AGENDA

PART 1
- DEGRADATION AND NDE FOR BRIDGE DECKS
- TECHNOLOGIES
- GOALS
- DATA COLLECTION AND RESULTS

PART 2
- CONDITION ASSESSMENT
- MODELING
- LIFE CYCLE COST ANALYSIS

CONCLUSIONS AND DISCUSSION
Concrete Condition

Rebar Corrosion

Delamination

Spalling

Half-Cell Potential

GPR

Impact Echo

Ultrasonics

Hammer Sounding/Chain Drag

IR Thermography

Visual Inspection

Time
BRIDGE DECK INSPECTION

Chain Drag

High Speed GPR

Coring

High Speed IR and HRV

SounDAR
Use conventional testing and innovative rapid NDE to assess current condition and predict future deterioration and service life analysis of reinforced concrete bridge decks

- Ability to manage large square footage of bridge deck assets
  - Larger signature bridges
  - Large quantities of inventory

- Provides owners the ability to proactively plan maintenance, repair, and preservation.
PHASED APPROACH

- PHASE 0 – High level screening to determine which decks need inspection
  - Typical NBIS data review
  - Aerial based HRV/IR surveys

- PHASE I – Highway speed testing with GPR, IR, and HRV
  - Network level inspection provides data on large quantities in a short period of time without the need for traffic control

- PHASE II – Deck acoustics and material sampling
  - Programmatic testing, provides additional data for analysis and modeling

- Phase III – Preservation
  - All data is combined to identify best approach for preservation – maintenance and/or monitoring
Electromagnetic waves penetrate elastic materials and reflections are based on the materials dielectric permittivity (ability to absorb light).

- Locates Rebar, Degradation due to corrosion, Moisture, Voids
INFRARED THERMOGRAPHY

Concrete Slab

Delamination

Delaminations
GPR COVER DEPTH

Frequency

Cover Depth (in.)

Concrete Cover (in.)

Distance from West Abutment (ft.)
Modular impactors – spheres can be adjusted from 6mm to 25mm
  - Smaller spheres result in shorter impact times and higher frequency dynamic induction.

Impacts are ~40ms apart to avoid acoustic crosstalk

Microphones are designed to focus the acoustic energy and isolate external noise (primarily traffic noise).
Impact-Echo (IE), performed and analyzed correctly, measures the $S_1$, zero group velocity (S1ZGV) Lamb Wave frequency.

During air-coupled IE, leaky surface waves (Rayleigh) and impact noise interfere with this signal, among other ambient noises.

Research performed to shield and capture the S1ZVG as well as perform digital signal analysis (DSA) to filter and efficiently capture the correct frequencies.


HOW DOES IE DIFFER FROM SOUNDING?

- IE has always focused on identifying a specific frequency that corresponds to the depth of some boundary (void, bottom of slab, etc.)

- Sounding relies on the human ear to perceive difference between an area of intact and non-intact concrete.
Deck Acoustic Response (DAR) is not IE.

- Common misconception

- Concepts are similar, but DAR is identifying changes of frequency response across an entire structure that correspond to flaws.
- Like the human ear and sounding.

- Data can then be analyzed for specific depths if needed.
SPECTROGRAM OF FILTERED DATA

- STRUCTURALLY SOUND
- DEGRADED
Thousands of impacts are analyzed through automated algorithm to identify flaws.

Cluster analysis performed to determine areas of intact and poor concrete.

Results mirror those identified with traditional sounding and are geospatial.
HRV stitched image base overlaid with highlights of patches and spalls, results from GPR attenuation, infrared thermography and digital acoustic response.
Corrosion-based service life

Cover depth

Distribution of clear cover indicates which top mat bars will be affected earliest

Statistical sampling can be derived from GPR linescans
Physical Cores/samples

- Compressive strength and modulus indicative of concrete quality
- Petrographic analysis to assess quality of concrete materials, overlay materials, estimated w/cm, air entrainment quality/quantity, absence/presence of deleterious reactive components and products that may influence service life. (ASR, DEF, F/T, etc.)
- pH and carbonation testing
- Chloride concentration profiles as a function of depth to indicate surface chloride loading and relative rate of chloride ingress (diffusion)
- Measure parameters for diffusion and corrosion prediction
  - Surface concentration of chloride
  - Effective rate of diffusion
Basic diffusion model

\[ C_{x,t} = C_o \left[ 1 - \text{erf} \left( \frac{x}{2\sqrt{D_c t}} \right) \right] \]

where:

- \( C_{x,t} \) = Concentration of species (Cl\(^-\)) at specified depth and time (lb Cl\(^-\)/yd\(^3\) concrete)
- \( C_o \) = Concentration of species (Cl\(^-\)) at/near surface that drives diffusion (lb Cl\(^-\)/yd\(^3\) concrete)
- \( D_c \) = Coefficient that describes diffusion rate of species through the medium (in\(^2\)/yr)
- \( x \) = Depth from the surface (in)
- \( t \) = time over which diffusion occurs (yrs)
- \( \text{erf} \) = mathematical error function
Synthesis of Conventional and NDE results

Use Utility function to a) assess current condition, and b) predict future condition

\[ CI\% = k_1 \times SL\% + k_2 \times GPR\% + k_3 \times IR\% + k_4 \times DAR\% + k_1 \times HVR\% \]

where:

- \( SL\% \) = Deck Surface Area predicted by service life analysis to be corroding
- \( GPR\% \) = Deck Surface Area identified by GPR attenuation to have precursors to corrosion
- \( IR\% \) = Deck Surface Area identified by IR as having delaminations
- \( DAR\% \) = Deck Surface Area identified by DAR as having delaminations
- \( HVR\% \) = Deck Surface Area identified by HRV as having spalls or patches
- \( k_1, k_2, k_3, k_4, k_5 \) = weighting coefficients chosen by engineering judgement;
- \( n = 1 \) to \( 5, kn < 1; \Sigma(k_1, k_2, k_3, k_4, k_5) = 1 \)
Current and Future Condition Assessment

- Emphasize DAR, IR and HRV for current damage assessment to define expected repair quantities for near-term repair
- Emphasize corrosion service life (SL) and GPR components to predict future needs

Trend in Patching Needs Based on Current Condition and Deterioration
Life-Cycle Cost Analysis

Condition Resulting from Deterioration and Intervention

Life Cycle Activity profile – Cost-flow diagram related to bridge activities

Comparison of scenarios for preservation, repair, rehabilitation and/or replacement

Consider life-cycle costs and funding versus needs
Deck Repair, Rehabilitation and Replacement Programming

- Comparison of the scenarios for life-cycle cost analysis for alternatives, including:
  - Sealing and crack repair
  - Patching
  - Selective thin or rigid overlays
  - Replacement (in-kind, ABC)

**What do we achieve?**

Comparison of life-cycle costs of options, taken over a uniform analysis period and summarized in present-day dollars allows an owner to make well-reasoned data-driven decisions on maintenance and capital programming.
Use conventional testing and innovative rapid NDE to assess current condition and predict future deterioration and service life analysis of reinforced concrete bridge decks – Yes, GPR, IR, HRV, SounDAR, and Chlorides all collected with minimal impact to traffic.

Ability to manage large square footage of bridge deck assets
- Larger signature bridges, ~600k sf of deck inspection in under 6 hours
- Large quantities of inventory Recently deployed for over 1.6M sf (137) decks in under 30 days of field time.

Provides owners the ability to proactively plan maintenance, repair, and preservation. Quantitative data sets are repeatable and reliable.
NDE and Materials Testing for Bridge Deck Condition and Service Life Assessment for Asset Planning