PAVEMENT RESILIENCE

IOWA NEEDS CONCRETE
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Leif G. Wathne, P.E.
American Concrete Pavement Association
Starting point...

- Climate change is happening…
  - Frequency and intensity of storms
  - Sea level rise
  - Temperature rise
- Not discussing causes of climate change
- About adapting as engineers
“Engineers...design...structures...and materials to fulfill functional objectives and requirements while considering the limitations imposed by practicality, regulation, safety and cost.”

[BLS September 2006]

For pavements, this means designing cost effective solutions to function in the environment and loading regime it is expected to be exposed to during its lifetime...
Recall from undergraduate civil engineering curriculum...
It all starts with geotechnical engineering...

- Sample in-place soils
- Classify (LL, PL etc.).
- Proctor curve (moisture and MDD)
- CBR test? Correlation? Soaked…?
- K-Value
- Design pavement section
Work the in-place soils (scarify, dry, wet, etc.)
Compact to some percentage of MDD at optimum in required number of lifts...
Similar for subbase, base...
Place pavement surface (concrete or asphalt)
Crown, super, ditches, drainage structures, etc. to direct and keep water away
Of course... don’t build in floodplains
Fundamental assumption of this process...

- Pavement layers will REMAIN at or near optimum... system was specifically designed to direct and keep water away.
- May have been reasonable when road network was developed... but the context has changed, in some cases substantially!

- Not designed to perform in an inundated condition
- Is BAU good engineering...?
2017 Homeland Security OIG report:
- 2/3 of flood maps out of date or inaccurate
- FEMA’s flood maps look **backwards** at past events for 100 and 500 year storms
- FEMA study predicts riverine flood areas increase by 45% by 2099
So what...?

- We’re in the pavement world...
Just last year, IDA caused flooding from Gulf to New England
Second most damaging hurricane to hit Louisiana ($50B+)

Near I-10 LaPlace LA

IS SUBGRADE AT OR NEAR OPTIMUM MOISTURE?

Philadelphia, PA

Deegan Expressway, Bronx NY
Carolinas have been hit by TWO 500-year flood events

With Hurricane Florence, NC had over 2500 road closures
HOUSTON (TX) AREA HAS BEEN HIT BY SEVERAL FLOOD EVENTS IN RECENT YEARS – THE WORST WAS HURRICANE HARVEY

IS SUBGRADE AT OR NEAR OPTIMUM MOISTURE?

Area roughly the same as the entire state of West Virginia
SEA LEVEL RISE IS ALREADY IMPACTING COASTAL ZONES

Sunny sky flooding is becoming a common or daily occurrence

Images: DE Photos courtesy of Jim Pappas, DELDOT, FL Photos courtesy of Amy Wedel, FC&PA
Nebraska DOT reported 1,500 road miles closed

Iowa I-29 Impacts

Flooding in the Plains States was severe March 2019

Flooding is NOT only a Coastal Issue
FLOODING ALONG THE MISSOURI RIVER - 2011 & 2019

Flooding is NOT only a Coastal Issue

2011 Reconstruction of I-680

2019 Spring flooding of I-680

IS SUBGRADE AT OR NEAR OPTIMUM MOISTURE?

Source: Todd Hanson and Greg Mulder
Flooding is a Primary Risk to U.S. Infrastructure

Will likely impact MOST of us!

Need to adjust how we design and rehabilitate pavements accordingly
Pavement Resilience...?
What Does Resilience Mean in the Pavement Context?

- FHWA Order 5520 - *Transportation System Preparedness and Resilience to Climate Change and Extreme Weather Events* (2014)

  Resilience ...is the ability to anticipate, prepare for, and *adapt* to changing conditions and *withstand*, respond to, and recover rapidly from disruptions.

![Diagram showing the performance over time with different states of resilience: Green, Red, and Blue. Green is more resilient than Red: Faster recovery time, Higher level of service. Blue is a hardened system as it has a higher final performance level.](image-url)
Rigid and Flexible Pavement Transmit Loads Differently

Flexible Pavement Structure

- Lowered subgrade strength & reduced modulus
  - Reduced load carrying capacity and >1 year recovery time
  - Loading accelerates pavement damage / deterioration
  - Consumes fatigue life faster → Reduced pavement life

Rigid Pavement Structure

- Maintains high level of strength / stiffness
- Subgrade is weak, but still uniform
- Spreading of the load means subgrade is not overstressed
- Little impact on the serviceability / life

Flooding does not impact concrete's load carrying capacity to the same degree as asphalt's
Much of the damage can occur during relief and rescue...
Making Pavement Resilient to Inundation....?
Design Stiffer Pavement Systems...

Stiffer Pavements are less impacted by subgrade strength loss and recover faster (stiffer = concrete, cement stabilized bases, increased asphalt thickness)

- **Performance**
  - **Time (years)**
  - **Design Life**

- **Rigid System**
  - 1) Lower drop in performance (Both Short and long term)
  - 2) Quicker opening
  - 3) Shorter recovery time
  - 4) Less Secondary impacts (less dependence on subgrade / base strength)

- **Flexible System**

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Stiffer Pavements are less impacted by subgrade strength loss and recover faster (stiffer = concrete, cement stabilized bases, increased asphalt thickness)
Modify Design Standards...

- Stiffen the pavement system and/or make less susceptible to moisture related strength loss
- Modify soils
- Stiffen the base
- Stiffen pavement

5.6.2 Determination of Moisture Conditions for Laboratory Testing

Fine-grained materials wet up through capillary action in high rainfall areas. For this reason, use a soaked CBR for design in these areas with a 10-day soaked period in accordance with test method T117 for cohesive soils, unless the rainfall and testing conditions shown in Table 7 support 4-day soaking.

For dry inland regions of NSW prepare the sample at the field moisture content (or the equilibrium moisture content (EMC) where applicable) and test with no soaking period unless the road is subject to inundation or located adjacent to irrigation channels. This approach is to be used in lieu of Table 7.

Table 7: Typical moisture conditions for laboratory CBR testing

<table>
<thead>
<tr>
<th>Median annual rainfall (mm)</th>
<th>Specimen compaction moisture content</th>
<th>Excellent to good drainage</th>
<th>Fair to poor drainage</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 600</td>
<td>OMC</td>
<td>Unsoaked</td>
<td>4-day soak</td>
</tr>
<tr>
<td>600 – 800</td>
<td>OMC</td>
<td>4-day soak</td>
<td>10-day soak</td>
</tr>
<tr>
<td>&gt; 800</td>
<td>OMC</td>
<td>10-day soak</td>
<td>10-day soak</td>
</tr>
</tbody>
</table>

[Source: RMS 11.050 v3.0 2018]
What we learned from Hurricane Katrina

Submerged pavement were weaker than ‘dry’ structures

Asphalt pavements
- Overall strength loss ≈ 2” of new asphalt concrete
- Damage occurred regardless of the length of time the pavement was submerged

Concrete Pavements
- Little relative loss of strength
- Resilient modulus (Mr) is similar for ‘dry’ and submerged pavement structures
Houston Experience... pavement opened immediately!

I-610 to I-45
11” CRCP UBOL & 14” CRCP (Const = 1995-2000)
Design = 43M ESALS, Carried = 92M ESALS

Opened roadway shortly after Hurricane Harvey

Southmore to Yellowstone
9” CRCP (Const = 1983 & 1984)
Design = 7M ESALS, Carried = 22M ESALS

Both sections have been flooded at least three times since original construction

[Source: Resilient Pavement Structures in Texas, Andrew Wimsatt, Ph.D., P.E., Texas A&M Transportation Institute and Lisa Lukefahr, P.E., TCPA]
Australian Experience is Similar

Rigid pavement performs the best at any probability of flooding, and flooding effect is not critical.

A pavement’s strength may be enhanced by:

- Strengthening with an overlay
- Layer Stabilization
- Converting the road into a rigid or composite pavement through granular layers’ stabilization

“It is settled that a rigid pavement is the more flood-resilient.” (p. 5)

[Source: Estimating Pavement’s Flood Resilience; Misbah U. Khan, CPEng; Mahmoud Mesbah, Ph.D.; Luis Ferreira, Ph.D.; and David J. Williams, Ph.D.; American Society of Civil Engineer’s Journal of Transportation Engineering, Part B Pavements, 2017]
What about our existing network...?
“Hardening” techniques for existing roadways...

(Concrete) Overlays

Full Depth Reclamation (FDR)
Concrete overlay increases both the height and the structural strength of the roadway.

- Pressure ~15 - 20 psi at the top of the Asphalt layer.
- Base & subgrade pressures are even lower.

Concrete Overlay as a Resilient Hardening Solution:

- Road Elevation raised the height of the overlay.
- 7000 lbs load.

Concrete overlay increases both the height and the structural strength of the roadway.
Concrete Overlays as an Airfield Resilience Solution
Reconstruction and Rehabilitation of Runways at JFK

The rehabilitation will provide aircraft a solid concrete runway that is more RESILIENT than asphalt and will increase the useful life of runway by four times”

[Source: Port Authority of NY & NJ Press Release, April 2019]
FDR as a Resilience Hardening Solution
Increases rigidity, reduces permeability, & reduces moisture susceptibility

Moisture infiltrates base
- Through high water table
- Capillary action
- Causing softening, lower strength, and reduced modulus

FDR reduces permeability
- Helps keep moisture out
- Maintains high level of strength and stiffness even when saturated

The stabilized base can be topped with either asphalt or CONCRETE surface

Un-stabilized Granular Base
- 100 psi
- 15 psi

FDR w/ Cement-Stabilized Base
- 100 psi
- 4 psi
So... what to do? Where do we start?

Can’t address it all...

- **New roadways:**
  - Assess inundation potential (updated maps)
  - Design stiffer pavement sections (soils, bases, pavement)

- **Existing roadways:**
  - When rehab is needed… re-assess inundation potential
  - Use resilient hardening solutions (overlay, FDR)
  - Start with evacuation routes, STRAHNET, NHS…
Resilience is about **good engineering**...

- Recognizing that the service environment of our pavements is changing...
- Adapting our designs to accommodate stiffer and/or less moisture sensitive pavement structures...
- **Concrete Pavement** uniquely adapted solution
- Starting with our most critical pavement assets

*Business as Usual is NOT Sustainable!*
Thank You,
and have a great afternoon!

www.acpa.org

Thanks to Greg Dean and Jim Mack