COMPARISON OF SKID RESISTANCE TESTING TO STOPPING DISTANCE TESTING

#OR-RD-98-13

by

Brett Sposito, E.I.T.

for

Oregon Department of Transportation
Research Unit
2950 State Street
Salem, OR 97310

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
OR-RD-98-13		

4. Title and Subtitle	5. Report Date
Comparison of skid resistance testing to stopping distance testing	January 1998
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Brett Sposito, E.I.T.	

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Oregon Department of Transportation Research Unit 2950 State Street Salem, Oregon 97310	
	11. Contract or Grant No.

12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
Oregon Department of Transportation Research Unit 2950 State Street Salem, Oregon 97310	Information Request Summary September to December 1997
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report is intended to statistically summarize the results of a side-by-side test of the skid resistance testing trailer utilized by the Oregon Department of Transportation (ODOT), and the stopping distance car utilized by the Oregon State Police (OSP). The ODOT skid trailer is used for testing skid resistance of pavement surfaces. The OSP method is used for collision reconstruction.

17. Key Words	18. Distribution Statement
Skid resistance, stopping distance	Oregon Department of Transportation, Research Unit

19. Security Classif. (of this report)	20. Security Classif. (of this page)	20. No. of Pages	22. Price
Unclassified	Unclassified	13	

Technical Report Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

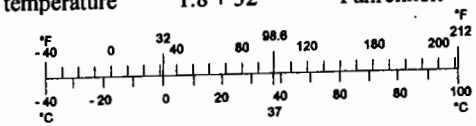
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	Millimeters	Mm
ft	feet	0.305	Meters	M
yd	yards	0.914	Meters	M
mi	miles	1.61	Kilometers	Km
		AREA		
in^2	square inches	645.2	Millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	Hectares	Ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	Milliliters	ML
gal	gallons	3.785	Liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

		MASS		
oz	ounces	28.35	Grams	G
lb	pounds	0.454	Kilograms	Kg
T	short tons (2000 lb)	0.907	Megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
Mm	millimeters	0.039	inches	in
M	meters	3.28	feet	ft
M	meters	1.09	yards	yd
Km	kilometers	0.621	miles	mi
		AREA		
Mm^2	millimeters squared	0.0016	square inches	in^2
M^2	meters squared	10.764	square feet	ft^2
Ha	hectares	2.47	acres	ac
Km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
ML	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
M^3	meters cubed	35.315	cubic feet	ft^3
M^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
G	grams	0.035	ounces	oz
Kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8 + 32	Fahrenheit	°F



(4-7-94 jbp)

* SI is the symbol for the International System of Measurement

ACKNOWLEDGEMENTS

Thank you to the following individuals for their efforts, assistance and guidance:

- Jeff Gower, ODOT Pavement Services, Manager
- Galen McGill, ODOT Research Unit, Manager
- Cole Mullis, ODOT Pavement Services
- George Ogilvie, OSP Senior Trooper, Collision Reconstructionist
- Tom Satchell, ODOT Pavement Services

DISCLAIMER

COMPARISON OF SKID RESISTANCE TESTING TO STOPPING DISTANCE TESTING

TABLE OF CONTENTS

LIST OF TABLES

1.0 INTRODUCTION

The frictional characteristics of a pavement surface describe the friction force of the interface between a vehicle tire and the roadway. Different methods have been developed to measure the friction of pavement surfaces. Usually, a unitless coefficient of friction is given from each of the methods. The method utilized by the Oregon Department of Transportation (ODOT) is the test, "Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire" (*ASTM E 274-90*). This is an American Society for Testing and Materials (ASTM) 1990 standard for testing. The method employed by the Oregon State Police (OSP) is similar to the test, "Standard Test Method for Stopping Distance on Paved Surfaces Using a Passenger Vehicle Equipped With Full-Scale Tires" (*ASTM E 445-88*). This is an ASTM 1988 standard for testing. As there was not any direct correlation between the two methods in the existing literature, a side-by-side test was planned. In this report, the project will be described, the test methodology will be explained, the data produced will be presented and analyzed, and conclusions will be drawn with recommendations made.

2.0 PROJECT DESCRIPTION

2.1 SET-UP

The side-by-side skid testing experiment was accomplished on Wednesday, November 19, 1997. The process started around 8:00 AM and finished by 2:00 PM. The two methods compared were the skid trailer test and the stopping distance car test. Both tests were administered as close as possible to a vehicle speed of 40 mph. Locations were marked with cones placed on the shoulder of the road, so the test vehicle operators were able to test nearly the same locations.

2.2 SKID NUMBER (SN)

The ODOT skid trailer test (*ASTM E 274-90*) measures skid number (SN). The SN is a unitless quantity that is multiplied by 100 (*ASTM E 274-90*).

2.3 DRAG FACTOR (DF)

The OSP stopping distance car test measures drag factor (DF). The DF is a unitless quantity that is multiplied by 100 for the purpose of comparison to SN within this report.

2.4 WEATHER CONDITIONS

The conditions for this experiment were approximately the same for each selected site. It was steadily raining (wet pavement surface) and gusting. The Preliminary Local Climatological Data was gathered from the Internet at http://nimbo.wrh.noaa.gov/portland. This daily climatological data is preliminary, and may in some cases be erroneous, but the official Local Climatological Data (LCD) is not available yet. The site used, Salem, Oregon, is assumed to have nearly the same weather as the test sites. The maximum temperature for the day was 51 degrees F. The minimum temperature for the day was 48 degrees F. The average temperature was 50 degrees F. Conditions were slightly foggy. The instantaneous peak wind speed was 52 mph, with a direction of 160 degrees. The two-minute peak wind speed was 37 mph, with a direction of 160 degrees. The average wind speed for the day was 23.5 mph. The precipitation accumulated was 1.06 inches. The greatest 24-hour period of rainfall in November, which occurred around this time (the19th and the 20th), accumulated 1.24 inches. This day was the windiest in November, with the highest average wind speed, and the wettest for November, with the greatest water accumulation. This weather data is representative of the test sites during the time of testing. The data is included to show the relative stability of the well above freezing temperature, the higher than normal winds, and the higher than normal rainfall.

2.5 SITE SELECTION

The site selection process for this study was not random. Documented in a letter dated June 24, 1997 (Appendix), Senior Trooper Ogilvie selected and tested one B-mix and two F-mixes in response to a fatality investigation. A correction to the letter is to change the 'Old F-Mix' listed with an average drag factor of '.51' to 'Old B-Mix'. In this current study, there were 11 test sites with three SN's and three DF's produced for each. Five sites were composed of two different F-mixes, and six sites were composed of three different B-mixes. So, there were 15 SN's and DF's each for F-mix and 18 SN's and DF's each for B-mix. These test sites include the three mixes tested in June of 1997.

3.0 METHODOLOGY

3.1 ODOT

Testing was performed using a K.J. Law Model 1290 Computer Controlled Pavement Friction Tester, in accordance with ASTM standards (*ASTM E 274-90*). The test apparatus consists of a vehicle towing a full-scale tire skid trailer, a transducer, instrumentation, a water supply and dispensing system, and actuation controls for the brake of the test wheel. The apparatus is brought to the test speed of 40 mph. Then the water wets the pavement in front of the test tire, and the test wheel is locked up, causing it to skid. The resulting friction force acting between the test tire and the pavement are recorded by the on board computer. This measurement represents the steady-state friction force on the locked test wheel as it is dragged over the wetted pavement under constant load and at a constant speed.

3.2 OSP

Testing was performed using a Ford Mustang patrol vehicle with radial tires and standard brakes. The vehicle was equipped with a Vericom VC200 performance computer (*Vericom, 1989*). The computer is a high-precision accelerometer, which measures motion as a rate-of-change of speed. The test was administered by bringing the vehicle to the test speed of 40 mph and then applying emergency braking. Emergency braking is locking all four wheels by depressing the brake pedal quickly and firmly, as a driver would in the avoidance of an accident. The computer recorded the data, which could be written down after the vehicle was pulled off the road onto the shoulder. This test measures the stopping distance representing the non-steady state skid resistance on four locked wheels as the vehicle decelerates, with the vehicle remaining essentially parallel to its original direction of motion.

4.0 DATA ANALYSIS

This study compares the results of the two test methods at the sites listed in Table 4.1 and Table 4.2, some of which were previously investigated by the OSP. Since these sites were not selected at random, all analysis and results should not be considered representative of other sites.

4.1 ODOT DATA

Table 4.1: Skid Number Results

LOCATION	MILEPOST	DIRECTION	MIX	MIX AGE	SN1	SN2	SN3
OR HR 22, (Hwy No. 30)	9.9	Westbound	F	New	40.3	40.0	46.0
	11.5	Eastbound	F	New	49.3	46.9	49.0
	11.7	Eastbound	B	Old	51.0	51.8	52.3
	11.7	Westbound	B	Old	53.4	53.3	55.2
	11.5	Westbound	F	New	52.4	52.3	52.2
OR HR 223, (Hwy No. 189)	0.9	Northbound	B	Old	46.4	49.9	53.1
	0.9	Southbound	B	Old	58.2	60.1	55.7
OR HR 99W, (Hwy No. 1W)	56.6	Southbound	F	~2 Years Old	57.6	56.8	57.6
	56.6	Northbound	F	~2 Years Old	53.7	54.4	53.5
Zena County Road, off OR HR 99W (Hwy No. 1W)	4.5	Westbound	B	Old	60.8	60.1	59.7
	4.5	Eastbound	B	Old	57.9	59.5	59.6

KEY:
Location: Oregon Highway Route (OR HR), and ODOT highway number.
Milepost: The test site milepost measured in miles from the start of that roadway.
Direction: The direction the testing vehicle was driving on the road.
Mix: The type of asphalt wearing course at that location.
Mix age: Either new (less than one year), ~2 years old, or old (over 2 years old).
SN1: The first ODOT skid number measured.
SN2: The second ODOT skid number measured.
SN3: The third ODOT skid number measured.

4.2 OSP DATA

Table: 4.2: Drag Factor Results

LOCATION	MILEPOST	DIRECTION	MIX	MIX AGE	DF1	DF2	DF3
OR HR 22, (Hwy No. 30)	9.9	Westbound	F	New	56.8	58.9	55.6
	11.5	Eastbound	F	New	55.9	55.0	55.0
	11.7	Eastbound	B	Old	60.1	57.3	58.1
	11.7	Westbound	B	Old	66.8	57.8	60.9
	11.5	Westbound	F	New	55.9	56.4	55.0
OR HR 223, (Hwy No. 189)	0.9	Northbound	B	Old	65.1	69.5	67.6
	0.9	Southbound	B	Old	69.2	70.0	70.6
OR HR 99W, (Hwy No. 1W)	56.6	Southbound	F	~2 Years Old	62.0	62.9	63.7
	56.6	Northbound	F	~2 Years Old	57.9	57.9	58.4
Zena County Road, off OR HR 99W (Hwy No. 1W)	4.5	Westbound	B	Old	64.5	66.2	69.3
	4.5	Eastbound	B	Old	62.5	64.2	65.4

KEY:

Location: Oregon Highway Route (OR HR), and ODOT highway number.
Milepost: The test site milepost measured in miles from the start of that roadway.
Direction: The direction the testing vehicle was driving on the road.
Mix: The type of asphalt wearing course at that location.
Mix age: Either new (less than one year), ~2 years old, or old (over 2 years old).
DF1: The first OSP drag factor measured.
DF2: The second OSP drag factor measured.
DF3: The third OSP drag factor measured.

4.3 COMPARISON OF TEST VALUES

4.3.1 Basic Statistics

The 95% confidence interval for:
Mean SN for the two F-mixes is 47.7 to 53.9 (mean 50.8 +/- 3.1).
Mean DF for the two F-mixes is 56.2 to 59.4 (mean 57.8 +/- 1.6).
Mean SN for the three B-mixes is 53.3 to 57.5 (mean 55.4 +/-2.1).
Mean DF for the three B-mixes is 62.5 to 66.9 (mean 64.7 +/- 2.2).

4.3.2 SN Vs DF

For the two F-mixes and the three B-mixes, DF is greater than SN. For the two F-mixes, the mean DF is approximately 12% greater than the mean SN (The mean DF can be expected to be 7.0 +/- 2.6 more than SN). For the three B-mixes, the mean DF is approximately 14% greater than the mean SN (The mean DF can be expected to be 9.3 +/- 2.5 more than SN). Since the DF's are greater on average than the SN's, then the SN's are most likely more conservative values. If this is valid, then the DF's do not add much value to the issue of minimum friction characteristics of pavements. The Paired Difference Test was used for the analysis of the matched samples (SN & DF). All confidence intervals are 95%.

4.3.3 Criteria For Potential Pavement Skid Resistance Issues

Since the lowest SN and the lowest DF for the five mixes tested are greater than the wet pavement potential skid resistance criteria for Oregon, these test sites do not require further evaluation. For SN, the lowest value for the two F-mixes was 40.0 and the lowest value for the three B-mixes was 46.4. In consideration of the wide variation in climate, quality and variability of materials, and design, construction and maintenance processes in the United States, the Federal Highway Administration (FHWA) does not support the selection of a minimum skid number, but requires each state to develop a skid accident reduction program (*Hibbs, B. and R. Larson, 1996*). Part of that program is to establish a wet pavement SN to be used as a criterion for pavement skid resistance evaluation. Oregon suggests that pavements with SN's less than 37, at 40 mph, should be evaluated for potential skid resistance issues.

There is not a similar criterion for potential pavement skid resistance issues for the DF's. Therefore, the DF's have been compared to the criteria used for SN's. The lowest DF for the two F-mixes was 55.0. The lowest DF for the three B-mixes was 57.3.

4.3.4 Mix Age

Newly constructed asphalt mixes are expected to have lower friction characteristics due to the asphalt coating on the aggregate. Increases will occur as the asphalt coating wears off from tire wear and ultraviolet degradation (*Younger, 1994*). The friction characteristics increase at around five months from placement for F-mix and at around two months for B-mix.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 FINDINGS

The analysis strongly concludes that there is a statistically significant difference between these two methods for the pavement sites tested. In review:

- For the two F-mixes and the three B-mixes, DF is greater than SN.
- Since the lowest SN and the lowest DF for the five mixes tested are greater than the wet pavement potential skid resistance criteria for Oregon, these test sites do not require further evaluation.

The experiment was conducted under very adverse conditions. The extreme precipitation and winds tested the worst case frictional properties of the roadways. The results confirm that SN and DF predict similar relative differences between the F-mixes and the B-mixes used for this study, and that all five mixes possess acceptable frictional characteristics.

5.2 OSP MEMORANDUM DISCUSSION

The DF's cited in the OSP memorandum (Appendix) are greater than the wet pavement potential skid resistance criteria for Oregon (Section 4.3.3), so these test sites do not require further evaluation. The DF's in the Appendix are 46 for a new F-mix, 40 for a just placed F-mix, 46 for a relatively new F-mix, and 51 for a B-mix (mislabeled). The DF's for the relatively new and new F-mixes, as well as the B-mix, increased by approximately 15-20% from the Appendix values to those of this study. For the just placed F-mix, the DF's increased by approximately 30% from the Appendix to this study. The vehicle speed during the test and the reduction of asphalt coating on the surface aggregate due to tire wear most likely explain the increases in DF's from the Appendix values to those of this study. The vehicle speed was approximately 25% greater for the Appendix results. The increased speed will increase stopping distance, thereby reducing the drag factor (*"Traffic Template", 1984*). Again (Section 4.3.4), for just placed F-mix, there is a period of approximately five months where tire wear reduces the asphalt coating on the surface aggregate, thereby increasing the frictional properties of the surface (*Younger, 1994*).

5.3 SN AND DF

From the literature review, it was clear that the absolute values of SN and DF are not readily comparable. As the SN represents a steady state environment and the DF represents a non-steady state environment, more information is required in order to assess the correlation between the two. The following quotes are included to describe the inherent difficulty in comparison:

- "The results from stopping distance tests cannot be correlated universally with the Skid Numbers (SN) even if the same tires are used and the pavement is wetted similarly in both cases. The reason is that in stopping distance tests vehicle speed changes during the test, while SN is measured at constant speed. Because SN changes differently with speed on different surfaces, supplementary information is needed for establishing correlations." (*Meyer, 1982*)
- "The values (SN) measured represent the frictional properties obtained with the equipment and procedures stated herein and do not necessarily agree or correlate directly with those obtained by other pavement friction measuring methods. The values are intended for use in evaluating the skid resistance of a pavement relative to that of other pavements or for evaluating changes in the skid resistance of a pavement with the passage of time. The values are insufficient to determine the distance required to stop a vehicle on either a wet or a dry pavement. They are also insufficient for determining the speed at which control of a vehicle would be lost, because peak and side force friction are also required for these determinations." (*ASTM E 274-90*)
- "The stopping distance values (SDN) measured by this test method with the equipment and procedures stated herein do not necessarily agree or correlate directly with other methods of skid-resistance measurements. This test method is suitable for research and development purposes, where direct comparison between pavement surfaces are to be made within the same test program." (*ASTM E 445-88*)

5.4 RECOMMENDATIONS

The SN is used nationally for management of pavement frictional properties and is not useful in directly predicting the speed of loss of vehicle control nor stopping distance (*ASTM E 274-90*). The Stopping Distance Number (SDN), or DF, is essential in reconstructing collision accidents, but is ineffective in correlation with all other tests. It is recommended that the values for these two testing methods be used solely for these prescribed assessments and not for attributes which they do not capture (*ASTM E 445-88*).

6.0 REFERENCES

ASTM E 274-90. "Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire." American Society for Testing and Materials. 1990.

ASTM E 445-88. "Standard Test Method for Stopping Distance on Paved Surfaces Using a Passenger Vehicle Equipped With Full-Scale Tires." American Society for Testing and Materials. 1988.

Hibbs, B. and R. Larson. "Tire Pavement Noise and Safety Performance." FHWA-SA-96-068, Federal Highway Administration. Washington D.C. 1996.

Kummer, H. W. and W. E. Meyer. "Tentative Skid-Resistance Requirements for Main Rural Highways." NCHRP Report 37. Washington D. C. 1967.

Meyer, W.E. "Synthesis of Frictional Requirements Research." FHWA/RD-81/159, Federal Highway Administration. Washington D.C. 1982.

"Traffic Template." Northwestern University Traffic Institute. SN1000. Evanston, Illinois. 1984.

"Vericom VC200 Performance Computer Owner's Manual." Quikset™. 1989.

Younger, K., R. Hicks and J. Gower. "Evaluation of Porous Pavements Used in Oregon." FHWA-OR-RD-95-13B, Oregon Department of Transportation. Salem, Oregon. 1994.

APPENDIX

MEMORANDUM – OREGON STATE POLICE

M E M O R A N D U M
OREGON STATE POLICE

DATE: June 24, 1997

TO: JAMES COOK, Manager
Oregon Department Of Transportation - McMinnville

FROM: GEORGE OGILVIE, Senior Trooper (Collision Reconstructionist)
Oregon State Police - McMinnville

SUBJECT: **F - MIX DRAG FACTORS**

On Tuesday June 24, 1997 at about 9:20am I performed Drag Tests in my patrol vehicle, a 1993 Ford Mustang equipped with Riken 225/P60 R15 "V" rated radial tires and standard brakes. My vehicle was equipped with the Véri Com 2000 speed analyzer. I did the tests on Highway 22 in the newly paved area and on Highway 99W in an older paved area. Both paved area's were paved with F-Mix. Northwestern Traffic Institute publishes tables of drag factors for asphalt pavement. Their tables show that "travelled asphalt" has a drag factor range of .55 to .70. and that "new asphalt" has a drag factor range of .65 to 1.00.

Surface	Average Drag Factor	Speed	Location
New F-Mix	.46	55 mph	Hwy 22 MP 11.5
Just layed F-Mix	.40	49 mph	Hwy 22 MP 9
Old F-Mix	.51	53 mph	Hwy 22 MP 12
Old F-Mix	.46	56 mph	Hwy 99W MP 57

It appears that F-Mix is has a lower drag factor than "normal" asphalt and as such it would take longer to slide to a stop.

GRO

16 1997