Report Number: WI-06-12

Statewide Pavement Friction Testing 2012

FINAL REPORT

November 2012

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Statewide Pavement Friction Testing

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Wisconsin Department of Transportation

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16. Abstract

In 2012, Dynatest conducted friction testing for the Wisconsin Department of Transportation (WisDOT) on a representative subset of its State Trunk Highway Network. Friction testing was performed at 3,394 sites in accordance with ASTM E274 using a Dynatest 1295 Pavement Friction Tester. Testing was conducted using the ASTM E501 standard rib tire and skid numbers were adjusted (if necessary) to a speed of 40 mph (SN40R).

The testing involved a variety of hot mix asphalt pavement mixtures (including stone matrix asphalt), concrete surface textures, pavement ages, and functional classifications throughout Wisconsin and the frictional characteristics were analyzed several different ways. In general, the weighted average SN40R for hot mix asphalt, stone matrix asphalt, and concrete pavements were 51.6, 42.5, and 49.5, respectively. The weighted average SN40R for the different functional classifications ranged from 50.4 to 55.5 for the rural classifications and from 41.4 to 49.9 for the urban classifications. The weighted average SN40R decreased slightly as HMA and concrete pavement ages increased. The average friction of SMA, on the other hand, was shown to increase slightly as the pavements aged. Lastly, some crash sites within the tested segments were identified and analyzed. The results showed that the frictional characteristics at these sites were comparable to other pavement sites throughout the state.

17. Key Words Friction testing, pavement friction, skid resistance, ASTM E274, texture, pavement surface characteristics, skid number, microtexture		**18. Distribution Statement** Distribution Unlimited Authorized for Public Release	
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1 EXECUTIVE SUMMARY

In June 2012, the Wisconsin Department of Transportation contracted with Dynatest Consulting Inc. to conduct friction testing on a representative subset of its State Trunk Highway Network. WisDOT constructs roads of hot mix asphalt (HMA) and concrete, and the specific mixes and/or surface textures have evolved over the years. The friction testing covered various HMA pavement mixtures, concrete surface textures, pavement ages, and functional classifications in service throughout the state. Specifically, 3,394 roadway sections were tested in 46 Wisconsin counties and the frictional characteristics were analyzed and reported herein.

Skid resistance testing was performed using a Dynatest 1295 Pavement Friction Tester on 3,394 roadway sections located throughout the State of Wisconsin. The ASTM E501 standard rib tire was used for the testing and all testing was conducted in the left wheelpath. The testing was conducted at 40 mph for a majority of the test sections, except when the posted speed limit was lower than 40 mph or when prevailing traffic speeds were significantly higher than 40 mph (e.g. on some interstate highway sections). All testing was performed in accordance with the procedures detailed in ASTM E274.

Pavement section data was provided by the Wisconsin Department of Transportation. This data included section location details, section lengths, surface types, construction year, concrete texture type, etc.

Friction testing was performed from Monday, August 13 through Saturday, October 20, 2012. The average air and pavement surface temperatures ranged from 48 to 103° F and the pavement surfaces were dry during testing. However, the friction testing was performed under simulated wet conditions as specified in ASTM E274.

The speed gradient was determined by performing a series of measurements on three different types of pavement surfaces: hot mix asphalt, concrete and stone matrix asphalt. The resulting speed gradient was used to adjust the skid numbers to a speed of 40 mph (SN40R).

This report provides a description of the measured data and subsequent analysis.

2 PROJECT DESCRIPTION

The Wisconsin Department of Transportation (WisDOT) provided a list of 3,399 roadway sections for friction measurement. This section of the report breaks these roadway segments down for analytical purposes. Out of these, a total of 3,394 roadway sections were tested using the Dynatest 1295 Pavement Friction Tester; five sections could not be tested as they were closed for construction activities. Of the 3,394 sections actually tested, six sections were eliminated from the analysis (further explained in Section 3.6). Thus, 3,388 sections were considered for the statistics and analyses presented in Sections 4 and 5.

2.1 Test Locations

The 3,399 test sections included in this project were spread across 46 counties. Water for the friction unit was available at seven locations at various WisDOT maintenance facilities. In order to effectively plan and schedule the testing, the section list was grouped in terms of contiguous sections as well as proximity to the availability of water required for friction testing. An innovative routing program was developed to aid and assist the operator in selecting a daily starting point, determining a sequence of test sections, and to generate route directions using a GPS device. This program also assisted the operator in finding the shortest route locations/directions to and from the WisDOT facilities.

Figure 1 shows an overview of all the pavement sections tested as part of this project. The red circles provide a general idea of the test section locations in reference to the WisDOT maintenance facilities mentioned above.

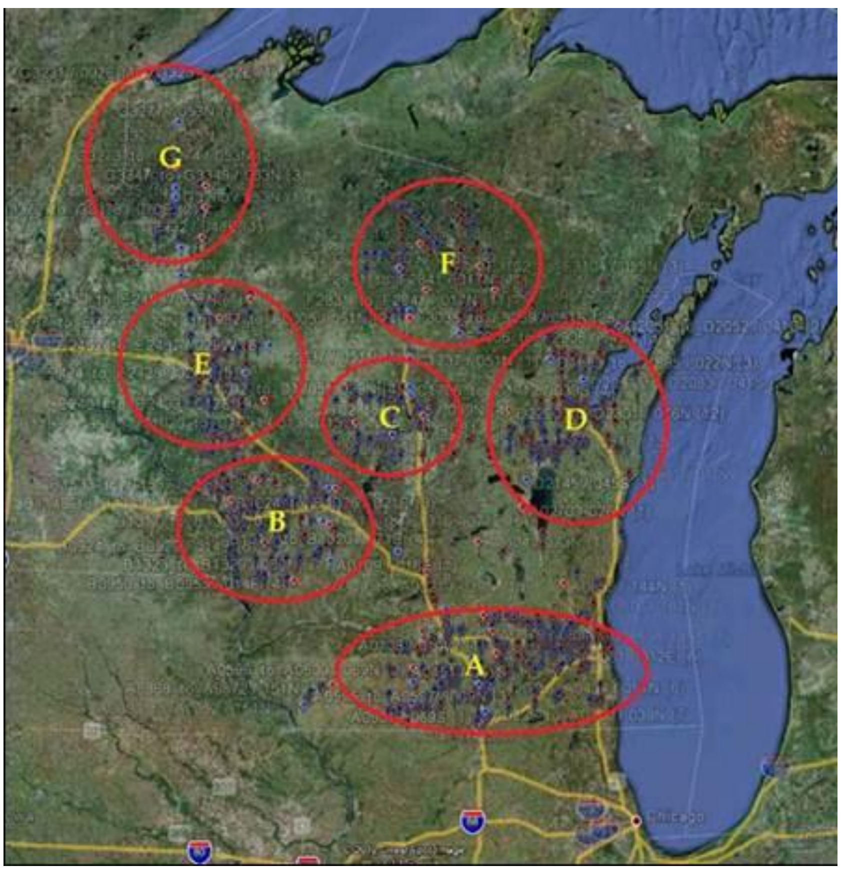


Figure 1 Friction Testing Locations in Wisconsin

The pavement sections were grouped as follows:

- Zone A: 878 sections
- Zone B: 670 sections
- Zone C: 312 sections
- Zone D: 494 sections
- Zone E: 428 sections
- Zone F: 448 sections
- Zone G: 169 sections
- Total: 3,399 sections

This allowed the operator to effectively plan the daily testing schedule and to minimize drive time between non-contiguous sections.

2.2 Pavement Section Data

Pavement section data provided by WisDOT included details pertaining to section limits (GPS coordinates and length), pavement surface type, functional classification code, construction year, concrete texture information, pavement thickness, etc. Section attributes were grouped and coded for analysis purposes as shown in Tables A through E on the following pages.

WisDOT has four different types of concrete pavements in service: jointed reinforced concrete pavements, jointed plain concrete pavements (undoweled), continuously reinforced concrete pavements, and jointed plain concrete pavements with dowels. However, since the surface texture of concrete pavements is the factor that contributes most to the skid resistance, the concrete pavements were analyzed as a whole and independently based on the surface texture rather than the pavement type. Concrete pavement surface texture data was available for a limited number of sections. Concrete sections that did not have a specific texture type identified were assumed to have a turf drag finish if constructed prior to 1977 and transversely tined if constructed in 1977 or later (as per directions from WisDOT).

The HMA mixes in Wisconsin (see Table B) have evolved over the years. The letter mixes (A, B, C, and D) were used from the early 1990s until 1992/1993. A number following a letter represented a version/change in the specification and a 'Q' meant that there was a call for the QMP (Quality Management Program) requiring field material production testing, which was just beginning in WisDOT during that same time frame. The "V" mixes—HV (high volume), MV (medium volume), and LV (low volume)—were used by WisDOT from late 1992/early 1993 until 1999/2000. WisDOT switched to the "E-" mixes in 2000 and is still using those. All the aforementioned HMA mixes differ based on the predicted traffic loading over a 20-year design life. WisDOT's aggregate structure gradation requirements of HMA mixes have also evolved over the years and that level of detail is not revealed by the mix type.

Although the frictional characteristics of the HMA mixes previously mentioned (and a few others not mentioned) were analyzed by mix type, they were also grouped into the "HMA" broad surface category since their dense-graded surface characteristics are similar in nature. It should be noted that although stone matrix asphalt (SMA) is a type of HMA, the gap-graded characteristics of SMA differ from typical dense-graded HMA mixes. Therefore, the SMAs were analyzed separately.

In addition, 182 out of 3,399 sections were identified as ‘crash sites’; sites at which four or more crashes have occurred. One of the goals of this project was to determine whether pavement friction (or lack thereof) was a concern on these sections. Statistics and other analyses are provided in the following sections of this report.

Table A: Regions and Counties

Region	County	Number of Sections
North Central	Forest, Green Lake, Langlade, Lincoln, Marathon, Oneida, Portage, Waupaca, Wood	729
Northeast	Brown, Door, Fond du Lac, Manitowoc, Marinette, Oconto, Outagamie, Sheboygan, Winnebago	529
Northwest	Barron, Buffalo, Calumet, Chippewa, Douglas, Eau Claire, St. Croix, Trempealeau, Washburn	729
Southeast	Kenosha, Milwaukee, Ozaukee, Racine, Walworth, Washington, Waukesha	263
Southwest	Columbia, Dane, Dodge, Grant, Green, Jefferson, Juneau, La Crosse, Lafayette, Monroe, Rock, Vernon	1,149
STATEWIDE		3,399

Table B: Surface Types

Surface Type	Detailed Surface Type	Number of Sections
Hot Mix Asphalt (HMA)	A1, AC, AC Warranty, B1, B1Q, C, C1, C1Q, D1, E-0.3, E-1, E-3, E-10, E-30, HV, LV, MV, Recycled HMA, Road Mix, Single Aggregate HMA, Superpave	2,417
Concrete	Transversely Tined, Longitudinally Tined, Diamond Ground, Turf Drag	898
SMA	Stone Matrix Asphalt (SMA)	84
All Surface Types		3,399

Table C: Categories

Section Description	Number of Sections
Regular	3,217
Crash Sites	182
All Sections	3,399

Table D: Functional Classifications

Category	Code	Description	Number of Sections
Rural	9	Principal Arterial (PA)-Interstate	269
	10	PA-Other	680
	14	PA-Expressway	225
	15	PA-Freeway	61
	20	Minor Arterial (MA)-Other	985
	30	Major Collector (MAC)-Other	238
	40	Minor Collector(MIC)-Other	6
Urban	49	PA-Interstate	203
	50	PA-Freeway: Connecting Link of Rural PA	173
	52	PA-Freeway: Non-connecting Link	1
	53	PA-Expressway: Connecting Link of Rural PA	16
	54	PA-Expressway: Connecting Link of Rural MA	29
	60	PA-Other: Connecting Link of Rural PA	184
	61	PA-Other: Connecting Link of Rural MA	204
	62	PA-Other: Non-connecting Link	67
	70	MA-Other: Connecting Link of Rural MA	34
	71	MA-Other: Connecting Link of Rural MAC	20
	73	MA-Other: Non-connecting Link	2
	90	Collector-Other: Connecting Link of Rural MAC	2
All Sections			3,399

Table E: Pavement Age

Pavement Age (Determined from Construction Year)	Age Band	Number of Sections
0 – 5	1	754
6 -10	2	724
11 – 15	3	822
16 – 20	4	527
> 20	5	572
All Sections		3,399

3 FRICTION TESTING

3.1 Dynatest 1295 Pavement Friction Tester

The Dynatest 1295 PFT measures average locked wheel (skid) and peak incipient (slip) friction characteristics on paved surfaces. The 1295 consists of a fully instrumented tow vehicle and test trailer which uses the Dynatest two-axis force transducer to provide dynamic vertical load and horizontal tractive force measurements. A picture of the Dynatest PFT system is shown in Figure 2.

Figure 2 Dynatest 1295 PFT System

As a pavement measuring device, the 1295 meets all the requirements of ASTM E274. A complete description of the Dynatest 1295 PFT is provided in Appendix A.

The Dynatest 1295 PFT was calibrated on July 27, 2012, at our Westland, MI office about one week prior to the Wisconsin Department of Transportation skid testing as shown in Appendix B.

The Dynatest 1295 PFT was also equipped with a 64 kHz texture laser for measurement of pavement texture. While measurement of texture data was a part of the project scope, texture data was acquired on approximately 80% of the pavement sections tested. The scope of the data analysis for this project was focused on the skid data and the texture data was not analyzed. Texture data was acquired and reported as Mean Profile Depth (MPD) and Estimated Texture Depth (ETD) in accordance with ASTM E1845, and has been included in the database provided to WisDOT. A picture of the texture laser is shown in Figure 3.

Figure 3 Texture Laser

3.2 Friction Testing Protocol

ASTM E274 allows the use of several different types of tires for friction evaluations including the most frequently used ASTM E-501 *Standard Rib Tire for Pavement Skid-Resistance Test* and ASTM E-524 *Standard Smooth Tire for Pavement Skid-Resistance*. It has been documented that the ribbed tire test is predominantly influenced by microtexture, whereas the smooth tire test is influenced to a greater extent by macrotexture (Henry, 2000).

For illustration purposes, both the rib and smooth tires are shown in Figure 4. For this project, all friction measurements were made using the ASTM E501 standard rib tire, and all measurements were made in the left wheelpath.

Figure 4 Photographic Illustration of a E501 (ribbed) and E524 (smooth) Test Tire

A number of test tires were utilized for this project. Prior to any friction measurements, each test tire was ‘worn in’ by driving it for a minimum of 200 miles.

The general test protocol was as follows:

1. Operator developed a daily test schedule and routing plan;
2. Operator performed all field validation of data, including test sections that needed to be re-tested;
3. Raw data files were uploaded to Dynatest’s FTP site at the end of each day;
4. Dynatest engineer reviewed and checked all data;
5. A master database containing all the measurements was maintained;
6. Weekly progress reports were sent to WisDOT personnel.

3.3 Test Schedule

Friction testing was performed from Monday, August 13 through Saturday, October 20, 2012. A total of 44 days were required to conduct the testing. All the testing was performed by one Dynatest operator using the same equipment.

Test times and schedules were affected by weather as well as the widely scattered locations of individual test sections. Friction testing was conducted only when the pavement surface was dry and the pavement temperature was above 40° F. However, the friction testing was actually performed under simulated wet conditions. Testing began in Zone A (Madison area) and progressed northwards.

3.4 Weather Conditions during Friction Testing

The following weather conditions were observed during friction testing. Figure 5 shows that the temperatures ranged from 48 to 103° F in this period. Note that these temperatures were measured with the 1295 system and represent the average temperature (during testing) for that day.

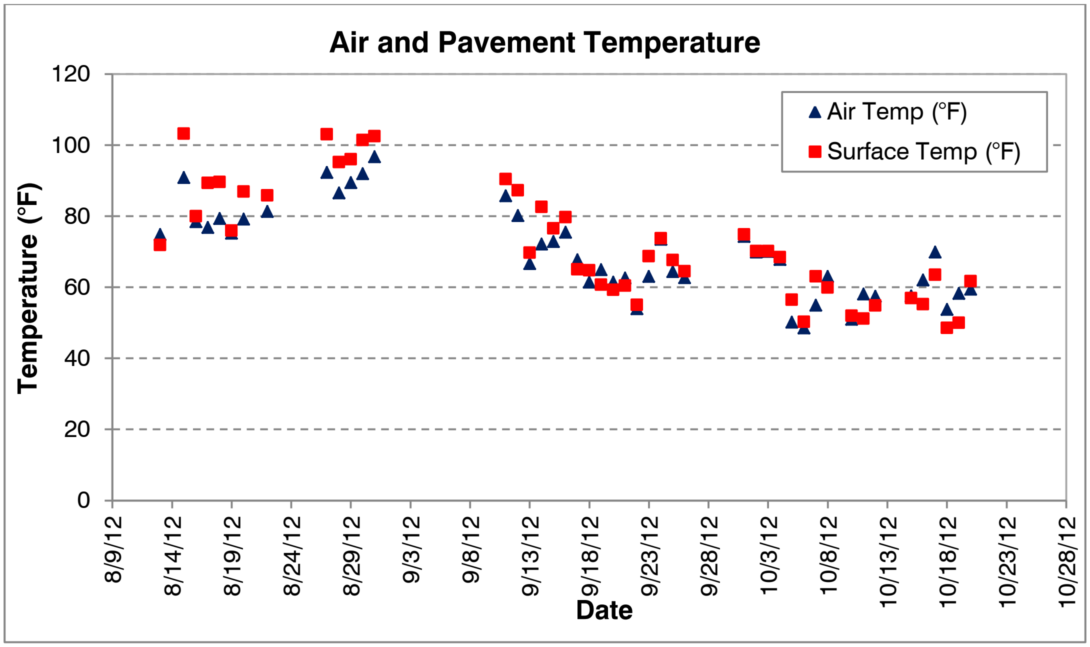


Figure 5 Average Air and Surface Temperature during Testing

3.5 Speed Gradient Testing

Since the friction testing was not performed at a constant speed of 40 mph for all sections, speed gradient testing was performed on four (4) test sites selected by WisDOT. These test sections included one hot mix asphalt (HMA) section, two stone matrix asphalt (SMA) sections and two concrete sections. The location details of these sections are presented in Table 1 below.

Table 1 Speed Gradient Test Locations

Section	Surface Type	Highway	Start Lat.	Start Long.	End Lat.	End Long.	Length (miles)	SN (WI ID)
HMA	HMA - E-3, 19 mm	061N	42.631010	-90.605543	42.639995	-90.622580	1.09	83380
SMA-1	SMA	053N	45.249170	-91.603710	45.257280	-91.611970	0.69	71690
SMA-2	SMA	10N	44.598627	-90.335863	44.599062	-90.315803	1	5250
Concrete – TT	Concrete – Trans. Tining	151N	42.773410	-90.312496	42.784581	-90.301785	0.95	124670
Concrete – LT	Concrete – Long. Tining	151N	42.665034	-90.550160	42.677784	-90.542784	1.02	124510

The speed gradient testing was performed at 30, 40, 50 and 60 mph to determine the speed gradient required for skid number adjustments. The testing was repeated at 30 mph to ensure that the skid numbers did not change between the two 30 mph runs.

The test results are shown in Table 2 on the following page.

Table 2 Skid Resistance Speed Gradient

Section ID	Count	Section Length (mile)	Skid Number (SN)				Average Speed (mph)
			Average	Std. Dev.	Min.	Max.	
HMA_30	5	1.09	55.90	0.96	54.3	56.7	29.6
HMA_40	5		49.46	1.36	48.1	51.7	39.8
HMA_50	5		44.22	0.95	43.3	45.7	50.0
HMA_30a	5		55.68	3.00	52.5	60.1	29.7
SMA-1_30	5	0.69	63.42	0.92	62.3	64.4	30.2
SMA-1_40	5		58.22	1.48	55.8	59.7	39.4
SMA-1_50	5		53.52	1.33	52.4	55.5	49.9
SMA-1_60	5		51.14	0.62	50.6	52.2	60.1
SMA-1_30a	5		62.18	1.78	60.2	65.0	30.0
SMA-2_30	5	1.0	55.50	1.43	53.7	57.0	30.4
SMA-2_40	5		51.12	0.65	50.2	51.9	40.4
SMA-2_50	5		48.18	1.28	46.6	50.0	50.2
SMA-2_60	5		45.32	1.22	43.5	46.5	60.0
SMA-2_30a	5		57.14	1.30	55.7	58.9	29.7
Concrete-30	5	0.95	61.36	2.23	59.1	64.0	30.0
Concrete-40	5		54.32	2.57	50.6	56.9	40.0
Concrete-50	5		48.58	2.44	44.6	51.3	50.0
Concrete-60	5		43.50	1.18	41.7	44.4	60.0
Concrete-30a	5		60.84	2.37	58.2	64.1	30.4
Concrete-30	5	1.02	59.84	3.31	55.2	63.0	30.6
Concrete-40	5		52.42	1.63	50.7	55.0	39.8
Concrete-50	5		47.18	3.15	43.4	51.5	50.4
Concrete-60	5		41.84	1.51	39.4	43.4	60.4
Concrete-30a	5		59.42	4.63	54.6	66.7	30.4

The average skid numbers were plotted against test speeds as shown in Figure 6 and the skid resistance speed gradient was calculated.

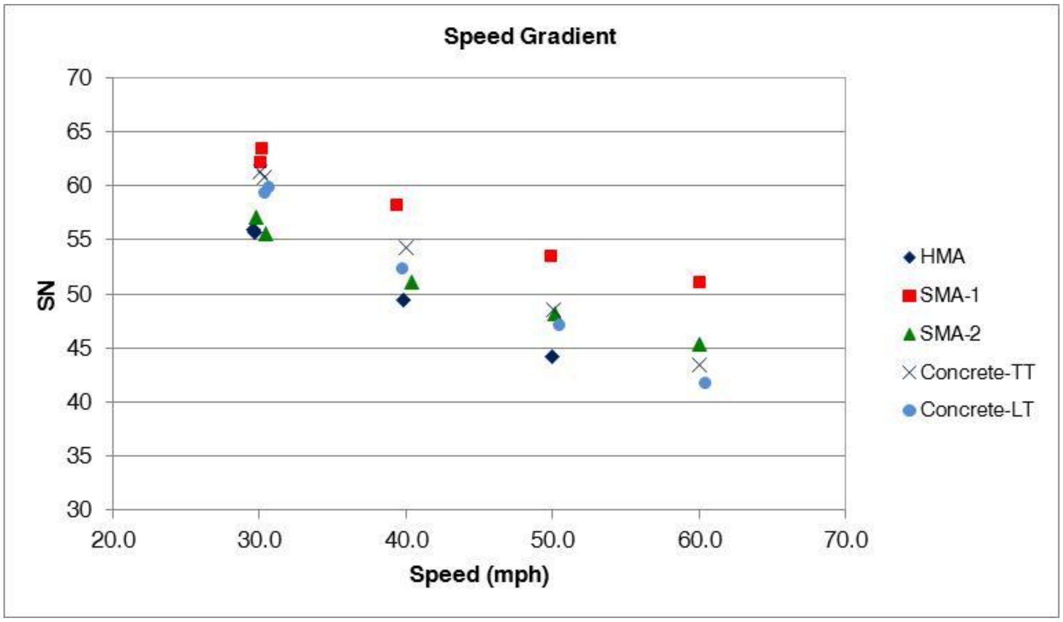


Figure 6 Skid Resistance Speed Gradient

Linear regression through the test points (for each individual pavement surface type) resulted in the speed gradients shown in Table 3.

Table 3 Speed Gradient Values

Section	Slope	Intercept	R^2 (%)	Average Slope
HMA	-0.57	72.67	1.00	-0.57
SMA-1	-0.40	74.62	0.97	-0.39
SMA-2	-0.37	67.20	0.97	
Concrete-TT	-0.60	78.87	1.00	-0.60
Concrete-LT	-0.59	77.30	0.99	

The speed gradients (as shown in the Average Slope column in the table above) were used to adjust the skid numbers and peak skid numbers to a speed of 40 mph, assuming that these gradients are representative of the tested sections.

For example, if an HMA section was tested at a speed of 45 mph, resulting in a measured SN of 55, the adjusted SN40R value was calculated as:

$$SN40R = (55) - \left((40 - 45) \times (0.57)\right) = 57.85$$

The skid numbers were not adjusted for average test speeds between 39 and 41 mph which meet the speed requirements of ASTM E274.

3.6 Sections Excluded from Analysis

As described earlier, a total of 3,399 pavement sections were included as part of this project. However, five sections could not be tested as they were closed for construction activities. So, a total of 3,394 roadway sections were tested using the Dynatest 1295 Pavement Friction Tester. Many of the pavement sections had posted speeds less than 40 mph, had high traffic volumes, were very short in length, etc. For most of these sections, the measured skid resistance data was adjusted to 40 mph using the speed gradients previously described. However, after a careful review of the data, it was decided to exclude six of the test sections that were tested at average speeds less than 23 mph. Therefore, a total of 11 of the original 3,399 pavement sections were eliminated from the analysis. Details of sections excluded from the analysis are shown in Table 4.

Table 4 Excluded Sections

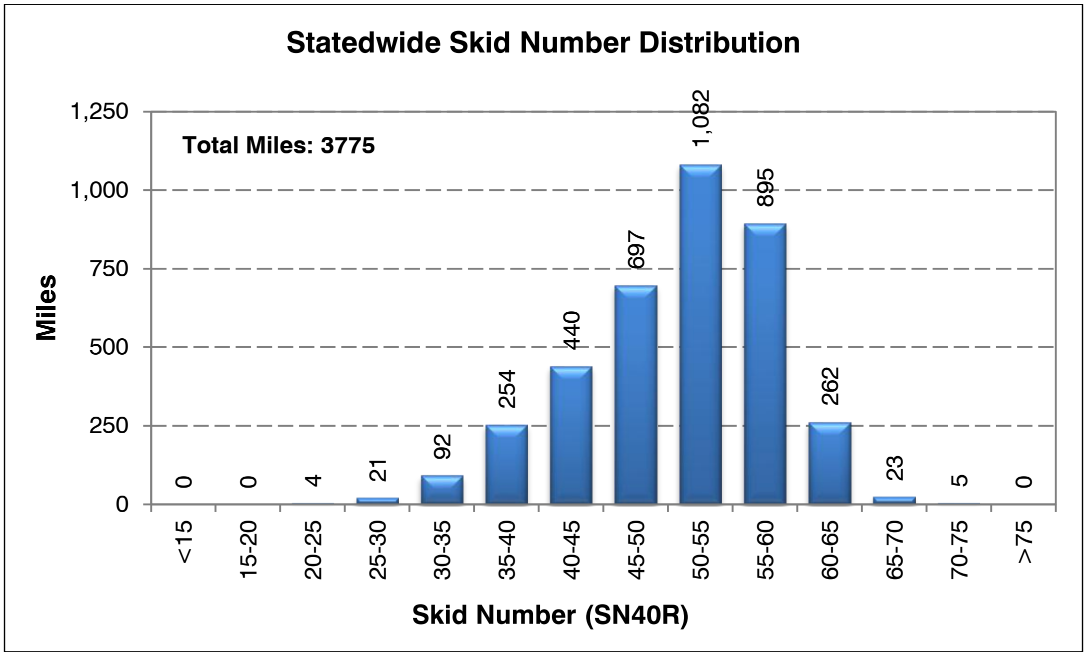
No.	Hwy.	PDP_ID	From_RP	Length	County	Reason for Exclusion
1	011W	13147	011W084B000	1.97	Green	Not tested – closed for construction
2	089N	7259	089N031_000	0.72	Jefferson	Low test speed
3	119W	14079	119W006_000	0.27	Milwaukee	Not tested – closed for construction
4	014W	9153	014W005_000	1.34	La Crosse	Test point was on a bridge
5	022N	2012	022N180_000	1.32	Oconto	Not tested – closed for construction
6	022N	2013	022N182_000	1.30	Oconto	Not tested – closed for construction
7	022N	10625	022N183_000	1.15	Oconto	Not tested – closed for construction
8	047N	4259	047N006_018	0.86	Outagamie	Low test speed
9	054E	5057	054E243M000	0.92	Brown	Low test speed
10	040N	3734	040N034_000	1.39	Chippewa	Low test speed
11	124N	18392	124N125P000	1.17	Chippewa	Low test speed

Note: PDP_ID and From_RP are WisDOT generated identifiers

Therefore a total of 3,388 sections have been considered for all statistical and analytical purposes in this report.

4 SUMMARY STATISTICS

Summary statistics provided in this section detail the overall distribution of friction numbers (SN40R) for Wisconsin statewide as well as for individual WisDOT regions. The skid number distributions are provided in terms of number of miles (Part a) of the figures below, as well as in terms of percentages (Part b) of the figures below. Note that Figures 7 through 12 include all pavement surface types, ages and functional classifications.



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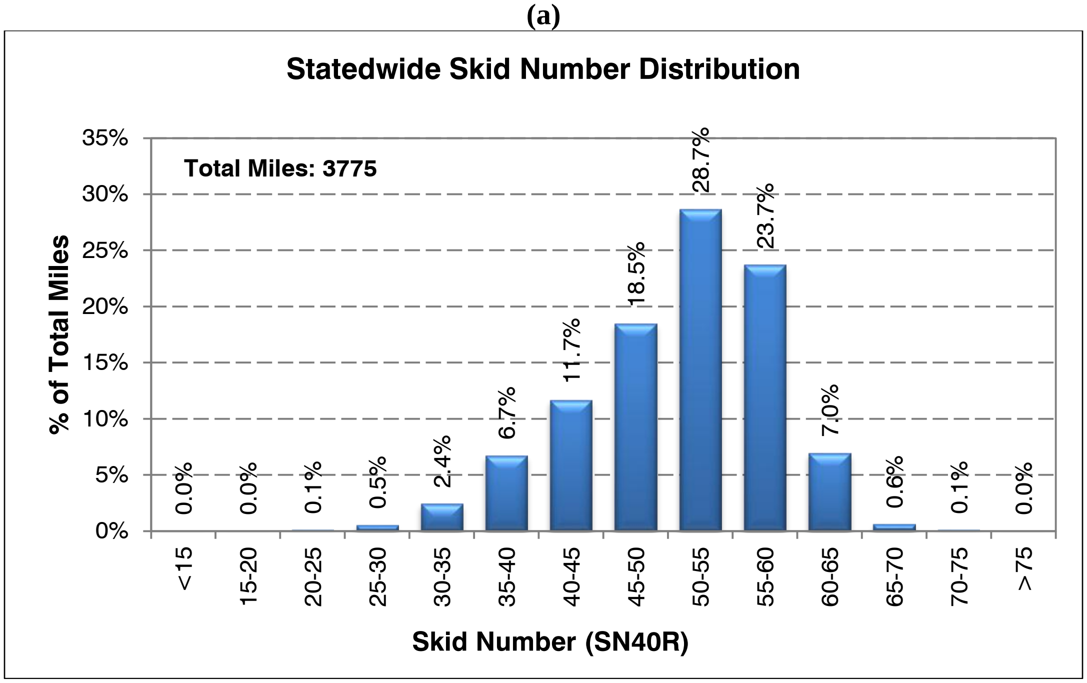
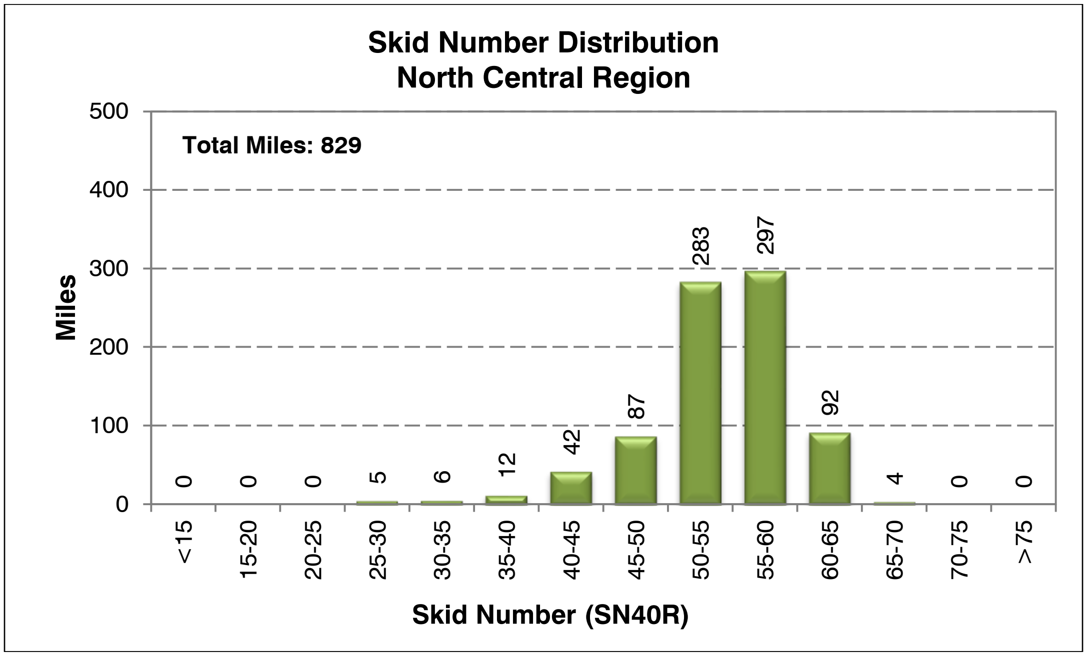


(b)

Figure 7 Skid Number Distribution – Statewide



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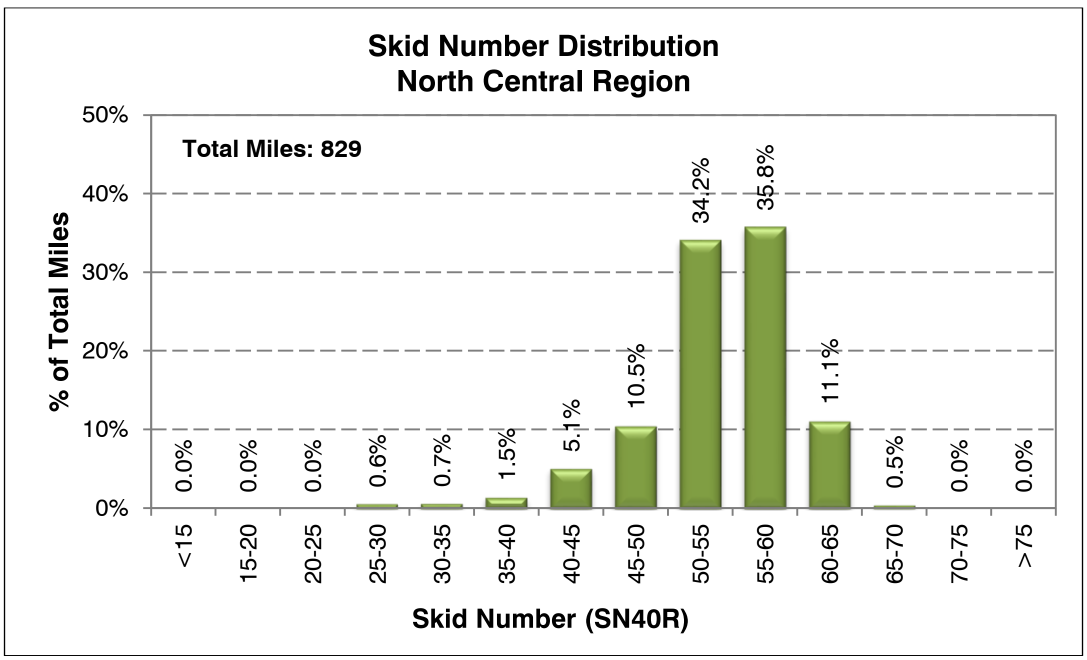

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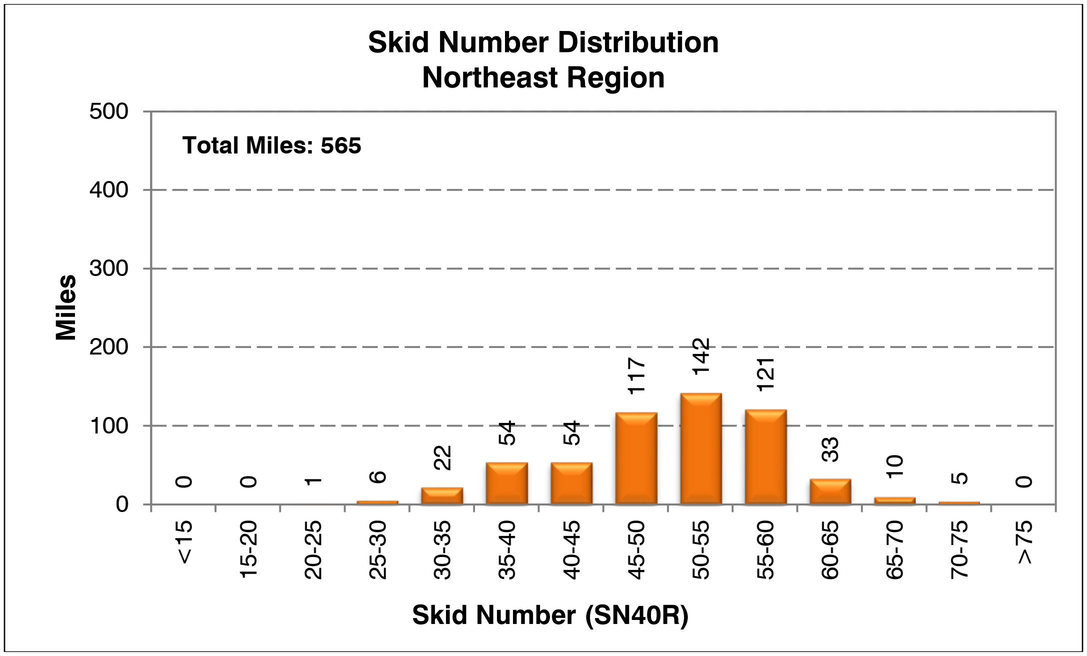
Figure 8 Skid Number Distribution – North Central Region



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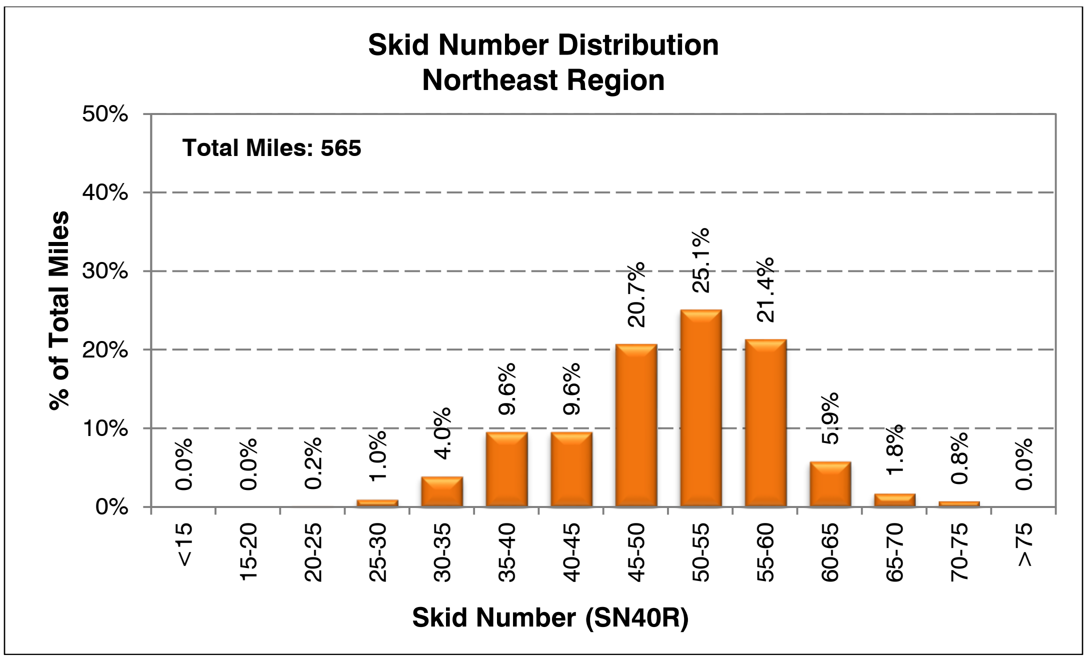
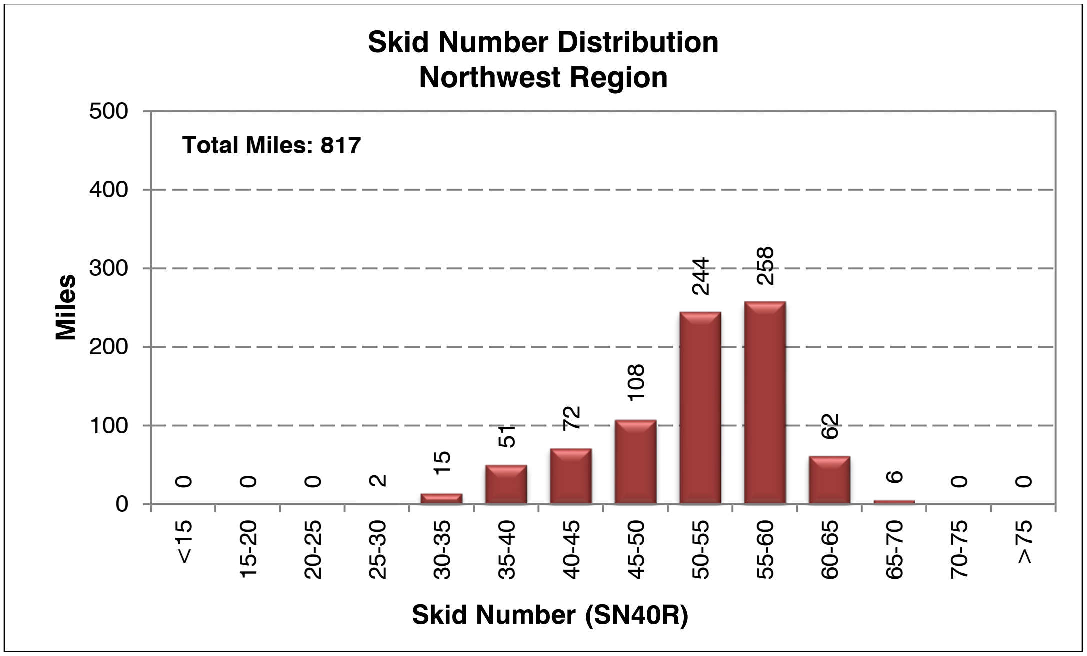


(b)

Figure 9 Skid Number Distribution – Northeast Region



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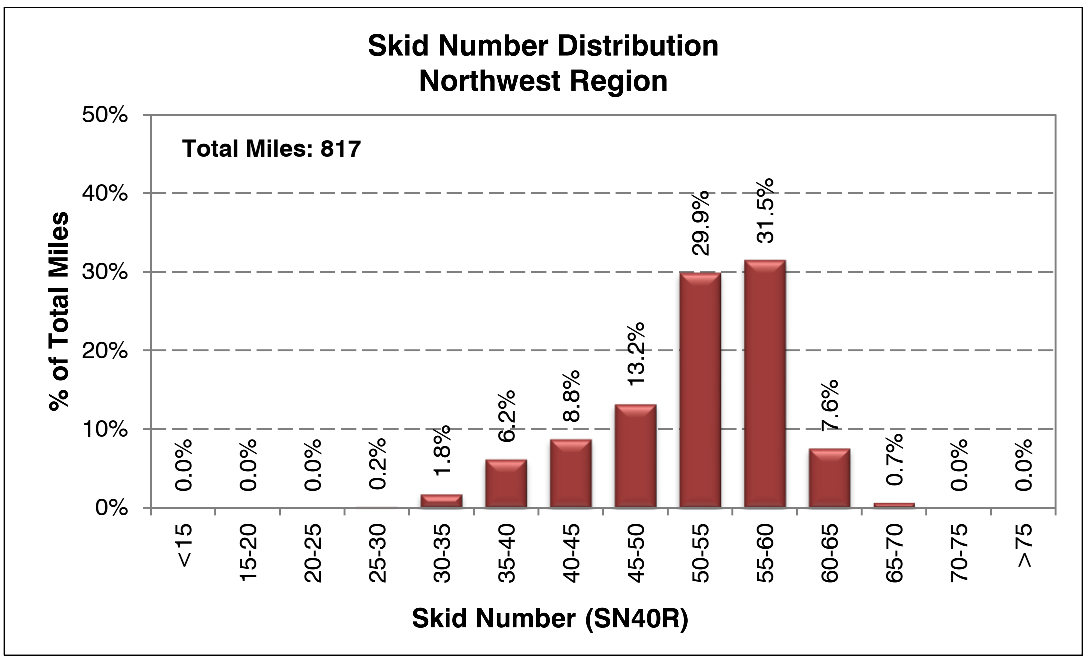

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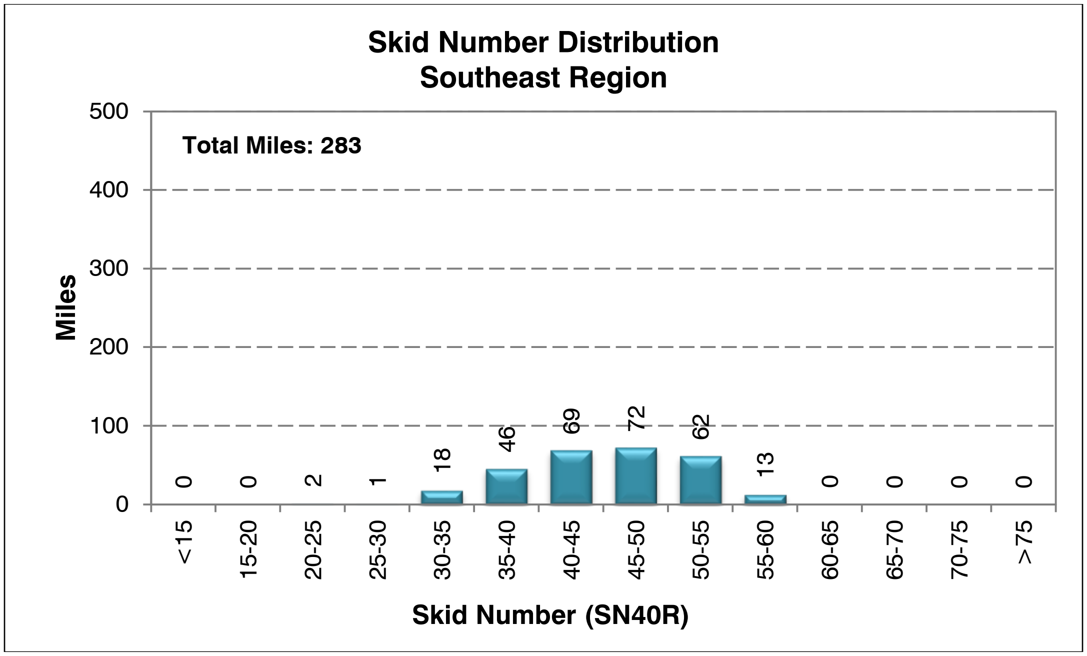
Figure 10 Skid Number Distribution – Northwest Region



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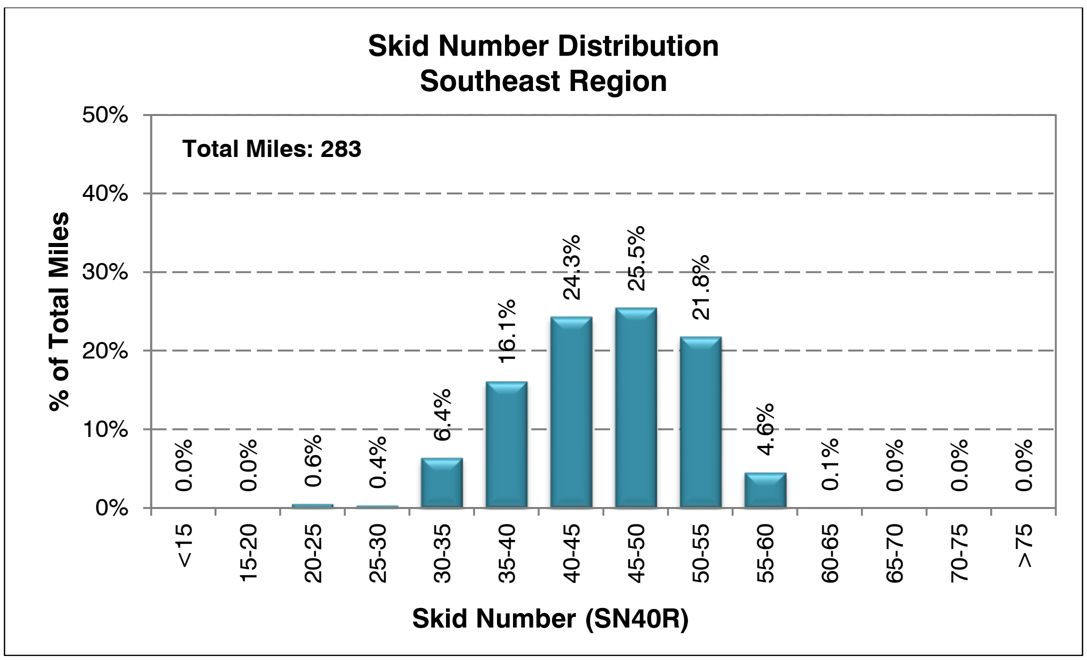
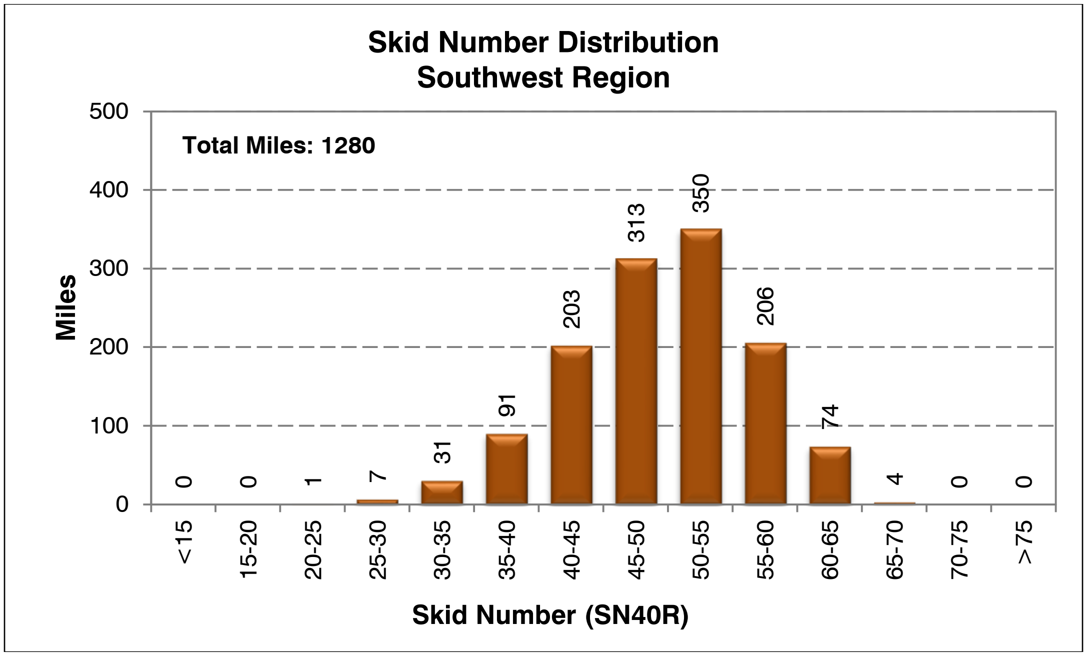


(b)

Figure 11 Skid Number Distribution – Southeast Region



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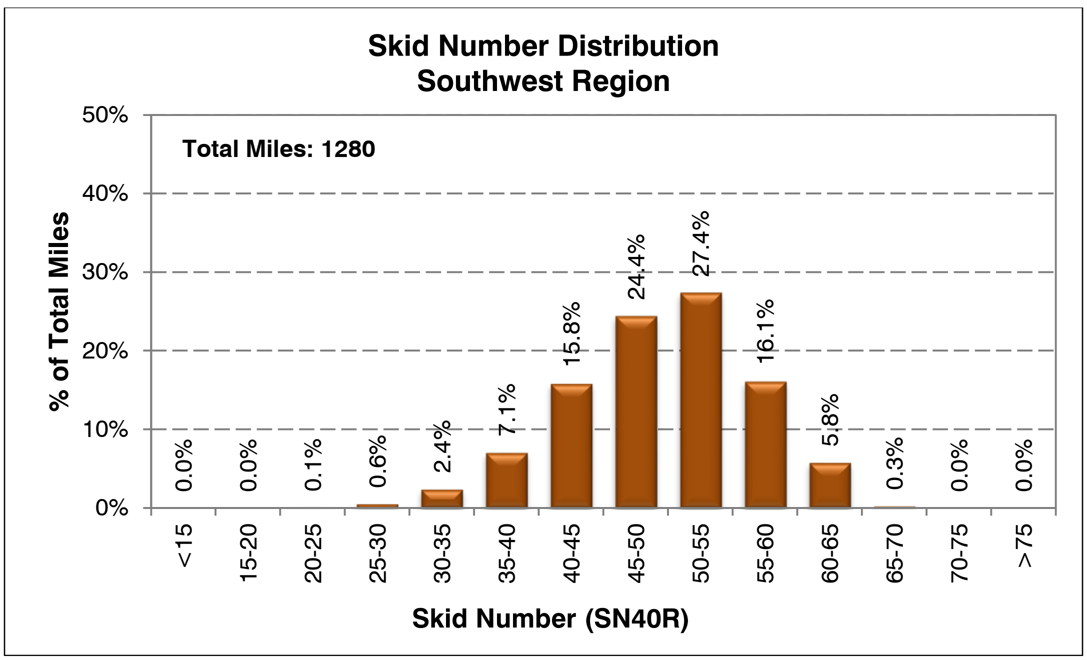

(b)

Figure 12 Skid Number Distribution – Southwest Region

Tables 5 through 10 show the skid number statistics statewide and for individual counties. Note that the average SN40R shown in these tables is a weighted average. An example calculation of weighted average is shown in Appendix C.

Table 5 Skid Number Statistics - Statewide

Region	Sections Tested	Length (miles)	Min. SN40R	Avg. SN40R	Max. SN40R	St. Dev.
STATEWIDE	3388	3774.5	24.0	50.8	72.9	7.5

Table 6 Skid Number Statistics – North Central Region

Region	County	Sections Tested	Length (mi)	Min. SN40R	Avg. SN40R	Max. SN40R	St. Dev.
NC	FOREST	1	1.4	49.3	49.3	49.3	
NC	GREEN LAKE	1	0.8	58.4	58.4	58.4	
NC	LANGLADE	118	138.8	27.1	54.1	62.8	7.6
NC	LINCOLN	157	181.4	33.9	55.9	64.2	5.5
NC	MARATHON	5	3.3	44.9	46.7	49.0	1.7
NC	ONEIDA	139	165.9	36.5	53.8	66.4	5.0
NC	PORTAGE	148	168.0	33.4	52.9	61.3	4.9
NC	WAUPACA	2	1.0	55.7	55.9	55.9	0.1
NC	WOOD	158	168.9	32.3	52.9	64.0	6.2
NC	**REGION WIDE**	**729**	**829.4**	**27.1**	**53.9**	**66.4**	**5.9**

Table 7 Skid Number Statistics – Northeast Region

Region	County	Sections Tested	Length (mi)	Min. SN40R	Avg. SN40R	Max. SN40R	St. Dev.
NE	BROWN	162	179.8	24.8	45.8	66.9	9.5
NE	DOOR	17	20.8	51.7	58.0	61.5	2.5
NE	FOND DU LAC	3	3.5	39.1	50.2	57.0	9.9
NE	MANITOWOC	2	1.4	34.3	50.7	53.2	13.4
NE	MARINETTE	21	22.3	44.6	54.1	60.6	4.7
NE	OCONTO	131	145.4	39.4	53.6	65.6	5.1
NE	OUTAGAMIE	185	190.8	29.3	50.3	72.9	8.2
NE	SHEBOYGAN	1	0.3	39.0	39.0	39.0	
NE	WINNEBAGO	2	0.6	51.6	54.0	59.9	5.9
NE	**REGION WIDE**	**524**	**564.8**	**24.8**	**50.1**	**72.9**	**8.5**

Table 8 Skid Number Statistics – Northwest Region

Region	County	Sections Tested	Length (mi)	Min. SN40R	Avg. SN40R	Max. SN40R	St. Dev.
NW	BARRON	22	25.7	34.2	48.8	58.2	6.4
NW	BUFFALO	1	1.7	43.8	43.8	43.8	
NW	CALUMET	1	1.0	51.1	51.1	51.1	
NW	CHIPPEWA	228	253.3	31.0	54.2	64.1	5.3
NW	DOUGLAS	2	0.4	34.1	45.4	50.3	11.5
NW	EAU CLAIRE	170	194.0	30.9	51.8	65.0	6.0
NW	ST. CROIX	1	0.2	32.8	32.8	32.8	
NW	TREMPEALEAU	157	175.0	28.3	49.7	69.6	9.3
NW	WASHBURN	145	165.5	32.7	52.6	62.1	6.5
NW	**REGION WIDE**	**727**	**816.8**	**28.3**	**52.2**	**69.6**	**7.0**

Table 9 Skid Number Statistics – Southeast Region

Region	County	Sections Tested	Length (mi)	Min. SN40R	Avg. SN40R	Max. SN40R	St. Dev.
SE	KENOSHA	6	4.5	49.3	54.0	61.1	4.3
SE	MILWAUKEE	12	4.2	30.5	41.4	51.7	6.4
SE	OZAUKEE	3	2.7	33.2	45.4	50.5	9.2
SE	RACINE	1	0.3	50.1	50.1	50.1	
SE	WALWORTH	4	6.1	40.4	48.5	58.3	7.4
SE	WASHINGTON	2	2.0	53.8	56.3	58.3	3.2
SE	WAUKESHA	234	263.5	24.1	44.8	57.1	6.3
SE	**REGION WIDE**	**262**	**283.3**	**24.1**	**45.1**	**61.1**	**6.5**

Table 10 Skid Number Statistics – Southwest Region

Region	County	Sections Tested	Length (mi)	Min. SN40R	Avg. SN40R	Max. SN40R	St. Dev.
SW	COLUMBIA	28	29.4	39.3	46.2	54.9	4.2
SW	DANE	95	98.2	24.0	48.7	64.5	8.2
SW	DODGE	1	1.0	46.0	46.0	46.0	
SW	GRANT	8	10.5	48.9	52.8	57.0	3.2
SW	GREEN	107	121.3	34.9	51.7	68.7	7.2
SW	JEFFERSON	154	172.8	28.8	51.0	63.9	7.3
SW	JUNEAU	1	1.4	52.5	52.5	52.5	
SW	LA CROSSE	162	167.3	29.5	47.8	65.0	7.8
SW	LAFAYETTE	5	4.6	48.2	51.3	54.7	3.0
SW	MONROE	226	259.7	33.6	50.4	64.0	6.7
SW	ROCK	210	238.4	27.4	48.5	64.1	6.0
SW	VERNON	149	175.7	31.8	48.8	63.6	7.5
SW	**REGION WIDE**	**1146**	**1280.2**	**24.0**	**49.5**	**68.7**	**7.2**

5 DATA ANALYSIS

5.1 Pavement Surface Type

As described in Section 2.2, pavement surface type information was provided by WisDOT personnel. Three broad surface types were defined: hot mix asphalt (HMA), Portland cement concrete (Concrete) and stone matrix asphalt (SMA). Skid number statistics for the three broad surface types are provided in Table 11 below.

Table 11 Skid Number Distribution by Broad Surface Type

Surface Type	Code	Sections Tested	Length (mi)	Min. SN40R	Avg. SN40R	Max. SN40R	St. Dev.
Hot Mix Asphalt	HMA	2413	2724.2	24.1	51.6	72.9	7.2
Concrete	Concrete	891	952.9	24.0	49.5	66.6	7.5
Stone Matrix Asphalt	SMA	84	97.4	26.1	42.5	55.0	6.8

Table 12 shows the skid number distributions for all detailed surface types.

Table 12 Skid Number Distribution by Detailed Surface Type

Surface Type	Detailed Surface	Sections Tested	Length (mi)	Min. SN40R	Avg. SN40R	Max. SN40R	St. Dev.
HMA	A1	9	11.3	46.1	48.5	50.3	1.5
HMA	HMA	376	422.5	28.1	51.6	68.7	7.8
HMA	HMA Warranty	328	378.5	34.1	53.4	65.6	5.0
HMA	B1	12	11.9	24.1	44.0	58.2	9.9
HMA	B1Q	5	5.3	40.5	44.5	47.3	2.7
HMA	C	4	6.1	48.6	51.1	53.3	2.1
HMA	C1	1	0.9	55.0	55.0	55.0	
HMA	C1Q	1	0.7	48.6	48.6	48.6	
HMA	D1	4	3.8	44.2	52.1	60.3	7.2
HMA	E-0.3	48	52.7	38.4	54.8	64.1	5.6
HMA	E-1	229	251.2	34.0	55.2	70.6	6.3
HMA	E-10	96	108.4	30.1	50.2	57.6	5.4
HMA	E-3	342	374.3	28.8	52.3	72.9	6.3
HMA	E-30	183	218.7	30.9	50.7	64.5	5.0
HMA	HV	89	97.3	30.4	45.3	58.9	7.8
HMA	LV	64	74.4	38.9	54.2	69.6	7.4
HMA	MV	365	414.3	25.7	50.5	66.9	8.2
HMA	Recycled HMA	104	118.9	31.8	47.4	64.0	7.7
HMA	Road Mix	15	17.7	40.3	53.3	63.2	6.3
HMA	Single Aggregate HMA	12	12.0	30.0	53.0	63.8	9.5
HMA	Superpave	126	143.2	31.3	49.5	65.8	7.3

Surface Type	Detailed Surface	Sections Tested	Length (mi)	Min. SN40R	Avg. SN40R	Max. SN40R	St. Dev.
Concrete	Transverse Tining	707	751.9	24.8	49.5	66.6	7.3
Concrete	Longitudinal Tining	114	127.1	34.2	52.9	61.5	5.9
Concrete	Diamond Grinding	21	21.7	24.0	47.1	62.1	10.5
Concrete	Turf Drag	49	52.3	27.4	42.3	56.6	7.1
SMA	SMA	84	97.4	26.1	42.5	55.0	6.8

The detailed surface types shown in Table 12 were obtained from WisDOT's database and provided by WisDOT. Many of the HMA surface types were identified by the specific HMA mixes that were used, while others were just characterized as HMA in general.

Skid number distributions for the three broad surface types are shown in Figures 13 and 14 on the following page.

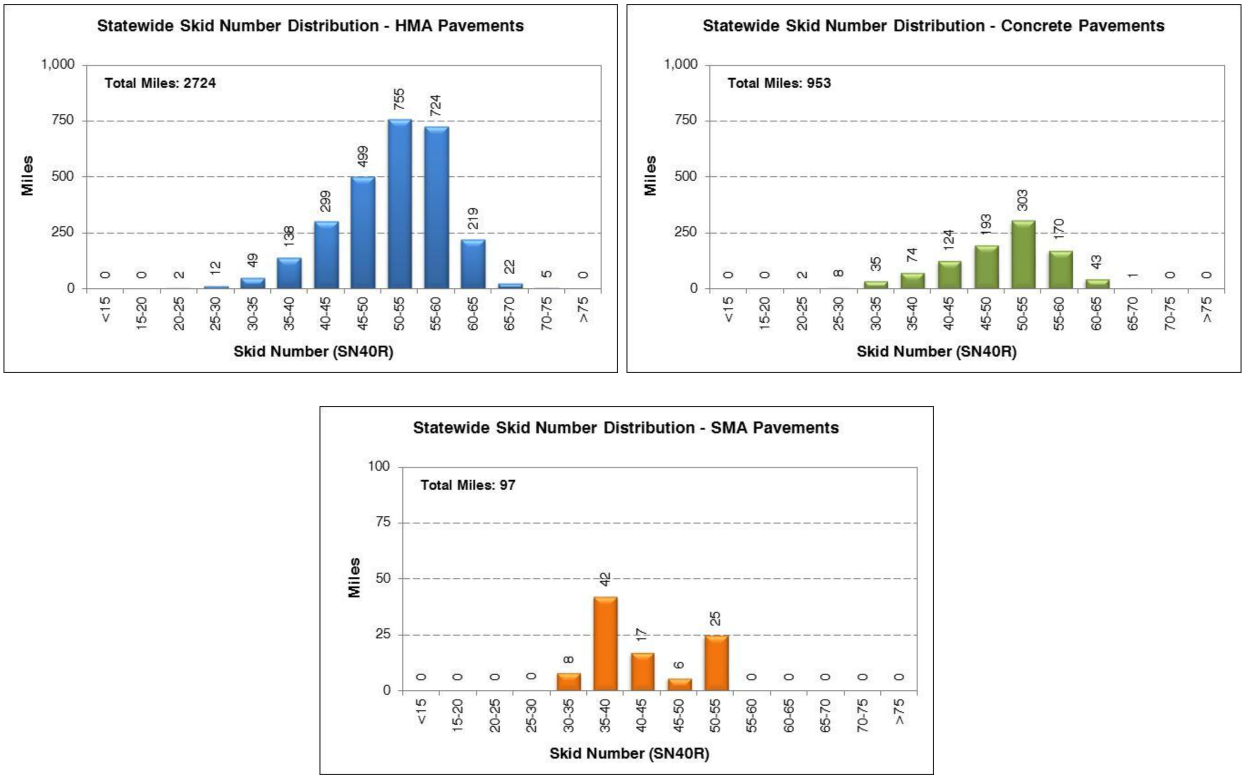

Figure 13 Skid Number Distribution by Surface Type (Length of Sections)

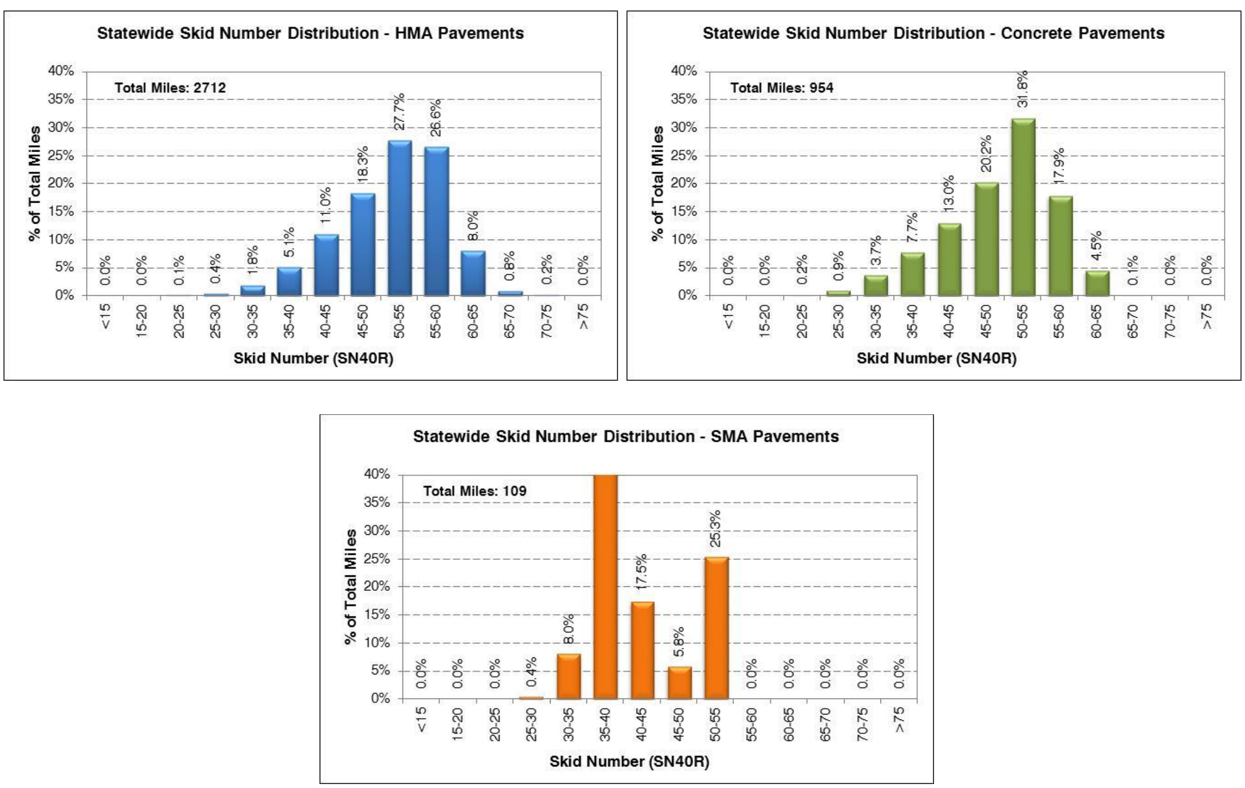

Figure 14 Skid Number Distribution by Surface Type (Percent of Sections)

5.2 Functional Classification

As described in Section 2.2, functional classifications were available for the pavement sections. Skid number statistics analyzed with respect to functional classifications are shown in Table 13.

Table 13 Skid Number Statistics by Functional Classification

Type	Description	Code	Sections Tested	Length (mi)	Min. SN40R	Avg. SN40R	Max. SN40R	St. Dev.
Rural	PA-Interstate	9	269	323.2	33.2	50.4	64.5	5.5
Rural	PA-Other	10	680	774.0	27.4	51.2	65.8	6.4
Rural	PA-Expressway	14	225	258.2	41.6	54.1	63.7	4.0
Rural	PA-Freeway	15	61	68.7	39.4	52.2	59.5	4.7
Rural	MA-Other	20	981	1099.2	25.7	52.9	67.9	7.0
Rural	MAC-Other	30	238	268.8	32.0	55.5	72.9	7.6
Rural	MIC-Other	40	6	7.8	50.3	54.8	59.5	3.4
Urban	PA-Interstate	49	203	231.6	26.1	46.9	63.1	6.5
Urban	PA-Freeway: Connecting Link of Rural PA	50	171	193.8	30.5	49.9	65.0	6.4
Urban	PA-Freeway: Non-connecting Link	52	1	0.1	45.6	45.6	45.6	--
Urban	PA-Expressway: Connecting Link of Rural PA	53	16	18.5	33.6	47.1	56.7	7.1
Urban	PA-Expressway: Connecting Link of Rural MA	54	28	29.7	24.0	43.9	58.0	9.1
Urban	PA-Other: Connecting Link of Rural PA	60	183	174.8	24.1	46.0	62.2	7.7
Urban	PA-Other: Connecting Link of Rural MA	61	201	201.0	29.5	42.9	64.0	6.4
Urban	PA-Other: Non-connecting Link	62	67	64.6	24.8	41.4	55.7	7.5
Urban	MA-Other: Connecting Link of Rural MA	70	34	39.2	33.3	46.4	60.7	7.4
Urban	MA-Other: Connecting Link of Rural MAC	71	20	18.5	33.6	43.1	55.3	6.9
Urban	MA-Other: Non-connecting Link	73	2	0.8	35.1	46.2	51.7	11.7
Urban	Collector-Other: Connecting Link of Rural MAC	90	2	2.4	34.7	47.4	56.4	15.3

Note: Code number obtained from WisDOT functional class code table.

Figure 15 shows the average skid number (SN40R) for the different functional classifications on the primary Y-axis. As additional information, the total length of sections in each functional class is also plotted (red line) on the secondary Y-axis.

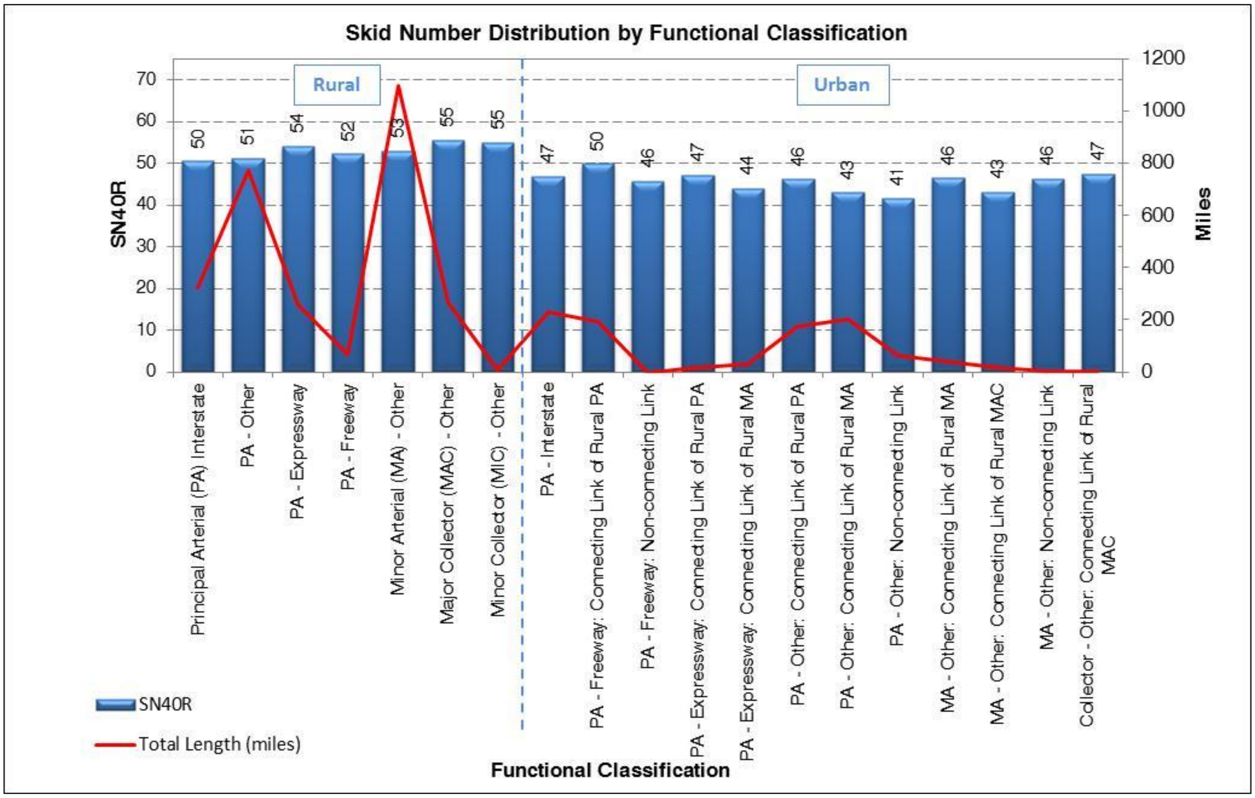

Figure 15 Skid Number Distribution by Functional Classification

Table 14 shows the percent of pavement sections (as determined by the overall length of the pavement sections per category), that fall in a given SN range.

Table 14 Distribution of Skid Data by Functional Classification

Type	Description	Code	Sections Tested	Length (mi)	Percentage of Sections with SN40R:			
					< 25	25-35	35-45	> 45
Rural	PA-Interstate	9	269	323.2			15%	84%
Rural	PA-Other	10	680	774.0		2%	17%	81%
Rural	PA-Expressway	14	225	258.2			2%	98%
Rural	PA-Freeway	15	61	68.7			7%	93%
Rural	MA-Other	20	981	1099.2		1%	13%	86%
Rural	MAC-Other	30	238	268.8		1%	10%	89%
Rural	MIC-Other	40	6	7.8				100%
Urban	PA-Interstate	49	203	231.6		5%	30%	66%
Urban	PA-Freeway: Connecting Link of Rural PA	50	171	193.8		3%	16%	81%
Urban	PA-Freeway: Non-connecting Link	52	1	0.1				100%
Urban	PA-Expressway: Connecting Link of Rural PA	53	16	18.5		11%	21%	68%
Urban	PA-Expressway: Connecting Link of Rural MA	54	28	29.7	3%	18%	31%	48%
Urban	PA-Other: Connecting Link of Rural PA	60	183	174.8	1%	8%	33%	58%
Urban	PA-Other: Connecting Link of Rural MA	61	201	201.0		11%	55%	34%
Urban	PA-Other: Non-connecting Link	62	67	64.6	2%	21%	46%	32%
Urban	MA-Other: Connecting Link of Rural MA	70	34	39.2		12%	36%	52%
Urban	MA-Other: Connecting Link of Rural MAC	71	20	18.5		17%	50%	33%
Urban	MA-Other: Non-connecting Link	73	2	0.8			33%	67%
Urban	Collector-Other: Connecting Link of Rural MAC	90	2	2.4		42%		58%

5.3 Pavement Age

As described in Section 2.2, details regarding the construction year were available for each pavement section. The pavement age was calculated and classified into five age bands as shown in Table E (Section 2.2). Skid number distributions by age bands are shown in Tables 16 and 17.

Table 15 Skid Number Statistics by Pavement Age

Age (Years)	Age Band	Sections Tested	Length (mi)	Min. SN40R	Avg. SN40R	Max. SN40R	St. Dev.
0 - 5	1	753	845.4	29.9	52.9	72.9	6.4
5 - 10	2	723	810.7	26.1	51.5	65.6	6.8
10 - 15	3	820	912.0	27.1	50.3	66.9	7.5
15 - 20	4	522	583.4	24.8	50.3	69.6	7.4
> 20	5	570	623.1	24.0	48.3	68.7	8.5

Table 16 Skid Number Statistics by Surface Type and Pavement Age

Surface	Age Band	Sections Tested	Length (mi)	Min. SN40R	Avg. SN40R	Max. SN40R	St. Dev.
HMA	1	591	665.7	30.1	53.7	72.9	5.8
HMA	2	465	531.1	28.8	52.2	65.6	6.1
HMA	3	697	780.5	27.1	50.4	66.9	7.4
HMA	4	342	384.3	25.7	50.7	69.6	7.7
HMA	5	318	362.5	24.1	50.2	68.7	8.6
Concrete	1	137	152.3	29.9	51.6	62.5	6.9
Concrete	2	199	209.5	30.5	52.5	63.7	6.3
Concrete	3	123	131.5	34.9	50.0	65.0	7.5
Concrete	4	180	199.1	24.8	49.5	62.1	6.7
Concrete	5	252	260.6	24.0	45.6	66.6	7.7
SMA	1	25	27.4	34.9	40.6	47.5	3.5
SMA	2	59	70.0	26.1	43.2	55.0	7.7
SMA	3	--	--	--	--	--	--
SMA	4	--	--	--	--	--	--
SMA	5	--	--	--	--	--	--

Table 17 shows the percent of pavement sections (as determined by the overall length of the pavement sections per category), that fall in a given SN range.

Table 17 Distribution of Skid Data

Surface Type	Pavement Age (years)	Sections Tested	Length (mi)	Percentage of Sections with SN40R:			
				< 25	25 - 35	35 - 45	> 45
HMA	0 - 5	591	665.7		0.9%	5.7%	93.4%
HMA	5 - 10	465	531.1		1.3%	10.2%	88.5%
HMA	10 - 15	697	780.5		2.8%	21.7%	75.5%
HMA	15 - 20	342	384.3		2.9%	21.8%	75.4%
HMA	> 20	318	362.5	0.5%	4.1%	25.6%	69.9%
Concrete	0 - 5	137	152.3		2.3%	18.6%	79.1%
Concrete	5 - 10	199	209.5		1.0%	9.3%	89.7%
Concrete	10 - 15	123	131.5		1.4%	28.7%	70.0%
Concrete	15 - 20	180	199.1	0.5%	3.9%	14.3%	81.2%
Concrete	> 20	252	260.6	0.4%	10.8%	32.0%	56.8%
SMA	0 - 5	25	27.4		3.8%	84.6%	11.7%
SMA	5 - 10	59	70.0		10.3%	51.0%	38.7%
SMA	10 - 15	0	0.0				
SMA	15 - 20	0	0.0				
SMA	> 20	0	0.0				

5.4 Category

The pavement sections were divided into two broad categories—regular and crash sites—as previously described in Section 2.2. Skid number distributions and statistics for these categories are shown in Table 18. Note that Table 18 includes all pavement types, functional classifications, surface types and pavement ages.

Table 18 Skid Number Statistics by Category

Category	Sections Tested	Length (mi)	Min. SN40R	Avg. SN40R	Max. SN40R	St. Dev.
Regular	3207	3603.8	24.0	50.9	72.9	7.5
Crash Sites	181	170.7	26.1	49.7	62.5	6.9

Figure 16 shows the overall skid number distribution (in terms of percent of pavement sections) for the regular and crash site sections. There does not seem to be any perceptible difference in the overall skid number distributions between these two categories. A more detailed analysis of the crash sites is presented in the following section.

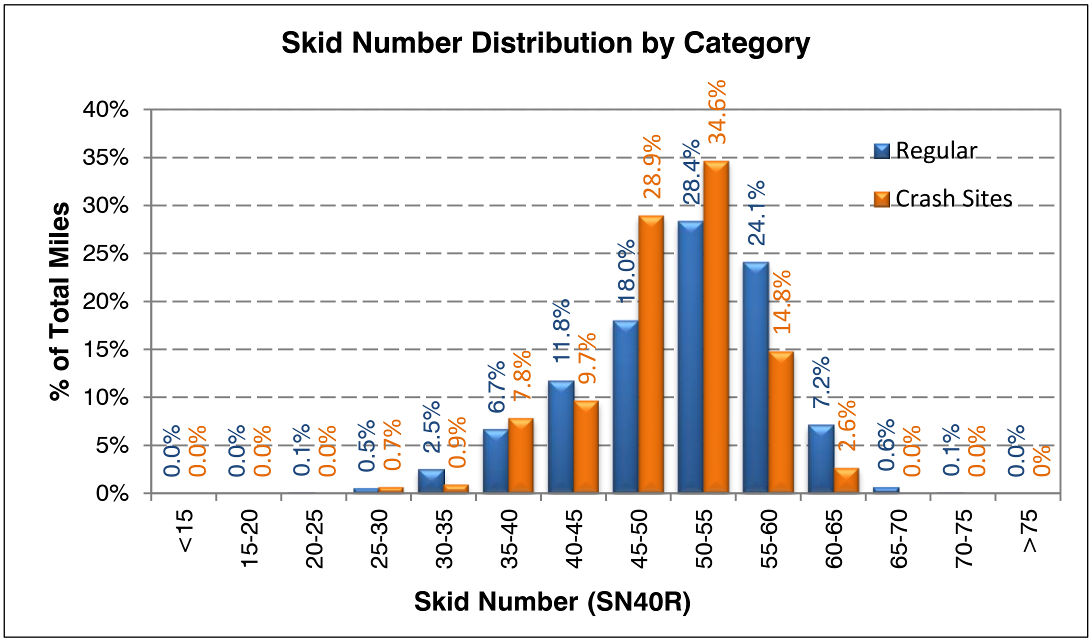

Figure 16 Skid Number Distribution by Category

5.5 Crash Site Sections

A total of 182 pavement sections were identified as sites at which four or more crashes have occurred. Out of these, the pavement section on Route 119W in Milwaukee County could not be tested as it was closed for construction related activities (refer to Table 4). The remaining 181 sections have been considered for analysis in this part of the report.

One of the goals of this project was to evaluate the frictional characteristics of the crash sites. The locations of these sections are shown in Table 19. Summary statistics are shown in Tables 21 through 23.

Table 19 Locations of Crash Site Pavement Sections

Number of Crash Site Pavement Sections	County
1	Buffalo, Calumet, Dodge, Forest, Green Lake, Juneau, Lincoln, Marinette, Oconto, Racine, Sheboygan, St. Croix
2	Douglas, Manitowoc, Oneida, Washburn, Washington, Waupaca, Winnebago
3	Columbia, Fond du Lac, Green, Ozaukee, Trempealeau
4	Chippewa, Outagamie, Vernon, Walworth
5	Marathon, Waukesha
6	Kenosha, Monroe
7	Eau Claire
11	Portage
12	Dane
13	Milwaukee
18	Brown
20	La Crosse
22	Rock

Table 20 Skid Number Statistics for Crash Sites by Pavement Type

Category	Surface Type	Sections Tested	Length (mi)	Min. SN40R	Avg. SN40R	Max. SN40R	St. Dev.
Crash Site	HMA	102	104.6	32.4	49.7	61.1	5.6
	Concrete	73	58.8	28.0	51.0	62.5	7.7
	SMA	6	7.2	26.1	37.8	39.7	5.3

Table 21 Skid Number Statistics for Crash Site Sections by Pavement Type and Age

Surface	Pavement Age	Sections Tested	Length (mi)	Min. SN40R	Avg. SN40R	Max. SN40R	St. Dev.
HMA	0 - 5	23	23.6	39.7	52.0	58.4	4.4
HMA	5 - 10	17	20.1	39.0	52.9	61.1	5.7
HMA	10 - 15	29	29.4	38.4	48.4	58.3	5.1
HMA	15 - 20	18	18.5	35.8	46.5	52.9	4.5
HMA	> 20	15	13.0	32.4	48.6	55.3	6.4
Concrete	0 - 5	7	5.9	47.3	55.6	62.5	6.0
Concrete	5 - 10	19	16.1	30.5	51.2	59.9	7.8
Concrete	10 - 15	11	10.2	35.6	54.4	60.7	7.3
Concrete	15 - 20	12	8.0	34.3	50.5	57.8	6.3
Concrete	> 20	24	18.5	28.0	47.7	56.9	8.5
SMA	0 - 5						
SMA	5 - 10	6	7.2	26.1	37.8	39.7	5.3
SMA	10 - 15						
SMA	15 - 20						
SMA	> 20						

In general, friction testing results showed that the crash sites had similar frictional characteristics to the rest of the pavement network tested. It should be noted that while pavement friction is considered to be an important factor in the evaluation of crash sites, there may be several other compounding factors that lead to the actual traffic crashes. For example, driver error, tire conditioning, faulty brakes, speeding, terrain, driving under the influence, poor visibility, weather conditions, unexpected events, etc. could all contribute to crashes.

Table 22 Distribution of Skid Numbers for Crash Site Sections

Surface Type	Pavement Age (years)	Sections Tested	Length (mi)	Percentage of Sections with SN40R:			
				< 25	25 - 35	35 - 45	> 45
HMA	0 - 5	23	23.6			2%	98%
HMA	5 - 10	17	20.1			1%	99%
HMA	10 - 15	29	29.4			25%	75%
HMA	15 - 20	18	18.5			34%	66%
HMA	> 20	13	12.4		3%	17%	80%
Concrete	0 - 5	7	5.9				100%
Concrete	5 - 10	19	16.1		1%	6%	93%
Concrete	10 - 15	11	10.2			2%	98%
Concrete	15 - 20	12	8.0		2%	6%	92%
Concrete	> 20	26	19.2		8%	25%	68%
SMA	0 - 5						
SMA	5 - 10	6	7.2		6%	94%	
SMA	10 - 15						
SMA	15 - 20						
SMA	> 20						

Crash data was also available for these pavement sections. This data included a description of the hotspot type, total number of crashes, number of weather related crashes and percent of weather related crashes. An analysis of the total number of crashes verses the skid number is shown in Figure 17. Figure 18 also shows this same information grouped by the three pavement surface types.

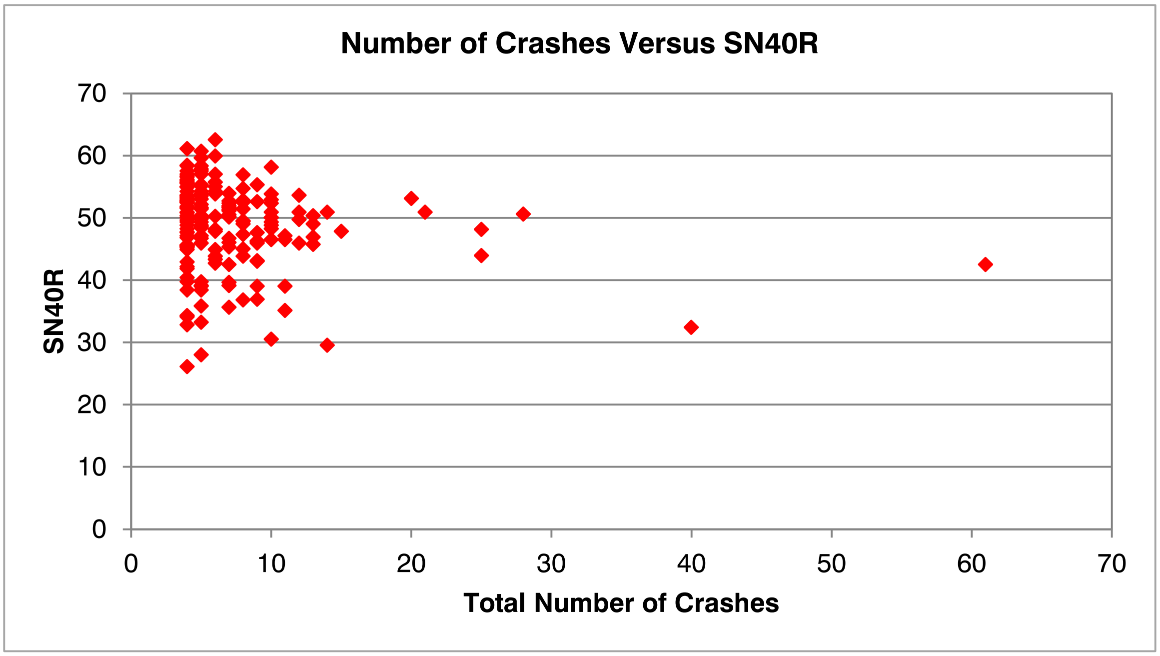

Figure 17 Number of Crashes versus SN40R

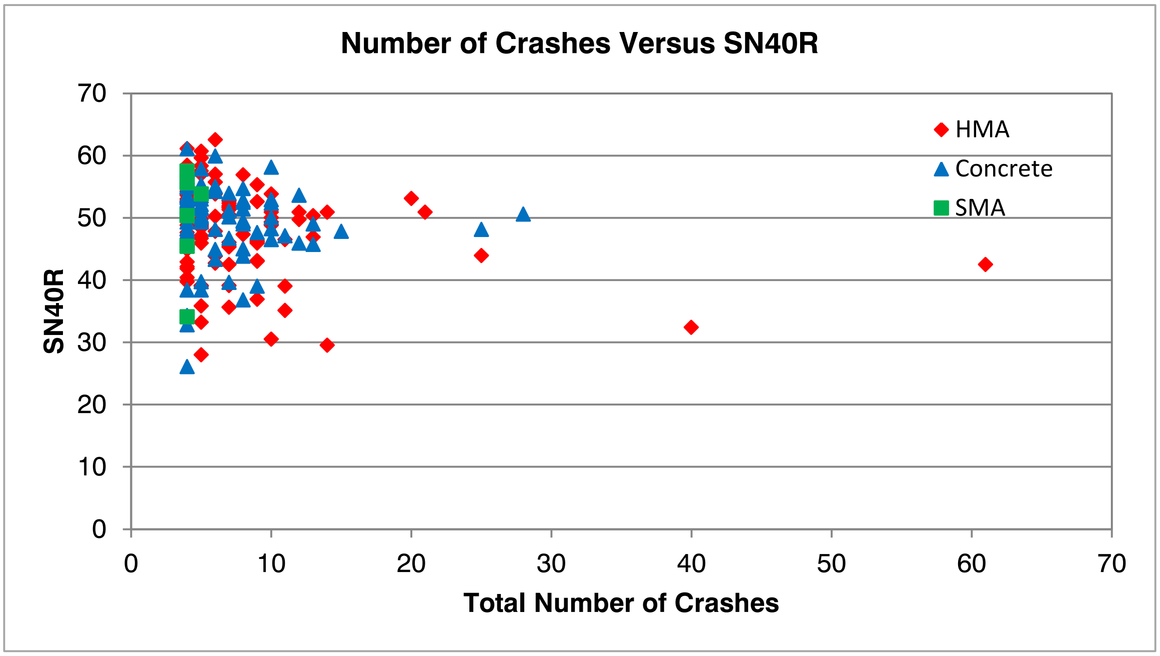

Figure 18 Number of Crashes versus Pavement Surface Type

6 DISCLAIMER

All preceding analyses were based on the friction testing results obtained in the field, as well as other input and analysis assumptions as outlined herein. Pavement section data was provided by the Wisconsin Department of Transportation. Dynatest has made every attempt to base their procedures on sound methodology. However, circumstances beyond the control of Dynatest could result in alterations to the above results which may be completely justifiable.

Please use the above data and information, therefore, as guidelines for the project analyzed and reported herein.

<u>Report prepared by:</u> Salil Gokhale, P.E.
Project Engineer

November 26, 2012

<u>Report reviewed by:</u> Frank Holt
Senior Vice President

7 REFERENCES

1. ASTM E-274. *Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire*. American Society for Testing And Materials, 1999.
2. ASTM 501. *Standard specification for Standard Rib Tire for Pavement Skid-Resistance Tests*. American Society for Testing And Materials, 1994.
3. Henry, J. J. *Evaluation of Pavement Friction Characteristics*. National Cooperative Highway Research Program Synthesis 291, Transportation Research Board, National Research Council, 2000.
4. ASTM E-1845-01 (Reapproved 2005). *Standard Practice for Calculating Pavement Macrotexture Mean Profile Depth.* American Society for Testing and Materials, 2005.

APPENDIX A Dynatest 1295 Pavement Friction Tester

Dynatest 1295 Pavement Friction Tester

The 1295 Pavement Friction Tester (PFT) measures average locked wheel (skid) and peak incipient (slip) friction characteristics on paved surfaces. It is especially useful for maintenance testing to evaluate changes or deterioration in pavement friction due to weathering, high usage, or aging for pavement management.

The 1295 consists of a fully instrumented tow vehicle and test trailer, which uses the Dynatest two-axis force transducer to provide dynamic vertical load and horizontal tractive force measurements. As a pavement measurement device, the 1295 meets all the requirements of ASTM-E274 "Specification For Skid Resistance Using A Full Scale Tire."

All electronic instrumentation is solid state. User friendly, menu-driven Windows® software allows the operator to enter and document multiple test parameters.

The field program calculates the dynamic Skid Number SN from the two-axis force transducer in real time, and displays the friction and speed traces for each test. Test headers, skid numbers, as well as curves and peak incipient fiction if desired, can be printed and/or stored.

Additional software capabilities include automatic system calibration, full system diagnostics, adjustable test cycle timing (within ASTM-E274 specifications), as well as the ability to exit the program and use commercially available software.

Vehicle Instrumentation

The system is equipped with digital optical encoders to accurately measure distance and monitor test speed, a hand remote switch to initiate the automatic test, Laptop PC and graphic printer.

Trailer Assembly

The two-wheel trailer is equipped with a parallelogram suspension, stabiliser bar and disc brakes. An axle mounted force transducer provides direct measurement of the horizontal tractive friction force and the dynamic vertical load on the wheel. A laminar flow nozzle (ASTM E274) is automatically raised and lowered for each test set. Utilises ASTM E501 or E524 test tires.

Real Time Dynamic Skid Curve

From the "Auto Test" menu the operator can display all test results both graphically and numerically. The computer automatically controls all phases of the friction testing cycle. All test results can be displayed and saved to hard drive.

Auto Calibration Menu

Auto Calibration allows the operator to automatically calibrate the electronic measurement equipment with the two-axis force transducer. The system's computer calculates the gain and the offset values for the force transducer and graphically displays the results.

The Friction Tester Field program

Transducer Output/System Diagnostics Menu

This specific part of the field program allows for general diagnostics of:

Force transducer

- View bridge characteristics (forces, gains, offsets)
- Activate bridge calibration circuitry (verify gains & offsets)

Tachometer

- Distance counting (wheel encoder distance pulse counting)
- Velocity measurement (timer latch counting)

Brake system

- Brake activation

Water system

- Nozzle activation

Options

- GPS, dual-side watering and texture laser

APPENDIX B Friction Tester Calibration Certificate

Dynatest®

CALIBRATION CERTIFICATE
1295 PAVEMENT FRICTION TESTER

CUSTOMER: **Dynatest Consulting, Inc.**

ITEM: 1295 Pavement Friction Tester #118

CALIBRATION DATE: July 27th, 2012

CALIBRATION RESULTS:

LEFT			**RIGHT**		
Wheel Load	=	1088	Wheel Load	=	1085
Load Cal	=	452	Load Cal	=	472
Trac Cal	=	456	Trac Cal	=	470

Calibration Certification is performed at a working ambient temperature that is stable within + /-10 degrees /Fahrenheit.

This Calibration Certification was performed in accordance with prescribed Dynatest Consulting standard operating procedures.

CALIBRATION TECHNICIAN
Paul R. Campbell

ISSUED: July 31st, 2012

Limitation of use: Maximum Traction & Load Force not to exceed 2000lbs.

Maintenance / repairs required: Re-Calibration recommended after (1) one year.

APPENDIX C Example Calculation of Weighted Average

C.1 Weighted Average

A weighted average is similar to an arithmetic average, where some data points contribute more toward the overall average than others. If all data points contribute equally, then the weighted average is the same as the arithmetic average.

The weighted average is particularly useful in describing pavement data statistics. Pavement data are frequently measured on pavement sections of varying length, while the requirement is to report an overall 'average' for that section.

The formula for the weighted average is given by:

$$\bar{x}_w = \frac{\sum_{i=1}^{N} w_i x_i}{\sum_{i=1}^{N} w_i}$$

Where x_w is the weighted average, w_i is the weight assigned to the i^{th} observation and x_i is the value for that observation. For example, friction measurements were performed on 12 pavement sections of varying length. The arithmetic and weighted averages are calculated as:

Section Length (miles)	SN40R	Weight (Length x SN40R)
0.54	42.50	22.95
1.20	51.70	62.04
0.23	43.00	9.89
0.10	45.60	4.56
0.38	32.40	12.31
0.25	35.10	8.78
0.64	42.50	27.20
0.09	30.50	2.75
0.17	35.60	6.05
0.67	36.90	24.72
0.40	45.30	18.12
0.26	45.90	11.93
∑ = 4.93	Avg. = 40.58	∑ = 211.3

Arithmetic average = 40.58

Weighted Average = (211.3/4.93) = 42.86

Further reading:
1. http://www.itl.nist.gov/div898/software/dataplot/refman2/ch2/weigmean.pdf