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

Site work...

- 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!

![](image)

Based on what we now know, is continuing to follow this process good engineering practice?

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Flood Mapping Today...

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- 2/3 of flood maps out of date or inaccurate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...

Carolinias have been hit by TWO 500-year flood events


I-95 Lumberton, NC (2016)

I-95 Lumberton, NC (2016)

I-40 Pender County 4-Days post hurricane (2018)

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

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
Flooding is NOT only a Coastal Issue

Nebraska DOT reported 1,500 road miles closed

Iowa I-69 Impacts

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
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.
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

Quantifying the loss of strength after saturation...

Soaked vs. Unsoaked CBR
- Laboratory study
- Soaking lowers CBR value
- Loss of strength typically between 20-50% depending on clay and silt content.

FDR Results after Saturation
- Florida field study, US 441
- Approx. 40-60% reduction in subgrade modulus (varies)
- Long recovery time (year(s))
- ~3 years loss of pavement life

Source: Comparison Between Soaked and Unsoaked CBR, Sathawara Jigar K & Prof. A.K.Patel; International Journal of Advanced Engineering Research and Studies E-ISSN249-8974
Much of the damage can occur during relief and rescue...

Hurricane Florence (2018)

Meals that Matter
#MtMFlorence Update

Location 1
98 S Trade Way
Rocky Point, NC

Location 2
7701 S Reelford Rd
Fayetteville, NC

Image: Google Images

... and continue for months!
Further exacerbating the pavement damage while weakened

Hurricane Harvey (2017) resulted in:
• Over 8M cubic yards (CY) of debris in Houston
• Over 2M CY in East Baton Rouge Parish, La.

Superstorm Sandy (2012) led to ~6M CY of debris in New York State

Hurricane Katrina – 38M CY of debris

[Source: Amy Wedel, PCPA]
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)
Modify Design Standards...

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

What we learned from Hurricane Katrina

Submerged pavement were weaker than ‘dry’ pavement

**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 pavements

Impact of Hurricane Katrina on Roadways in the New Orleans Area, Technical Assistance Report No. 07-2TA
Kevin Gaspard, Mark Martinez, Zhongjie Zhang, and Zhong Wu; LTRC Pavement Research Group, March 2007
Houston Experience... pavement opened immediately!

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

(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.”

(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 as a Resilient Hardening Solution

Concrete overlay increases both the height and the structural strength of the roadway.

Concrete Overlay Adoption Growing...

Concrete overlays included in FHWA’s EDC6
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

- 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
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… assess inundation potential
  - Use resilient hardening solutions (overlay, FDR)
  - Start with evacuation routes, strahnet, NHS…

Priority of both Congress and Administration

- Resilience is prominent in both House and Senate draft bills
- Biden’s American Jobs Plan “modernize 20,000 miles of highways, roads, and main streets, not only “fixing them first” but “fixing them right,” with safety, resilience, and all users in mind.”
- Must be ready to respond to their challenge…
Fundamentally...

Resilience is about good engineering...
- Recognizing that the service environment of our pavements is changing...
- Adapting our designs to accommodate
  - Stiffer & and less moisture sensitive structures...
- Starting with our most critical pavement assets

Thank You!

[Image: Google Images]

Thanks to Greg Dean and Jim Mack

www.acpa.org