THE HYDROLOGY OF ROAD DEFECTS

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ABSTRACT

Hydrologic principles used in roadway design and defects identification processes are crucial to improving roadways and, therefore, the safety of the driving public. Wet pavement accidents provide valuable information to locate defective surfaces. The accumulation of storm water on pavement surfaces creates a danger to motorists. Hydrologists are trained to identify areas of the roadway that are susceptible to the accumulation of unwanted storm water. Understanding the elements of storm water runoff on pavement surfaces provides the hydrologist with valuable tools for identifying the critical areas of the roadway that are most susceptible to hazardous conditions. The hydrologist working with the roadway design engineer can provide the critical information for designing safer roads. The hazards of hydroplaning from roadway defects increase as the depth of water on pavement surfaces increases. Therefore, quantitative evaluation of the effectiveness of water flow across pavement surfaces—along with other hydrologic principles—is employed to calculate the water depth. Because the pooling of water creates conditions for hydroplaning, the depth and length of these pools as well as the basin areas, coefficient of runoff, time of concentration, roadway surface texture, and rainfall intensity are used to study such conditions. Each of these hydrologic elements should be analyzed and evaluated as part of the design process. A review of the types of roadway defects is emphasized to illustrate the critical coordination needed between the roadway design engineer and the hydrologist.

INTRODUCTION

In 2002, the National Highway Traffic Safety Administration (NHTSA) reported that 2,981 fatal crashes and 207,000 injury crashes occurred while roadways were wet.

Paul Pisano[1] examined all crashes that occurred between 1995 and 2005. In his paper, he states that 24 percent of all crashes are weather-related. Each year, nearly 7,400 people are killed and more than 673,000 people are injured in these crashes. He further acknowledges that—in terms of crash frequency, rate, and severity—wet weather is far more dangerous than winter weather. Most weather-related crashes happen during rainfall and on wet pavement. Rain occurs year-round in every part of the country, while snow and ice are limited to one season and a portion of the country.

One significant finding of reconstructing vehicular traffic accident cases is the number of traffic accidents resulting from localized defective areas of roadways. An investigation of roadway conditions at various accident locations revealed roadway defects that could have been easily and economically addressed for safety. The hydrologist working with the roadway design engineer and the reconstructionist can identify these roadway hazards.

One of the most obvious reasons that the roadway design engineer and the hydrologist should corroborate is to identify critical areas on the roadway surface that create the potential for hydroplaning. In the design process, the hydrologist focuses on the means and methods for addressing the hazardous conditions on roadways. His expertise and experience raise awareness of the benefits to looking closely at potential hydrologic drainage. Both the design and maintenance phase should be carefully studied. The tendency of water to accumulate in certain areas of the roadway reveals the need to better understand water sensitive areas, particularly why these areas are critical in the design, the construction, and the maintenance of roadways. The joint effort of the hydrologist and the roadway designer strengthens the awareness for scrutiny of defective roadway sections.

Water on the roadway surface creates hazardous conditions by decreasing the friction between the tire/pavement interfaces. The accumulation of water on the pavement surface increases the depth of the water, and vehicles become susceptible to hydroplaning. Finally, splash and spray from vehicles cause drivers to lose visibility of the roadway and other passing vehicles.

The areas on roadways found to be most susceptible to hydroplaning are:

- Depressions or ruts in the pavement surface
- Transitions into and out of super-elevation sections for horizontal curves
- Irregular pavement surfaces (which can create greater lengths of travel for water to traverse)
- Areas of accumulation that prevent proper drainage of water from the roadway
- Locations where improper construction of the slope of the curb and gutter prevent efficient flow of water
- Areas of storm water overtopping due to insufficient capacity of culverts and storm drainage systems
- Sinkholes from the undermining of the roadway embankment due to deteriorated culverts and storm pipes

A study of the accident reports involving run-off-the-road and wet pavement incidents will help identify the high crash rate areas. The need for improved drainage on roadway pavements is prompted by the numerous vehicular accidents occurring on wet pavements. The tendency for hydroplaning is minimized by the attention to design and construction of the roadway affected most by roadway defects. This study examines the areas on a roadway where conditions are most likely to cause a vehicle to hydroplane.

SYNTHESIS OF HYDROLOGY OF ROADWAY SURFACES

A hydrologist studies the movement of water across pavement surfaces and determines the quantity of water estimated to pass over the surface. Hydrologic methods are used to determine the depth of water crossing roadways. The hydrologist uses weather data to calculate the quantity of the storm water flow resulting from rainfall.

Hydrologists have been studying the flow of water over land surfaces for decades, and some rather sophisticated methodologies have been developed to describe the process of water flow. Hydrologists are trained to identify the factors and parameters that influence surface runoff.

A qualitative analysis of the flow of water requires proper field data, determination of runoff coefficients, rainfall intensity, and sound judgment from qualified experience. By application of the accepted principles of hydrology, the hydrologist can obtain solutions that are functionally sound. The result is a higher-quality design of drainage structures under the highway as well as reduced depths of storm water on the highway surface. This paper will address some of the principles and techniques used by hydrologists to estimate the depth of water on roadways. First, however, it is desirable to discuss some of the basic hydrologic concepts that will be used in storm water discharge and how the hydrologic analysis relates to the flow of water across roadway pavements.

Rainfall occurs in an irregular pattern across the earth's surface. Over the past 100 years, a great deal of research has been performed to compile rainfall data in the United States. The U.S. Weather Bureau published *Rainfall Frequency Atlas of the United States* (Technical Paper 40)[2] to provide maps of the expected size of storm events throughout the country. The report covers rainfall durations of 30 minutes to 24 hours and return periods from 1 to 100 years.

The number of inches of rainfall and the duration of the rainfall defines the size of the storm in inches per hour. Most rainfall data reports present the rainfall in inches of storm water falling over a 24-hour period. Thus, the rate of rainfall during the study period will differ depending on the time frame in which the rain fell. A 6-inch rain that is recorded for a 24-hour period may have actually fallen during a four-hour period. Therefore, the rate of rainfall would be 6 inches for the four hours—the rate being 1.5 inches per hour. If the rain had fallen during a two-hour time period, the rate would be 6 inches in two hours or 3 inches per hour. Both measurements define the rate of rainfall over a specified time period and show the 3 inches of rain over two hours to be more intense. The rate of rainfall in inches per hour is the data needed for hydrologic calculations.

Rainfall frequency is known as the return period. It is the average number of years between two rainfall events that equal or exceed a given number of inches over a specified amount of time. It does not mean that a given storm event will happen only once in the specified period. A 100-year storm event is a 1 percent chance that a 100-year storm will occur in any given year. It does not mean that a 100-year rain event will only occur once every 100 years. For example, a rainfall frequency of 25 years is best described as a 4 percent chance that the 25-year rainfall event will happen in any given year.

The hydrologist uses intensity-duration-frequency (IDF) curves to select the return period for a given storm. By knowing the duration (time) of the rainfall and the quantity (inches) of rainfall, the rainfall event or frequency of the storm can be determined. The rainfall intensity is the average rainfall rate in inches per hour for a specific rainfall duration and frequency. The duration is equal to the time of concentration. The rainfall intensity is determined using the rainfall intensity-duration-frequency (IDF) curves.

The National Weather Service, Technical Paper Number 40[3] provides rainfall data for durations from 30 minutes to 24 hours and return periods from 1 to 100 years. The depth of rain water for selected durations and frequencies are provided in the form of maps that show lines of equal rainfall depths. Because of the importance of the intensity-duration-frequency relationship in hydrologic analyses, IDF curves have been complied for most localities. The IDF curve is most often used by entering the duration and the frequency to find the intensity.

The general shape of a rainfall intensity-duration-frequency curve slopes down as time increases. As rainfall duration tends towards zero, the rainfall intensity tends towards infinity. The rainfall intensity/duration relationship is based on the duration being equal to the time of concentration.

The rational method is used by the hydrologist to determine the peak runoff in small drainage basins. Hydrologists have long used this method since its introduction to England in 1889. It attempts to estimate the peak runoff, the greatest quantity of flow during a rain event. The rational method determines the peak. Once the peak is reached, the hygrograph curve decreases to zero. The rational method uses the drainage area, the rainfall intensity, and the runoff coefficient.

The size of drainage basins is required to determine the area contributing storm water to the study point. In calculating the rate of runoff, the drainage area contributing flow to a point of investigation is determined. The drainage basin is simply the area of land that drains to the point where investigation is necessary. An accurate topographic survey is required of small drainage basins. For larger drainage areas, topographic drainage maps may be used.

The time of concentration is the amount of time needed for runoff to flow from the most hydraulically remote point in the drainage basin to the point of analysis. When the rain at this remote point contributes to the point of analysis, all areas within the basin reach the study point. The rational formula requires a time of concentration for each design point within the drainage basin. The duration of rainfall is then set to equal the time of concentration and used to estimate the design rainfall intensity.

The hydrologist considers three possible components of flow that characterize the progression of runoff along a travel path: overland flow (sheet flow), shallow concentrated flow, and pipe and open channel flow (concentrated channel flow). All possible paths are considered in determining the longest travel time.

The assignment of the runoff coefficients is based on the judgment of the hydrologist. The hydrologist studies the characteristics of each drainage basin. The coefficient varies with topography, land use, vegetation, soil types, and the moisture content of the soil. When the land use varies within a watershed, watershed segments are considered individually by calculating a weighted runoff coefficient value.

WET WEATHER ACCIDENT SITES

Dire need exists to identify defective highway locations causing wet pavement accidents. Defective areas are conducive to a high incident of vehicle crashes that cause property damage and accident fatalities. The critical need to improve the removal of water from the highway pavement surface is prompted by the increased number of vehicular accidents during rain events. The relationship between the high probability of accident locations and the wet weather roadway defects warrant more focused study. The need to bring these areas to the attention of highway system caretakers is critical. Attention to these areas will result in the reduction of vehicle accidents during wet pavement conditions. Roadway safety officials look to hydrologists for methods to predict and control the flow of storm water across the pavement surface. Therefore, focus needs to be directed towards the hydrology of roadway defects.

The National Highway Traffic Safety Administration's (NHTSA) Fatality Analysis Reporting System (FARS)[3] reports that since the 1970s, annual highway fatalities in the United States have held steady at about 40,000 people per year. About 14 percent of all fatal crashes occur on wet pavement.

State departments of transportation have access to accident reports. These reports identify the weather conditions at the time of the accident. A review of the data of wet weather accidents sites can direct roadway maintenance engineers to the problem areas. This data reveals the areas of multiple accidents and identifies which of the accidents occurred on wet pavement.

HYDROPLANING

The greatest danger for motorists on wet pavement surfaces is hydroplaning. Hydroplaning is a phenomenon that occurs when a moving tire lifts up on a film of water, the front tires lose contact with the pavement, and the driver loses control of the direction of the vehicle. The probability of vehicle collisions involving hydroplaning increases as the speeds of vehicles increase.

The grooves in tires are designed to move water from beneath the tire. Hydroplaning occurs when a tire encounters more water than it can dissipate. At the point that the tire cannot disperse the water between the tire and the roadway surface, a wedge of water builds in front of the tire, causing the tire to lift off the surface. The tire then rides on a sheet of water with little or no direct contact with the roadway surface. When multiple tires hydroplane, the vehicle loses directional control and continues in the direction of the velocity vector until its speed decreases and contact with the roadway is regained or the vehicle collides with another object.

Road defects such as ruts and pavement depressions hold water. A driver that hits a pocket of water is surprised by the sudden loss of control and panics, which may cause a number of involuntary reactions. Some drivers over steer to correct their driving, while some just close their eyes and hope for the best. The loss of control that results from hydroplaning leaves the driver feeling helpless. No amount of steering will change the direction of a vehicle while its tires are riding on a film of water.

Several factors must be present for hydroplaning to occur. The likelihood of hydroplaning increases when the vehicle's speed increases and there are depths of the water present on roadways. The odds are also determined by the depth of tire treads, the length of pools of water, the roadway texture, decrease of pavement cross-slopes, tire pressure, and the deterioration of the micro-texture and the macro-texture of roadway surfaces.

ROADWAY DEFECTS

Roadways often exceed the design volume before the anticipated design year. This is one of the major reasons for pavement failure. Typically, pavement failure occurs in the travel path of the vehicle. The 1984 AASHTA publication *A Policy on Geometric Design of Highways and Streets*[4] defines the design volume as the traffic estimated to use a certain type of facility during the design year, which is a year usually 10 to 20 years in the future. In high growth areas, the design volume can be surpassed before the highway is completed.

Over time, the load of vehicles may cause pavements to rut . Rutting of wheel tracks creates depressions in the roadway pavement. The depressed wheel track acts as a channel that directs water along the roadway, preventing it from flowing off as needed. Depressions increase the depth of water during rain events and are often the source of hydroplaning conditions. Vehicles traveling at hydroplaning speeds will lose traction control and often leave the roadway or collide into another vehicle.

Insufficient cross-slopes can create hazardous driving conditions during heavy rains. These cross-slopes create extended distances for the water to travel before leaving the surface. The water increases in depth as it travels along its path to the edge of the travel lane; longer paths of water will have increased depths. Bob Gallaway reports in *The Effects of Rainfall Intensity, Pavement Cross Slope, Surface Texture, and Drainage Length on Pavement Water Depths*[5] factors that affect the depth of the water along its travel path. These factors include the average water depth above the top of the surface texture in inches, average texture depth in inches, drainage-path length in feet, rainfall intensity in inches per hour, and cross slope in foot/foot.

The hydrologist and roadway designer evaluate the cross-slopes of proposed roadways and recommend proper cross-slope geometry. The maintenance engineer monitors the traffic volume as well as the potential wheel track depressions. Failure to have adequate cross-slope increases the possibility of hydroplaning. Multiple lanes create longer travel paths for water and, therefore, a greater depth before the water exits the pavement surface.

Many scientific studies have been conducted on vehicle hydroplaning. These studies have measured the ability of the pavement to provide adequate tire-gripping under all operating conditions. Side slipping and skidding are phenomena that occur when frictional demands on the vehicle tires exceed the available friction.

Tire-gripping ability is best when the pavement surface is dry and has a good surface texture. When the pavement is wet and has very low surface texture, gripping ability decreases, causing a longer stopping . A flooded surface has the least tire-gripping ability and is the most likely surface for hydroplaning. When this occurs, the occupants of the vehicle along with the people or property in the path of a hydroplaning vehicle are put in danger.

Tire-gripping ability is important for the dissipation of kinetic energy. A moving vehicle produces kinetic energy at a rate increasing with the square of its velocity. Dissipation of this energy is required in order for the moving body to come to rest. A moving vehicle dissipates energy between the tire and the pavement by creating a friction force opposing the vehicle's direction of motion. The locked wheel develops the friction force between the tire and the pavement interface.

Both the stopping distance and the directional control of a vehicle are improved with a higher pavement friction coefficient, which is measured by the tire-gripping ability. The pavement surface loses surface mortar and texturing over time as exposed coarse aggregate is worn down.

The importance of drainage in curve design can be appreciated by considering the fact that an increase in water depth from 0.02 inches to 0.04 inches can mean an effective drop of six or seven skid number units for pavement skid resistance. If the water reaches a depth of 0.10 inches to 0.15 inches, hydroplaning is likely. Essentially all cross-sections should be designed to limit the depth of surface water to a maximum value. If it can be expected that this maximum will be exceeded, pavement skid resistance should be increased as a compensating measure.[6]

A maximum design water depth of 0.02 inches is desirable. If a water depth design value greater than 0.02 inches is used, the skid resistance of the pavement should be increased to compensate.[6]

Brush and tine textures are used for concrete surfaces to improve skid resistance. Brush texture has a tendency to get worn out relatively early. One of the reason textures is lost during construction is due to washing out of texture by unexpected rain.

Rain can cause damage to both textured and un-textured surfaces during the placement of concrete. The finished surface may not get the necessary time for texturing due to unanticipated downpour.

Another cause of poor surface texture is the use of a poor quality of concrete mix and rock. The aggregates exposed, therefore, get polished. Polishing of aggregates is more severe when the micro-texture of the stone is denser. Wearing of texture due to constant traffic movement is a natural phenomenon. The texture is normally grooved in the cement mortar on the pavement surface. Due to the wearing action, the sharp texture formed by brush initially gets rounded and flattens. Whereas, texture created by tinning is not subject to this type of wearing.

Super-elevated highways present a special problem for removal of water from the roadway. The roadway engineers look at the safety and comfort of the driver to negotiate horizontal curves. The super-elevated pavements in horizontal curves are necessary in order for high speed vehicles to move safely around curves.

The Hydrologist studies the super-elevated curve for the efficient removal of storm water from the pavement surface. The flow pattern of water is changed as the roadway transitions from the crown of a tangent section to the slope required in a super-elevated curve.

The cross slopes of the roadway are super-elevated to offset the outward force of vehicles moving around horizontal curves. The inertia of the vehicle tends to continue in a straight line, which means the vehicle would leave the road as the curve continues around the roadway. The super-elevation of the curve helps the driver to overcome the outward forces and steer the vehicle safely around the curve. The faster the vehicle travels, the greater the outward force. If the vehicle is traveling faster than the equilibrium speed, the resultant lateral force acts outward on the vehicle and its occupants.

The roadway cross section for super-elevated curves transitions from a normal crown in the tangent section of the roadway to full super-elevation in the curve. Four locations define where and how the transition occurs. First, the cross section starts with a “normal crown” and transitions to an “adverse crown removed”—the point at which the high side of the curve is a level plane. From this point, the cross section transitions to the third point: “crown removed”—where the entire roadway is on one plane at the normal cross slope. From this point, the cross section transitions to the fourth point, which is full super-elevation.

The adverse crown location has a zero percent cross slope and will tend to hold water on a roadway on a flat grade. In a downhill grade, the travel length of water is increased dramatically causing the depth of water to increase. An analysis of this situation alerts the roadway design engineer to the potential of an increased storm water depth on the pavement surface.

Irregular pavement slopes in a roadway are the result of localized changes in the pavement surface that comes from poor construction control. The change in the slope increases the storm water's path length, which increases the depth of the water as it travels to the edge of the pavement surface. In areas of tire track rutting, the accumulation of storm water increases dramatically with irregular slopes.

Curbs with gutters allow roadways to be constructed within minimum right-of-way widths. The water on the pavement surface is collected in the gutter and is directed to an inlet or catch basin. Gutter configurations along with the longitudinal and lateral pavement slopes are factors in collecting water from a pavement surface. The design flow determines the spread of water onto the travel lane of the roadway. The hydrologist calculates the distance the water flows outwardly into the travel lanes. The hydrologist determines the type and configuration of curb and gutter needed to minimize the depth of water on the pavement surface and, therefore, minimize the danger of vehicle hydroplaning.

Sags in vertical curves are important locations to investigate. The flow can exceed the allowable design spread values as water approaches the low point in a vertical curve. The spread in these areas should be checked by the hydrologist to insure that the water remains within allowable limits. The hydrologist can determine if additional inlets are required to collect the water to prevent an excessive depth of water on the pavement.

The *Urban Drainage Design Manual*[7] states that the hydraulic capacity of a storm drain inlet depends upon the geometry as well as the characteristics of the gutter flow. Inlet capacity governs both the rate of water removal from the gutter and the amount of water that can enter the storm drainage system. Inadequate inlet capacity or poor inlet location can cause flooding on the roadway, resulting in a hazards for drivers.

Grass shoulders that accumulate dirt result in elevated shoulders. The build-up of soil and debris creates a shoulder higher than the edge of the pavement, which prevents water from leaving the roadway pavement surface. Since most two-lane and many four-lane highways are constructed with grass shoulders, the danger of hydroplaning increases. The accumulation of material on grass shoulders in the sag of a vertical curve is especially problematic. When the shoulder is higher than the pavement, water depth causes vehicles to lose control. The hydrologist can advise on these situations and also provide guidance for highway maintenance in areas that have a high probability of shoulder buildup. These areas are prone to heavy growth and development as well as roadways of haul routes for excavation and disposal pits.

Storm water flowing across multi-lanes presents special challenges to the roadway design engineer. *The AASHTO's Policy on Geometric Design of Highways and Streets*[8] addresses the acceptable range of cross slopes. The design cross slope is a compromise between the steering comfort of the driver and the pavement surface's ability to remove the water from the roadway. It goes on to say that, "Cross slopes up to 2 percent are barely perceptible as far as effect on vehicle steering is concerned, but cross slopes steeper than 2 percent are noticeable."

On roadways that have three or more lanes sloped in the same direction, it is desirable to design the roadway to increase the cross slope in the outermost lanes. The increase in slope of the outermost lanes will increase the efficiency in the removal of water from the roadway and provide safer highways during rain events.

The Pavement and Geometric Design Criteria for Minimizing Hydroplaning[9] concluded from its model study that cross-slope values up to 2 percent showed no significant detrimental effects on friction demand or driver effort.

Hydroplaning and roadway defects are not always associated as the cause of vehicle accidents. Too often the accident is classified as human error or the driver was driving too fast for conditions. Therefore, all wet-pavement accidents should be investigated for potential roadway defects.

In 1980, The National Transportation Safety Board (NTSB) used the National Highway Traffic Safety Administration's (NHTSA) Fatal Accident Reporting System to analyze fatal accidents on wet pavements.[10] The wet-pavement exposure used precipitation data from the National Weather Service. The study developed a wet fatal accident index by using the data regarding fatal accidents and precipitation to reflect the relative severity of the problem in each State. The NTSB concluded that wet-pavement accidents occur 3.9 to 4.5 times more frequently than expected.[11]

Safe removal of water from roadways is a major concern of the roadway design engineer. The pavement surface is evaluated for safe removal of water from the roadway. The evaluation of longitudinal slopes and cross slopes often reveals potential dangerous pavement surface conditions. A study of the pavement surface data on micro-texture and macro-texture pavements reveal if the pavement surface will efficiently remove the water from the roadway. The potential for the expulsion of water between the tire treads and the macro-texture surface of the pavement is evaluated. The Hydrologist uses this data to determine the roadways that need immediate attention.

HIGH WET-WEATHER CRASH LOCATIONS

Isolated areas that have frequent incidents of hydroplaning can be identified using the above information. Instead of waiting for funds to come available to reconstruct an entire roadway, the maintenance department can address shorter lengths of defective pavements. The Hydrologist's role can be significant in reducing the number of traffic accidents and reducing fatality rates on the highway.

The State of Georgia Department of Transportation (DOT) estimates approximately 350,000 accidents on State Highways each year. Georgia experienced 70,531 wet weather crashes in 2003. This accounted for approximately 21% of the total crashes, which is significant when evaluated against the number of wet versus dry days. Wet weather crashes have a variety of contributing factors, including speed, vehicle condition, and pavement conditions.

The DOT is the keeper of the traffic accident reports for the state. The DOT can filter specific information from the database on any specified section of roadway in the state. The analysis can filter the data to determine areas with a high incident of wet pavement accidents and bring this information to the attention of maintenance departments.

For example, if the data reveals a high incident of fatal accidents or property loss occurring between certain mile markers during rain events, the hydrologist can study the roadway surface conditions to determine the cause of the crashes. Many times these accidents will be occurring in a transition into or out of a super-elevation of a horizontal curve. Often, it may be determined that a short section of the roadway has an insufficient cross slope to drain the water across the pavement. The maintenance department can initiate a remediation of that section of roadway. Many times an overlay of the section with Hot Asphalt Mix will decrease or eliminate hydroplaning of vehicles for a minimum amount of money. Portland Cement Concrete pavements can be tined to increase the surface texture. The cost would be minimal and the benefit would be great.

Cost is a major factor in decision making for every state's Department of Transportation. Identification of isolated lengths of roadway can be easily identified, with a solution determined and implemented quickly. Thereby, the state will save lives, as well as costs for state trooper investigation, emergency medical services, lawyers, reconstruction of accident sites, and property damage.

Instead of waiting for large sums of funds to become available for long lengths of roadway reconstruction, maintenance departments—with the assistance of a Hydrologist—can identify short lengths of roadway that are problematic when wet. Problem areas such as sags in vertical curves, transitions into and out of super-elevations, irregular pavement grades, and areas of decreased effective micro and macro-texture can be rehabilitated quicker.

Overall, the focus on fatal and serious injury crashes in localized locations will maximize DOT maintenance dollars.

SUMMARY AND RECOMMENDATIONS

The intent of this document is to provide guidance and awareness for the necessary involvement of the Hydrologist, the roadway design engineer, and the Reconstructionist to evaluate localized roadway defects. The proposed storm water specialists, as presented in this document, can work together, using their resources to identify and eliminate areas susceptible to hydroplaning.

Excessive depths of water on pavements creates defective roadways. This condition endangers the lives of the driving public. Attention to these wet weather conditions on our highway system will decrease the fatalities and the destruction of property. The Hydrologist's involvement in the pavement' surface design as well as in the construction and maintenance of our highways adds the expertise to anticipate high potential areas of wet pavement accidents. Focus on localized roadway defects and the expertise of the hydrologist will enable state DOTs to reduce the potential areas where water accumulations on roadways cause hydroplaning.

The phenomenon of hydroplaning involves a number of factors. The one factor that can be controlled through pavement design and maintenance is water film thickness. Other factors, such as driver behavior, tire pressure, tread depth, and rainfall intensity are clearly not within the control of designers.

The texture of the pavement affects the roadway surface drainage. A good macro-texture provides a channel for water to escape from the tire-pavement interface, decreasing the potential for hydroplaning.

Portland cement concrete pavements can be tinned while still in the plastic state to produce a high level of macro-texture. Existing Portland cement concrete can be re-textured by pavement grooving and cold milling. Both longitudinal and transverse grooving are very effective in achieving macro-texture in concrete pavement. Traverse grooving removes the surface water quickly, resulting in less wet pavement time.

Resurfacing improves the safety performance of roads that experience an abnormally high frequency of wet weather crashes. Resurfacing provides an opportunity to correct a deficient pavement's cross slope. The corrected cross slope allows for better drainage off the pavement surface and improves vehicle control in wet weather.

A relatively new method to increase pavement friction is a high-friction surfacing system[10], which consist of combining resins and polymers with a binder topped with a natural or synthetic hard aggregate. These polymers are usually urethane, silicon, or epoxy. The high friction surfacing system typically uses much smaller and harder aggregates. These aggregates are generally less than one quarter of an inch thick and provide high skid resistance. The high-friction surface can be put in place during off-peak traffic volume hours and opened to traffic in a few hours.

Efforts to improve pavement skid resistance for wet weather conditions have shown the advantages of using open-graded asphalt paving mixtures. The open-graded asphalt friction course consists predominantly of a narrowly-graded coarse aggregate fraction. The coarse aggregate fraction provides the structure of the composite mixture while the fine aggregate fraction acts as filler and imparts a chocking action to stabilize the coarse aggregate.

The final recommendation is to establish a position of State Hydrologist for each state. The State Hydrologist's responsibility would be to closely examine all wet-weather accidents. The State Hydrologist would work with DOT roadway design engineers and accident reconstructionists to identify specific locations of high wet-weather accidents. This person would also work with the maintenance engineers to address these defective roadway locations. A properly trained Hydrologist would provide a high level of reliability and assurance that the roadway system is constructed in accordance with current standards for wet pavement conditions. A Hydrologist with training in automobile accident reconstruction would add additional expertise to the engineers overseeing our highway systems.

A heightened awareness of water film thickness on highway pavements is greatly needed to offset the number of wet-weather accidents. Almost 25 percent of all accidents occur during wet-weather conditions. The involvement of the State Hydrologists and even reconstructionists would focus their attention on this deadly problem. The wet pavement accident team would have the expertise to identify high accident areas and the authority to address these roadway defects.

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