IMPROVING PAVEMENT RESILIENCY & DISASTER RECOVERY
A Case for Concrete Pavements

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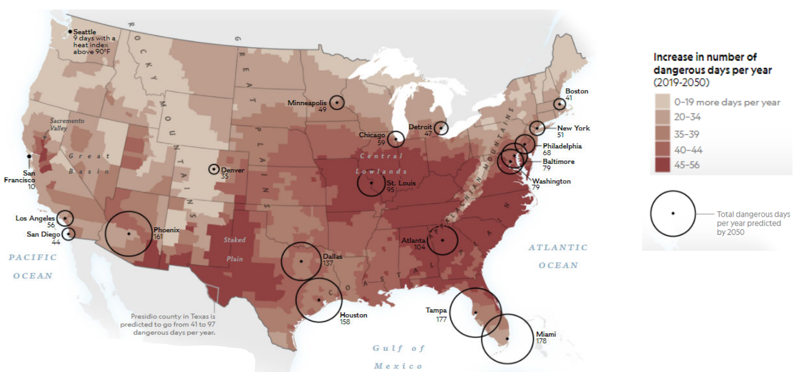
September 2020

TOPICS COVERED

- **The Need for Resilient Pavements**
- **Defining Resiliency**
- **Improving a Pavement's Resiliency**

INCREASE OF DAYS WITH HEAT INDEX > 90° F DEGREES BY 2050

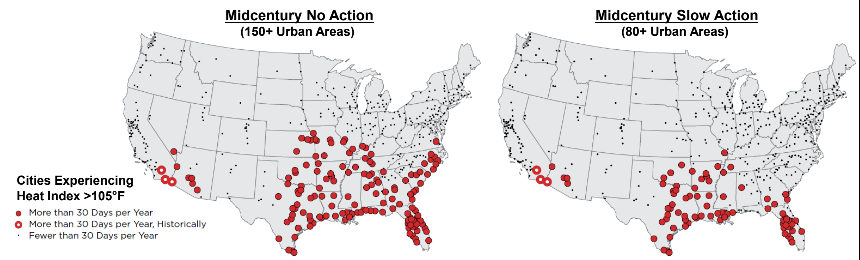
Many cities will experience a month or more sweltering days each year.



Sources:
- https://www.nationalgeographic.com/environment/2019/07/extreme-heat-to-affect-millions-of-americans/#close;
- Killer Heat in the United States: Climate Choices and the Future of Dangerously Hot Days, Union of Concerned Scientists, July 2019

THE NUMBER OF EXTREME HEAT DAYS WILL INCREASE DRAMATICALLY

Urban Areas exposed to 30 or more days with a heat index > 105° F degrees
Compared with just 3 urban areas historically

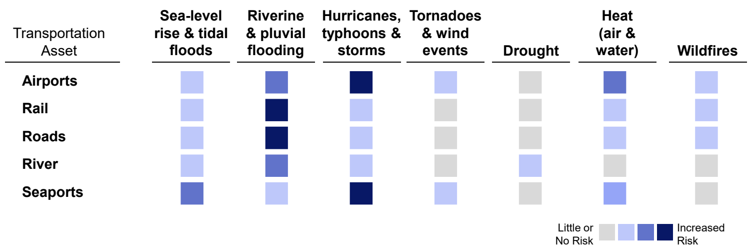


Extreme heat will not occur in isolation. There will also be droughts, wildfires, floods, and other extreme weather events that will compound the impacts of the heat

Sources:
- https://www.nationalgeographic.com/environment/2019/07/extreme-heat-to-affect-millions-of-americans/#close
- Killer Heat in the United States: Climate Choices and the Future of Dangerously Hot Days, Union of Concerned Scientists, July 2019

INCREASED TEMPERATURES CREATE OTHER CLIMATE RISK

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

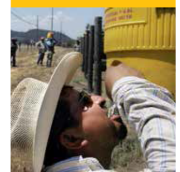
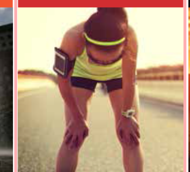


Climate risk increases operating costs & exacerbates the infrastructure funding gap

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

WARMER SUMMERS WILL AFFECT THE ABILITY TO WORK OUTDOORS

In extreme cases, this could put human lives at risk.

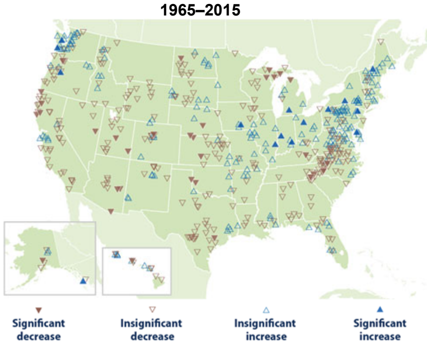
Heat Index Above 90°F	Heat Index Above 100°F	Heat Index Above 105°F	Heat Index Off the Charts
			
Outdoor workers become more susceptible to heat-related illness.	Children, elderly adults, pregnant women, and people with underlying conditions are at heightened risk of heat-related illness.	Anyone could be at risk of heat-related illness or even death as a result of prolonged exposure.	Undetermined: any level of exposure is presumed extremely dangerous for all people and likely to result in heat-related illness or even death.
		Extreme Heat Days	

Left to right: AP Photo/Napa Valley Register, Lianne Milton; AP Photo/Julio Cortez; lzf/iStock; logoboom/Shutterstock

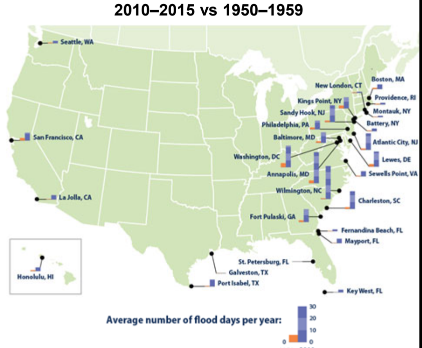
Sources:
- https://www.nationalgeographic.com/environment/2019/07/extreme-heat-to-affect-millions-of-americans/#close;
- Killer Heat in the United States: Climate Choices and the Future of Dangerously Hot Days, Union of Concerned Scientists, July 2019

EXTREME FLOOD EVENTS ARE INCREASING IN BOTH FREQUENCY AND MAGNITUDE

Change in Magnitude of U.S. River Flooding, 1965–2015



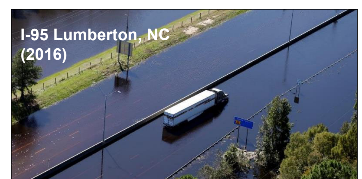
Frequency of Flooding Along U.S. Coasts, 2010–2015 vs 1950–1959

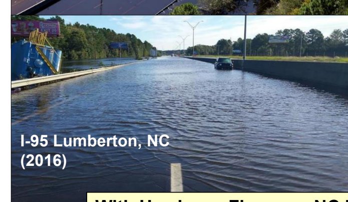


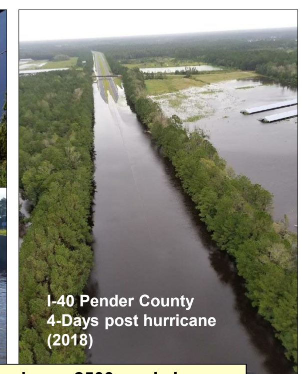
Source: https://www.epa.gov/climate-indicators

NORTH CAROLINA HAS BEEN HIT BY TWO 500 YEAR FLOOD EVENTS

Hurricane Matthew (2016) & Hurricane Florence (2018)

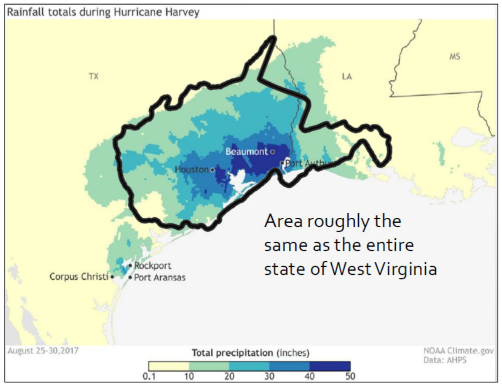


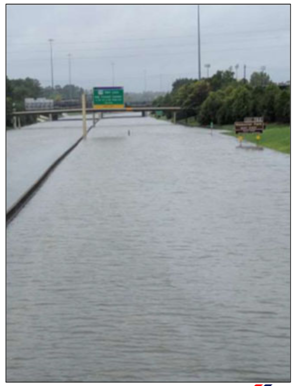




With Hurricane Florence, NC had over 2500 road closures

HOUSTON TEXAS HAS BEEN HIT BY 4 FLOOD EVENTS IN THE LAST SEVERAL YEARS – THE WORST WAS HURRICANE HARVEY



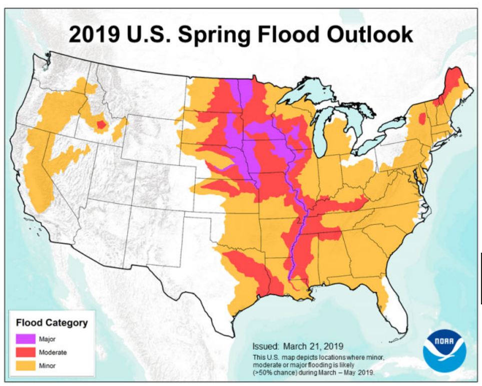


HURRICANE SALLY IS THE LATEST STORM TO HIT THE USA

But it will not be the last

Flooded streets, Hurricane Sally Pensacola, Florida on September 16, 2020.

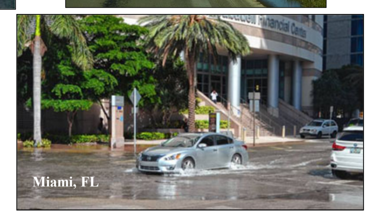
RIVER FLOODING IN THE PLAIN STATES HAS BEEN SEVERE THE LAST SEVERAL YEARS



At one point, the Nebraska DOT reported 1,500 road miles were closed

SEA LEVEL RISE IS ALREADY IMPACTING COASTAL ZONES

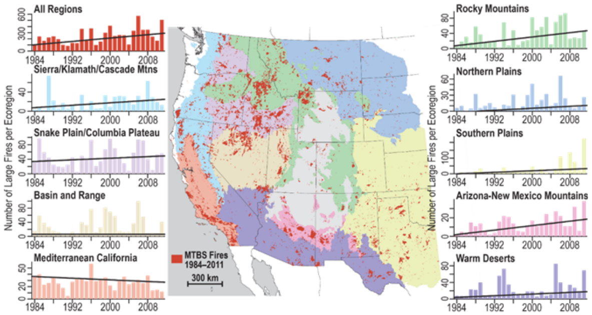
Sunny sky flooding is becoming a common or daily occurrence



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

EXTREME HEAT INCREASES THE INCIDENCE OF LARGE FOREST FIRES

The number of fires has increased with high statistical significance in 7 out of 10 western US States[1]



Contributing Factors

- Warmer & drier conditions
- Increased pest populations
- Increased land management practices
- Increased fire suppression practices
  - Denser vegetation (increased fuel)

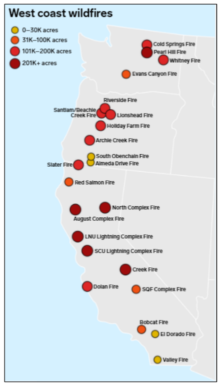
"Outdated policies and human-caused climate change [have] increased burn area [by] 900% across the western U.S. since 1984"

1. USGCRP, 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II:
2. Patrick Gonzalez, UC Berkeley forest ecologist and climate change scientist, https://www.capradio.org/articles/2020/09/03/wildfires-in-california-will-continue-to-get-worse-climate-change-experts-explore-why/

CEMEX

2020 IS THE WORST YEAR ON RECORD FOR FOREST FIRES

More than 85 large wildfires are ripping across the West Coast



California – more than 3.2 million acres have burned

Oregon – 46 large fires burned more than 1 million acres between Sept 7 – 13.

- **Double the state's average of 500,000 acres burned annually**

Washington - over 500,000 acres have burnt in seven days,

- **Twice the state's total from all of 2019.**

Highway 162
Bear Fire burns in Oroville, California, Wednesday, September 9, 2020.

https://www.insider.com/west-coast-wildfires-map-of-biggest-fires-color-coded-2020-9#:~:text=More%20than%2085%20large%20wildfires,California's%20biggest%20wildfire%20season%20ever.
Photo: Noah Berger/AP

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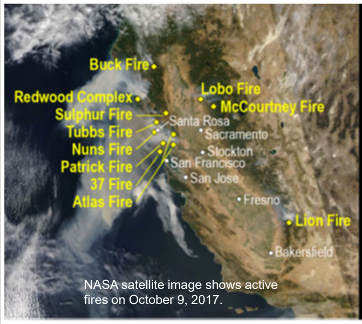
HUMANS HAVE MOVED CLOSER TO FORESTLANDS

Expanded the Wildland–Urban Interface



NASA satellite image shows active fires on October 9, 2017.

Tubbs Fire - burned parts of Napa, Sonoma, and Lake counties

- $1.2 billion in damages
- over 5,000 structures destroyed (5% of the housing stock in the city of Santa Rosa)

The results is larger and more damaging fires
60% increase in wildfire-related property damage costs since 2008

USGCRP, 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II:
Patrick Gonzalez, UC Berkeley forest ecologist and climate change scientist, https://www.capradio.org/articles/2020/09/03/wildfires-in-california-will-continue-to-get-worse-climate-change-experts-explore-why/

CEMEX

TOPICS COVERED

The Need for Resilient Pavements

Defining Resiliency

Improving a Pavement's Resiliency

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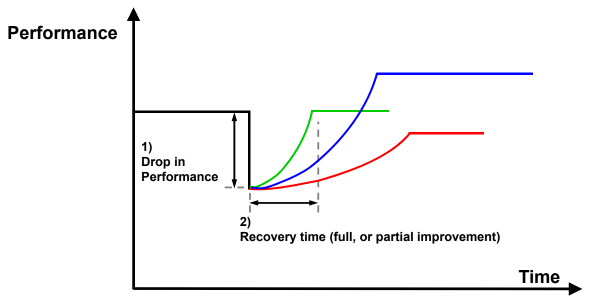
INTRODUCTION TO RESILIENCE

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.

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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

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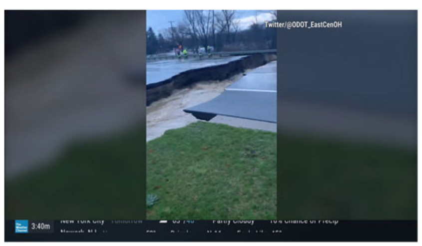
INCREASED FLOODING IS IMPACTING OUR PAVEMENT STRUCTURES

Need to distinguish between Inundation and Washout Impacts

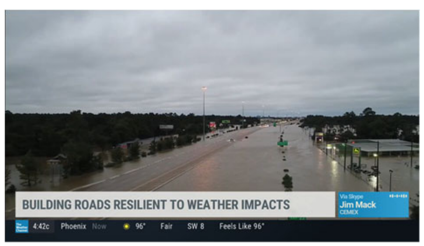
Washout



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

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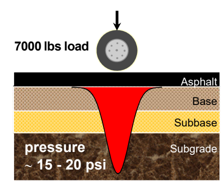
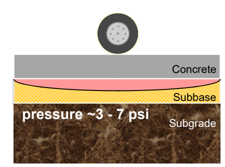
CONCRETE AND ASPHALT PAVEMENTS ARE DIFFERENT DUE TO HOW THEY TRANSMIT LOADS TO THE SUBGRADE



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

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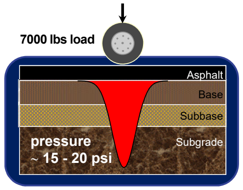
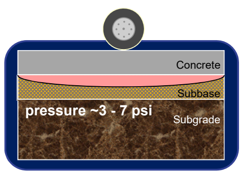
FLOODING CAUSES THE SUBGRADE TO BECOME SUPERSATURATED

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

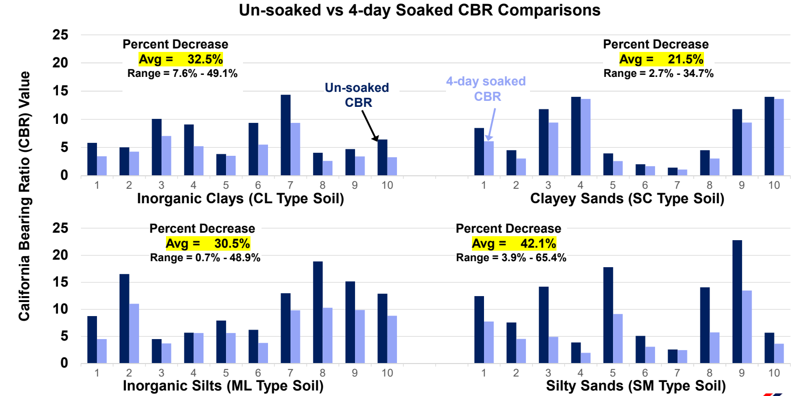
- Maintains high level of strength / stiffness
- Subgrade is weak, but still uniform
- Spreading of the load means subgrade is not overstressed
- Little impact on the serviceability / life

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) react differently but all decrease

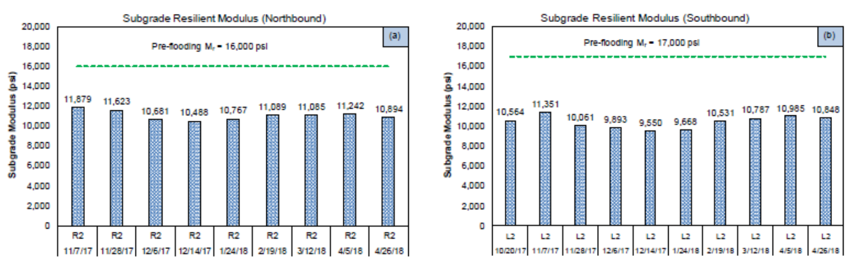
Un-soaked vs 4-day Soaked CBR Comparisons



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**

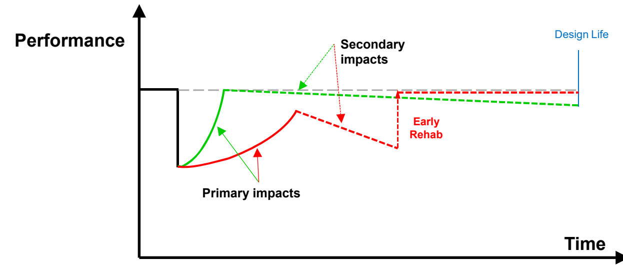
To have a resilient pavement system requires that both aspects be addressed

RELIEF AND RESCUE EFFORTS WILL TAKE PLACE

Loading occurs both during the crisis and long after

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**

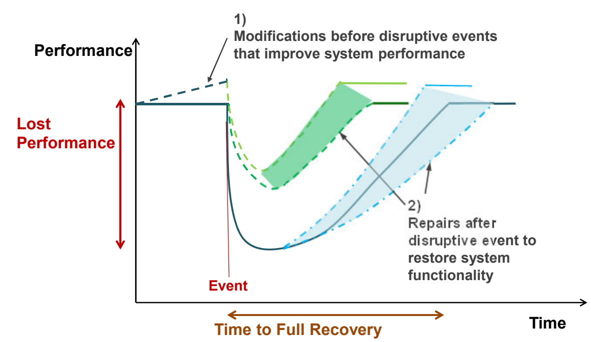
TOPICS COVERED

The Need for Resilient Pavements

Defining Resiliency

Improving a Pavement's Resiliency

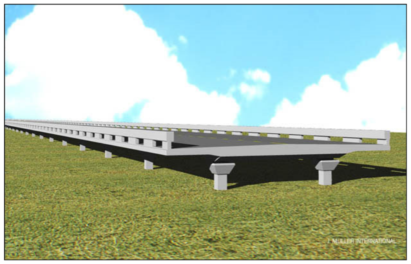
APPROACHES TO IMPROVE A HIGHWAY'S / PAVEMENTS RESILIENCE



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

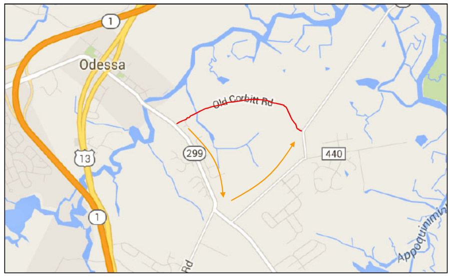


Elevation View of SR54 Viaduct From Old SR54 Alignment, Fenwick DE
Cost = $16 M in 2001

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

ANOTHER APPROACH IS ROAD ABANDONMENT

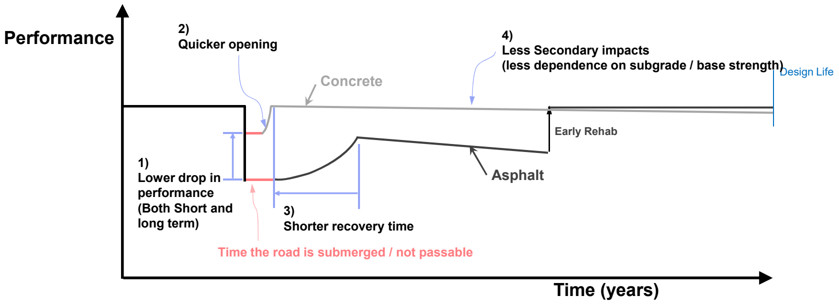
Old Corbitt Road – Odessa, Delaware



- 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

STIFFER PAVEMENTS ARE MORE RESILIENT TO INUNDATION FLOODING

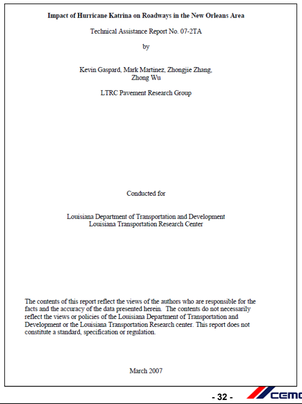


Stiffer Pavements are less impacted by subgrade strength loss and recover faster
(stiffer = concrete, cement stabilized bases, increased asphalt thickness)

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 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.**

Estimating Pavement's Flood Resilience

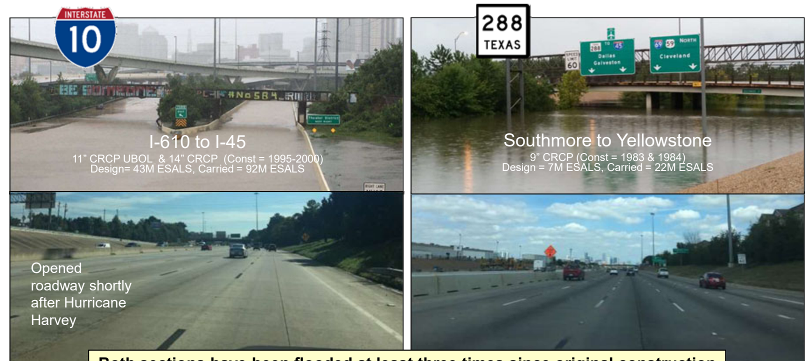
Misbah U. Khan, CPEng.[1]; Mahmoud Mesbah, Ph.D.[2]; Luis Ferreira, Ph.D.[3]; and David J. Williams, Ph.D.[4]

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

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



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

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.

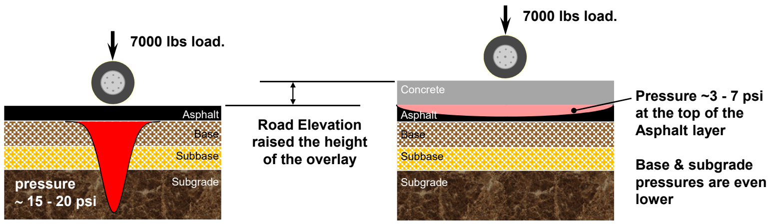
Table 7: Typical moisture conditions for laboratory CBR testing

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

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

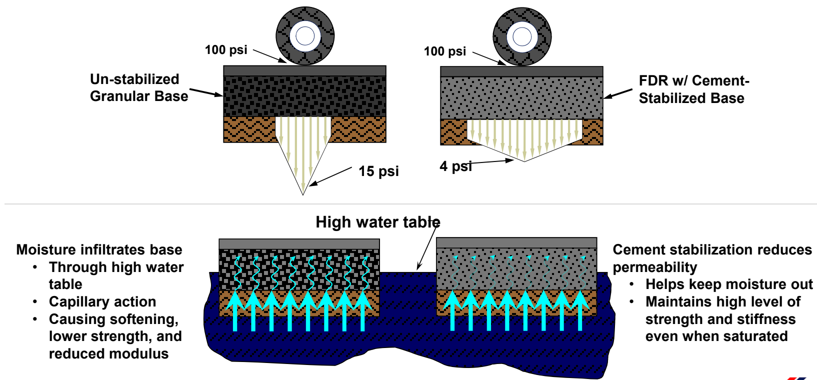
Use Concrete Overlays



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

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

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



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

DEFINING A PAVEMENT'S FIRE RESILIENCY

Howe Ridge Fire from across Lake McDonald in Montana's Glacier National Park (2018)

USGCRP, 2018: Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II

FIRE DAMAGES CONCRETE & ASPHALT PAVEMENTS DIFFERENTLY

While there are no studies on wildfires & pavements, there are studies from tunnel fires

Concrete Pavements are Non Combustible

- Concrete is a fire resistance material
- Inert due to its purely mineral composition
- Minimal or no emission of toxic gases.
- Can get minor cracks, popouts, etc. as the water in the concrete / aggregate vaporizes

Asphalt Pavements are Combustible

- Approximate ignition temperatures is 300 – 450°C (based on asphalt material / type)
- At lower temperatures, asphalt "melts" and has some thermal degradation (calcination and the detachment of aggregates)
- Burning / melting releases considerable toxic gases (CO, SO_2, NO, NO_2)

Figure 1 Comparison of specimens of asphalt (left) and concrete (right) after heating to 750°C

Source: Characterisation of asphalt exposed to high temperature: Application to fire case of asphalt pavement, Albert Noumowe, Cergy Pontoise University, 2003.

While most wild fires do not generate enough heat to cause the road to ignite
There is still considerable damage

1. IMPROVING FIRE SAFETY IN TUNNELS: The concrete pavement solution: CEMBUREAU / BIBM / ERMCO
2. Emanuele Toraldo (2013), *Comparative laboratory investigation into pavement materials for road tunnels*, Road Materials and Pavement Design
3. Rudi van Staden and Sam Fragomeni (2017) *Fire damaged flexible pavement deterioration under dynamic loading: a finite element study*,

SOURCES OF ASPHALT PAVEMENT DAMAGE

Pavement Scarring Due to Car Fire & Weakened Asphalt Binder / Structure are the Most Common

Binder / emulsion at the surface burns and melts from aggregate / rock
Results in Raveling, shoving, & rutting

Emanuele Toraldo (2013), *Comparative laboratory investigation into pavement materials for road tunnels*, Road Materials and Pavement Design
Rudi van Staden and Sam Fragomeni (2017) *Fire damaged flexible pavement deterioration under dynamic loading: a finite element study*,

CONCRETE PAVEMENT DAMAGE IS OFTEN LIMITED TO SURFACE SPALLING

Intense heat causes the moisture inside the concrete to boil and fracture

Tanker explosion on I-465 south to I-70 east ramp, Feb 20, 2020, Indianapolis Indiana

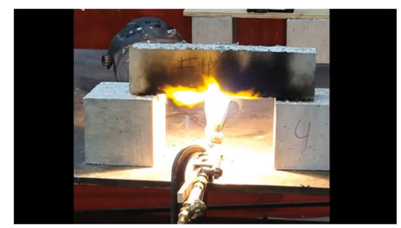
Surface was sandblasted, railing and guardrail replaced and re-opened to traffic in ~12 hours

CONCRETE CAN BE MADE FIRE RESISTANT BY ADDING POLYPROPYLENE FIBERS (roughly 2% by wt)

No Fibers

Water in the concrete boils, forms steams and Violently spalls (moisture clog spalling)

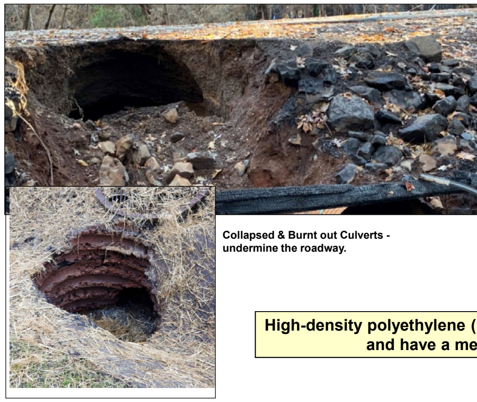
Fibers



Polypropylene fibers melt and provide escape path for the steam, preventing spalling

Videos: Courtesy of Dr Tyler Ley, Oklahoma State University,
https://www.youtube.com/watch?v=xNFFcaljlzM

ANOTHER SOURCES OF PAVEMENT DAMAGE IS DRAINAGE PIPE FIRES



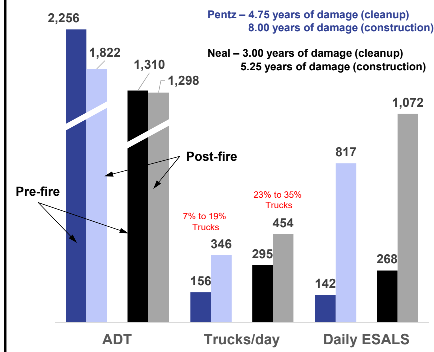
Collapsed & Burnt out Culverts - undermine the roadway.

Slope failure due to burnt out HDPE Pipe

High-density polyethylene (HDPE) or polypropylene (PP) are plastic, and have a melting point of about 120 – 180 °C

THE MAJOR SOURCE OF DAMAGE IS INCREASED / HEAVIER TRAFFIC

Damage can be a lot or a little; and depends on traffic, weight, and pavement design



INCREASED / HEAVIER TRAFFIC DOES DAMAGE THE PAVEMENT

Damage can be a lot or a little; and depends on traffic, weight, and pavement design

Before

After

Comparing Normal Verse Cleanup/Construction Traffic

Pentz

ADT	Timing	Percent Trucks	Trucks/Day	LEF	Daily ESALs
1822	Current	19%	346.18	2.36	817
2256	Pre-Fire	7%	155.664	0.91	142

4.75 Extra years of damage per year of cleanup at this rate

8.00 Extra years of damage per year of construction at this rate

Neal

ADT	Timing	Percent Trucks	Trucks/Day	LEF	Daily ESALs
1298	Current	35%	454.3	2.36	1072
1310	Pre-Fire	23%	294.75	0.91	268

3.00 Extra years of damage per year of cleanup at this rate

5.25 Extra years of damage per year of construction at this rate

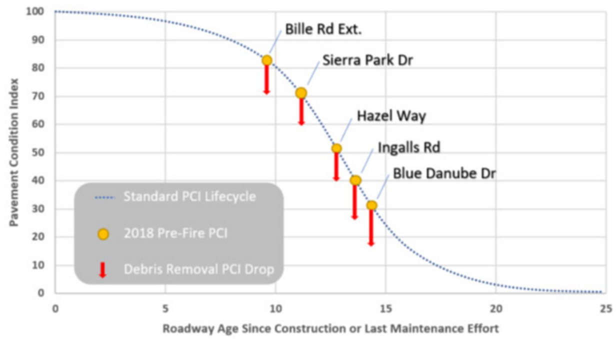
Creating this type of structural damage makes the road more susceptible to water and environmental damage – further/rapidly exacerbating the damage!

Butte County

#CAMPFIRE

The average loss of Pavement Condition Index score was conservatively calculated as a reduction of 20 basis points

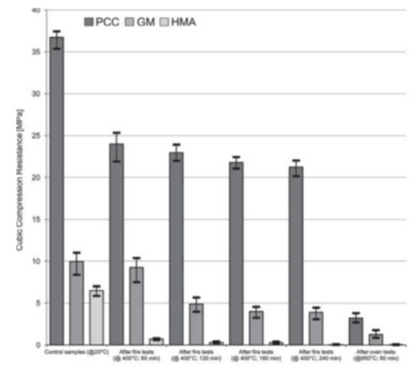
Don't use until final;



Camp Fire Paradise Private Road Damage Report: Quantifying Private Road Damage Costs Due to the Fire, Utility Restoration, Debris Removal, Hazard Tree Removal and Rebuild Efforts. Draft Report – Jan 2020

LONG TERM EXPOSURE TO INTENSE HEAT DOES IMPACT PAVEMENT STRENGTH

Change in Cubic Compression Resistance (CCR) results due to fire exposure



- First bar chart = Control (no thermal stress)
- Next four bar charts = Specimens subjected to fire tests at 400 °C
  - Durations ranging from 60 to 240 min
- Last bar chart = specimens subjected to high-temperature oven test
  - 650 °C for 60 min
- Concrete ~ 35% to 40% Strength Reduction (due to the micro-evaporation of water)
- Asphalt ~ 90% to 98% Strength Reduction (due to the bitumen burning, which occurs after only 15 min of fire exposure)

GM = Grouted Macadam. An open-grade bituminous mixture (voids content equal to 30%) filled with cement mortar

Emanuele Toraldo (2013), *Comparative laboratory investigation into pavement materials for road tunnels*, Road Materials and Pavement Design

About the Presenters

Jim Mack, P.E. – Director, Market Development, CEMEX
- Provides customer & internal support to identify and develop cement and concrete pavement application opportunities
- Works with State DOTS, Federal Agencies and industry Assns. to improve and develop standards related to cement and concrete pavement applications

30 years of pavement engineering experience
- Concrete pavement design, rehabilitation; construction; forensic evaluation, materials and specifications
- Pavement management, life cycle cost analysis and life cycle assessment (environmental impact).

Education
- MBA – University of Chicago
- MSCE – University of Illinois at Urbana-Champaign
- BSCE – University of Illinois at Urbana-Champaign

Registered Professional Engineer – Illinois and Texas