JCSS

Joint Committee
on Structural Safety

Workshop on Assessment of Existing Structures
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Standardization for Assessment of Existing Structures in the USA

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Outline of Presentation

- *Guidelines for Structural Condition Assessment (ASCE 11)*
- *Seismic Evaluation and Retrofit of Existing Buildings (ASCE Standard 41-17)*
- *Code Requirements for Assessment, Repair and Rehabilitation of Existing Concrete Structures (ACI 562)*
- *International Existing Building Code (IEBC)*

- *Specification for Structural Steel Buildings, Appendix 5: Evaluation of existing structures*
- *Manual for Bridge Evaluation (AASHTO, 2018)*

ASCE 11 *Guideline for Structural Condition Assessment of Existing Buildings*

- Recommendations for scope of work
- A catalogue of techniques useful for evaluation and assessment of structural materials
- Recommendations regarding applicable techniques for given conditions

ASCE 11, cont'd

- There is no criterion for how safe is safe enough, or for serviceability; the importance of such criteria is recognized and left to the responsible professional
- Companion ASCE 30 *Guideline for Condition Assessment of the Building Envelope* follows a similar format

ASCE 41 – Seismic Evaluation and Retrofit of Existing Buildings

- Mandatory language standard with multiple performance objectives
- Scope goes beyond the seismic force resisting structure to address nonstructural components and systems within buildings
- Highly quantitative

ASCE 41 Performance Objectives

Risk Category	Hazard Level	
	BSE-1E	BSE-2E
I and II	Life Safety for structural and nonstructural systems	SS - Collapse Prevention
		NS – Hazards Reduced – 5
III	SS - Damage Control	SS - Limited Safety
	NS – Position Retention -2	NS – Hazards Reduced – 4
IV	SS – Immediate Occupancy	SS – Life Safety
	NS – Position Retention -1	NS – Hazards Reduced - 3

ASCE 41 Hazard Levels

- Basic reference point “BSE-2N”: “Risk-targeted Max Considered EQ Ground Motion”
  - Hazard level computed such that probability of failure = 1% in 50 years given conditional probability of failure = 10% at design point and lognormal fragility of structure with log std dev = 60%
  - Generally corresponds to 2% probability of exceedance of motion in 50 years, *but with caps*

ASCE 41 Hazard Levels

- BSE-1N = (BSE-2N) * 2/3; the standard point for design of new buildings
- BSE-2E = 5% prob of exceedance in 50 years
- BSE-1E = 20% prob of exceedance in 50 years
- Authority having jurisdiction can mandate different hazard levels for a specific project

ASCE 41 – Evaluation Tiers

- 1: screening with checklists and simple quick calculations
- 2: deficiency-based linear analysis and report
- 3: systematic evaluation: knowledge factor applied in process of determining expected capacities; sophisticated analyses

ASCE 41

- Bottom line is that it is a sophisticated standard that is usually voluntary.
- The mandatory language is intended to deliver a “truth in advertising” result
- It is imposed as a mandatory requirement by a few jurisdictions for a limited set of buildings

ACI 562: *Code Req'ts…Assessment, Repair…of Existing Concrete Structures*

- Relatively new standard; mandatory language
- Safety criterion adapted from LRFD for new structures
- Strong emphasis on durability issues
- Defers to ASCE 41 for seismic

ACI 562: Safety

- $U/\phi R > 1.5$ definition of dangerous, using *current* codes for U, ϕ, and R
  - R and ϕ can be adjusted for improved knowledge of as-built condition
- $U/\phi R > 1.0$ using *original* code for structure or > 1.1 using *current* codes triggers repair req’t

ACI 562

- Also has ratios of capacity before and after a damage event to define “substantial structural damage,” which can trigger repair req’ts
- Designed to work under IEBC or independently

International Existing Building Code (IEBC)

- Complex criteria to determine scope of application; addresses:
  - Repair of damaged structure
  - Proposed change in occupancy
  - Proposed rehabilitation, remodel, or addition
  - Abatement of hazardous building

IEBC

- Three basic compliance methods for work other than repair:
  - Prescriptive
  - Work area method; concept that upgrading is not required throughout and existing
  - Performance

IEBC

- Not just structural; covers all aspects of buildings that are regulated – fire safety, health & sanitation, etc.
- Structural focuses heavily on repair of damage, including earthquakes, but it also does directly reference ASCE 41

Appendix 5: Evaluation of existing structures

- **Purpose**
  - Verification of design loads
  - Determining in situ strength of member or system
  - Strength and stiffness under static vertical gravity loads
- **Analysis, load tests or a combination thereof**

Evaluation by analysis

- **Material properties**
  - **Tensile properties**
  - **Yield strength, tensile strength, percent elongation**
  - **Chemical composition of plate and weld material if rehabilitation involves welding**
  - **Charpy V-notch**
- **Dimensional data from field survey unless project design documents are available**
- **Strength from applicable provisions in the *LRFD Specification***

Evaluation by load tests

- **Analyze the structure**
- **Prepare a testing plan**
- **Develop a written procedure of test, considering catastrophic collapse or excessive permanent deformation and procedures for precluding the aforesaid**

Evaluation by load tests

- Load test levels
  - Test strength = $D + Q_{test}$
  - Target strength for floors = $1.2\ D_n + 1.6\ L_n$
  - Target strength for roofs = $1.2\ D_n + 1.6\ (L_r \text{ or } S \text{ or } R)$
- Test strength > Target strength
- Additional considerations
  - Loading in stages
  - Deformations shall not exceed 10% during maintenance of maximum test load for 1 hour
  - Deformations shall be recorded 24 hr following removal of test load
- No structural reliability basis

Manual for Bridge Evaluation (AASHTO 2018)

Decisions on rehabilitation or replacement of bridges

- **Condition rating/inspection (largely visual, every 24 months)**
- **Load rating**
- Functionality
- Traffic demand
- Availability of funding

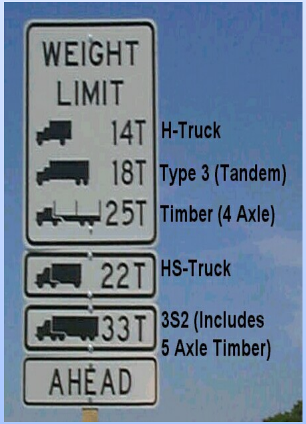
Bridge rating and evaluation

Causes

Deterioration
Increased traffic demand
Deferred maintenance

Maintenance

Road Closing ($$$)
Posting ($$$)
Strengthening
Replacement



Manual for Bridge Evaluation (AASHTO 2018)

- **Current bridge rating practices**
  - **National Bridge Inventory (NBI)**
  - **PONTIS**
- **A look to the future**

FHWA Bridge Component Rating

Bridge Condition Rating

- Reflects the bridge's deterioration level
- Is on a scale of 0-9
- Based on bridge inspections

Good

Fair

Poor

Code	Description
N	NOT APPLICABLE
9	EXCELLENT CONDITION
8	VERY GOOD CONDITION – No problems noted
7	GOOD CONDITION – Some minor problems
6	SATISFACTORY CONDITION – Structural elements show some minor deterioration
5	FAIR CONDITION – All primary structural elements are sound but may have minor Section loss, cracking, spalling or scour
4	POOR CONDITION – Advanced section loss, deterioration, spalling or scour
3	SERIOUS CONDITION – Loss of section, deterioration, spalling or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete.
2	CRITICAL CONDITION – Advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored, it may be necessary to close the bridge until corrective action is taken.
1	IMMINENT FAILURE CONDITION – Major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affection structure stability. Bridge is closed to traffic but corrective action may put back in light service.
0	FAILED CONDITION – out of service. Beyond repair

LRFR Bridge Rating Framework

Calibrated to LRFD Bridge Design Specification

$$RF = \frac{\phi R - \gamma_{DC} DC - \gamma_{DW} DW \pm \gamma_P P}{\gamma_L LL(1 + IM)}$$

$$\phi = \phi_R \phi_S \phi_C$$

Deterioration Condition	Condition Rating	ϕ_c
Good	6 or higher	**1.00**
Fair	5	**0.95**
Poor	4 or lower	**0.85**

LRFR Bridge Rating – Example

Simple-span 5-girder steel bridge – inventory loads

Dead load, DC, for interior beams: M_{DC} = 295 k-ft, V_{DC} = 30 k
Dead load, DW, for interior beams: M_{DW} = 48 k-ft, V_{DW} = 4.8 k
Live load, LL(1+IM) for interior beams: M_{LL} = 566 k-ft, V_{LL} = 75 k
Resistance of interior beams: M_n = 2,061 k-ft, V_n = 307 k

$$\gamma_{DC} = 1.25,\ \gamma_{DW} = 1.5,\ \gamma_{P} = 1.0,\ \gamma_{LL} = 1.75$$

Ratings for interior (exterior) beams

- RF_M =1.63 (**1.50**)
- RF_V = 2.00 (2.05)

Allowable live load = RF x LL = **1.50 x LL**

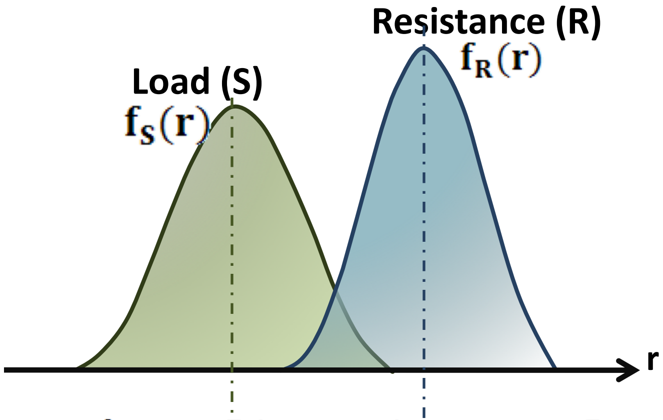
LRFR Bridge Rating Framework

Critical appraisal

- **LRFR is component-based**
- **System effect is not properly considered through φ_s**
- **In situ knowledge is not incorporated through φ_c**
  - In situ material strength
  - In situ load distribution
  - Deterioration
  - Performance history

Reliability Basis for Bridge Rating

Updating failure probability



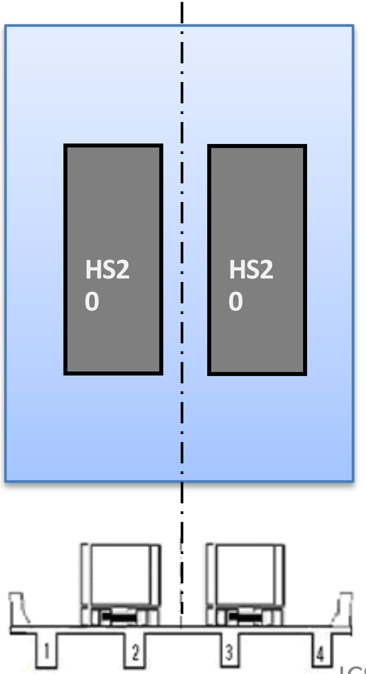
$$P_f' = P[(R - S) < 0 \,|\, \boldsymbol{H}]$$

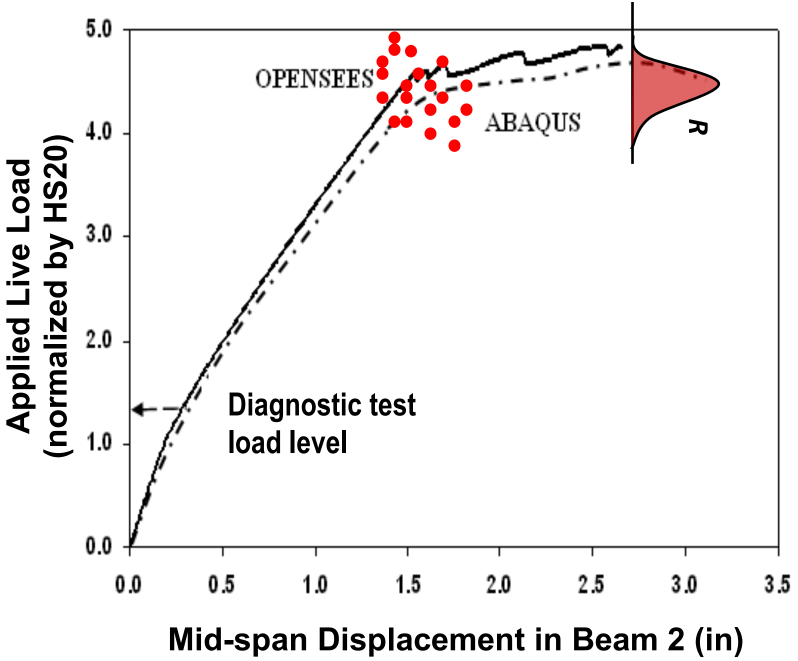
$$P_f' = \frac{P[(R - S) < 0 \cap \boldsymbol{H}]}{P[\boldsymbol{H}]}$$

H **: available site-specific knowledge**

Multi-level Bridge Rating Framework

Bridge system resistance

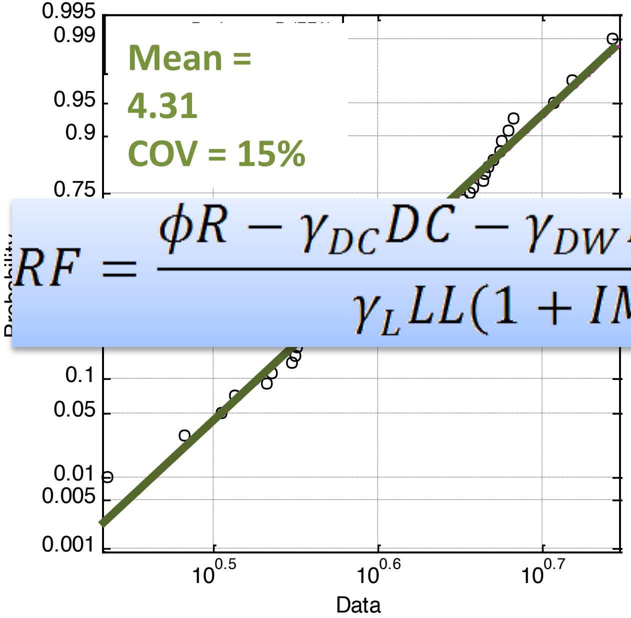




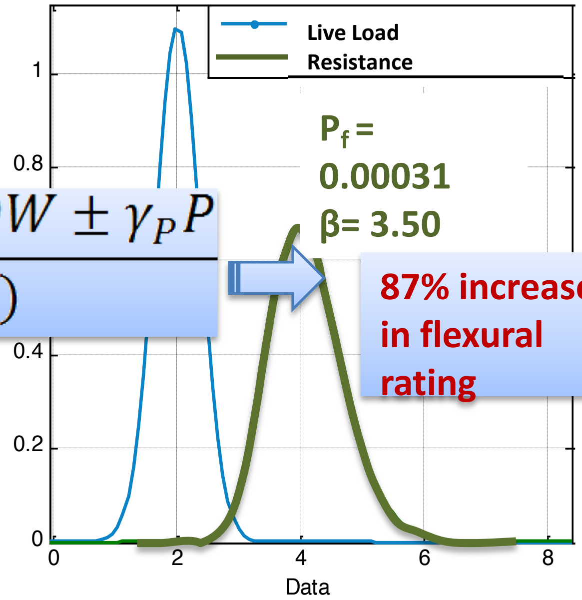
Multi-level Bridge Rating Framework

Bridge system resistance

Lognormal fit of the bridge system resistance



Probability density function of live load and system resistance



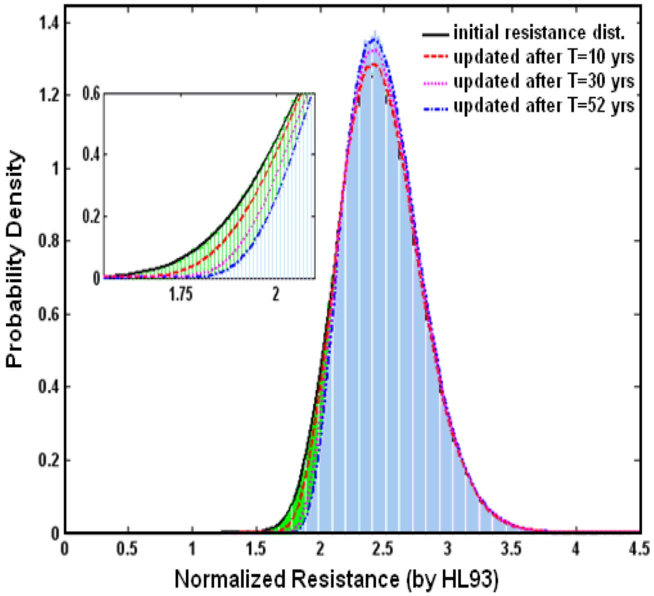
$$RF = \frac{\phi R - \gamma_{DC}DC - \gamma_{DW}DW \pm \gamma_P P}{\gamma_L LL(1 + IM)}$$

87% increase in flexural rating

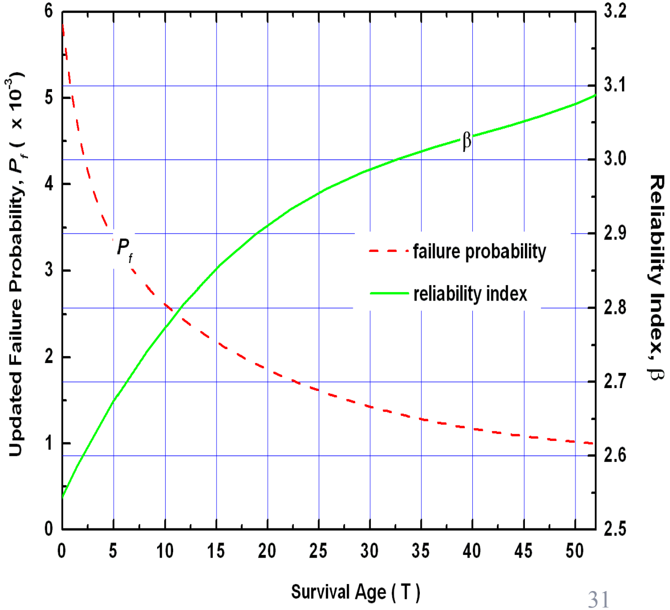
Capacity analysis of aging bridge structure

Successful performance history impacts reliability

Updated resistance distribution using performance history



Updated failure probabilities and reliability indices



Bridge rating - a look to the future

Multi-level bridge rating framework

- **Level 1**
  - Bridge physical condition
- **Level 2**
  - In situ material strength
  - Girder load distributions
- **Level 3**
  - Bridge system resistance
  - Successful performance history

Benefits

- Adding 25% LL capacity to a new bridge may increase costs by 3%
- Adding 25% LL capacity of an existing bridge may be as costly as replacement

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