PAVEMENT RESILIENCE

National Concrete Consortium
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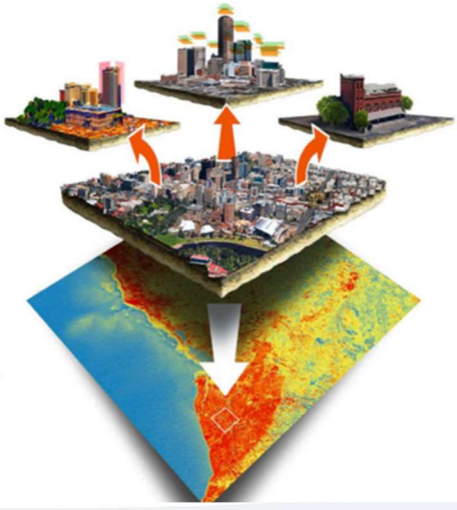
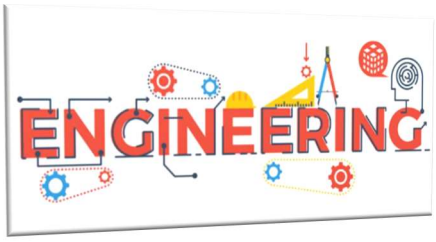
American Concrete Pavement Association

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…

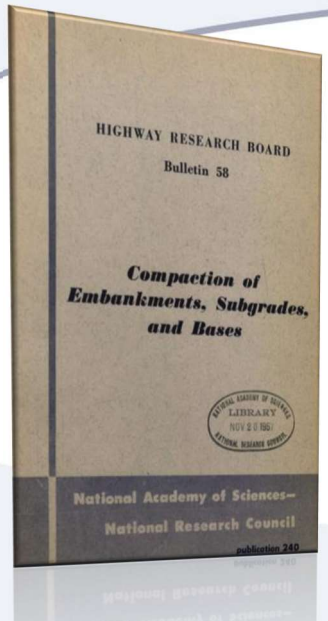
[Image: Google Images]

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

[Images: IndiaMart.com]

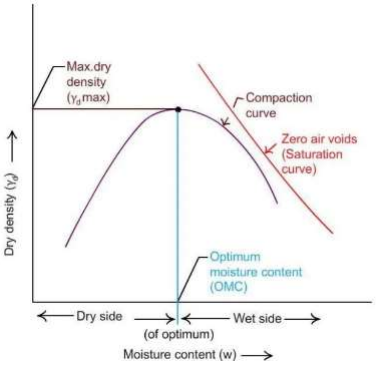
Site work…

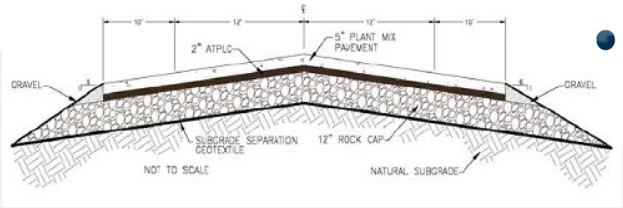


- Work the in-place soils (scarify, dry, wet, etc.)
- Compact to some percentage of MDD at optimum in required number of lifts…
- Similar for subbase, base…
- Place pavement surface (concrete or asphalt)
- Crown, super, ditches, drainage structures, etc. to direct and keep water away
- Of course… **don't build in floodplains**

Fundamental assumption of this process…

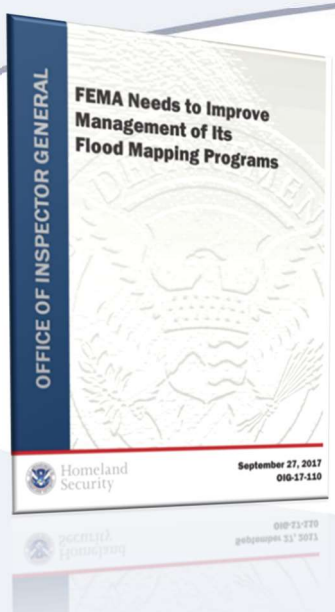
- Pavement layers will **REMAIN** at or near optimum… system was specifically designed to direct and keep water away.
- May have been reasonable when road network was developed… but the **context has changed**, in some cases substantially!





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

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…

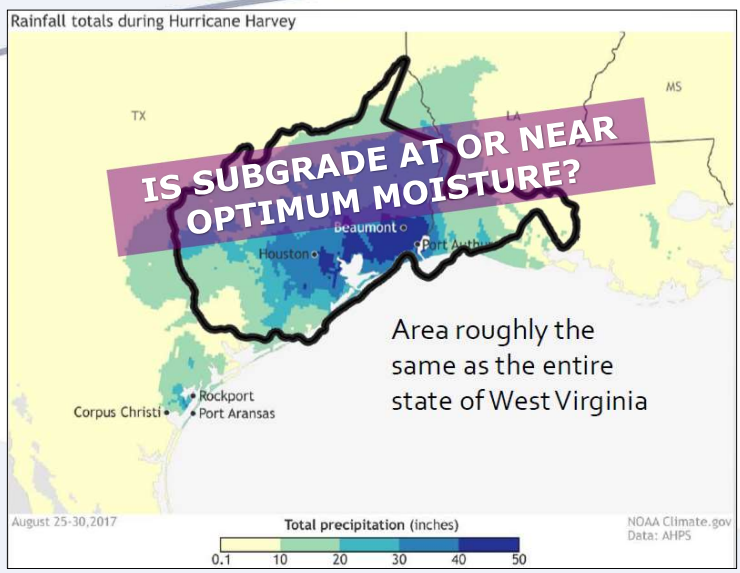
[Images:CBO 2019]

Carolinas have been hit by TWO 500-year flood events

Hurricane Matthew (2016) & Hurricane Florence (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



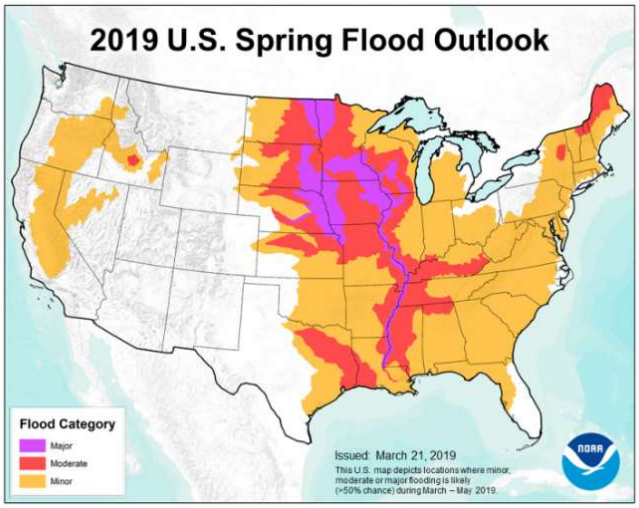
SEA LEVEL RISE IS ALREADY IMPACTING COASTAL ZONES

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 IN THE PLAIN STATES WAS SEVERE MARCH 2019

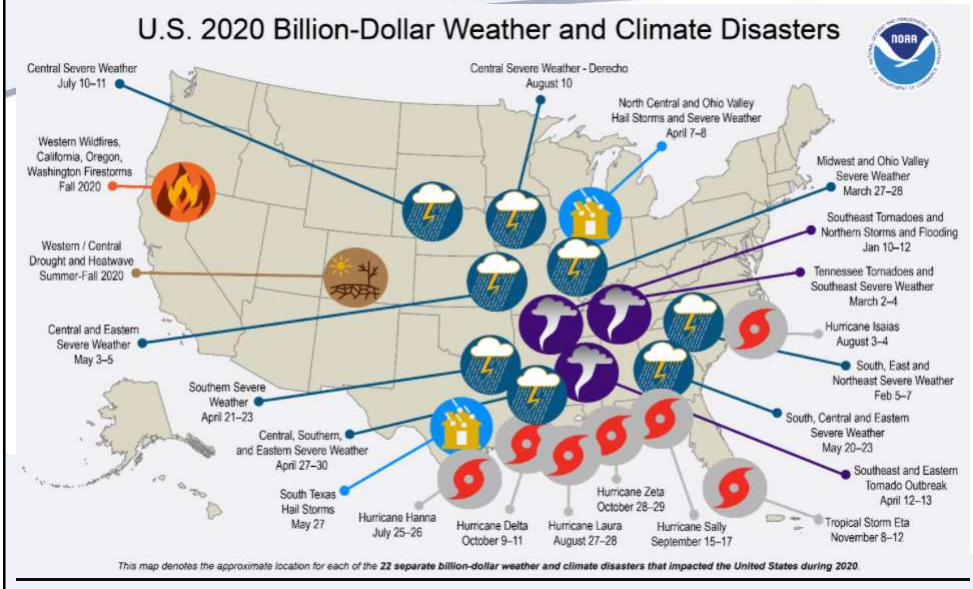
Flooding is NOT only a Coastal Issue



Nebraska DOT reported 1,500 road miles closed

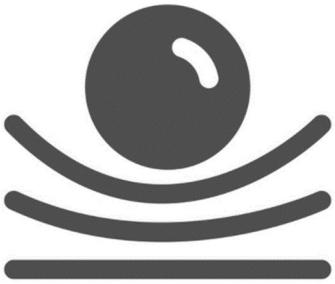
Iowa I-69 Impacts

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

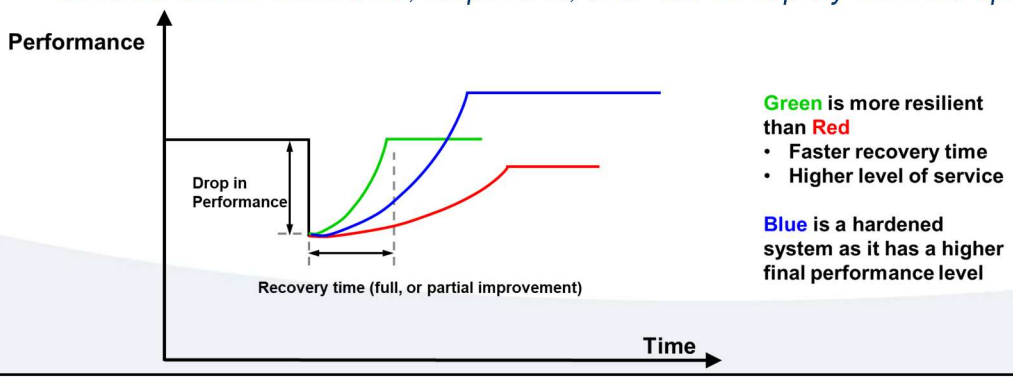
Pavement Resilience…?



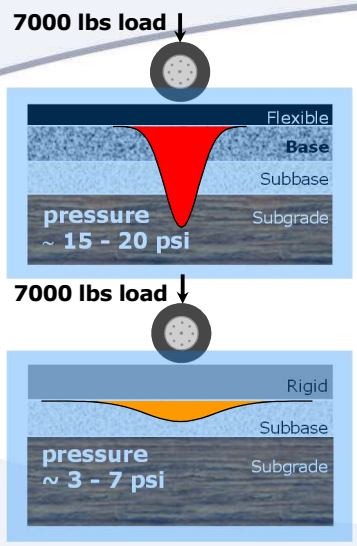
[Icon: Google Images]

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.

Source: Comparison Between Soaked and Unsoaked CBR, Sathawara Jigar K & Prof. A.K.Patel; International Journal of Advanced Engineering Research and Studies E-ISSN2249–8974

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: Decision Support Criteria for Flood Inundated Roadways: A Case Study, A. Gundla, Ph.D., E. Offei, Ph.D. G. Wang, Ph.D., P.E. C.Holzschuher, P.E. and B. Choubane, Ph.D., P.E., Presented at the 2020 TRB Annual Mtg

Much of the damage can occur during relief and rescue…

[Image: Google Images]

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

[Source: Amy Wedel, FCPA]

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

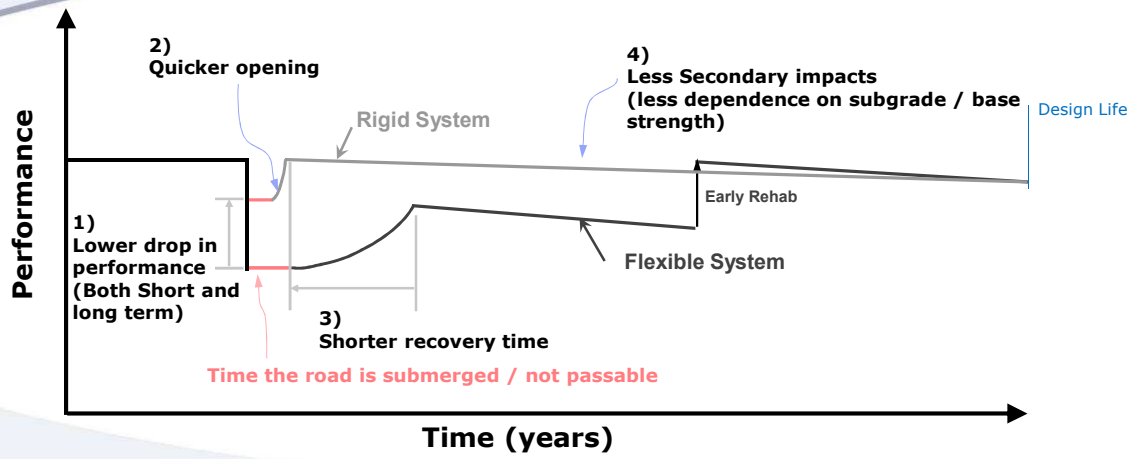
Hurricane Katrina – 38M CY of debris

Capacity = 10 to 17 cubic yards
1M CY ~ 65,000 Dump Trucks

Making Pavement Resilient to Inundation….?

[Image: Google Images]

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**

NSW

Roads and Maritime Supplement to Austroads Guide to Pavement Technology

Part 2: Pavement Structural Design

Document No: RMS 11.050 Version 3.0 | August 2018

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

Median annual rainfall (mm)	Specimen compaction moisture content	Testing condition	
		Excellent to good drainage	Fair to poor drainage
< 600	OMC	Unsoaked	4-day soak
600 – 800	OMC	4-day soak	10-day soak
> 800	OMC	10-day soak	10-day soak

[Source: RMS 11.050 v3.0 2018]

What we learned from Hurricane Katrina

Submerged pavement were weaker than 'dry' pavement

Asphalt pavements

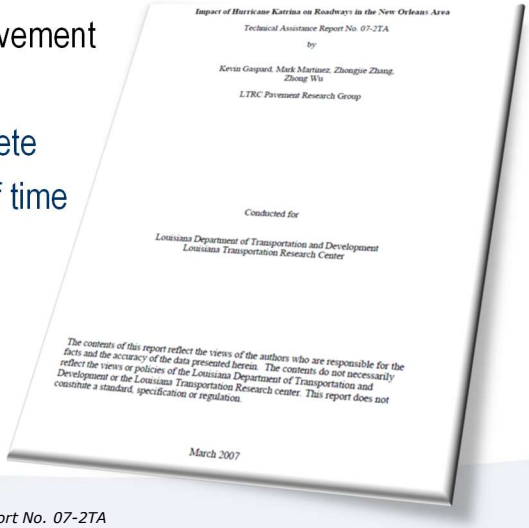
Overall strength loss ≈ 2" of new asphalt concrete

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

by

Kevin Gaspard, Mark Martinez, Zhongjie Zhang, Zhong Wu

LTRC Pavement Research Group

Conducted for

Louisiana Department of Transportation and Development
Louisiana Transportation Research Center

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the views or policies of the Louisiana Department of Transportation and Development or the Louisiana Transportation Research center. This report does not constitute a standard, specification or regulation.

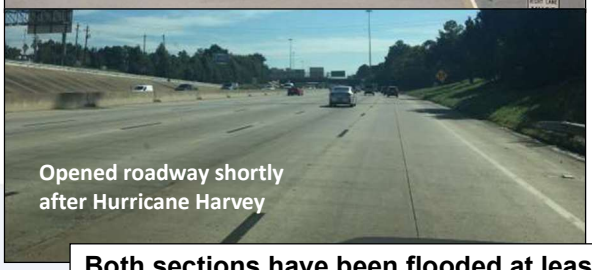
March 2007

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!

I-610 to I-45

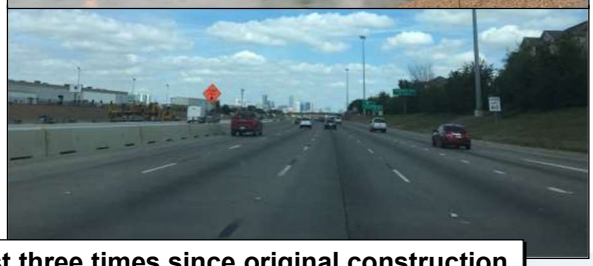
11" CRCP UBOL & 14" CRCP (Const = 1995-2000)
Design= 43M ESALS, Carried = 92M ESALS



Opened roadway shortly after Hurricane Harvey

Southmore to Yellowstone

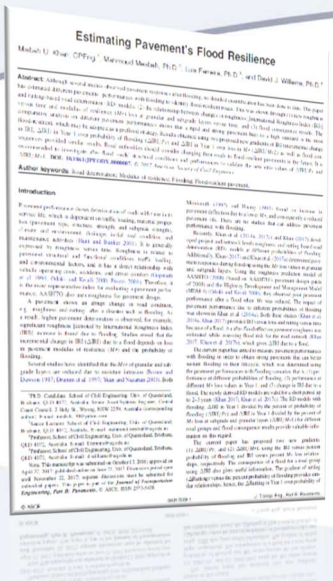
9" CRCP (Const = 1983 & 1984)
Design = 7M ESALS, Carried = 22M ESALS



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



Estimating Pavement's Flood Resilience

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)

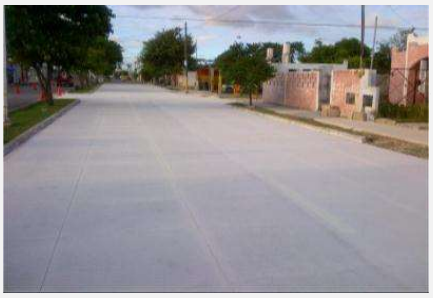
[Source: Estimating Pavement's Flood Resilience; Misbah U. Khan, CPEng; Mahmoud Mesbah, Ph.D.; Luis Ferreira, Ph.D.; and David J. Williams, Ph.D.; American Society of Civil Engineer's Journal of Transportation Engineering, Part B Pavements, 2017]

What about our existing network…?

[Image: Google Images]

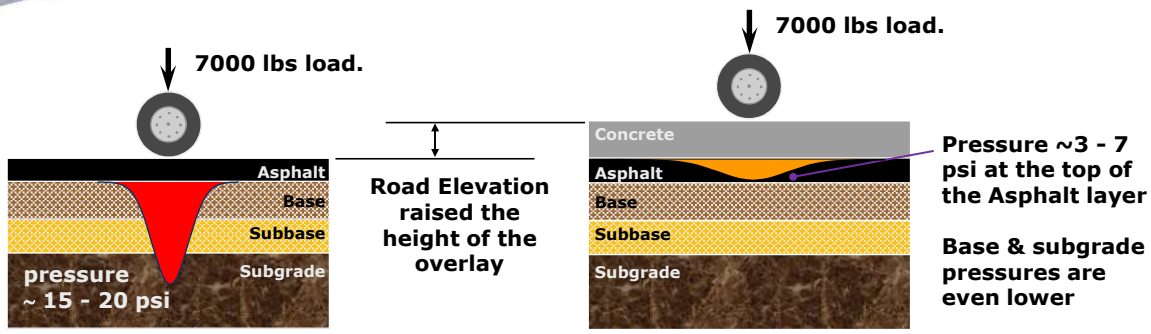
"Hardening" techniques for existing roadways…

(Concrete) Overlays



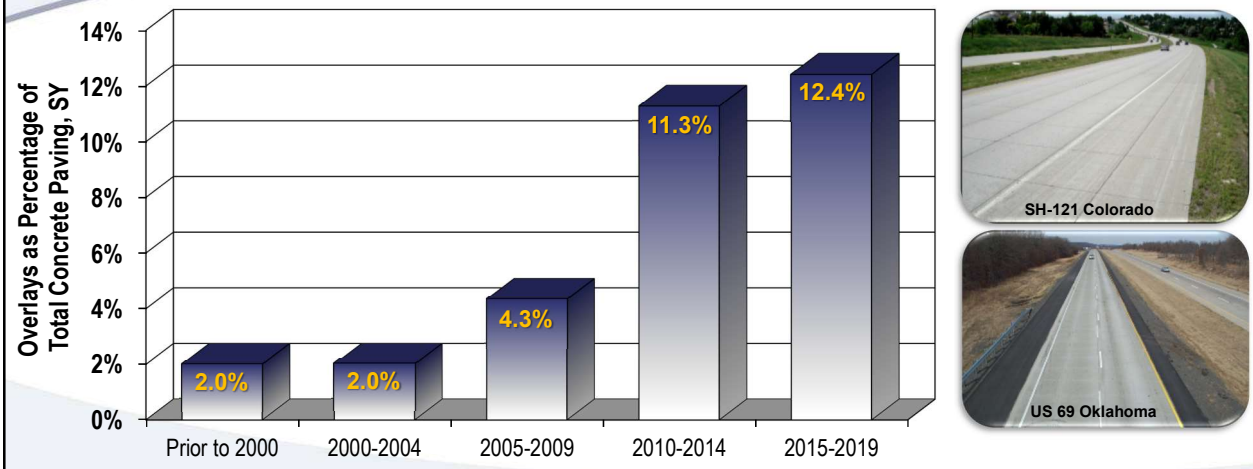
Full Depth Reclamation (FDR)

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

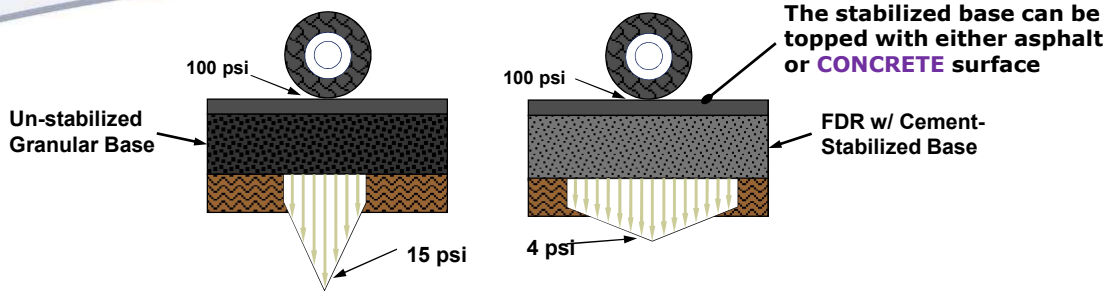
Reconstruction and Rehabilitation of Runways at JFK

*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"*

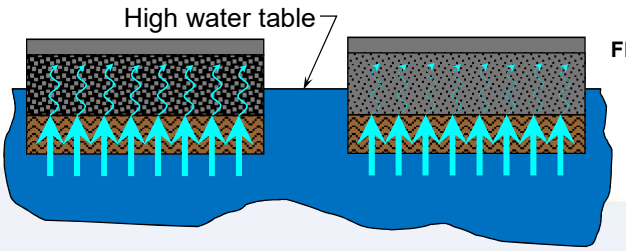
[Source: Port Authority of NY & NJ Press Release, April 2019]

FDR as a Resilience Hardening Solution

Increases rigidity, reduces permeability, & reduces moisture susceptibility



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**

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…

[Image: Google Images]

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…

[Image: Google Images]

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

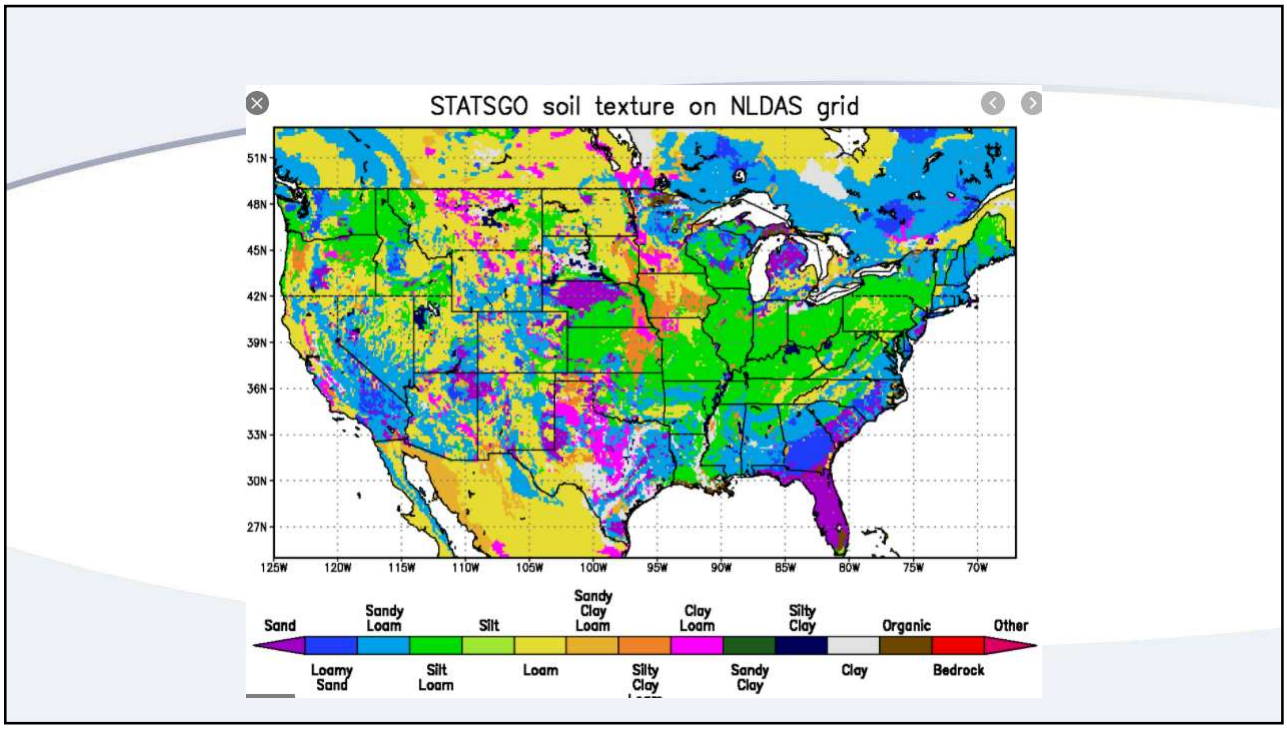
[Image: Google Images]

Thank You!

ACPA

www.acpa.org

- *Thanks to Greg Dean and Jim Mack*


STATSGO soil texture on NLDAS grid
51N
48N
45N
42N
39N
36N
33N
30N
27N
125W
120W
115W
110W
105W
100W
95W
90W
85W
80W
75W
70W
Sand
Loamy Sand
Sandy Loam
Silt Loam
Silt
Loam
Sandy Clay Loam
Silty Clay Loam
Clay Loam
Sandy Clay
Silty Clay
Clay
Organic
Bedrock
Other