel Tracker Device (HWTD) has been used for over thirty years to evaluate the performance of pavements (*1*). However, most highway agencies have shied away from using the HWTD as a formal requirement for acceptance due to its lack of repeatability in its results and inability to predict pavement performance. One of the reasons creating these problems is the lack of standardization in the procedures used to prepare the samples. In other words there is a standard procedure for testing, but no procedure exists for preparing the specimen that will be used in the evaluation process. AASHTO T324: Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Hot-Mix Asphalt (HMA) addresses the testing procedures, but it does not address the preparation of the specimen.

This paper will focus on the initial preparation process to determine if any part of the preparation is the cause of the large variability often seen in the results of the HWTD (*Izzo, 1997; Romero, 2010; Aschenbrener, 1993*). The goal of this paper will be to establish a standard practice for specimen preparation so that the results are within a reasonable standard deviation and to establish a precision and bias for the procedure. These results will allow highway agencies to use this practice to ensure rut resistant pavements that are not susceptible to moisture damage.

Background

The use of the HWTD test requires test specimens be prepared using the same material and specifications. Thus the materials (aggregates and asphalt) are combined and compacted into a test specimen. The compacted specimen is then placed in the mold and secured in place inside the testing HWTD device The HWDT device is filled with water and the specimens submerged. Once the water has reached the correct temperature, the weighted wheels are lowered onto the specimens. The specimens are subjected to 20,000 passes of the weighted wheels in a water bath at a uniform temperature and the depth of indentation into the specimen is measured in millimeters (*Romero, 2008; Izzo, 1997*).A schematic is shown in *Figure 1*. Because the test was giving different results on samples prepared by the Department of Transportation (DOT) and those prepared by the local contractor's laboratories, concern was raised as to why the tests could not be performed with consistency. The department decided to run an inter-laboratory study (ILS) in an attempt to isolate the cause of the inconsistent results. After review of the preliminary test results, it was decided that variation in sample preparation was the probable cause of the inconsistencies and thus the hypothesis for the ILS.

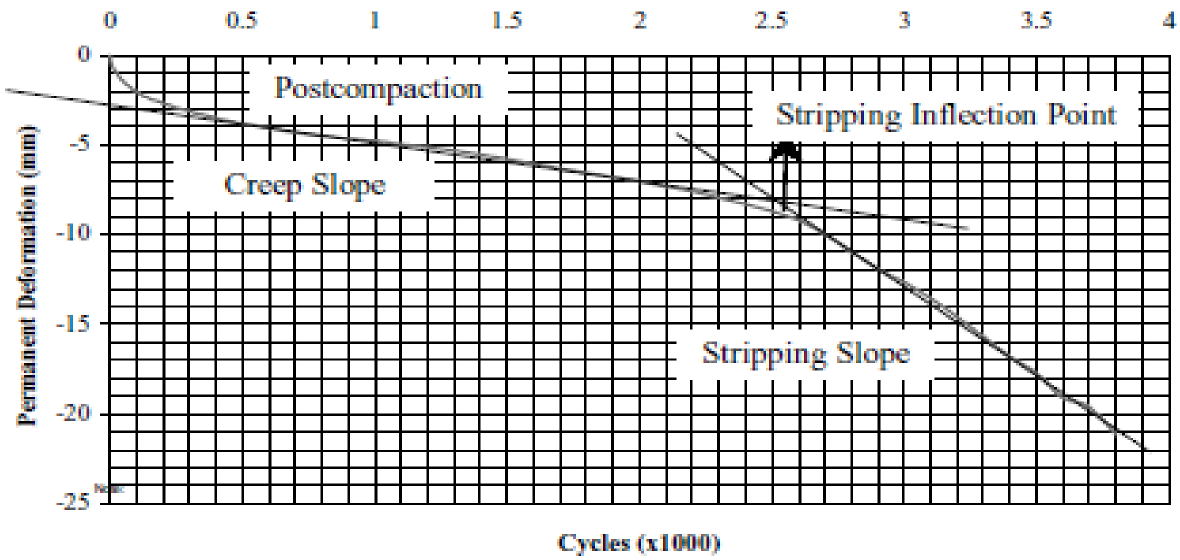

Figure 1: Schematic of HWDT results. (Solaimanian M. H. J., 2003)

The DOT uses the HWTD as a test method to determine the rutting and moisture susceptibility of (HMA) and specifies the following testing procedures. See *Figures 2 and 3*.

1. DOT Materials Manual- Part 8, Section 990 the Method of Test for Hamburg Wheel-Track testing of Compacted Hot Mix Asphalt (HMA). This procedure identifies DOT's modifications to AASHTO T 324, Hamburg Wheel-Track Testing of Hot Mix Asphalt (HMA),

2. AASHTO R 30, Standard practice for Mixture Conditioning of Hot-Mix Asphalt (HMA),

3. AASHTO T 209, Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixture Specimens, DOT Materials Manual –Part 8, Section 988- Guidelines for Laboratory Mixing of HMA.

Even though the DOT laboratories have been following these test procedures, the tests results have not been repeatable causing disputes between contractors and DOT's results

Figure 2: Linear Kneading Compactor.

Figure 3: Hamburg Wheel Tracker Device.

Procedures

As previously mentioned, it was the hypothesis that most of the variability in the results was the inconsistent preparation of the specimens used for the test. The DOT opted to run an ILS series of tests with the intent to isolate the areas where the inconsistency of its sample preparation would result in error. The ILS testing involved a total of nine laboratories: a Central Materials Lab and the Eight DOT's Materials Laboratories participated in the testing. Each laboratory was provided enough of the same material (asphalt binder and aggregate) so that enough HWTD samples could be made to run the required tests. The **suggested guidelines** for a test program to confirm precision and bias of HWTD test procedures were:

- Select a commonly used marginal aggregate and an asphalt binder readily available from a known source.
- Obtain materials for test validation and certification. Obtain and store enough materials in sufficient quantities for present and future tests to minimize the effect of changing materials.
- Ship aggregate component to each participant laboratory. The sample size should be twice the amount needed to run the test.
- Ship the asphalt binders in approved containers to the laboratories. The asphalt binder is to be the type used during the initial mixture design stage.
- Compact the specimens to an air void level of 7.0 percent +/- 1%. The air voids should be reported with the test results for each specimen.
- Have the laboratories prepare, compact and run the test and fill out a HWTD Data form.
- Report the mean test results and Standard Deviation.
- Modify guidelines as the testing progresses if necessary.

The HWTD test data form is shown as a reference. Each laboratory was asked to keep a complete record of their procedure, fill in the blanks and make comments on the areas they felt were causing the results to vary. The results were then compiled, concerns and comments addressed and a new protocol for each succeeding test round was suggested. **The HWDT test data detail form used by each laboratory is included at the end of this paper for informational purposes only**.

Data Results for all the ILS tests are shown in Table A.

***Results and Findings*:**

Five ILS test cycles were necessary to obtain enough information to lower the variability. Three initial testing cycles and two additional validation cycles were run to insure repeatability.

Background of ILS Test Cycle #1

The first test cycle was initiated in June 2005 using the modification to AASHTO by a DOT's Materials Manual Part 8-990 to reflect procedure each laboratory had been using previously. The individual laboratories were to prepare the samples themselves and run the tests, as they understood the procedures. The results used for analysis were the maximum impression in millimeters, since that is the criteria the DOT had chosen for acceptance of the mixture.

Summary of Hamburg results Test Cycle #1

The individual laboratories were to compact the test specimen slabs from windrow gathered samples from the given aggregate source. The aggregate from this source is marginal when tested against aggregate specifications. The asphalt binder was obtain from the supplier to the given aggregate hot plant and certified by the Central laboratory for the testing.

The concerns reported by the participant laboratories on the sample as they prepared and ran the specimens were:

- What size of specimen is needed for 93% compaction?
- Do the plates need to be heated to compaction temperature prior to compaction of the specimen?
- Is it necessary to obtain a uniformly compacted specimen?
- Is sealing the edges properly around the mold necessary?
- When to place specimens in the wheel-tracker device to equalize temperature.
- When time limits are placed on the test, from start of heating of sample for compaction to start of wheel-tracker cycles, it makes the testing cycle at night or odd hours.
- Is the 7% voids only for laboratory compacted specimens?
- Time from oven to compaction start may result in a drop in temperature.

As a result of these concerns and observations, the procedures were modified for the next test cycle.

Background of Test Cycle #2

After the input from the first test cycle, the second test cycle specimens were prepared using the original materials. However, this time all of the specimens were all compacted at DOT Central Laboratory and then delivered to the individual participants to run the Hamburg Wheel-Tracker test. The instructions were as follows:

a. Prepare the specimens with Plaster of Paris in the testing trays the afternoon or prior to quitting time before testing the next morning.

b. Record the time the slabs are submerged under water prior to the testing starting.

Summary of Hamburg results Test Cycle # 2

The Central Laboratory was to compact the slabs from windrow samples from the given aggregate source and then deliver them to the individual laboratories to run the test. The range of the test values in the first test cycle was 15.98 mm and the range in the second test cycle was 4.12 mm. This was a decrease in range value of 11.86 mm. **A decrease of almost 75%.This essentially verified that the variation was in the compaction procedures used by the participating laboratories.**

Background of Test Cycle # 3

It was observed from test cycle #2 the maintaining temperature in the linear kneading compactor, and the amount of material for the specimen mold, was critical to uniform compaction. When the mold plates were preheated and mold heaters were not present in the compactor, it was observed that it took longer to place the material and start the compaction and therefore more temperature was lost. Cooler temperatures caused more density variation resulting in greater test variability. The ability to provide the right amount of material also became crucial to the compaction effort and desired density.

Based on the experience from preparation of the specimens and dialogue of the preparers, it was believed that these two factors along with the heating of the molds were causing most of the deviations in test results. The amount of material was initially being obtained by trial and error, with poor results. The method was then changed to a calculation of the mold volume (V) with the compaction roller running hard against the top of the mold, determining the maximum theoretical specific gravity (Gs), determining a density factor (.93) and obtaining the weight of the specimen(W) using the formula $V*Gs*0.93=W$. The weighed material is placed in the mold and the specimen compacted until the roller is on the rim of the mold. The density of the specimen is then verified. With these adjustments in the initial heating and compaction procedure the individual laboratories prepared the specimens to run test cycle #3.

Summary of Hamburg results Test Cycle # 3

The individual laboratories were to compact the specimens from Central Laboratory prepared samples from the given aggregate source.

Validation Tests of Procedures used for compaction

Background of Validation Test Cycles # 4 and # 5

The next two validation test cycles are data gathering, to find out if the changes have allowed for more uniform results and that the testing could be replicated. Test Cycle # 4 and # 5 were performed with the same criteria as Test Cycle # 3.

Table A Results of Test and Validation Test Cycles

TC-1	Central	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5	Lab 6	Lab 7	Lab 8	Range	C of Var.
Lt. Max	4.06	19.90	15.30	4.50	9.04	16.35	X	X	X		
Rt. Max	4.61	20.04	8.42	9.50	6.11	13.14	X	X	X		
										15.98	0.54
TC-2											
Lt. Max (1)	5.13	3.33	4.97	5.03	5.67	4.65	X	X	X		
Rt. Max (1)	4.23	5.97	4.33	4.56	4.25	4.49	X	X	X		
Lt. Max (2)	7.45										
Rt. Max (2)	4.09										
Lt. Max (3)	3.47										
Rt. Max (3)	4.57										
Lt. Max (4)	3.64										
Rt. Max (4)	3.87										
Lt. Max (5)	3.95										
Rt. Max (5)	4.34										
										4.12	0.21
TC-3											
Lt. Max	2.60	X	3.24	3.35	4.28	X	7.74	7.49	3.08		
Rt. Max	2.58	X	3.23	3.72	4.61	X	9.21	9.46	4.27		
										6.88	0.50
VTTC-4											
Lt. Max (1)	6.67	6.34	4.64	8.87	10.91	6.09	11.65	8.65	X		
Rt. Max (1)	5.04	13.57	3.90	6.75	9.95	9.40	4.59	7.89	X		
Lt. Max (2)	6.58										
Rt. Max (2)	6.74										
Lt. Max (3)	7.14										

Rt. Max (3)	5.30										
										7.75	0.30
VTTC-5											
Lt. Max (1)	6.22	9.10	5.68	3.70	7.70	6.42	20.76	0.00	3.48		
Rt. Max (1)	5.69	5.32	7.92	4.28	5.82	8.47	9.46	4.93	3.00		
Lt. Max (2)	8.00										
Rt. Max (2)	4.66										
										5.76	0.27

X = Invalid test data or data not submitted. Units are in millimeters. Shaded numbers were outliers and not used.

SUMMARY of Test Cycle Tests 1-3 and Validation Tests Cycles 4&5:

TC # 1	**TC # 2**	**TC # 3**	**VTTC # 4**	**VTTC # 5**
Mean= 10.91mm	**M = 4.60mm**	**M = 4.92mm**	**M = 7.22mm**	**M = 6.46mm**
Std. Dev.= 5.88	**SD = 0.95**	**SD = 2.45**	**SD = 2.20**	**SD = 1.77**
Range = 15.98	**Range = 4.12**	**Range = 6.88**	**Range = 7.75**	**Range = 5.76**
C of V = 0.54	**C of V = 0.21**	**C of V = 0.50**	**C of V = 0.30**	**C of V = 0.27**

ANALYSIS OF VARIABILITY IN HWTD RESULTS

From the results of Test Cycle # 2 an analysis was performed to determine if there were any differences between results of the Central Laboratory and the results of the other eight participating laboratories. Analysis shows that there were no statistical differences between the Central laboratory tests results and the other laboratory test results.

Analysis of TC # 2 Central laboratory results and other eight laboratory results:

Central laboratory results: 5.13, 4.23, 7.45, 4.09, 3.74, 4.57, 3.64, 3.87, 3.95 and 4.34.

Other Laboratory results: 3.33, 5.97, 4.97, 4.33, 5.03, 4.56, 5.67, 4.25, 4.65 and 4.49

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance	Range
Central	10	45.01	4.501	1.265277	3.81
Other Labs	10	47.25	4.725	0.556872	2.64

ANOVA

Source of Variation	SS	df	MS	F	P-value	F-Crit.
Between Groups	0.25088	1	0.25088	0.275367	0.606157	4.413863
Within Groups	16.39934	18	0.911074			
Total	**16.65022**	**19**				

Result: Since F crit >> F and P >> than 0.05, the Null Hypothesis cannot be rejected.

Conclusion:

There is no difference between Central Laboratory running the HWTD on the Central Laboratory prepared specimen and the other eight laboratories running a Central Laboratory prepared specimen. This implies that the differences are not in the Hamburg Wheel Tracker Device. Any of the results of specimens run at Central Laboratory, using the new protocol, can be combined with the results of any specimens run in other labs, on Central Laboratory prepared specimens, to obtain the precision of test for a single lab about the average rut depth.

Additional results run under the new protocol after Test Cycle Two by the Central Laboratory. The results of TC#3 and VTTC #4 & VTTC#5 ran by Central.

Central: 2.60, 2.58, 6.67, 5.04, 6.58, 6.74, 7.14, 5.30, 6.22, 5.69, 8.00 and 4.66.

Mean: 5.60

Range: 5.42

Standard Deviation: 1.34

Variance: 0.24

Conclusion: For a test mean of 5.6, a single laboratory precision SD should be +/- 1.34. If the variance (1S %) = SD/Mean + 0.24 (24%) and if the mean = 10, the SD_{10} = 2.4. These results are certainly consistent with TC#3.VT# 4 and VT# 5 results present an even tighter grouping.

Thus the precision statement for a single lab (1S %) = 24 % and for multiple labs (2S %) = (1S %)*2.8 = 67%.

Summary of Observations

The specimens, from those individual testing laboratories that did not following the instructions in the Manual of Instruction, resulted in tests which gave erroneous or outlier answers. The tests from one lab were only run for

10,000 passes instead of the 20,000 passes that the other labs were completing and therefore the tests were invalid. The location of equipment in relation to the oven is an important factor in preventing cooling of the specimens before compaction. The ability to load the Linear Kneading Compactor specimen molds from both sides of the compactor eliminates a time factor between the concurrently processed specimens. Heating of the compaction plates and limiting the time from the oven to start of compaction reduces the loss of heat and the possibility of a heat sink by the Linear Kneading Compactor. The care of calculating and measuring the amount of material for loading the compaction molds is essential to obtaining a uniform density across the specimen. The procedure for preparing and placing the specimens in the Hamburg Wheel Tracker Device is also important to the consistent results that were being sought in the ruggedness tests. The time the specimen is in the water and the temperature of the water were factors in the process that could not be over looked to standardize the procedure. Temperatures of the prepared specimens were taken before placing them in the water and time logged until they were at the testing temperature. The time for the specimens to come to uniform temperature was determined to be one-half an hour when the water in the Hamburg Wheel Tracker Device was at testing temperature. It is important to have a way to heat the water (a hot water heater) to keep the time of the test to a reasonable period of time for the specimen. The statistical data shows that the equipment is capable of performing the compaction, rutting and moisture damage test as designed and that the errors that were being introduced were from the preparation and handling of the specimens. This was evident from the 75% drop in range values from TC#1 testing to TC#2 testing results. When specific limits were adhered to the results became more uniform (Romero, 2008).

Conclusions

The compaction process can introduce variability by non-uniform density across the specimen. Calculation and measuring or weighing of material for the mold is extremely important. Compaction to top rim of mold is necessary for uniform compaction. Heating of the compaction plates and the time from oven to loading and compaction of molds is critical. With proper compaction procedures, the HWTD will provide consistent results. Rutting and moisture susceptibility results will be reliable.

Precision and bias for this procedure can be stated at (1S%= 24% and 2S%= 67%).

Recommendations

The placement and installation of Linear Kneading Compactor should be done to insure the shortest distance from the oven to the compactor is maintained, to allow a maximum temperature in the mix. Training for technicians is necessary, to insure each technician maintains consistency in procedure. Adequate compaction temperature should be maintained by being efficient in movements and preparation. Uniformly load the compaction mold with the proper amount of calculated material to insure proper densification of the specimen. Follow the Manual of Instruction to insure consistency. It is imperative to take compaction variability out of the test so the materials can be evaluated correctly, as the HWTD is very consistent in the procedure. Density should be within +/- 1/4% across the specimen to achieve accurate results. Density between labs should be with +/- 1/2%.

FOR INFORMATION ONLY

Hamburg Wheel Tracker Device Test Data report form

Lab: Date Test begins: Technician:

Sample heated for combination and splitting

Begin:

Remove from oven: Time Temp

Comments

Did you hold the sample at low temp? Explain.

Slab Preparation Date:

Reheat

Slab # 1 Begin:
Remove from oven Time Temp

Slab # 2 Begin: Time Temp

Remove from oven Time
Temperature

How did you heat the plates? How did you heat the molds?

Comments:

Compaction

Slab # 1: Begin Time End Tim
Size H/W/T
Slab # 2: Begin Time End Tim
Size H/W/T
Temperature
How did you determine the temperature at the beginning of compaction?
How did you determine the temperature at the end of compaction?
Comments:
Cooling
Slab # 1: Begin Time End Tim
Slab # 2: Begin Time End Tim
Comments: (any special handling)
Set Slab in Mounting Tray
Slab # 1: Begin Time End Tim
Slab # 2: Begin Time End Tim
Comments: (centering techniques)
Hamburg Wheel Tracker Test Date:
Time tank is filled:
Time tank reaches temperature:
Time slabs are placed in device:
Micro Control LVDT readout:
Time of first tracking cycle:
Time of end tracking cycle:
Comments:
Other comments on the procedure:

References

Aschenbrener, T. and G. Currier. *Influence of Testing Variables on the Results from the Hamburg Wheel-Tracking Device.* Report CDOT-DTD-R-93-22, Colorado Department of Transportation, Denver, Colo., Dec. 1993

Izzo, R.P., and Tahmoressi, M. *Testing Repeatability of the Hamburg Wheel Tracking Device and Replicating Wheel Tracking Devices among Different Laboratories.* Journal of the Association of Asphalt Paving Technologists, Vol. 68, pp. 589-612, 1999.

Izzo, R.P., and M. Tahmoressi., *Comparative Analysis of Superpave Gyratory Compacted*

Specimens with Linear Kneading Compacted Slabs using the Hamburg Wheel-Tracking Device. Texas Department of Transportation, Bituminous Section, Materials and Tests Division, Austin, 1997.

Izzo, R.P., and M. Tahmoressi. *Comparative Analysis of Superpave Gyratory Compacted*

Specimens with Linear Kneading Compacted Slabs using the Hamburg Wheel-Tracking Device. Texas Department of Transportation, Bituminous Section, Materials and Tests Division, Austin, 1997.

Public Roads, *Volumes- July and August* 1998.
http://www.tfhrc.gov/pubrds/julaug98/evaluating.htm

Romero, P., VanFrank, K., and Nielson, J. *Effect of Temperature on the Moisture Susceptibility of Hot-Mix Asphalt.* Presented at the 45th Petersen Asphalt Conference. Jul 2008. http://www.petersenasphaltconference.org/

Romero, P. and VanFrank, K. *Asphalt Mixture Performance Testing; Superpave Requirements and UDOT's Response.* 2010 Utah DOT Engineering Conference.

Solaimanian M., H. J. (2003). *Topic 3- Test Methods to Predict Moisture Sensitivity of Hot Mix Asphalt Pavements.* A National Seminar (pp. 76-113). San Diego, California: Transportation Research Board.