Center for Advanced Infrastructure and Transportation (CAIT)
A University Transportation Center

Improving the Life-Cycle Performance of Bridges through Accelerated Testing

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Some Critical, Open (and billion dollar) Questions

- What are the primary factors that lead to poor bridge durability and how do they interact with one another?
  - Construction techniques, quality? Structural and/or material characteristics, design details? Environmental inputs? Live load? De-icing agents? Others?
- What are the best practice design and maintenance actions to ensure good long-term bridge performance?
- What are the most reliable techniques to identify and predict the onset of deterioration?
- What are the best practices to mitigate deterioration once it has initiated, and when is the optimum time to deploy them?
Usage of Bridge-Related Terms

...as a surrogate for perceived importance, knowledge

Appearance of Bridge-Related Terms in Books Published in English 1840-2000

- Pacific Railroad Act (1862)
- Ford Model T Introduced (1908)
- WWI (US)
- Great Depression (1929)
- Federal-Aid Highway Act (1956)
- AASHTO LRFD Introduced (1994)
Key goal of bridge performance research

\[ f(\text{Attributes, Inputs}) = \text{Bridge Performance} \]

- Age/time
- Design details
- Materials
- Structural Characteristics
- Construction Quality

- Live load
- Environmental inputs
- Maintenance
- Preservation

- Structural Safety
- Serviceability and Durability
- Functionality and Utility
- Cost

...
Approaches to Studying Bridge Performance

**Breadth**
(Diversity and Size of Bridge Population)

- **Total Bridge Population**
- **Hundreds of Bridges**
- **Dozens of Bridges**
- **Individual Bridges**

**Depth**
(Resolution, Quantitative/Objective)

- **Visual Inspection**, **Conventional Load Rating**
- **High Resolution NDE**, **Load Testing**, **Sensing/Monitoring**, **Refined FE Modeling**

**Top-down research**

**Deductive Approach**
(General to Specific)

*Hypothesis – Truck traffic reduces bridge life*

**Bottom-up research**

**Inductive Approach**
(Specific to General)

*Question – What is causing this observed deterioration?*
Top-Down Approaches to Studying Bridge Performance

Example, Available Data Sources
• National Bridge Inventory (NBI) (1992 – 2016)
  • Historical Condition Data
  • Historical Traffic Data
• Element Level Inspection (~1997 – 2014)
• Environmental Data (1992 – 2016)
  • No. of snowfalls
  • No. of freeze-thaw cycles

Example Tools
• Graphical Information Systems
• Probabilistic Models
  • Markov
  • Weibull
• Machine Learning
  • Is fundamentally data driven – generates models directly from input-output data
  • Does not rely on explicit, static programming
Fundamental Limitations of Top-down Studies

Deterioration Modeling (Weibull) – Mid-Atlantic Cluster

1. Variability*
2. Limited applicability to contemporary bridges
3. Limited Data of Time-in-State for CR 5 and 4*

* Mitigated by element-level inspection

Bridges built before 1960

NBI Condition Rating

Bridge Age
Example Bottom-up Approaches
Nondestructive Evaluation, Sensing and Monitoring, Remote Sensing
Synergies Between Research Strategies

Understanding bridge performance requires... quantitative, objective data... across large populations of bridges... in a timely manner.

Top-down Approaches

Bottom-up Approaches
Principal Challenge – Slow Feedback Loop

The long-durations of the current feedback loop are stifling innovation

Best Cell Phone (2007)
“Offers everything you could want in a cell phone”
-PC World

AT&T Phone (1997)
Big Breakthrough...
- Internal antenna
Accelerate deterioration in a realistic manner through the application of live load, environmental, and maintenance demands on full-scale bridge superstructures to enable...

• **Perform longitudinal studies** to observe the full life cycle of bridge performance (deterioration, initiation, and propagation) in a highly condensed time, and quantify the performance through high-resolution (both spatial and temporal) data collection efforts.

• **Perform comparative studies** that aim to establish the relative influences on long-term bridge performance of competing materials, construction practices, design details, and preservation/maintenance actions.

• **Decouple influences** associated with different demands on various deterioration processes of bridges through controlling the levels of live load, environmental, and maintenance exposure.
Accommodates complete bridge superstructures 50 ft by 28 ft by 5 ft.

Precipitation and salt brine application (up to 18% NaCl).

Two-axle live loading at 10 to 60 kips continuous at 20 mph; 17,500 cycles per day.

Control system and high-speed data acquisition.

0 to 104F degrees rapid-cycling temperature fluctuation.

Precipitation and salt brine application (up to 18% NaCl).
Example Loading Approaches - Live Load

Maximum, Realistic Deck Force Effects

Maximum, Unrealistic Deck Force Effects

Minimum Deck Force Effects

Examination of Live Load Magnitude

6.4 million cycles/year ~ADTT of 875 (20 years)
Example Loading Approaches – Freeze-Thaw

**Notes**
- Needs to be finalized based on simulation
- 12% brine solution applied during min temperature stages
- ~ 8 hour dwell time during freeze-thaw and hot dry cycles
- Accommodates periodic assessments during median temperature cycles
- Over 9 months this results in approximately 270 freeze-thaw cycles (Note ASTM C 666 uses a maximum of 300 freeze-thaw cycles)
Potential Testing Approach – Influence of Rebar

Phase 1 Configuration

Direction of Traffic

- Reinforcement A
- Reinforcement B

Inclusion of holidays in epoxy-coating, variation of cover, variation in shear stud embedment, etc.
Potential Testing Approach – Effectiveness of Overlays

Phase 2 Configuration

Direction of Traffic

Reinforcement A
Reinforcement B

Overlay A
Overlay B
Overlay C

Note: Top of overlays must all be at the same elevation
Potential Testing Approach – Performance of Steel Coatings

Coating systems
- Girder 1: Hot-dipped galvanized
- Girder 2: TSM 100% Zn
- Girder 3: TSM 85% Zn, 15% Al
- Girder 4: Conventional Paint

Girders placed at a longitudinal slope of 2 in. over 50 ft.
Deck is placed without longitudinal slope
Haunch varies from 1-3 in.

Details to allow examination of “corrosion traps”
Open Joint
Poured Joint

Girders placed at a longitudinal slope of 2 in.

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- **quantitative, objective data**
- **across large populations of bridges**
- **in a timely manner**

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Summary

• The current bridge-related (and infrastructure) challenges facing the U.S. do not stem from a lack of competence, but a lack of attention

• Top-down (deductive) and bottom-up (inductive) research approaches are necessary, but not sufficient, to answer our most pressing performance questions

• The primary shortcoming of these approaches is related to their inability to provide information on long-term performance in the near-term

• Accelerated testing is complementary in nature and fills a critical need related to establishing the performance of contemporary bridge systems as well as the effectiveness of emerging interventions

• You don’t get something for nothing
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Currently, technologies present a linear trade-off between cost/time and accuracy/reliability.