Evaluation of Various Hamburg Wheel-Tracking Devices and AASHTO T 324 Specification for Rutting Testing of Asphalt Mixtures

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Outline

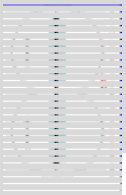
- Background
  - NCHRP Project 20-07/Task 361
- Objective
- Methodology
- Review Available Hamburg Test Equipment
- Experimental Program
- Summary
- Recommended changes to AASHTO T-324

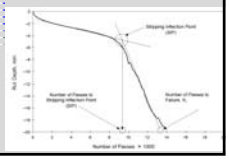
Acknowledgement

- **NCHRP**
  - **Dr. Ed Harrigan**
  - **Technical Review Panel**
- **Louisiana DOTD**
- **Research Group**
  - **Mostafa A. Elseifi**
  - **Wei Cao**
  - **Amar Raghavendra**
  - **Mengqiu Ye**

Background

- HWTT device is a laboratory-controlled rut depth test that uses loaded wheel to apply a moving load on compacted asphalt mixture specimens to simulate traffic load applied on asphalt pavements
- Helmut-Wind (1970s) of Hamburg proposed a test method
  - rutting and stripping susceptibility
  - 8" Diameter x 1.85"
  - 158 ± 1.0 lbs
  - 52 ± 2 passes / minute
- Agency specification
  - Water Temperature
  - Number of Passes
  - Rut Depth Measurement Locations
  - Maximum Rut Depth
  - Stripping Inflection Point
- Standard Test Method
  - AASHTO T-324
  - State DOTs (CA, CO, IA, IL, LA, MT, OK, TX, UT, WA, WI, LA,…)
- Concern with AASHTO T-324-11
  - Task force SOM TS 2C





Objective

- *Document* capabilities of available commercial Hamburg test equipment,
- *Determine* Hamburg test equipment capabilities, components, or design features
  - proper testing
  - Accurate and reproducible results
- *Provide* proposed revisions with commentary to AASHTO T-324 to enable the use of a performance type specification for Hamburg test equipment

Methodology

- Review Available Hamburg Test Equipment Specifications
- Conduct Engineering Analysis of Existing Hamburg Test Systems:
  - Evaluate capability of existing equipment to accurately *measure*, *control*, and *maintain* desired test conditions
  - identify issues with AASHTO T 324 procedure
    - » Loading mechanisms;
    - » Temperature measurement and control system;
    - » Impression measurement system;
    - » Specimen dimensions; and
    - » Data collection and reporting.
- Propose Revisions to AASHTO T 324
- Propose A Framework for Future Laboratory Evaluation

Review Available Hamburg Test Equipment

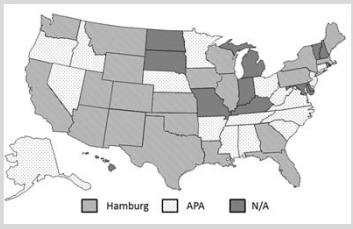
- Nationwide Survey:
  - state agencies on the use of HWTs
  - 100% response rate
  - 13 questions
    - Types of HWTT
    - Agency Specifications
    - Calibrations/Verifications Procedures
    - Studies/Research Reports

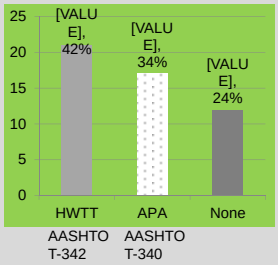
Review Available Hamburg Test Equipment

- Nationwide Survey:
  - state agencies on the use of HWTs
  - 100% response rate
  - 13 questions
    - What type of LWT do you use? (Please choose one or more manufacturers)
    - Does your machine have a single wheel or two wheels?
    - Which specification do you use? (Please choose one)
    - How often do you calibrate your LWT (months)?
    - What does the calibration include?
    - Is your laboratory AMRL certified for AASHTO T-324?
    - What test temperature(s) do you use? (°C)
    - What is the acceptance criteria used in your state? Please attach a copy of your specifications.
    - What type of specimens do you use?
    - Does you agency specify requirements for the Hamburg test specimen fabrication?
    - Do you have test data that you can share? (Please choose one)
    - How is the result of the Hamburg test reported?
    - How do you use the data you obtain from the machine

Review Available Hamburg Test Equipment

- Nationwide Survey
  - state agencies on the use of HWTs





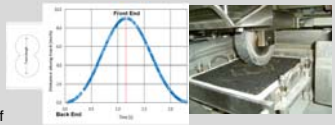
Review Available Hamburg Test Equipment

- Five commercially available HWTT equipment
- Four vendors (A, B, C, D)
  - AASHTO T-324

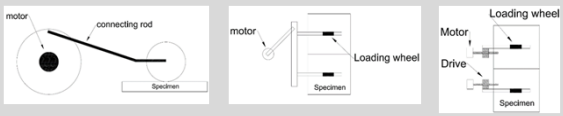
Review of Test Equipment Specifications
AASHTO T-324-14

- Loading mechanisms;
- Temperature measurement and control system;
- Impression measurement system;
- Specimen dimensions; and
- Data collection and reporting.

Test Equipment Specifications
AASHTO T-324-14



- Loading mechanism
  - Load (dead weight, pneumatic),
  - Sinusoidal Wheel Speed,
  - Speed on front half = speed on rear half
  - Drive (Slider-crank, Scotch-yoke, etc.)
  - Consequences of non-sinusoidal wheel speed
    - time of loading of *front half* of specimen < *rear half* of the specimen;
    - average speed on *front half* of specimen > average speed on *rear half* of specimen; and
    - maximum speed is not achieved at mid-point of stroke, but rather at some point on the front specimen.



Review of Test Equipment Specifications
AASHTO T-324-14

- Temperature measurement and control system

Vendor		A		B	C	D
		Standard model	Economy model			
Sensor	Type	Type T	Type T	Type J	RTD	RTD
	Range (°C)	-200 to 350	-200 to 350	0 to 760	Room temp to 70	-25 to 199
	Number	2	1	1	2	3
	Location	Next to each specimen	Right side	Bottom tank	Next to each specimen	One between specimens, two to be positioned by user
Tank volume (gal)		40	18	15 (2 tanks)	34 (3 tanks)	22.9
Heater (kW)		2 x 4.5 Immersion Heaters	4.5	4.5	4.0	2 x 1.5
Circulating pump (gpm)		34	9	11	10	17
Temperature control tolerance (± °C)		0.3	0.3	1	1	0.5

Review of Test Equipment Specifications
AASHTO T-324-14

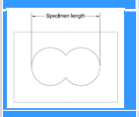
- Impression measurement system

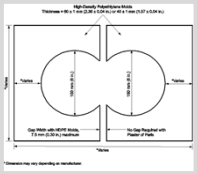
Vendor	A		B	C	D
	Standard model	Economy model			
Sensor type	LVDT	LVDT	Magnetostrictive	LVDT	Potentiometric position sensor
Range (mm.)	50.8	50.8	101.6	50.8	50.0
Tolerance (± mm)	0.15	0.15	0.0762	0.1	0.045
Location	Mounted on side of specimen	Mounted on side of specimen	Top of cylinder	Attached to back of loading arm	Mounted on side of frame in line with wheel

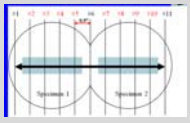
Requirement: Linear Variable Differential Transformer to measure the rut depth The minimum range of this sensor is specified as 20 mm, with an accuracy requirement of 0.15 mm

Review of Test Equipment Specifications
AASHTO T-324-14

- Cylindrical Specimen: length and track length

Vendor	A		B	C	D
	Standard model	Economy model			
	10.671 inch	10.671 inch	10.100 inch	10.700 inch	10.700 inch
	9.000 inch	9.000 inch	9.000 inch	9.000 inch	9.060 inch

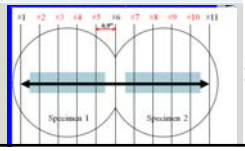


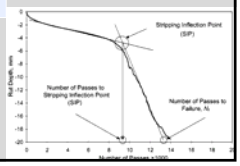


Review of Test Equipment Specifications
AASHTO T-324-14

- Data collection and reporting

Vendor	A		B	C	D
	Standard model	Economy model			
Number of data points collected across specimen	11	11	5	Selectable up to 21	227
Range (± from midpoint), inch	4.5	4.5	4.5	4.5	4.45
A/D resolution (bit)	16	16	12	17	16





Experimental Program

- Identify issues with different aspects of AASHTO T 324 standard procedure:
  - Wheel position waveform, frequency, and maximum speed;
  - Impression measurement system;
  - Temperature measurement and control system;
  - Wheel dimensions and loads;
  - Specimen and track length;
  - Free Circulating Water on Mounting System; and
  - Data collection and reporting.

Experimental Program

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  - Wheel position waveform, frequency, and maximum speed;
  - Impression measurement system;
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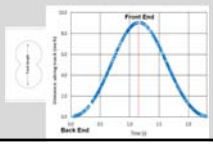
  - Wheel dimensions and loads;
  - Specimen and track length;
  - Free Circulating Water on Mounting System; and
  - Data collection and reporting.

Experimental Program
Wheel position waveform, frequency, and maximum speed

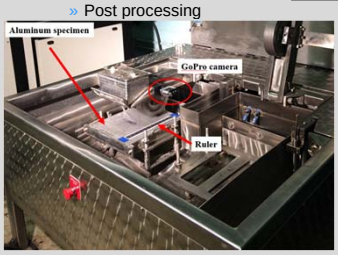
- Section 5.1: *Movement of wheel over the specimen*
  - *wheel is required to reciprocate over specimen such that its position varies sinusoidally over time.*
  - *Frequency of movement is specified to be 52 ± 2 passes per minute.*
  - *Maximum speed is specified to be 0.305 m/s (1 ft/s) and is expected to be reached at the midpoint of the specimen.*
- Two approaches considered to record position of wheel as a function of time.
  - Accelerometer
  - Video camera
    - » Capture images
    - » analyze

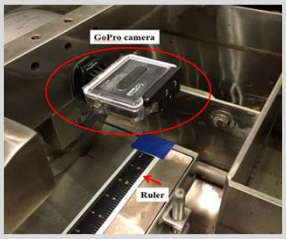


Experimental Program
Wheel position waveform, frequency, and maximum speed

- Video camera
  - GoPro
    - » Capture images
    - » Post processing

Ruler type
camera mounting systems
camera-to-specimen distances
Light source

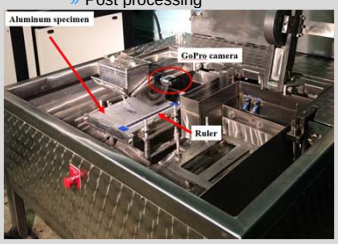


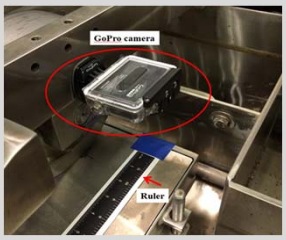


Experimental Program
Wheel position waveform, frequency, and maximum speed

- Video camera
  - GoPro
    - » Capture images, 240 fps
    - » Post processing

non-reflective paper ruler (1/16 in. subdivision),
adhesive mount,
focus distance of 5 in.,
Professional lighting source (Lowel DP).

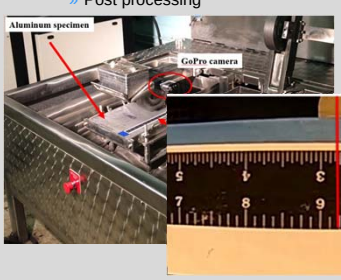


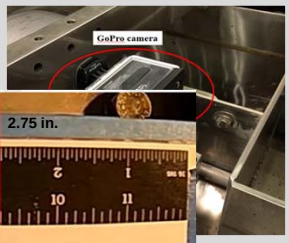


Experimental Program
Wheel position waveform, frequency, and maximum speed

- Video camera
  - GoPro
    - » Capture images, 240 fps
    - » Post processing

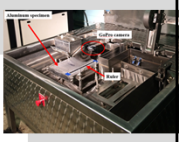
non-reflective paper ruler (1/16 in. subdivision),
adhesive mount, smooth Aluminum slab
focus distance of 5 in.,
Professional lighting source (Lowel DP).

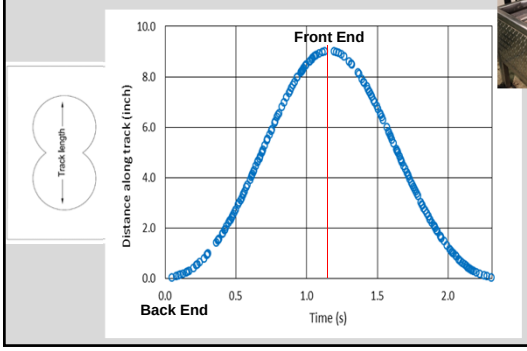




Experimental Program
Wheel position waveform, frequency, and maximum speed

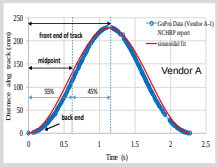
- Wheel position as a function of time

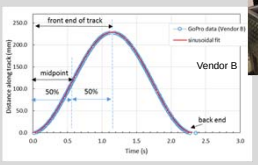


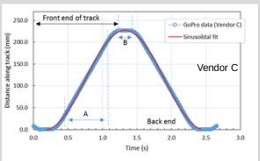


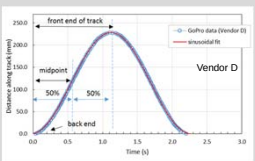
Experimental Program
Wheel position waveform, frequency, and maximum speed

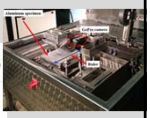
- Wheel Position Analysis





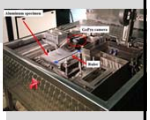


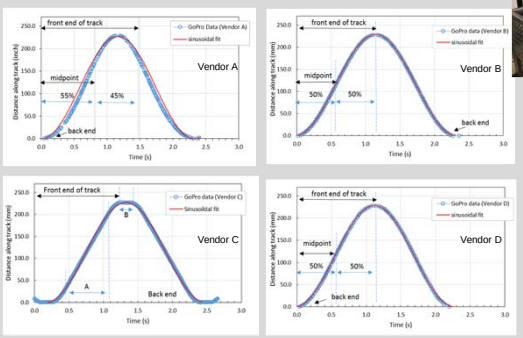




Experimental Program
Wheel position waveform, frequency, and maximum speed

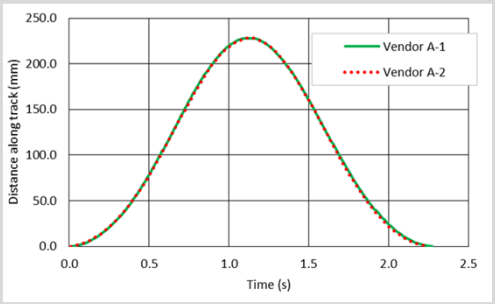
- Wheel Position Analysis





Experimental Program
Wheel position waveform, frequency, and maximum speed

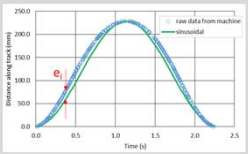
- Wheel Position Analysis -- Repeatability



Experimental Program
Wheel position waveform, frequency, and maximum speed

- Wheel Position Analysis – Deviation from pure-sinusoidal waveform
- Root Mean Square Error

$$RMSE = \sqrt{\frac{\sum e_i^2}{n}}$$



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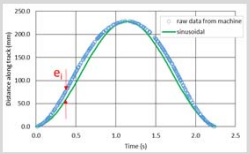


- Absolute Mean Deviation

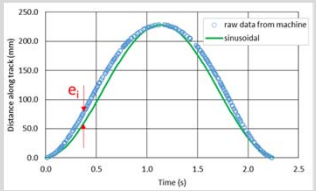
$$AMD = \frac{1}{n}\sum_{i=1}^{n}|x_{mi} - x_{si}|$$

- x_{mi} = measured distance along track, and
- x_{si} = theoretical distance along track for a sinusoidal wave.

Experimental Program
Wheel position waveform, frequency, and maximum speed

- Wheel Position Analysis

	Vendor A-1	Vendor A-2	Vendor A-3	Vendor B	Vendor C	Vendor D
Waveform RMSE (mm)	13.21	14.48	13.21	1.02	3.05	1.02
Waveform AMD (mm)	11.43	14.48	13.20	0.88	3.05	1.01



Experimental Program
Wheel position waveform, frequency, and maximum speed

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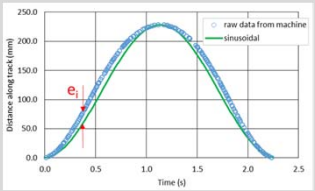


Experimental Program
Wheel position waveform, frequency, and maximum speed

- Wheel Position Analysis

		Vendor A-1	Vendor A-2	Vendor A-3	Vendor B	Vendor C	Vendor D
Waveform RMSE (mm)		13.21	14.48	13.21	1.02	3.05	1.02
Waveform AMD (mm)		11.43	14.48	13.20	0.88	3.05	1.01
Frequency (passes per minute)		51.8	52	52	51.2	52.1	52.2
Speed	Maximum (m/s)	0.33	0.33	0.30	0.27	0.31	0.31
	Distance of maximum speed location from midpoint (mm)	17.02	8.89	14.22	0.00	0.00	0.51

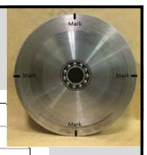
Sec 5.1: Maximum speed is specified to be 0.305 m/s (1 ft/s) and is expected to be reached at the midpoint of the specimen

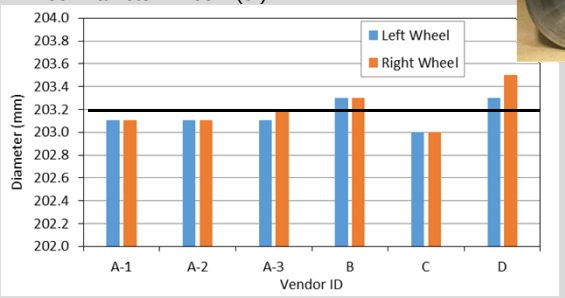
Experimental Program

- Identify issues with different aspects of AASHTO T 324 standard procedure:
  - Wheel position waveform, frequency, and maximum speed;
  - Impression measurement system;
  - Temperature measurement and control system;
  - Wheel dimensions and loads;
  - Specimen and track length; and
  - Data collection and reporting.

Experimental Program
Wheel Dimensions

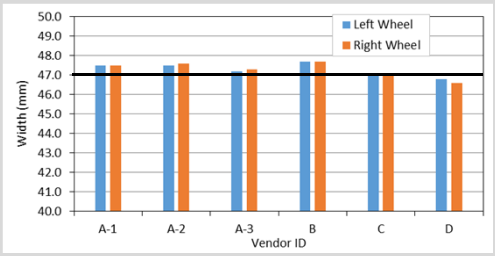
- Wheel Diameter = 203.2 (8")





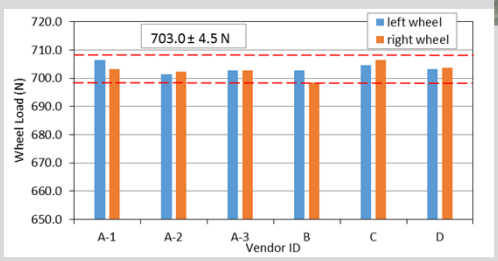
Experimental Program
Wheel Dimensions

- Wheel Thickness = 47 mm (1.85")



Experimental Program
Wheel Load

- Wheel Load = 703 ± 4.5 N (158 ± 1 lbs.)



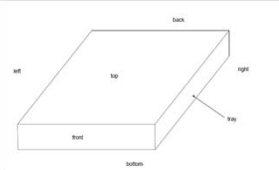
Experimental Program

- Identify issues with different aspects of AASHTO T 324 standard procedure:
  - Wheel position waveform, frequency, and maximum speed;
  - Impression measurement system;
  - Temperature measurement and control system;
  - Wheel dimensions and loads;
  - Specimen and track length;
  - Free Circulating Water on Mounting System; and
  - Data collection and reporting.

Experimental Program

Free Circulating Water on Mounting System

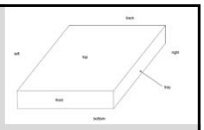
- Sections 5.5 and 5.6 of AASHTO T-324 *requires that the specimen mounting system (slab or cylinder) must suspend the specimen and provide a minimum of 20 mm (0.8 in.) of free circulating water on all sides*



Experimental Program

Free Circulating Water on Mounting System

- Mounting system needs to provide at least 20 mm (0.8 in.) of free circulating water on all sides



Distance, mm	Vendor A-1	Vendor A-2	Vendor A-3	Vendor B	Vendor C	Vendor D
Top	38.1	22.3	34.9	17.5	27.3	20.6
Bottom	108.0	108.0	98.4	22.2	88.6	90.5
Left	44.5	47.6	6.4	73.0	71.2	71.4
Right	227.0	227.0	0.0	0.0	108.0	69.9
Front	257.2	266.7	217.2	98.4	70.62	196.9
Back	231.8	231.8	101.6	152.4	179.8	82.6

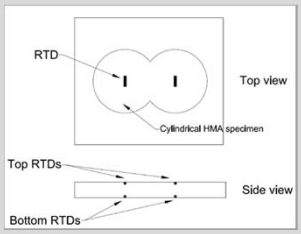
Experimental Program

- Identify issues with different aspects of AASHTO T 324 standard procedure:
  - Wheel position waveform, frequency, and maximum speed;
  - Impression measurement system;
  - Temperature measurement and control system;
  - Wheel dimensions and loads;
  - Specimen and track length; and
  - Data collection and reporting.

Experimental Program

Temperature measurement and control system

- Section 5.2: Specifies that A water bath capable of controlling the temperature within ±1.0°C over a range of 25 to 70°C with a mechanical circulating system stabilizing the temperature within the specimen tank
- T -324 verification requirements
  - temperature in the bath at four locations
  - preconditioning time = 30 minutes

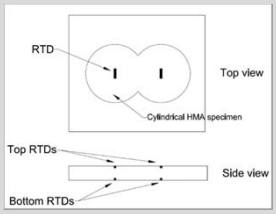


Experimental Program

Temperature measurement and control system

- Four RTDs on each SGC
  - Two at top
  - Two at bottom
  - DATAQ DI-718Bx data acquisition
  - 8 Hz

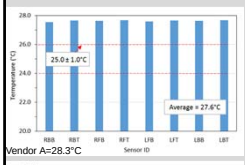
	Side	Specimen	Sensor position	Sensor ID
1	Left	Front	Top	LFT
2	Left	Front	Bottom	LFB
3	Left	Back	Top	LBT
4	Left	Back	Bottom	LBB
5	Right	Front	Top	RFT
6	Right	Front	Bottom	RFB
7	Right	Back	Top	RBT
8	Right	Back	Bottom	RBB



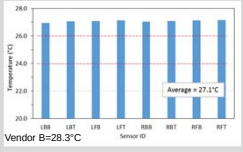
Experimental Program

Temperature Measurement and Control System – 25°C

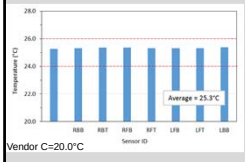
- temperatures after 30 minutes conditioning



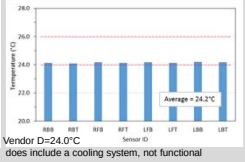
Vendor A=28.3°C



Vendor B=28.3°C

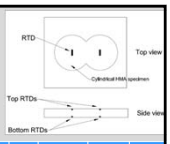


Vendor C=20.0°C



Vendor D=24.0°C

does include a cooling system, not functional

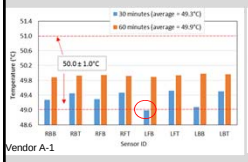


	Side	Specimen	Sensor position	Sensor ID
1	Left	Front	Top	LFT
2	Left	Front	Bottom	LFB
3	Left	Back	Top	LBT
4	Left	Back	Bottom	LBB
5	Right	Front	Top	RFT
6	Right	Front	Bottom	RFB
7	Right	Back	Top	RBT
8	Right	Back	Bottom	RBB

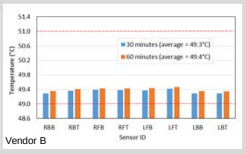
Experimental Program

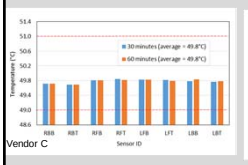
Temperature Measurement and Control System – 50°C

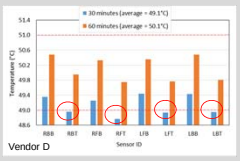
- temperatures after 30 and 60 minutes conditioning

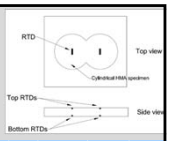


Vendor A-1


Vendor B


Vendor C


Vendor D



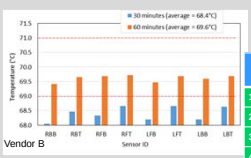
	Side	Specimen	Sensor position	Sensor ID
1	Left	Front	Top	LFT
2	Left	Front	Bottom	LFB
3	Left	Back	Top	LBT
4	Left	Back	Bottom	LBB
5	Right	Front	Top	RFT
6	Right	Front	Bottom	RFB
7	Right	Back	Top	RBT
8	Right	Back	Bottom	RBB

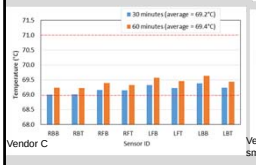
Experimental Program

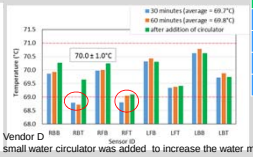
Temperature Measurement and Control System – 70°C

- temperatures after 30 and 60 minutes conditioning

Vendor A

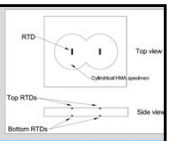

Vendor B


Vendor C



Vendor D

small water circulator was added to increase the water movement



	Side	Specimen	Sensor position	Sensor ID
1	Left	Front	Top	LFT
2	Left	Front	Bottom	LFB
3	Left	Back	Top	LBT
4	Left	Back	Bottom	LBB
5	Right	Front	Top	RFT
6	Right	Front	Bottom	RFB
7	Right	Back	Top	RBT
8	Right	Back	Bottom	RBB

Experimental Program

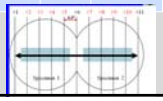
- Identify issues with different aspects of AASHTO T 324 standard procedure:
  - Wheel position waveform, frequency, and maximum speed;
  - Impression measurement system;
  - Temperature measurement and control system;
  - Wheel dimensions and loads;
  - Specimen and track length; and
  - Data collection and reporting.

Experimental Program

Impression measurement system

- Calibrated LVDTs
- Developed calibration specimens
  - Verify the locations of impression readings
  - Curvature
    - » depression at any location along track is known
    - » Max depth = 0.75" at center

Vendor	A		B	C	D
	Standard model	Economy model			
Number of data points collected across specimen	11	11	5	Selectable up to 21	227
Range (± from midpoint), inch	4.5	4.5	4.5	4.5	4.45



Experimental Program

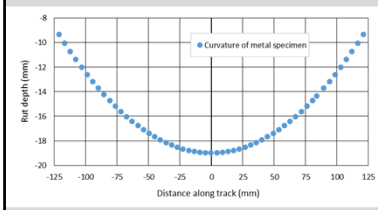
Impression measurement system

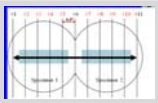
- Verify vendor's calibration of impression measurement systems
- Install Developed calibration specimens
  - Verify the locations of impression readings
  - Curvature
    - » depression at any location along track is known
    - » Max depth = 0.75" at center

Experimental Program

Impression measurement system

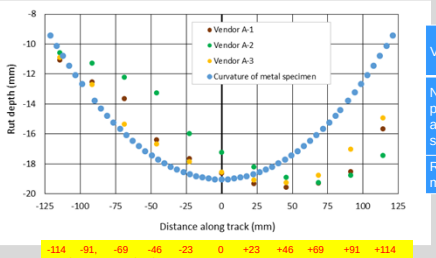
- Reference profile
  - machine LVDT connected to external data acquisition system





Experimental Program
Impression Measurement System

- significant deviations from reference profile, with a marked skew to the right

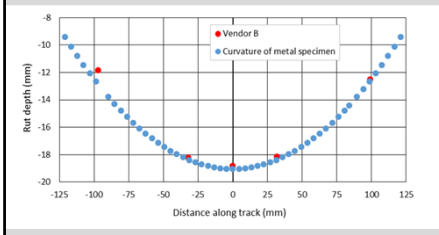


-114 -91, -69 -46 -23 0 +23 +46 +69 +91 +114
Spacing = 22.9mm (0.9")
Total 11

Vendor	A	
	Standard model	Economy model
Number of data points collected across specimen	11	11
Range (± from midpoint), inch	4.5	4.5

Experimental Program
Impression Measurement System

- reasonably good agreement with reference profile

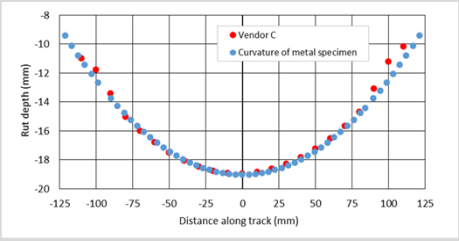


-97 -32 0 32 99

Vendor	B
Number of data points collected across specimen	5
Range (± from midpoint), inch	4.5

Experimental Program
Impression Measurement System

- Good agreement with reference profile: -80 to +80 mm
- Slight deviation outside -80 to + 80mm

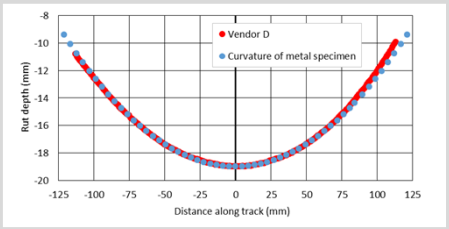


-110, -100, -90, -80, -70, -60, -50, -40, -30, -20, -10, 0, +10, +20, +30, +40, +50, +60, +70, +80, +90, +100, +110
23 equally-spaced locations

Vendor	C
Number of data points collected across specimen	Selectable up to 21
Range (± from midpoint), inch	4.5

Experimental Program
Impression Measurement System

- Good agreement with reference profile



-113 to +113
Total = 227
Spacing = 1 mm

Vendor	D
Number of data points collected across specimen	227
Range (± from midpoint), inch	4.45

Experimental Program
Impression Measurement System

- Deviation from reference profile

Vendor	RMSE (in.)	AMD (in.)
A-1	0.10	0.08
A-2	0.14	0.12
A-3	0.08	0.06
B	0.02	0.01
C	0.02	0.01
D	0.01	0.00

$$RMSE = \sqrt{\frac{\sum e_i^2}{n}}$$

$$AMD = \frac{1}{n}\sum_{i=1}^{n}|x_{mi} - x_{si}|$$

Experimental Program
Impression Measurement System

- Deviation from reference profile

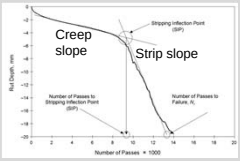
Vendor	RMSE (in.)	AMD (in.)
A-1	0.10	0.08
A-2	0.14	0.12
A-3	0.08	0.06
B	0.02	0.01
C	0.02	0.01
D	0.01	0.00

$$RMSE = \sqrt{\frac{\sum e_i^2}{n}}$$

$$AMD = \frac{1}{n}\sum_{i=1}^{n}|x_{mi} - x_{si}|$$

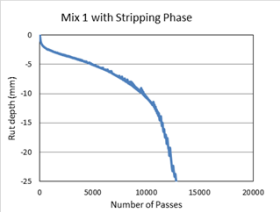
Experimental Program
Data collection and reporting

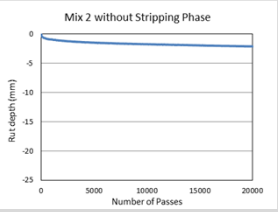
- Section 10: *requires five parameters to be collected and reported to quantify the performance of a mixture to rutting and moisture susceptibility*:
  - Number of passes at maximum impression,
    - » At a fixed maximum impression value (e.g., 12.5mm), an asphalt mixture with a larger number of passes is more resistant to rutting
  - Maximum impression,
    - » obtained at completion of test
  - Creep slope
    - » Inverse of deformation rate in the creep phase.
    - » starts after consolidation phase
    - » ends before stripping starts.
  - Strip slope
    - » inverse of deformation rate at where the rut depth increases tremendously as moisture damage occurs.
  - Stripping Inflection Point (SIP)
    - » occurs where curve has a sudden increase in rut depth



Experimental Program
Data collection and reporting

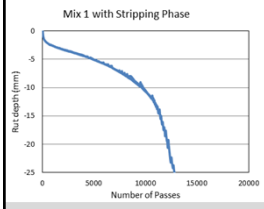
- Section 10: *requires five parameters to be collected and reported to quantify the performance of a mixture to rutting and moisture susceptibility*:
  - There were not sufficient details to allow for consistent analysis and reporting





Experimental Program
Data collection and reporting

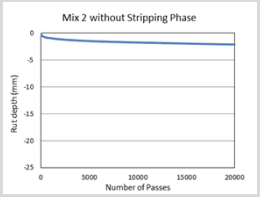
- Section 10: *requires five parameters to be collected and reported to quantify the performance of a mixture to rutting and moisture susceptibility*:
  - There were not sufficient details to allow for consistent analysis and reporting



	Number Of Passes at max impression	Max Impression (mm)	Creep Slope (*10⁻⁴)	Strip Slope (*10⁻⁴)	SIP
Vendor A	12,800	25	N/A	N/A	10,712
Vendor B	N/A	N/A	N/A	N/A	473
Vendor C	12,800	25	64	34	9,471
Vendor D	12,850	26	8	25	9,104
Iowa DOT	12,806	25	4	53	10,552
Oklahoma DOT	N/A	N/A	6	107	11,295

Experimental Program
Data collection and reporting

- Section 10: *requires five parameters to be collected and reported to quantify the performance of a mixture to rutting and moisture susceptibility*:
  - There were not sufficient details to allow for consistent analysis and reporting



	Number Of Passes at max impression	Max Impression (mm)	Creep Slope (*10⁻⁴)	Strip Slope (*10⁻⁴)	SIP
Vendor A	20,000	2.1	N/A	N/A	N/A
Vendor B	20,000	2.1	N/A	N/A	-3,211
Vendor C	20,000	2.1	0.07	0.07	19,892
Vendor D	20,000	2.1	No stripping	No stripping	No stripping
Iowa DOT	20,000	1.9	0.3	0.4	No stripping
Oklahoma DOT	20,000	2.1	1	3	180

Experimental Program
Data collection and reporting

- Section 10: *requires five parameters to be collected and reported to quantify the performance of a mixture to rutting and moisture susceptibility*:
  - There were not sufficient details to allow for consistent analysis and reporting

	Number Of Passes	Max Impression (mm)	Creep Slope	Strip Slope	SIP
Vendor A	Y	Y	N	N	Y
Vendor B	N	N	N	N	Y
Vendor C	Y	Y	Y	Y	Y
Vendor D	Y	Y	Y	Y	Y
Iowa DOT	Y	Y	Y	Y	Y
Oklahoma DOT	N	N	Y	Y	Y

Summary

- Differences between HWT machines evaluated
  - Four vendors
  - Lack of detailed requirements for different aspects of test method
- Waveform
  - Two machines were able to produce a sinusoidal wave
    - » Vendors B and D
- Temperature control system
  - Majority of machines do not have a cooling system
    - » 25°C dependent on the incoming water temperature
  - Average temperatures at end of 30 minutes of conditioning were within the specification limit of 50 ± 1°C (Section 8.9.2),
    - » some locations in HMA specimen were not within specified range.
    - » Longer pre-conditioning time is recommended.

Summary

- Impression measurement
  - Section 5.3: does not specify *locations of deformation* readings or *number of deformation readings.*
    - » discrepancies among manufacturers,
      - 5 locations - 227 locations along the track length.
      - deformation readings are sometimes not being recorded at the pre-determined locations along the track
- Data collection and reporting
  - Differences were observed amongst different analysis methods especially in reporting of the SIP
  - Analysis methods are machine specific
- Based on results, revisions to AASHTO T 324-14 are recommended are recommended
  - ensure repeatable measurements and results from different manufacturers are comparable
- Proposed laboratory experimental program
  - compare results obtained with HWT devices from various vendors when testing the asphalt mixture

Proposed Modifications
AASHTO T-324

- Section 5.1: Define a tolerance for wheel dimensions.
  - Diameter = 203.2 ± 2 mm (8 ± 0.08-in)
  - Width = 47.0 ± 0.5 mm (1.85 ± 0.02-in).
  - Wheel dimensions tend to change with wear and deviation from recommended specifications
  - Necessitate replacement of the loading wheel
- Section 5.1: Define a tolerance for "*wheel be required to reciprocate over the specimen such that its position varies sinusoidally over time*"
  - Root Mean Square Error (RMSE) < 2.54 mm (0.1 in)

Proposed Modifications
AASHTO T-324

- Section 5.1: Define tolerance for maximum speed
  - ± 0.02 m/ s (± 0.066 ft/s)
- Section 5.2**:** Results of temperature experiment revealed shortcomings in this part of the specification
  - Three of four machines evaluated do not have a cooling system,
  - Limitation to set target temperature to 25°C, especially during summer time.
  - Recommended to modify low range to 35°C (95°F).
  - Recommended to modify upper range 64°C (147.2°F).
  - increase the preconditioning time to 45 min

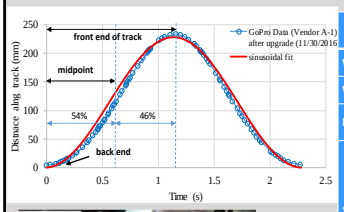
Proposed Modifications
AASHTO T-324

- Section 5.3**:** AASHTO T 324 does not currently specify the locations of the deformation readings or number of deformation readings
  - Recommend deformation readings at 11 locations along the length of the track.
    - » -114, -91, -69, -46, -23, **0**, +23, +46, +69, +91, + 114 mm
    - » with zero being the midpoint of the track.
    - » Midpoint of track should be marked by different manufacturers to assist users.
  - Recommend verification of location of deformation measurements using developed in this study.
    - » Maximum total RMSE at the 11 pre-set locations = 1.27 mm (0.05")

Proposed Modifications
AASHTO T-324

- Section 9.2: Report average rut depth based on five middle deformation sensors
  - Recommend sensors located at
    - » -46, -23, **0**, + 23, + 46 mm
  - Similar to work reported by Schram and Williams
- Section 9.3**:** Recommended method to calculate stripping inflection point (SIP) and other reporting parameters not clearly defined in the current specification

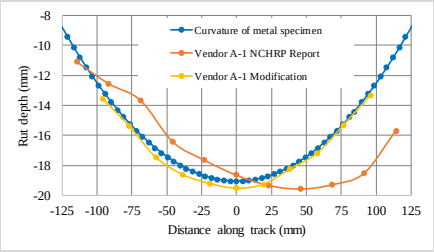
Vendor A-1 Modification
Wheel position waveform, frequency, and maximum speed



		Vendor A-1	Vendor A-1 Modified
Waveform RMSE (mm)		13.21	10.50
Waveform AMD (mm)		11.43	8.55
Frequency (passes per minute)		51.8	52.1
Speed	Maximum (m/s)	0.33	0.335
	Distance of maximum speed location from midpoint (mm)	17.02	9.53

Vendor A-1 Modification

Impression Measurement System



~~-114 -91 -69 -46 -23 0 +23 +46 +69 +91 +114~~
~~-96~~ -76.8 -57.6 ~~-38.4~~ -19.2 0 +19.2 +38.4 +57.6 +76.8 ~~+96~~
~~Spacing = 22.9mm (0.90")~~
Spacing = 19.2mm (0.76")

Total 11

- Deviation from reference profile

Vendor	RMSE (in.)	AMD (in.)
A-1	~~0.10~~	~~0.08~~
	0.02	0.01

THANK YOU