Resilience-Based Geotechnical Asset Management

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Outline

- **Resilience and its Role in Geotechnical Practice**
- Design Philosophy
- Load and Resistance During Asset Life
- Resilience Assessment During Asset Management
- Concluding Remarks and Future Directions

Why Resilience-Based Design?

- Increasing numbers of extreme weather events are affecting assets (climate change).
- Extreme events will accelerate the deterioration of assets.
- Increased demand and vulnerability.
- Aging Infrastructure is more susceptible to damage
- Design and management of assets are becoming more integrated.

Damage occurred in many Vermont communities due to flash flooding including Ludlow

Teton Pass Mountain Highway in Wyoming

British Columbia Ministry of Transportation

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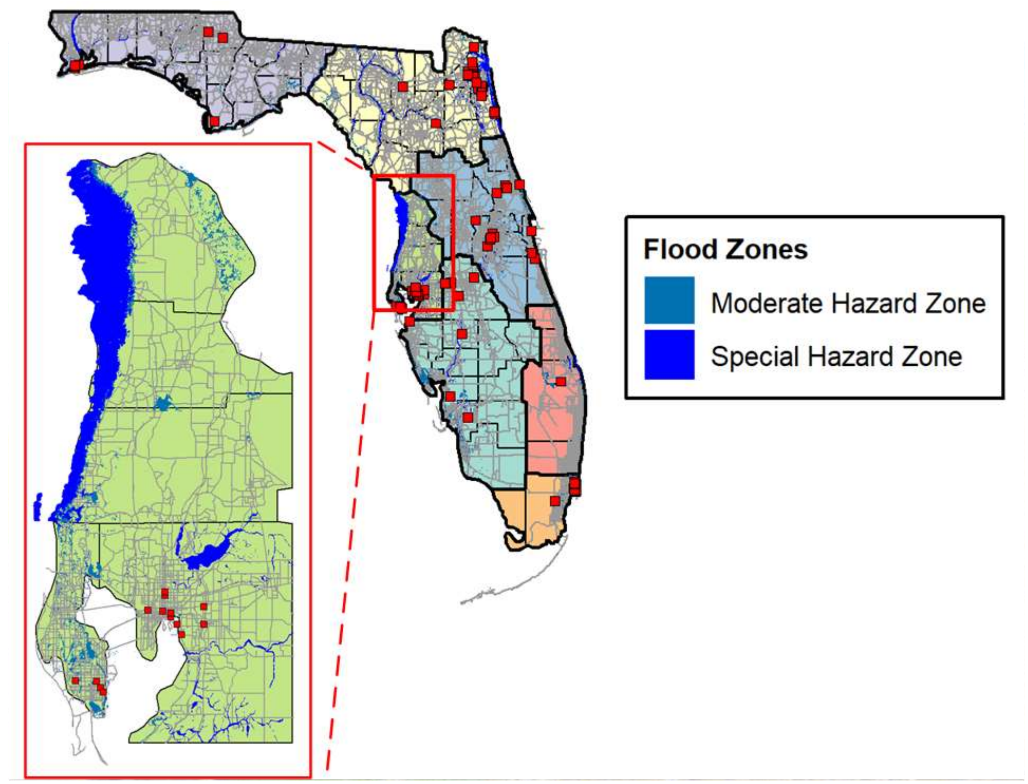
Defining Scale

- Resilience was originally developed to describe systems.
- Network resilience has different measures and requirements.
- The next level of detail is localized system (Asset) resilience.
- If we zoom in it could reach an element level.
- A grand scheme should be able to capture all levels.



FDOT Project: Improved Resilience of Rigid Pavement Systems (Hydrology ARA)
Jamal Nusairat, Slope Stabilization Using Drilled Shafts Design Methodology and Case History, DFI, 2019

Geotechnical Assets and Foundations

- Resilience of geotechnical assets is the foundation of the overall network resilience.
- Bridge Foundations are not always evaluated especially during the asset life.

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Defining Condition, Performance, and Capacity

- Condition reflects the physical condition of the asset in relation to its degradation from the newly constructed condition.
- Performance relates to the intended purpose of the asset or network and their functionality.
- Capacity is how much load (could be permanent or transient loads) can the asset withstand before reaching the service or ultimate limit states.

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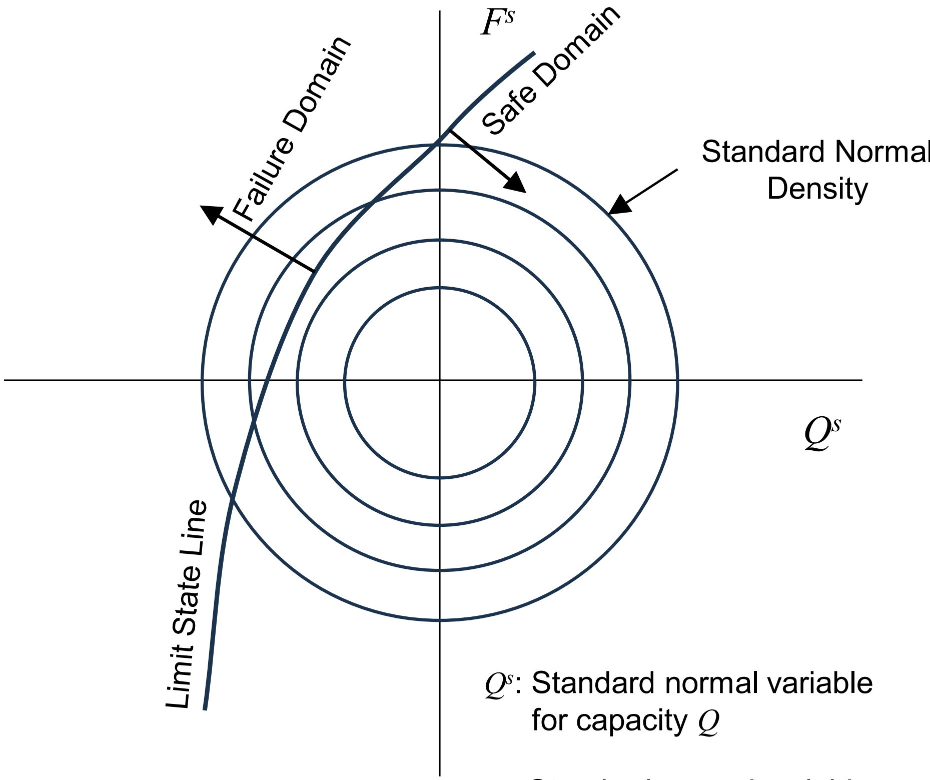
Design Objectives (Allowable Stress Design and Load and Resistance Factor Design)

- Provide acceptable performance levels to serve the intended function of the asset at a minimum feasible cost.
- In a probabilistic analysis, we translate performance requirements to limit states and assess how far the design is from the limit states under uncertainty!
- In very few cases, we think of cumulative damage, performance, and benefits.



Q^s: Standard normal variable for capacity Q

F^s: Standard normal variable for Load F

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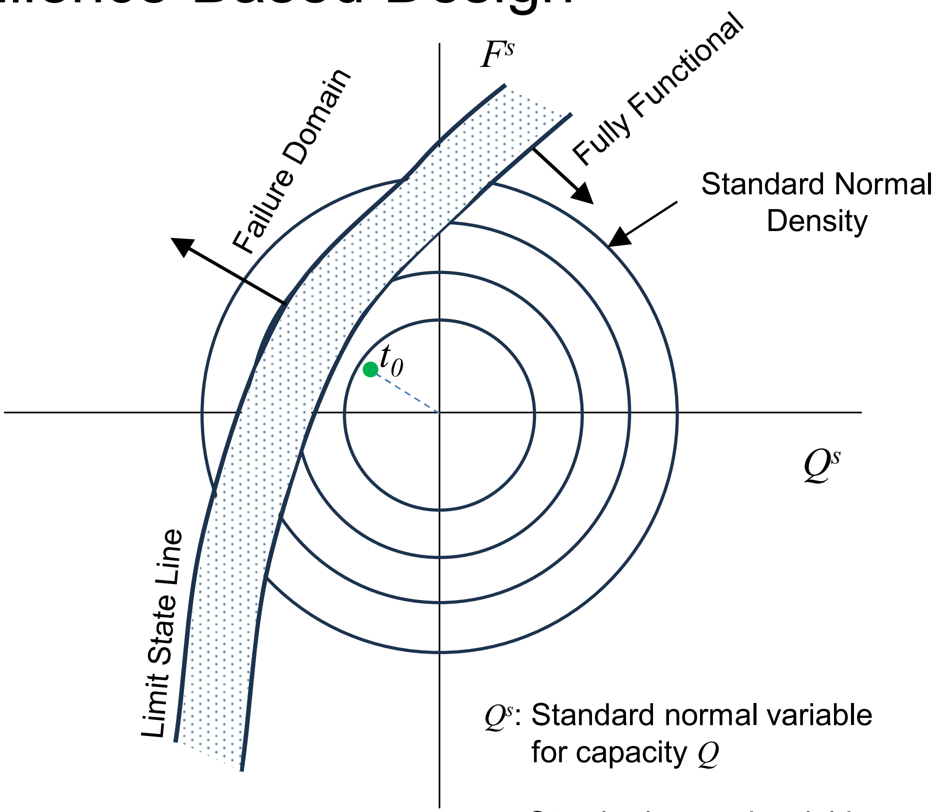
Design Objectives: Geotechnical Resilience-Based Design

- Achieve acceptable capacity levels throughout the asset life (design Life).
- Maintain acceptable asset condition, to avoid accelerated deterioration and progressive failure throughout the asset life (service life).
- Provide acceptable performance levels to serve the intended function of the asset within a network throughout the asset life (service life).
- Incorporate potential corrective activities during the asset life (service life).



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Scour Considerations in Bridge Foundation RBD

- Scour is a critical aspect in bridge foundation design under changing climate.
- We are focusing on long-term degradation and local scour.
- Scour is well-suited for RBD application since we can define cumulative damage, marginal performance, and recovery/mitigation strategies.
- The full process requires an interdisciplinary team of engineers with expertise in hydraulic, geotechnical, and structural design.

US 101 Bridge, Washington

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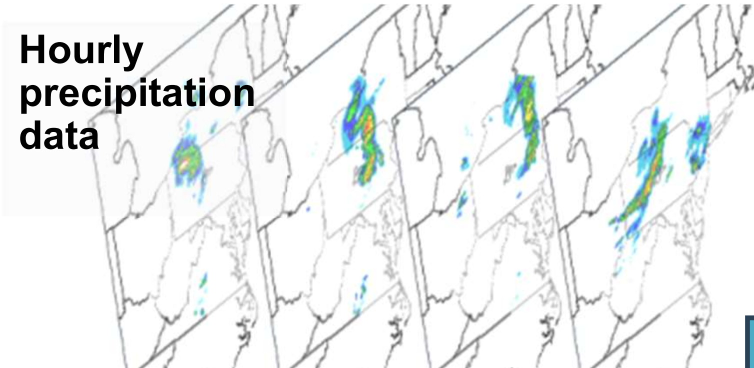
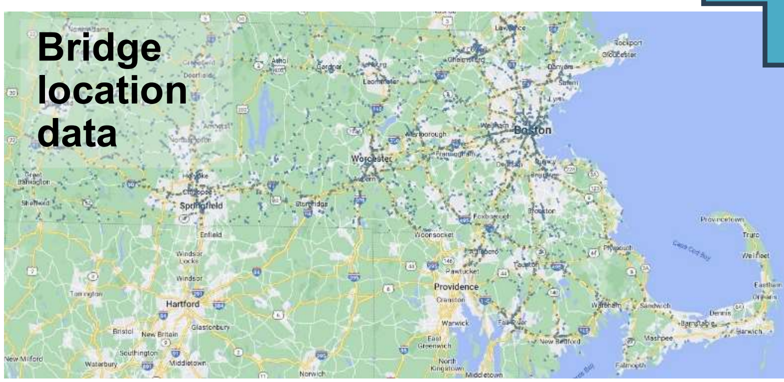
Asset Level Rainfall Analyses Exercise (ALRAE)





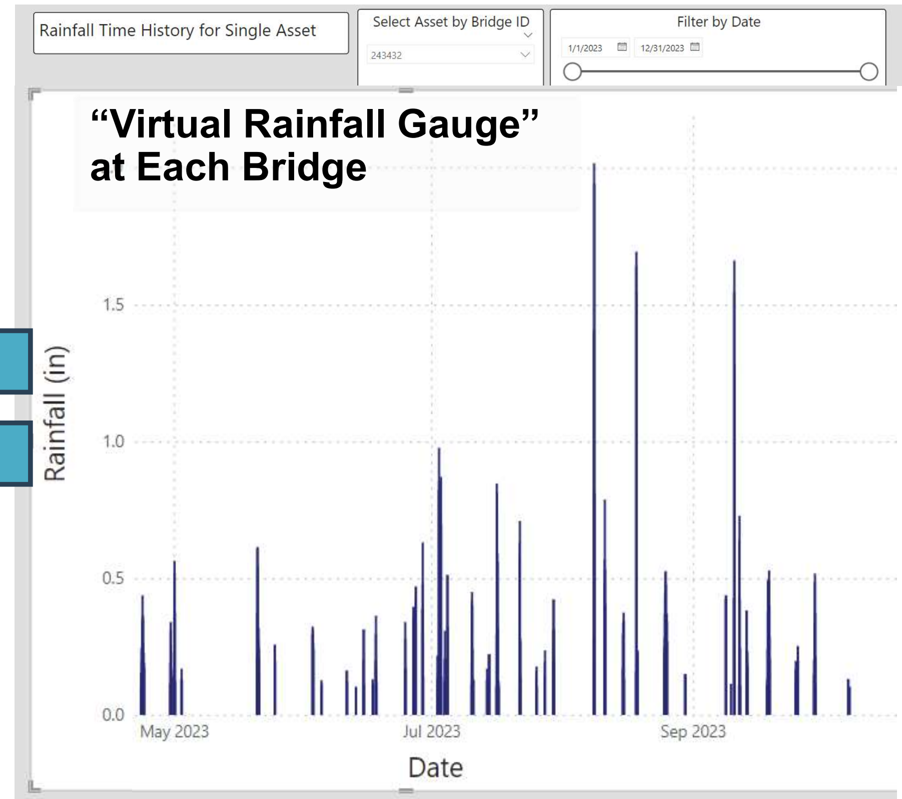
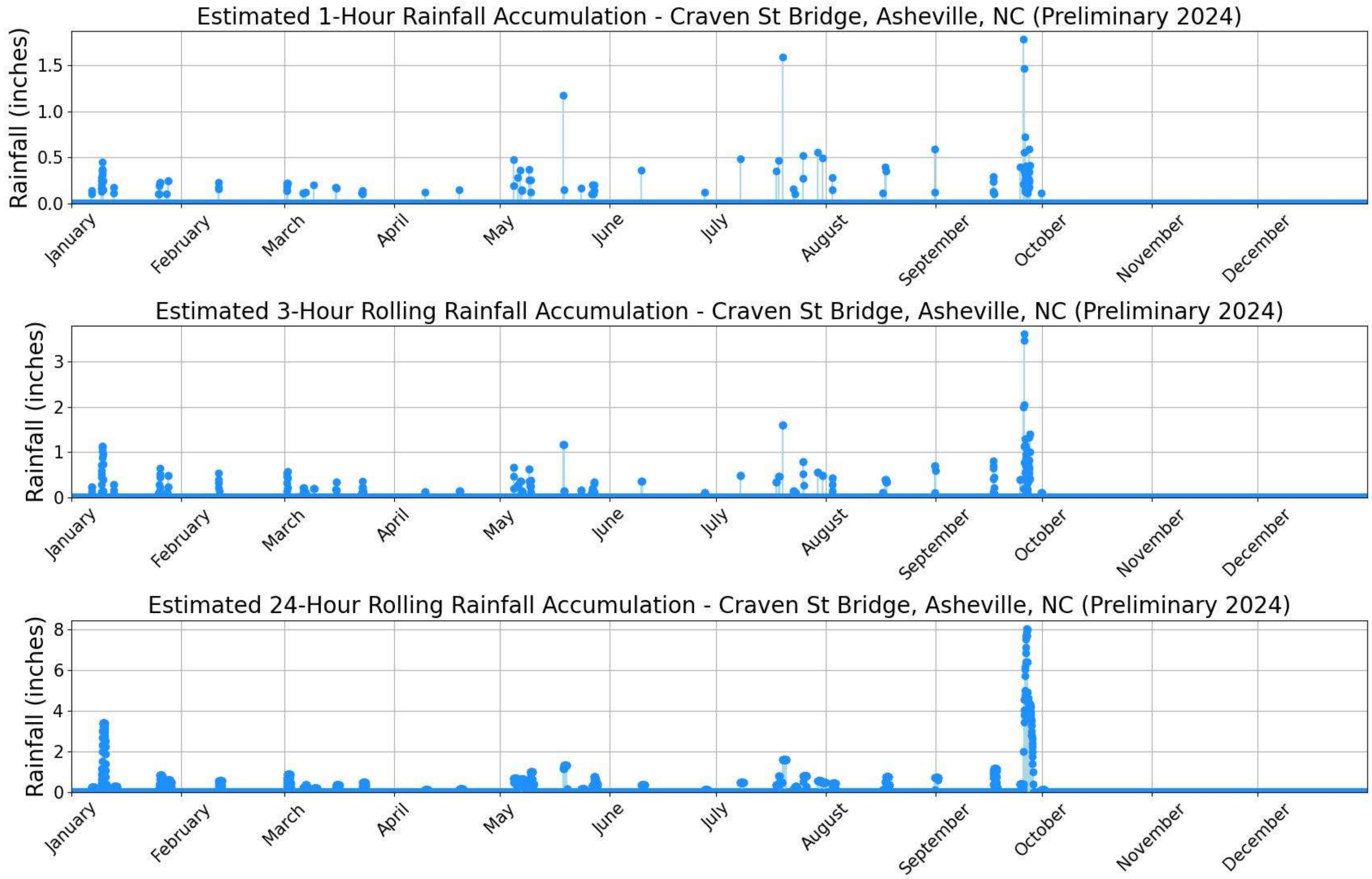


Image credit: USACE (top), InfoBridge (FHWA) (bottom)

All data and work products remain preliminary (Erik Zuker, HNTB)

Location Specific Data



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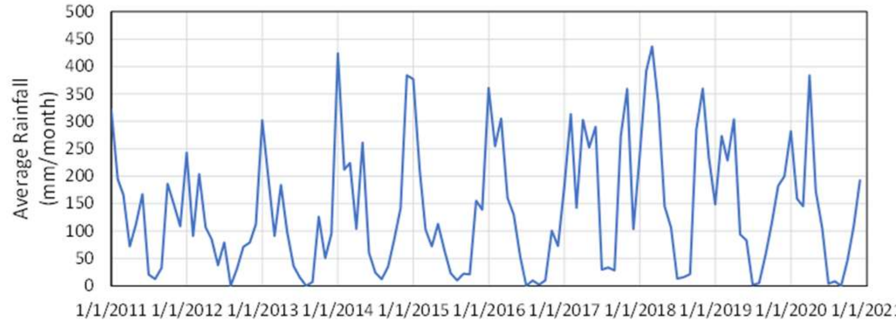
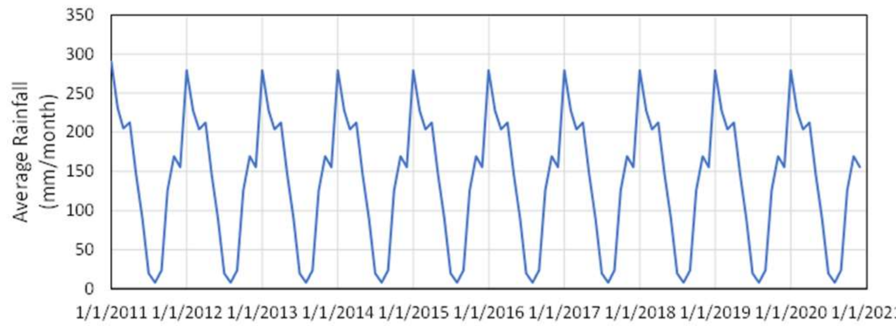
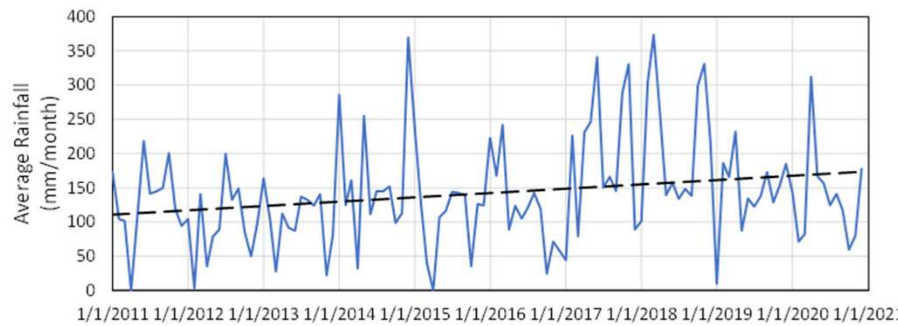
Define Disruptive Events

- Consider stochastic and non-stationary models.
- The sequence of events matters since they accumulate damage.
- The story does not end here.
- We have been looking into the past to design for the future.
- Learn from the past and forecast for the future!







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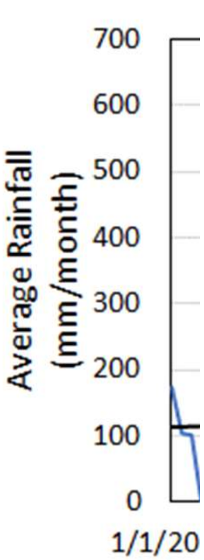
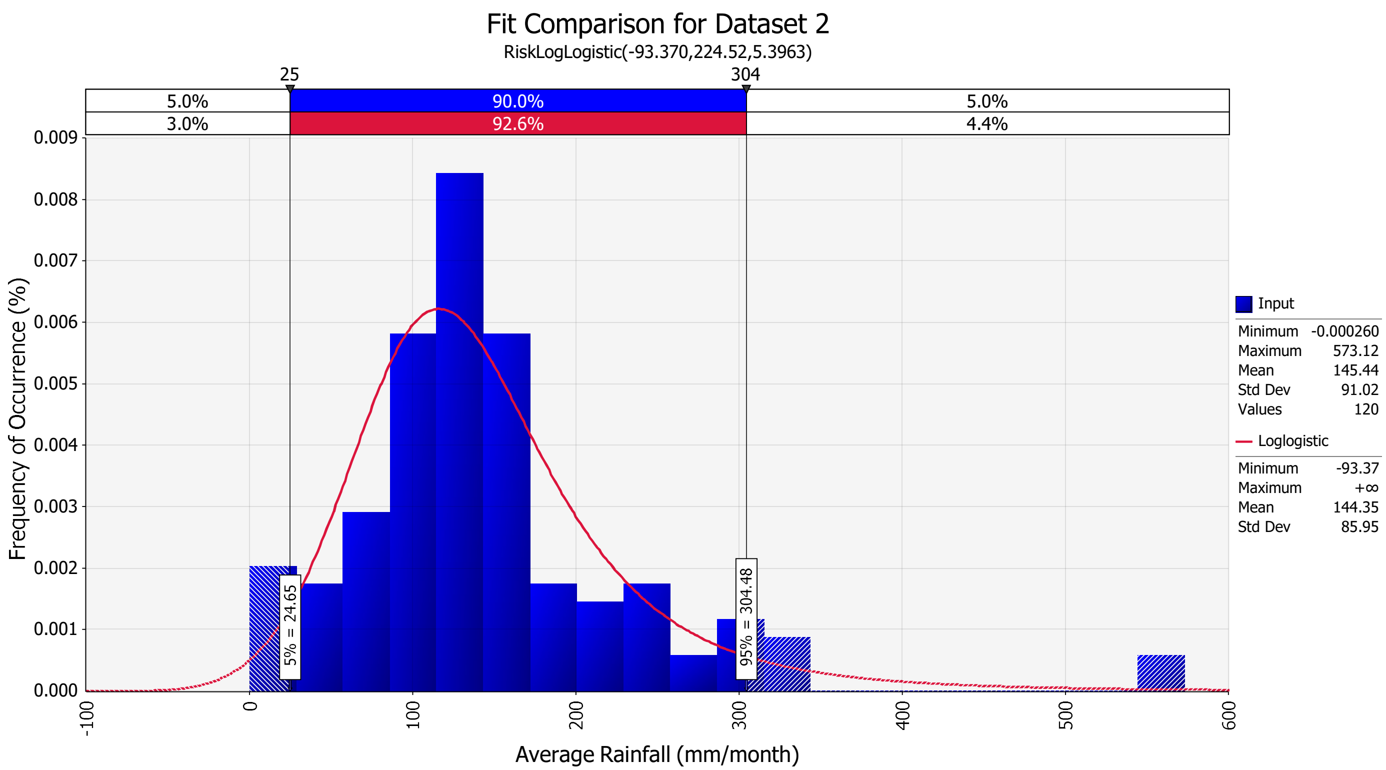
Disruptive Events in Time Series

- Traditional probabilistic analysis collapses the time series into a distribution.
- Traditional time series analysis cannot incorporate extreme values.
- Explori … rizing extrem … nction.





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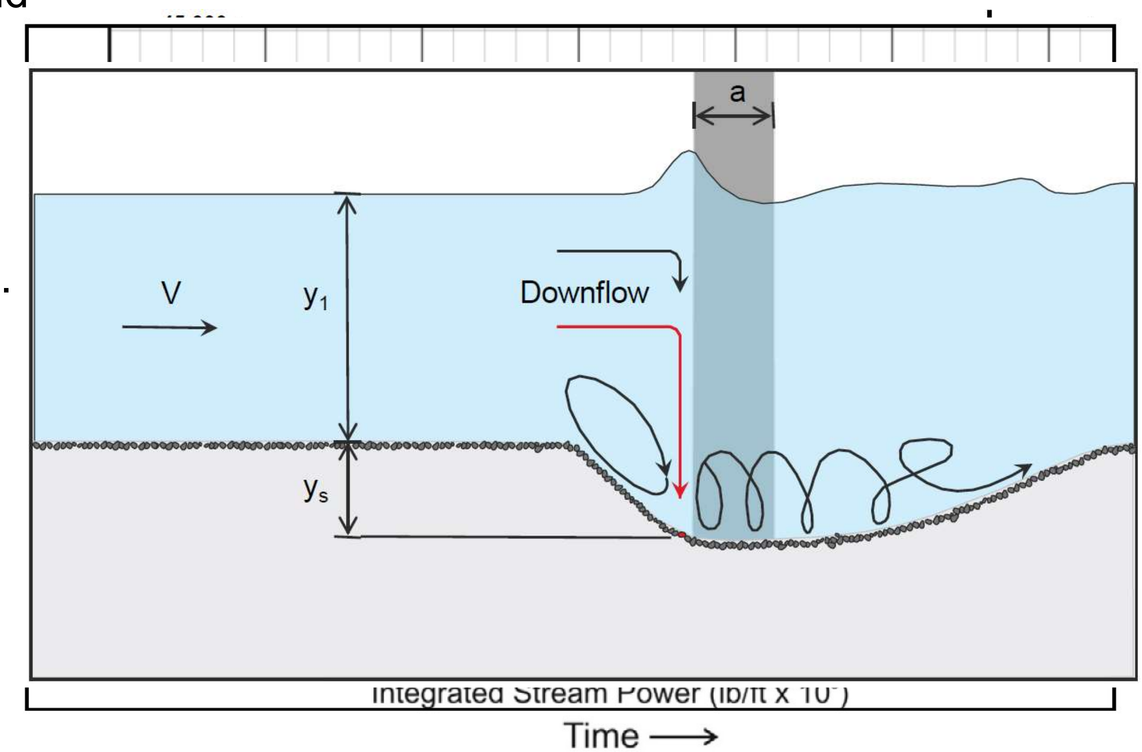
Cumulative Scour Over Service Life

- Consider non-stationary time series and multiple events in a Monte Carlo (MC) simulation.
- Develop a cumulative power for each scenario.
- Estimate long-term cumulative erosion.
- Incorporate local scour (probabilistic event) and any potential contraction scour.



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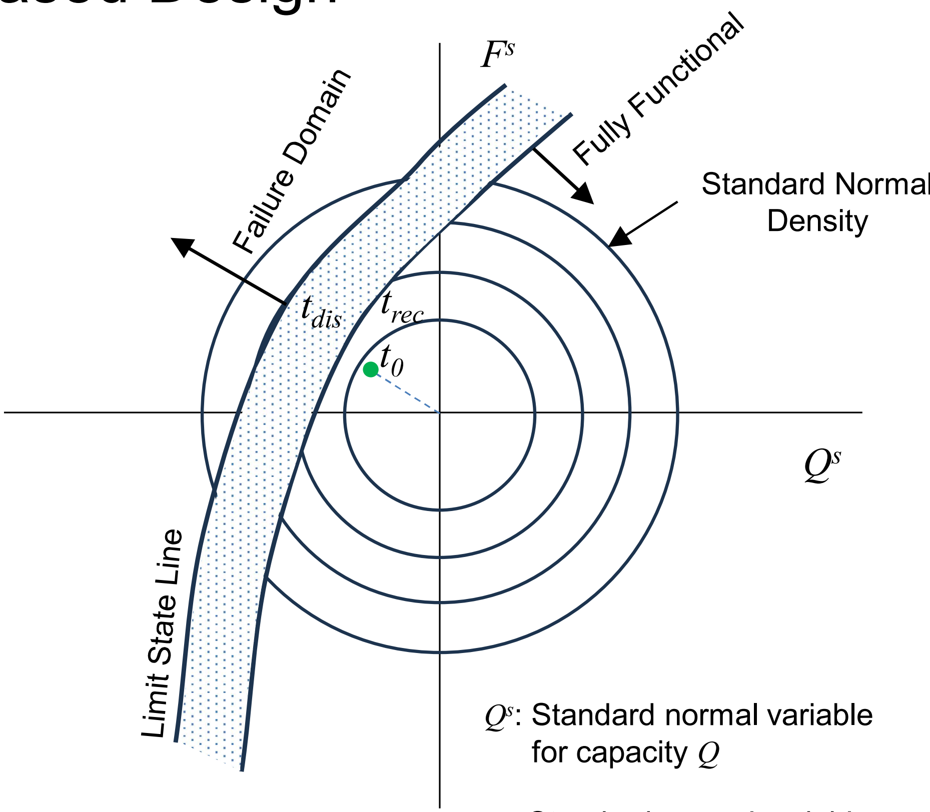
Scour Considerations in Resilience-Based Design

- Summarize MC simulations in a joint probability distribution.
- Define performance measures and tolerable risk levels based on network level performance.
- Recommend risk-based monitoring strategy.
- Identify counter measures.
- Establish design scenario and parameters.



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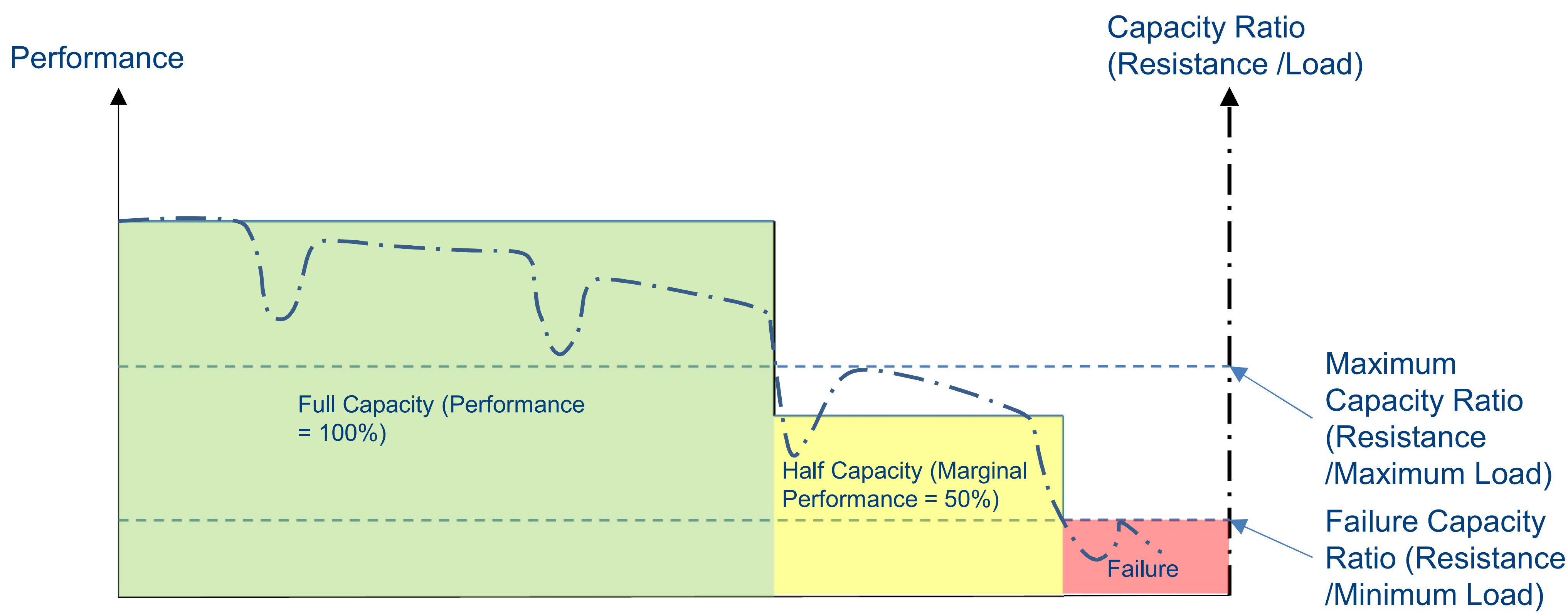
Impact of Time and Repeated Events



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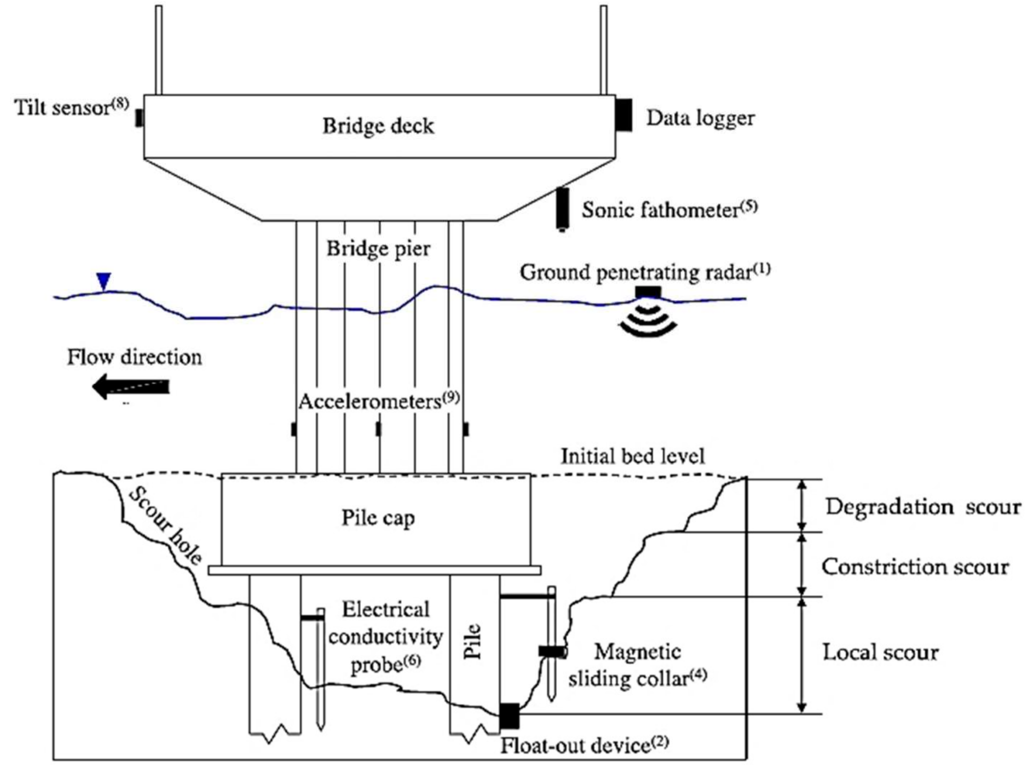
Foundation Assessment and Monitoring

- Bridge foundations are rarely evaluated during their service life.
- Foundation system's deterioration is not easily evaluated.
- Risk-based monitoring can be necessary.
- Many technologies were discussed in an NCHRP report: Nondestructive Evaluation of Highway System Asset Foundational Condition and Capability (2023).



Maroni, A.; Tubaldi, E.; Ferguson, N.; Tarantino, A.; McDonald, H.; Zonta, D. Electromagnetic sensors for underwater scour monitoring. Sensors 2020, 20, 4096

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Concluding Remarks and Future Directions (1 of 2)

- Traditionally we have evaluated loading conditions by investigating the past events. With the changing conditions and climate impacts, loading conditions should be properly modeled and forecasted into the future using proper data driven procedures.
- Loading conditions have been showing non-stationary trends and increased frequency, which should not be ignored or oversimplified, even if using probabilistic analysis.
- The most appropriate tool to consider the loading conditions is to simulate future time series scenarios with extreme events and identify the most critical loading conditions and sequence of events.

Concluding Remarks and Future Directions (2 of 2)

- It is important to consider the condition and performance of geotechnical assets in addition to their capacity using response functions to a given time series scenario.
- Life cycle analysis (part of asset management) plays a significant role to develop more adaptive designs with planned maintenance and rehabilitation activities.
- A proper RBD should also consider the serviceability and economic impacts of geotechnical asset during their service life, and the ability of the asset to rebound after extreme events.
- Designing an ASCE course for resilience-based design framework (expected to be offered on 2026)

Discussion:

Resilience-Based Geotechnical Asset Management

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