State Practices to Reduce Wet Weather Skidding Crashes

U.S. Department of Transportation
Federal Highway Administration

Safe Roads for a Safer Future
Investment in roadway safety saves lives

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16. Abstract

This report provides guidance to states for implementing a program focused on reducing wet weather skidding crashes and identifies the four common components of existing state programs. These components include identification of wet pavement crashes, friction testing procedures, investigation and remedial action of wet pavement crash locations, and project/program evaluations. The report identifies existing guidance from the Federal Highway Administration (FHWA) and the American Association of State Highway Transportation Officials (AASHTO) related to each of the four components. It also provides detailed case studies on existing state programs in California, Florida, Michigan, New York, and Virginia, all of which have shown success in reducing wet weather skidding crashes. The report concludes with a comparison of the five state programs and identifies common procedures for each of the four program components. This report provides states with valuable information to launch a wet weather crash reduction program or to improve an existing program.

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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	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	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 (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

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	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

Table of Contents

List of Tables

List of Figures

Abbreviations

AASHTO – American Association of State Highway and Transportation Officials
AWI – Aggregate Wear Index
ASTM – American Society for Testing and Materials
CAR – Crash Analysis Reporting
CRASH – Crash Reduction Analysis System Hub
CRF – Crash Reduction Factor
DOT – Department of Transportation
FARS – Fatality Analysis Reporting System
FHWA – Federal Highway Administration
FN – Friction Number
HFST – High-Friction Surface Treatment
HRTIS – Highway Traffic Records Inventory System
HSIP – Highway Safety Improvement Program
IFI – International Friction Index
NCDC – National Climatic Data Center
NCHRP – National Cooperative Highway Research Program
NTSB – National Transportation Safety Board
OGAC – Open-Grade Asphalt Concrete
PCC – Portland Cement Concrete
PDO – Property Damage Only
PIL – Priority Investigation Location
PWAH – Potential Wet Accident Hotspot
SHSP – Strategic Highway Safety Plan
SKARP – Skid Accident Reduction Program
SN – Skid Number
Sp – Speed Gradient
TRB – Transportation Research Board
TASAS – Traffic Accident Surveillance and Analysis System
VMT – Vehicle Miles Traveled
VTRC – Virginia Transportation Research Council
WARP – Wet Accident Reduction Program
WSF – Wet Safety Factor

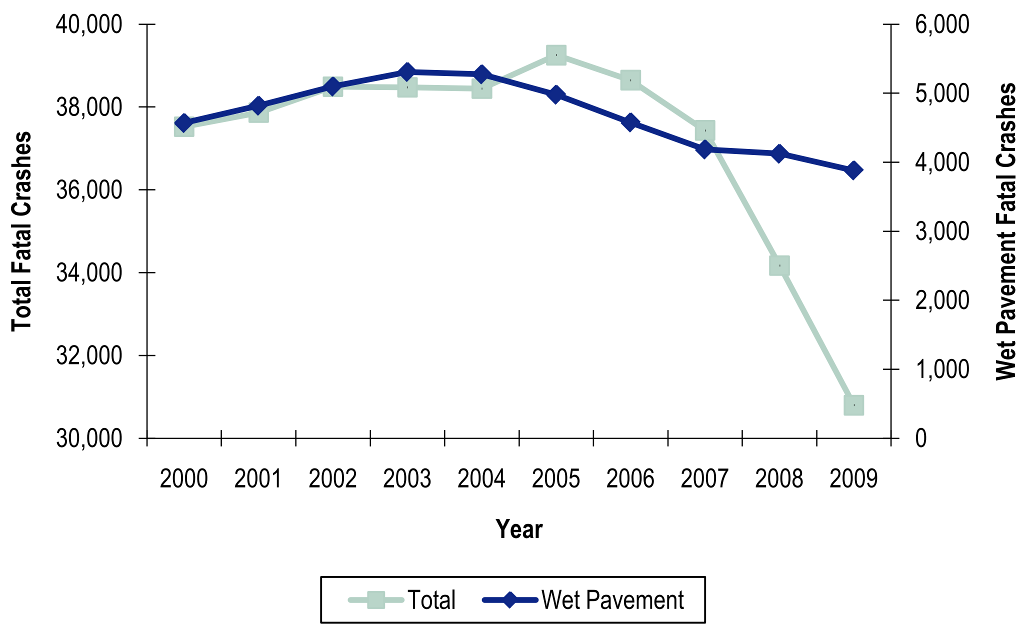
1.0 Introduction and Background

This section provides an overview of the wet weather crash problem, the purpose of this guide, the research methodology used, and the organization of this guide.

1.1 Wet Weather Crash Problem

Between 2000 and 2009, there were a total of 371,104 fatal crashes in the United States; 46,811, or 12.6 percent, of these crashes occurred on wet pavement. Total fatal crashes and wet pavement fatal crashes[1] for this 10-year period are illustrated in Figure 1.1.

Figure 1.1 U.S. Total Fatal and Wet Pavement Fatal Crashes (2000-2009)



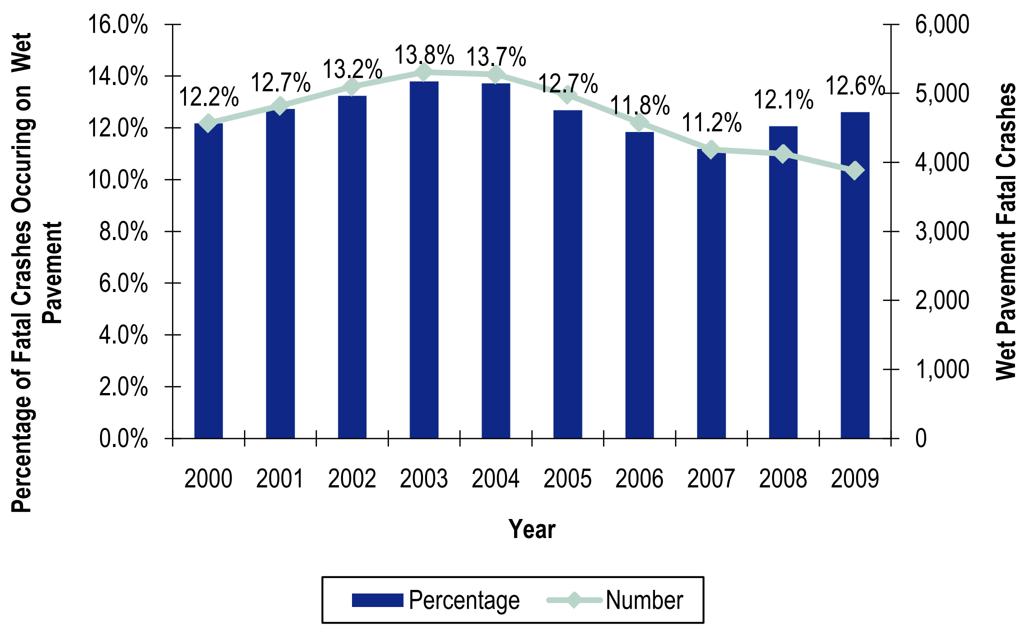
Source: Fatality Analysis Reporting System [1].

[1] Wet pavement fatal crashes in Figures 1.1 and 1.2 are based on crashes in the Fatality Analysis Reporting System (FARS) identified with a "wet roadway surface condition" variable in the police crash report. Other roadway surface conditions field variables include: blank, dry, snow/slush, ice/frost, sand/dirt/mud/gravel, water (standing or moving), oil, other, and unknown. These other variables are not included in the "wet" crash analysis.

As shown in Figure 1.1, wet pavement fatal crashes have consistently decreased from a high of 5,308 in 2003 to a low of 3,881 in 2009, a 26.9 percent reduction. Total fatal crashes have also consistently decreased from a high of 39,252 in 2005 to a low of 30,797 in 2009, a 21.5 percent reduction.

Figure 1.2 shows wet pavement fatal crashes as a percentage of all fatal crashes and the number of wet pavement fatal crashes. While the number of wet pavement fatal crashes has declined over the last several years, the percentage of fatal crashes occurring on wet pavement has increased the last couple of years.

Figure 1.2 Proportion of Fatal Crashes Occurring on Wet Pavement



Source: Fatality Analysis Reporting System [1].

According to research conducted by the Federal Highway Administration (FHWA) and the National Transportation Research Board (NTSB), a significant proportion of the wet pavement crashes occur on surfaces with inadequate pavement friction, and about 70 percent of wet pavement crashes could be prevented or minimized by improving pavement friction.

1.2 Purpose of This Guide

Following a motorcoach crash on Interstate 35 near Hewitt, Texas on February 14, 2003, the NTSB issued five safety recommendations to FHWA:

- **H-05-12 –** Issue guidance to your field offices describing the inadequate stopping sight distance that could occur when poor vertical geometries exist at locations with low coefficients of friction and speeds higher than the design speed and work with states to inventory such locations.

- **H-05-13 –** Once the locations in Safety Recommendations H-15-12 have been identified, assist the states in developing and implementing a plan for repaving or other roadway improvements.
- **H-05-14 –** Issue guidance recommending the use of variable speed limit (VSL) signs in wet weather at locations where the operating speed exceeds the design speed and the stopping distance exceeds the available sight distance.
- **H-05-15 –** Conduct research on commercial vehicle tire and wet pavement surface interaction to determine minimum frictional quality standards for commercial tires on wet pavement; once completed, 1) revise the tire requirements for commercial vehicle operating on wet pavement at highway speeds, and 2) develop minimum acceptable pavement coefficients of friction and maximum permissible pavement rut depths as part of roadway maintenance requirements, as appropriate.
- **H-05-16 –** Review state programs that identify and eliminate locations with a high risk of wet weather accidents and develop and issue a best practice guide on wet weather accident reduction.

This project was conducted in response to NTSB recommendation H-05-16. The project has two main objectives:

- Identification of state Department of Transportation (DOT) practices and procedures for improving pavement friction to reduce the occurrence of wet weather crashes; and
- Preparation of a best practice guide.

This report represents a guide that covers identification of wet pavement crashes, friction testing procedures, investigation, and remedial action of wet pavement crash locations, and project/program evaluations. It is based on the practices and procedures documented in five of those states, selected because of their well-established programs.

1.3 RESEARCH METHODOLOGY

A three-tiered approach was used to identify states with formal wet weather crash reduction programs. This approach involved outreach to FHWA Division Offices, review of the literature, and analysis of crash data.

Outreach

A message was posted on the FHWA Safety Exchange web site requesting FHWA Division Offices to respond if any of the states in their division had a formal program to address wet weather skidding crashes. Select FHWA Division Office personnel and colleagues were contacted directly to inquire about existing programs.

Literature Search

A literature scan was conducted to identify states with existing programs for reducing wet weather crashes. The review included reports published by FHWA, Transportation Research Board (TRB), National Cooperative Highway Research Program (NCHRP), American Association of State Highway and Transportation Officials (AASHTO), as well as individual state DOT documents such as Strategic Highway Safety Plans (SHSPs) and DOT web sites. A full scan of the literature found few examples of state programs focused on wet weather issues. Although most states describe some elements of a program to improve transportation safety by focusing on countermeasures for locations with wet weather skidding crashes, few states have comprehensively documented their policy or methods for identifying wet weather "hot spot" locations and evaluating the countermeasures applied.

Review the Data

Finally, wet weather fatal crashes provided in the Fatality Analysis Reporting System (FARS) and precipitation data provided by the National Climatic Data Center (NCDC) were reviewed. This information was used to identify states that appear to have made progress in reducing the number of wet weather crashes from a purely numerical standpoint. These states were considered for interviews. Many other and more complex factors may have had an impact on the reduction in wet weather crashes but are beyond the scope of this effort.

Interviews

Phone interviews were conducted with the following eight states identified with formal wet weather crash reduction programs:

- California;
- Florida;
- Kentucky;
- Maryland;
- Michigan;
- New Jersey;
- New York; and
- Virginia.

Each state provided information on when and why they began their wet weather crash reduction program, their program structure, procedures for identifying sites, mitigation techniques, and program results. The results of this research and the state interviews were documented for one of the tasks in this project.

1.4 ORGANIZATION OF THIS GUIDE

This guide is based on the four common components of wet weather crash reduction programs focused on friction improvements. These components include identification of wet pavement crashes, friction testing procedures, investigation and remedial action of wet pavement crash locations, and project/program evaluations. Section 2.0 describes each of these four components in detail and provides suggested procedures based on FHWA and AASHTO guidance on friction management programs. Section 3.0 provides case studies which outline the four common program components in California, Florida, Michigan, New York, and Virginia. Finally Section 4.0 provides a summary of the findings of this research effort.

2.0 Components of a Wet Weather Crash Reduction Program

The review of state wet weather crash reduction programs identified four common program components: identification of wet pavement crash locations, friction testing procedures, investigation and remedial action of wet pavement crash locations, and project and program evaluations. This section describes the importance of each component and related FHWA guidance.

2.1 IDENTIFICATION OF WET WEATHER CRASH LOCATIONS

The identification of locations with a high frequency or proportion of wet pavement crashes is a key component of a wet weather crash reduction program. The FHWA Technical Advisory on Pavement Friction Management [2] provides three common approaches for agencies to use to analyze the data in the state crash database to identify wet weather crash locations:

- Identify locations with a wet crash ratio[2] above a specified value as a high wet weather crash location. The specified value varies between agencies depending on geometric and climatic circumstances; typically the ratio varies between 0.25 and 0.50.
- Identify locations with a wet crash ratio above the average wet crash ratio for the corresponding functional classification of highways. If a location is above the average by a specified percentage, the location is identified as a wet weather crash location.
- Identify locations that exceed an established wet crash ratio and a minimum number of wet weather crashes within a specified segment length as a wet weather crash location. As an example, one agency uses a minimum of six wet road crashes in rural areas and a minimum of 10 in urban areas.

Segment lengths used to compute wet crash ratios vary by agency, but typically a segment length of 0.2 to 2.0 miles is used. Once sites are initially identified through an analysis of the crash database, the sites should be friction tested and further investigated for potential remedial action.

[2] The ratio of the wet weather crashes to total (wet+dry) crashes.

2.2 Friction Testing Procedures

Pavement friction testing is an integral component of any wet weather crash reduction program focused on skidding crashes. Typically, as pavement friction decreases, the number of wet weather crashes will increase. The FHWA Technical Advisory on Pavement Friction Management [2] provides guidance to state and local agencies in managing pavement surface friction.

Two types of surface texture affect wet pavement friction: microtexture (wavelengths of 1μm to 0.5mm) and macrotexture (wavelengths of 0.5mm to 50mm). Microtexture is generally provided in asphaltic pavements by the relative roughness of the aggregate particles and in concrete surfaces by the fine aggregate. Macrotexture is generally provided in asphalt pavement by proper aggregate gradation and in concrete surfaces by a supplemental treatment such as diamond grinding or grooving, exposed aggregate texture, transverse or longitudinal tining, burlap or artificial turf dragging, and transverse brooming.

Friction Testing Methods

Four types of full-scale test equipment exist for measuring pavement friction, including locked wheel, fixed slip, side force, and variable slip. However, the recommended methods for evaluating pavement friction on U.S. highways are the locked wheel and fixed slip methods; currently side force and variable slip friction measurement systems are not widely available or used in the U.S. Table 2.1 identifies the advantages of each of these four testing methods.

Table 2.1 Advantages of Friction Testing Methods

Method	Advantage
Locked wheel (ASTM E 274)	• Simulates emergency braking without anti-lock brakes. • Can be used with either the ribbed tire (ASTM E 501) or the smooth tire (ASTM E 524).
Fixed slip	• Relates to braking with anti-lock brakes. • Ability to operate continuously over a test section.
Side force	• Measures the ability to maintain control on curves.
Variable slip	• Relates to braking with anti-lock brakes

Source: FHWA Technical Advisory on Pavement Friction Management [2].

The ribbed tire (ASTM E 501) is the most common test tire used by U.S. state highway agencies with the locked wheel method, but it is considered less sensitive to pavement macrotexture and water film depth compared to the smooth tire (ASTM E 524). However, all friction test methods can be insensitive to macrotexture under specific circumstances, so it is recommended that friction testing be complemented by a macrotexture measurement (ASTM E 1845).

Macrotexture measurements can be independently used to compute the Speed Gradient (Sp).[3] The Sp can then be combined with friction results from most friction testers to determine the International Friction Index (IFI). The IFI can be used to directly compare friction test results using different test methods. The AASHTO Guide to Pavement Friction [3] provides models to use for these conversions.

To ensure reliable friction test results, it is essential to proper calibrate and maintain friction testing equipment as specified by the manufacturer.

Friction Testing Conditions

Friction test results can be impacted by various factors such as surface temperature, test speed, and ambient weather conditions. Conducting friction testing under standardized conditions helps to minimize the effects of these factors, which minimizes variability and produces repeatable measurements. Table 2.2 summarizes AASHTO's guidance on standardized test conditions [3].

Table 2.2 Standardized Test Conditions

Factors	Consideration
Season	Limit friction testing to a specific season or time of year when friction is typically the lowest to maintain year-to-year consistency and reduce variability in measured data. When this is not possible, correction factors can be developed to normalize raw friction test data to a common baseline season or coordinate initial and subsequent section testing to occur during a specific season.
Test speed	The standard speed recommended by AASHTO T 242 for pavement friction tests (locked wheel) is 40 miles per hour. However, since most agencies conduct friction tests without traffic control and posted or operational speeds vary throughout the roadway network, it is difficult for the operator to conduct testing at just this speed. Therefore, results of friction testing conducted at speeds other than 40 miles per hour should be adjusted to the 40 miles per hour baseline to make friction measurements comparable. This requires establishing correlations between friction measurements taken at 40 miles per hour and those taken at other speeds.
Test lane and line	Friction testing must be done in the most heavily trafficked lane, since it expected to have the highest rate of friction loss due to wear. Two-lane highways with a near 50-50 directional distribution of traffic only need to be tested in one lane; otherwise, the lane direction with the higher traffic volumes should be tested. For multilane highways, the outermost lane in both directions is typically the most heavily traveled and should be tested. Testing must be carried out within the wheel path, since this is the location where friction loss is the greatest. Testing should be carried out in the same lane and wheel path to maintain consistency between test results and reduce variability. If it is necessary to deviate from typically practice, the test data should be marked accordingly.

[3] Sp defines the relationship between measured friction and vehicle tire free rotation or slip speed.

Factors	Consideration
Ambient conditions	It is important to standardize and document ambient test conditions, as they can have an effect on friction test results. Avoid testing in extremely strong side winds as these can create turbulence under the vehicle causing the water jet to divert from the correct line and affect the measurement results. Avoid testing in heavy rainfall or where there is standing water on the pavement surface. Excess water on the surface can affect the drag forces at the pavement-tire interface and influence the measurements. Do not conduct testing when the air temperature is below 41ºF (5ºC).
Contamination	Avoid testing locations where the pavement surface is contaminated by mud, oil, grit, or other contaminants.

Source: AASHTO Guide to Pavement Friction [3].

Establishing Friction Thresholds

There is not a specific friction test value that represents the difference between a safe and potentially unsafe pavement surface. Each agency determines their own investigatory (or desired) friction levels or friction-level ranges for specific facility types, based upon factors such as traffic volume, geometrics (e.g., curves, grades, sight distance), potential conflicting vehicle movements, speed, and intersections. Once sites fall into the investigatory friction-level range, they are further investigated. Many states also develop intervention friction-level thresholds that represent a minimum level of pavement friction. Once sites reach the intervention level, some type of action is required. These thresholds can help an agency in prioritizing improvement projects for sites identified as wet crash locations.

The AASHTO Guide for Pavement Friction [3] identifies three methods for establishing investigatory and intervention-level friction thresholds. The first method establishes thresholds by examining historical pavement friction data to determine at what pavement age significant decreases in friction occur and set thresholds based on those friction values. The second method compares historical friction and crash data and establishes an investigatory level based on large changes in friction loss and an intervention level based on when there is a significant increase in crashes. Finally, the third method establishes thresholds based on friction distribution and crash rate.

Resurfacing Projects

A program targeting the reduction of wet weather crashes through surface friction improvements, should give consideration to the resulting friction of the surface treatment. Friction testing and friction-related specifications on new hot-mix asphalt or concrete surfaces may be justified unless historical evidence indicates that existing pavement mix-design requirements, aggregate specifications, or construction specifications have resulted in pavement surfaces that provide adequate pavement friction.

2.3 INVESTIGATION AND REMEDIAL ACTION OF WET WEATHER CRASH LOCATIONS

Sites identified during the crash data analysis need to be further investigated to determine potential contributing factors to the crashes. The friction number is evaluated as part of this investigation. Typically if the friction number falls below the investigatory threshold, the site is reviewed in the field to identify existing conditions and determine potential contributing factors and potential improvements. This investigation also may include a detailed analysis of the individual crash reports to identify collision patterns. The field review will also identify any site conditions that may have contributed to the crashes, including potential cross-section and pavement deficiencies. If low pavement friction is identified as a contributing factor, the next step is to identify the appropriate remedial action. The FHWA Technical Advisory on Surface Texture for Asphalt and Concrete Pavements [4] identifies several techniques to provide adequate surface friction on new pavements and overlays and to restore surface friction of existing pavements. These techniques are summarized in Table 2.3.

Table 2.3 Techniques to Provide Adequate Surface Friction

Technique	Description
Concrete Surfaces	
Transverse tining	Achieved by a mechanical device equipped with a tining head that moves laterally across the width of the pavement surface. A width of 3mm (±0.5mm) and a maximum depth of 3mm are recommended. Recommended random spacing average tine spacing of either 13 mm with a tine spacing pattern of 10/14/16/11/10/13/15/16/11/10/21/13/10 mm or 26 mm with a time spacing pattern of 24/27/23/31/21/34 mm.
Longitudinal tining	Achieved by a mechanical device equipped with a tining head that moves parallel to the pavement centerline. A width of 3mm (±0.5mm) and a maximum depth of 3mm are recommended. Narrower, deeper grooves are better than wider, shallower grooves (within the limits) for minimizing noise. Straight, uniformly spaced grooves at 19mm have been shown to provide adequate handing characteristics for small vehicles and motorcycles.
Exposed aggregate	Normally constructed in two layers. The top layer consists of 30% siliceous sand of 0-1 mm and 70% high-quality chips of 4-8 mm. A water cement ratio of 0.38 and a mean texture depth of 0.77 mm are recommended.
Diamond grinding	Typically provides grooves of approximately 3mm width, spaced at 5-6 mm intervals. Specific groove depth and spacing is dependent on hardness of aggregate.
Diamond grooving	Transverse or longitudinal can provide adequate friction characteristics. Groove geometry should be consistent with recommendations for tining.

Technique	Description
Burlap drag	Typically produced by trailing a moistened, course burlap from a construction bridge that spans the pavement. Striations of 1.5-3 mm depth are typical.
Artificial turf drag	Typically produced by trailing an inverted section of artificial turf from a construction bridge that spans the pavement. Striations of 1.5-3 mm depth are typical when using turf with 77,500 blades per square meter.
Transverse broom	Typically obtained using a hand broom or mechanical broom device that lightly drags stiff bristles across the surface. Striations of 1.5-3 mm depth are typical.
Thin epoxy laminates	Typically aggregates are 4-6 mm.
Asphalt-based surface treatments	May include micro-surfacing.
Asphalt surfaces	
Surface treatments or thin asphalt overlays	Generally, hot-mixed asphalt pavements designed in conformance with Superpave mix design will provide adequate macrotexture and microtexture without supplemental treatments. When supplies of durable nonpolishing aggregate are limited, an agency may choose to construct an asphalt pavement using high-durability aggregates optimized for friction properties only in the top layer.
Concrete overlays	May be considered as an option to restore adequate surface texture on asphalt pavements.

Source: FHWA Technical Advisory Surface Texture for Asphalt and Concrete Pavements [4].

There are several different techniques for improving pavement friction, and due to widely varying conditions of different sites, it is unlikely that one texturing method will be the optimal choice for all projects within a state. The selection of the appropriate technique should consider the existing conditions at each individual site. FHWA [4] identified several factors to consider when selecting a method to improve pavement friction, including:

- **Splash and Spray –** Reduced visibility caused by splash and spray may increase the probability of wet-weather crashes. Adequate pavement cross-slope or the use of porous surfaces will provide improved surface drainage and has been shown to reduce splash and spray.
- **Climate –** The increased probability of wet-weather conditions would justify a higher level of texture.
- **Traffic Volume and Composition –** Pavements with higher traffic volumes can justify a higher level of texture. Increased traffic would decrease the reaction/recovery time in the event of loss of control of a vehicle. Additionally, roadways with a higher composition of truck traffic typically demand a higher level of friction compared to corresponding highways comprised predominately of passenger cars.

- **Speed Limit –** Higher speed facilities may justify a higher level of texture. Friction test results will decrease with increasing speed, reaching a minimum at approximately 60 mph. Friction on surfaces with low texture falls more rapidly with speed than on high-textured surfaces.
- **Roadway Geometry –** Research has shown that curves tend to lose pavement friction at a faster rate than other roadway locations, and therefore, curves may justify a higher level of texture.
- **Potential Conflicting Movements or Maneuvers (Frictional Demand) –** Intersections and presence of pedestrians will justify a higher level of texture due to the increased likelihood of sudden braking movements.
- **Materials Quality and Cost –** The availability and cost of high-quality durable, nonpolishing materials will influence the choice of materials and techniques to provide increased friction.
- **Presence of Noise-Sensitive Receptors –** A pavement located near a school, hospital, or other noise-sensitive receptor may justify a higher consideration of noise effects when selecting the appropriate surface treatment for a pavement.

New and/or innovative pavement friction improvement techniques, without evidence of improved safety performance, should only be used on an experimental basis and monitored for safety performance.

2.4 PROJECT AND PROGRAM EVALUATIONS

The purpose of a wet weather skidding crash reduction program is to reduce the number of crashes occurring on wet pavement due to inadequate pavement friction. Conducting project and program evaluations enables an agency to determine if their efforts have met their intended purpose and provides a quantified measure of success. Individual projects can be evaluated based on the occurrence of wet pavement crashes before and after an improvement. States evaluate safety projects implemented for the Highway Safety Improvement Program (HSIP) on an annual basis, and these same methods can be used to evaluate the effectiveness of pavement improvements at wet weather crash locations.

As part of the Technical Advisory on Pavement Friction Management [2], FHWA identified the "wet safety factor" (WSF) as an appropriate metric for evaluating the effectiveness of a wet weather crash reduction factor. The WSF is the reciprocal of the risk of having a wet pavement crash relative to a dry pavement crash and is calculated as follows:

$$WSF = \frac{(DC) \times (PWT)}{(WC) \times (PDT)}$$

Where,

DC = Number of dry weather crashes;

WC = Number of wet weather crashes;

PDT = Percent of dry pavement time; and

PWT = Percent of wet pavement time.

To determine a composite statewide WSF, the network is divided into analysis areas based on similar percentages of wet and dry pavement time. The total number of dry and wet weather crashes are determined for each analysis area and used to calculate a WSF for each analysis area. Then, the WSF for each analysis area is weighted by the vehicle miles traveled (VMT) and aggregated to determine a composite statewide WSF. In a successful program one would expect the WSF to increase over time with an upper limit of 1.0. A WSF less than 0.67 suggests a potential wet weather problem. This value is based on the conservative estimate of the overall likelihood of a wet weather crash being 1.5 times greater than a dry pavement crash.

3.0 State Practices to Reduce Wet Weather Skidding Crashes

This section describes the current state practices for reducing wet weather skidding crashes used in California, Florida, Michigan, New York, and Virginia and provides some additional state practices used to identify and mitigate wet crash locations.

3.1 CALIFORNIA

In 1972, Caltrans developed their Traffic Accident Surveillance and Analysis System (TASAS) to identify high-collision concentration locations. Included in this system was a methodology for identifying locations with a high concentration of wet crashes known as Wet Table C.

Identification of Wet Weather Crash Locations

Caltrans State Office of Traffic Safety Program analyzes the crash data to develop the Wet Table C on an annual basis. The Wet Table C identifies locations with a minimum of 9, 6, or 3 wet crashes within a 36-, 24-, or 12-month period, respectively and are significantly higher than the statewide average. Wet collisions are identified by those with a road surface coded as "wet."

A significance test is conducted to determine if the defined highway segments, ramps, or intersections have a wet crash count significantly higher than the number of crashes required for significance (N_R). For a segment to have significantly high crashes, the segment crash count must be greater than or equal to N_R. N_R was derived from the Poisson's distribution one-tail test for a 99.5 percent confidence interval and is defined by the following equation:

$$N_R = N_E + 2.57(N_E)^{0.5} + 1.329$$

Where,

N_R = Number of crashes required for significance; and

N_E = Average number of crashes.

N_E is calculated using the following equation:

$$N_E = ADT \times t \times L \times R_{E(Wet)} \times 10^{-6}$$

Where,

ADT = Average daily traffic (vehicles per day);

t = Analysis period (days);

L = Length (miles); and

$R_{E(wet)}$ = Average wet crash rate (wet crashes/million vehicles or wet crashes/ million vehicle miles).

$R_{E(Wet)}$ is calculated as follows:

$$R_{E(Wet)} = \frac{0.3(1 - wt\%) + 3.2(R_E)}{1 + 2.2(wt\%)}$$

Where,

wt% = Percentage of wet time (decimal).

R_E is calculated as:

$$R_E = Base\,rate = \frac{ADT\ factor}{Total\ ADT}$$

Where

Base rate = Base crash rate for specific highway segment type (provided by TASAS);

ADT factor = Adjustment factor for specific highway segment type (provided by Caltrans tables); and

Total ADT = Average daily traffic for the specific segment (provided by TASAS).

The percent of wet time is determined for each county in the State. The percent of wet time was initially developed in 1972 using 11 years of data from 1957 to 1967. In 2008, Caltrans conducted a study with the assistance of the Western Transportation Institute at Montana State University to update the percent of wet time values to reflect current climatic trends. The 2008 values were not found to be significantly different than the 1972 values [5].

The analysis is based on crash data from July 1 to June 30, so that the entire wet season is included in each analysis period. The analysis starts at the beginning of a route and evaluates one 0.2-mile segment at a time using a sliding scale of 0.02 miles. If the first 0.2-mile segment is not found to be significant, the analysis moves ahead 0.02 miles and evaluates the next 0.2-mile segment. If a segment is found to be significant it is added to the output table. This process is repeated for the entire roadway length.

The results of the analysis are documented in an annual report. The report is sent out to the 12 districts in August or September; this time period corresponds with the wet season and is appropriate for conducting field reviews. The districts conduct data analysis of the locations and perform field reviews to identify recommended safety improvements.

Friction Testing Procedures

As part of their highway inventory, Caltrans maintains an active friction data set for the outer two lanes of the highway network with one test per lane-mile. The program tries to maintain a regular rotating schedule of every three years; however, staffing and equipment issues have had a profound impact on the schedule. Skid testing is also conducted at locations identified with wet high-collision concentration locations; however, an active file of these testing locations is not kept. For their highway inventory and wet weather crash investigations, Caltrans uses a locked wheel towed trailer tester with ASTM standard ribbed tires according to ASTM E 274 procedures.

Investigation and Remedial Action of Wet Weather Crash Locations

The list of locations identified in the Wet Table C is provided to the District Traffic Safety Engineers to follow up with a safety investigation. Locations identified in the Wet Table C are evaluated within a 12-month period. For each location, the investigator gathers and analyzes relevant data in an effort to identify contributing factors and potential countermeasures. The *Caltrans Traffic Safety Program* [6] provides recommended procedures for conducting site investigations. Several processes are used to identify the most effective improvement strategy. This includes a detailed analysis of the collision history, collision diagrams, friction test results, field investigations, and a review of roadway geometrics at the site to assist in identifying collision patterns that may susceptible to correction. Additional data elements such as time of day, direction of travel, movement preceding collision, or other factors may help in investigating crash patterns.

To mitigate the locations identified in the Wet Table C where improvements are recommended, Caltrans typically implements pavement improvements such as superelevation changes, open-grade asphaltic concrete (OGAC) overlays, pavement grooving, high-friction surface treatments, or drainage improvements. Caltrans also installs “Slippery When Wet” signs if recommended by an investigation and will consider a reduction in the posted speed limit, if justified by a spot speed study.

Project and Program Evaluations

Caltrans evaluates wet weather crash location improvements that are funded through the HSIP program. These evaluations compare three years of both before and after improvement crash data using total, fatal, injury, and property damage only (PDO) crashes. However, Caltrans does not evaluate individual projects or subprograms; the safety program is evaluated as a whole.

3.2 FLORIDA

The State Safety Office conducts an analysis to identify wet weather crash locations on the state roadway network using Florida's Crash Analysis Reporting (CAR) System. The State Safety Office provides a report to the District Safety Engineers (DSEs) on an annual basis. However, the CAR system also provides the DSEs with the ability to conduct analyses of wet weather crashes in their districts at their discretion.

Identification of Wet Weather Crash Locations

The State Safety Office conducts an analysis of wet weather crashes on the state roadway network using five years of crash data through the CAR system. The analysis identifies sections with either a minimum of four wet weather crashes with 25 percent or more wet weather crashes or 50 percent or more wet weather crashes during a five-year period. The analysis uses a sliding window with 0.3-mile segments and increments of 0.1 miles. Intersections are included in the segment analysis. The State Safety Office conducts the analysis on an annual basis and provides a report to the DSEs. The CAR system also allows the DSEs to run an analysis to identify wet weather crash locations in their districts at any given time. For example, to identify wet weather crash locations, District 5 (Orlando/Daytona Beach area) runs an analysis on a quarterly basis, and District 7 (Tampa area) runs an analysis on a monthly basis. The DSEs then make requests to the State Materials Office to conduct friction tests at the locations identified through the crash analysis.

Friction Testing Procedures

The Florida DOT State Materials Office maintains a database of skid test results and conducts skid tests on all state roadways on a three-year rotating schedule. The friction testing procedures are outlined in the *Skid Hazard Reporting System User Documentation* [7]. Skid tests are typically conducted at a speed of 40 miles per hour in the left wheel path using a standard two-wheel trailer towed by a one-ton pick-up truck conforming to ASTM E 274 requirements. Testing equipment is calibrated in-house at intervals of 30 to 45 days per ASTM specifications. The normal testing procedure is to conduct three tests per mile or section (if less than a mile). A mean friction value is determined based on the arithmetic average of the tests conducted on a section of roadway. In addition to the routine test schedule, tests are also conducted when:

- Initiated by District Safety Engineer based on crash data;
- After construction or resurfacing;
- There is a special request (e.g., research project, county/city roadways); or
- There are roadway surfaces approaching the questionable range of friction values.

The DSEs review the most recent friction test results of the identified segments to determine if the friction number is low, 28 (FN40R) or less for posted speed limit of 45 miles per hour or less and 30 (FN40R) or less for posted speed greater than 45 miles per hour.

Investigation and Remedial Action of Wet Weather Crash Locations

If the friction number is low for locations identified through the crash analysis, the DSEs review the work program to determine if the roadway is programmed for resurfacing. When the location is not included in the work program, the DSE must further investigate the site to identify potential contributing crash factors. The DSE reviews the traffic crash reports and field conditions (e.g., geometrics, surface condition, drainage, etc.). If inadequate pavement friction is identified as a contributing factor, the DSEs identify the appropriate mitigation techniques.

Florida has developed high-friction surface treatments for ramps, curves, or other locations with wet weather crashes. A specification for asphalt concrete friction courses has been developed to support this effort. Specific provisions are provided for using different aggregates, including granite. However, the specification does not specifically address the required friction value at the conclusion of compaction and rolling. Some of the districts use granite in the friction course if a skid hazard exists. The percent of granite changes in different parts of the State. Higher percentages of limestone aggregate are used in the southern part of the State, where the source mines are locally available. Florida is currently working on specifications for hybrid mixes with granite and limestone. As a temporary improvement, the District Maintenance Engineer will install warning signs at locations with a low friction number until a project can be implemented to improve the pavement surface friction.

The District 4 office (Broward County) has experimented with the use of high-friction surface treatments (HFST) in areas where friction-based crashes are a concern [8]. The HFST used a modified exothermic epoxy resin as a binder material and was top dressed with specific aggregates. Evaluation data found significant friction number increases after the application of the HFST. For example, one location reported a friction number of 35 (FN40R) before the treatment and a friction number of 104 after application. Evaluations concluded the HFST was effective in increasing the friction value of the roadway.

Typically it takes about two and one-half to three years to implement a resurfacing project (one year for programming, one year for design, and one year for construction). Currently, District 7 is piloting a design build or "push button" program. With this program, multiple projects are programmed at one time; allowing design and construction to occur within nine months.

Project and Program Evaluations

Florida DOT developed a web-based database application called the Crash Reduction Analysis System Hub (CRASH), which is used to record and maintain safety improvement projects, update crash reduction factors (CRF), and apply CRFs to conduct a benefit/cost analysis of proposed safety improvement projects. The DSEs input all HSIP-funded projects, including improvements for wet weather crash locations, into CRASH. CRASH uses before and after crash counts to evaluate the safety projects and develop CRFs for the countermeasures implemented. The CRFs are typically calculated based on five years of both before and after data, but the system administrator may specify any specific time period for the calculation.

Florida has not conducted any recent formal evaluations of their Skid Hazard Elimination Program but anticipates conducting an evaluation over the next year. Although not a formal process, typically the status of previously identified wet pavement crash locations are investigated to determine how many remain from year to year.

3.3 MICHIGAN

Michigan DOT has a long-standing program for addressing wet weather crashes that has been in place for approximately 25 years. The Safety Programs Section leads the program and develops a list of locations for the regions to investigate.

Identification of Wet Weather Crash Locations

The identification of potential wet weather crash locations is carried out by Michigan DOT's Safety Programs Section. The identification of locations is based on the results of the statewide friction testing program. Annually, the Safety Programs Section develops a list of locations with a skid number of less than 30 (SN40R). This list is then provided to each of the regions to investigate further and evaluate the need for action.

Friction Testing Procedures

Michigan DOT conducts friction testing on each lane of all state-maintained roadways on a three-year cycle (approximately one-third of roads each cycle). The tests are conducted using a Dynatest 1295 (locked wheel) friction tester according to ASTM E 274 requirements. Tests are conducted using an ASTM E 501 ribbed tire for level testing and an ASTM E 524 smooth tire for special testing. Friction tests are also conducted on corridors, spot locations, or intersections identified with a potential rear-end wet weather crash problem. The skid test results are available on the Michigan DOT network for regions to review.

Typically friction tests are not conducted on new construction or resurfacing projects, unless by special request. To ensure adequate surface friction, Michigan developed and implemented a wear track-based polishing test called the Michigan Aggregate Wear Index (AWI). The AWI is used to evaluate aggregates used in the top surface of hot mixed asphalt pavements. Each source of aggregate is tested and assigned AWI values which are updated as quarrying progresses into new areas. There is also a process to assign an AWI value to blended aggregates.

Investigation and Remedial Action of Wet Weather Crash Locations

The investigation of the sites identified by the Safety Programs Section with a skid number of less than 30 (SN40R) is carried out by the individual regions. The regions consider four factors in the evaluation:

1. Wet surface friction tests result is less than 30 (SN40R);
2. Estimated reduction in wet crashes is equal to at least three crashes per year per spot (intersection approach) or 0.5-mile segment location;
3. A field review to identify factors not related to surface friction qualities, such as “wheel tracking” or a clogged drainage structure that may contribute to a higher percentage of wet crashes; and
4. The time-of-return on the investment is five years or less.

Michigan DOT developed a tool in Microsoft Excel for determining if the location warrants action. The spreadsheet contains the Region’s wet crashes, wet crash percentages, and total crashes. The analyst must enter data for each of the locations identified based on the friction number, including project location, limits, number of nonwet crashes, number of wet crashes, and analysis period. The spreadsheet then calculates the expected reduction factor used in the time-of-return (benefit/cost) analysis.

If the location warrants action, the regions review the five-year plan to see if a project is scheduled for resurfacing. If the location is included in the schedule, they might be able to schedule the resurfacing at a sooner date. If it is not in the plan, typically the regions will do an overlay, ultra thin overlay, mill and resurface, microsurfacing, paver placed surface seal, chip seal, or diamond grinding. The regions can submit these improvements as part of the annual call for safety projects. Once the regions have decided on a course of action, they must report it and the results of the analysis to the Safety Programs Section.

Michigan DOT is currently working with the FHWA Office of Pavement Technology on a pilot project on surface treatments. The project is focused on freeways ramps with curves. They are currently pilot testing Tyregrip on curves.

Project and Program Evaluations

Michigan conducts before and after evaluations of all safety projects. Michigan has not conducted a recent evaluation of their wet weather crash reduction program; however, the overall number of wet weather crashes has gone down. In addition, fewer locations are being identified each year.

3.4 NEW YORK

New York established their Skid Accident Reduction Program (SKARP) in the mid 1990s to address a problem with the aggregate (dolomite) becoming polished. The program identifies and treats wet road crash locations on state-owned roadways and arterials (data is not available for local roads). Program requirements are outlined in Engineering Instruction 02-007, Skid Accident Reduction Program [9].

Identification of Wet Weather Crash Locations

The Office of Modal Safety and Security is responsible for the identification of wet weather crash locations. During April of each year, the Office of Modal Safety and Security analyzes the crash data to identify locations with an unusually high proportion of wet road crashes and develops a Wet Road Accident Priority Investigation Location (PIL) listing. The two primary considerations for identifying high wet road crash locations are the proportion of wet road crashes compared to total crashes and the occurrence of a specified minimum number of wet road crashes over a two-year period. Locations are identified if there are at least six wet road crashes during a two-year period in rural areas and at least 10 in urban areas with at least 35 percent of the total crashes occurring on wet road conditions. The PIL listing is sent to the Office of Technical Services to schedule friction testing for the locations identified on the list.

Friction Testing Procedures

Generally, the Office of Technical Services conducts friction tests from April to November at all locations included on the PIL list. However, there are a couple exceptions:

- Locations tested during the previous two years are not retested unless the regional offices specifically request the test; and
- Locations previously tested and found to exhibit one or more friction test results below an FN40R of 32 are not retested, even if more than two years has lapsed.

The tests are conducted with a skid trailer according to ASTM E 274 requirements using a ribbed tire meeting ASTM E 501 requirements. Tests are conducted at 0.1-mile intervals. The Materials Bureau maintains a file of all friction testing data.

The Wet Road Accident PILs are categorized into two classes depending on the friction test results:

- **Class 1 –** Locations where one or more friction test results are below 32 (FN40R); or
- **Class 2 –** Friction test results are greater than or equal to 32 (FN40R).

Following the friction testing, the results are transmitted to the regions for review and consideration in the regions' capital programming and preventive maintenance paving activities. The regions must investigate all locations with a friction number below 32. All sites with a friction number less than 26 must be remediated immediately. A friction number of 32 provides a stopping distance consistent with AASHTO design standards for highway sight distance and is consistent with design requirements for curves. A friction number of 26 was identified as a threshold coefficient of crash frequency based on analysis of wet weather PIL locations that had been friction tested.

Friction tests are not routinely conducted on resurfacing projects but are done occasionally. To provide for adequate surface friction, New York evaluates every aggregate source for both asphalt and concrete pavements. Petrographic evaluations are conducted on a biennial basis to qualify aggregates for the *Approved List of Fine and Coarse Aggregates* and on plant samples to provide quality assurance (QA) of aggregates during production for state contracts. Friction performance is monitored annually on selected sections in the *Pavement Friction Inventory*.

Investigation and Remedial Action of Wet Weather Crash Locations

The Wet Road Accident PIL listing and the results of the friction tests are forwarded to the Regional Offices for consideration in the regions' capital programming and preventive maintenance paving activities. The region's investigate the locations on the PIL listing and are responsible for identifying and implementing remedial actions.

The remedial actions of wet road crash locations typically include resurfacing with one and one-half inches of hot mix asphalt using the appropriate friction aggregates, or a thin cold emulsion microsurfacing (using noncarbonate aggregates). Superpave hot mix asphalt is the standard for New York State contracts.

The regions are required to report on pending and completed remedial actions for all locations including in the PIL listing to the Office of Modal Safety and Security in May each year.

Project and Program Evaluations

New York conducts evaluations of SKARP projects funded through the HSIP. The evaluations are based on three years of before improvement fatal and injury crash data and three years of after improvement fatal and injury crash data. As part of the analysis, a benefit/cost ratio is calculated to determine if the project achieved its purpose. If the projects are not part of the HSIP, evaluations are conducted at the discretion of the region.

New York conducted a formal evaluation of the program in 2002 but has not since evaluated the overall program. The previous evaluation developed crash modification factors for resurfacing with high wet road crash locations based on the evaluation of 40 improved sites. The results indicated that resurfacing treatments at wet road crash locations are expected to reduce total crashes by approximately 20 percent, total wet road crashes by approximately 60 percent, and severe (fatal and injury) wet road crashes by approximately 70 percent [10].

Overall, the frictional quality of the State's pavements has improved since the program's inception. A summary of PIL testing from 1996 through 2006 shows a steady decline in the number of sites requiring treatment from 91 sites in 1996 to 19 sites in 2006. In 2007, 14 sites required treatment.

3.5 VIRGINIA

In 1976, the Virginia Transportation Research Council (VTRC) developed a procedure for systematically identifying and evaluating wet crash sites or low skid number sites and established the Wet Accident Reduction Program (WARP). The program procedures are outlined in Virginia's Wet Accident Reduction Program: A User's Manual [11].

Identification of Wet Weather Crash Locations

The Traffic Engineering Division conducts an analysis of the crash data on an annual basis to identify Potential Wet Accident Hotspots (PWAH). Crashes are located at 0.1-mile intervals and serve as the principal database for identifying PWAHs. The identification process is as follows:

1. Crashes involving snow and ice are discarded.
2. Crash files are scanned by district, county, route, and mile point.
3. When a wet weather crash is registered, an additional 0.2 miles on either side of the site is scanned for additional wet weather crashes.
4. If one or more wet weather crashes are found, an additional 0.2 miles of the road is scanned for wet weather crashes.
5. Locations are classified as PWAHs when:
    a. There are a minimum of three wet weather crashes, each separated by less than 0.2 miles; and
    b. The proportion of wet weather crashes (wet/(wet+dry)) is at least 20 percent higher than the ratio for all roads in the area.

Sites meeting these criteria are then friction tested by the Materials Division and locations. Virginia uses the conservative requirement of three wet weather crashes to designate a PWAH so as not to overlook a potentially dangerous condition. While the crash data is the primary source for identifying PWAHs, locations may also be identified based on field requests or Virginia's ongoing program of annual skid tests of the primary and Interstate systems.

Friction Testing Procedures

The Materials Division conducts skid tests of the PWAH locations. Tests are conducted using an ASTM E 274 trailer unit on a wetted pavement at a speed of 40 miles per hour. Each unit includes force and speed transducers, a control system, a record system, and a pavement wetting system. Test wheels are incorporated into the trailer. The test tire is a standard smooth tire.

Skid units are routinely (weekly, monthly, and yearly) calibrated following the manufacturer's recommendations. Virginia DOT has a comprehensive calibration and verification program to ensure quality test results.

PWAH locations are tested using the following guidelines:

- Tests are conducted at a minimum frequency of one test for every tenth of a mile; for sites less than 1 mile in length, as many tests as possible are conducted with up to one test for every 0.05 mile.
- Unless a jurisdictional or construction project interferes, each section should have a minimum of three tests evenly spaced at 0.1-mile intervals beyond the limits of the referenced site (both before and after). If the skid number is less than 24 (SN40S), the sections are extended until three consecutive skid numbers greater than 24 (SN40S) are recorded. This ensures that any questionable areas are accurately identified.
- If possible, a minimum of one test is conducted within 200 feet prior to an intersection with a stoplight or stop sign.
- Data is reported by county-relative mileposts. Straight line diagrams from the Highway Traffic Records Inventory System (HRTIS) are used by the operator for reference and locating starting nodes in the field.
- Friction test results are uploaded into the HRTIS at the completion of testing for a district.

Locations with a friction number less than 20 (SN40S) are flagged for review by the districts. A friction number of 20 (SN40S) was selected as the threshold, to be consistent with other agencies. However, a more recent study conducted by VTRC and Virginia Tech has recommended use of a higher value (25-30).

The Virginia DOT conducted a study to identify and characterize Virginia's nonpolishing aggregates in terms of their wet skid resistance for pre-evaluating the skid resistance of nonpolishing aggregates [12]. This was done by comparing the effect of different asphalt mixtures on pavement surface macrotexture using the ASTM E 965-87 sand patch method and considering the effect of texturing on pavement surface friction. Fifty-seven sources of nonpolishing aggregates, representing 18 lithologies, were studied. Using the ASTM E 274-90 procedure skid testing of the 18 lithologies was carried out on 1,246 bituminous pavement sections. Aggregate groups with the highest and lowest wet friction rankings were identified.

Investigation and Remedial Action of Wet Weather Crash Locations

After the PWAHs are friction tested, the districts are responsible for reviewing the sites with a skid number of 20 (SN40S) or less and making decisions on possible remediation. The State does not mandate resurfacing if the friction is less than 20 (SN40S) without further review. Typically the districts will first check to see if the location is included in the maintenance schedule for resurfacing.

For asphalt pavement, micro surface treatments are widely used to restore pavement with inadequate friction characteristics. Seal coats or chip seals are also used to restore pavement friction characteristics and extend the life of pavements. Pavement preservation activities also provide an opportunity to improve both the pavement condition and surface characteristics in a very cost-effective manner. Depending on the pavement distress condition, the section could also be overlaid.

For Portland Cement Concrete (PCC) pavements, diamond grinding can be used to increase concrete pavement friction by enhancing surface macro texture. Adequate macro texture reduces the potential for hydroplaning. Saw cut grooving is used traditionally to restore adequate frictional characteristics of PCC pavements. Grooving can be either longitudinal or transverse.

If no action can be taken immediately, the district may temporarily put up “Slippery When Wet” signs until a more permanent improvement can be made. Districts have the option to apply for safety improvement program funding to improve these sites. HSIP projects are typically implemented within a three-year timeframe.

Project and Program Evaluations

Project evaluations are conducted for all safety improvements, including WARP projects funded through the HSIP. The evaluations are conducted using three years of both before and after improvement data.

Virginia DOT’s *2007 Wet Accident Reduction Program Report* [13] provides a comparison of the 2007 PWAH sites to historical results. The findings include:

- Between 2002 and 2007, the total number of traffic crashes and the number of dry crashes increased in the State by almost 13 percent and 17 percent respectively, while the number of wet weather crashes decreased by almost 7 percent. During this time period, the wet to dry crash ratio also decreased from 0.182 to 0.145.
- Between 2002 and 2007, the total number of PWAH sites reduced by almost 27 percent. The number of PWAH sites in terms of million vehicle-miles traveled also reduced from 0.009 to 0.006.
- From 2006 to 2007, there was a 23 percent decrease in the number of low friction (less than or equal to 20) sites.

- As wet weather crashes are directly related to pavement friction, this decrease in the number of wet weather crashes, the number of PWAHs identified, and the number of low skid number sites, could probably be indicative of improving pavement friction on Virginia's primary and Interstate routes. All these reductions occurred despite an increase in overall crashes.

3.6 ADDITIONAL STATE PRACTICES

While not all of the interviewed states procedures are included in this guide, this section provides some additional notable practices and additional countermeasures being used to address wet weather crashes.

Identification of Wet Weather Crash Locations

New Jersey was the only State to incorporate crash severity into the initial site identification process. New Jersey originally identifies sites with an overrepresentation of wet weather crashes, based on statewide averages, and then ranks the locations by weighting the crash frequency by the crash severity. However, it should be noted that other states may incorporate severity into the process by prioritizing projects using of a benefit/cost analysis.

Kentucky did not have a program specifically focused on wet weather crashes; however, the State recently developed a Roadway Departure Safety Implementation Plan [14], which included the identification of roadway segments for implementing friction treatments to reduce wet pavement crashes. The analysis used to identify roadway sections for friction improvements evaluated 3,000 feet roadway segments and identified sections that met a minimum criterion of eight or more crashes and 35 percent or more occurring on wet pavement during the five-year period between 2004 and 2008. The analysis identified 227 segments for potential friction improvements. Kentucky started to implement the pavement friction improvements during the 2010 construction season, and it is anticipated the plan will be implemented over a five-year period.

Additional Countermeasures to Address Wet Weather Crashes

While the focus of this guide is on surface treatments to reduce wet weather skidding crashes, many of the states identified additional countermeasures to reduce wet weather crashes as a whole.

Florida is currently looking into the development of specifications for wet weather pavement markings to address nighttime, wet weather, and lane departure crashes. Florida also implemented a policy to use audible and vibratory markings on rural roadways (excluding limited access facilities) to address lane departure crashes, but the policy also indicates audible and vibratory pavement marking can be used in areas with a history of wet weather crashes. It is implied that the marking will be more visible and conspicuous during wet weather conditions. Similarly, Florida also uses inverted rib profile markings to improve the conspicuity of lane markings under all weather conditions. As a temporary improvement to address wet weather crashes occurring on the ramps at the interchange of two Interstate routes in FDOT District 5, optical speed bars and variable speed advisory signs were installed until the project can be completed.

In the Detroit metropolitan area, wet weather tape has become the standard pavement marking for freeways to provide for better reflectivity. It is being installed systematically as part of overlay projects.

New York is currently investigating grooved in epoxy pavement markings with wet-night visibility elements mixed with standard glass beads as an option. They have done a few trial placements. The New York State Thruway Authority is now moving to all grooved in epoxy with special retroreflective elements. New York has also been implementing Type 9 sheeting on signs for more visibility and is looking into a policy on rumble strips.

4.0 Summary

This section provides a comparison of the five state programs and general findings on the practices used for crash reduction programs focused on wet weather skidding crashes.

4.1 Identification of Wet Weather Crash Locations

All states reviewed conduct a statewide analysis on an annual basis and consider both concrete and asphalt pavements. Table 4.1 provides a summary of the procedures and factors used by each of the five states for identifying locations with wet weather crashes to investigate further.

Table 4.1 State Analysis Procedures

State	Factors for Identifying Locations	Screening Frequency
California	A wet crash count significantly higher than statewide average and includes a factor which represents the percent wet time for each county in the State. Analysis evaluates 0.2-mile segments using a 95% confidence interval.	Annually
Florida	Minimum of 4 wet weather crashes with 25% or more wet weather crashes or 50% or more wet weather crashes during a 5-year period on 0.3-mile segments.	Statewide – annually Districts – at their discretion
Michigan	Identifies locations with a friction number less than 30 (SN40R).	Annually
New York	At least six wet road crashes during a 2-year period in rural areas and at least 10 in urban areas with 35 percent or more of the total crashes occurring on wet road conditions.	Annually
Virginia	Three or more wet weather crashes in the previous year and if the location has a wet to wet plus dry ratio 20 percent greater than the ratio for all roads in the area (excluding ice and snow crashes).	Annually

The review of state analysis procedures for identifying wet weather crash locations identified three distinct methods. The three methods are as follows:

1. Sites exceeding a set threshold of the number of wet weather crashes and a threshold proportion of wet crashes are identified as potential problem locations;
2. Sites with a friction test result below a set threshold are identified as potential problem locations; and
3. Sites with the number of wet weather crashes exceeding the statewide average by a particular significance level are identified as potential problem locations.

While any one of these three methods is appropriate for identifying potential wet weather crash locations, the first method is the most commonly used by states.

4.2 FRICTION TESTING PROCEDURES

Friction test results are a consideration in all of the states programs, and all of the states maintain an active pavement friction database. All of the five states conduct friction tests using the locked wheel method, and with the exception of Virginia, they all use a ribbed wheel for the testing. Table 4.2 summarizes the friction testing procedures and thresholds.

Table 4.2 State Friction Testing Procedures and Thresholds

State	Testing Frequency	Testing Equipment and Procedures	Friction Threshold
California	Conducted on a 3-year rotating schedule for the highway inventory program. Also conducted at locations identified with high wet-collision concentrations (locations tested based on wet weather crash experience are not included in the State's friction database).	Uses a locked wheel towed trailer tester with ASTM standard ribbed tires according to ASTM E 274 procedures. Caltrans maintains an active friction data set for the outer two lanes of the highway network with one test per lane-mile as part of their highway inventory.	30 (SN40R)
Florida	Conducted on a 3-year rotating basis on all state roadways as well as on overlays and new construction, locations with a high frequency of wet crashes, and special requests.	Standard two-wheel trailer towed by a one-ton pick-up conforming to ASTM E 274 requirements. Conducted in the left wheel path at 40 mph. Normal testing procedure is to conduct 3-5 tests per mile or section (if less than a mile). A mean skid value is determined based on the arithmetic average of the tests conducted on each section of roadway.	Posted speed >45 mph = 30 (FN40R); Posted speed < 45 mph = 28 (FN40R)

State	Testing Frequency	Testing Equipment and Procedures	Friction Threshold
Michigan	Conducted on all state-maintained roads on a 3-year rotating schedule or at locations identified with a high crash experience. Intersections tested only if potential issues are identified.	Conducted using a Dynatest 1295 friction tester according to ASTM E 274 requirements using an ASTM E 501 ribbed tire for level testing and an ASTM E 524 smooth tire for special testing.	30 (SN40R)
New York	Conducted at wet road crash locations and select locations for the Pavement Friction Inventory.	Conducted from April to November according to ASTM E 274 requirements using a ribbed tire meeting ASTM E 501 requirements.	32 (FN40R)
Virginia	Conducted at locations with three or more wet weather crashes in the previous year with a 20 percent or greater wet to dry ratio.	Conducted using ASTM E 274 trailer units on a wetted pavement at a speed of 40 miles per hour with a standard smooth tire. Tests are conducted at a minimum frequency of one test for every 0.1 mile; for sites less than 1 mile, as many tests as possible are conducted with up to one test for every 0.05 mile.	20 (SN40S)

Florida was the only State that conducts friction testing on new construction or resurfacing projects. However, most of the states indicated that they evaluated the friction characteristics of the aggregates used for pavement surfaces.

Most states utilize the locked wheel method according to ASTM E 274 requirements to conduct friction tests. The ribbed tire is most commonly used with friction thresholds ranging from 28 to 32.

4.3 Investigation and Remedial Action of Wet Weather Crash Locations

To date, the states have been focusing on spot improvements. While many of the states are implementing systematic improvements, such as rumble strips and raised pavement markings, no state has implemented systemic improvements focused specifically on addressing skidding-related wet weather crashes.

Table 4.3 provides a summary of the mitigation techniques used by the interviewed states to improve pavement friction.

Table 4.3 State Mitigation Techniques

State	Mitigation Techniques
California	Improvements include superelevation changes, open-grade asphalt concrete (OGAC) overlays, pavement grooving, high-friction surface treatments, or drainage improvements.
Florida	A specification for asphalt concrete friction courses has been developed for ramps, curves, or other locations with wet weather crashes. Specific provisions are provided for different aggregates usages, including the use of granite. Florida is currently working on specifications for hybrid mixes with granite and limestone. The District 4 office (Broward County) has experimented with the use of high-friction surface treatments in areas were friction-based crashes are a concern.
Michigan	If an identified location is not in the current work plan for resurfacing, typically the regions will do an overlay, ultra thin overlay, mill and resurface, microsurfacing, paver placed surface seal, chip seal, or diamond grinding. Signing is used only as a short-term solution.
New York	Treatments typically include resurfacing with one and one-half inches of hot mix asphalt using the appropriate friction aggregates, or a thin cold emulsion microsurfacing (using noncarbonate aggregates). Superpave hot mix asphalt is the standard for New York State contracts.
Virginia	For asphalt pavement, micro surface treatments are widely used to restore pavement with inadequate friction characteristics. Seal coats or chip seals are also used to restore pavement friction characteristics and extend the life of pavements. Depending on the pavement distress condition, the section could also be overlaid. For Portland Cement Concrete (PCC) pavements, diamond grinding increases concrete pavement friction. Saw cut grooving (longitudinal or transverse) is used traditionally to restore adequate frictional characteristics of PCC pavements.

Site investigations are a key element for identifying appropriate mitigation techniques for locations identified as potential wet weather crash locations. All states include a field investigation in their process for identifying appropriate mitigation.

4.4 Project and Program Evaluations

Evaluations are a critical element of any safety program. Projects should be evaluated to verify the desired results have been achieved and to ensure the investments have been worthwhile. Evaluating the program helps measure its impact on the entire system. All of the states indicated they used before and after studies to evaluate improvements at wet weather crash locations funded through the HSIP. However, projects funded through other funding sources are generally not being evaluated for their safety effectiveness. While all of the states indicated they were identifying fewer sites year after year, only a couple indicated they had conducted a program evaluation. New York evaluated their program back in 2002, but has not conducted a formal evaluation since. Virginia's *2007 Wet Accident Reduction Program Report* [13] provided an evaluation of the program for the years of 2002 to 2007 and demonstrated positive results. Table 4.4 summarizes the project and program evaluations conducted by the states.

Table 4.4 State Project and Program Evaluations

State	Project Evaluations	Program Evaluations
California	Caltrans evaluates wet weather crash location improvements funded through the HSIP program. The evaluation compares 3 years of both before and after improvement crash data based on total, fatal, injury, and PDO crashes.	Caltrans does not evaluate individual subprograms; the safety program is evaluated as a whole.
Florida	Florida conducts evaluations on all HSIP-funded projects using their CRASH database. The evaluations are used to calculate CRFs for various countermeasures. The CRFs are typically calculated based on 5 years of both before and after data.	Florida has not conducted any recent formal evaluations of their Skid Hazard Elimination Program but anticipates conducting an evaluation over the next year. Although not a formal process, typically the status of previously identified wet pavement crash locations are investigated to determine how many remain from year to year.
Michigan	Michigan conducts before and after evaluations of all safety projects.	Michigan has not conducted a recent evaluation of their wet weather crash reduction program; however, the overall number of wet weather crashes has gone down. In addition, fewer locations are being identified each year.
New York	New York conducts evaluations of all safety projects funded through the HSIP. The evaluations are based on 3 years of before improvement fatal and injury crash data and three years of after improvement fatal and injury crash data. As part of the analysis, a benefit/cost ratio is calculated to determine if the project achieved it purpose. If the projects are not part of the HSIP, evaluations are conducted at the discretion of the region.	New York conducted a formal evaluation of the program in 2002. The evaluation developed crash modification factors for resurfacing with high wet road crash locations and found resurfacing treatments at wet road crash locations are expected to reduce total crashes by approximately 20%, total wet road crashes by approximately 60%, and severe (fatal and injury) wet road crashes by approximately 70%. A summary of Priority Investigation Locations (PIL) testing from 1996 through 2006 shows a steady decline in the number of sites requiring treatment from 91 sites in 1996 to 19 sites in 2006. In 2007, 14 sites required treatment.
Virginia	Project evaluations are conducted for all safety improvement projects funded through the HSIP. The evaluations are conducted using 3 years of both before and after improvement data.	Between 2002 and 2007, the total number of traffic crashes and the number of dry crashes increased in the State by almost 13% and 17% respectively. The number of wet weather crashes decreased by almost 7%. During this time period, the wet to dry crash ratio also decreased from 0.182 to 0.145. During this same time period, the number of Potential Wet Accident Hotspot (PWAH) sites reduced by almost 27%, and the number of PWAH sites in million vehicle-miles traveled reduced from 0.009 to 0.006. From 2006 to 2007 there was a 23% decrease in the number of low friction sites identified in the crash analysis.

Evaluations of improved wet weather crash locations are typically conducted through a before and after study. Before and after studies compare the number of crashes at a site before an improvement to the number of crashes at a site after an improvement for a corresponding time period. The evaluation should focus specifically on wet weather crashes. A reduction in crashes during the after period provides an indication the surface treatment contributed to the reduction in wet weather crashes.

Program evaluations can be conducted in a number of ways. A program evaluation might compare the trend in overall crashes, wet weather crashes, and dry crashes over a specified time period. It could evaluate the trend in the number of sites identified for treatment on an annual basis over a long-term period. Finally a program evaluation could be conducted by calculating the wet safety factor, as outlined in Section 2.4.

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