# PAVEMENT RESILIENCE:
# U.S. Experiences & Recommendations

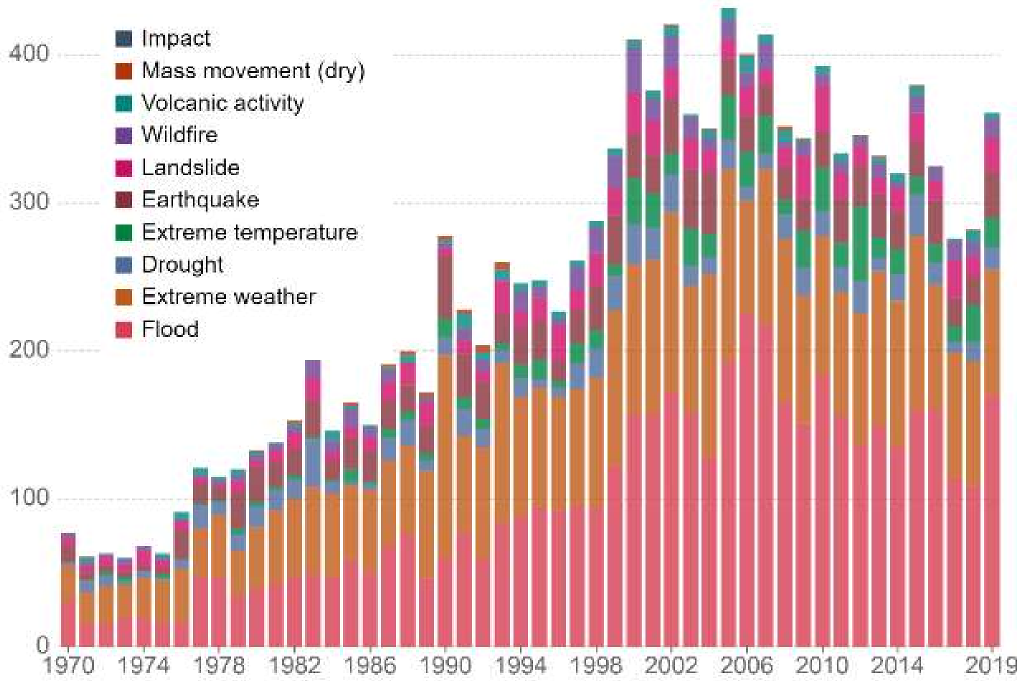
**Jim Mack, P.E.**
**Director of Market Development – Infrastructure**

**EUPAVE EU Debate: "Climate resilience and long-term road investment"**
**25 January 2022**

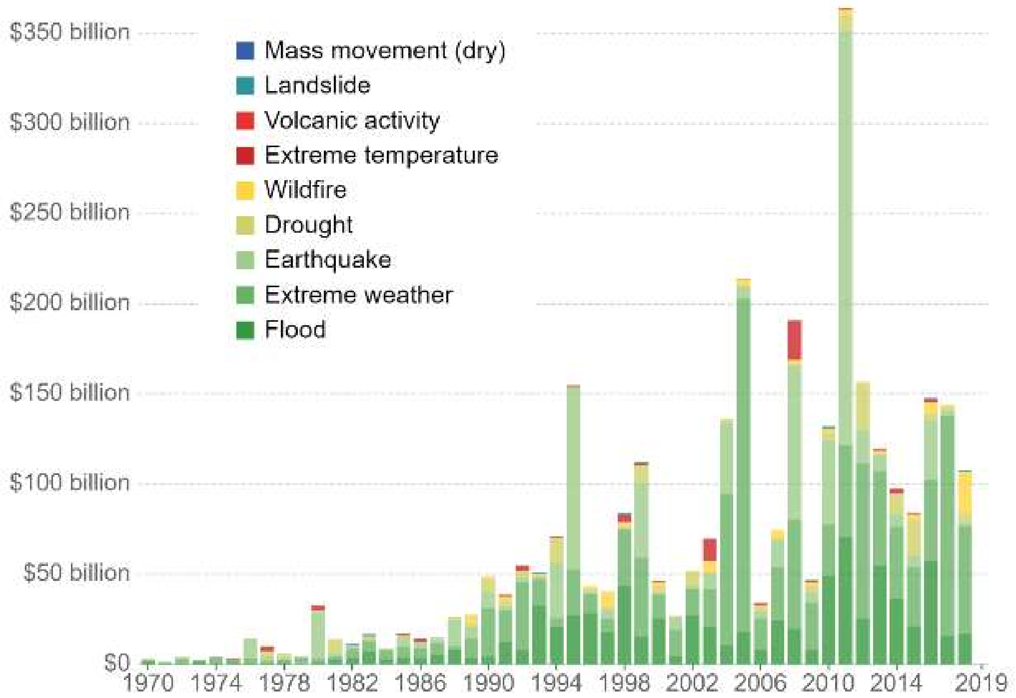
# WE ARE SEEING MORE CLIMATE RELATED DISASTERS

## Global Reported Number and Economic Damage of Natural Disaster by Type, 1970-2019

### Number of Climate Related Disasters




### Economic Impact



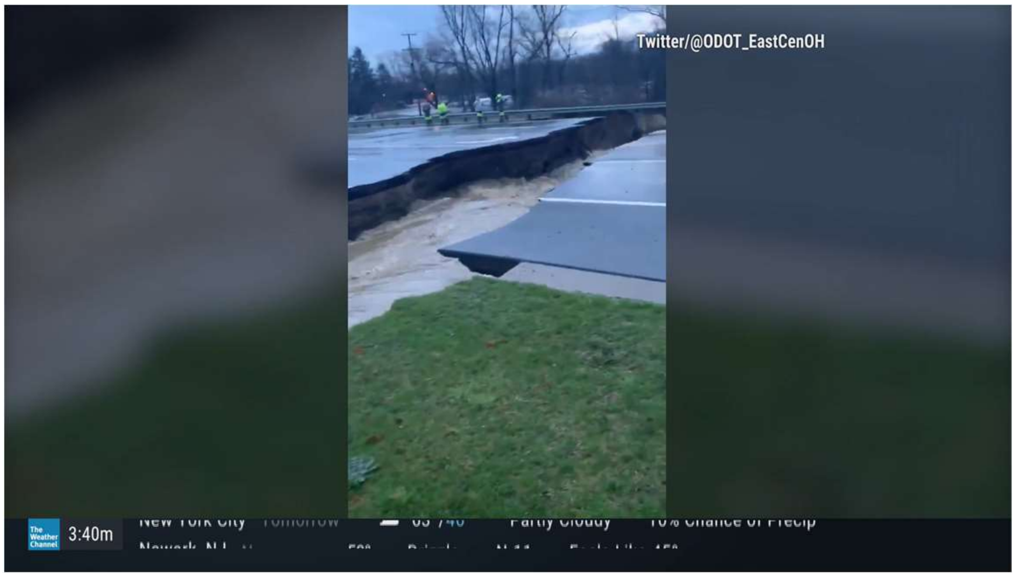

**Flooding is the most common, and most expensive climate related hazard**

Source:
https://ourworldindata.org/natural-disasters#
EMDAT (2020): OFDA/CRED International Disaster Database, Université catholique de Louvain – Brussels – Belgium

# WITH FLOODING OF ROADS / PAVEMENTS, NEED TO DISTINGUISH BETWEEN INUNDATION AND WASHOUT IMPACTS

**In the USA, 2M miles of road (25%) are at risk for flooding***

## Washout




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

**While Dramatic, its also isolated**

## Inundation


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

**Not dramatic, but widespread**

* Source: The 3rd National Risk Assessment: Infrastructure on the Brink , First Street Foundation, Oct 2021
https://assets.firststreet.org/uploads/2021/09/The-3rd-National-Risk-Assessment-Infrastructure-on-the-Brink.pdf

# THERE ARE 3 DIFFERENT FLOODING TYPES OF FLOODING EVENTS

**Riverine & pluvial flooding**


St. Louis, MO 2015

Nebraska 2018

**At one point, Nebraska DOT had 1,500 road miles closed**

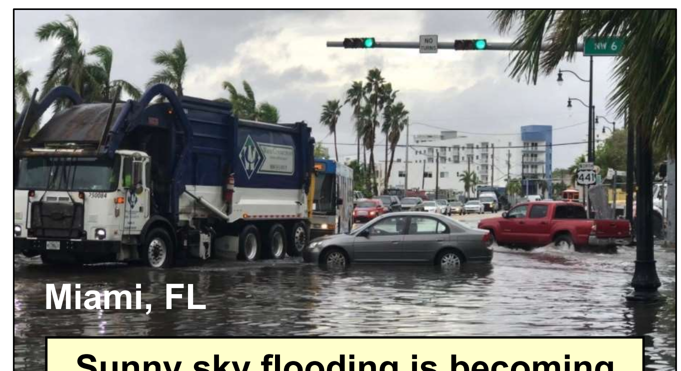
**Hurricanes, typhoons & storms**

I-40 Pender County
4-Days post Hurricane
Florence (2018)

**With Hurricane Florence, NC had over 2500 road closures**

**Sea-level rise & tidal floods**

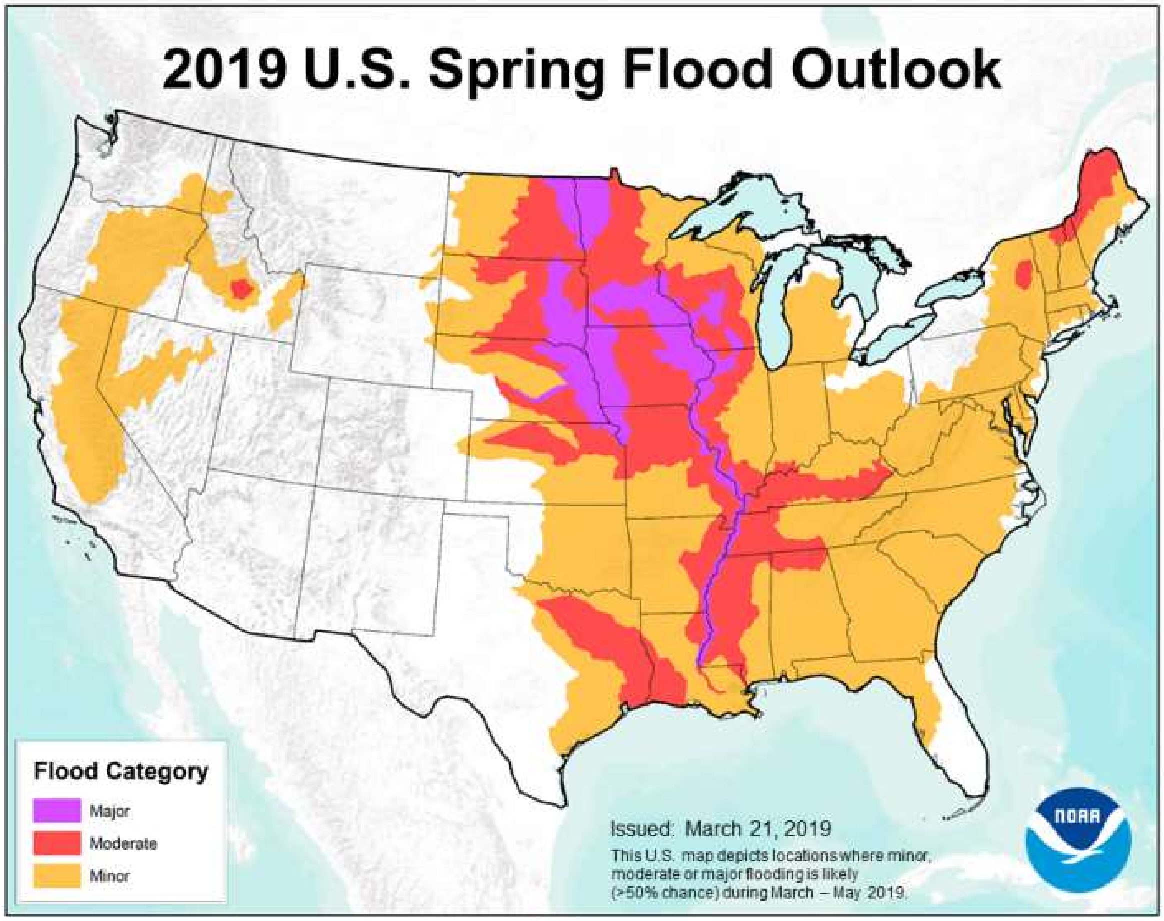
SR54 East of Fenwick, DE



Miami, FL

**Sunny sky flooding is becoming a common or daily occurrence**

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



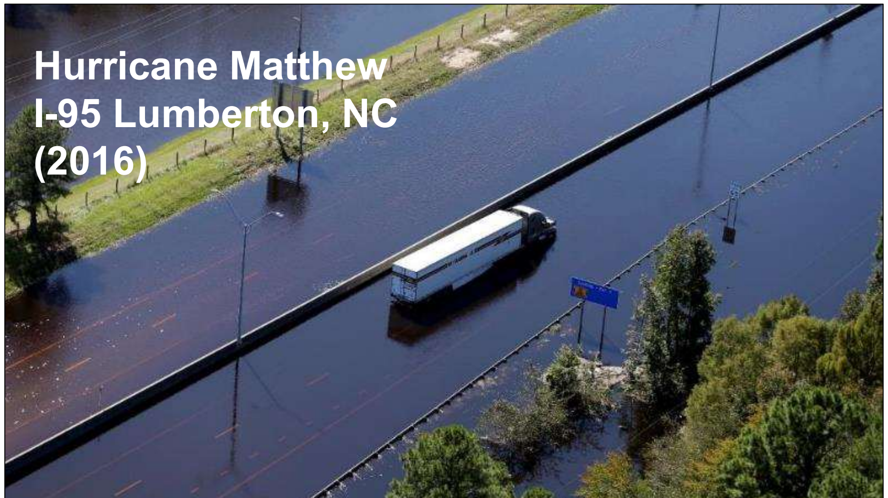


# RIVER FLOODING WAS ESPECIALLY DESTRUCTIVE IN GERMANY AND BELGIUM THIS PAST YEAR



# THE PRIMARY ISSUE WITH HURRICANE FLOODING IS INUNDATION

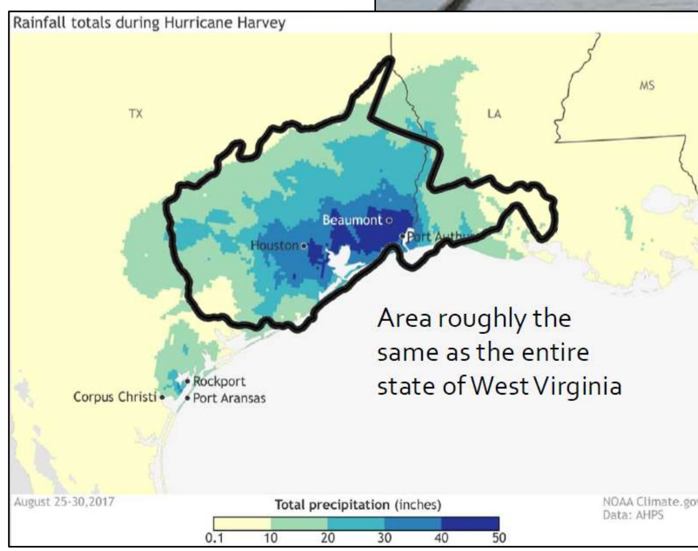
**Though washout can occur with swollen rivers and steams**



Hurricane Matthew
I-95 Lumberton, NC
(2016)

Hurricane Sally
Pensacola, FL (2020)

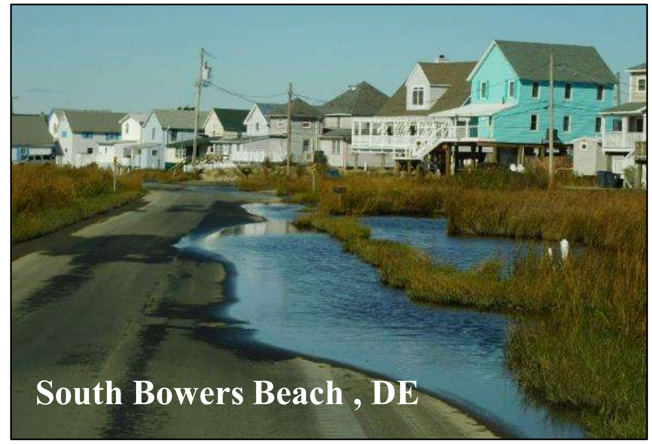
Hurricane Harvey
Houston, Texas
(2017)



# SEA LEVEL RISE IS ALREADY IMPACTING COASTAL ZONES

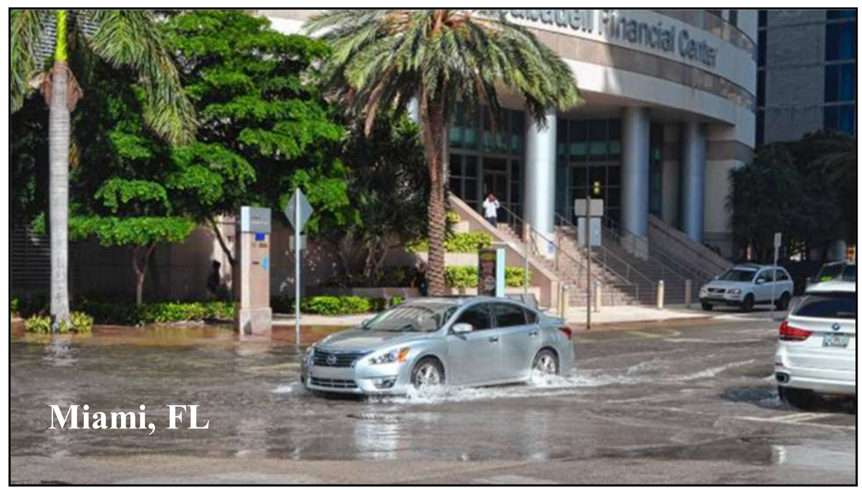
## "Sunny sky" inundation flooding is becoming a common

SR54 East of Fenwick, DE



South Bowers Beach , DE

Miami, FL



Miami, FL

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

# ADDRESSING RESILIENCY AND THE ENVIRONMENT

1 **Framework to building resiliency**

- **The ability … to resist, absorb, accommodate, and recover from the effects of a hazard in a timely and efficient manner**

2 **Apply Resiliency Planning Fundamentals to:**

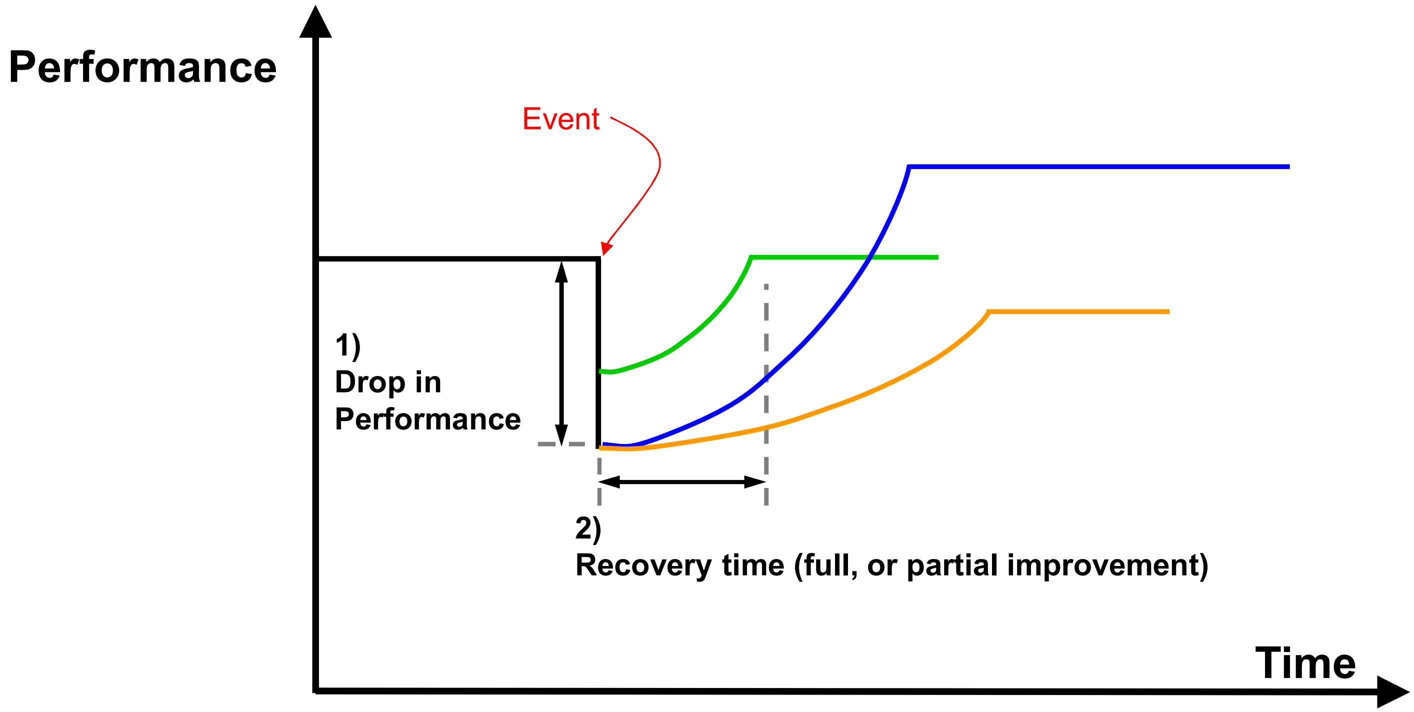
1. **Prevent: stop a … manmade or natural disasters**
2. **Protect: secure against …manmade or natural disasters**
3. **Mitigate: reduce …. by lessening the impact of disasters**
4. Respond: … meet basic human needs after an incident
5. Recover: …assist communities affected by an incident to recover effectively`

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

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

# INTRODUCTION TO RESILIENCE

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




**Green is more resilient than Orange**

- **Lower drop in Service**
- **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.

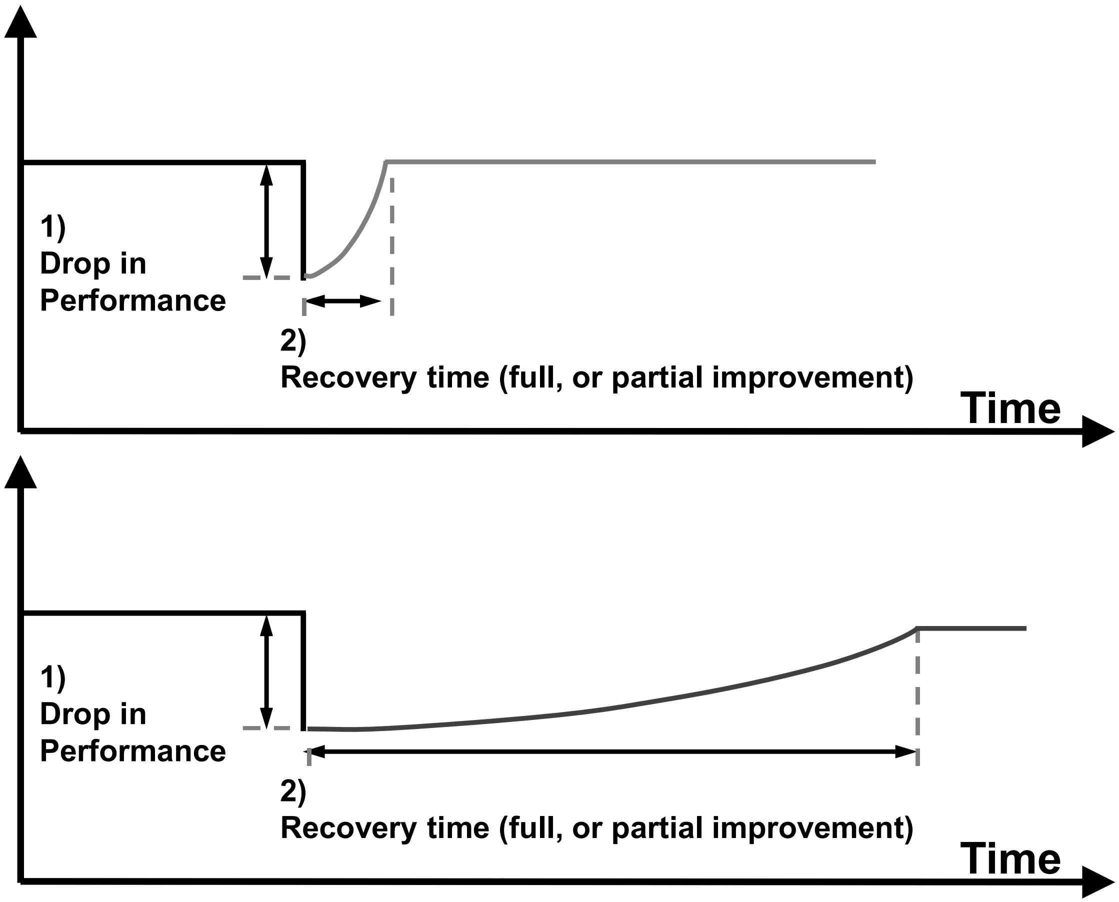
# A KEY QUESTION WITH RESILIENCE IS "WHAT IS PERFORMANCE?"
## Performance means different things to different people

**Functional Performance**

Is the road/pavement open to emergency vehicles or the general public

**Structural Performance**

Is the road/pavement able to carry its intended traffic




**Functional Resilience for pavements is easy to see and often relatively quick**

**Structural Resilience for pavements is often hidden and may take years to recover**

1. *FHWA Order 5520: Transportation System Preparedness and Resilience to Climate Change and Extreme Weather Events*
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# PAVEMENT DAMAGE COMES FROM 2 DIFFERENT SOURCES / TIMES

## Impact Types / Timing

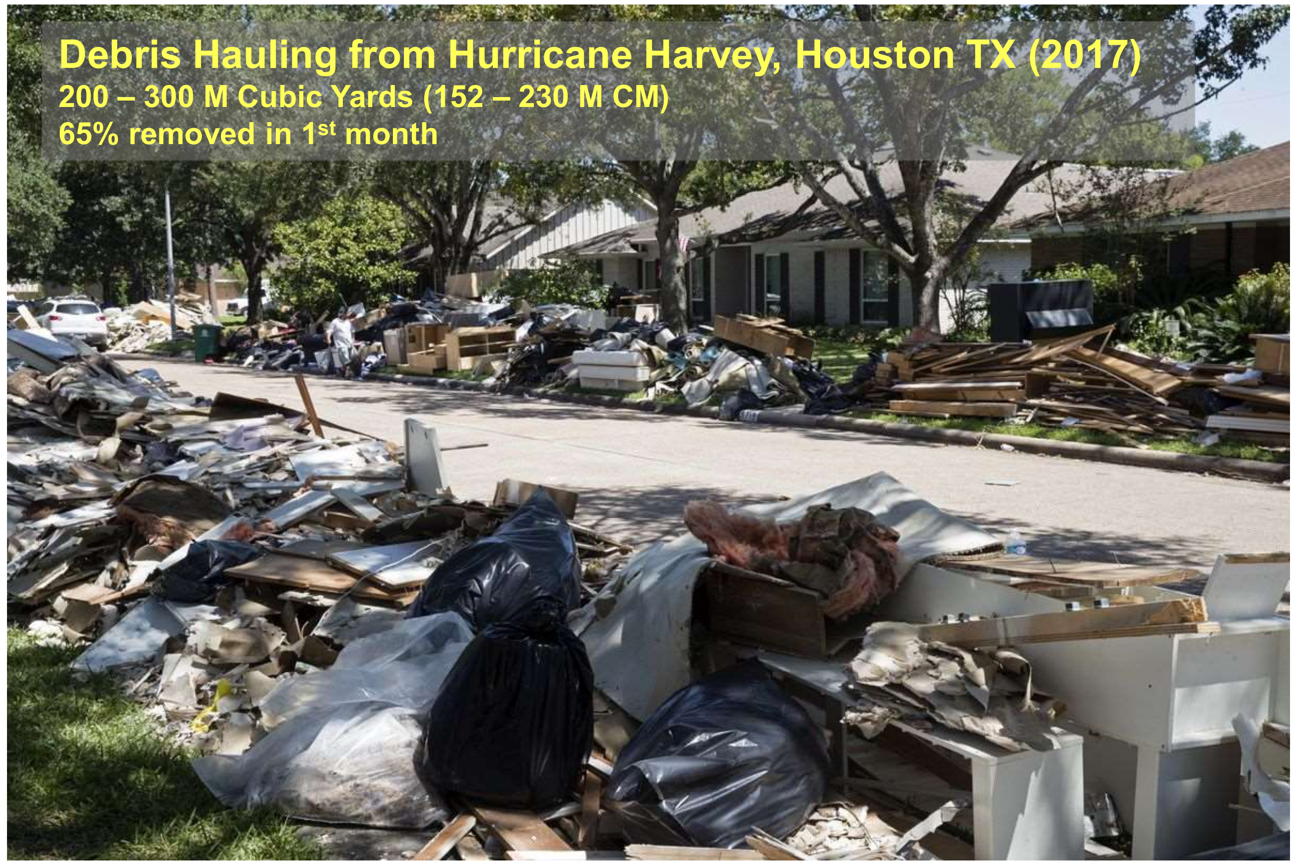
1. **Primary / Direct Impacts – alters the pavement structural or functional capabilities (Immediate Use)**

2. **Secondary / Indirect Impacts – Impacts due to loading / recovery activities over the long term while in a weakened state**
   - **Rescue and Emergency response during the disaster**
   - **Recovery activities (clean up and rebuilding) after the disaster**
   - **Normal Activities**

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

# SECONDARY IMPACTS OCCUR WHEN RELIEF AND RESCUE EFFORTS TAKE PLACE

**Hurricane Florence (2018)**



**Debris Hauling from Hurricane Harvey, Houston TX (2017)**

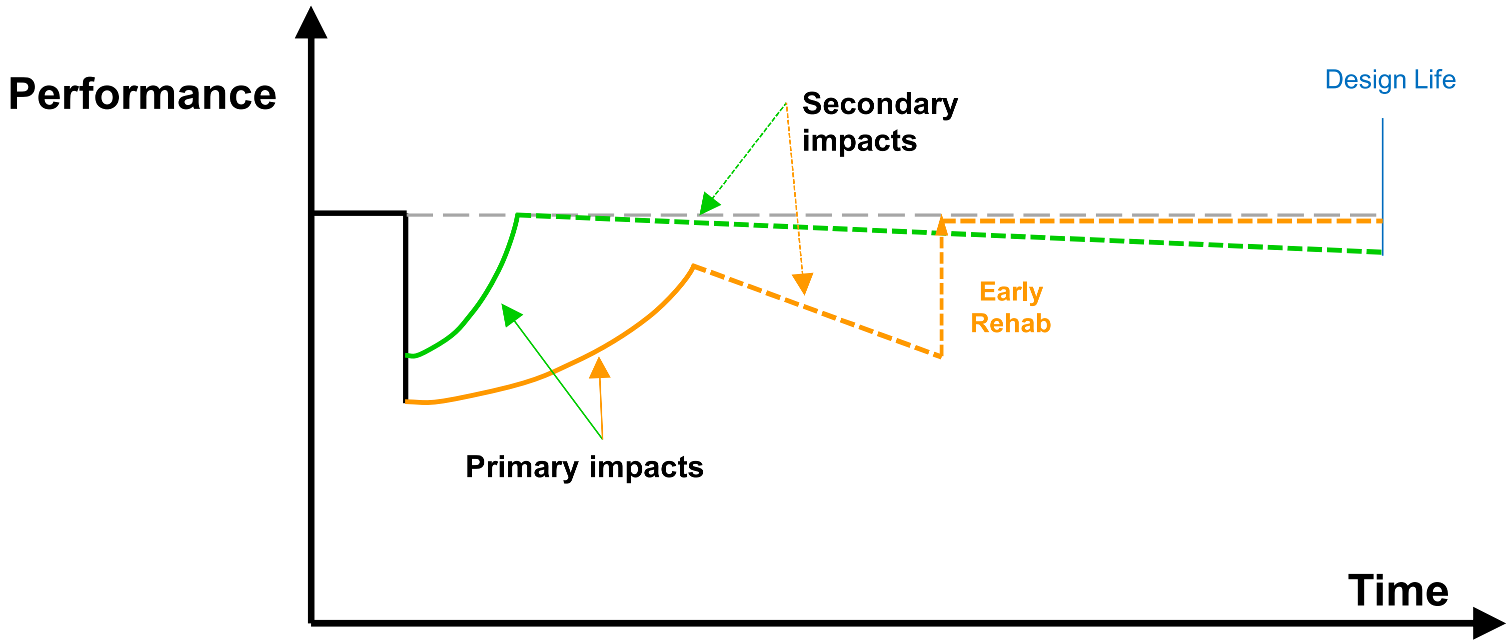
**200 – 300 M Cubic Yards (152 – 230 M CM)**

**65% removed in 1st month**

**Loading occurs both during the crisis and long after**

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

**Additional loading (& weakened pavement) can lead to early rehabilitation needs**




**Green is more resilient than Orange**

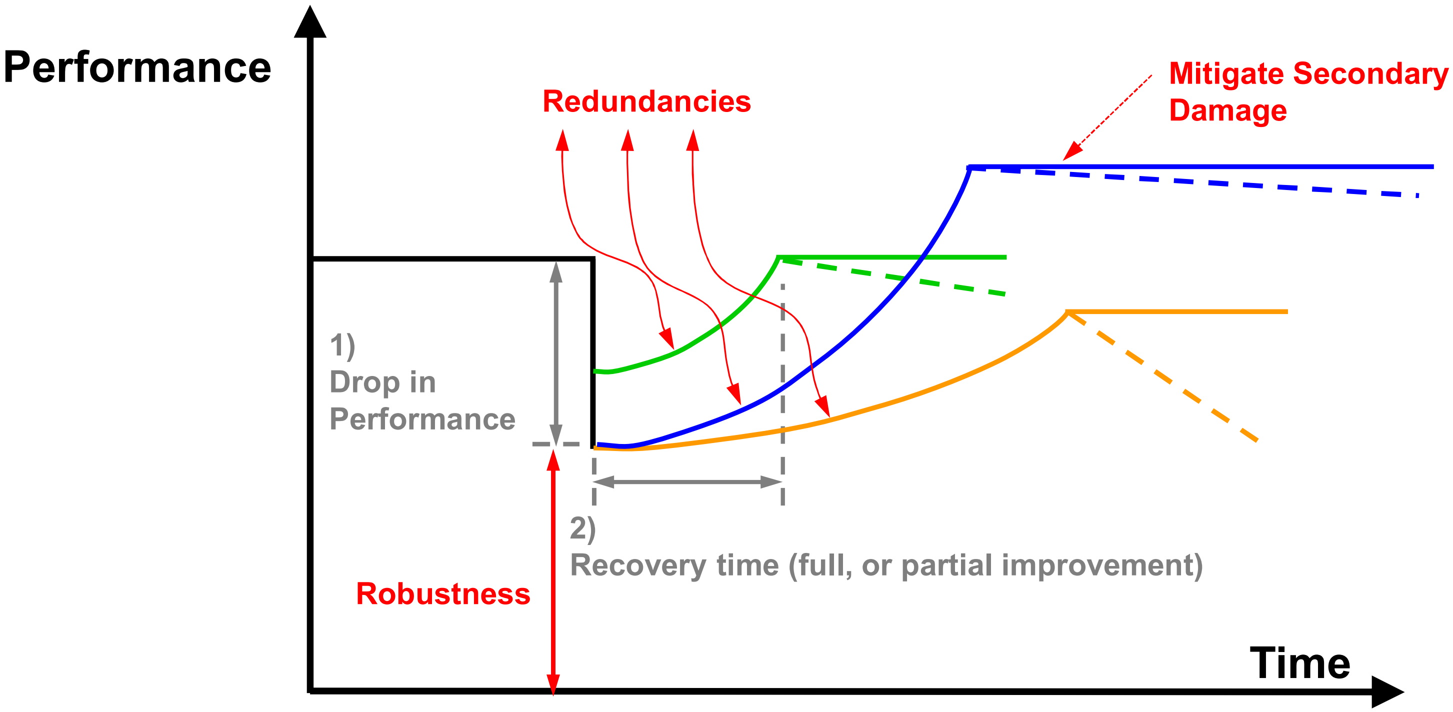
- **Less Drop in Service**
- **Faster recovery time**
- **Higher level of service**

- **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 loading while in a weakened state (emergency & recovery activities)**

# TO IMPROVE A SYSTEM'S (i.e. PAVEMENT) RESILIENCE




**Improve Robustness –**
- Decrease the drop in performance

**Increase Redundancies –**
- Add extra elements in case of failure in other elements

**Mitigate Secondary damage –**
- Improve / use better designs

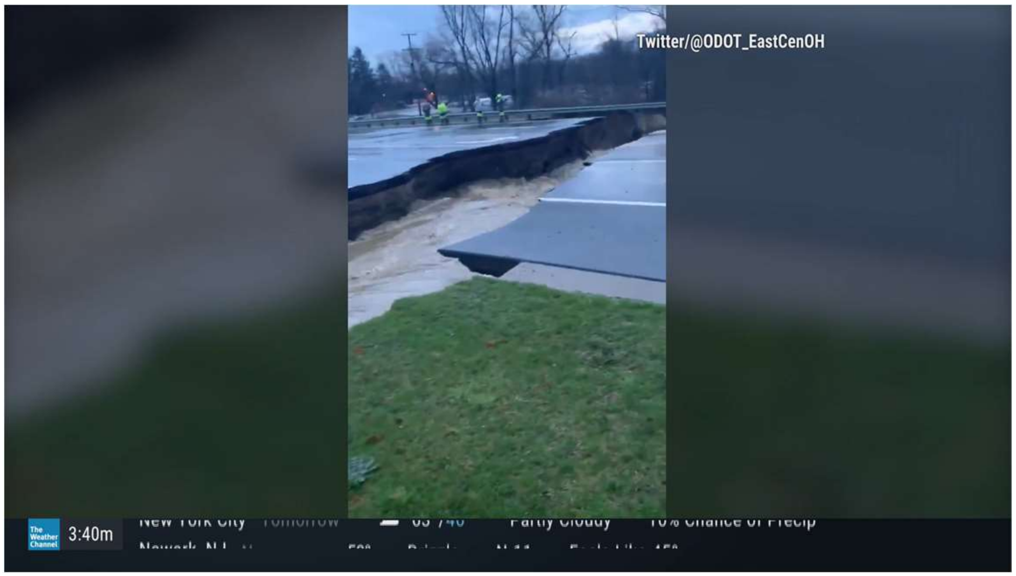
**Developing resilient system requires an understanding the vulnerability caused for each climate hazards**

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.

# WITH FLOODING OF ROADS / PAVEMENTS, NEED TO DISTINGUISH BETWEEN INUNDATION AND WASHOUT IMPACTS

**In the USA, 2M miles of road (25%) are at risk for flooding***

## Washout




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

**Pavement type has little impact**

## Inundation

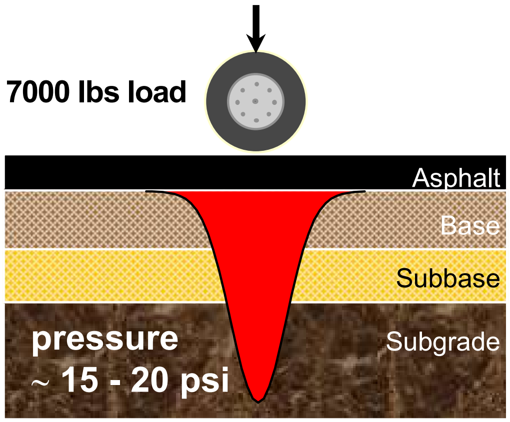

**The rise of water that submerges the pavement. No rapid flow or current**

**Pavement type does have an impact**

* Source: The 3rd National Risk Assessment: Infrastructure on the Brink , First Street Foundation, Oct 2021
https://assets.firststreet.org/uploads/2021/09/The-3rd-National-Risk-Assessment-Infrastructure-on-the-Brink.pdf

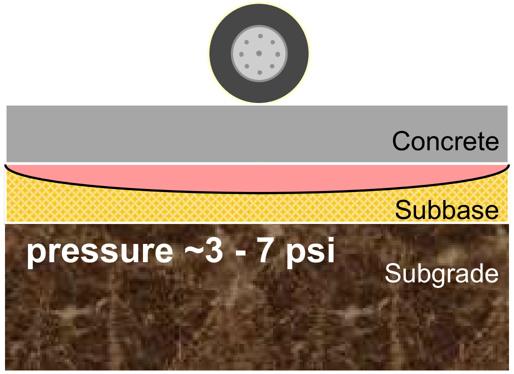
# CONCRETE & ASPHALT PAVEMENTS CARRY LOADS DIFFERENTLY

**Pavements are designed for optimum moisture conditions and optimum density**




## 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**



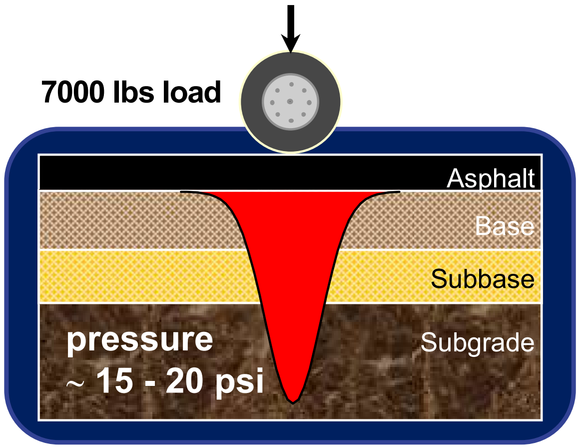

## Concrete Pavements are Rigid

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

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

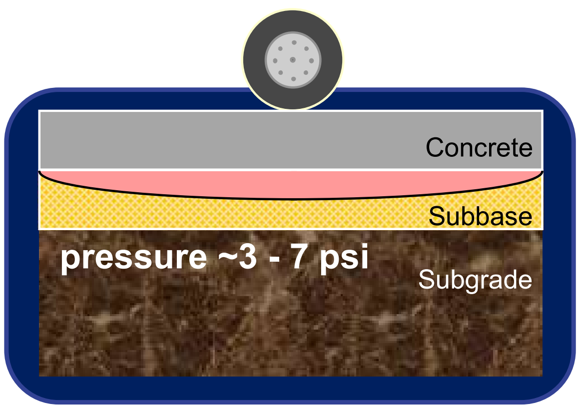
# FLOODING CAUSES THE SUBGRADE TO BECOME SUPERSATURATED

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




## Asphalt Pavements are Flexible

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



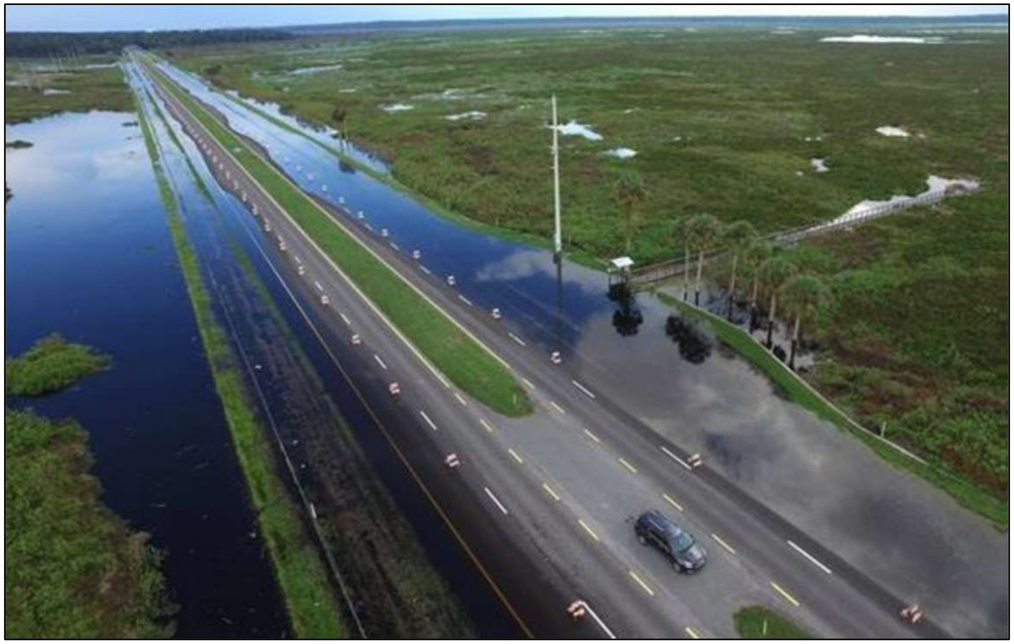

## Concrete Pavements are Rigid

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

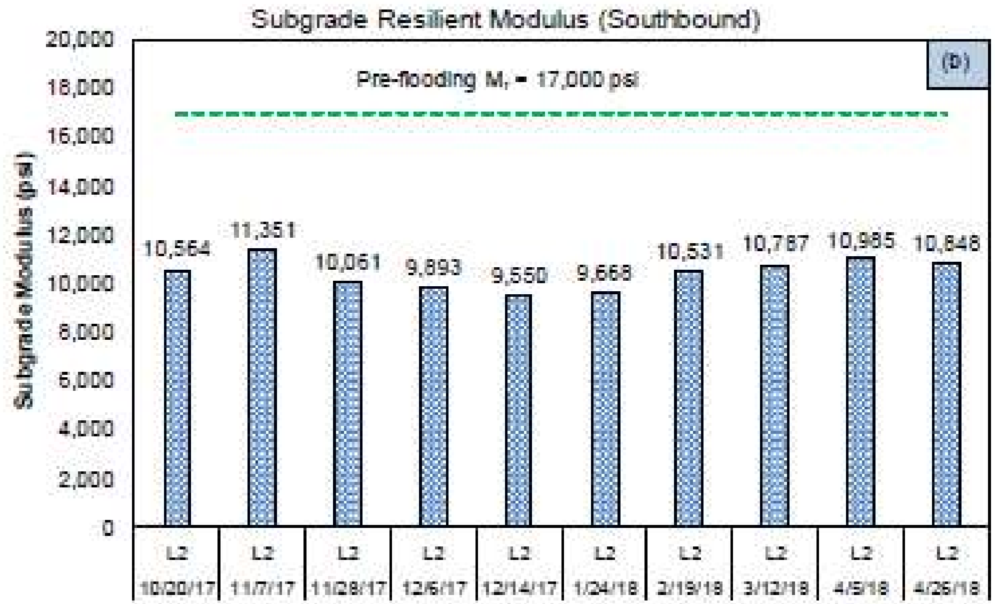
**Flooding does not impact the concrete's load carrying capacity to the same degree as asphalt's**

# ASPHALT PAVEMENTS IN FLORIDA DID NOT RECOVER STRENGTH

## Even after the flood waters recede, the asphalt 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**

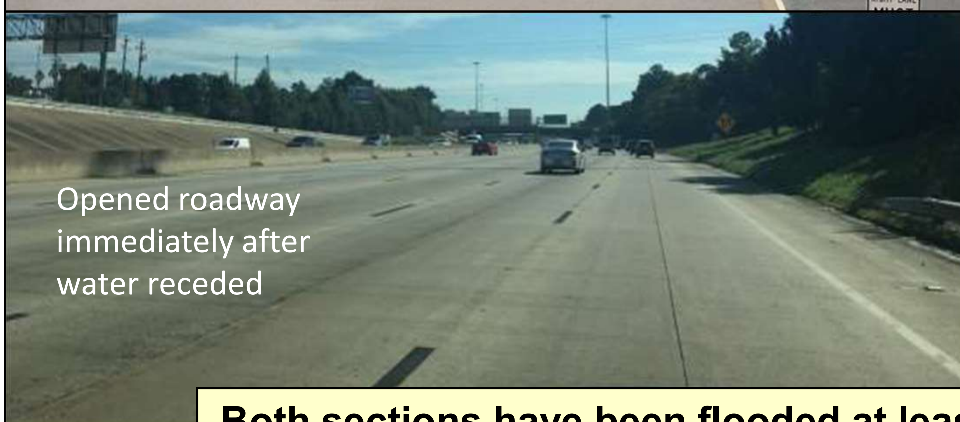
Sources:

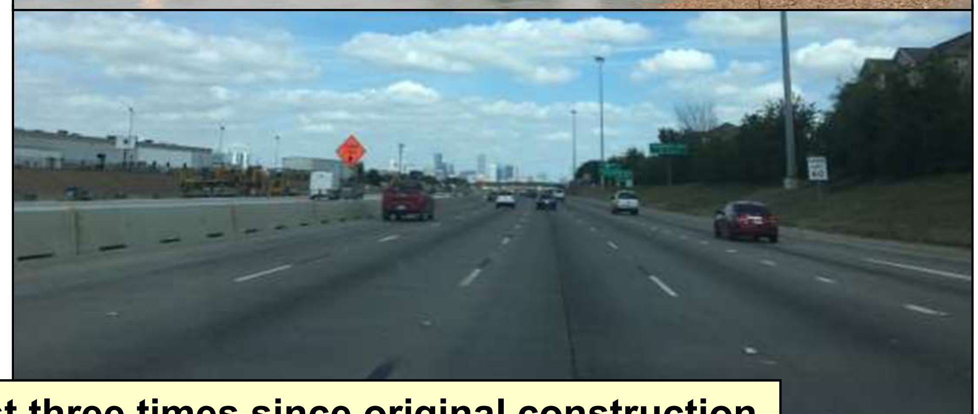
1. Decision Support Criteria for Flood Inundated Roadways: A Case Study, A. Gundla, Ph.D., E. Offei, Ph.D. G. Wang, Ph.D., P.E. C.Holzschuher, P.E. and B. Choubane, Ph.D., P.E., Presented at the 2020 TRB Annual Mtg

# PAVEMENTS IN HOUSTON ARE CONCRETE & ARE VERY "STIFF"

## Also have cement treated bases & stabilized subgrades





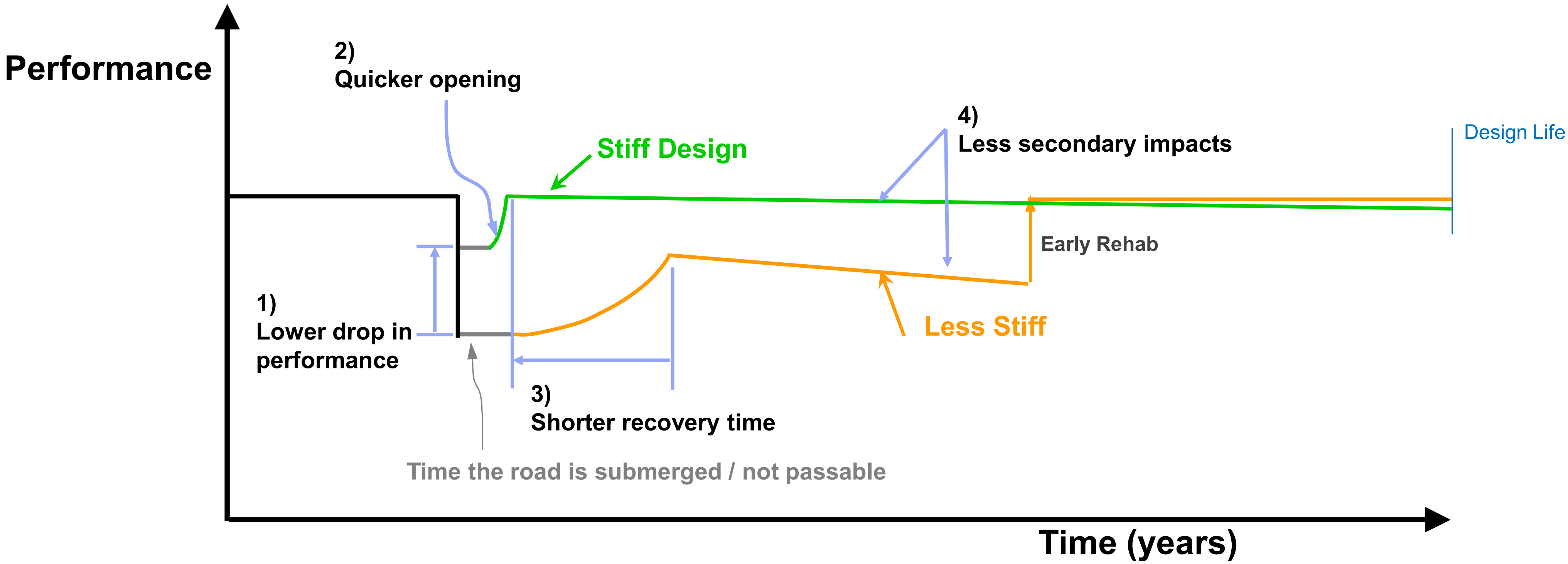
**Both sections have been flooded at least three times since original construction and were immediately opened to traffic as soon as water receded**

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

# STIFFER PAVEMENTS ARE MORE RESILIENT TO FLOODING

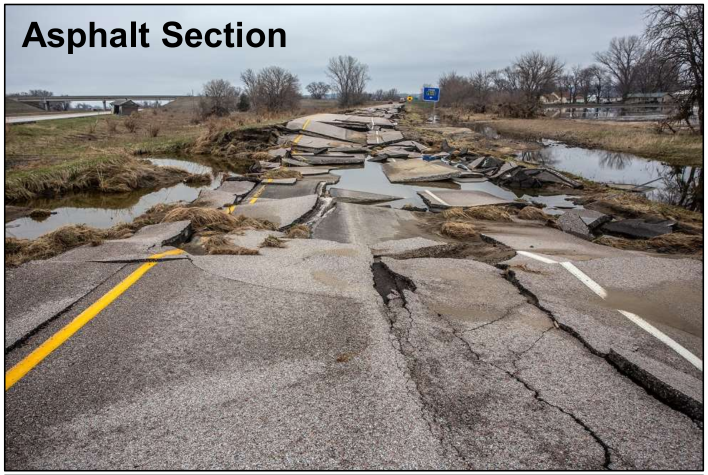
## (less damage to the subgrade / base)




**Stiffer Pavement Systems are less impacted by subgrade strength loss and recover faster**
**(stiffer = concrete, stabilized bases, increased asphalt thickness, modified "Design Standards" )**

# WHILE STIFFER SYSTEMS DO NOT ALWAYS PREVENT WASHOUT DAMAGE

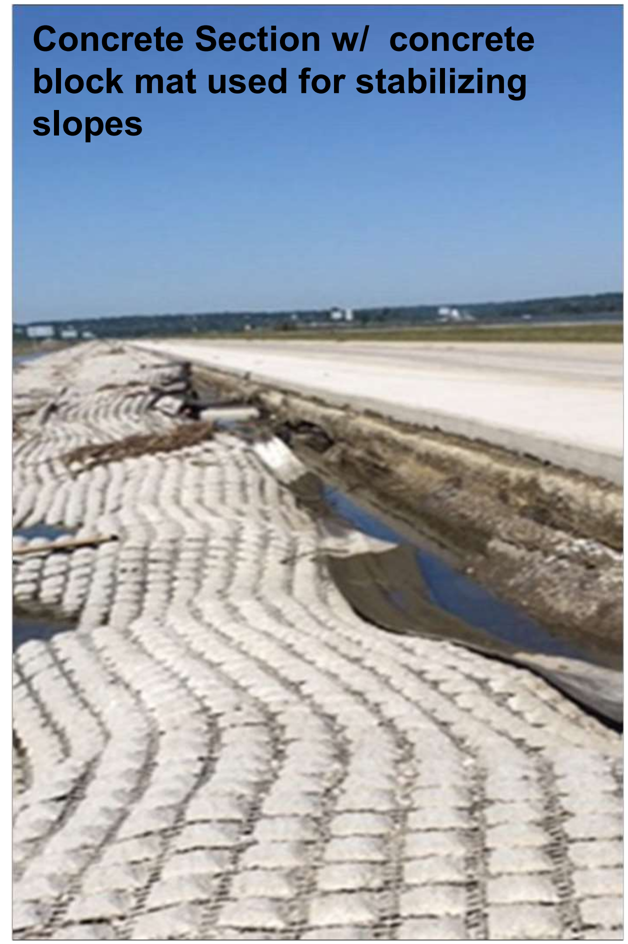
## Stiffer pavement systems do tend to perform better



Asphalt Section

Concrete Section

Concrete Section w/ Concrete shoulder



Concrete Section w/ concrete block mat used for stabilizing slopes

Western Iowa, to Missouri River Flooding – 2015 & 2019

# MODIFY DESIGN STANDARDS TO "STIFFEN" THE PAVEMENT SYSTEM

## Base the Design on a flooded / 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

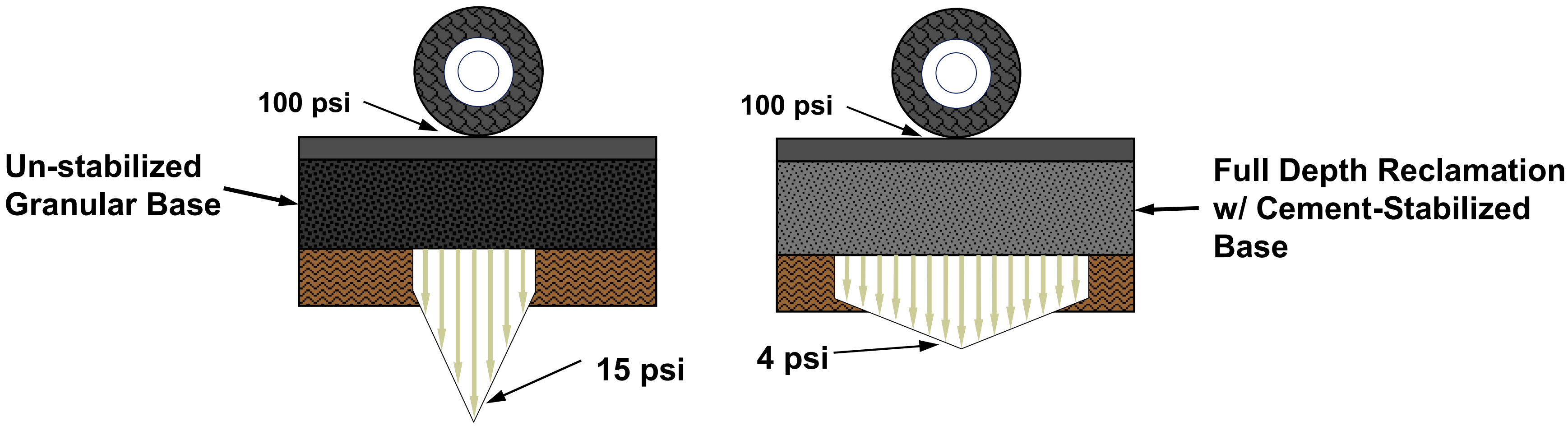
| Median annual rainfall (mm) | Specimen compaction moisture content | Testing condition | |
|---|---|---|---|
| | | Excellent to good drainage | Fair to poor drainage |
| < 600 | OMC | Unsoaked | 4-day soak |
| 600 – 800 | OMC | 4-day soak | 10-day soak |
| > 800 | OMC | 10-day soak | 10-day soak |

OMC = Optimum Moisture Content

**Almost All Pavement Designs in Australia are based on soaked (lowered strength) subgrade conditions**

# STABILIZE THE BASE SYSTEM

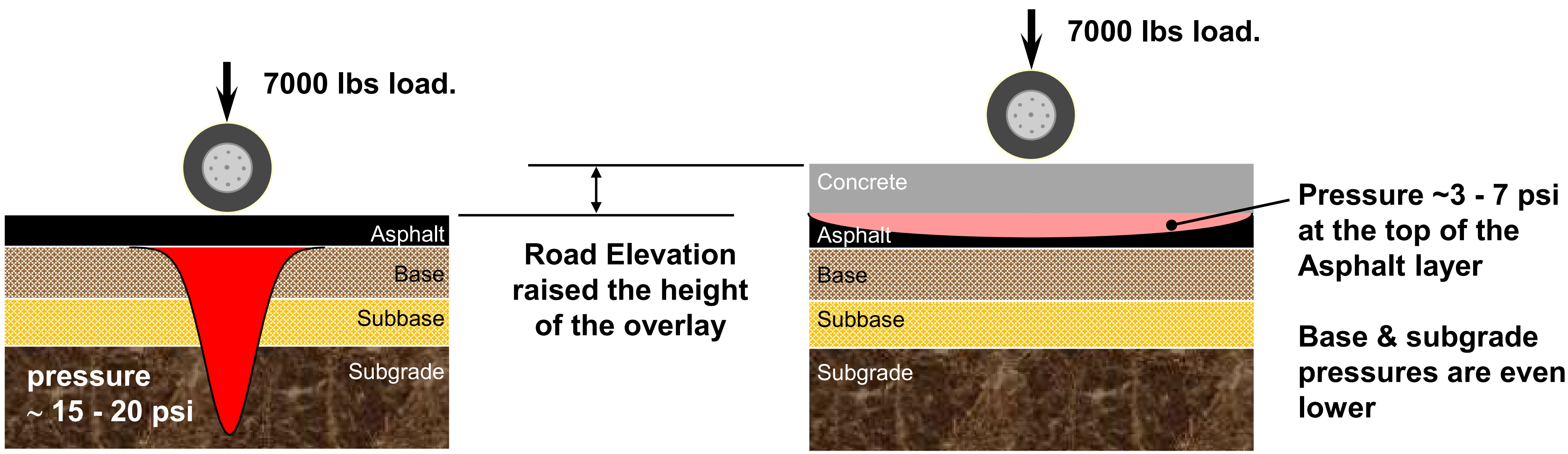
**Use stabilization techniques to increase rigidity, reduces permeability, & reduces moisture susceptibility**




**Stabilization with Cement strengthens the base the stresses on the lower layers**
**(also reduces the impact of moisture)**

# STIFFEN THE SURFACE LAYER

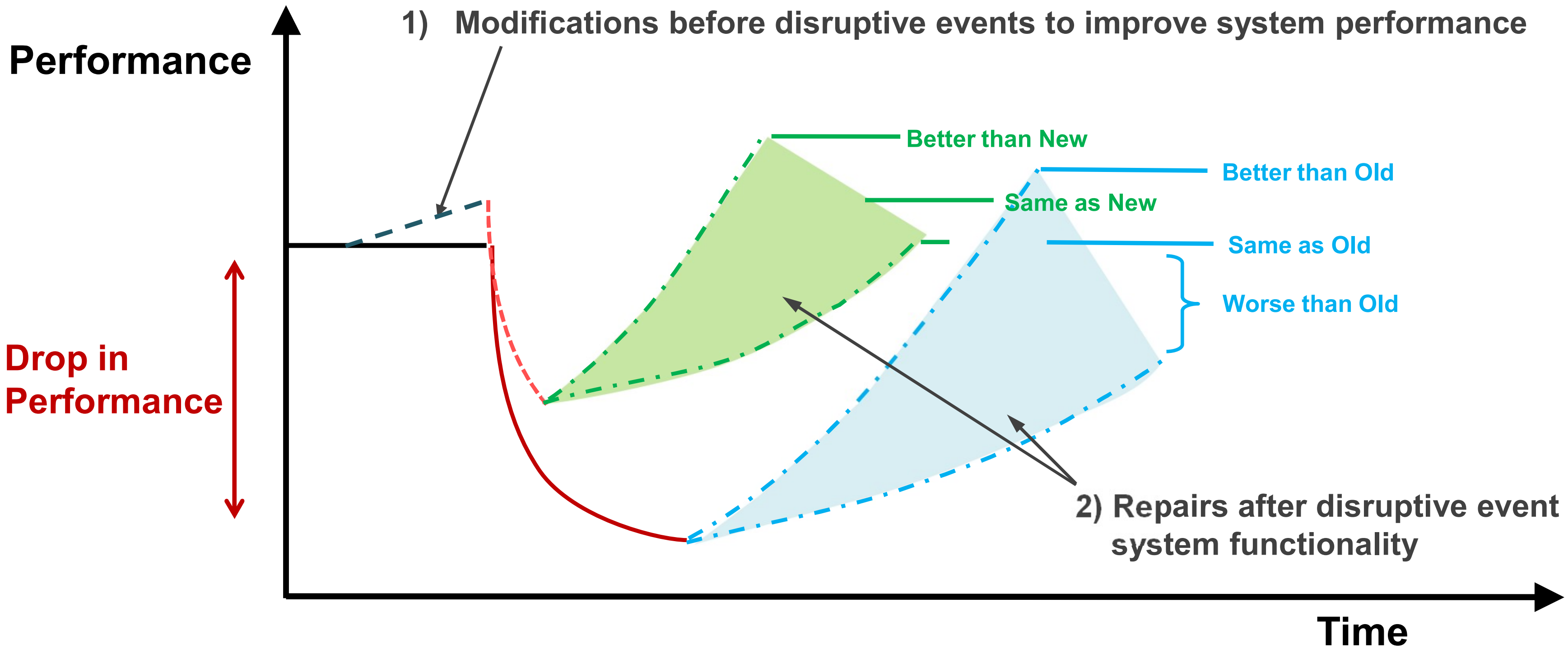
**Concrete overlays raise elevation & change how loads are delivered to the underlying layers**




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

# 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**




**Agencies must monitor their road network and upgrade their systems to minimize future damage**

Adapted from Bruneau (2003); McDaniels (2008); and Kurth et al (2018)

# SUMMARY

1. **We recognize the need to make our infrastructure "Resilient"**
   - **Flooding is the biggest "climate risk" to pavement systems**
   - **Must account for both Primary and Secondary impacts**

2. **Specific actions to consider to increase a pavement's flooding resilience**
   - **Use Stiffer or stiffen the existing pavement**
   - **Require new pavement designs to be based on <u>Lowered</u> Subgrade Strength**
   - **For existing roads, two viable & low costs as mitigation / hardening strategies that can be used are:**
     - **Concrete Overlays**
     - **Full Depth Reclamation (FDR) with cement**

# Thank You
## & Any Questions?

**Jim Mack, P.E.**
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# Selected References


1. Gaspard, K., Martinez, M., Zhang, Z., and Wu, Z., (2007) “Impact of Hurricane Katrina on Roadways in the New Orleans Area,” Technical Assistance Report No. 07-2TA, Louisiana Transportation Research Center.
2. Khan, M., Mesbah, M., Ferreira, L., and Williams, D., (2017) “Estimating Pavement’s Flood Resilience,” Journal of Transportation Engineering, Part B: Pavements.
3. 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
4. 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
5. Lu, D., Tighe, S., and Xie, W., (2018) “Impact of Flood Hazards on Pavement Performance,” International Journal of Pavement Engineering, 21(6), 746-752.
6. Oyediji, R., Lu, D., and Tighe, S., (2021) “Impact of Flooding and Inundation on Concrete Pavement Performance,” International Journal of Pavement Engineering, 22 (11), 1363-1375.
7. Mack, J., (2020) “Improving Pavement Resiliency and Disaster Recovery,” Presentation for the National Concrete Pavement Technology Center.