AASHTO SCOBS MEETING

Multi-hazard Bridge Design Criteria

June 12, 2017

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Outline

- Challenges: From LRFD to Multi-hazard LRFD
- Multi-hazard Design Guide Development
- Roadmap for Future Study

Bridge Design Specifications

Past, Present, and Moving Forward

WSD

↘

LFD

↘

LRFD (non-extreme loads) - - - - - - - - Present

↘

MH-LRFD (all loads)

↘

MH-LRFD (performance-based)

↘

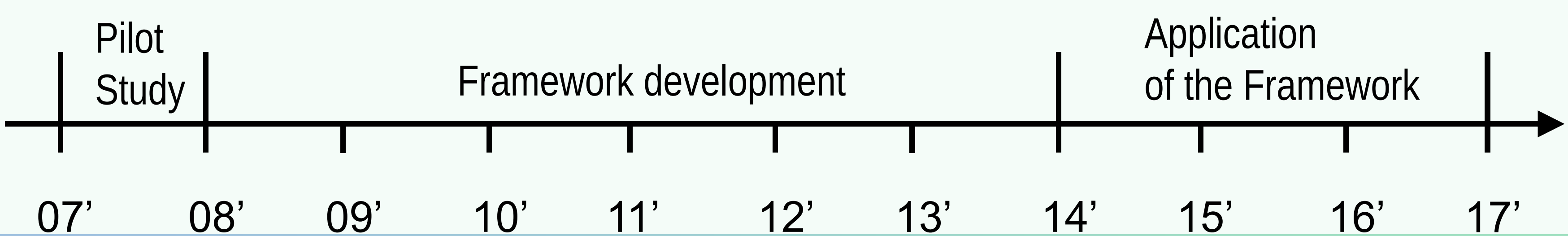
Sustainability Design

The Goals for the Multi-hazard Bridge Design Development

- What?
  - Risk-based design
  - Straightforward implementation
  - Consistent with current LRFD
- Why?
  - Need more consistent safety
  - Need less waste in over-design
  - Need ease of future development/implementation

FHWA Studies on Consistent Multi-hazard Design

- Study Carried out by MCEER
  - Pilot Study, 2007-2008
    - Monograph stating the present problems and potential approaches
  - Framework Development and Survey, 2008-2014
    - Principles for considering all hazards on a consistent basis
    - Procedures for Multi-hazard calibration
- Current Study Led by Genex
  - Applies the Framework for calibration of select Limit States



Current Project: Multi-hazard Bridge Design Criteria

- Period: 9/2014 - 6/2017
- Research Team
  - Genex Systems (Contact: Jerry Shen)
  - MCEER
  - Modjeski and Masters
  - Arora and Associates
  - FHWA: Starting: W. Philip Yen
Current: Sheila Duwadi (COR)

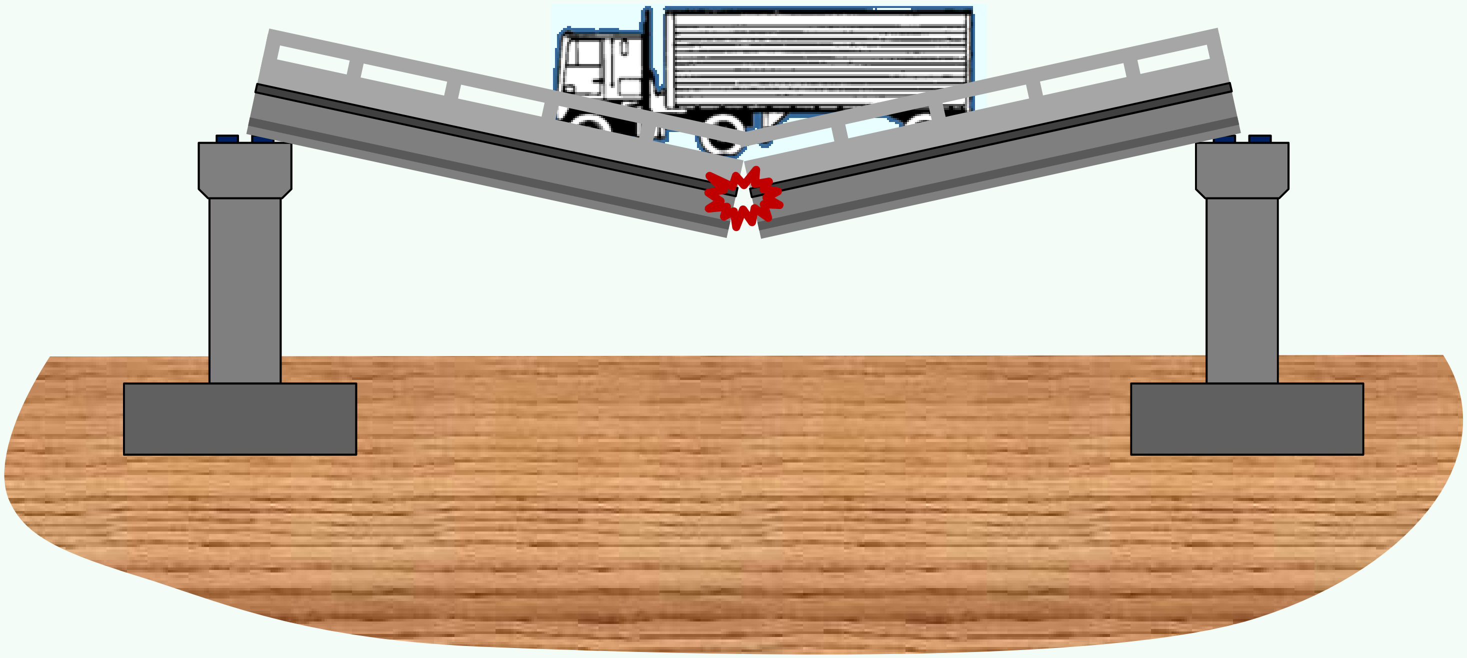
Relevant Projects

- FHWA Multi-hazard Design Research 2011
- NCHRP 12-48 (Extreme Hazard)
- NCHRP 12-49 (Seismic)
- NCHRP 12-33 (LRFD Calibration)
- NCHRP 24-31, 24-35 (Foundation Calibration)
- NCHRP 12-36, 12-47, 12-86 (Redundancy)
- NCHRP 24-34 (Scour)
- FHWA Identification of Redundancy Factor Modifiers (ongoing)

Extreme Events

- Working Definition: Those limit states where we allow the structure to exhibit behavior beyond that expected at the strength and service limit states.
- Have not generally been calibrated to achieve any specific reliability.
- Limited current guidance on which loads/conditions to combine.

Limit State—defined deterministically

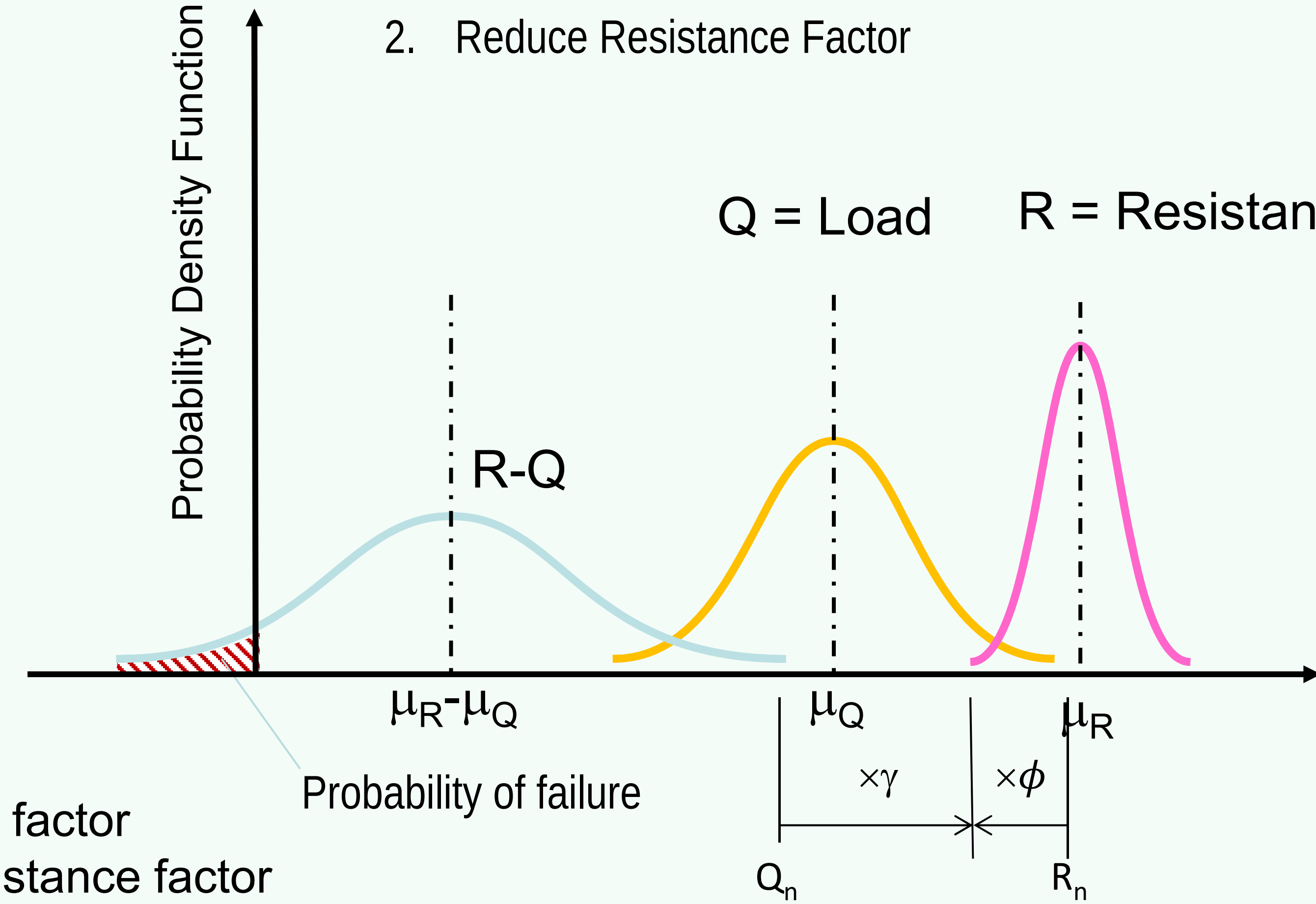


AASHTO LRFD Design Limit State Equations

$\phi R_n = \gamma Q_n$

To increase bridge reliability, i.e., reduce probability of failure

1. Increase Load Factor
2. Reduce Resistance Factor



γ: Load factor
ϕ: Resistance factor

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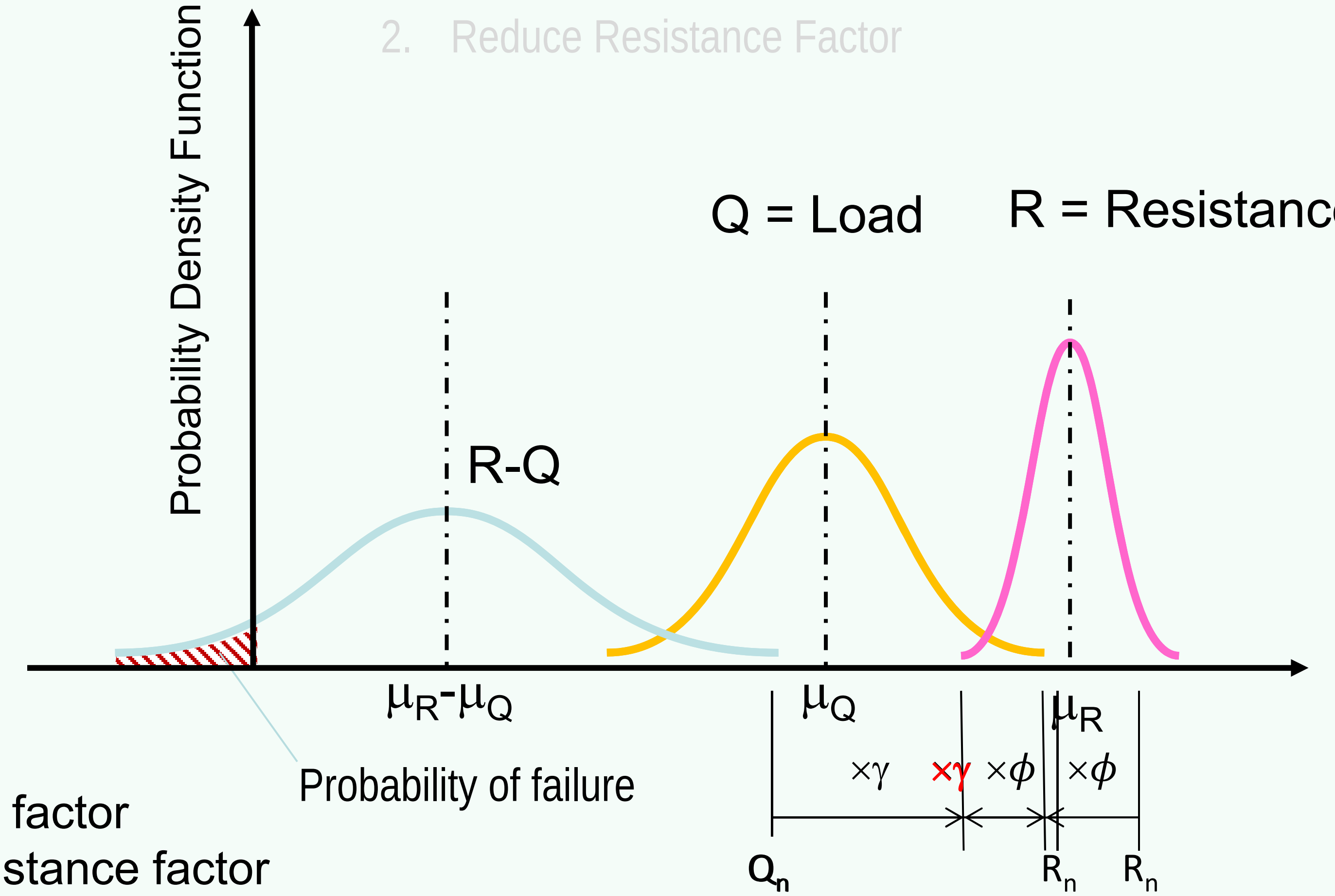

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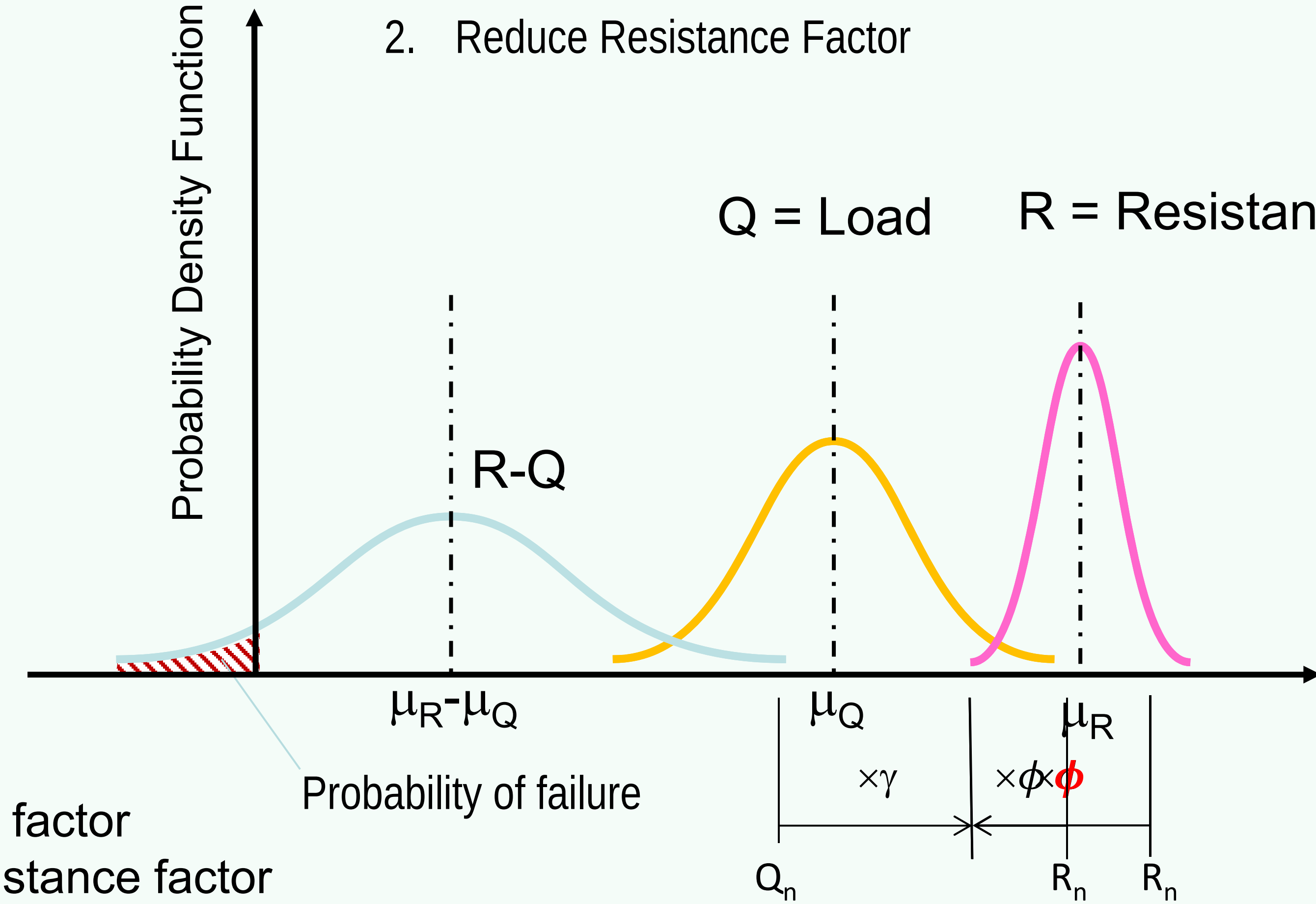


γ: Load factor

ϕ: Resistance factor

LRFD with Extreme Events (Multi-hazard)

- Reliability of LRFD is calibrated for dead load and live load applied on superstructure.
- Reliability for other loads and components are NOT fully calibrated.
- Extreme Events: higher risk, but less frequent.

Load Combination Limit States	Dead Load*	Live Load	Water Load	Wind Load on Bridge	Wind Load on Truck	Use One of These at a Time				
						Earth-quake	Blast	Ice Load	Vehicular Collision	Vessel Collision
Strength I	1.25	1.75	1.00	--	--	--	--	--	--	--
Strength II	1.25	1.35	1.00	--	--	--	--	--	--	--
Strength III	1.25	--	1.00	1.40	--	--	--	--	--	--
Strength IV	1.50	--	1.00	--	--	--	--	--	--	--
Strength V	1.25	1.35	1.00	0.40	1.00	--	--	--	--	--
Service I	1.00	1.00	1.00	0.30	1.00	--	--	--	--	--
Service II	1.00	1.30	1.00	--	--	--	--	--	--	--
Service III	1.00	0.80	1.00	--	--	--	--	--	--	--
Service IV	1.00	--	1.00	0.70	--	--	--	--	--	--
Extreme Event I	1.25	0/0.5	1.00	--	--	1.00	--	--	--	--
Extreme Event II	1.25	0.5	1.00	--	--	--	1.00	1.00	1.00	1.00

Calibrated for superstructure

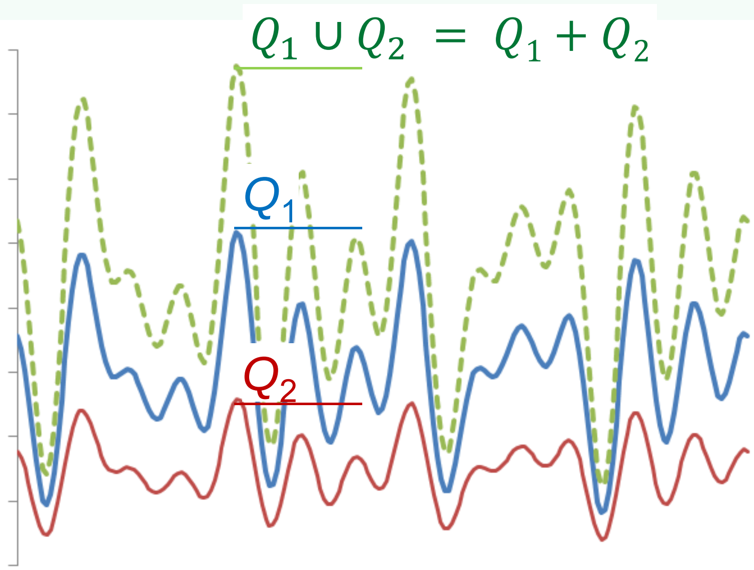
Not calibrated & Unknown risk

Challenges in the Probabilistic Analysis

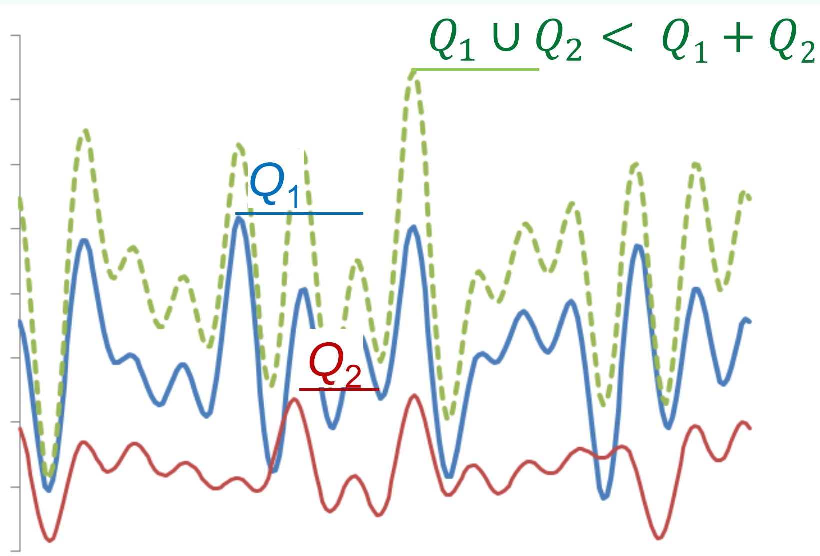
- Characteristics of loads
  - Time-variable vs. time-invariable
  - Correlation among loads/conditions and resistance
- Redundancy (System Reliability)
- Variation in practice
- Multidisciplinary design considerations (structure, geotech, hydraulics, seismic, etc.)
- Simplicity of design formulas

Correlation of Time-Variable Loads

Correlated Loads

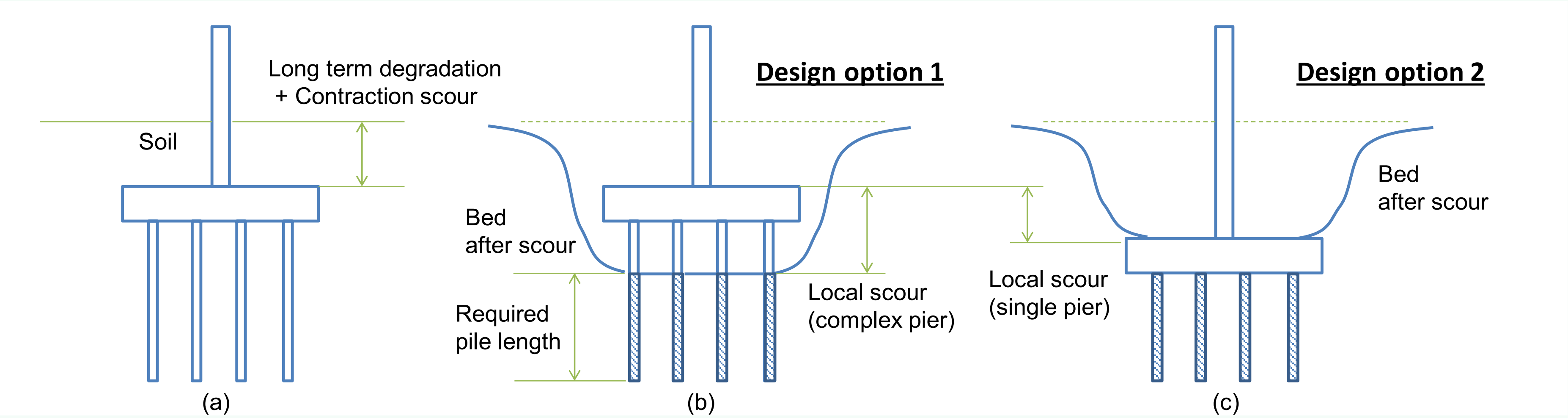


Independent Loads

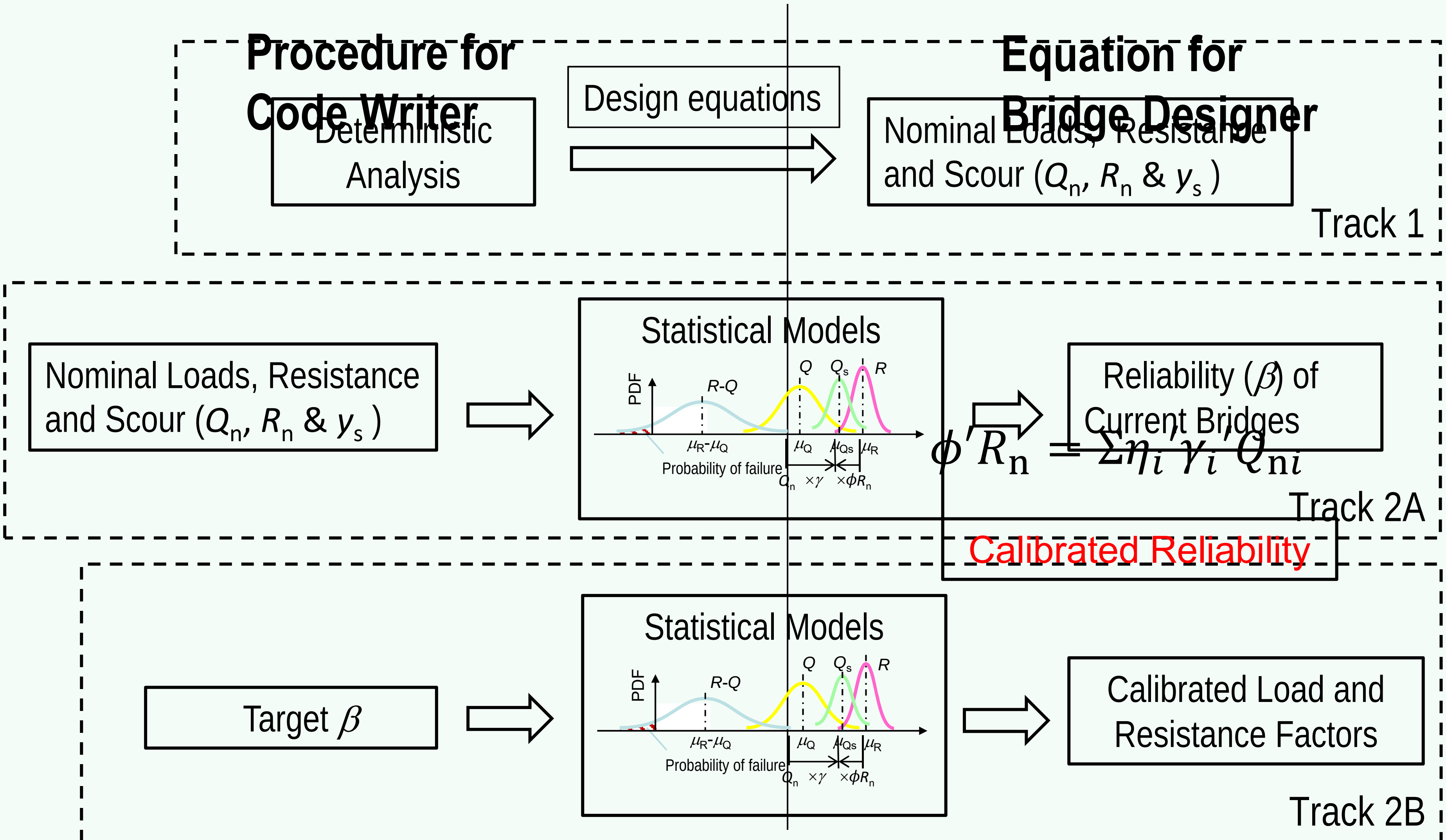


Variations in Practice

- Example: foundation design with scour consideration



Calibration Approach



Calibration Cases

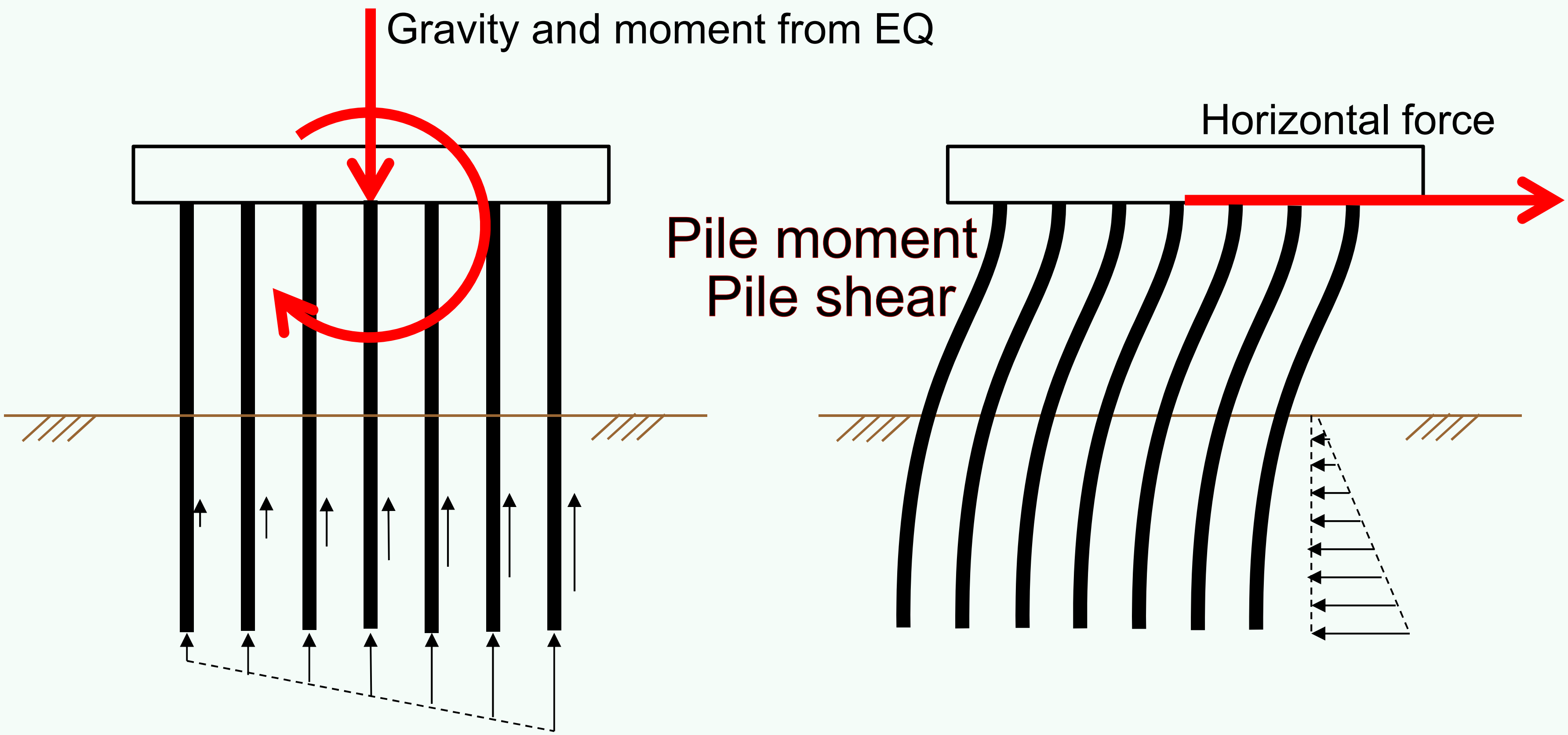
- Calibration1—Strength I
  - DL + LL ∪ SC
  - Current Design: Full factored dead load and live load with 1.0 total scour from design flood
  - 90 Bridges of three bridge spans, three hydrology uncertainties, two types of piles and five design methods
- Calibration 2—Extreme Event I
  - DL + LL ∪ SC ∪ EQ
  - Current Design: Full factored dead load ~0.5 live load with 1.0 or less total scour from design flood (scour varies among states) and 1.0 earthquake
  - Vertical Forces on Piles
  - Lateral Forces on Piles

Demo Calibration Case – DL + LL ∪ SC ∪ EQ

Pile Loads and Resistance

Seismic Loading

- Seismic load from plastic hinge—capacity protection design



Soil reaction force

Variation of Design Cases

- Pile capacity method
  - Meyerhof (Sand)
  - Nordlund (Sand)
  - α-Tomlinson (Clay)

  DL+LL+SC+EQ

  - β method (Clay)
  - λ method (Clay)
- Displacement pile and non-displacement pile
- Bridge span (varies DL/LL and scour components)
- Hydrological uncertainty (varies scour)

Design Limit State Equations—Vertical

- Identify possible failure mechanisms
  - Different failure mechanisms can lead to different limit state equations.
    - Force demand

$$\phi(1-\gamma_{SR}q_{SR})R_n \geq \gamma_D Q_D + \gamma_L Q_L + \gamma_{E_{ARS}}(1-\gamma_{SQ}q_{SQ})Q_E$$ Vertical

$$\phi R_n \geq S_n\left(\gamma_D Q_D + \gamma_L Q_L + \gamma_{E_{ARS}}(1-\gamma_{SQ}q_{SQ})Q_E\right)$$ Lateral

    - Capacity protection

$$\phi(1-\gamma_S S_n)R_n = \gamma_D Q_D + \gamma_L Q_L + \gamma_E Q_E \qquad S_n = \frac{Y_n - (Y_{cs1} + T)}{H_n}$$ Vertical

$$\phi R_n = S_n(\gamma_D Q_D + \gamma_L Q_L + \gamma_E Q_E) \qquad S_n = \frac{1.225}{\left(1 + 0.0222\frac{1}{D}Y_n\right)}$$ Lateral

    - Displacement demand

$$\phi_{\Delta_C}[(1+\gamma_{S\Delta_C}q_{S\Delta_C})\Delta_f + \Delta_Y^{col} + \Delta_p] \geq \gamma_{E\Delta_D}(1+\gamma_{S\Delta_D}q_{S\Delta_D})\Delta_D$$ Lateral

Recommended Live Load and Scour Factors—Vertical

- Option 1: Constant Reliability for all Methods (Target $\beta = 2.00$)
  No Constraint on Factors
- Option 2: Constant Reliability for all Methods (Target $\beta = 2.00$)
  Fix $\phi = 1.00$, $\gamma_D = 1.25$, $\gamma_L = 0.50$
- Option 3: Constant Reliability for all Methods (Target $\beta = 2.00$)
  Fix $\phi = 1.00$, $\gamma_D = 1.25$, $\gamma_L = 0.50$, $\gamma_s = 0.00$
- Option 4: Constant Reliability for all Methods (Target $\beta = 2.00$)
  Fix $\phi = 1.00$, $\gamma_D = 1.25$, $\gamma_L = 0.50$, $\gamma_s = -1.00$
- Option 5: Constant Reliability for all Methods (Target $\beta = 2.00$)
  Fix $\gamma_E = 1.00$, $\gamma_D = 1.25$, $\gamma_L = 0.50$, $\gamma_s = -1.00$
- Option 6: Constant Reliability for all Methods (Target $\beta = 2.00$)
  Fix $\gamma_E = 1.00$, $\gamma_D = 1.25$, $\gamma_L = 0.50$, $\gamma_s = -1.50$
- Option 7: Different Reliability for each Methods (Target β Varies)
  Fix $\gamma_E = 1.00$, $\gamma_D = 1.25$, $\gamma_L = 0.50$, $\gamma_s = -1.50$

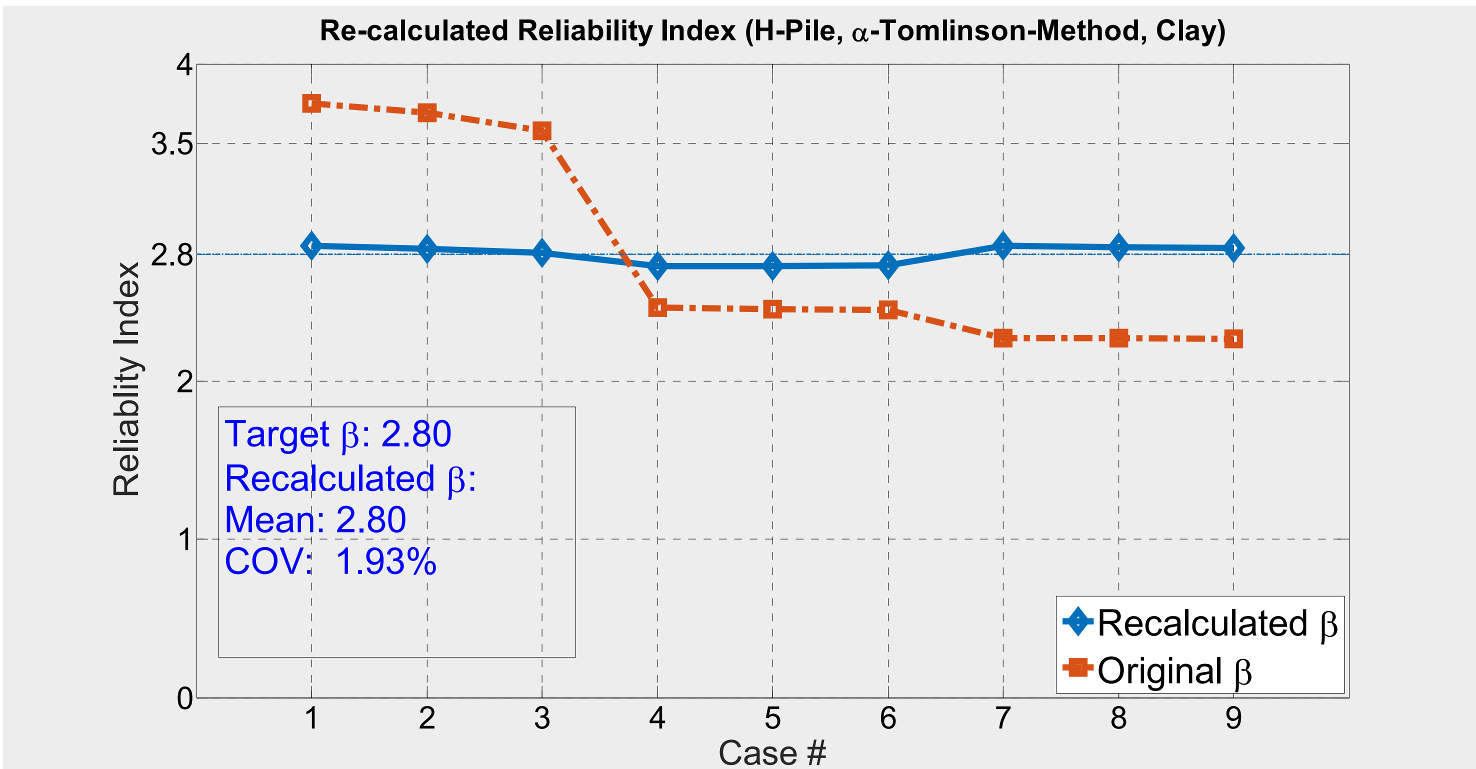
Method		Nordlund (Sand)	α-Tomlinson (Clay)
H-Pile	ϕ	0.835	0.773
Concrete-Pile	ϕ	0.802	0.761

Recommended

Reduced Variation of Reliability—Vertical

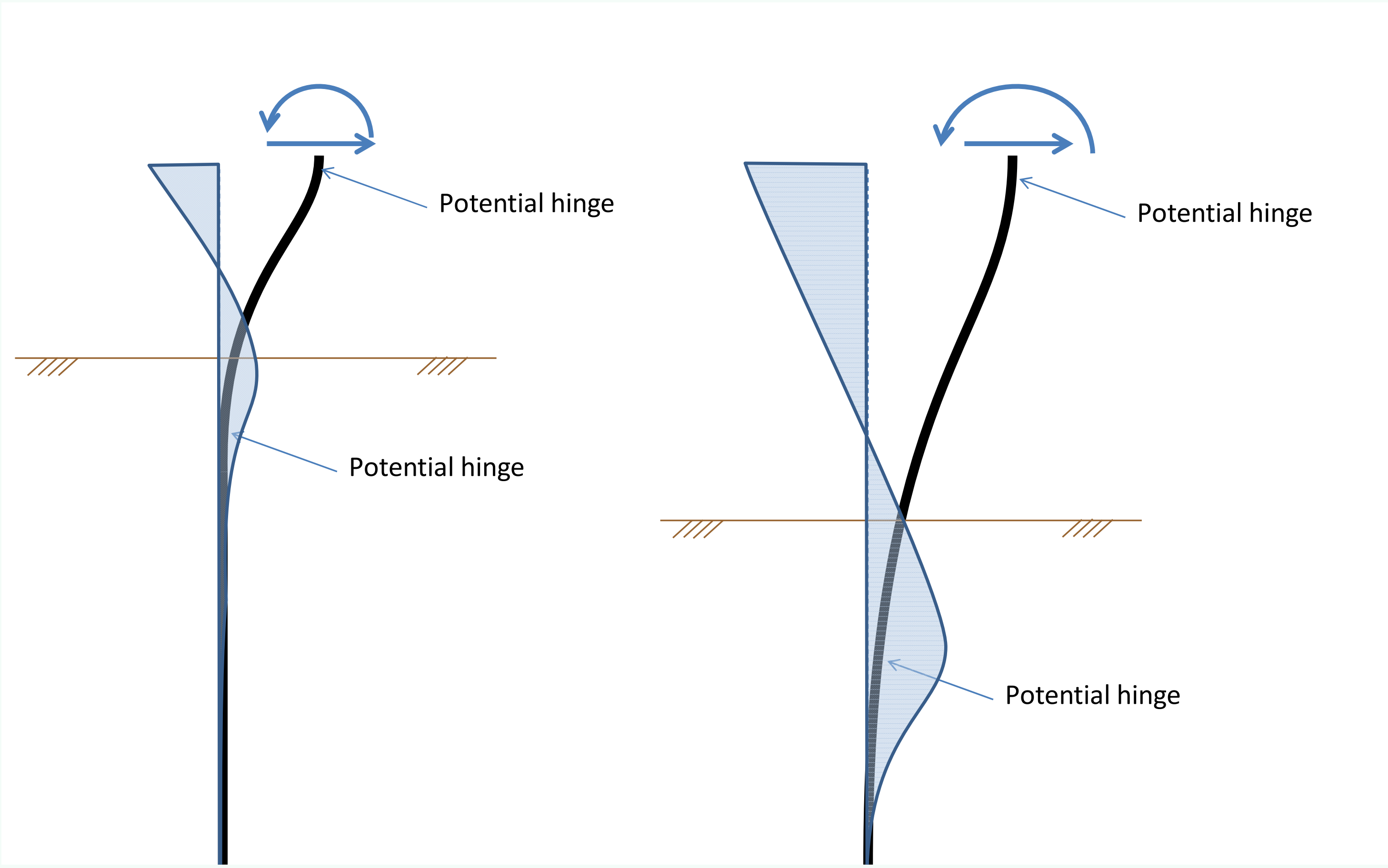
- Reliability for proposed bridge design equation

$$\gamma_E = 1.00, \gamma_D = 1.25, \ \gamma_L = 0.50, \gamma_s = -1.50$$



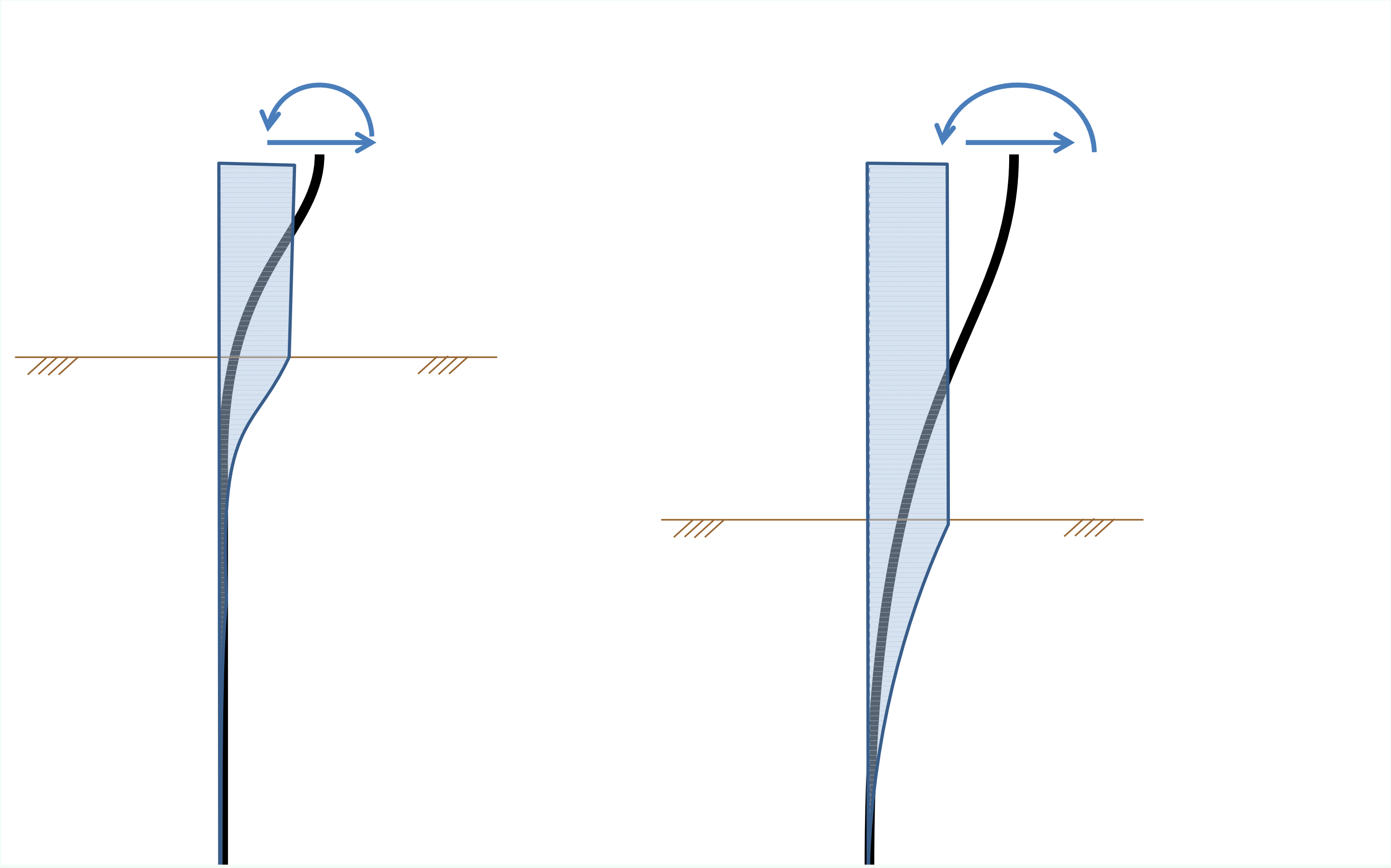
Seismic Load on a Pile—Lateral (moment)

- Potential DLSE formulation for lateral force



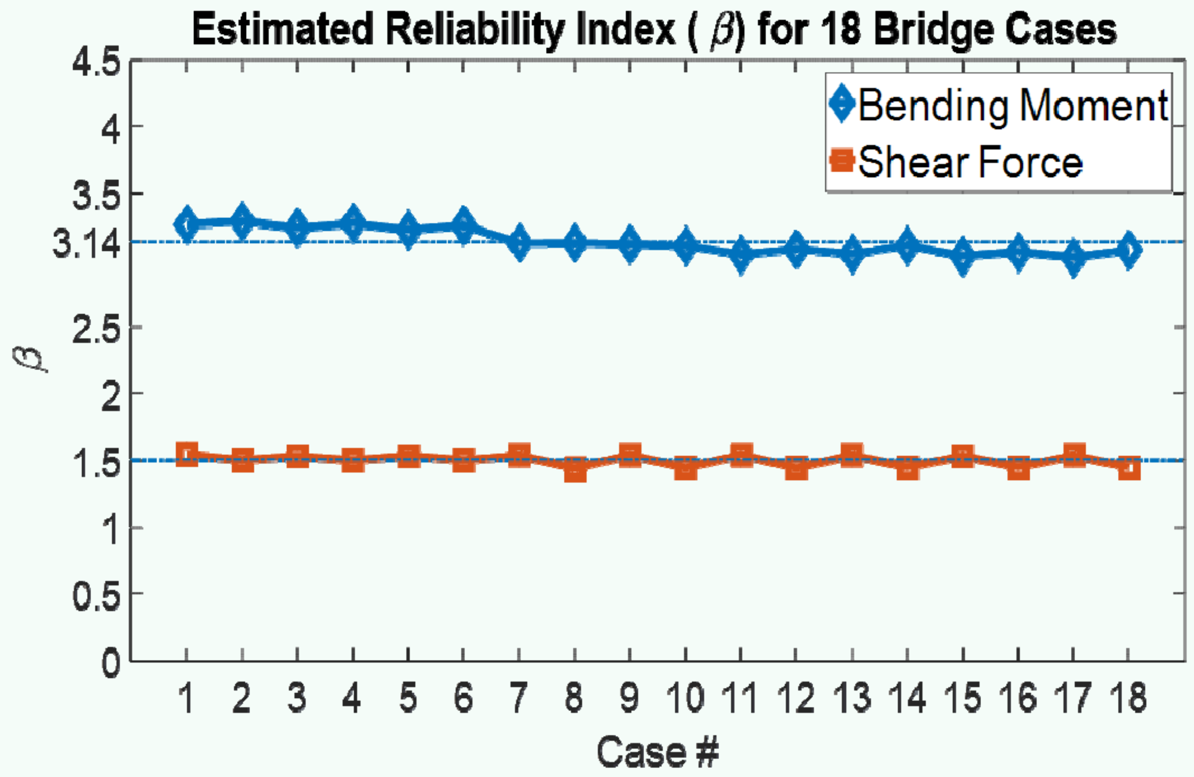
Seismic Load on a Pile—Lateral (shear)

- Potential DLSE formulation for lateral force



Seismic Load on a Pile—Lateral

- Track 2A - Calibrate the reliability for current bridge design - Lateral



Findings/Accomplishments in this Project

- Probabilistic analysis tools based on MCEER Framework were developed in this study to consider the complex cases in multi-hazard LRFD calibration.
- Strength I and Extreme Event I Limit States were calibrated for deep (pile) foundation with consideration of scour.
- Scour exhibited significant conservativeness in the vertical load and bending moment on piles, but not in shear load on piles.
- More calibration cases needs to be done considering all practical design details in multiple disciplines.

Roadmap

- A maximum set of calibration cases was composed.
- Unnecessary calibration cases were eliminated when possible.
- Keep formulas simple as possible.
- May need to repeat when new data/technology is available
- Prioritization

Roadmap for Future Study

Dimensions of the Task Matrix

Bridge Components	Loads
• Bridge Elements – Beam-Slab – Truss – Piers, Abutments and Walls – Foundations • System/Sub system	• Load Components – Moment – Shear – Axial Force – Displacement
• Failure Mechanism / Performance Level – Rupture of longitudinal rebars – Concrete crushing – Buckling – Soil failure (displacement limit) – Unseating – Shear bar failure	• Load Combinations – $\mathrm{DL} + \mathrm{LL} \cup \mathrm{EQ} \cup \mathrm{SC}$ – $\mathrm{DL} + \mathrm{SC}$ – $\mathrm{DL} + \mathrm{LL} \cup \mathrm{EQ}$ – $\mathrm{DL} + \mathrm{LL} \cup \mathrm{CV} \cup \mathrm{SC}$ – …

Data Guidelines

- Guidance for loads and resistance
- Important properties:
  - Model uncertainties and randomness from nature
  - Time-dependent /Time-independent intensity
  - Correlation
  - Annual rate of events
  - Duration of an event
- Sample Immediate Needs:
  - Resistance models
  - Scour distribution

Recommended Future Effort

- The complete calibration of LRFD will benefit the bridge owners by offering better basis for decision making.
- It is recommended to set up a plan to gradually complete the calibration of LRFD.
- Bridge design specification is a living document that continues taking advantage of new data and technology.
  - A small cross-disciplinary team working with the SCOBS and bridge community continuously
  - 5 year may be a good calibration/planning cycle

Acknowledgement

- Oversight committee
  - Bruce Johnson, Oregon DOT (Co-chair)
  - Susan Hida, California DOT
  - Richard Pratt, Alaska DOT
  - Wahid Albert, New York DOT
  - Bijan Khaleghi, Washington DOT
  - Wassem Dekelbab, NCHRP
  - Phil Yen, FHWA (Former Chair)
  - Sheila Duwadi, FHWA (Chair)
- Meeting/Documentation
  - Richard Land, GPI
  - Eric Thorkildsen, GPI

Thank you !

Questions? Please contact:

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