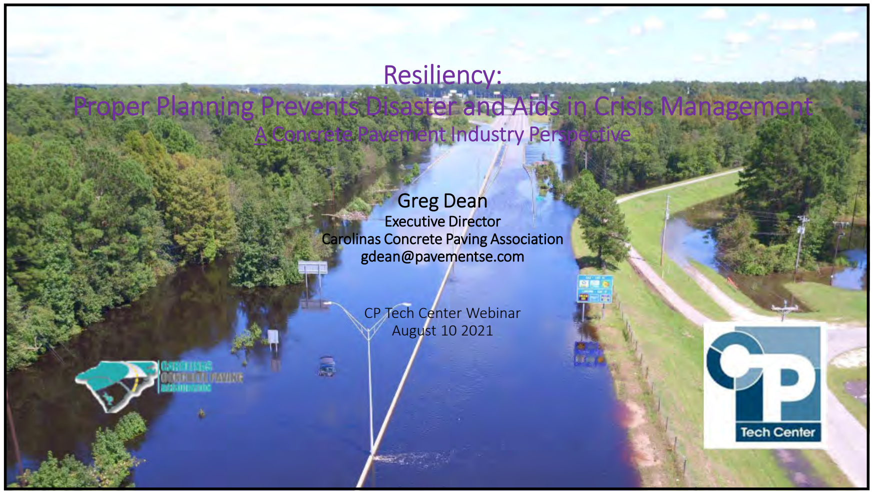

Resiliency:
Proper Planning Prevents Disaster and Aids in Crisis Management
A Concrete Pavement Industry Perspective

Greg Dean
Executive Director
Carolinas Concrete Paving Association
gdean@pavementse.com

CP Tech Center Webinar
August 10 2021

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aka
Boosting Pavement Resilience in a Changing Climate

<u>The Need</u> for Resilient Pavements

Well-documented in prior webinars, peer exchanges, ETC

https://youtu.be/LdQ8ELIk3IM (Jim Mack, Cemex, FC&PA PaveWise concrete conference)

https://sites.google.com/view/resiliency-peer-exchange-1/home **FHWA Peer Exchange #1-Oct 2020**

https://sites.google.com/view/resiliency-peer-exchange-2/home FHWA Peer Exchange #2-Dec 2020

Improving a Pavement's Resiliency

https://cptechcenter.org/events/spring-2021-national-concrete-consortium/ (Leif Wathne, ACPA)

Current knowledge, research gaps and design trends for various transportation modes

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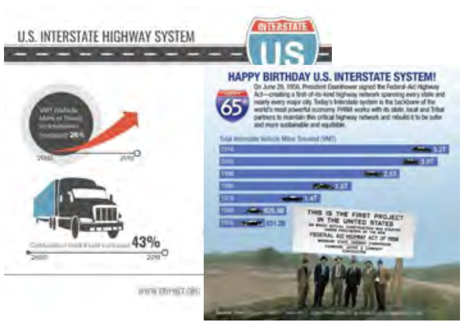
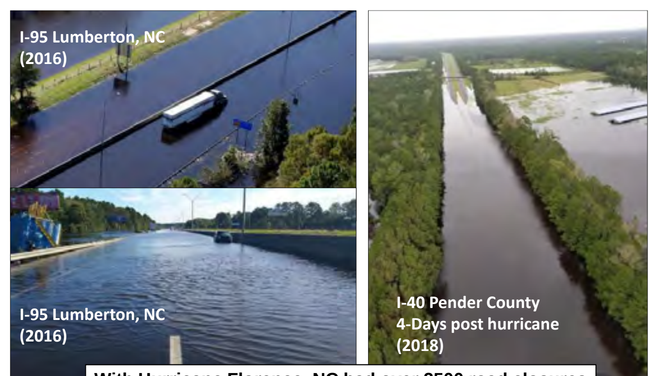
Resilience will be tested
Freight (loads) will continue to rise significantly



Carolinas impacted by TWO 500-year flood events
Hurricane Matthew (2016) & Hurricane Florence (2018)

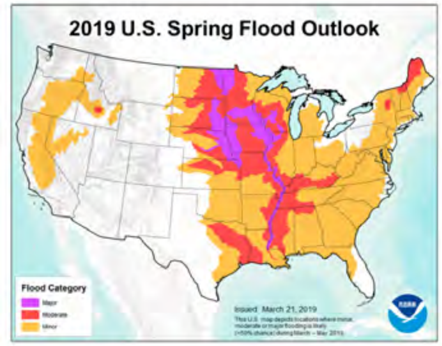


With Hurricane Florence, NC had over 2500 road closures

2020
A Very Busy, Record-Breaking Year

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

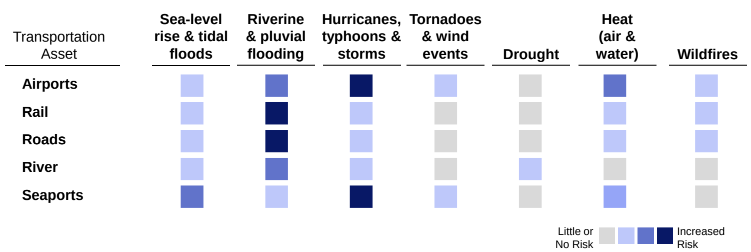
FLOODING IN THE PLAIN STATES WAS SEVERE MARCH 2019
Flooding is NOT only a Coastal Issue



Nebraska DOT reported 1,500 road miles closed

Iowa I-29 Impacts

FLOODING IS THE PRIMARY CLIMATE RISK TO INFRASTRUCTURE
Risk can occur as both sudden shocks & long-term recurring chronic pressures



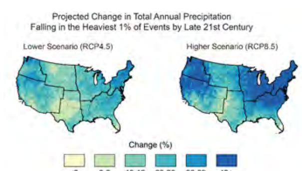
Climate risk increases operating costs & exacerbates the infrastructure funding gap

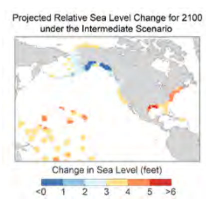
Source: McKinsey & Company, Will infrastructure bend or break under climate stress?, McKinsey & Company, August 19, 2020
https://www.mckinsey.com/Videos/video?vid=6180836320001&plyrid=HkOJqCPWdb&aid=A21DD0A9-7DA8-44A2-87E0-B4944177F295

- 7 -

FUTURE CLIMATE CONDITIONS WILL NOT RESEMBLE THE PAST

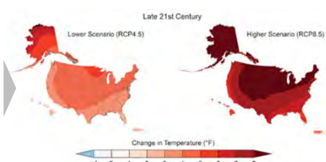
U.S. severe storms, heavy precipitation events:
Greater intensity *and* frequency
Continued increases expected





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



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 too common occurrence

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

High Tide (Charleston SC) Flood Days

Low to Intermediate (Middle)

Number of experienced NUISANCE Days / Year		
Charleston, SC	Sea Level Rise	
Year	Low (~1 foot)	Middle (~3 feet)
2022	7 Days	16 Days
2042	22 Days	73 Days
2052	34 Days	130 Days

BOOTS required!

Source: U.S. High Tide Flooding Probability Scenarios through 2100 (esri.com)

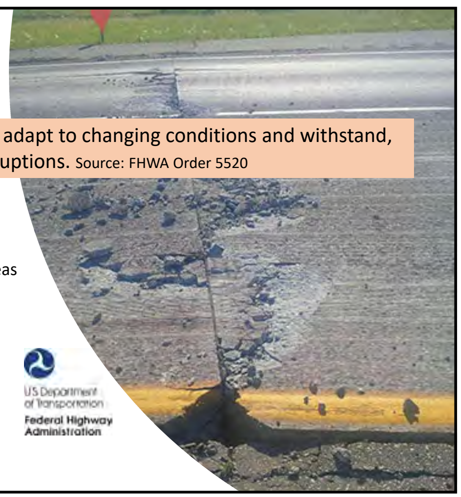
Defining Resiliency

The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions. Source: FHWA Order 5520

- Identify risks posed by climate change and extreme weather events
- Integrate consideration of these risks into its planning, operations, policies and program areas

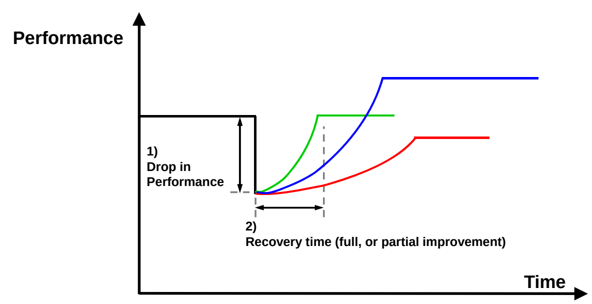
SUSTAINABLE PAVEMENTS PROGRAM

U.S. Department of Transportation Federal Highway Administration



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 (e.g. Flooding, fire, earthquake, etc) is characterized by two parameters:
1. Drop in performance, induced by the event (e.g. reduced ability to carry load).
2. Recovery time to reinstate or improve performance.

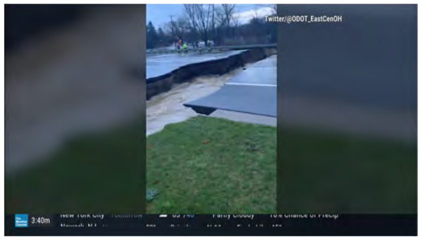
1. *FHWA Order 5520: Transportation System Preparedness and Resilience to Climate Change and Extreme Weather Events*
2. *Hardening Infrastructure – Elevating, upgrading, relocating assets, flood walls, berms and levees, etc.*

- 12 -

INCREASED FLOODING IS IMPACTING OUR PAVEMENT STRUCTURES

Need to distinguish between Inundation and Washout Impacts

Washout
Mobility Disruptor



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

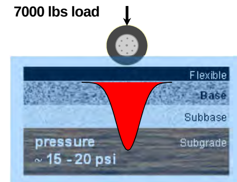
Pavement type has little impact

Inundation
Silent Killer

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

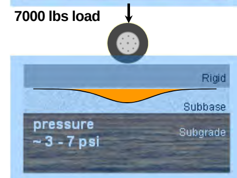
Pavement type does have an impact

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



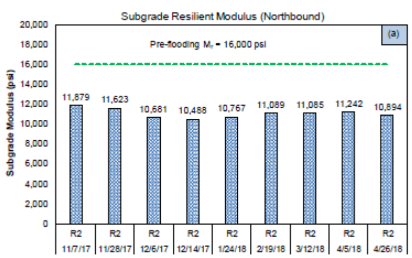
Rigid Pavement Structure

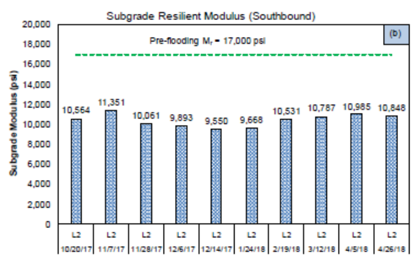
- Maintains high level of strength / stiffness
- Subgrade is weak, but still uniform
- Spreading of the load means subgrade is not overstressed
- Little impact on the serviceability / life

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

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

- 17 -

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

Source: Amy Wedel, FC&PA

- 18 -

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.**

- 19 -

Boosting Pavement Resilience in a Changing Climate

The Need for Resilient Pavements

Well-documented in prior webinars, peer exchanges, ETC

https://youtu.be/LdQ8ELIk3IM (Jim Mack, Cemex, FC&PA PaveWise concrete conference)

https://sites.google.com/view/resiliency-peer-exchange-1/home FHWA Peer Exchange #1-Oct 2020

https://sites.google.com/view/resiliency-peer-exchange-2/home FHWA Peer Exchange #2-Dec 2020

Improving a Pavement's Resiliency

https://cptechcenter.org/events/spring-2021-national-concrete-consortium/ (Leif Wathne, ACPA)

Current knowledge, research gaps and design trends in various transportation modes

Low-hanging fruit that can make a pavement more resilient? (FHWA Peer Exchange priorities)

Low Hanging Fruit for Improved Pavement Resilience
GOOD resources can be found…

Articles & 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

CLIMATE CHANGE ADAPTATION FOR PAVEMENTS

Pavement Resiliency
FHWA – Climate Change Adaptation for Pavements

HOTTER

Table 1a. Pavement Design - Temperature Items (adapted from Meyer et al. 2014)

Climate Change Impact	Affected Components & Strategies
Higher Extreme Maximum Temperature	**Flexible Pavement** • Increased potential for asphalt rutting and shoving during extreme heat waves
Higher Extreme Maximum Temperature	**Rigid Pavement** • Increased risk of concrete pavement "blow ups" due to excessive slab expansion 1. Use Shorter Joint spacing in new designs 2. Keep joints clean and in extreme cases, install expansion joints in existing pavements

- 22 -

Pavement Resiliency
FHWA – Climate Change Adaptation for Pavements

WETTER

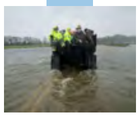


Table 1b. Pavement Design - Precipitation Items (adapted from Meyer et al. 2014)

Climate Change Impact	Affected Components & Strategies
More Extreme Rainfall Events	• Increased need for surface friction meaning potentially more focus on surface texture and maintaining skid resistance 1. Maintain positive cross slope to facilitate flow of water from surface 2. Increase resistance to rutting 3. Reduce splash/spray • Increased need for functioning subdrainage o Adequacy of Design, installation and maintenance of subdrainage • **Reduction of structural capacity of unbound bases and subgrade when pavements are submerged** o Develop a better understanding of how submergence affects pavement layer structural capacity and strategies to address it

- 23 -

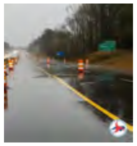
Pavement Resiliency
FHWA – Climate Change Adaptation for Pavements

WETTER

Table 1b. Pavement Design - Precipitation Items (adapted from Meyer et al. 2014)

Climate Change Impact	Affected Components & Strategies
Higher Average Annual Precipitation	• Reduction in pavement structural capacity due to increased levels of saturation 1. Reduce moisture susceptibility of unbound base/subgrade materials through **stabilization** 2. Ensure resistance to moisture susceptibility of asphalt mixes • Improved surface and subsurface pavement drainage • Will likely negatively impact construction scheduling

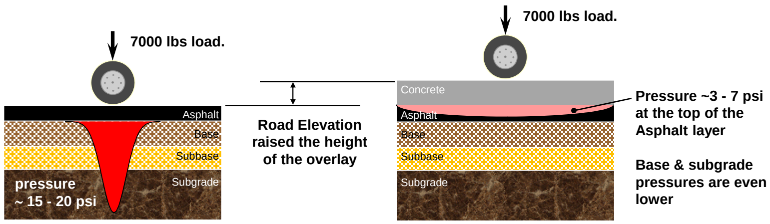
Nov 2020 / I-95 rainfall damage



- 24 -

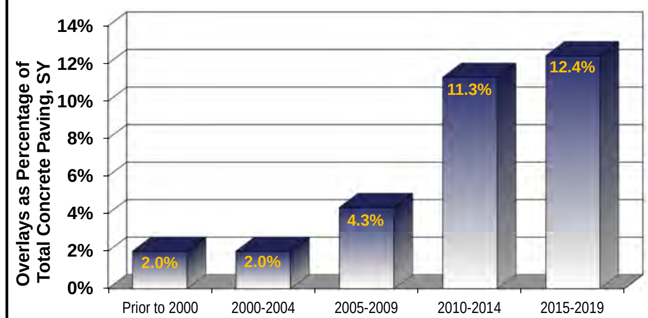
ACTIVITIES THAT CAN BE USED TO "HARDEN THE PAVEMENT SYSTEM"

Use Concrete Overlays



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

Concrete Overlay Adoption Growing…



Unbonded Example

BCOA Example

Concrete overlays included in FHWA's EDC6

OVERLAYS can IMPROVE the PAVEMENT'S RESILIENCE

INNOVATOR
Bi-monthly Newsletter

US Department of Transportation
Federal Highway Administration

Innovations in Overlays

Create a Top-Notch Pavement Network with TOPS | Innovator | 2021 | July / August (dot.gov)

Overlays reduce maintenance, maximize previous investments, and reduce user delays (fewer work zones) due to extended service life of pavement structures. In addition, some TOPS products increase skid resistance, improve resiliency in flood-prone areas, reduce splash and spray, and reduce noise.

Examples of Inundation of Airfield Pavements

Coastal NC Airport exposed to Hurricanes

MS Airport exposed to Riverine Floods

Federal Aviation Administration Design Circulars Comparison of 2016 & 2021

AC 150/5320-6F (Nov 2016)

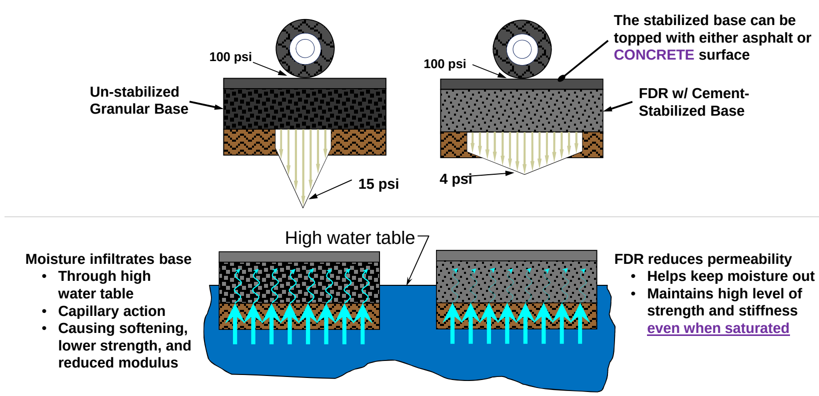
- The term "water inundation" is NOT mentioned within the prior circular
- The term "water table" mentioned Four times within the prior circular

NEW AC 150/5320-6G (June 2021)

- The term "water inundation" used TWO times within new circular
- The term "water table" used Five times within new circular
- Added discussion regarding subgrade stabilization (Chapter 2)
- Expanded discussion of stabilized base course and drainage layers
- P-207 Full Depth Reclamation (FDR) shown as a viable stabilized base course when certain conditions are met

FDR as a Resilience Hardening Solution

Increases rigidity, reduces permeability, & reduces moisture susceptibility



- 30 -

Elizabeth City Airport

FDR & P-501 (Concrete) combine for a RESILIENT Pavement Solution

Federal Aviation Administration

Advisory Circular 150/5320-6G (June 2021)

2.3.9.11.1 **Laboratory CBR (California Bearing Ratio)**

Perform laboratory CBR tests in accordance with ASTM D1883, Standard Test Method ETC. Conduct laboratory CBR tests on materials obtained from site and remolded to the moisture and density that will be required during construction. Samples should be soaked prior to testing. Pavement foundations tend to reach nearly complete saturation after about 3 years. The use of a soaked CBR test simulates the condition of a pavement that has been in service. A soaked CBR also represents the time of year when the weakest subgrade is present, i.e. periods of high moisture such as spring thaw or following seasonal storm events.

AC 150/5320-6G (June 2021)

2.4 **Subgrade Stabilization**

2.4.1 Where the mean subgrade strength is lower than CBR 5 (elastic modulus approx. 7,500psi) it is **recommended** to improve the subgrade chemically, mechanically, or by replacement with suitable subgrade material.

2.4.2 When the mean subgrade strength is less than a CBR 3 (elastic modulus approx. 4,500 psi) **improve the subgrade through stabilization** or replacement with suitable subgrade material.

Federal Aviation Administration
Advisory Circular 150/5320-6G (June 2021)

2.4 **Subgrade Stabilization**

2.4.3 In addition, **consider subgrade stabilization** if any of the following conditions exist: poor drainage, adverse surface drainage, frost, periodic water inundation or the need to establish a stable working platform. Use chemical agents, mechanical or geosynthetic methods to stabilize subgrades.

2.4.4 Stabilize subgrade materials to a minimum depth of 12 in (300 mm), or to the depth recommended by the geotechnical engineer.

Stabilized Drainage Layer
Improved Resiliency

Pope Army Airfield

6-inch cement stabilized drainage layer (COE Spec)

Charleston Executive (JZI) Airport
Johns Island, SC

11-inch Unbonded Overlay (2010 Construction)

Owner's Quotes (During Open House Event)

A Concrete Overlay kept us "out of the subgrade" vs. reconstruction option.

A Concrete Overlay raised our pavement elevation out of the high water table (e.g. boosting *resilience*)

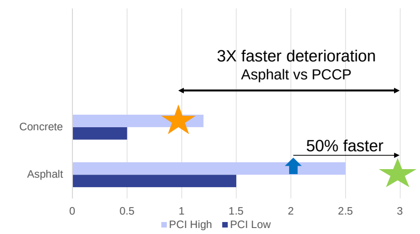
Our original concrete surface lasted 60+ years, no reason why this (new concrete) surface cannot last another 60 years!

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)

High Water / Flood Inundation Matters
Charleston Exec (JZI) Airport

Deterioration PCI Points/year



Summary

Airfield concrete pavements deteriorate at rate of 0.5 to 1.2 PCI points per year

JZI Concrete (RW) deteriorating at 1 point per year

Asphalt pavements deteriorate at rate of 1.5 to 2.5 PCI points per year (avg = 2)

JZI Asphalt (TW) deteriorating at 3 points per year (50% faster than typical)

Source: Performance Trends in Airport Runway Pavements (2014 FAA Worldwide Airport Tech Transfer Conference) and SC 2016 Airfield Pavement Management Report (JZI PCI data)

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"*

Rehabilitation of Runways 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."

East Coast Greenway Design Guide

Concrete trails typically have the longest lifespan of any trail surface...

- **Longest-lasting (25+ year) & lowest maintenance surface**
- **Suitable for Areas prone to flooding**

Sunny Day Flooding can lead to Early Pavement Deterioration

Spread the Load by using Concrete Pavement

Yacht Harbor Manor Neighborhood Improvements, Riviera Beach, Florida

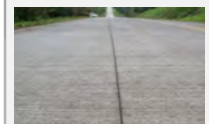
Figure 1. The city reduced the minimum cover required over a water main under a concrete road allowing the drainage to fit above the sewer in some locations.

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

In Summary…Concrete Pavement Industry offers: several HARDENING TECHNIQUES

Conventional Concrete Pavement

Thin Concrete Pavement



Concrete Overlays

Roller Compacted Concrete (RCC)

Full Depth Reclamation (FDR) w/ Cement

Pervious Concrete

CONCLUSIONS

Pavements are being negatively impacted by our changing climate. Green and Grey solutions will be required to improve our nation's infrastructure resilience.

1. **There is greater recognition toward making our pavements more "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**
   - **Viable low-cost solutions, such as concrete overlays and cement stabilization strategies can be used as mitigation / hardening strategies**

- 43 -

Thank you!

Greg Dean
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gdean@pavementse.com

CAROLINAS CONCRETE PAVING ASSOCIATION

Wishing to learn more on pavement resiliency?
12th International Conference on Concrete Pavements
Sep 27 – Oct 1 Register

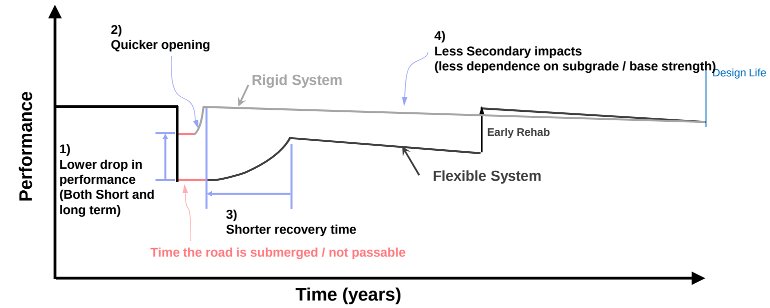
Greg Dean, *Executive Director* - Carolinas Concrete Paving Association

Greg's responsibilities include the education and marketing of concrete pavements for Airport, Highway and Local Road applications within North and South Carolina. He currently serves on the ACPA's Engineering and Design Committee and a member of the *resiliency group* as part of ACPA's Sustainability initiative.

During his time (2008-2013) as Airport Director of the ACPA-SE Chapter he began observing how deterioration rates of airfield pavements differ in various climatic conditions and regions. After witnessing 2016 / 2018 extreme weather events within his home state (NC), his desire to learn more about the role of pavement resilience strengthened.

Along with being a concrete pavement resource for the members, design consultants and local agencies, Greg enjoys spending time with his family, traveling and rooting on his alma mater, North Carolina State University (BS CE).

Design Stiffer Pavement Systems…



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

- 46 -

Federal Aviation Administration

Advisory Circular 150/5320-6G (June 2021)

2.3.9 **Subgrade Support for Pavement Design**

2.3.9.4 The FAA recommends selecting a subgrade strength value for design that is one standard deviation (sample) below the mean of laboratory tests. Use a value for design that reflects the expected long-term subgrade support. Document and support the value used in the geotechnical report.

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

Modify "Design Standards" to be based on weakened subgrade condition

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

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.

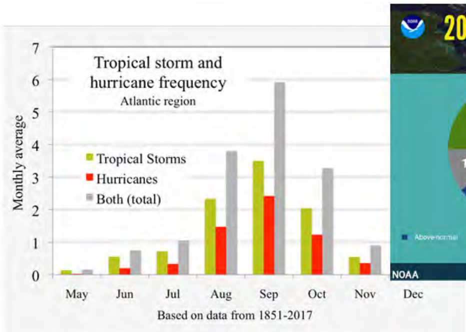
Table 7: Typical moisture conditions for laboratory CBR testing

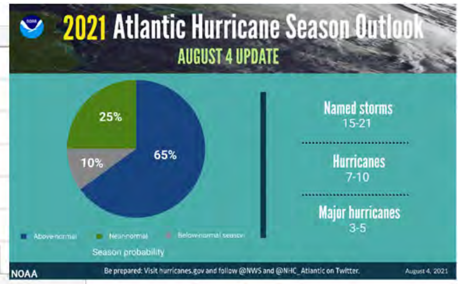
Median annual rainfall (mm)	Specimen compaction moisture content	Testing condition	
		Excellent to good drainage	Fair to poor drainage
< 600	OMC	Unsoaked	4-day soak
600 – 800	OMC	4-day soak	10-day soak
> 800	OMC	10-day soak	10-day soak

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

- 48 -

Year to Year, the trends and RISK are there…





TS / H1 Elsa impacts early July