NCHRP 15-55 Guidance to Predict and Mitigate Dynamic Hydroplaning on Roadways - Project Update

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30th RPUG Conference
Best Western Ramkota, Rapid City, SD
Sep 19 to 21, 2018
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- Integrated Hydroplaning Model
- Hydroplaning & Hydroplaning Potential
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NCHRP 15-55 Objective

- To develop a comprehensive hydroplaning risk assessment tool that can be used by transportation agencies to help reduce the potential of hydroplaning.
  - Treating hydroplaning as a multidisciplinary and multi-scale problem
  - Solutions for areas with a high potential of hydroplaning based on a fundamental and meaningful understanding of the problem.
Final Product: Guidance and tools to predict and mitigate hydroplaning on roadways

- Applicable to all types of roadways
- Site-specific factors such as geometric design, etc.
- Appropriate for new construction, reconstruction, and maintenance/retrofit projects.

Two Supporting products:
- A Hydroplaning Risk Assessment Tool
- An Integrated Hydroplaning Model
Research Approach Overview

Mitigation Measures

- Pavement & Highway Engineering
- Advice & Education
- Enforcement & Traffic Control

Inputs

- Weather Conditions: Rainfall
- Road Characteristics: Geometry, Smoothness, Texture, Drainability
- Maneuver
- Speed Limits
- Vehicle Characteristics: Type of vehicle, Safety Features
- Tire Characteristics: Type, Condition

Integrated Hydroplaning Model

- Road Model
- Driver Response
- Vehicle Dynamics
- Tire Model
- Tire-water-pavement Interaction (CFD)

Hydroplaning Risk Assessment Tool

- Water Accumulation
- Water Film Thickness
- Speed
- Simple relationships between road characteristics, vehicle speed and water film thickness and hydroplaning potential

Verification & Validation

- Simulations
- Crash Databases & Road Measurements

Mitigation Strategies

- Mitigation Measures
- Enforcement & Traffic Control
- Advice & Education
- Pavement & Highway Engineering
### Integrated Hydroplaning Model (IHM) Water Film Model

**Three conditions**

1. Straight segment
2. Curve
3. Transition

<table>
<thead>
<tr>
<th>Horizontal Alignment</th>
<th>Grade</th>
<th>Cross-slope</th>
<th>Number of lanes</th>
<th>Macrotexture</th>
<th>Drainability</th>
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<tbody>
<tr>
<td>Straight</td>
<td>0%</td>
<td>0%</td>
<td>2 undivided</td>
<td>Low</td>
<td>Non-permeable</td>
</tr>
<tr>
<td>Curve</td>
<td>1%</td>
<td>1%</td>
<td>4 undivided</td>
<td>Medium</td>
<td>Permeable</td>
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<tr>
<td>Transition</td>
<td>2%</td>
<td>2%</td>
<td>4 divided</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4%</td>
<td></td>
<td>6 divided</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8 divided</td>
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</table>
Transition Results
Example of Results

Graphs showing the relationship between rainfall rate (mm/hr) and WFT (mm) with different conditions:
- Max at road shoulder interface
- Max at 30 cm from shoulders
- Mean on the road

Graphs also show the relationship between Lanes Number and WFT (mm).
Integrated Hydroplaning Model (IHM) Vehicle Model

FSI Validation
Completed

3D Road Surface Model

Water Accumulation

Vehicle Response

Fluid-Solid Interaction (FSI)
Deformed tire structure
Pressure, Critical Velocity

Tire Model (Abaqus)

Tire-water-pavement Interaction (Star-CCM+)

Coupling (Star-CCM+)

Spindle position, lateral and longitudinal forces from tire, vertical hydrodynamic force

Vehicle Dynamics (CarSim)

Effective friction
Roll, pitch, yaw, stability factor

Type of vehicle

Driver
Speed

Vehicle Characteristics

Type of tire Condition (tread depth)

Tire Characteristics

Roughness Texture

Type of vehicle

Vehicle Characteristics

Water Film Thickness

Hydroplaning Potential

Almost done

VT Center for Sustainable Transportation Infrastructure
FSI Model

Inflow

Outflow

Water Level

Pavement Level

Water 5 mm

Water 30 mm
FSI Simulation Results: Lateral Force for the Case Study of 4100N, 50 mph
FSI simulation results for lift and lateral forces under different conditions.

<table>
<thead>
<tr>
<th>Vertical Fz (N)</th>
<th>Speed (mph)</th>
<th>Tire Pressure (psi)</th>
<th>Slip Angle (degree)</th>
<th>Tire Tread(2)</th>
<th>WFT (mm)</th>
<th>Lift Force by water (N)</th>
<th>Lateral Force (N)</th>
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<td>32</td>
<td>2</td>
<td>New tread</td>
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<td>1050</td>
<td>1650</td>
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<tr>
<td>4100 (1)</td>
<td>40</td>
<td>32</td>
<td>2</td>
<td>New tread</td>
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<td>1676</td>
<td>1490</td>
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<td>2</td>
<td>1250</td>
<td>1270</td>
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<td>2100</td>
<td>40</td>
<td>25</td>
<td>5</td>
<td>Half Tread</td>
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<td>X</td>
<td>1260</td>
</tr>
</tbody>
</table>
“Magic” Tire Model

\[ F_y(\alpha, B, C, D, F_z) = D \times F_z \times \sin(C \times \tan(B\alpha)) \]

Where,

\[ B \approx B_0 + B_1 \times \Delta \text{speed} + B_2 \times \Delta \text{pres} \]
\[ C \approx C_0 + C_1 \times \Delta \text{speed} + C_2 \times \Delta \text{pres} \]
\[ D \approx D_0 + D_1 \times \Delta \text{speed} + D_2 \times \Delta \text{pres} \]

\[ B_1 = \left. \frac{\partial B}{\partial \text{speed}} \right|_{s_0} \]
\[ B_1 = \left. \frac{\partial B}{\partial \text{pressure}} \right|_{s_0} \]
\[ C_1 = \left. \frac{\partial C}{\partial \text{speed}} \right|_{s_0} \]

...
Hydroplaning Definition

Hydroplaning potential

\[
H_P = P(H/VSW) = \left( 1 + \left( \frac{PM}{\alpha} \right)^{4\alpha\beta} \right)^{-1}
\]
Hydroplaning Definition (cont.)

✓ Hydroplaning risk

\[ H_R = P(H/ S) = \sum_V \sum_W P(H/W) P(W/S) \]

Vehicle/tire combinations (e.g., sedan with new tires);

Water Film Thicknesses

Pavement surfaces, including many discrete levels of grade, cross-slope, roughness, and texture
Vehicle Dynamic Simulation

Hydroplaning Vehicle Simulator

Hydroplaning Vehicle Simulator allows the user to do a batch simulation by changing the CarSim simulation factors (vehicle type, road characteristic, maneuver, and tire models) automatically by writing CarSim own code file (.par file)

1. G Matrix
2. Text File with the simulation information
Final Outcomes
(Still under development)

✓ Guide for Assessing and Mitigating Hydroplaning Potential

✓ Hydroplaning Risk Assessment Tool
Guide for Assessing and Mitigating Hydroplaning Potential

1. Introduction

2. Understanding Hydroplaning
   2.1. Definitions
   2.2. Accumulation of Water on the Pavement
   2.3. Vehicle Response to Driver Behavior and Road Conditions
   2.5. Integrated Hydroplaning Model

3. Assessment of Hydroplaning Risk
   3.1. Hydroplaning Risk Assessment Tool
   3.2. Evaluation of Pavement Surface Properties
   3.3. Precipitation Estimations
   3.4. Prediction of Hydroplaning Potential and Risk

4. Hydroplaning Mitigation Strategies
   4.1. New Roadways
   4.2. Existing Roadways
   4.3. Case Studies

5. Implementation Recommendations
Hydroplaning Risk Assessment Tool

**Inputs**
- Location
  - Weather databases
- Type of Road Segment
  - Tangent
  - Curve
  - Transition
- Road Characteristics
  - Grade
  - Cross-slope
  - Curvature
  - Lengths
  - Smoothness
  - Macrotexture
  - Drainability
- Vehicle Characteristics
  - Hatchback
  - Sedan
  - SUV
- Tire Characteristics
  - Bald
  - Minimum tread depth
- Speed

**Processes**
- Simplified Water Film Thickness Prediction
- Performance Degradation Estimation (Simple IO Model)
- Hydroplaning risk/Potential Estimation
- Vehicle Response

**Outputs**
- Design Rainfall
- Water Film Thickness
- Effective Friction
- Hydroplaning Risk

Average wet over dry crash rate in Virginia

**Simple Input-Output Model**

**Simple Risk/Potential Model**

**Simple IO Model**
Hydroplaning Potential (Effective Friction) Calculation and Verification

Create Simple Input-Output Model
- INPUT: Vehicle, Road, Tire, WFT
- OUTPUT: Effective Friction

Simple Risk/Potential Model
- INPUT: Effective $\mu$, G Values
- OUTPUT: Risk/Potential

Method to Estimate Hydroplaning Risk/Potential

GUI

Simple IO Model

G Values

Simple Risk/Potential Model

Hydroplaning Risk/Potential

Hydroplaning Factor

Vehicle Type
- A-class Hatchback

Cross-Slope
- 0%

Water Film Thickness
- 0 mm

Grade
- 0%

Tread Depth
- 2.4 mm

Roughness
- ISO A

Dry Friction
- 0.85

Operating Condition
- Braking Deceleration (g/s): 0
- Vehicle Speed (km/h): 0
- Radius of Curvature (m): 0

Initial Plot

Performance Margin: 0.00
Hydroplaning Risk Validation

✓ “Network-level” verification

\[ \text{Average wet over dry crash rate in Virginia} \]

\[ \text{Wet Crash Ratio} = \frac{C_{\text{wet}}/H_{\text{wet}}}{C_{\text{dry}}/H_{\text{dry}}} \]