Boosting Pavement Resilience in a Changing Climate

A Concrete Pavement Industry Perspective

Greg Dean
Executive Director
Carolinas Concrete Paving Association

Southern Plains Transportation Center
December 16 2020
Webinar

CAROLINAS CONCRETE PAVING ASSOCIATION

Boosting Pavement Resiliency in a Changing Climate

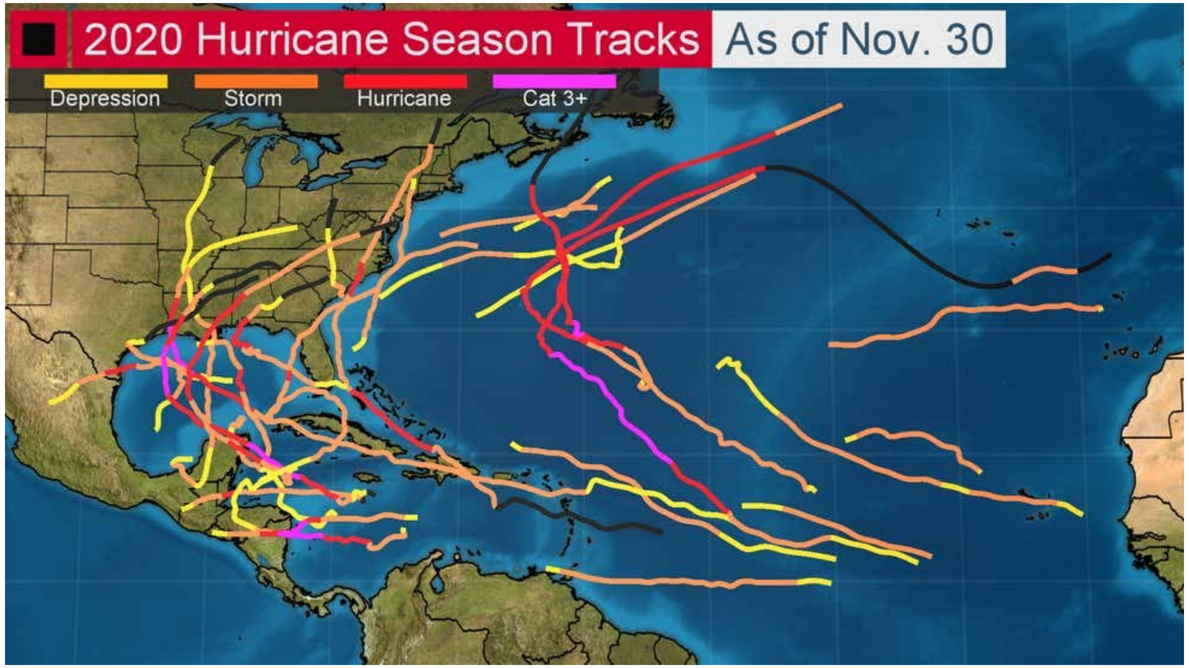
1. The Need for Resilient Pavements
    a) Current knowledge, gaps and trends?

2. Defining Resiliency

3. Improving a Pavement’s Resiliency

2020

A Very Busy, Record-Breaking Year




Greek Names 2020

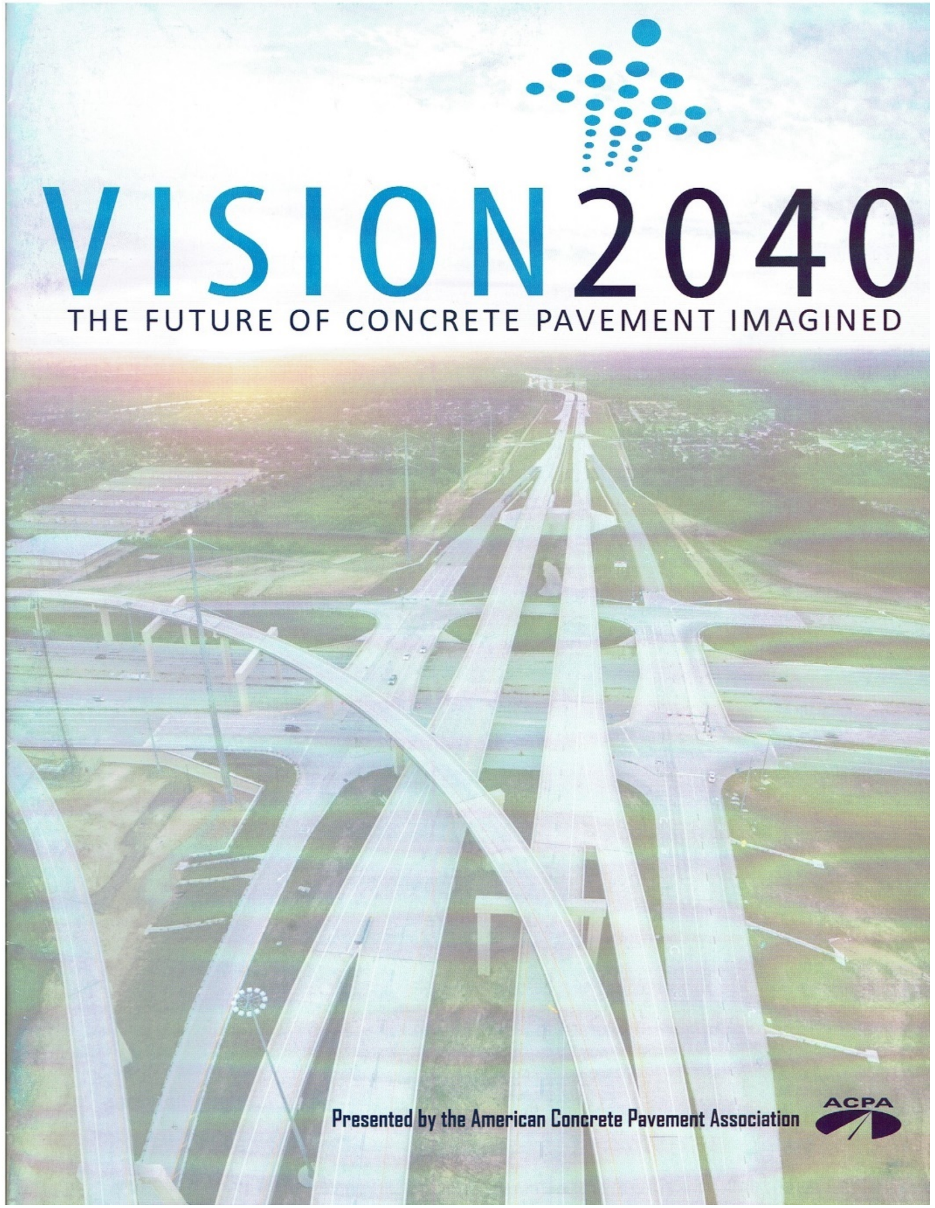
- ✓ Alpha
- ✓ Beta
- ✓ Gamma
- ✓ Delta
- ✓ Epsilon
- ✓ Zeta
- ✓ Eta
- ✓ Theta
- ✓ Iota
- Kappa
- Lambda
- Mu
- Nu
- Xi
- Omicron
- Pi
- Rho
- Sigma
- Tau
- Upsilon
- Phi
- Chi
- Psi
- Omega

- Most Active (30) and 7th costliest, nearly $47B in estimated damages
- 5th Consecutive year above average activity
- 12 Storms made landfall in the US

The Future of Transportation and the Role of Concrete Pavements

- **Blue-Ribbon Panel of 25 Experts**
  - **Convened in Sept 2017**
  - **Diverse group (DOT, FHWA, Consultants, Industry)**

- **What will transportation look like in 2040?**
  - **Role of Concrete and Cement Based Solutions?**
  - **Agencies' needs for pavement solutions?**
    - ☐ **Pavement Adaptability**
    - ☐ **Capitalize on Current Assets**
    - ☐ **Responsible Stewardship of Resources**
    - ☐ **Safety Goals**
    - ☐ **Instilling Competition**
    - ☐ **Solidified the Need for Resilience**



VISION2040

THE FUTURE OF CONCRETE PAVEMENT IMAGINED

Presented by the American Concrete Pavement Association

ACPA

NORTH CAROLINA HAS BEEN HIT BY TWO 500 YEAR FLOOD EVENTS

Hurricane Matthew (2016) & Hurricane Florence (2018)

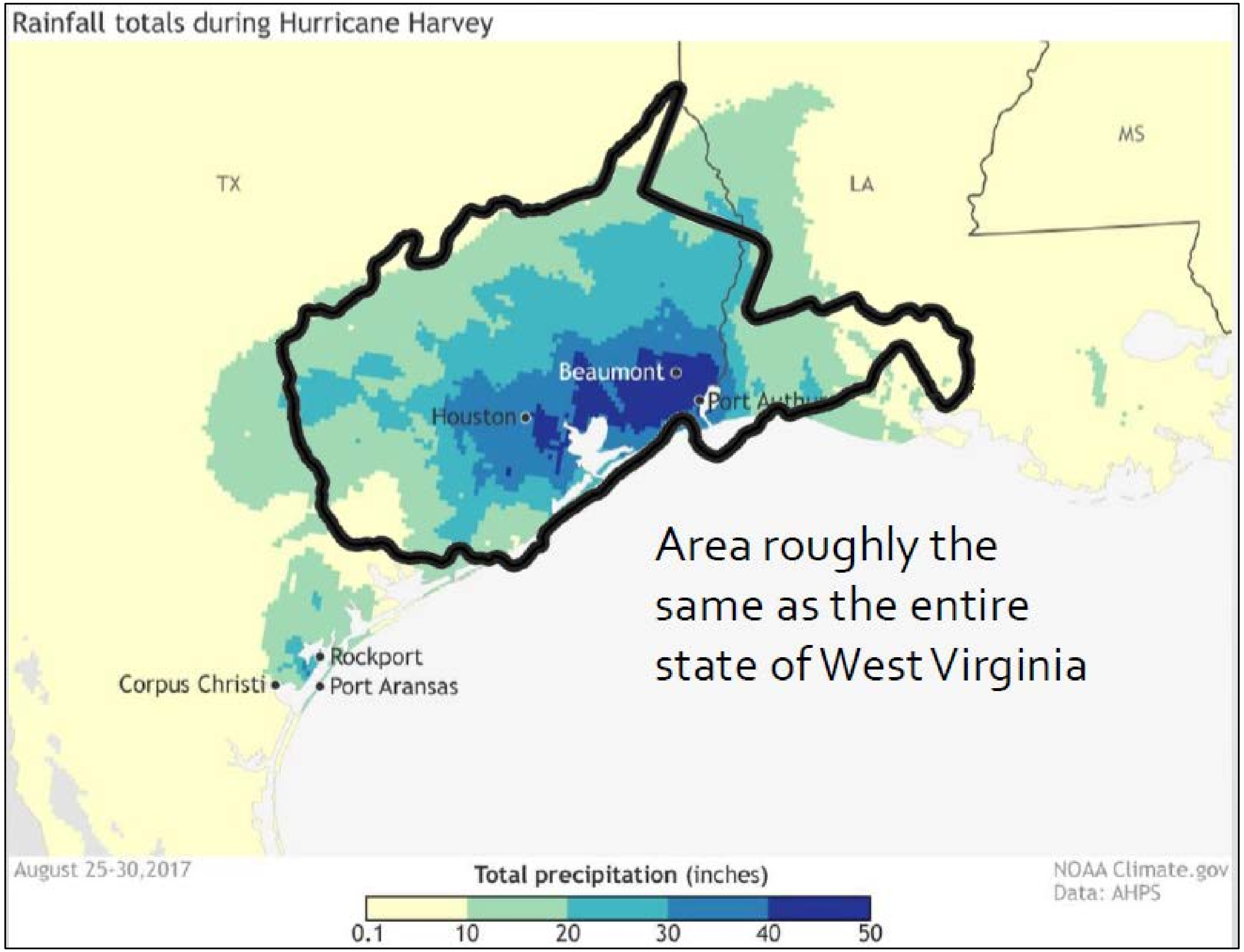
I-95 Lumberton, NC (2016)

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



Rainfall totals during Hurricane Harvey

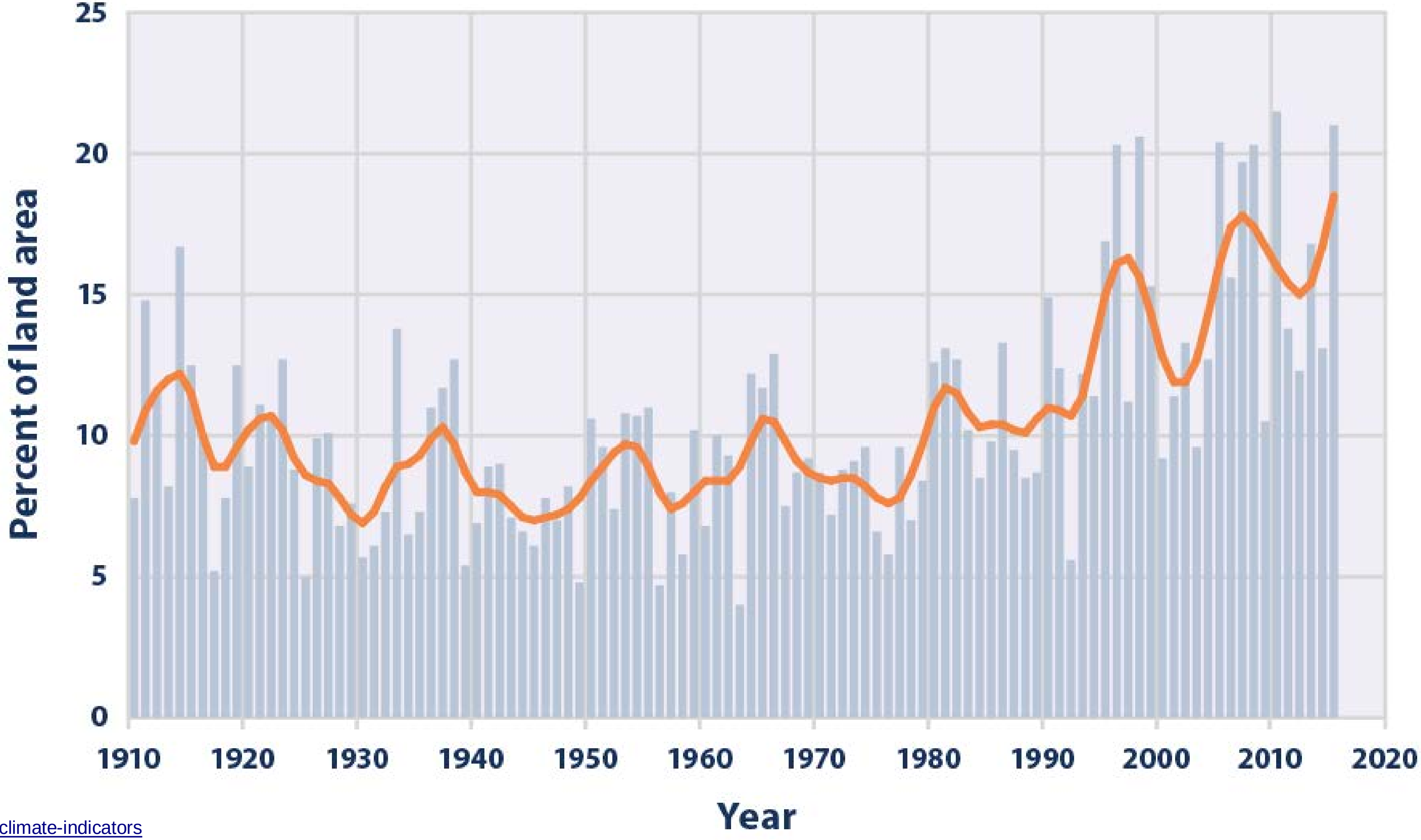
Area roughly the same as the entire state of West Virginia

August 25-30,2017

NOAA Climate.gov
Data: AHPS

EXTREME FLOOD EVENTS ARE INCREASING IN BOTH FREQUENCY AND MAGNITUDE

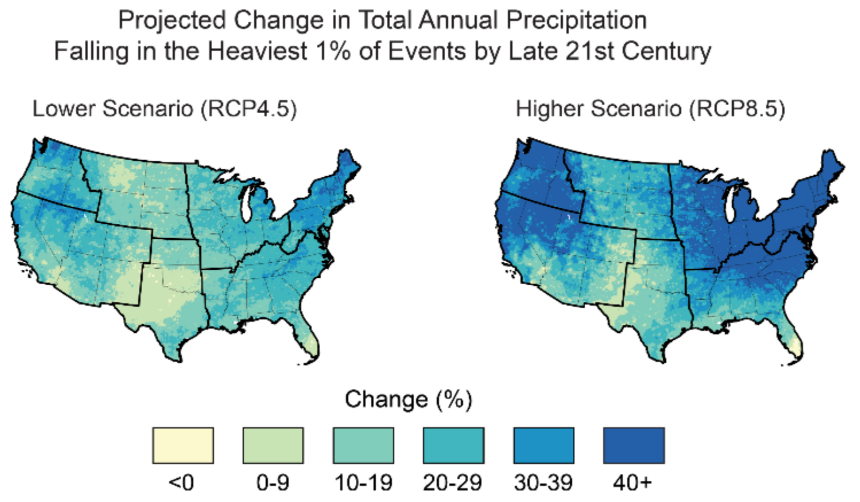
Extreme One-Day Precipitation Events in the Contiguous 48 States, 1910–2015

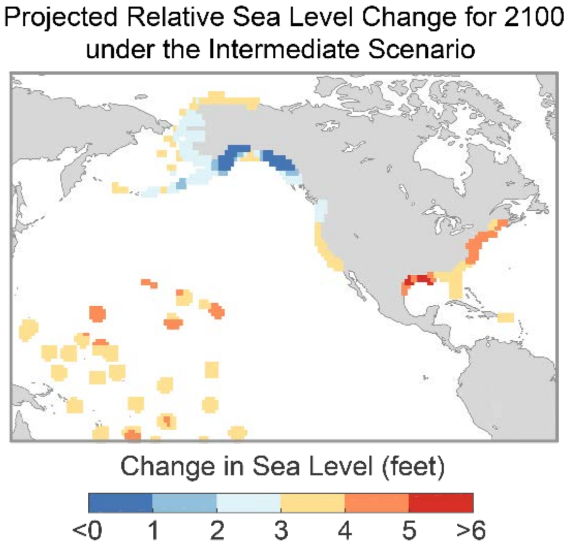


Source: https://www.epa.gov/climate-indicators

FUTURE CLIMATE CONDITIONS WILL NOT RESEMBLE THE PAST

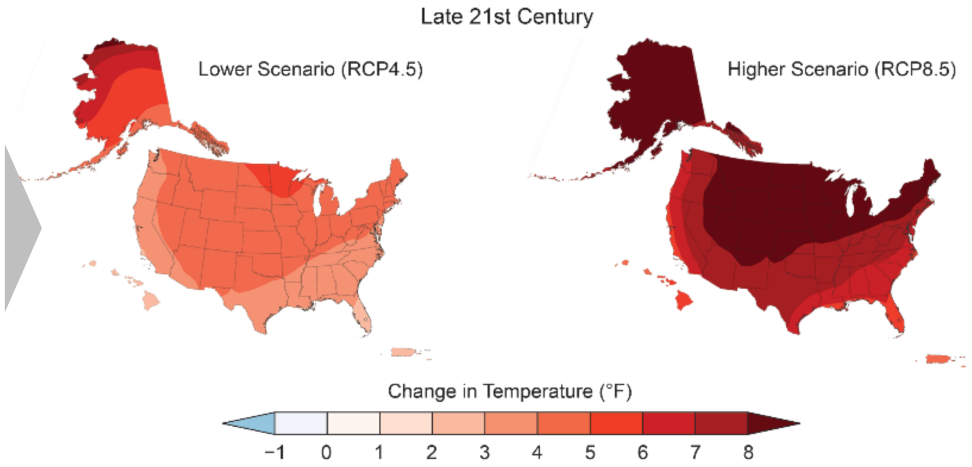
U.S. severe storms, heavy precipitation events:
Greater intensity *and* frequency
Continued increases expected


Projected Change in Total Annual Precipitation Falling in the Heaviest 1% of Events by Late 21st Century


Projected Relative Sea Level Change for 2100 under the Intermediate Scenario

Global mean sea level:
7–8 inches higher since 1900 - about half since 1993
Expected to rise by 1–4 feet by 2100

Increased Extreme heat events and drought:
Increased incidence of large forest fires


Late 21st Century

USGCRP, 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II: Report-in-Brief [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 186 pp.

SEA LEVEL RISE IS ALREADY IMPACTING COASTAL ZONES

Sunny sky flooding is becoming a common or daily occurrence


SR54 East of Fenwick, DE


South Bowers Beach , DE

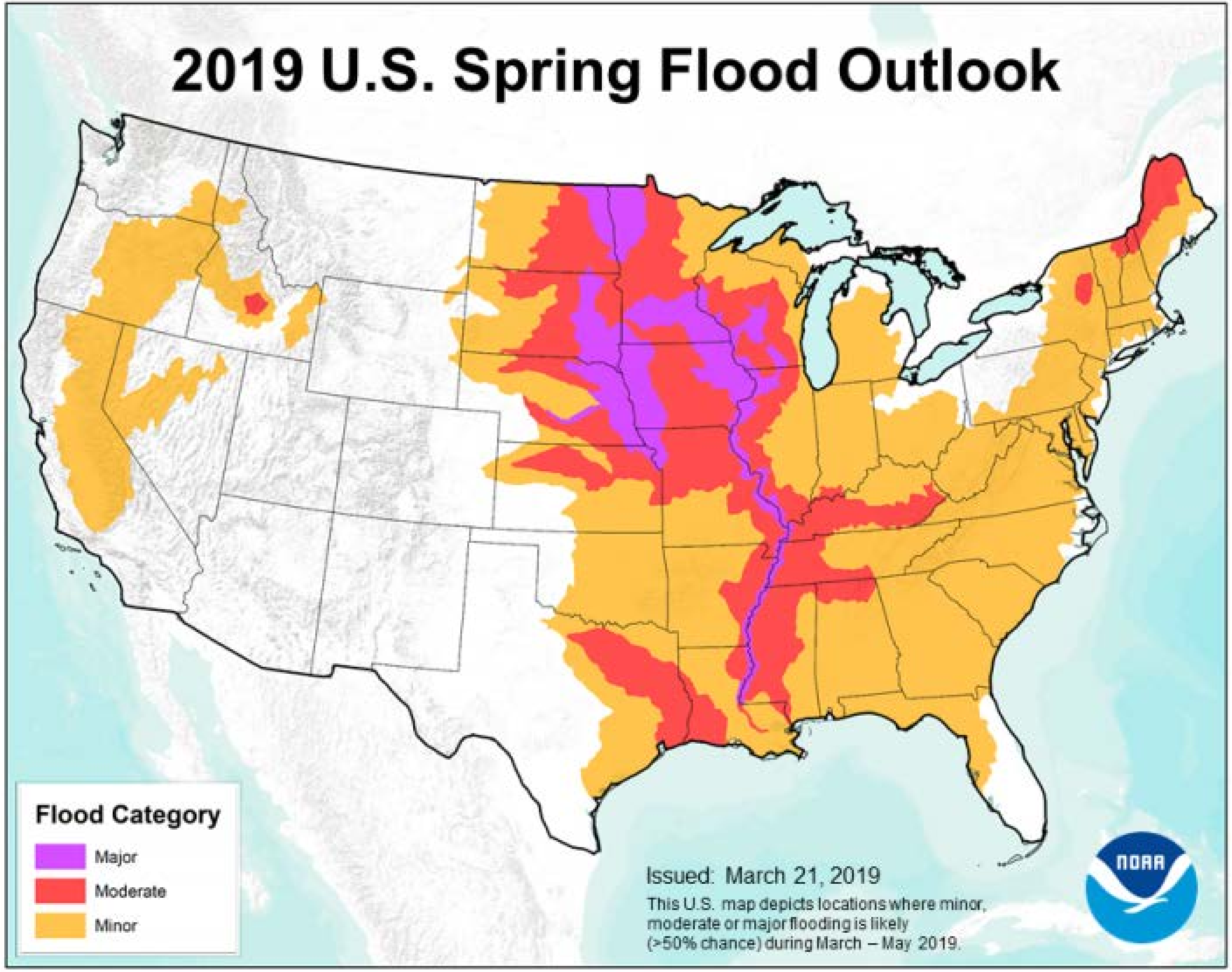

Charleston, SC


Miami, FL

DE Photos courtesy of Jim Pappas, DELDOT
FL Photos courtesy of Amy Wedel, FC&PA

FLOODING IN THE PLAIN STATES WAS SEVERE THIS PAST YEAR

Flooding is NOT only a Coastal Issue



Issued: March 21, 2019

This U.S. map depicts locations where minor, moderate or major flooding is likely (>50% chance) during March – May 2019.

Nebraska DOT reported 1,500 road miles were closed

Iowa I-69 Impacts

The Need for Pavement Resiliency

GOOD resources can be found…

Articles & New Polling

How Severe Weather Damages our Roadways (August 2019)

Extreme Weather and Climate Adaptation (June 2019)

Federally Funded Infrastructure Must Be Flood Ready

Public Roads - Boosting Pavement Resilience (Autumn 2018)

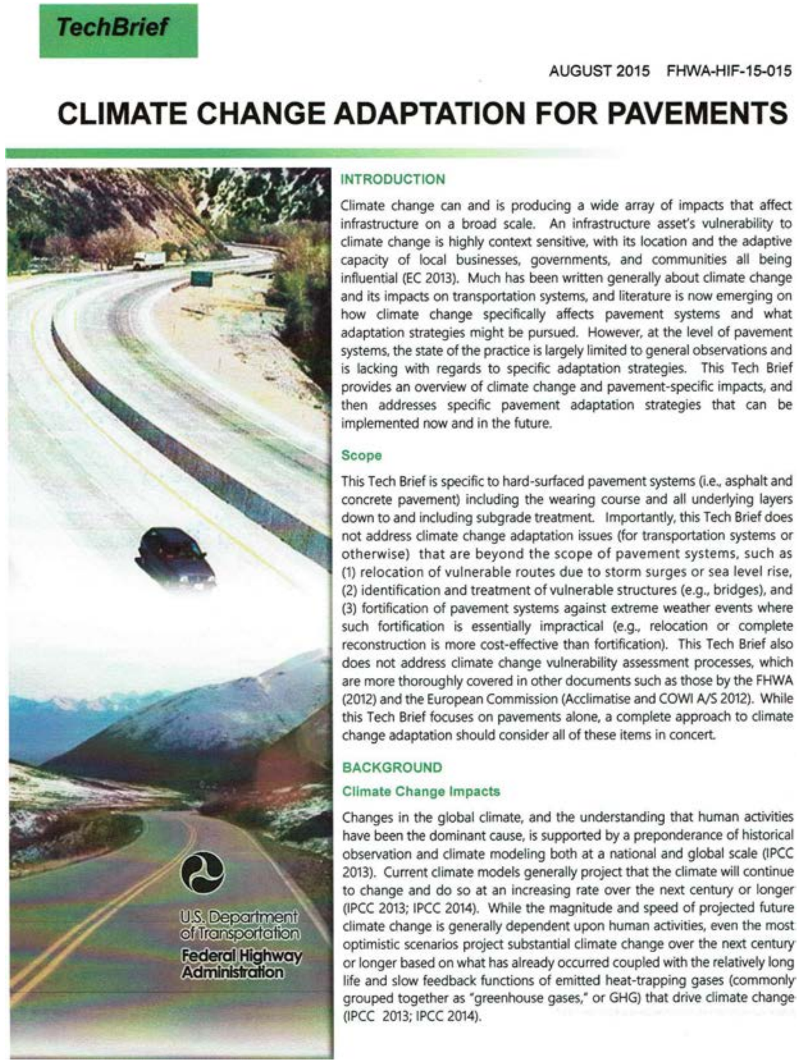
Texas Roadways Proven Resilient After Hurricane Flooding

PEW Charitable Trusts Flood Infrastructure Survey (Feb 2020)

Reports and Publications

LTPP Tech Brief - Impact of Environmental Factors on Pavement Performance (Dec 2016)

FHWA - Climate Change Adaptation For Pavements (August 2015)



TechBrief

AUGUST 2015 FHWA-HIF-15-015

CLIMATE CHANGE ADAPTATION FOR PAVEMENTS

U.S. Department of Transportation
Federal Highway Administration

INTRODUCTION

Climate change can and is producing a wide array of impacts that affect infrastructure on a broad scale. An infrastructure asset's vulnerability to climate change is highly context sensitive, with its location and the adaptive capacity of local businesses, governments, and communities all being influential (EC 2013). Much has been written generally about climate change and its impacts on transportation systems, and literature is now emerging on how climate change specifically affects pavement systems and what adaptation strategies might be pursued. However, at the level of pavement systems, the state of the practice is largely limited to general observations and is lacking with regards to specific adaptation strategies. This Tech Brief provides an overview of climate change and pavement-specific impacts, and then addresses specific pavement adaptation strategies that can be implemented now and in the future.

Scope

This Tech Brief is specific to hard-surfaced pavement systems (i.e., asphalt and concrete pavement) including the wearing course and all underlying layers down to and including subgrade treatment. Importantly, this Tech Brief does not address climate change adaptation issues (for transportation systems or otherwise) that are beyond the scope of pavement systems, such as (1) relocation of vulnerable routes due to storm surges or sea level rise, (2) identification and treatment of vulnerable structures (e.g., bridges), and (3) fortification of pavement systems against extreme weather events where such fortification is essentially impractical (e.g., relocation or complete reconstruction is more cost-effective than fortification). This Tech Brief also does not address climate change vulnerability assessment processes, which are more thoroughly covered in other documents such as those by the FHWA (2012) and the European Commission (Acclimatise and COWI A/S 2012). While this Tech Brief focuses on pavements alone, a complete approach to climate change adaptation should consider all of these items in concert.

BACKGROUND

Climate Change Impacts

Changes in the global climate, and the understanding that human activities have been the dominant cause, is supported by a preponderance of historical observation and climate modeling both at a national and global scale (IPCC 2013). Current climate models generally project that the climate will continue to change and do so at an increasing rate over the next century or longer (IPCC 2013; IPCC 2014). While the magnitude and speed of projected future climate change is generally dependent upon human activities, even the most optimistic scenarios project substantial climate change over the next century or longer based on what has already occurred coupled with the relatively long life and slow feedback functions of emitted heat-trapping gases (commonly grouped together as "greenhouse gases," or GHG) that drive climate change (IPCC 2013; IPCC 2014).

Pavement Resiliency

FHWA – Climate Change Adaptation for Pavements

HOTTER

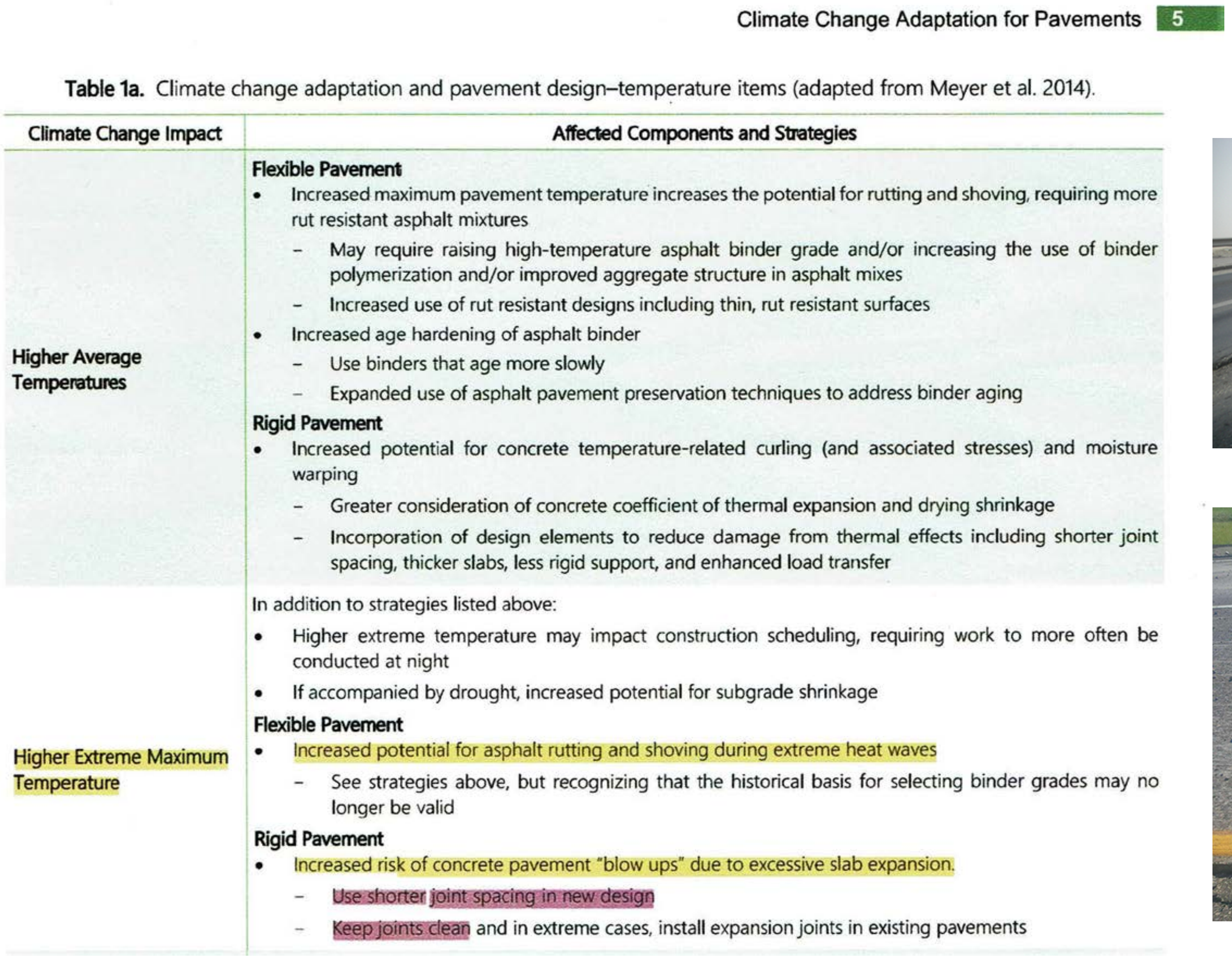


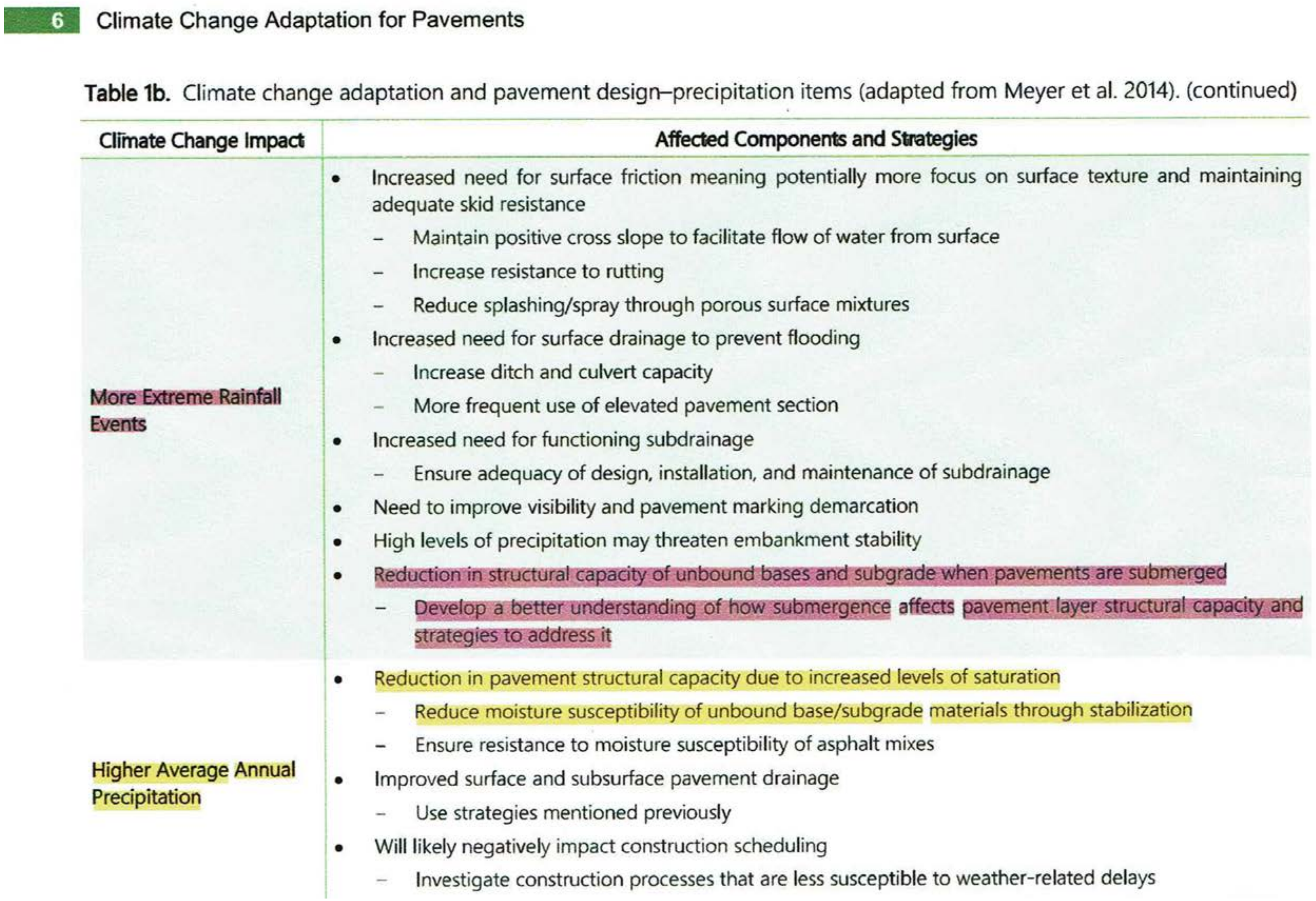
Table 1a. Climate change adaptation and pavement design–temperature items (adapted from Meyer et al. 2014).

Climate Change Impact	Affected Components and Strategies
Higher Average Temperatures	**Flexible Pavement** • Increased maximum pavement temperature increases the potential for rutting and shoving, requiring more rut resistant asphalt mixtures – May require raising high-temperature asphalt binder grade and/or increasing the use of binder polymerization and/or improved aggregate structure in asphalt mixes – Increased use of rut resistant designs including thin, rut resistant surfaces • Increased age hardening of asphalt binder – Use binders that age more slowly – Expanded use of asphalt pavement preservation techniques to address binder aging **Rigid Pavement** • Increased potential for concrete temperature-related curling (and associated stresses) and moisture warping – Greater consideration of concrete coefficient of thermal expansion and drying shrinkage – Incorporation of design elements to reduce damage from thermal effects including shorter joint spacing, thicker slabs, less rigid support, and enhanced load transfer
Higher Extreme Maximum Temperature	In addition to strategies listed above: • Higher extreme temperature may impact construction scheduling, requiring work to more often be conducted at night • If accompanied by drought, increased potential for subgrade shrinkage **Flexible Pavement** • Increased potential for asphalt rutting and shoving during extreme heat waves – See strategies above, but recognizing that the historical basis for selecting binder grades may no longer be valid **Rigid Pavement** • Increased risk of concrete pavement "blow ups" due to excessive slab expansion. – Use shorter joint spacing in new design – Keep joints clean and in extreme cases, install expansion joints in existing pavements

Pavement Resiliency

FHWA – Climate Change Adaptation for Pavements

WETTER



6 Climate Change Adaptation for Pavements

Table 1b. Climate change adaptation and pavement design–precipitation items (adapted from Meyer et al. 2014). (continued)

Climate Change Impact	Affected Components and Strategies
More Extreme Rainfall Events	• Increased need for surface friction meaning potentially more focus on surface texture and maintaining adequate skid resistance – Maintain positive cross slope to facilitate flow of water from surface – Increase resistance to rutting – Reduce splashing/spray through porous surface mixtures • Increased need for surface drainage to prevent flooding – Increase ditch and culvert capacity – More frequent use of elevated pavement section • Increased need for functioning subdrainage – Ensure adequacy of design, installation, and maintenance of subdrainage • Need to improve visibility and pavement marking demarcation • High levels of precipitation may threaten embankment stability • Reduction in structural capacity of unbound bases and subgrade when pavements are submerged – Develop a better understanding of how submergence affects pavement layer structural capacity and strategies to address it
Higher Average Annual Precipitation	• Reduction in pavement structural capacity due to increased levels of saturation – Reduce moisture susceptibility of unbound base/subgrade materials through stabilization – Ensure resistance to moisture susceptibility of asphalt mixes • Improved surface and subsurface pavement drainage – Use strategies mentioned previously • Will likely negatively impact construction scheduling – Investigate construction processes that are less susceptible to weather-related delays

Nov 2020 rainfall
I-95 damage

FHWA Pavement Resiliency Peer Exchange (#1)

Poll Results from (39) Attendees

ACPA, NAPA, DOT's (10), Universities (5), Consultants

TOP ISSUES of Concern

- Q1 Poll following 1st Break-out

1. **Inundation due to flooding**
2. **Erosion/washouts/scour**
3. **Sea-level rise related issues**
4. **Temperature impacts on pavement materials and pavement design process.**
5. **Repeated occurrence of extreme events at the same location.**

Source: FHWA Pavement Resiliency Peer Exchange

Most Pressing PAVEMENT Issues

- Q2 Poll following 2nd Break-out

1. **Pavement designs that take flooding concerns into account**
2. **Making existing pavements more resilient (primarily due to inundation)**
3. **Pavement-ME calibration for forward-looking climate-related inputs**
4. **Planning for and rapidly responding to extreme events to maintain and restore operations**
5. **Uncertainty about structural integrity of base layers.**

FHWA Pavement Resiliency Peer Exchange (#1)

Research Gaps & Needs

Q3 Poll, following the 3rd Break-out

1. **Better/simpler models amenable to pavement design to help account for vulnerability and predict impacts**
2. **(TIE) Rapid evaluation/assessment criteria for pavement damage after extreme event occurs**
3. **Quantify spending needed to achieve a certain level of resilience and develop performance metrics and thresholds of resilience for pavements**
4. **Incorporating climate vulnerability issues into asset management process**
5. **(TIE) National top-down effort to make resiliency a priority.**

Source: FHWA Pavement Resiliency Peer Exchange

FLOODING IS THE PRIMARY CLIMATE RISK TO INFRASTRUCTURE

Risk can occur as both sudden shocks & long-term recurring chronic pressures

Transportation Asset	**Sea-level rise & tidal floods**	**Riverine & pluvial flooding**	**Hurricanes, typhoons & storms**	**Tornadoes & wind events**	**Drought**	**Heat (air & water)**	**Wildfires**
Airports	▒	▓	█	▒	░	▓	▒
Rail	▒	█	▒	░	░	▒	▒
Roads	▒	█	▒	░	░	▒	▒
River	▒	▓	▒	░	▒	░	░
Seaports	▓	▒	█	▒	░	▓	░

Little or No Risk ░ ▒ ▓ █ Increased Risk

Climate risk increases operating costs & exacerbates the infrastructure funding gap

Source: *McKinsey & Company, Will infrastructure bend or break under climate stress?, McKinsey & Company,* August 19, 2020
https://www.mckinsey.com/Videos/video?vid=6180836320001&plyrid=HkOJqCPWdb&aid=A21DD0A9-7DA8-44A2-87E0-B4944177F295

Boosting Pavement Resiliency in a Changing Climate

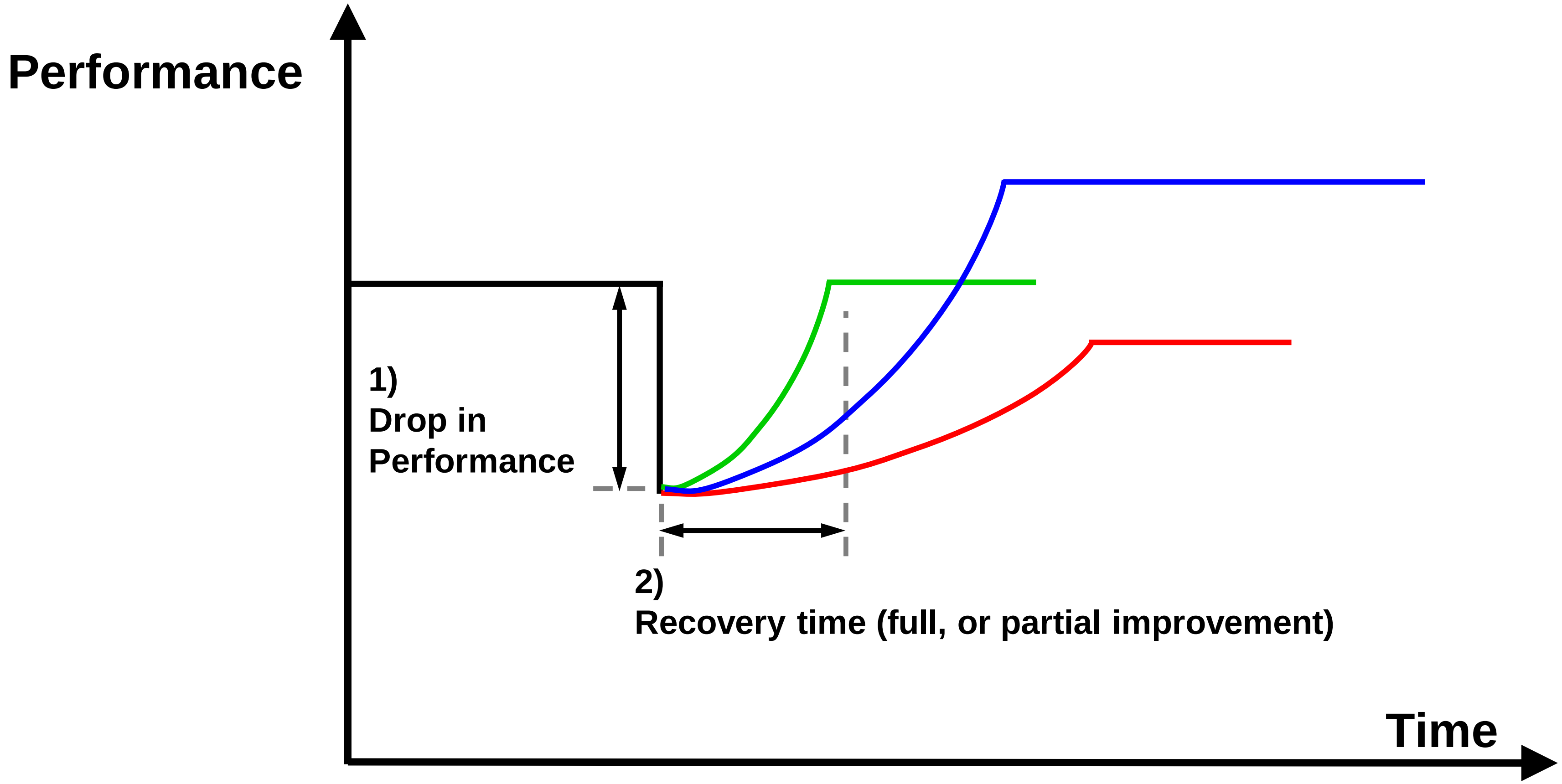
a) The Need for Resilient Pavements

b) Defining Resiliency
    a) An academic and scientific approach relating to pavements

c) Improving a Pavement’s Flood Resiliency

INTRODUCTION TO RESILIENCE

The ability to … anticipate, prepare for, and adapt … withstand, respond to, and recover rapidly…[1]



Green is more resilient than Red

- **Faster recovery time**
- **Higher level of service**

Blue is a hardened[2] **system as it has a higher final performance level**

Resilience with respect to an event (eg. Flooding, fire, earthquake, etc) is characterized by two parameters:

1. Drop in performance, induced by the event (eg. reduced ability to carry load).
2. Recovery time to reinstate or improve performance.

---

1. ***FHWA Order 5520****: Transportation System Preparedness and Resilience to Climate Change and Extreme Weather Events*
2. *Hardening Infrastructure* – Elevating, upgrading, relocating assets, flood walls, berms and levees, etc.

FUNDAMENTALS TO CREATING RESILIENT SYSTEMS

Prevention, Protection & Mitigation Strategies have Benefit / Cost Ratios range from 2:1 to 9:1

Hierarchy to Resilient Systems [1]

1. **Prevention: stop a … manmade or natural disasters**
2. **Protection: secure against …manmade or natural disasters**
3. **Mitigation: reduce …. by lessening the impact of disasters**
4. Response: … meet basic human needs after an incident
5. Recovery: …assist communities affected by an incident to recover effectively

Developing a resilient pavements / roadway infrastructure requires an understanding the risk and damaged caused for each climate hazards

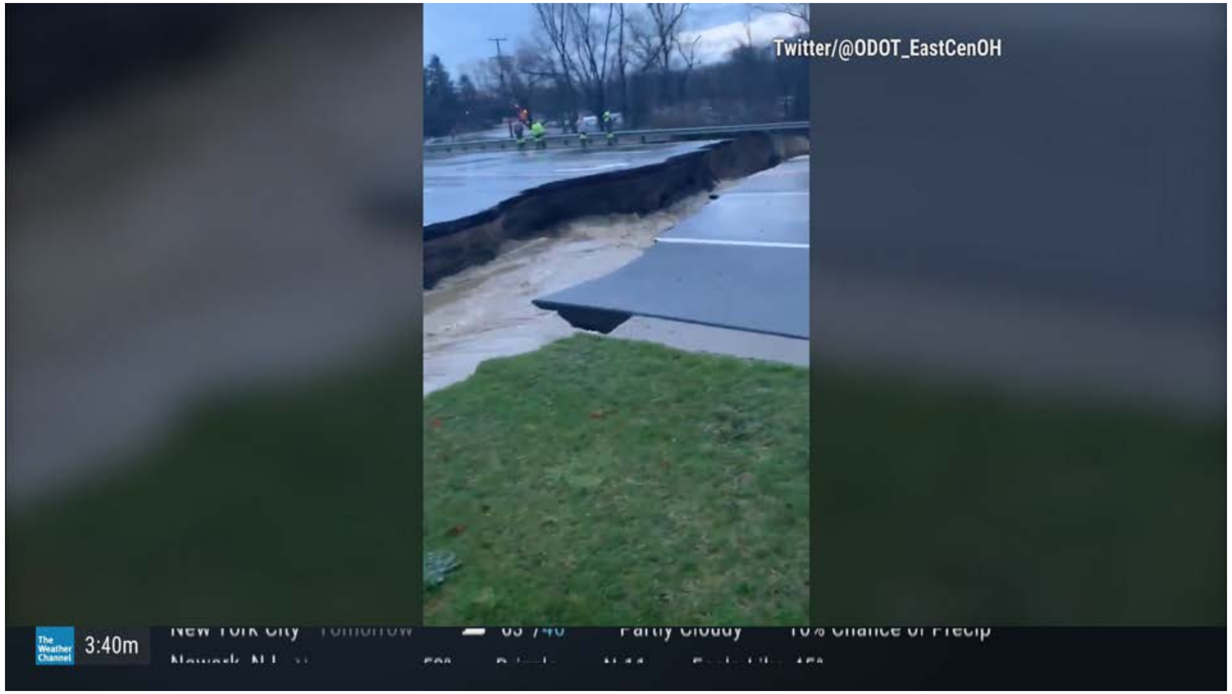
---

1. AASHTO. *Fundamentals of Effective All Hazards Security and Resilience for State DOTs*, 2015.
2. *Mitigation Saves: Utilities and Transportation Infrastructure Investments Can Provide Significant Returns*, The National Institute of Building Sciences, 2019
3. *Estimating the benefits of Climate Resilient Buildings and Core Public Infrastructure (CRBCPI)*, Institute for Catastrophic Loss Reduction, February 2020

INCREASED FLOODING IS IMPACTING OUR PAVEMENT STRUCTURES

Need to distinguish between Inundation and Washout Impacts

Washout



Rapid flow of flood water / high current that scours and washes out the pavement structure

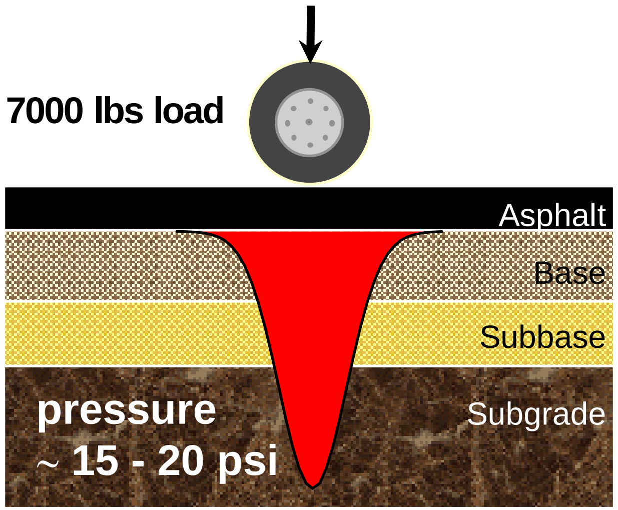
Pavement type has little impact

Inundation

The rise of water that submerges the pavement. No rapid flow or current

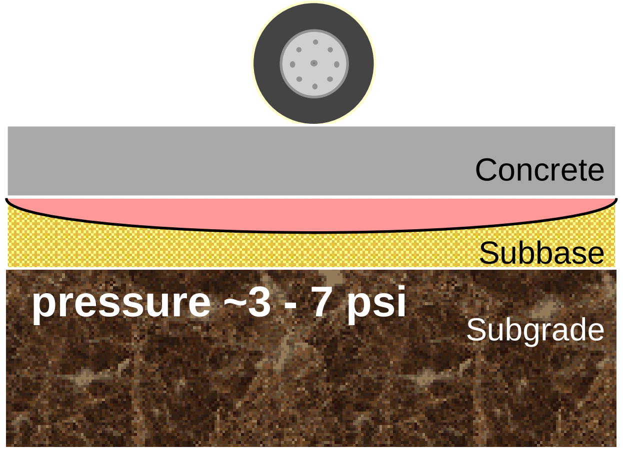
Pavement type does have an impact

CONCRETE AND ASPHALT PAVEMENTS ARE DIFFERENT DUE TO HOW THEY TRANSMIT LOADS TO THE SUBGRADE



Asphalt Pavements are Flexible

- Load - more concentrated & transferred to the underlying layers
- Higher deflection
- Subgrade & base strength are important
- Requires more layers / greater thickness to protect the subgrade



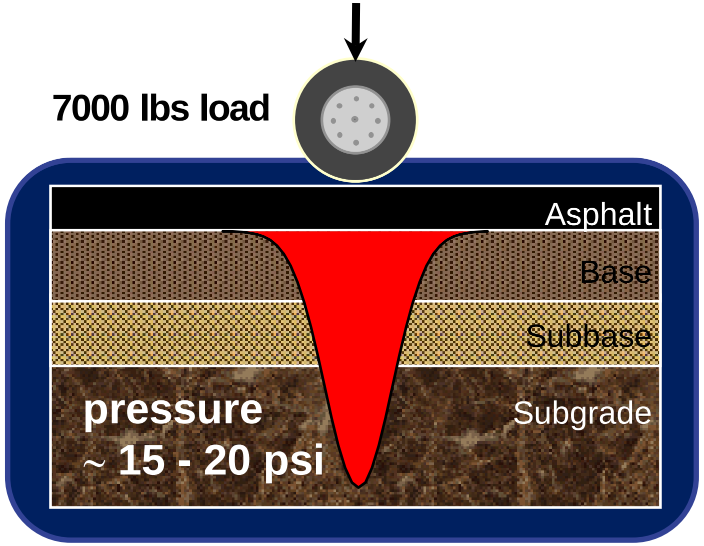
Concrete Pavements are Rigid

- Load – Carried by concrete and distributed over a large area
- Minor deflection
- Low subgrade contact pressure
- Subgrade uniformity is more important than strength

Concrete’s rigidity spreads the load over a large area & keeps pressures on the subgrade low

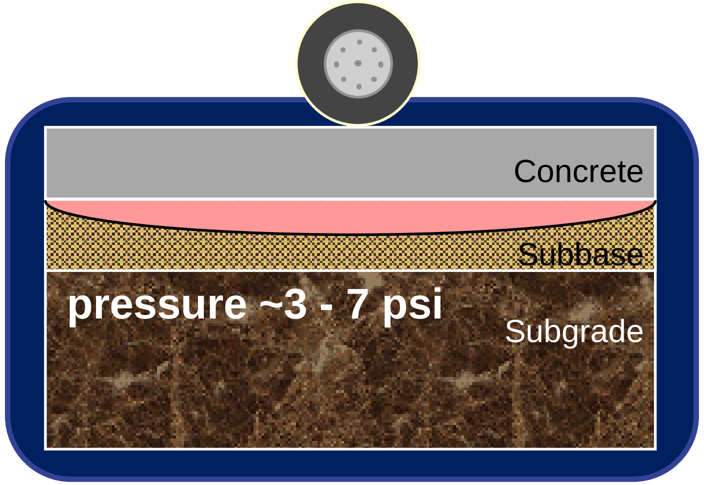
FLOODING CAUSES THE SUBGRADE TO BECOME SUPERSATURATED

Moisture infiltrates base, pushes the subgrade particles apart and weakens the system



Asphalt Pavements are FLEXIBLE

- Lowered subgrade strength & reduced modulus
  - Reduced load carrying capacity
  - Takes ~1 year to regain strength
- Loading during this times accelerates pavement damage / deterioration
  - Reduced pavement life



Concrete Pavements are RIGID

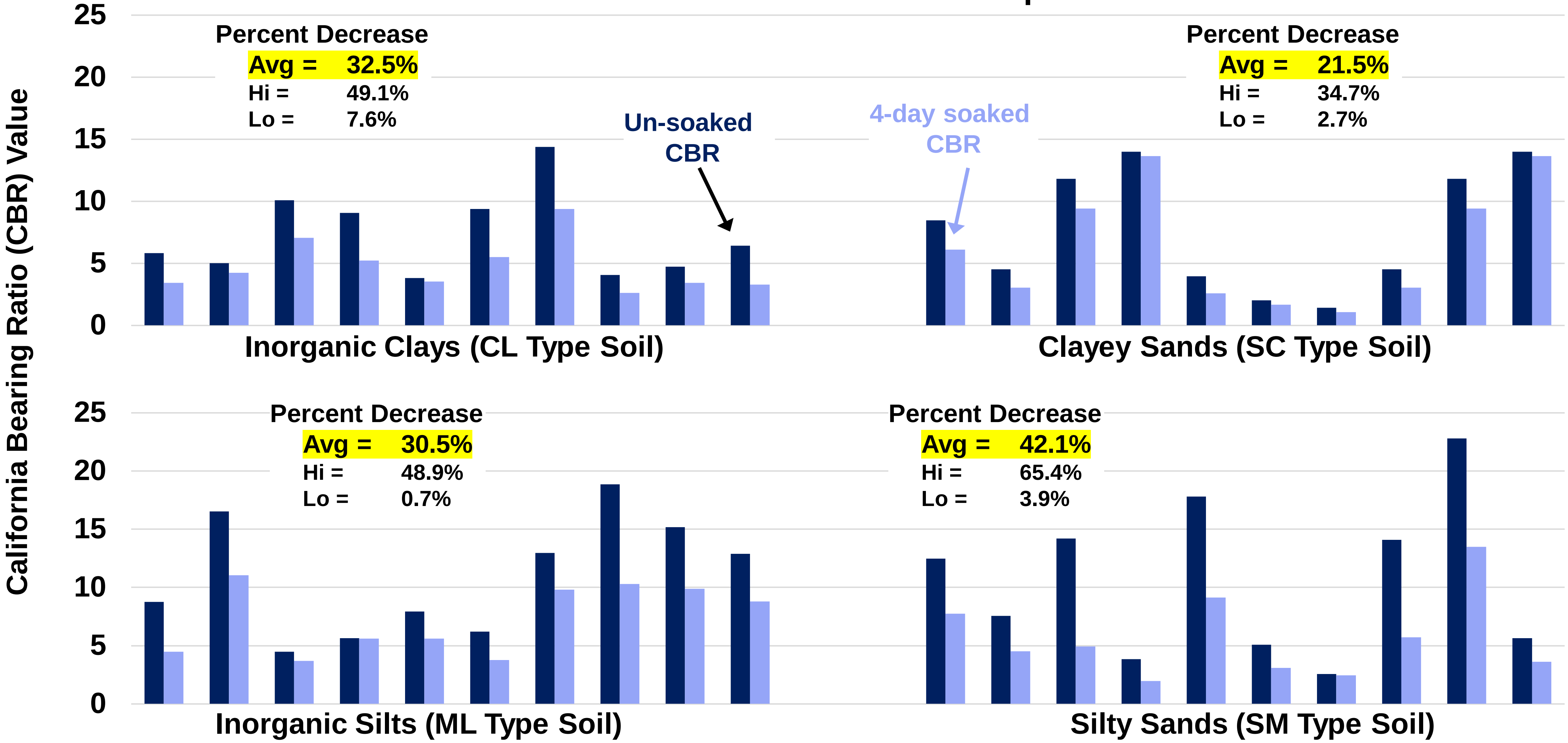
- Maintains high level of strength / stiffness
- Subgrade is weak, but still uniform
- Spreading of the load means subgrade is not overstressed
- Little impact on the serviceability / life

Flooding does not impact the concrete's load carrying capacity to the same degree as asphalt's

SOAKING REDUCES STRENGTH OF SOILS BY 20 TO 40%

Different Soils (clays, silts, sands, clay sands, etc) all react differently but all decrease

Un-soaked vs Soaked CBR Comparisons



Inorganic Clays (CL Type Soil)

Percent Decrease
Avg = 32.5%
Hi = 49.1%
Lo = 7.6%

Clayey Sands (SC Type Soil)

Percent Decrease
Avg = 21.5%
Hi = 34.7%
Lo = 2.7%

Inorganic Silts (ML Type Soil)

Percent Decrease
Avg = 30.5%
Hi = 48.9%
Lo = 0.7%

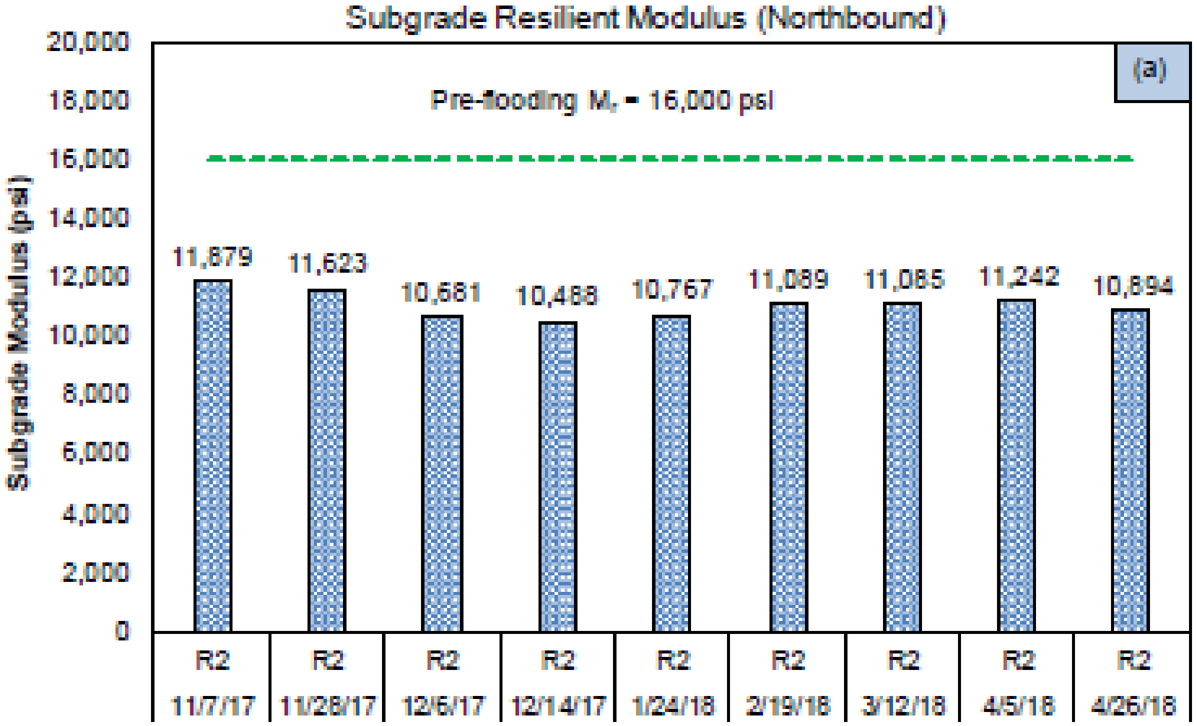
Silty Sands (SM Type Soil)

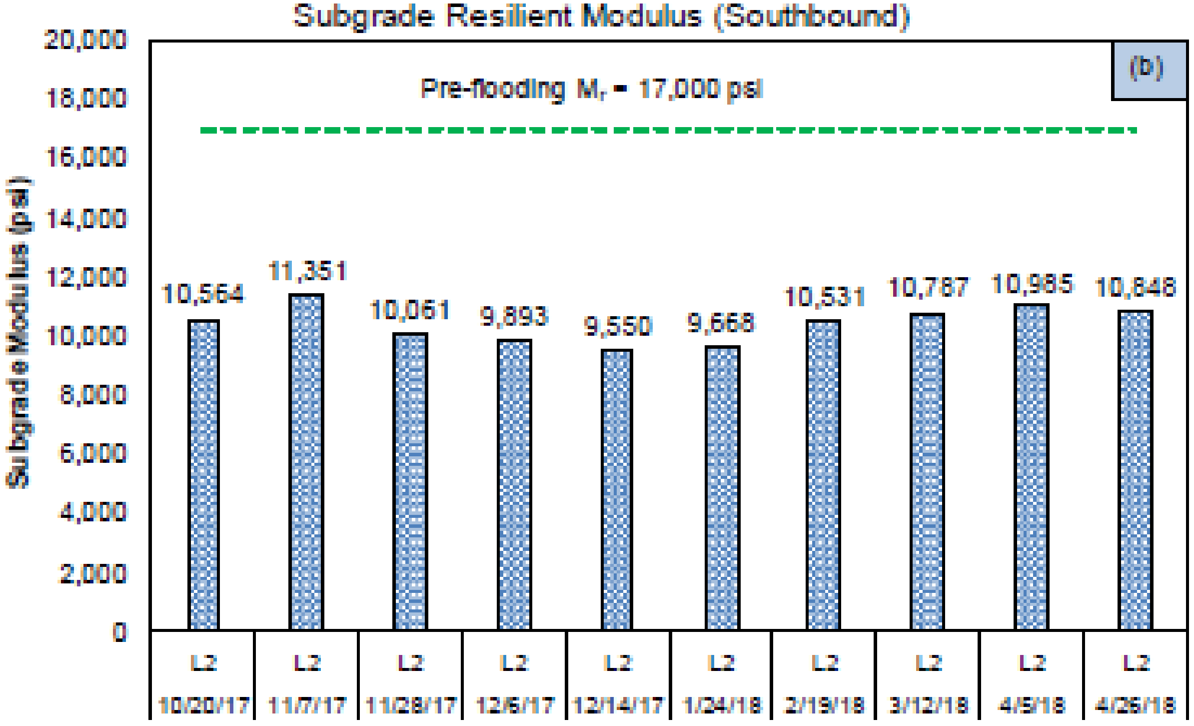
Percent Decrease
Avg = 42.1%
Hi = 65.4%
Lo = 3.9%

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

RESEARCH FINDINGS INDICATE IT TAKES UP TO 1 YEAR FOR THE SUBGRADE STRENGTH TO RECOVER FROM FLOODING

After the flood waters recede, the pavements are structurally vulnerable





US 441 in Alachua County, Florida between MP 7.960 to MP 9.680

For this case, this strength loss is a 40 to 60% reduction load carrying capacity and about 3 years of life

Sources:
1. 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
2. Western Iowa Missouri River Flooding— Geo-Infrastructure Damage Assessment, Repair, and Mitigation Strategies; Center for Earthworks Engineering Research, Iowa State University, Report No. IHRB Project TR-638

WHEN LOOKING AT PAVEMENT'S RESILIENCY, NEED TO RECOGNIZE DAMAGE FROM 2 DIFFERENT SOURCES / TIMES

Impact Types / Timing

① **Primary / Direct Impacts – alters the pavement structural or functional capabilities**

② **Secondary / Indirect Impacts – Impacts due to recovery activities or use**

- **Rescue and Emergency response during the disaster**
- **Recovery activities (clean up and rebuilding) after the disaster**

To have a resilient pavement system requires that both aspects be addressed

RELIEF AND RESCUE EFFORTS WILL TAKE PLACE

Loading occurs both during the crisis and long after

Hurricane Florence (2018)

Meals that Matter

#MtMFlorence Update

(New) Location 1
98 S Trade Way
Rocky Point, NC

Location 2
7701 S Raeford Rd
Fayetteville, NC

Joplin, MO Tornado (2011)

Debris Hauling from Camp Fire, Paradise, CA (2018)

3.66 million tons removed over a nine-month period

DEBRIS REMOVAL CAN TAKE PLACE 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.

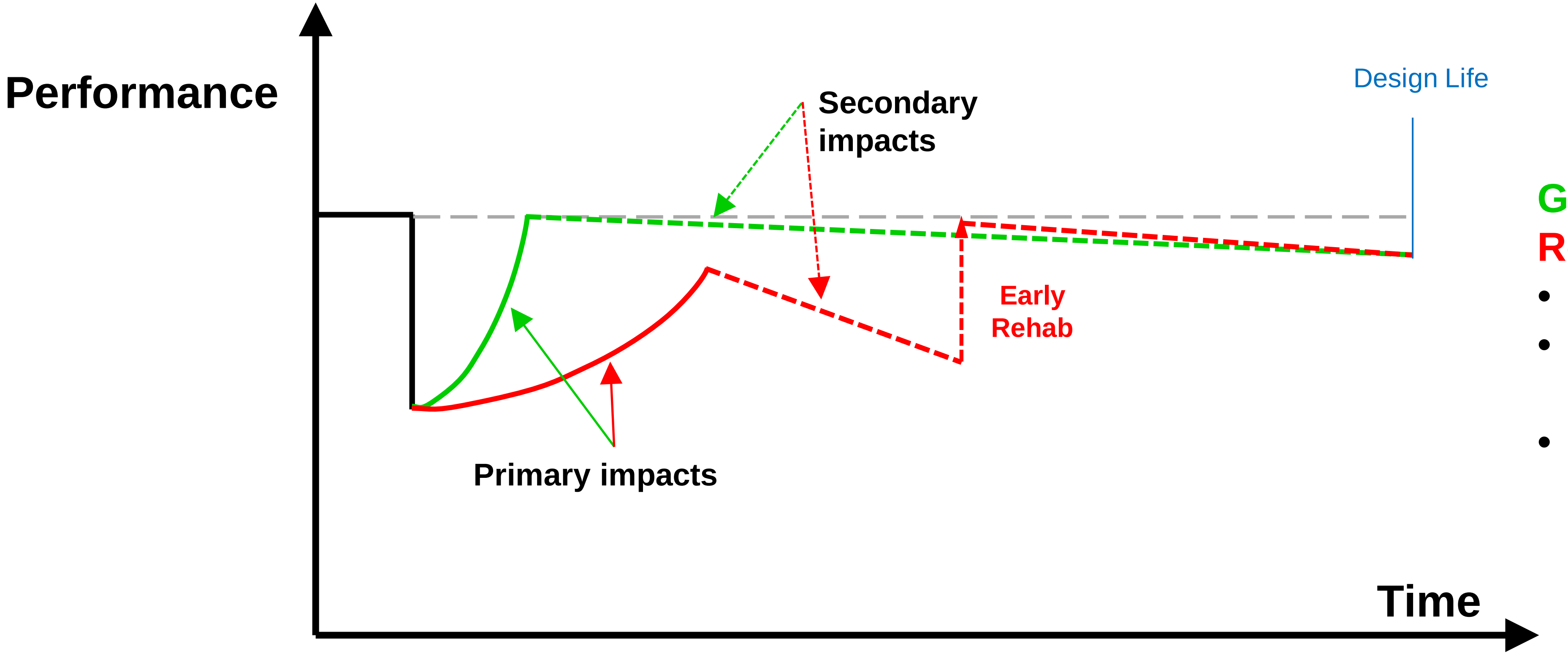
Superstorm Sandy (2012) led to ~6M CY of debris in New York State

Hurricane Katrina – 38M CY of debris

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

NEED TO ACCOUNT FOR LONG TERM SECONDARY IMPACTS WHEN DISCUSSING PAVEMENT RESILIENCE

Weakened pavement & additional loading can lead to early rehabilitation needs



Green is more resilient than Red

- **Faster recovery time**
- **Higher level of service**

- **Less Secondary damage**

Pavement Resilience should be characterized by three parameters:

1. Drop in performance, induced by the event (eg. reduced ability to carry load).
2. Recovery time to reinstate or improve performance.
3. **Ability to withstand emergency and recovery activities**

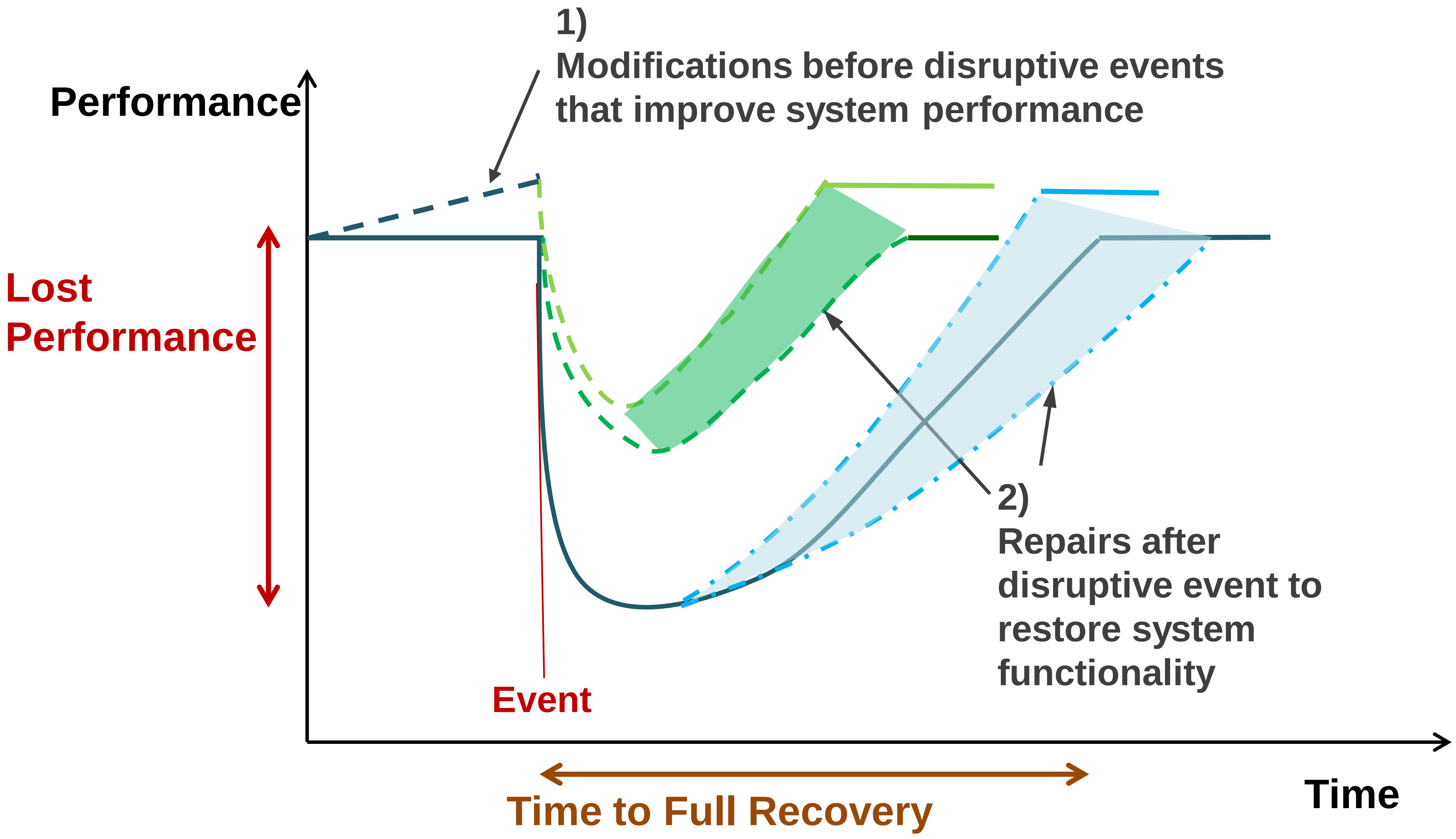
Boosting Pavement Resilience in a Changing Climate

1. The Need for Resilient Pavements

2. Defining Resiliency

3. **Improving a Pavement's Resiliency**
   a. **Pavement Solutions to improve your <u>flood</u> resiliency**
   b. **What can be accomplished within pavement selection policies?**

APPROACHES TO IMPROVE A HIGHWAY'S / PAVEMENTS RESILIENCE



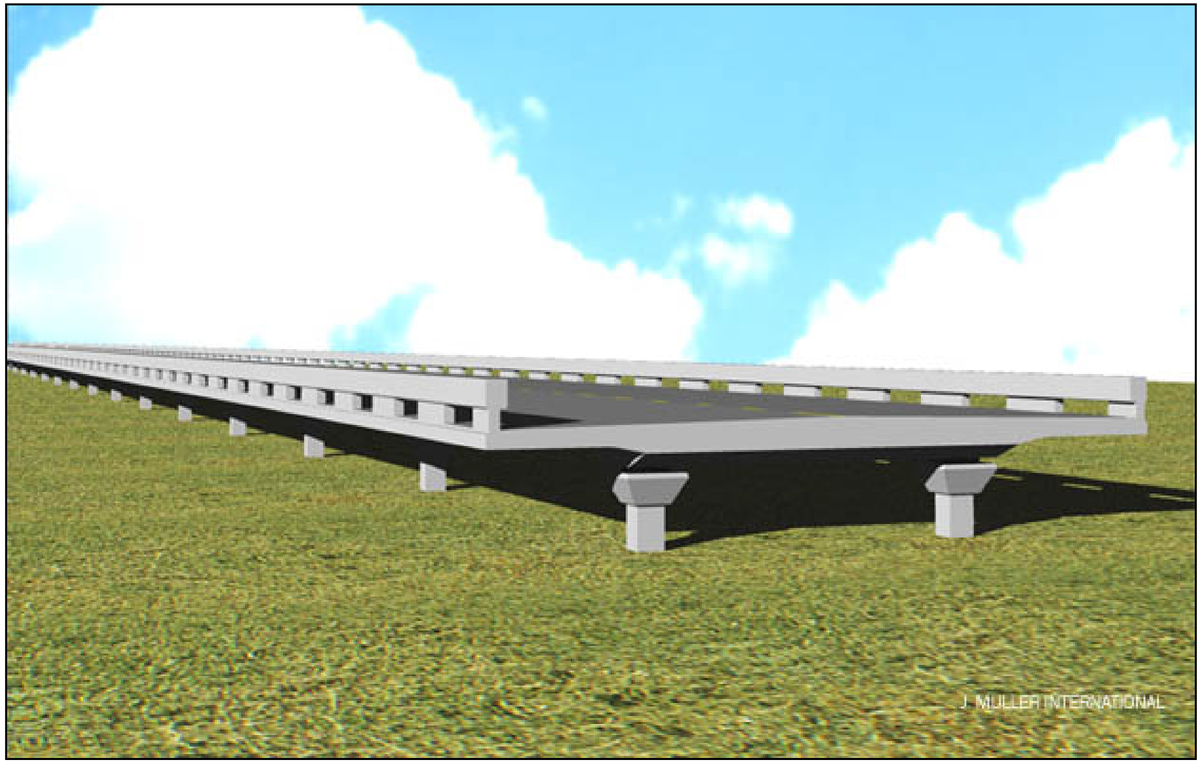
1)
Modifications before disruptive events that improve system performance

2)
Repairs after disruptive event to restore system functionality

Adaptive Resilience – Capacity to learn and make decisions to avoid future loss based on the type of disturbance

Adapted from Bruneau, 2003 and McDaniels, 2008

ONE OFTEN DISCUSSED APPROACH IS ELEVATING THE ROAD ABOVE FLOODING ELEVATION



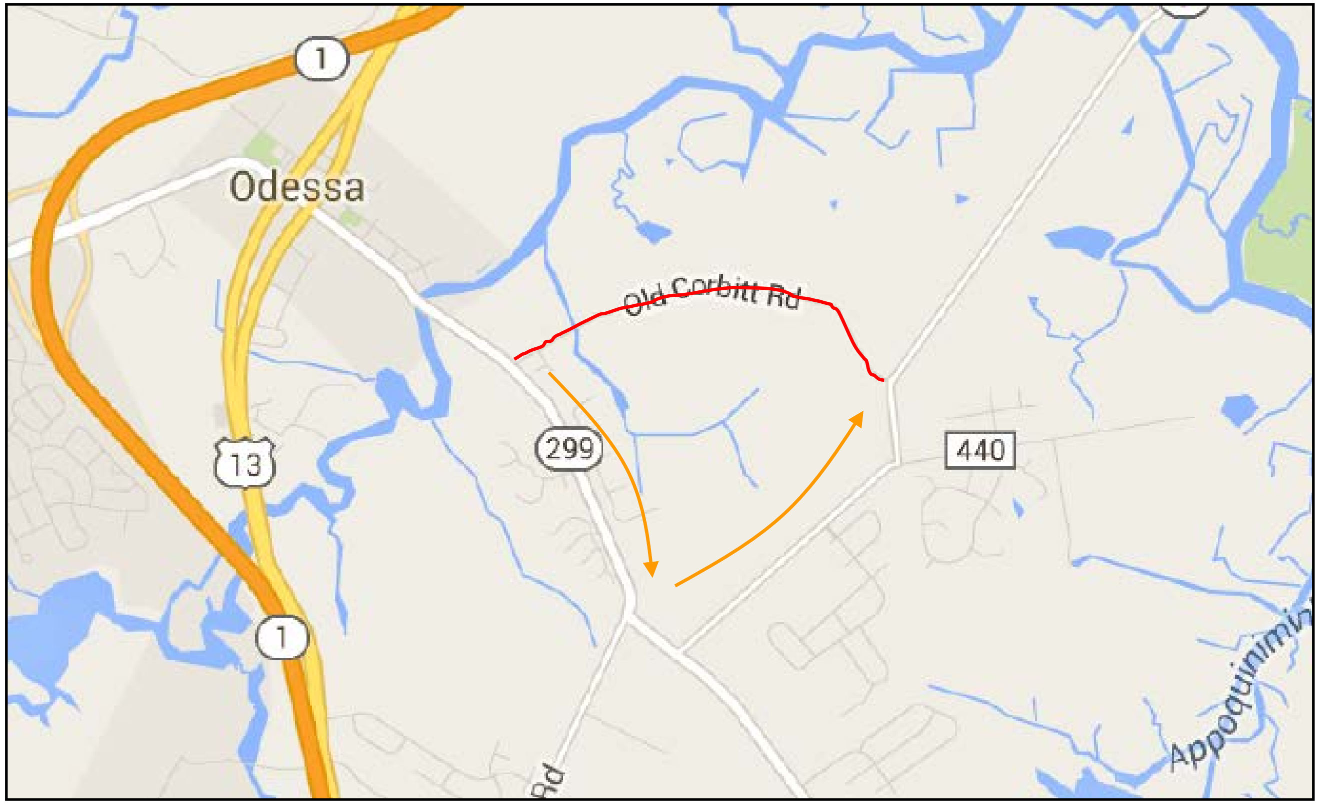
Elevation View of SR54 Viaduct From Old SR54 Alignment, Fenwick DE
Cost = $16 M in 2001

Elevating the roadway is not cheap and it is not possible to raise all roadways

Schematic and Photo courtesy of Jim Pappas, DELDOT

ANOTHER APPROACH IS ROAD ABANDONMENT

Old Corbitt Road – Odessa, Delaware



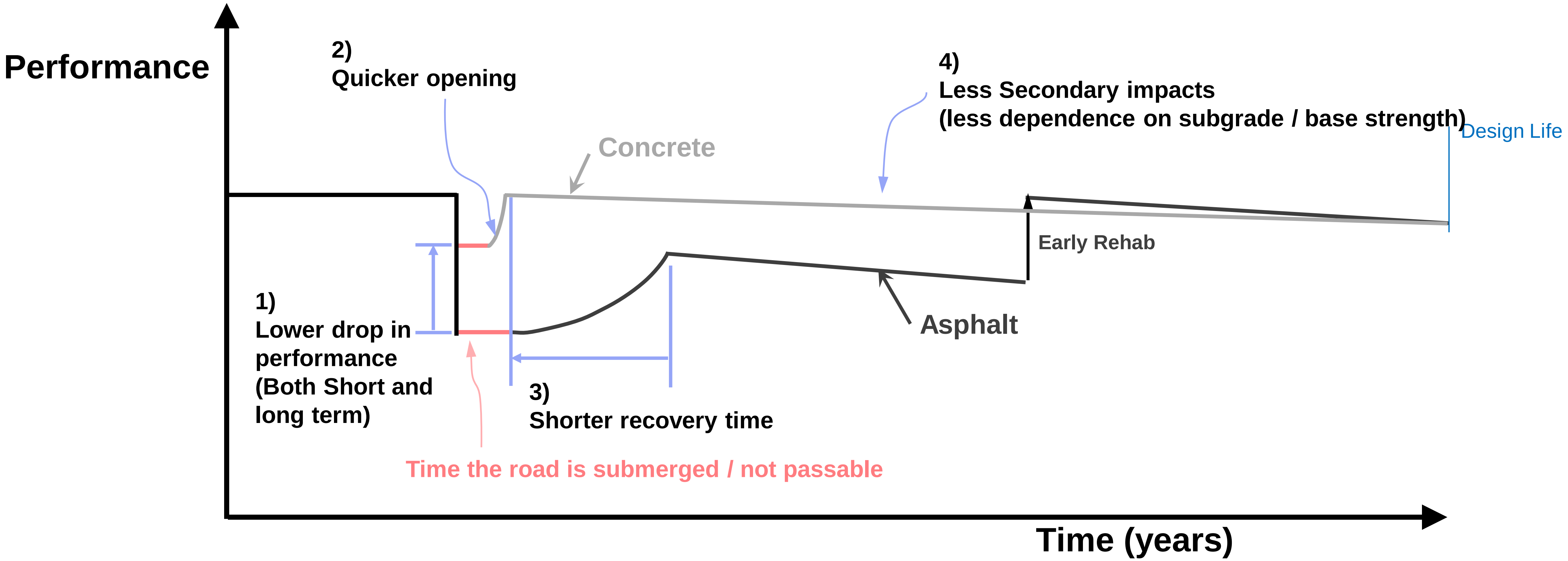
- **Overtops daily due to tides**
- **340 Avg Daily Traffic (ADT)**
- **Traveling time will be slightly increased by approximately 2 to 3.5 minutes.**

- **Alternate - 250’ long concrete structure. Estimated cost = $2.5M**

Abandoning the roadway is not always possible

Schematic and Photo courtesy of Jim Pappas, DELDOT

STIFFER PAVEMENTS ARE MORE RESILIENT TO INUNDATION FLOODING

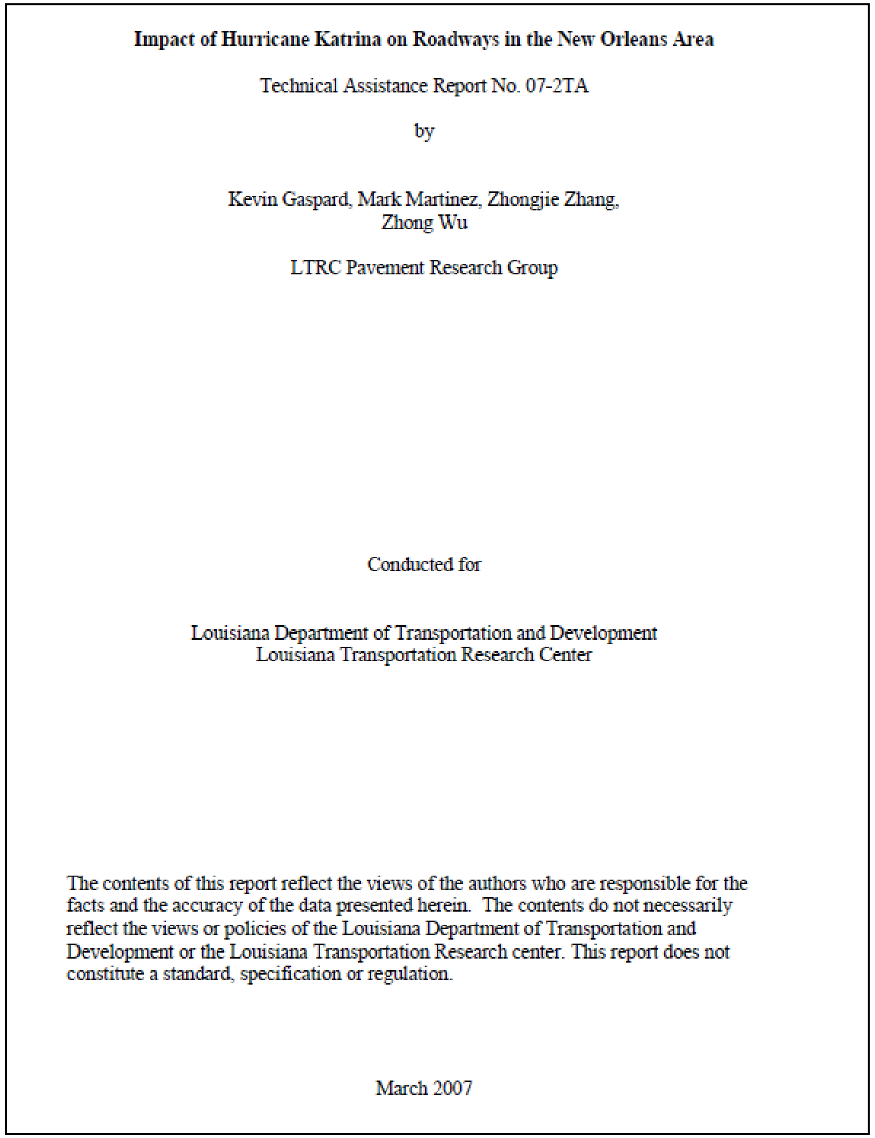


Stiffer Pavements are less impacted by subgrade strength loss and recover faster
(stiffer = concrete, cement stabilized bases, increased asphalt thickness)

KEY FINDINGS FOR PAVEMENTS THAT WERE SUBMERGED BY HURRICANE KATRINA

Submerged pavements were weaker than non-submerged pavements

- **Asphalt pavements**
  - **Overall strength loss ≈ two inches of new asphalt concrete**
    - **Damage occurred regardless of the length of time the pavement was submerged**
  - **Cost: $50 million to rehabilitate 200 miles of submerged asphalt roads**
- **Concrete Pavements**
  - **Little relative loss of strength due to flooded conditions**
    - **Resilient modulus(Mr) is similar for submerged and non-submerged pavements**
  - **No information given on repairs or repair costs**



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

FLOODED PAVEMENTS RESEARCH IN AUSTRALIA FOUND SIMILAR RESULTS

Road authorities may want to consider changing their roads into flood-resilient pavements.

A rigid pavement performs better than composite and flexible road groups

- **Composite and flexible road groups show similar performance up to 2–3 years.**
- **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)

Estimating Pavement's Flood Resilience

Misbah U. Khan, CPEng.[1]; Mahmoud Mesbah, Ph.D.[2]; Luis Ferreira, Ph.D.[3]; and David J. Williams, Ph.D.[4]

Abstract: Although several studies observed pavement responses after flooding, no detailed quantification has been done to date. This paper has estimated different pavements' performances with flooding to identify flood-resilient roads. This was shown through (1) new roughness and rutting-based road deterioration (RD) models, (2) the relationship between changes in roughness [International Roughness Index (IRI)] versus time and modulus of resilience (Mr) loss at granular and subgrade layers versus time, and (3) flood consequence results. The comparative analysis on different pavement performances shows that a rigid and strong pavement built to a high standard is the most flood-resilient, which may be adopted as a preflood strategy. Results obtained using two proposed new gradients of IRI (incremental change in IRI, ΔIRI) in Year 1 over probability of flooding ($\Delta\text{IRI}/Pr$) and ΔIRI in Year 1 over loss in Mr ($\Delta\text{IRI}/MrL$) as well as flood consequences provided similar results. Road authorities should consider changing their roads to flood-resilient pavements in the future. It is recommended to investigate after flood roads' structural conditions and performances to validate the new ratio values of $\Delta\text{IRI}/Pr$ and $\Delta\text{IRI}/MrL$. **DOI: 10.1061/JPEODX.0000007.** *© 2017 American Society of Civil Engineers.*

Author keywords: Road deterioration; Modulus of resilience; Flooding; Flood-resilient pavement.

Introduction

Pavement performance shows deterioration of roads with time in its service life, which is dependent on traffic loading, material properties (pavement type, structure, strength, and subgrade strength), climate and environment, drainage, initial road condition, and maintenance activities (Hunt and Bunker 2001). It is generally expressed by roughness versus time. Roughness is related to pavement structural and functional conditions, traffic loading, and environmental factors, and it has a direct relationship with vehicle operating costs, accidents, and driver comfort (Gopinath et al. 1994; Odoki and Kerali 2000; Prozzi 2001). Therefore, it is the most representative index for evaluating a pavement performance. AASHTO also uses roughness for pavement design.

A pavement shows an abrupt change in road condition, e.g., roughness and rutting, after a disaster such as flooding. As a result, higher pavement deterioration is observed, for example, significant roughness [denoted by International Roughness Index (IRI)] increase is found due to flooding. Studies reveal that the incremental change in IRI (ΔIRI) due to a flood depends on loss in pavement modulus of resilience (Mr) and the probability of flooding.

Several studies have identified that the Mrs of granular and subgrade layers are reduced due to moisture intrusion (Brown and Dawson 1987; Drumm et al. 1997; Yuan and Nazarian 2003). Both Monismith (1992) and Huang (1993) found an increase in pavement deflection due to a lower Mr, and consequently a reduced pavement life. There are no studies that can address pavement performance with flooding.

Recently, Khan et al. (2014a, 2017c) and Khan (2017) developed project and network levels roughness and rutting-based road deterioration (RD) models at different probabilities of flooding. Additionally, Khan (2017) and Khan et al. (2017a) determined pavement responses during flooding using the Mr loss values in granular and subgrade layers. Using the roughness prediction model of AASHTO (2008) (based on AASHTO's pavement design guide of 2008) and the Highway Development and Management Model (HDM-4) (Odoki and Kerali 2000), they observed poor pavement performance after a flood when Mr was reduced. The impact of pavement performance due to different probabilities of flooding was shown in Khan et al. (2014a). Both these studies (Khan et al. 2014a; Khan 2017) provided IRI versus time and rutting versus time because of a flood. An after-flood effect on pavement roughness was estimated while assessing flood risk for the road network (Khan 2017; Khan et al. 2017b), which gives ΔIRI due to a flood.

The current paper has aimed to measure pavement performances with flooding in order to obtain strong pavements that can better sustain flooding in their lifecycle, which was determined using the pavement performances with flooding scenarios, that is, (1) performance at different probabilities of flooding, (2) performance at different Mr loss values in Year 1, and (3) change in IRI due to a flood. The newly derived RD models are valid for a short period up to 2–3 years (Khan 2017; Khan et al. 2017c). The RD models with flooding, ΔIRI in Year 1 divided by the percent of probability of flooding ($\Delta\text{IRI}/Pr$) and ΔIRI in Year 1 divided by the percent of Mr loss at subgrade and granular layers ($\Delta\text{IRI}/MrL$) for different road groups and flood consequence results provide valuable information in this regard.

The current paper has proposed two new gradients: (1) $\Delta\text{IRI}/Pr$, and (2) $\Delta\text{IRI}/MrL$ using the IRI versus percent probability of flooding and IRI versus percent Mr loss relationships, respectively. The consequence of a flood for a road group using ΔIRI also gives useful information. The gradient of rutting (ΔRutting) versus the percent probability of flooding provides similar relationships; hence, the ΔRutting in Year 1 over probability of

---

[1] Ph.D. Candidate, School of Civil Engineering, Univ. of Queensland, Brisbane, QLD 4072, Australia; Senior Asset Systems Engineer, Central Coast Council, 2 Hely St., Wyong, NSW 2259, Australia (corresponding author). E-mail: misbah_70@yahoo.com

[2] Senior Lecturer, School of Civil Engineering, Univ. of Queensland, Brisbane, QLD 4072, Australia. E-mail: mahmoud.mesbah@uq.edu.au

[3] Professor, School of Civil Engineering, Univ. of Queensland, Brisbane, QLD 4072, Australia. E-mail: l.ferreira@uq.edu.au

[4] Professor, School of Civil Engineering, Univ. of Queensland, Brisbane,

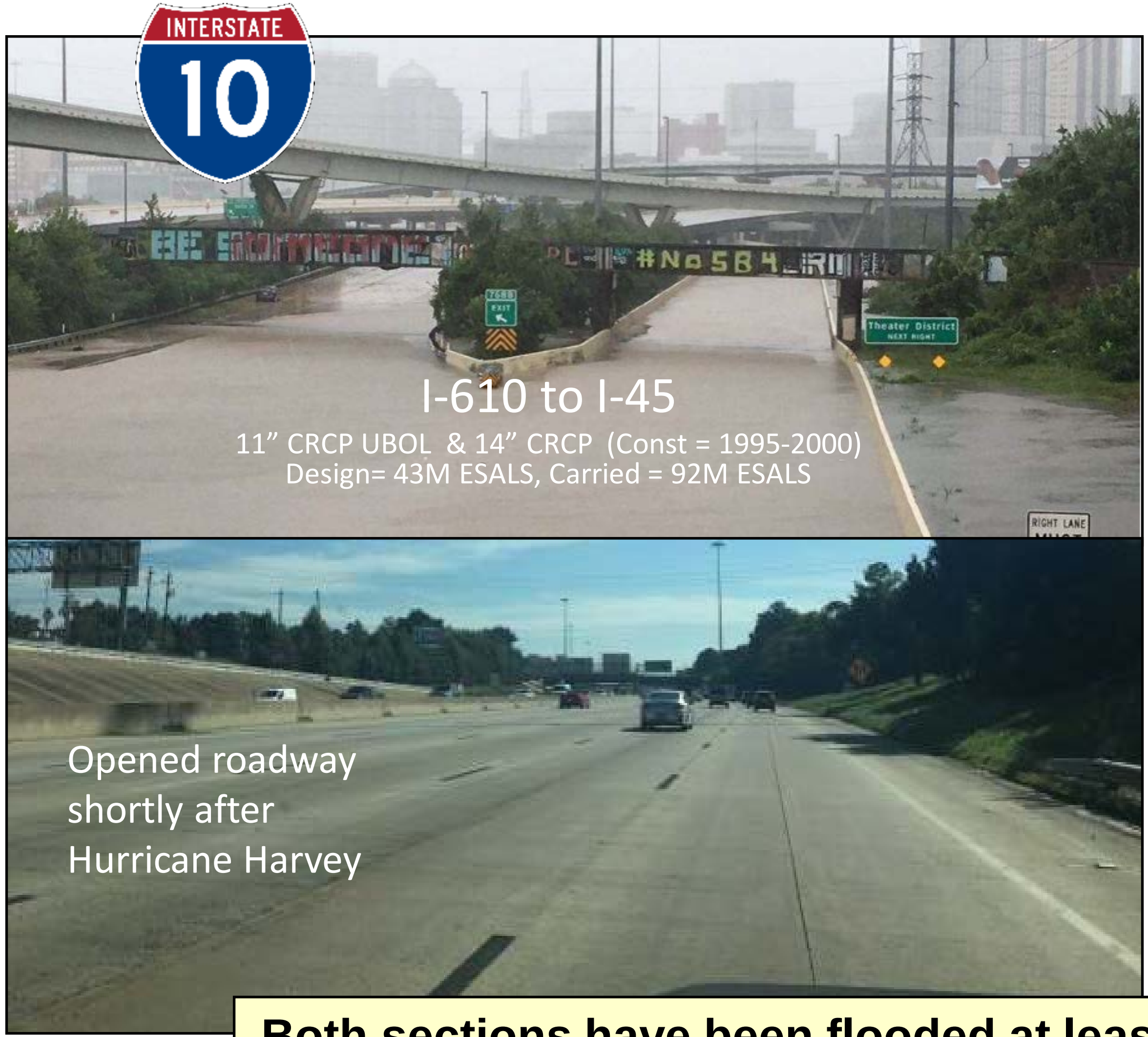
2016; approved on
ussion period open
be submitted for
of Transportation
Engineering, Part B: Pavements, © ASCE, ISSN 2573-5438.

© ASCE 04017009-1 J. Transp. Eng., Part B: Pavements

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

PAVEMENTS IN HOUSTON HAVE BEEN FLOODED SEVERAL TIMES

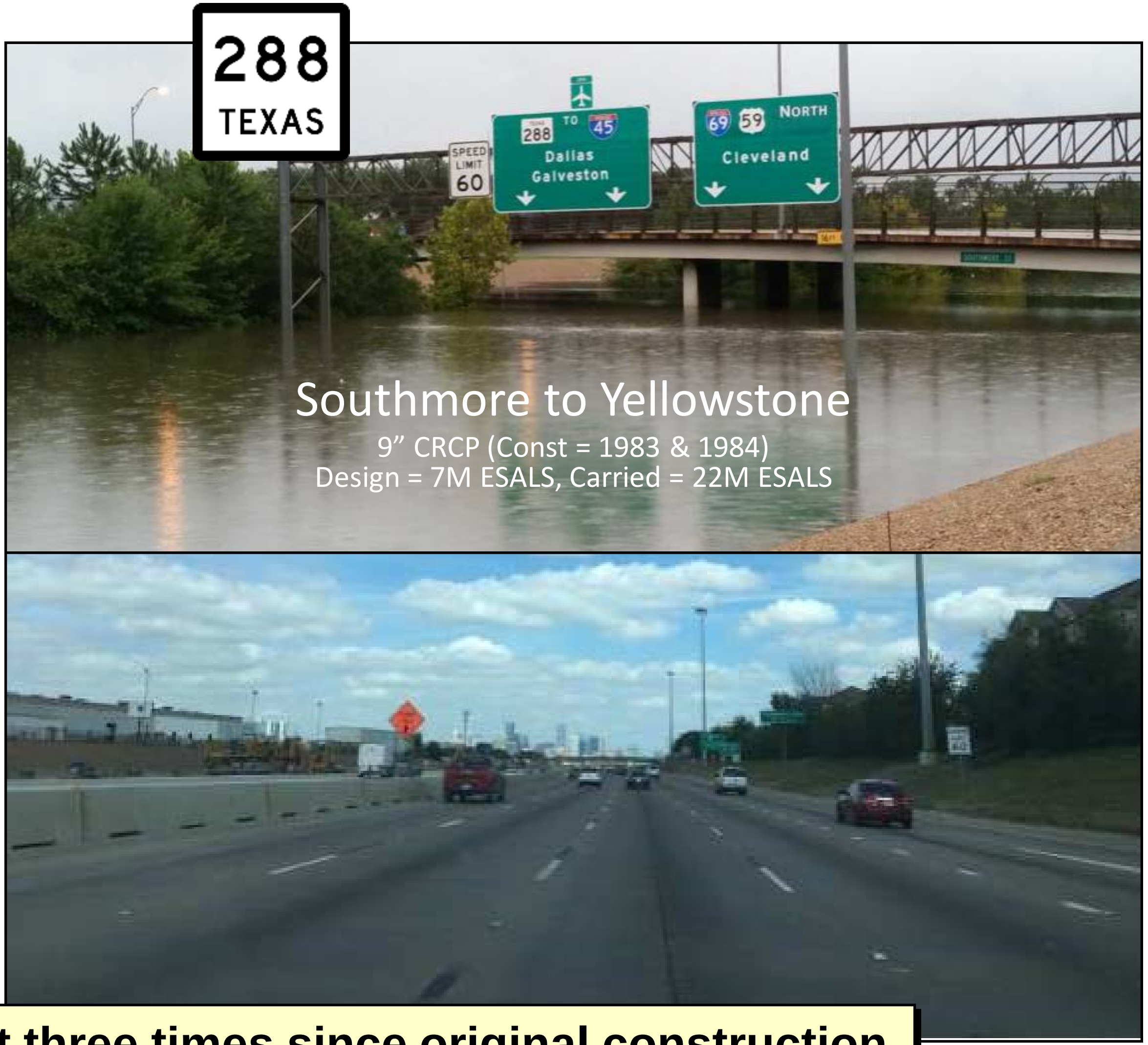
But roadways are opened as soon as water has receded



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

Resilient Pavement Structures in Texas, Andrew Wimsatt, Ph.D., P.E., Texas A&M Transportation Institute and Lisa Lukefahr, P.E., Texas Concrete Pavement Association

ESALS – Equivalent Single Axle Loads. It is how pavement engineering defines traffic

ACTIVITIES THAT CAN BE USED TO “HARDEN THE PAVEMENT SYSTEM”

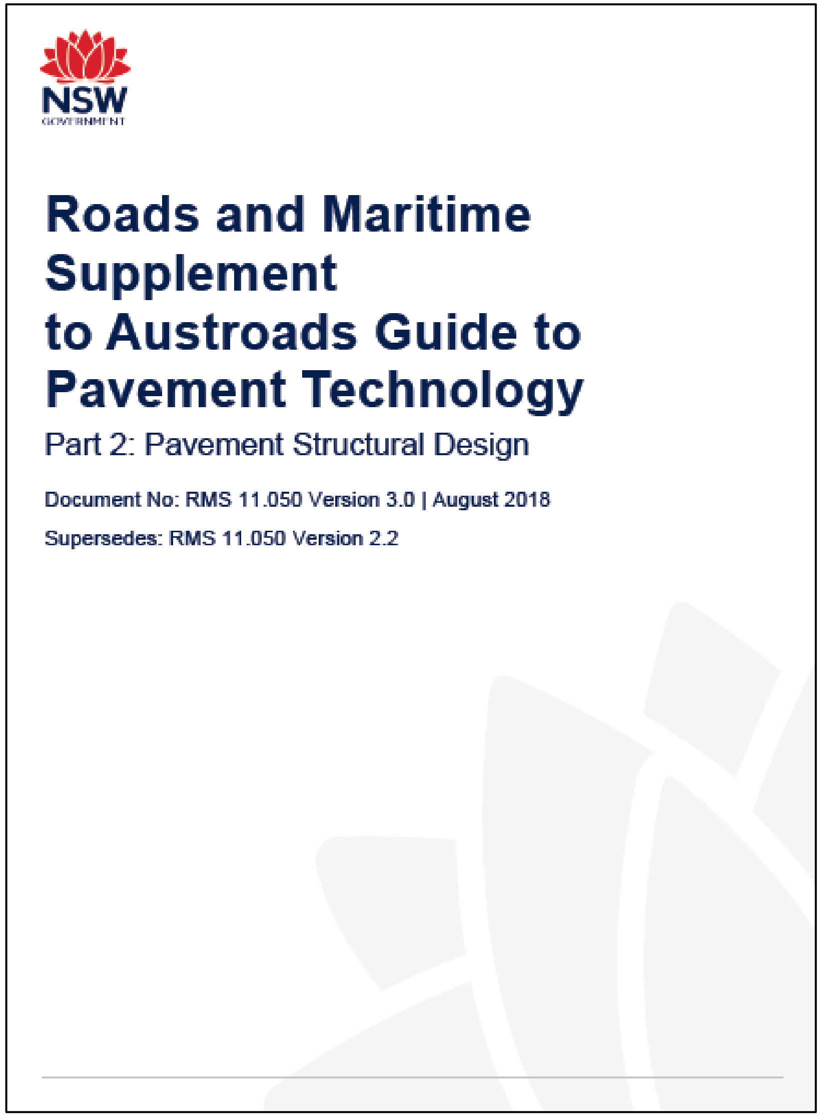
Adopt & Use Concrete Pavement

Yacht Harbor Manor Neighborhood Improvements, Riviera Beach, Florida

Photos courtesy of Erdman Anthony
https://www.erdmananthony.com/Our-Projects/project/484

ACTIVITIES THAT CAN BE USED TO “HARDEN THE PAVEMENT SYSTEM”

Modify “Design Standards” to be based on weakened subgrade condition



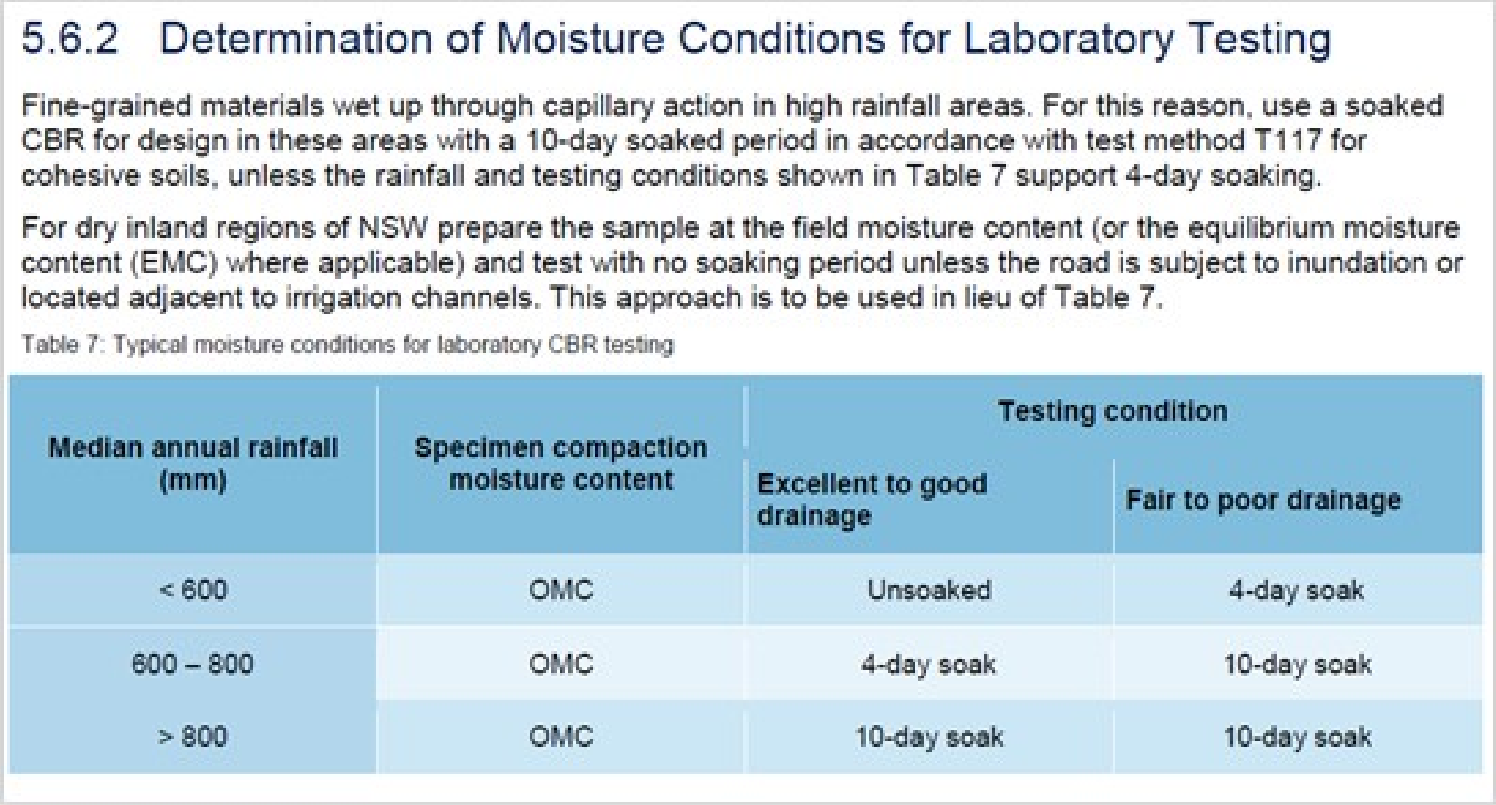
NSW GOVERNMENT

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

Supersedes: RMS 11.050 Version 2.2



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

Almost All Pavement Designs in Australia are based on soaked subgrade conditions

SOME RESILIENT CEMENT-BASED PAVEMENT SOLUTIONS THAT CAN BE USED AS HARDENING TECHNIQUES

Conventional Concrete Pavement

Thin Concrete Pavement

Concrete Overlays

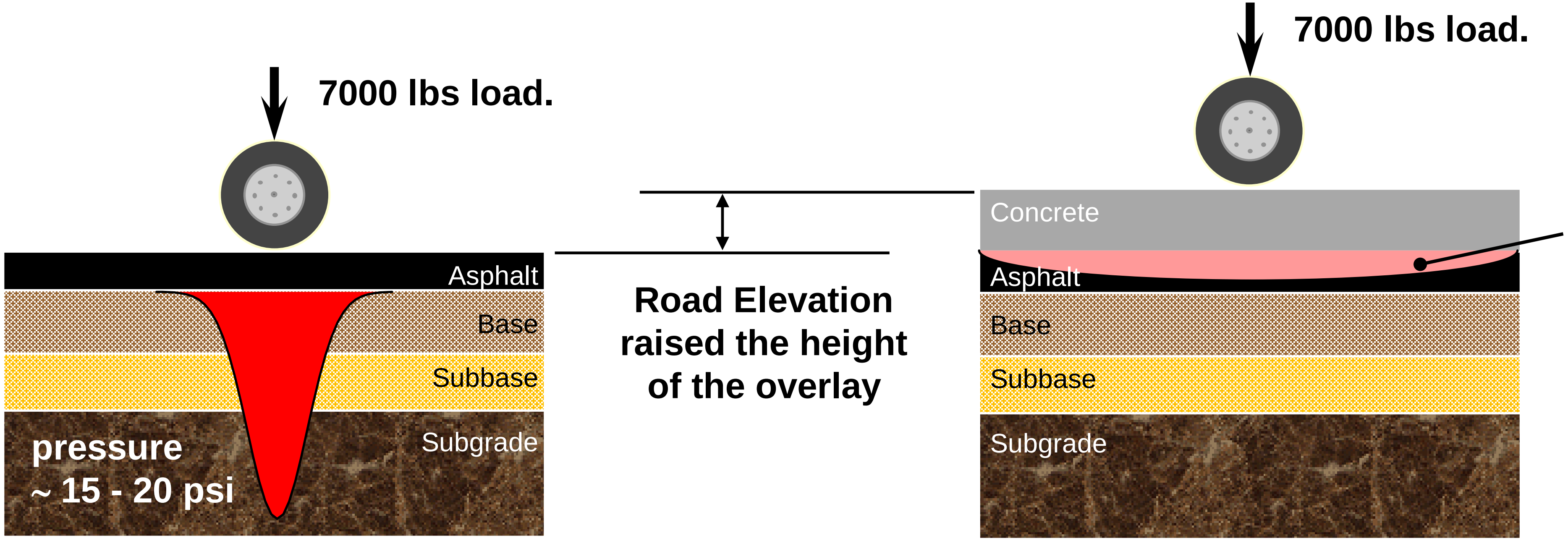
Roller Compacted Concrete (RCC)

Full Depth Reclamation (FDR) w/ Cement

Pervious Concrete

ACTIVITIES THAT CAN BE USED TO “HARDEN THE PAVEMENT SYSTEM”

Use Concrete Overlays



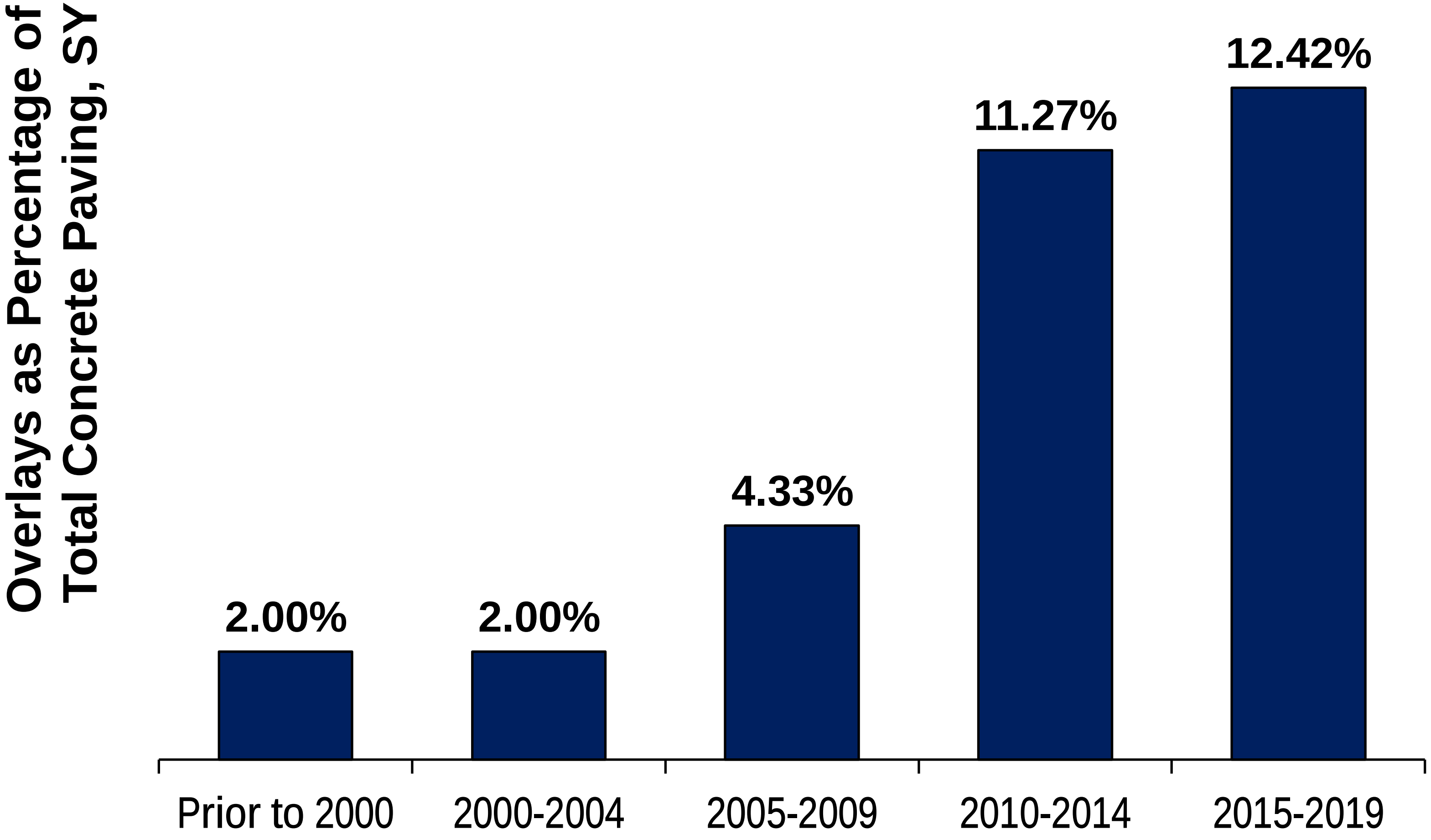
Road Elevation raised the height of the overlay

Pressure ~3 - 7 psi at the top of the Asphalt layer

Base & subgrade pressures are even lower

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

NATIONWIDE CONCRETE OVERLAY USAGE IS GROWING



BCOA Examples

US 69, Pittsburg Co., OKDOT

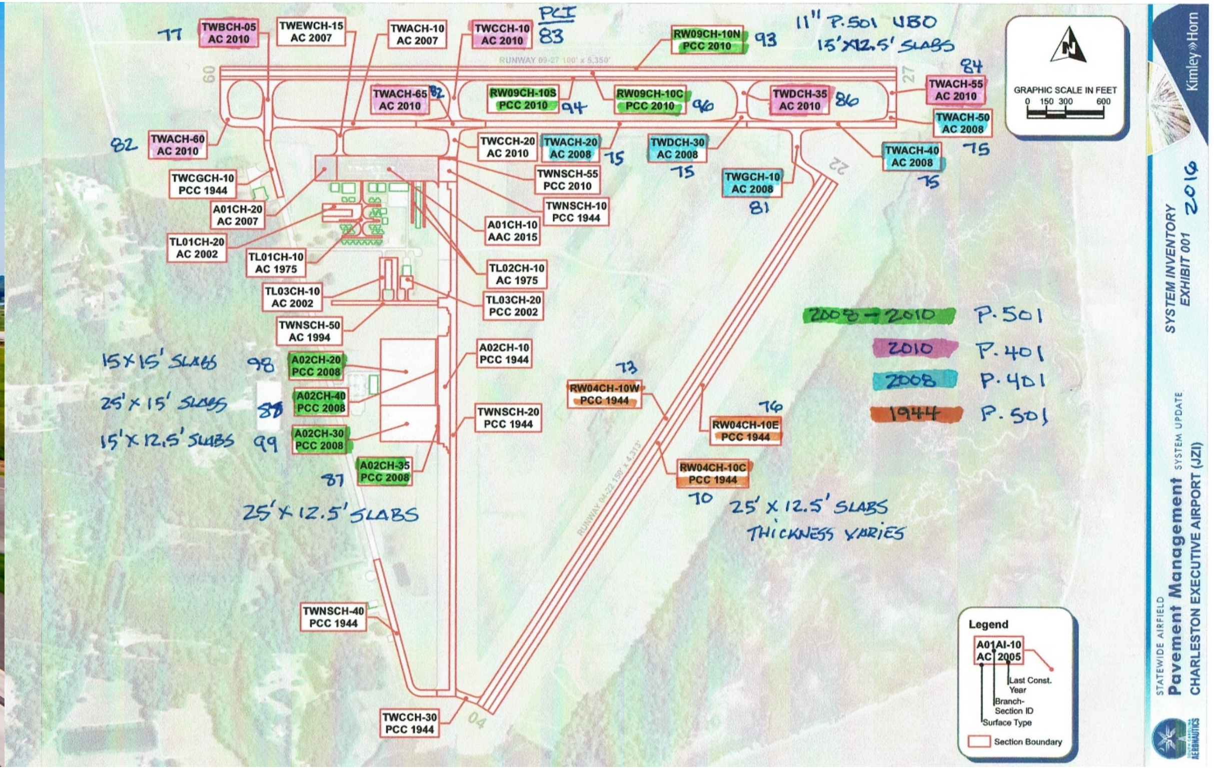
Colorado
SH-121, Wadsworth Ave
Constructed in 2001
Photo in 2013

Source: From data submitted by ACPA chapters/state paving associations and other sources, including Oman Systems, Bid Express and DOT websites.

Charleston Executive Airport

Johns Island, SC

11-inch Unbonded Overlay (2010 Construction)



2016 PCI Data from Pavement Management Report

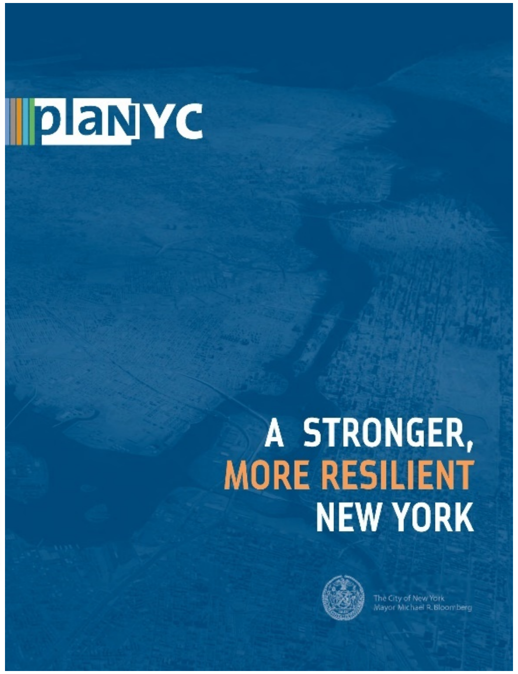
2010 LCD-RW **Concrete Overlay** range from 93 to 96 (weighted average 94, 1 point per year drop)
2010 LCD-TW Connectors (Tie-Ins) **Asphalt** range from 77 to 86 (weighted average 82, 3 points per year drop)
2008 LCD – Taxiway A **Asphalt** = 75 (drop of 3.1 points per year)

Resiliency of Concrete Recognized

“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”*

Reconstruction of Runway 13L-31R at JFK

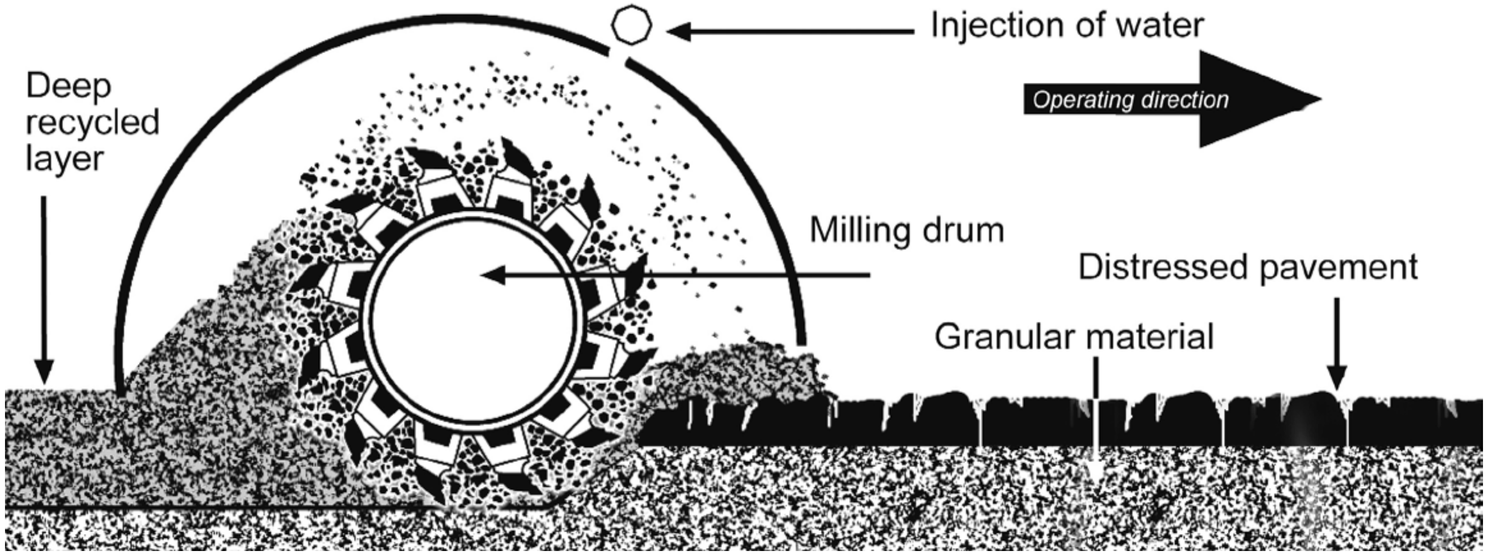
Port Authority of NY & NJ Press Release (April 2019)



“Use of Concrete will extend runway’s useful life to 40 years, rather than 8-12 years with asphalt.”

FULL-DEPTH RECLAMATION (FDR) WITH CEMENT RECYCLES AN EXISTING DETERIORATED ASPHALT PAVEMENT INTO A NEW STABILIZED BASE

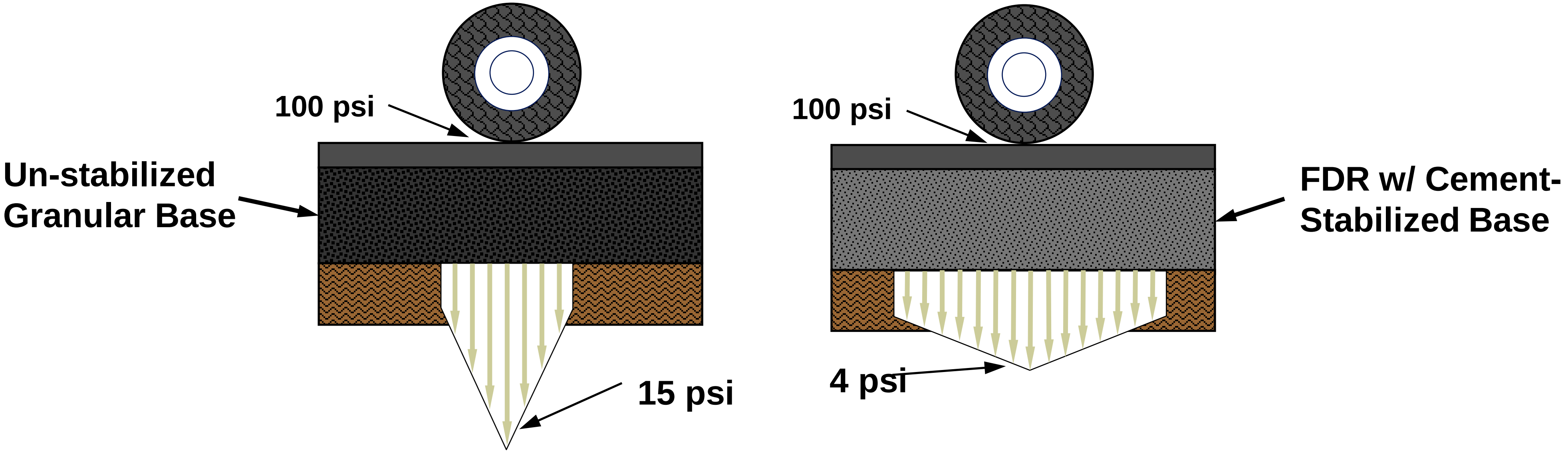
The stabilized base can be topped with an asphalt or concrete surface

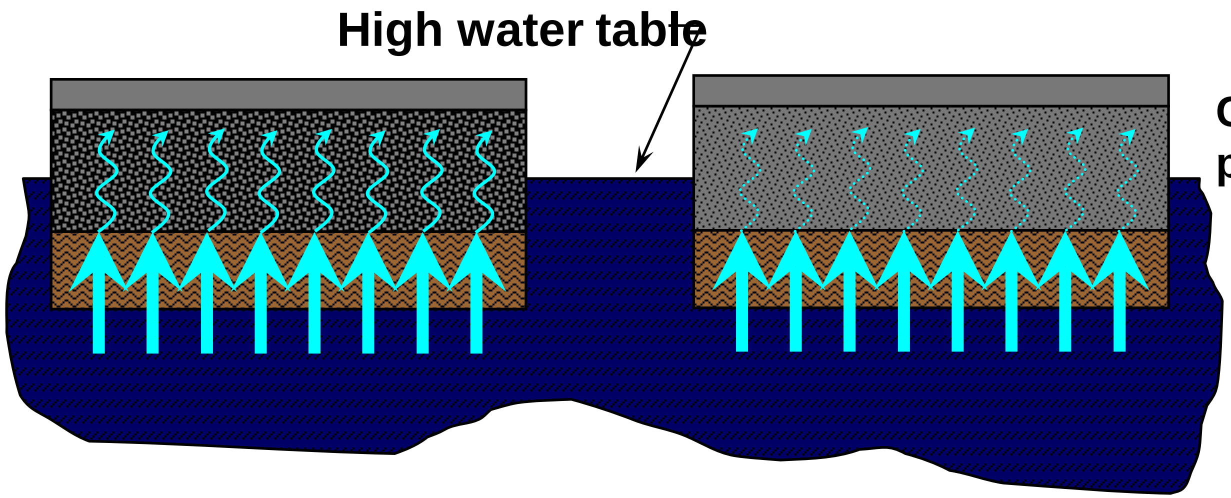


- **Utilizes In-Place Materials (reduces cost)**
- **Saves Energy by Reducing Trucking Requirements**
- **Increased Rigidity Spreads Loads**
- **Minimizes Rutting**
- **Reduced Moisture Susceptibility**

ACTIVITIES THAT CAN BE USED TO "HARDEN THE PAVEMENT SYSTEM"

FDR w/ Cement increases rigidity, reduces permeability, & reduces moisture susceptibility





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

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

Full-Depth Reclamation (FDR)

Promotion Spotlights : SCPA (secement.org)

SOUTHEAST CEMENT PROMOTION ASSOCIATION

www.secement.org

PROMOTION SPOTLIGHT | 2020

FDR with Cement Fixes High Water and Heavy Truck Issues on SR88 West of Halls, TN

In Lauderdale County, Tennessee, just before reaching the Mississippi River, there lies a two-lane road serving a high number of fully-loaded grain trucks. State Route 88 (SR88) has seen its fair share of not only heavy truck traffic but environmental threats as well. For years, sections of SR88 have spent days, if not weeks, under water, as it runs parallel with the Obion River. The Obion River is the primary surface water drainage system of northwest Tennessee and drains into the mighty Mississippi River. According to a U.S. Environmental Protection Agency's *Section 319 Nonpoint Source Program* article written by Sam Marshall, PhD, of the Tennessee Department of Agriculture, "In the last century, landowners channelized sections of the Obion River and many of its small tributaries to increase flow efficiency for agricultural uses. Unfortunately, channelizing the waterways also caused increased erosion, downstream flooding, and a loss of wildlife habitat."

These problems are especially true for this section of SR88 as several banks are right up against the shoulder of the road, and erosion is apparent.

High water, erosion and heavy traffic are a known recipe for road failure. It was no surprise that Tennessee Department of Transportation (TDOT) chose SR88 as its next Full-Depth Reclamation (FDR) project.

In 2019, TDOT awarded a grant study on FDR to the University of Tennessee at Chattanooga (UTC) and Middle Tennessee State University (MTSU). The two-year study will take raw data from either TDOT or county-owned roads and run data points as well as mix designs in hope of preparing a solid platform for TDOT's materials and test team and the pavement design team to use when determining a road's candidacy for FDR.

UTC's Civil Engineering program and MTSU's Concrete Industry Management program joined forces and collected over 300 pounds of samples from SR88, as well as cored asphalt depths and falling weight deflectometer points.

The Universities then ran all necessary proctor tests, moisture tests, gradation tests and strength tests in MTSU's CIM lab. Even with a couple of decent-sized pockets of clay, the cement percentage was constant at 5.5% cement, which TDOT rounded up to 6% for the project.

RoadWorx, Inc. was awarded the reclamation par of the project with Pavement Restorations, Inc. (PRI) as the prime contractor. RoadWorx President Barry Wilder and his team started reclaiming the 9.36-mile road on August 27, 2020 with a control strip and immediately jumped into full action on September 1. The reclamation was completed by October 2 with only a couple of days delay due to weather. PRI preformed a double bituminous surface treatment, more commonly known as DBST, and finished on October 5, all of which was on schedule with TDOT requirements.

The mix design was the same 13" depth at 6% cement, but due to the material's density and moisture levels changing throughout the road, the road was sectioned in three groups with the spread rates changing from 74.9 lb/sy to 73.6 lb/sy to 72.8lb/sy. The first layer of DBST was a number 7 aggregate with a TDOT-chosen CRS-2P emulsion. The second course was the same emulsion but with a number 8 aggregate. The entire DBST was then treated with a CHPF-1 High Performance Fog Seal in order to help prevent any additional chip loss. Both Barry Wilder of RoadWorx and PRI Director of Business Development Casin Swann were proud to be a part of TDOT's largest FDR project to date.

It should also be mentioned that TDOT Commissioner Clay Bright made the long drive to SR88 in order to witness this "new tool" in TDOT's bag. In a Tweet made by the Commissioner on September 3, 2020 at 9:19 pm, he stated "Great day in Lauderdale County seeing a Full-Depth Reclamation project by PRI. [The] road will be much better and safer for all the truck traffic delivering to the river for years to come."

2011.1

① State Route 88 was in poor condition

② Reclamation in process

③ State Route 88 is now in better condition

By:
Jessie Boone
Pavement Applications Director - Tennessee
Southeast Cement Promotion Association

Spotlight Excerpts

For years, sections of SR88 have spent days, if not weeks, under water, as it runs parallel with the Obion River

High water, erosion and heavy traffic are a known recipe for road failure. It was no surprise that TDOT chose SR88 as its next Full-Depth Reclamation (FDR) project.

CONCLUSIONS

① We are beginning to recognize the need to make our infrastructure “Resilient”

- Need to define specific actions that agencies should consider when dealing with pavements
- Need to define how each specific “climate risk” will impact the system
- Must account for secondary impacts

② In areas where pavements have a history of flooding (or in flood prone areas)

- Require pavement designs be based on lowered subgrade strength
- Use Stiffer or stiffen the existing pavement
- There are many solutions that are viable that are low costs, such as concrete overlays and FDR with cement that can be used as mitigation / hardening strategies

Thank you

Use chat box for Q&A

gdean@pavementse.com

CAROLINAS
CONCRETE PAVING
ASSOCIATION