



TRC0201

# **ERSA Wheel Track Testing for Rutting and Stripping**

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Final Report

**FINAL REPORT**

**TRC-0201**

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by

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Fayetteville, Arkansas 72701

July 2005

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**EXECUTIVE SUMMARY**

Permanent deformation (*rutting*) and moisture damage (*stripping*) are common distress mechanisms or failure modes of flexible pavements. While many methods have been developed to assess the susceptibility of a hot-mix asphalt (HMA) mixture to rutting and stripping, wheel-track testing is one of the most common methods. The Evaluator of Rutting and Stripping in Asphalt (ERSA) was developed at the University of Arkansas; it is a wheel-tracking device that is capable of detecting both rutting and stripping failures in HMA mixtures.

Previous research sponsored by the Arkansas State Highway and Transportation Department (AHTD) and the Mack-Blackwell National Rural Transportation Center (MBTC) recommended ERSA testing for assessing the rutting and stripping susceptibility of hot-mix asphalt during mixture design. The research also established operating characteristics and sample preparation techniques for routine wheel-track testing using ERSA.

A second-generation ERSA device was obtained by the University of Arkansas. The second device was validated against the original ERSA unit through a series of split-sample wheel-tracking tests featuring six HMA mixtures. A standard test method, nominally in AASHTO format, was developed for the ERSA device. Guidelines were developed for ERSA rutting/stripping data interpretation.

An additional series of wheel-track tests were conducted to establish HMA mixture acceptance criteria for design. The recommended criteria include: (1) for high-volume (interstate/major traffic routes), a maximum allowable rut depth of 10 mm at 10,000 cycles, with no evidence of stripping (no stripping inflection point); (2) for medium to high traffic volume routes, a maximum rut depth of 10 mm at 7,500 cycles, with no evidence of stripping (no stripping inflection point); and (3) for low to medium traffic volume routes, a maximum rut depth of 10 mm at 5,000 cycles, plus (if stripping is evident) a minimum stripping inflection point of 7,500 cycles.

It is recommended that for a period of one year, AHTD conduct ERSA testing on all mixes verified in the Materials Division central laboratory to validate the recommended performance criteria and assess the impact of implementing ERSA testing on routine HMA mix design activities.

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## CHAPTER ONE

### Problem Statement and Project Objectives

Two primary distress mechanisms experienced by hot-mix asphalt (HMA) pavements include permanent deformation and moisture damage. These two mechanisms may lead to pavement distresses such as *rutting* and *stripping*, may result in a loss of serviceability of the HMA pavement, and can pose certain safety risks as well. A variety of laboratory test methods have been developed to better characterize HMA in terms of its susceptibility to these mechanisms; a common laboratory procedure is wheel tracking. Wheel-tracking devices subject asphalt pavement samples to repeated loads by a moving wheel in order to estimate the anticipated permanent deformation characteristics of the pavement. By performing the test while submerged in water, a measure of moisture susceptibility for the mixes can also be assessed. Such testing in the laboratory would enable potentially poor performing mixes to be identified while still in the design phase. Thus, a mix that is susceptible to the failure modes of rutting and/or stripping could be detected prior to investing the substantial cost for constructing a pavement.

In research projects MBTC 1104 (sponsored by the Mack-Blackwell National Rural Transportation Center, MBTC) and TRC 9804 (sponsored by the Arkansas State Highway and Transportation Department, AHTD) the University of Arkansas developed a wheel-tracking device called the Evaluator of Rutting and Stripping in Asphalt (ERSA). The ERSA is similar to a European device, the Hamburg Wheel-Tracking Device (HWTD). A complete description of the development of ERSA is given by Williams and Hall. (1) Initial studies performed in research project TRC-9804 demonstrated that ERSA could discriminate the rutting and stripping potential of HMA in the laboratory and could provide a basis for HMA mixture acceptance. (1)

The next major step to implement ERSA wheel-tracking testing within HMA mixture design involves the development of a standardized testing procedure and the establishment of HMA acceptance criteria.

### **Project Objectives and Tasks**

The overall objective of this research was to propose criteria for hot-mix asphalt mixture acceptance based on the stripping potential of the mix, as measured by ERSA wheel tracking. To successfully accomplish this objective three primary tasks were identified: (1) develop a standardized testing procedure for ERSA wheel tracking testing; (2) obtain and validate a second ERSA unit for use by AHTD during HMA mixture acceptance procedures; and (3) establish final HMA mixture acceptance criteria. Full descriptions of each of these tasks are given in subsequent chapters of this report.

## CHAPTER TWO

### Background

A very comprehensive literature review regarding HMA laboratory testing and the development of wheel tracking tests was prepared by Williams. (2) This review was subsequently provided in the initial ERSA-related research project final report (TRC-9804). (1) For brevity, only the highlights of these discussions directly concerning rutting, stripping, and ERSA/Hamburg wheel track testing are reproduced here.

#### **Permanent Deformation**

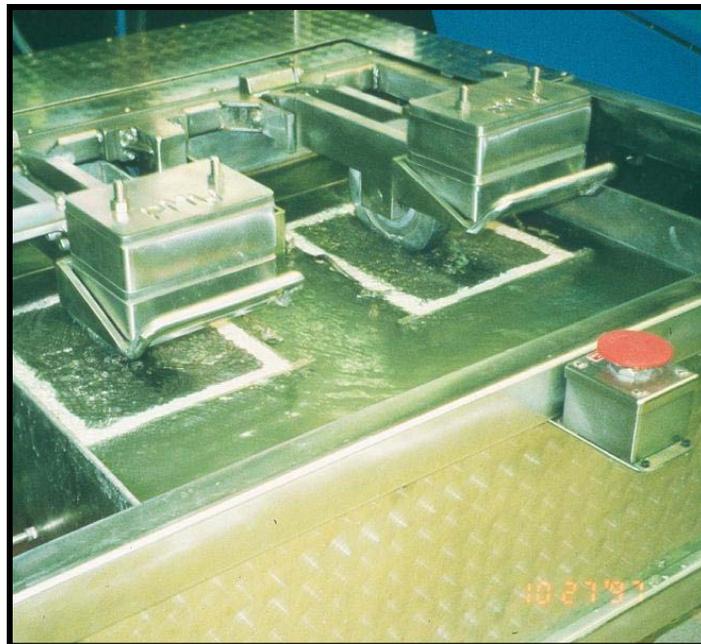
Permanent deformation, or rutting, is the accumulation of small deformations caused mainly by repeated heavy loads. One type of rutting is a structural problem, and can be the result of an under-designed pavement section or a subgrade that has been weakened by moisture. (3) The other type of rutting is a mixture problem, and is the result of accumulated unrecoverable strain in the asphalt layers due to either densification and/or repeated shear deformations under applied wheel loads. This type of deformation is caused by consolidation, lateral movement, or both, of the HMA under traffic. (4)

#### ***Permanent Deformation Tests: Wheel Tracking***

Wheel tracking tests are likely the most common type of laboratory equipment used for the determination of rutting susceptibility. (4). The loaded wheel test (LWT) offers an excellent device for quantitatively comparing the relative rutting susceptibility of one HMA mix with another – and in a sense, it becomes a “proof test” to assure the HMA mix will withstand the rigors traffic and environmental loading. All LWTs operate under the same general premise – a loaded moving wheel travels along the sample lengthwise while applying a load to the sample in

order to simulate rutting. Depressions, or ruts, are created in the sample. The magnitudes of the rut depths are measured and recorded. LWT data can be used to rank the performance of a variety of mixes, or pass/fail criteria can be applied for mixture acceptance. The parameters of air voids and test temperature are usually specified, while other parameters, such as sample type, pressure, load, and length of test can be variable and must be determined based on experience or manufacturer recommendations.

The Hamburg Wheel-Tracking Device (HWTD), shown in Figure 1, was developed in the 1970s by Esso A.G. of Hamburg, Germany. (5) It is based on a similar British device using a rubber tire. The HWTD is currently marketed by Helmut-Wind Incorporated of Hamburg, Germany. It is used as a specification requirement for some of the most traveled roadways in Germany with regard to rutting and stripping. (6)



**Figure 1. Hamburg Wheel-Tracking Device**

The HWTD was originally used to measure rutting susceptibility. The test required 9540 wheel passes at temperatures of 40 C (104 F) and 50 C (122 F). The test was then lengthened to 19,200 passes, and it was discovered that some mixes could deteriorate shortly after 10,000 passes. Therefore the length of the test was increased. According to the manufacturer, a contact stress of 0.73 MPa approximates the stress produced by one rear tire of a double-axle truck. (5)

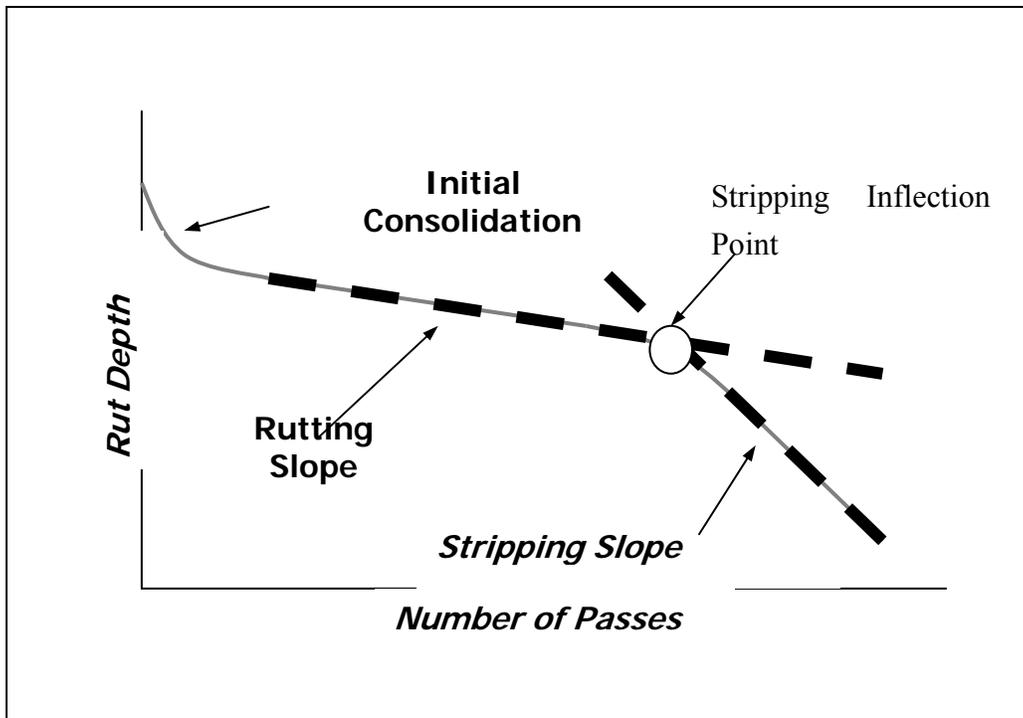
The HWTD, in its present form, is capable of testing two samples simultaneously. Sample types can be either prismatic beams or cylindrical specimens. Slabs are compacted to  $7 \pm 1$  percent air voids in a linear kneading compactor to a width of 260 mm (10.2 in) and a length of 320 mm (12.6 in). Slabs range from 40 mm (1.6 in) to 90 mm (3.5 in) in thickness. (7,8) Cylindrical specimens are typically compacted in the Superpave gyratory compactor (SGC) to  $7 \pm 1$  percent air voids and are 150 mm (6 in) in diameter. When cylindrical specimens are tested, a pair of specimens must be molded within the sample so that the wheel will maintain contact with the sample throughout its entire length of travel. Samples are typically cast in plaster of paris or in acrylic sample molds within a sample tray. (9)

Samples are tested submerged in a water bath and loaded with 705 N (158 lb) by a steel wheel that is 47 mm (1.8 in) wide. Samples can also be tested in the dry condition, but since stripping occurs in the presence of water, samples are usually submerged. The temperature of the test can be varied from 25 C (77 F) to 70 C (158 F), but tests are most often performed at 50 C (122 F). (7)

As the steel wheel travels linearly back and forth over the slab, deflection measurements are taken by a data acquisition system at one point in the center of the specimen. Rut depths are recorded every 100 passes, and are accurate to 0.01 mm. (9, 10) A test is complete when a total of 20,000 wheel passes have been applied or the sample accumulates 20 mm (0.8 in) of rut depth.

The wheel makes 50 passes over each sample per minute. The maximum velocity of the wheel is 34 cm/sec (1.1 ft/sec) in the center of the sample. At this rate, a HWTD test takes approximately 6.5 hours. (7, 10)

Recorded rut depths are plotted against the number of passes. A typical data plot is given in Figure 2. A typical sample will experience some initial consolidation, or post-compaction, then deform at a rate known as the creep slope, or rutting slope. Results from the HWTD include the rutting slope, stripping slope, and stripping inflection point. The rutting slope relates to rutting from plastic flow. It is defined as the inverse of the rate of deformation in the linear region of the deformation curve, after initial consolidation effects have ended and before the onset of stripping. In other words, it is the number of passes after the initial consolidation required to create a 1-mm rut.



**Figure 2. Typical Hamburg Wheel-Tracking Test Result and Interpretation**

## **Moisture Susceptibility**

Moisture susceptibility, or stripping, can be defined as the weakening or eventual loss of the adhesive bond mainly due to the presence of moisture and/or moisture vapor between the aggregate surface and the asphalt cement in an HMA pavement or mixture. Often, water is trapped at the bottom of the asphalt layer, so the failure begins at the bottom of the asphalt and gradually progresses upward to the surface. As the asphalt binder is separated from the aggregate particles, the aggregate is no longer held in place. It begins to shift and condense, causing a depression in the surface of the pavement, and often appears as rutting. Stripping in the field can be differentiated from rutting by an experienced pavement engineer. Traffic-induced stripping appears as rutting where the rise and flow from shear failure is centered on the wheel path but has an irregular width. It may also appear as a localized shear failure that is centered on the wheel path. In extreme cases of stripping, bare aggregate particles are actually visible at the surface. Ultimately raveling occurs, meaning that the loose particles are forced from the surface by the action of traffic loadings. *(1)*

### ***Moisture Damage Tests: Wheel Tracking***

The Hamburg wheel track device (and subsequently the ERSA device) has the ability to assess HMA mixtures regarding the susceptibility for moisture damage (stripping). A typical test result from an ERSA-type wheel tracking device was shown previously as Figure 2. Characteristics of the test result that relate to moisture damage are discussed in the paragraphs that follow.

The stripping slope is the inverse of the rate of deformation in the linear region of the deformation curve, after stripping begins and until the end of the test. It is the number of passes required to create a 1-mm impression from stripping. The stripping slope is related to the severity of moisture damage. The stripping inflection point is the number of passes at the

intersection of the rutting slope and the stripping slope. It is the point where rutting begins to be dominated by moisture damage, and is related to the resistance of the HMA to moisture damage.

*(11)*

Failure, according to the German specification, is defined as having a rut depth greater than 4 mm (0.16 in) after 20,000 wheel passes. *(8)* This criteria was considered to be too harsh for many pavements in the U.S. The state of Colorado currently uses a maximum rut depth criteria of 10 mm (0.4 mm). *(12)* The Texas Department of Transportation (TxDOT) adopted the Hamburg wheel-track test for assessing moisture damage susceptibility in 2003; current TxDOT specifications call for a minimum number of passes at 50C to reach 12.5 mm (0.5 in) of 10,000 for PG 64 binder, 15,000 for PG 70 binder, and 20,000 for PG 76 binder. *(13)* The repeatability of the device has been reported to be acceptable. *(14)*

## CHAPTER THREE

### Research Approach

As mentioned previously, three primary tasks were identified as necessary for accomplishing project objectives: (1) develop a standardized testing procedure for ERSA wheel tracking testing; (2) obtain and validate a second ERSA unit for use by AHTD during HMA mixture acceptance procedures; and (3) establish final HMA mixture acceptance criteria. A description of the approach taken for each task follows.

#### **Task 1: Develop a Standardized Testing Procedure for ERSA Wheel Tracking Testing**

General testing parameters and specimen preparation procedures for ERSA testing were recommended by Williams. (2) These recommendations have been incorporated into a standardized test protocol, prepared nominally in AASHTO format. The recommended testing procedure is contained in Appendix A. Highlights of the testing procedure are given in the listing that follows.

- Test specimens
  - Laboratory-compacted or field cores, 150 mm diameter by 75 mm height.
    - The 75 mm height may be obtained by compacting to a target height or by sawing *one face* (which will, subsequently, be the “bottom” face of the test specimen) to desired height. It is not permitted to saw both faces of the specimen to obtain the required specimen height.
  - Air Voids: 7±1 percent
- Test Protocols
  - Test temperature: 50 C
  - Wheel load: 589 N (132 lb)
  - Speed: 550±50 wheel passes per hour

## Task 2: Validate “Second Generation” ERSA Unit for AHTD

A second-generation ERSA unit (hereinafter, ERSA II) was obtained from the manufacturer for this project. A validation study was performed to ensure consistency between the new unit and the original ERSA unit used in previous research efforts (hereinafter ERSA I). Details of the validation study follow.

Hot-Mix Asphalt Concrete Mixtures. Six HMA mixes, listed in Table 1, were used in the validation study. Each mix was a surface mix (12.5 mm nominal maximum aggregate size) having an AHTD-approved mix design. Aggregates and asphalt binder comprising the mixes were sampled from hot-mix asphalt plants at which the mixes were being produced. Test specimens were mixed according to the job mix formula as shown on the mix design. Compaction was accomplished using the Superpave gyratory compactor. Air voids were verified to be within specification for each specimen prior to testing. Testing was accomplished in accordance with the standard testing protocol developed for the project (Appendix A).

<b>HMA Mixture Source (Designation)</b>	<b>PG Binder Grade</b>
Forum (FOR)	64-22
Batesville (BAT)	64-22
Sharp’s (I-540)	76-22
Duffield (DUF)	64-22
Granite Mountain (GMQ)	64-22
Jet Asphalt (JET)	64-22

**Table 1. Hot-Mix Asphalt Mixes Used in the Study**

The study was designed to perform a total of six replicate tests for each HMA mixture; however, numerous ERSA-related and computer-related difficulties rendered some test results either totally unusable or only partially usable (computer or ERSA experienced difficulty part-way through a test). Table 2 summarizes the number of replicate test results used in subsequent analyses for the project.

<b>Source</b>	<b>ERSA I</b>	<b>ERSA II</b>
FOR	5	5
BAT	6	6
I-540	3	3
DUF	6	6
GMQ	6	5
JET	5	5

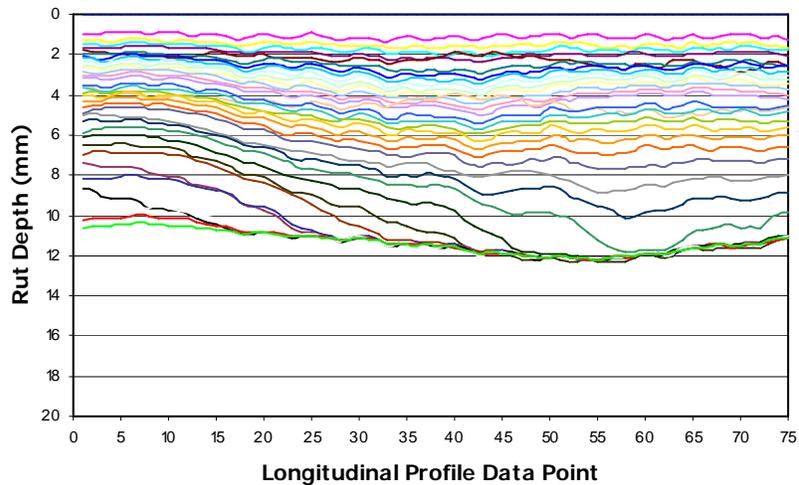
**Table 2. Number of Replicate Test Results Used for Analyses**

Data Analysis. As described previously, a number of data items are obtained from an ERSA test, including rut depth at a given number of cycles, total rut depth, rut slope, stripping slope, and stripping inflection point. In addition, it is helpful in a comparative study to note how a given test procedure/device “ranks” specimens from a variety of sources. The identification and calculation of rutting and stripping slopes can be highly subjective, depending on the particular data set. Therefore in terms of rutting data, two data types were selected to validate the results obtained from ERSA II compared to ERSA I: total rut depth at a given number of cycles, and comparative rankings of mixtures. Specific analyses comprising the validation effort follow.

- Rut Depth Comparisons: Analysis of Variance (ANOVA) with “device” as factor

- Rut depth at 5,000 cycles
- Rut depth at 10,000 cycles
- HMA Mixture Ranking Comparisons: Qualitative Assessment between devices
  - Rut depth at 5,000 cycles
  - Rut depth at 10,000 cycles

Williams and Hall (*I*) provide a comprehensive discussion relating to the interpretation of data obtained from ERSA. It is helpful to review salient points here. ERSA collects deformation data along the entire length of wheel travel in both directions. A total of 150 measurements are recorded during one cycle of the wheel - 75 points in the forward direction, and 75 points in the backward direction. Only the forward measurements are retained. The length of travel in one direction is approximately 300 mm, so the 75 measurements are taken at 4-mm intervals. When plotted using “location along the sample’s length” as the X-axis, the deformation data shows, in effect, the sample profile; a typical sample profile series is shown in Figure 3.



**Figure 3. Typical Longitudinal Rutting Profile of an ERSA Sample**

To minimize “end effects” regarding sample deformation (end effects are related to the intersection of two cylindrical specimens “butting up” against each other, and to the wheel

slowing down at the end of its travel to reverse direction thereby producing more load on the specimens at the ends), data points measured at each end of each specimen are ignored. Thus, only the rut data representing approximately the center 100 mm of each individual cylindrical specimen in the testing “pair” is considered. All data is compared to the original profile of the sample. Approximately 10 – 15 cycles of the wheel are exerted in order to “seat” the wheel. Then the recording begins. The profile of the first cycle is set to zero, which normalizes all further profile data as an increase in deformation from its original condition.

To obtain “rut depth” for a given cycle, a number of options are available:

- Average all deformation measurements along the longitudinal profile of the sample pair;
- Select the maximum deformation measurement along the longitudinal profile of the sample pair;
- Calculate some percentile-level deformation using the longitudinal profile of the sample pair.

For routine ERSA testing, the average deformation of each profile is calculated and plotted versus time, or number of cycles, where one cycle is equivalent to two wheel passes. The resulting graph will exhibit some level of initial consolidation. A linear portion of the curve will then characterize the rutting slope. If the sample strips, the slope will change, providing information about the stripping characteristics of the sample. The general pattern of data follows the same concept as the Hamburg wheel tracking data, previously presented in Figure 2.

### **Task 3: Establish Acceptance Criteria for HMA Mixtures**

Ideally, the establishment of HMA mixture acceptance criteria would be based on a comprehensive database of corresponding laboratory/field performance data, similar to efforts completed by the Colorado (6, 11, 12) and Texas (13) departments of transportation.

Unfortunately, this study was hampered by a lack of quantitative, measured field rut depth data.

Anecdotal data regarding field performance of the mixes used both in this and the previous (TRC-9804) study was considered. ERSA test data generated in both AHTD studies were examined to recommend initial acceptance criteria. The final recommended criteria were also compared to that used by other states specifying Hamburg-type testing for HMA mixture performance.

## CHAPTER FOUR

### Results and Discussion

Table 3 shows the average rut depths at 5,000 and 10,000 cycles generated during the study, for both ERSA I and ERSA II.

<b>ERSA I</b>						
<b>Rut Depth (mm) at 5,000 Cycles</b>						
<b>Replicate</b>	<b>Source</b>					
	<b>FOR</b>	<b>BAT</b>	<b>I-540</b>	<b>DUF</b>	<b>GMQ</b>	<b>JET</b>
<b>1</b>	1.1	6.7	0.0	12.5	6.9	4.3
<b>2</b>	0.0	2.2	0.0	16.1	1.6	3.0
<b>3</b>	2.5	3.6	0.0	10.5	2.8	4.1
<b>4</b>	2.0	4.0		15.3	4.5	4.4
<b>5</b>	5.5	2.7		8.3	3.3	1.9
<b>6</b>		3.2		14.2	5.2	
<b>Rut Depth (mm) at 10,000 Cycles</b>						
<b>Replicate</b>	<b>Source</b>					
	<b>FOR</b>	<b>BAT</b>	<b>I-540</b>	<b>DUF</b>	<b>GMQ</b>	<b>JET</b>
<b>1</b>	2.1	9.5	3.2	17+	10.7	5.1
<b>2</b>	3.8	9.9	1.8	17+	3.1	3.1
<b>3</b>	4.0	4.8	1.4	17+	6.4	4.3
<b>4</b>	3.3	9.5		17+	7.6	5.0
<b>5</b>	7.5	6.9		17+	9.1	4.3
<b>6</b>		6.8		17+	9.5	
<b>ERSA II</b>						
<b>Rut Depth (mm) at 5,000 Cycles</b>						
<b>Replicate</b>	<b>Source</b>					
	<b>FOR</b>	<b>BAT</b>	<b>I-540</b>	<b>DUF</b>	<b>GMQ</b>	<b>JET</b>
<b>1</b>	1.5	2.1	0.0	8.8	5.7	2.6
<b>2</b>	1.7	3.5	0.0	4.5	3.2	6.3
<b>3</b>	1.9	1.6	0.0	8.4	4.8	3.1
<b>4</b>	2.5	1.4	0.0	10.9	6.0	3.3
<b>5</b>	2.2	2.0	0.0	4.6	3.2	9.4
<b>6</b>	1.6	1.6		7.7		2.3
<b>Rut Depth (mm) at 10,000 Cycles</b>						
<b>Replicate</b>	<b>Source</b>					
	<b>FOR</b>	<b>BAT</b>	<b>I-540</b>	<b>DUF</b>	<b>GMQ</b>	<b>JET</b>
<b>1</b>	2.7	2.5	1.9	17+	11.2	4.6
<b>2</b>	3.2	4.7	5.2	17+	7.5	11.7
<b>3</b>	3.1	2.6	3.0	17+	8.7	8.7
<b>4</b>	7.5	4.6	2.7	17+	8.6	3.2
<b>5</b>	5.5	2.3	3.8	17+	5.3	11.5
<b>6</b>	2.6	2.7		17+		5.7

**Table 3. Summary of Average Rut Depths**

## Validation of ERSA II

As mentioned in Chapter 3, the first analyses of rutting data employ a single-factor analysis of variance (ANOVA), setting that factor as the individual ERSA unit. Two analyses are presented, one for rut depth at 5,000 cycles and one for rut depth at 10,000 cycles, shown as Tables 4 and 5 respectively.

Rut Depth (mm) at 5,000 Cycles							
Source	ERSA I		ERSA II		F	F <sub>crit</sub>	Difference Significant?
	Average	Standard Deviation	Average	Standard Deviation			
FOR	2.2	2.06	1.9	0.38	0.141	5.117	NO
BAT	3.7	1.59	2.0	0.77	5.584	4.965	YES
I-540	0.0	0.00	0.0	0.00	N/A		NO
DUF	12.8	2.99	7.5	2.80	11.193	4.965	YES
GMQ	4.0	1.89	4.6	1.33	0.274	5.117	NO
JET	3.5	1.07	4.5	2.79	0.518	5.117	NO

*Note: Level of Significance = 5 percent ( $\alpha = 0.05$ )*

**Table 4. ANOVA Results Comparing ERSA I and ERSA II at 5,000 Cycles**

Rut Depth (mm) at 10,000 Cycles							
Source	ERSA I		ERSA II		F	F <sub>crit</sub>	Difference Significant?
	Average	Standard Deviation	Average	Standard Deviation			
FOR	4.1	2.02	4.1	1.98	0.001	5.117	NO
BAT	7.9	2.05	3.2	1.11	24.150	4.965	YES
I-540	2.1	0.95	3.3	1.25	1.967	5.987	NO
DUF	17+	N/A	17+	N/A	N/A		NO
GMQ	7.7	2.73	8.3	2.12	0.119	5.117	NO
JET	5.0	1.64	7.6	3.62	2.562	4.965	NO

*Note: Level of Significance = 5 percent ( $\alpha = 0.05$ )*

**Table 5. ANOVA Results Comparing ERSA I and ERSA II at 10,000 Cycles**

In most cases, rut depths recorded by ERSA II compare favorably (no significant difference) with those recorded by ERSA I. The hot-mix asphalt mixture representing “Duffield” exhibited notable rutting and stripping in each ERSA unit – the actual rut depths were significantly different, but as will be shown, each ERSA unit ranked this mixture as the mix having the highest moisture damage susceptibility. The HMA mixture representing “Batesville” also demonstrated significantly different rutting behavior among the two ERSA units. It was with these specimens that a potential problem with test temperature was discovered in the ERSA II unit. It is suspected that the test temperature in ERSA II unit was significantly less than 50 C during testing; hardware problems with the water heater/recirculation unit were addressed prior to additional tests being performed.

The second validation study uses a comparative ranking of mixes with regard to rutting / stripping behavior produced by each ERSA unit. Table 6 summarizes the rankings of mixtures with regards to average rut depths. Due to the difficulties encountered during testing Batesville (BAT) mixes – described in the previous paragraph – the BAT mixtures are not included in Table 6. It is evident that each ERSA unit ranked the mixtures in the same manner.

Rank	Rankings at 5,000 Cycles		Rankings at 10,000 Cycles	
	ERSA I	ERSA II	ERSA I	ERSA II
1	I-540	I-540	I-540	I-540
2	FOR	FOR	FOR	FOR
3	JET	JET	JET	JET
4	GMQ	GMQ	GMQ	GMQ
5	DUF	DUF	DUF	DUF

**Table 6. Mixture Rankings by ERSA Units**

Based on the ANOVA analyses and mixture rankings, it is reasonable to conclude that the second-generation ERSA wheel-track device (ERSA II) does indeed provide rutting results similar to those produced by the original (ERSA I) unit. Therefore, results obtained using ERSA II may be used with confidence. In addition, data sets from both ERSA units may be considered together when establishing acceptance criteria.

### **Establishment of Acceptance Criteria for HMA Mixtures**

The challenge of developing mixture acceptance criteria based on laboratory test results is twofold. First, the precision of the test method must be considered. Secondly, “risks” associated with mixture acceptance/rejection must be balanced – that is, the risk to the purchasing agency (e.g. AHTD) of accepting poor-performing mixes must be balanced against the risk to the seller (e.g. the contractor) of rejecting good-performing mixes. Statistically, it is possible to quantify these risks given a comprehensive data set; however, the data set available for this project is not suitable for such a detailed risk analysis.

Table 7 presents the variability of the data generated in this study, in terms of the coefficient of variation (COV). The use of COV is reasonable – in this manner, variability (in terms of the standard deviation of replicate test results) is “normalized” against the mean value for the individual data sets and can thus be compared across HMA mixture sources. With a couple of exceptions, the COV for the test data in this study generally range between twenty and fifty percent for rut depths at both 5,000 and 10,000 cycles – producing an “average COV” of approximately thirty-six percent. These variability measures are consistent with other reported studies. (*14*) Consideration of testing variability in specification writing results in practical implications, to wit: if it were desired to ensure that 95 percent of test results fell below a given maximum-rut-depth threshold (thus addressing the concept of “risk”, as discussed previously),

the “target mean” of those results would necessarily fall below the given threshold value by 1.7 times for a COV of 36 percent. For example, if it were desired to have 95 percent of all values fall below 10 mm rut depth (and given the 36 percent COV), the target mean of those results would be approximately 5.9 mm. Thus, a reasonable specification would be written (in this example) with an acceptable maximum rut depth of 6 mm.

<b>Rut Depth (mm) at 5,000 Passes</b>						
<b>Source</b>	<b>Average</b>	<b>ERSA I Standard Deviation</b>	<b>COV</b>	<b>Average</b>	<b>ERSA II Standard Deviation</b>	<b>COV</b>
FOR	2.2	2.06	93.6	1.9	0.38	20.0
BAT	3.7	1.59	43.0	2.0	0.77	38.5
I-540	0.0	0.00	N/A	0.0	0.00	N/A
DUF	12.8	2.99	23.4	7.5	2.80	37.3
GMQ	4.0	1.89	47.3	4.6	1.33	28.9
JET	3.5	1.07	30.6	4.5	2.79	62.0

<b>Rut Depth (mm) at 10,000 Passes</b>						
<b>Source</b>	<b>Average</b>	<b>ERSA I Standard Deviation</b>	<b>COV</b>	<b>Average</b>	<b>ERSA II Standard Deviation</b>	<b>COV</b>
FOR	4.1	2.02	49.3	4.1	1.98	48.3
BAT	7.9	2.05	25.9	3.2	1.11	34.7
I-540	2.1	0.95	45.2	3.3	1.25	37.9
DUF	17+	N/A	N/A	17+	N/A	N/A
GMQ	7.7	2.73	35.5	8.3	2.12	25.5
JET	5.0	1.64	32.8	7.6	3.62	47.6

**Table 7. Variability of ERSA Test Data**

In establishing specific acceptance criteria for HMA mixes, it is helpful to re-consider the “rankings” of mixes based on ERSA testing. Table 8 reproduces the Table 6 mixture rankings, but indicates statistical groupings of the HMA sources – that is, which test results were statistically not-different, and which results exhibited a statistically significant difference. The statistical determinations were made using analysis of variance (ANOVA) and Duncan’s

multiple range test (DMRT), with a level of significance of 5 percent ( $\alpha = 0.05$ ). In general, three fairly distinct groupings are evident when considering the data set as a whole: the I-540 mix performed significantly better than all others; the Duffield (DUF) mix performed significantly worse than all others; and mixes representing Forum, Granite Mountain, Jet Asphalt (and Batesville, not shown) all showed similar performance.

Rank	Rankings at 5,000 Cycles		Rankings at 10,000 Cycles	
	ERSA I	ERSA II	ERSA I	ERSA II
1	I-540	I-540	I-540	I-540
2	FOR	FOR	FOR	FOR
3	JET	JET	JET	JET
4	GMQ	GMQ	GMQ	GMQ
5	DUF	DUF	DUF	DUF
<i>Color represents statistical groupings of data</i>				

**Table 8. Statistical Groupings of ERSA Data**

Based on variability considerations, the performance of the mixtures in the study, limited anecdotal accounts of field performance, and criteria set by other agencies, preliminary performance criteria are suggested in Table 9. For ease of implementation, the criteria are subdivided into groupings based on design gyrations for hot-mix asphalt. In addition, the criteria operate with one rut depth criteria; the characteristic distinguishing various levels of performance is the minimum number of cycles necessary to achieve the target rut depth. Another notable feature of the criteria is that medium to high traffic mixes (design gyrations of 100 and 125) are not allowed to exhibit stripping behavior – no stripping inflection point is allowed. Lower traffic

mixes (e.g. 50 and 75 gyrations) are allowed to exhibit moisture damage characteristics, but only after passing the minimum number of gyrations to the target total rut depth.

<b>Design Gyrations (<math>N_{des}</math>)</b>	<b>Maximum Gyrations (<math>N_{max}</math>)</b>	<b>Minimum Cycles To Maximum (10 mm) Rut Depth</b>	<b>Minimum Stripping Inflection Point (cycles)</b>
50 / 75	75 / 115	5,000 cycles	7,500 cycles
100	160	7,500 cycles	No SIP (>10,000 cycles)
125	205	10,000 cycles	No SIP (>10,000 cycles)

**Table 9. Recommended Mixture Acceptance Criteria**

The recommended mixture acceptance criteria agree favorably with criteria implemented by other agencies, but are less conservative than the criteria originally recommended by Williams.

(2) Table 10 shows a comparison of mixture criteria.

<b>Researcher / Agency</b>	<b>Recommended / Implemented Criteria<sup>a</sup></b>	
	<b>Rutting</b>	<b>Stripping</b>
Williams (2001)	5 mm max @ 20,000 cycles (high traffic volume) 10 mm max @ 20,000 cycles (med to low traffic volume)	None recommended
Colorado (1993)	10 mm max @ 10,000 passes	None recommended
Texas (2003)	12.5 mm max @ 10,000 passes (PG 64) 12.5 mm max @ 15,000 passes (PG 70) 12.5 mm max @ 20,000 passes (PG 76)	None recommended
TRC-0201 (2005)	10 mm max @ 5,000 cycles ( $N_{des}$ = 50 or 75) 10 mm max @ 7,500 cycles ( $N_{des}$ = 100) 10 mm max @ 10,000 cycles ( $N_{des}$ = 125)	No Stripping for $N_{des}$ = 100/125  Stripping Infl. Pt. minimum 7500 cycles $N_{des}$ = 50/75

*<sup>a</sup>Note: 1 ERSA "cycle" equals 2 Hamburg "passes"*

**Table 10. Comparison of HMA Mixture Acceptance Criteria**

## CHAPTER FIVE

### Conclusions and Recommendations

All project objectives were generally met. Specific observations, conclusions, and recommendations related to the project are contained in the listing that follows.

- A standardized testing procedure for ERSA wheel track testing has been developed, and should be used for all ERSA tests.
- A second-generation ERSA machine (“ERSA II”) was obtained, validated, and delivered to AHTD. Validation studies indicate the ERSA II machine produces test results similar to those produced by the original ERSA device; the ERSA II results may be used with confidence.
- In general, the variability of ERSA test results is approximately 36 percent, in terms of the Coefficient of Variation (COV) of replicate test results.
- Preliminary hot-mix asphalt mixture acceptance criteria have been developed for the ERSA wheel track test. The criteria are based on a maximum rut depth of 10 mm; the minimum number of ERSA cycles required to achieve the maximum rut depth is based on the HMA mixture type, in terms of the design number of gyrations for the mix.
- Preliminary mixture acceptance criteria do not have a robust field-performance comparative basis. Therefore, it is recommended that AHTD delay full implementation of ERSA testing for routine mixture design and acceptance until a database of ERSA results can be assembled and compared with known field mixture performance.
- It is recommended that AHTD test all mixtures presented to the Central Laboratory by contractors for verification using ERSA for a minimum of one year, after which the preliminary mixture acceptance criteria may be re-evaluated for suitability and potential impact on mixture verification and acceptance rates.

Appendix A contains the ERSA Standard Test Method.

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## **APPENDIX A**

### **ERSA Standard Test Method**

Standard Test Method for  
DETERMINING RUTTING AND STRIPPING SUSCEPTIBILITY USING THE  
EVALUATOR OF RUTTING AND STRIPPING IN ASPHALT (ERSA)

1. SCOPE

- 1.1 This method covers the procedure for testing the rutting and stripping susceptibility of hot mix asphalt (HMA) mixtures using the Evaluator of Rutting and Stripping in Asphalt (ERSA).
- 1.2 The units stated for values are to be regarded as the standard. The values given in parentheses are for information only.
- 1.3 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and to determine the applicability of regulations prior to use.

2. REFERENCED DOCUMENTS

2.1 AASHTO Standards:

- PP2 Short- and Long-Term Aging of Bituminous Mixes
- TP4 Preparation of Compacted Specimens of Modified and Unmodified Hot Mix Asphalt by Means of the SHRP Gyrotory Compactor
- T166 Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens
- T168 Standard Practice for Sampling Bituminous Paving Mixtures
- T209 Theoretical Maximum Specific Gravity and Density of Bituminous Paving Mixtures
- T269 Percent air Voids in Compacted Dense and Open Bituminous Paving Mixtures

3. APPARATUS

- 3.1 Evaluator of Rutting and Stripping in Asphalt (ERSA) – A thermostatically controlled device designed to test the rutting susceptibility of hot mix asphalt by applying repetitive linear loads to compacted test specimens by a steel wheel.
  - 3.1.1 ERSA shall be thermostatically controlled to maintain the test temperature in the testing chamber at any setting between 20 C and 65 C, accurate to 1 C.
  - 3.1.2 ERSA shall be capable of maintaining a constant temperature in two recirculating water baths at settings in the range of 20 C to 65 C, accurate to 1 C. The water recirculation unit shall be capable of continuously monitoring the temperature of the water in the water baths.
  - 3.1.3 ERSA shall be capable of independently applying loads up to 705 N (158 lb) to each wheel. The loads shall be calibrated to the desired test load by a load cell.
  - 3.1.4 ERSA shall contain at least two sample trays and be capable of testing at least two samples simultaneously.
  - 3.1.5 ERSA shall have a master cycle counter.
  - 3.1.6 ERSA shall have an automated data acquisition system for the purpose of collecting cycle number and vertical deformation information for the

entire profile of each sample. Rut depth measurements shall be accurate to 0.01 mm.

- 3.2 Balance, 6,000 gram capacity, accurate to 0.1 gram.
- 3.3 Mixing utensils (bowls, spoon, spatula)
- 3.4 Ovens for heating aggregate and asphalt cement.
- 3.5 Compaction device and molds.

#### 4. PREPARATION OF TEST SPECIMENS

- 4.1 Number of test specimens – Each ERSA test will consist of four cylindrical specimens (150 mm in diameter), comprising two ERSA samples. Sample height should be at least 75 mm and not more than 175 mm. Samples should be compacted to contain  $7.0 \pm 1.0$  percent air voids.
- 4.2 Laboratory Prepared Mixtures
  - 4.2.1 Mixture proportions are batched in accordance to the desired Job Mix Formula.
  - 4.2.2 The asphalt binder and aggregates shall be mixed and compacted in accordance with AASHTO TP4.
  - 4.2.3 Test samples shall be aged in accordance with the short-term aging procedure in AASHTO PP2.
- 4.3 Plant Produced Mixtures
  - 4.3.1 Samples of plant-produced mixtures shall be obtained in accordance with AASHTO T169. Representative samples should be split from the sampled quantity such that the desired sample height will be obtained following specimen compaction.
  - 4.3.2 Specimens shall be compacted in accordance with AASHTO TP4.

#### 5. DETERMINATION OF AIR VOID CONTENT

- 5.1 Determine the bulk specific gravity of the test specimens in accordance with AASHTO T166.
- 5.2 Determine the maximum specific gravity of the test mixture in accordance with AASHTO T209.
- 5.3 Determine the air void content of each test specimen in accordance with AASHTO T269.
- 5.4 Pair specimens such that two cylindrical specimens will comprise one ERSA test sample.

#### 6. MOLDING SPECIMENS

- 6.1 Wire the specimens lengthwise to a non-flexible plate, such that the plate will span the length of the sample tray.
- 6.2 Place acrylic spacer blocks to occupy mold volume not needed for the sample. The spacer blocks should not touch the HMA samples when molded.
- 6.3 Place HMA sample such that its top surface is flush with the plane of the top of the sample mold.
- 6.4 Mix plaster of paris according to manufacturer instructions, and fill all voids in the sample mold.  
NOTE: A plastic membrane placed in the bottom of the sample mold may help to prevent leaks.
- 6.5 Allow the plaster to cure overnight.
- 6.6 Remove the lengthwise plate and place molded sample in ERSA.

## 6. TEST TEMPERATURE, SPEED, AND LOAD

- 6.1 The test shall be performed at a temperature of 50 C in the submerged condition.
- 6.2 The wheel speed shall be set such that approximately  $550 \pm 50$  cycles are applied to the sample each hour.
- 6.3 The load applied to the sample shall be 132 lb (589 N).

## 7. SPECIMEN PREHEATING

- 7.1 Samples shall be subjected to a static soak conditioning period in the temperature calibrated ERSA water bath. The conditioning period should last a minimum of four hours and a maximum of eight hours.

## 8. PROCEDURE

- 8.1 Apply the 132 lb load to each test sample.
- 8.2 Provide a unique filename for the file containing sample data.
- 8.3 Prepare the data acquisition system for the test.
- 8.4 Apply 10 to 15 cycles to seat the samples prior to the initial deformation measurement.
- 8.5 Apply 20,000 cycles to the samples.

## 9. CALCULATIONS

- 9.1 Use the average of ten profile points at the interior of each cylindrical specimen making up the test sample as the basis for all calculations. Average rut depth shall be plotted graphically against number of cycles.
- 9.2 Calculate the rut depth as the difference in the final and initial rut depth measurements, in millimeters.
- 9.3 Initial consolidation is determined as the depth of compaction experienced by the sample prior to the start of the rutting slope.
  - 9.3.1 Initial consolidation should occur within the first hour of testing.
- 9.4 The rutting slope is the inverse of the slope of the linear portion of the rutting response curve, prior to the onset of stripping.
  - 9.4.1 Rutting slope is presented as the number of cycles required to create a 1-mm rut depth.
- 9.5 The stripping slope, if present, is the inverse of the slope of the linear portion of the stripping response curve, after the onset of stripping.
  - 9.5.1 Stripping slope is presented as the number of cycles required to create a 1-mm rut depth.
- 9.6 The stripping inflection point, if present, is the point of intersection of the rutting slope and stripping slope.
  - 9.6.1 Stripping inflection point is presented as the number of cycles corresponding to the intersection of the rutting and stripping slopes.
- 9.7 An example calculation is contained in the APPENDIX.

## 10. REPORT

- 10.1 The test report shall include the following information:
  - 10.1.1 The laboratory name, technician name, and data of test.
  - 10.1.2 The mixture type and description.
  - 10.1.3 The sample type.
  - 10.1.4 The average air void content of the test samples.

- 10.1.5 The test temperature and load.
- 10.1.6 The average rut depths at 20,000 cycles to the nearest 0.01 mm.
- 10.1.7 The initial consolidation to the nearest 0.01 mm.
- 10.1.8 The rutting slope to the nearest cycle/mm.
- 10.1.9 The stripping slope to the nearest cycle/mm.
- 10.1.10 The stripping inflection point to the nearest 10 cycles.

## 11. PRECISION AND BIAS

- 11.1 No statement is currently available regarding the precision and bias of this test method.

### ANNEX (Mandatory Information)

#### A. CALIBRATION

The following items should be checked for calibration no less than once per year: (1) ERSA water temperature, (2) ERSA wheel loads, and (3) ERSA wheel speed. Instructions for each of these calibration checks is included in this section.

##### A.1 ERSA Water Bath Temperature Calibration

- A.1.1 The thermometer on the recirculation unit shall be verified and/or calibrated using a NIST traceable liquid-in-glass calibration thermometer in the range of the testing temperature. During verification, the calibration thermometer shall be at least partially submerged in the filled water bath.
- A.1.2 When the water temperature has stabilized, allow the thermometer to remain in the water bath for a minimum of one hour. After one hour, record the temperature quickly, without completely removing the thermometer from the water bath. Return the thermometer to its original position.
- A.1.3 Thirty minutes after obtaining the first reading, obtain another reading of the thermometer. Again, do so quickly, without completely removing the thermometer from the water bath.
- A.1.4 Repeat step 1.3 until three consecutive readings are within 0.5 C of each other. If necessary, apply a temperature correction factor to the recirculation unit.
- A.1.5 Repeat steps 1.1 through 1.4 for each water bath.

##### A.2 ERSA Wheel Load Calibration

- A.2.1 Perform the load calibration using a calibrated load cell.
- A.2.2 Position the load cell directly beneath the center of the wheel in its lowered position.
- A.2.3 Zero the load cell.
- A.2.4 Lower the wheel and apply the normal testing load.
- A.2.5 Allow the load cell reading to stabilize. Record the load.
- A.2.6 Repeat steps 2.2 through 2.5 for each ERSA wheel.

##### A.3 ERSA Wheel Speed Calibration

- A.3.1 Using a stopwatch, record the number of wheel cycles completed in one minute. Multiply this value by 60. If the result is not within the specified tolerance, adjust the speed of the motor.
- A.3.2 Repeat this process until three consecutive readings are acceptable.

APPENDIX  
(Nonmandatory Information)

X1. Calculation of Test Data

X1.1 Inverse of linear slope (cycles/mm) =  $(C_2 - C_1) / (R_2 - R_1)$

Where  $C_1$  = Number of Cycles at Beginning of Linear Portion  
 $C_2$  = Number of Cycles at End of Linear Portion  
 $R_1$  = Rut Depth at Beginning of Linear Portion (mm)  
 $R_2$  = Rut Depth at End of Linear Portion (mm)

X1.2 Sample Data Plot

