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INFRASENSE

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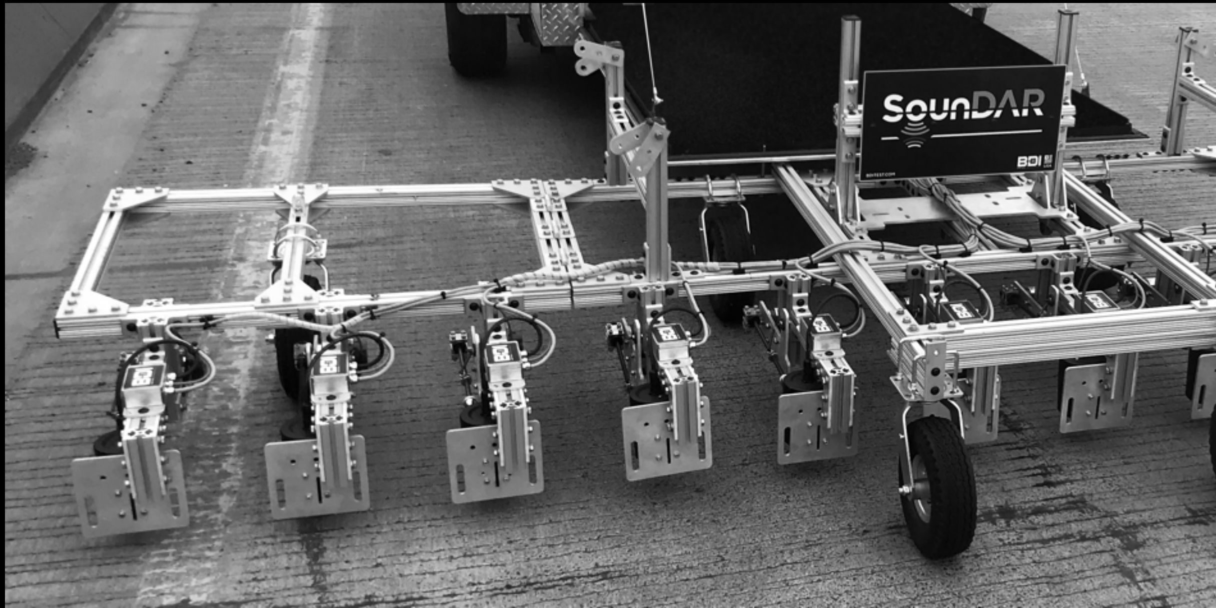
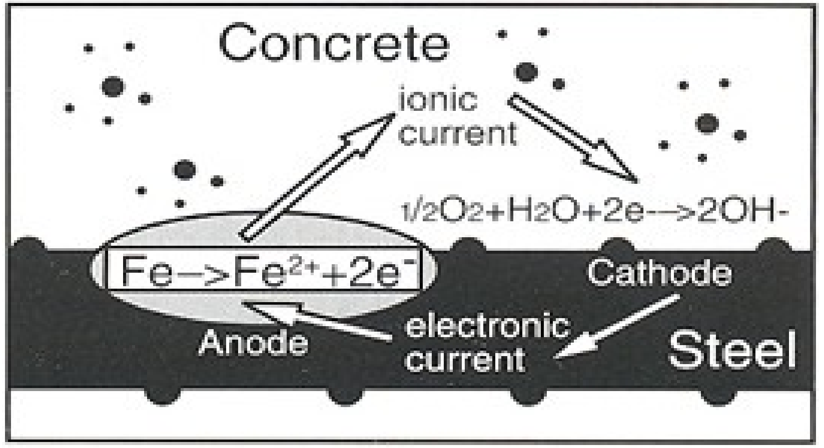
NDE and Materials Testing for Bridge Deck Condition and Service Life Assessment for Asset Planning

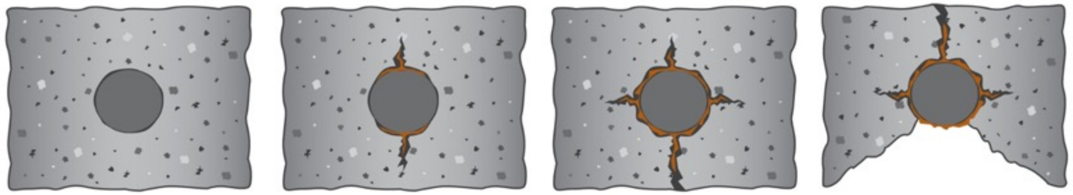
AGENDA

- 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 DISCUSISON



BRIDGE DECK DEGRADATION





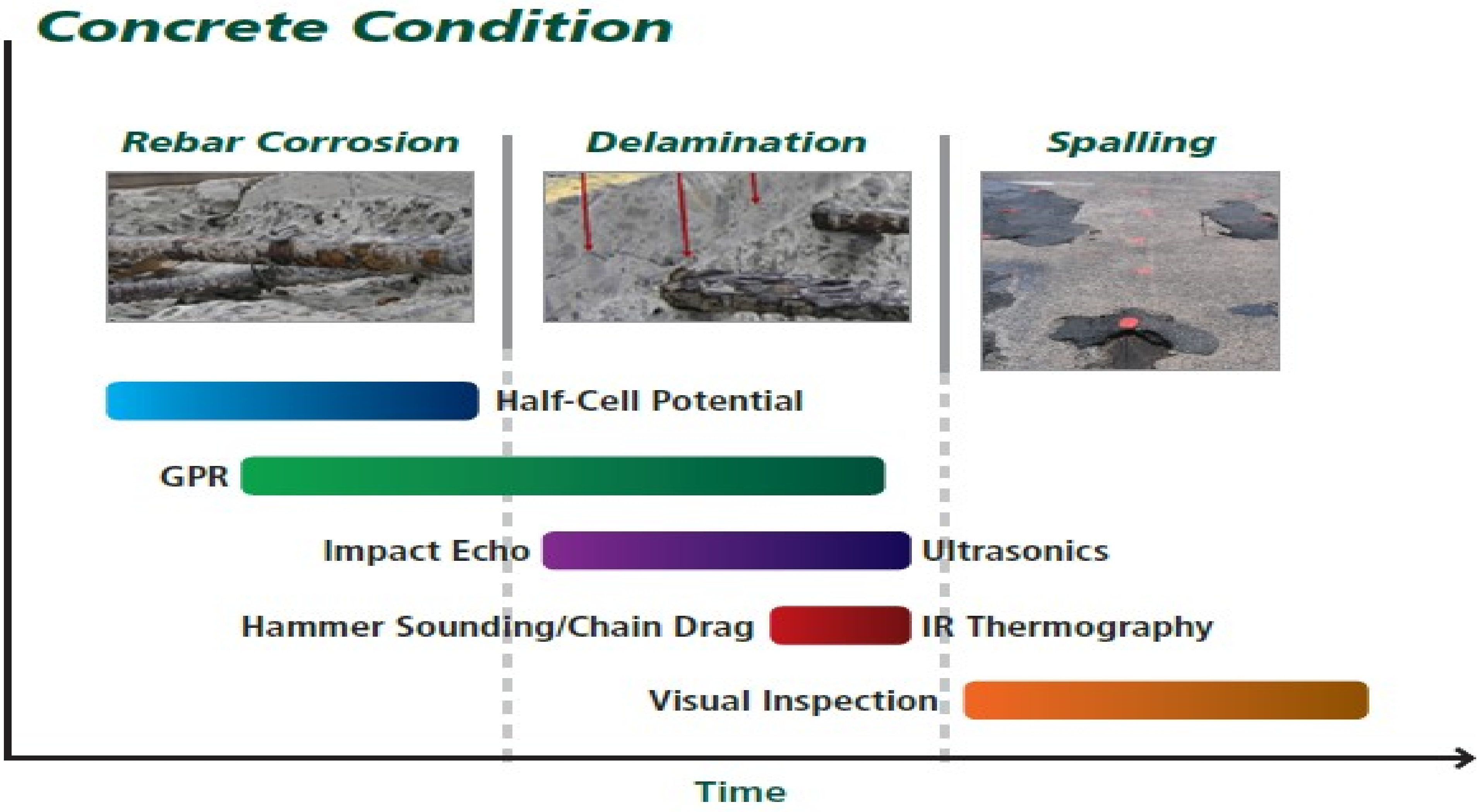
BEFORE CORROSION.

BUILD-UP OF CORROSION PRODUCTS.

FURTHER CORROSION. SURFACE CRACKS. STAINS.

EVENTUAL SPALLING. CORRODED BAR. EXPOSED.

CONCRETE DEGRADATION DETECTION WITH NDE



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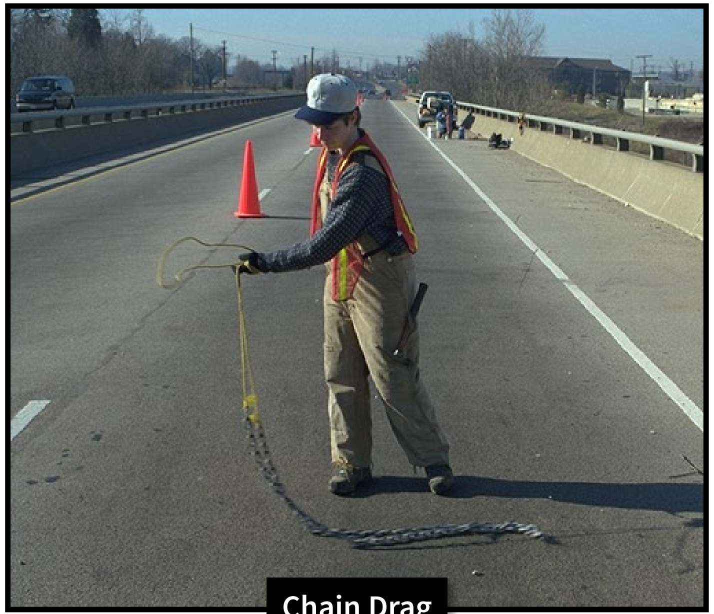
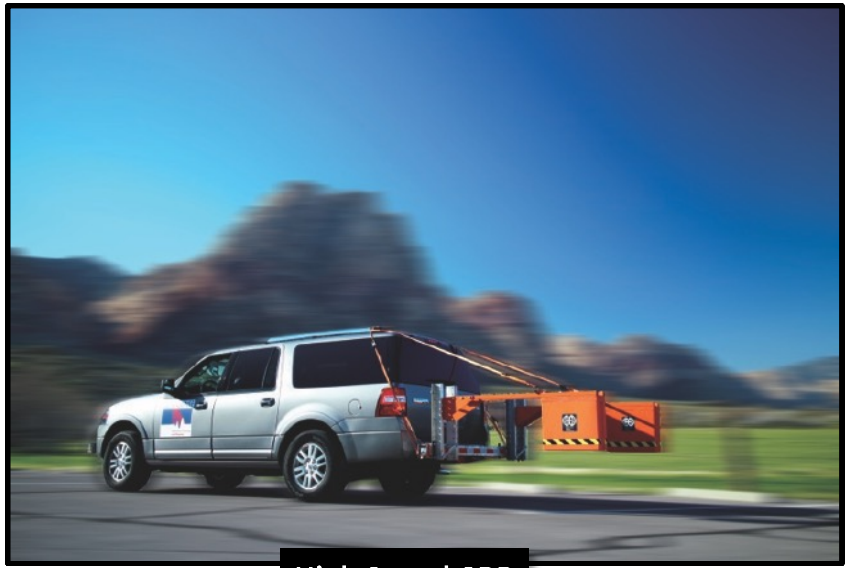
BRIDGE DECK INSPECTION


Chain Drag


High Speed GPR


Coring


High Speed IR and HRV

SounDAR

RAW DATA.
REFINED RESULTS.

GOALS

- 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

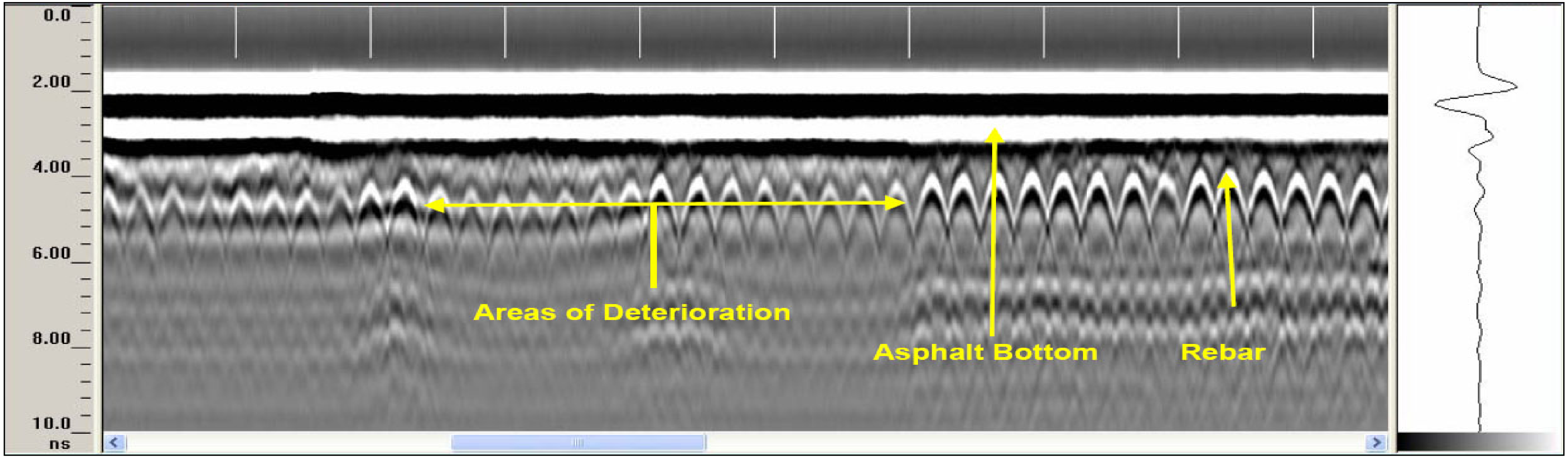
- Provides owners the ability to proactively plan maintenance, repair, and preservation.

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

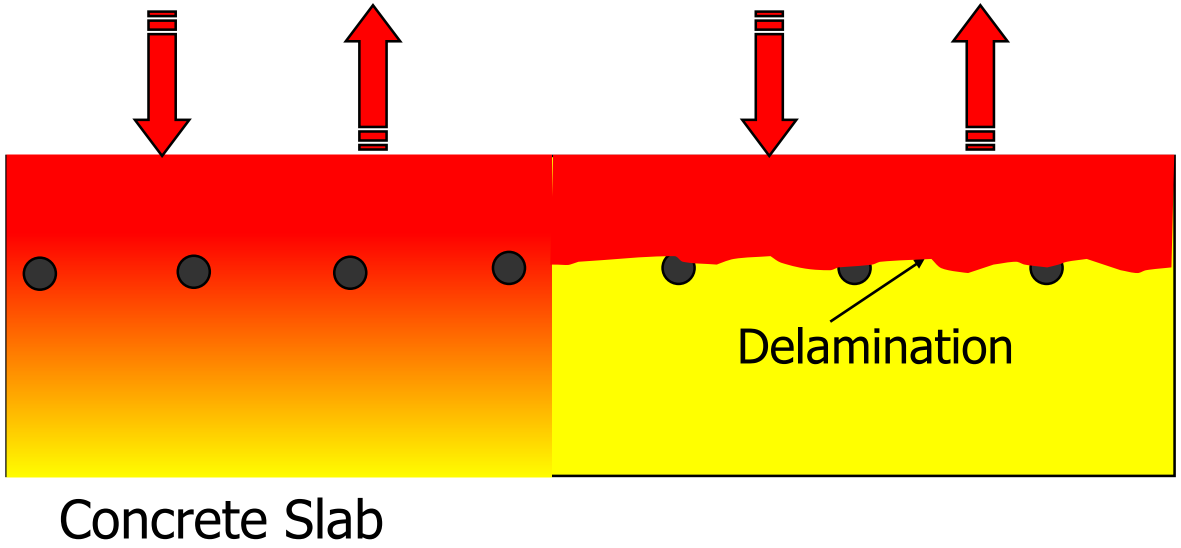
PHASE I – HIGH SPEED GPR, IR, AND HRV

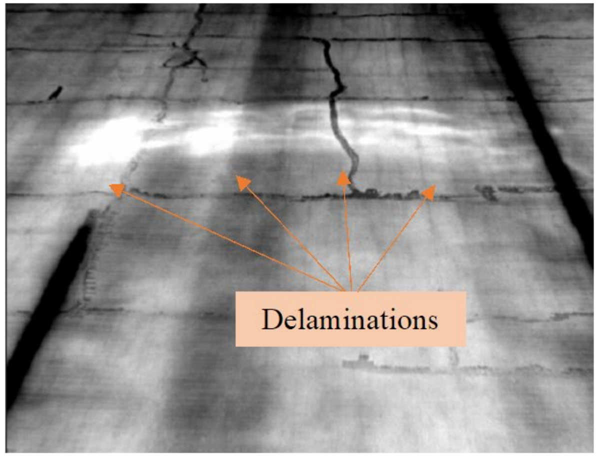
GPR FOR BRIDGE DECKS



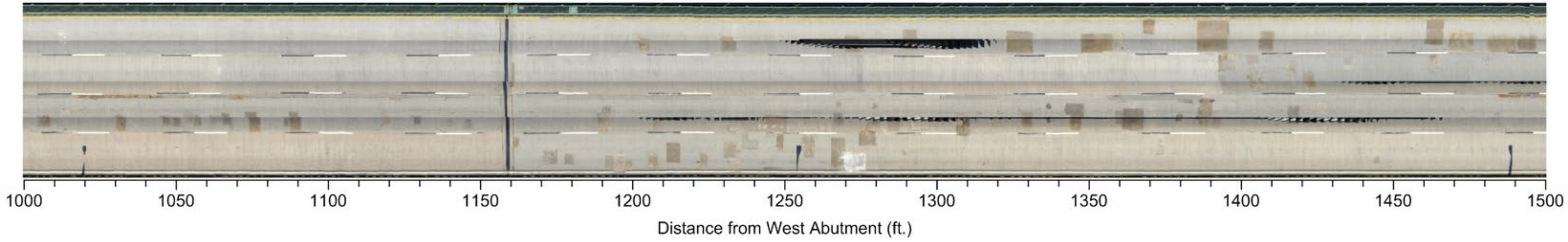
- Electromagnetic waves penetrate elastic materials and reflections are based on the materials dielectric permittivity (ability to absorb light).
- Locates Rebar, Degradation due to corrosion, Moisture, Voids

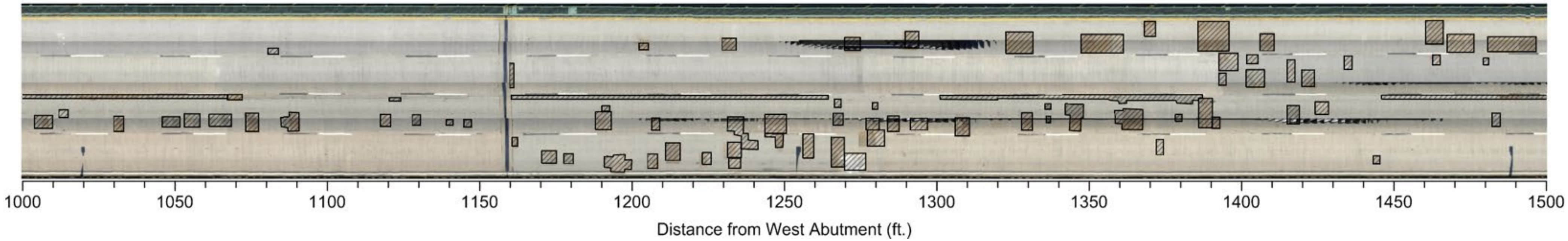
INFRARED THERMOGRAPHY



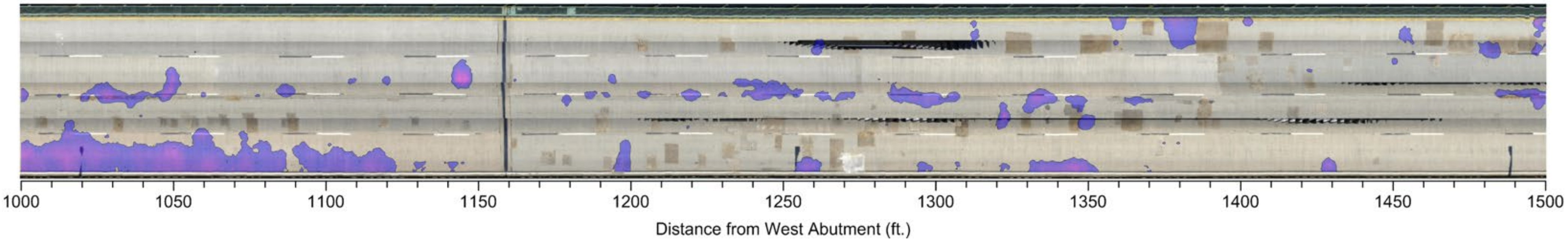


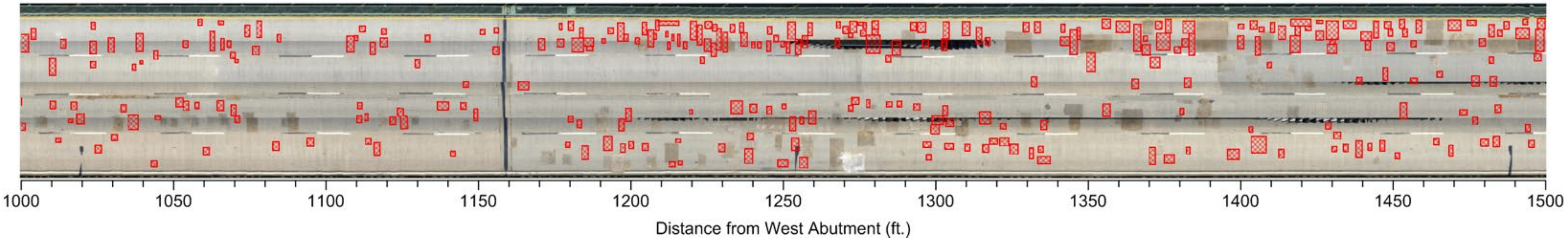
HIGH RESOLUTION VIDEO





GPR AND IR





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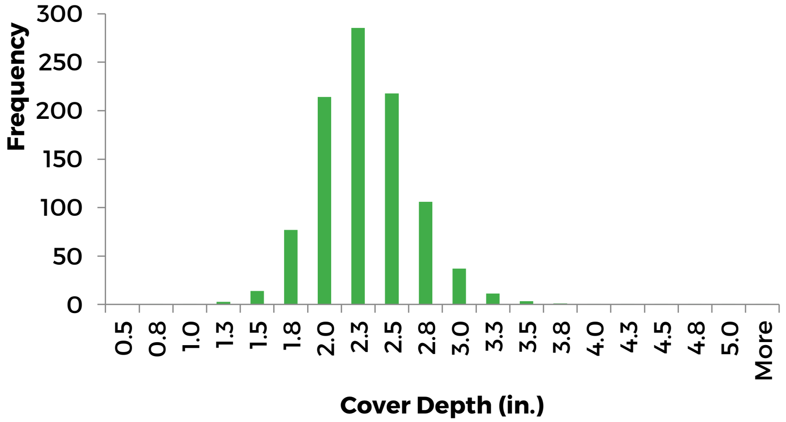
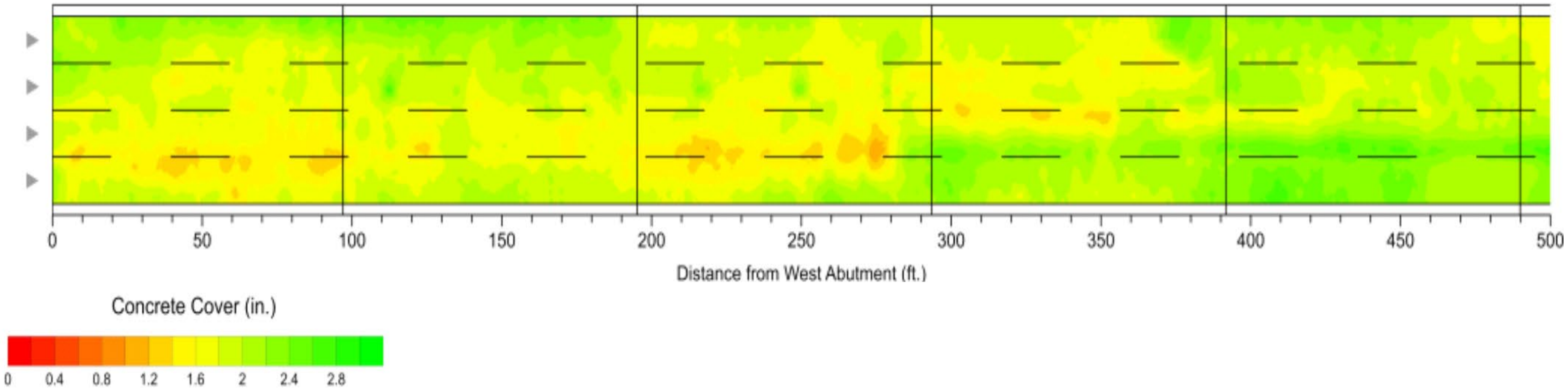
GPR COVER DEPTH





SounDAR

SounDAR

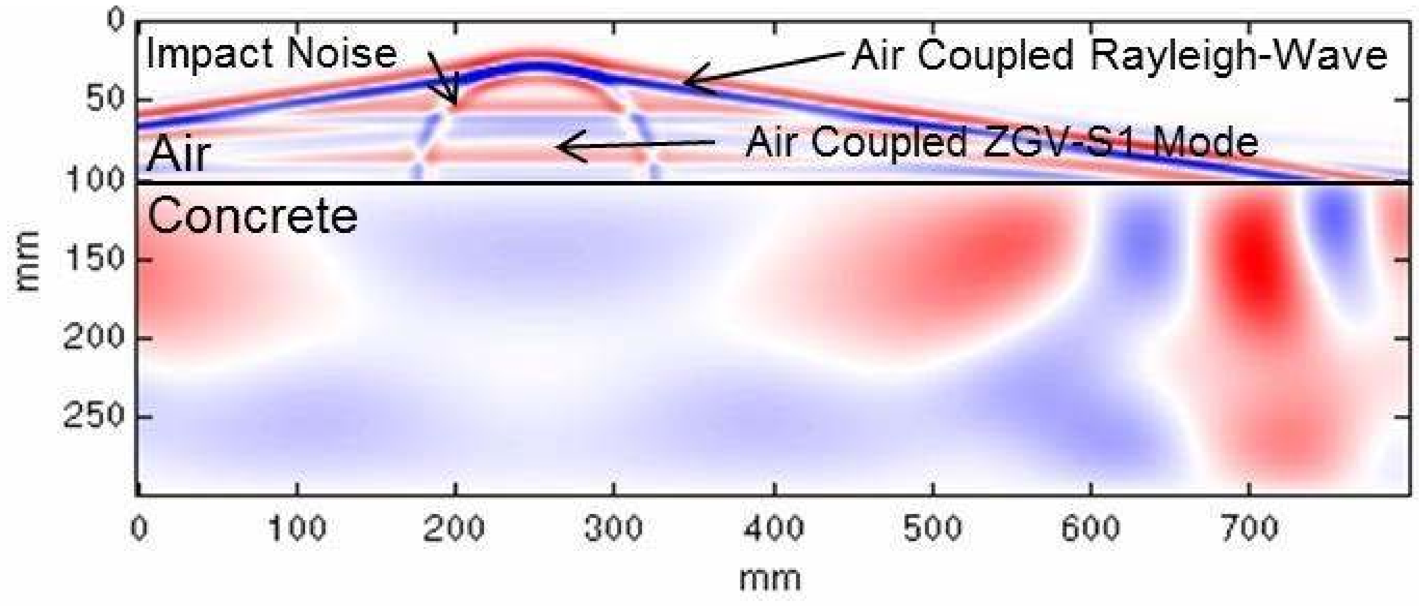
AIR COUPLED IMPACT ECHO

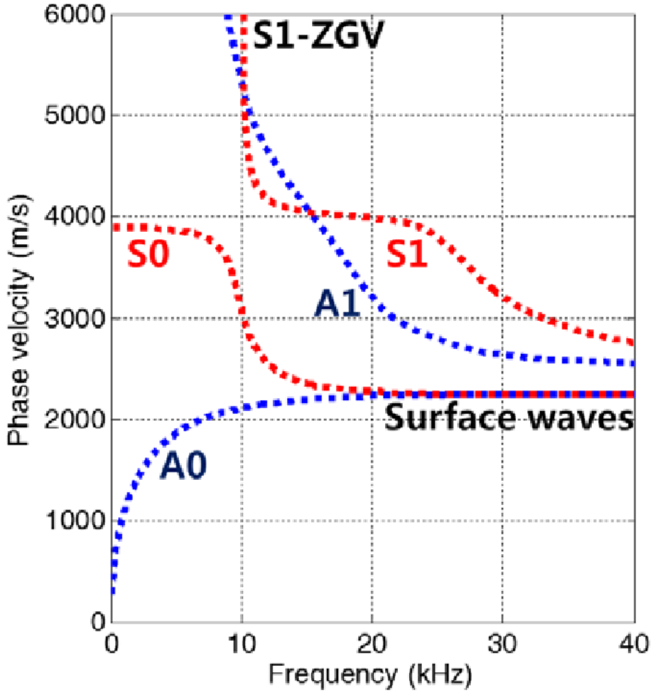
- Modular impactors – spheres can be adjusted from 6mm to 25mm
  - Smaller spheres result in shorter impact times and higher frequency dynamic induction.
- Impacts are ~40ms apart to avoid acoustic crosstalk
- Microphones are designed to focus the acoustic energy and isolate external noise (primarily traffic noise).

Source: Groschup, R., Ugrosse, C., 2015.
Hajin, C., Azari, H., 2018 ®@

AIR COUPLED IMPACT ECHO

- 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.





Source: Groschup, R., Ugrosse, C., 2015.
Hajin, C., Azari, H., 2018

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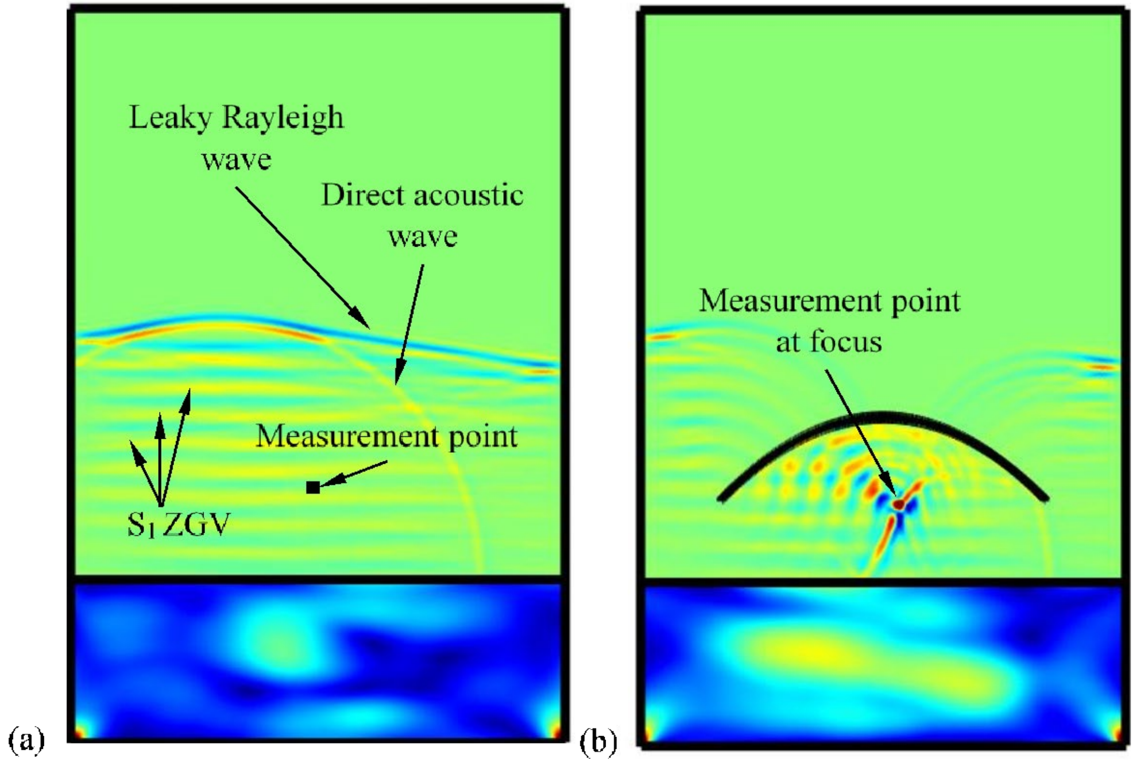
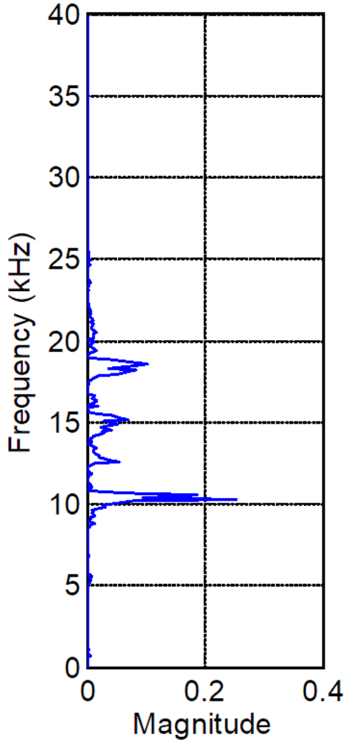
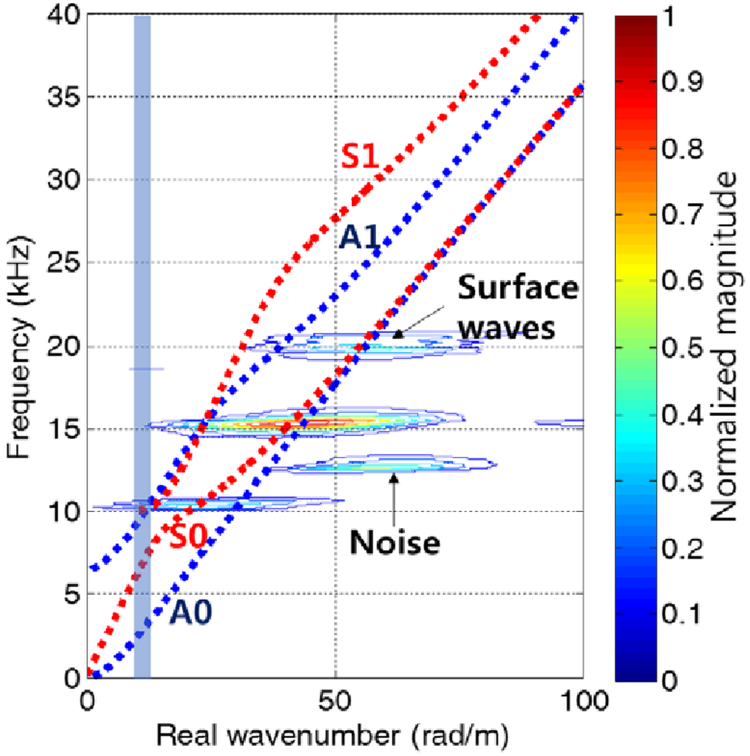
EFFORTS TO FOCUS S1ZGV WAVE

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







Source: Ashlock, J., Phares, B., 2015.
Choi, H., Azari, H., 2018

LITERATURE

- Zhu, J., Popovics, J., "Imaging Concrete Structures Using Air-Coupled IE," ASCE 2007.
- Tinkey, Y., Olson, L., "Vehicle-Mounted Bridge Deck Scanner," NCHRP IDEA 132, 2010.
- Popovics, J., "Full-Lane Acoustic Scanning Method for Deck NDE," NCHRP IDEA 134, 2010.
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- Ashlock, J., Phares, B., "Evaluation of Air-Coupled IE Test Method," MATC-ISU: 231, 2015.
- Groschup, R., Ugrosse, C., "Enhancing Air-Coupled IE with Microphone Arrays," BAM, 2015.
- Epp., T., et al., "Automated Air-Couple IE based on NDT using Machine Learning," SPIE, 2017.
- Choi, H., Azari, H., "DSP of Air-Coupled IE Using Guided Wave Analysis," FHWA, 2018.

HOW DOES IE DIFFER FROM SOUNDING?

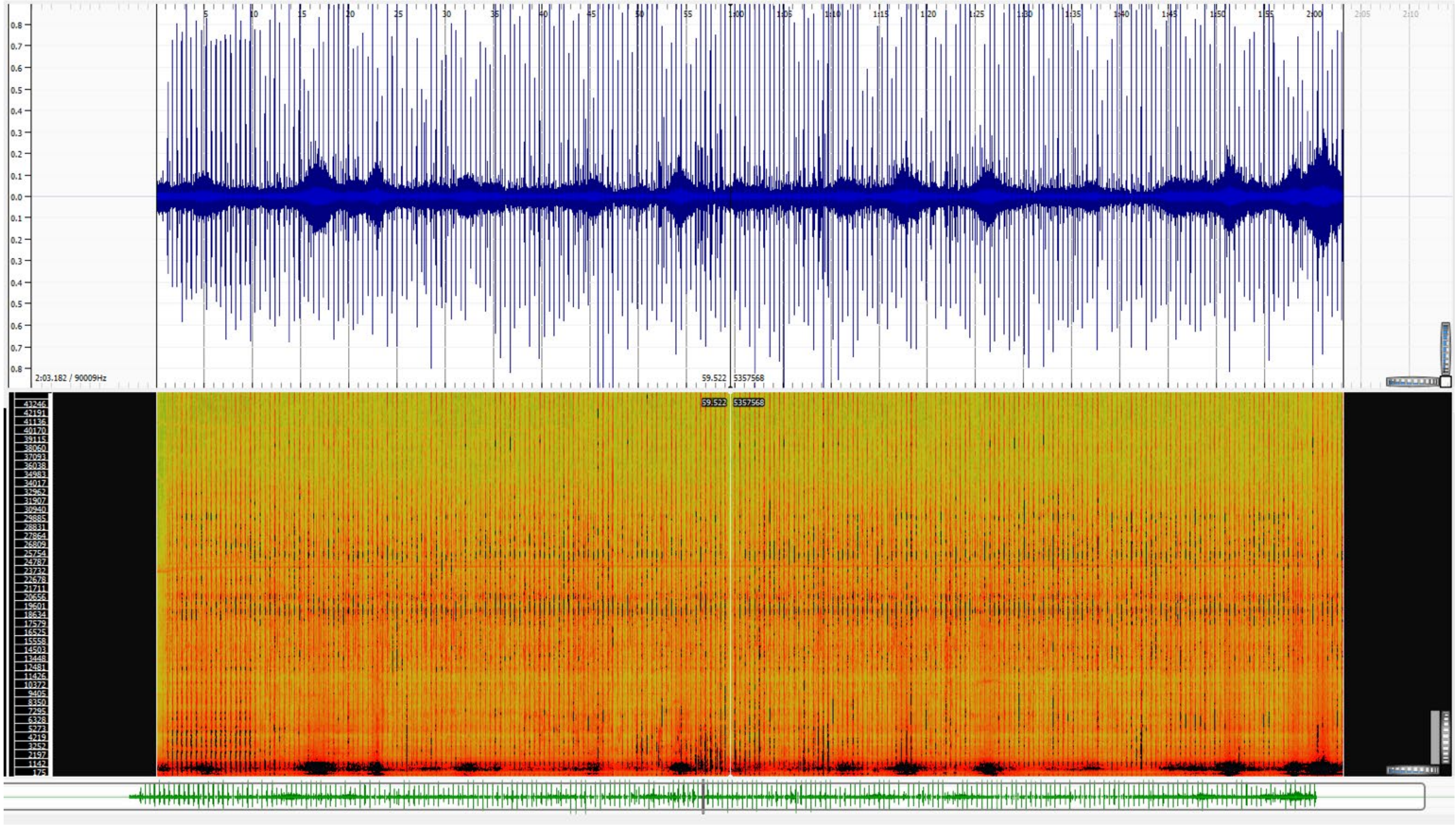
- IE has always focused on identifying a specific frequency that corresponds to the depth of some boundary (void, bottom of slab, etc.)
- Sounding relies on the human ear to perceive difference between an area of intact and non-intact concrete.

- 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.

UNFILTERED DATA



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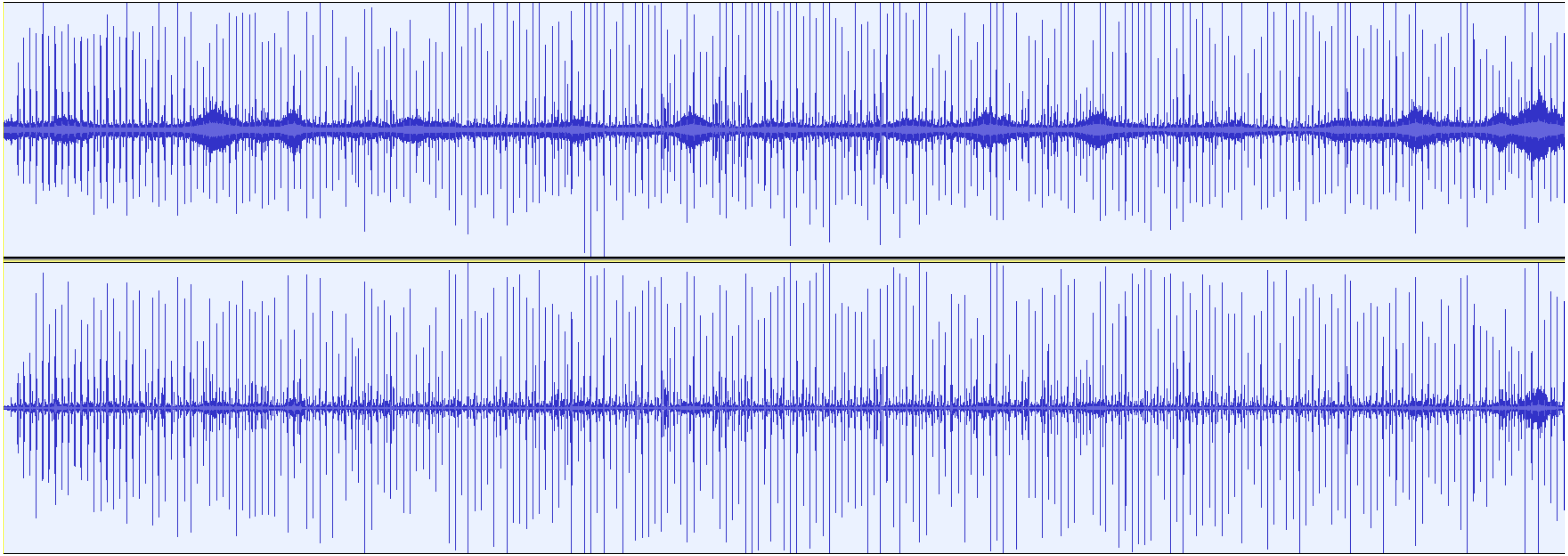
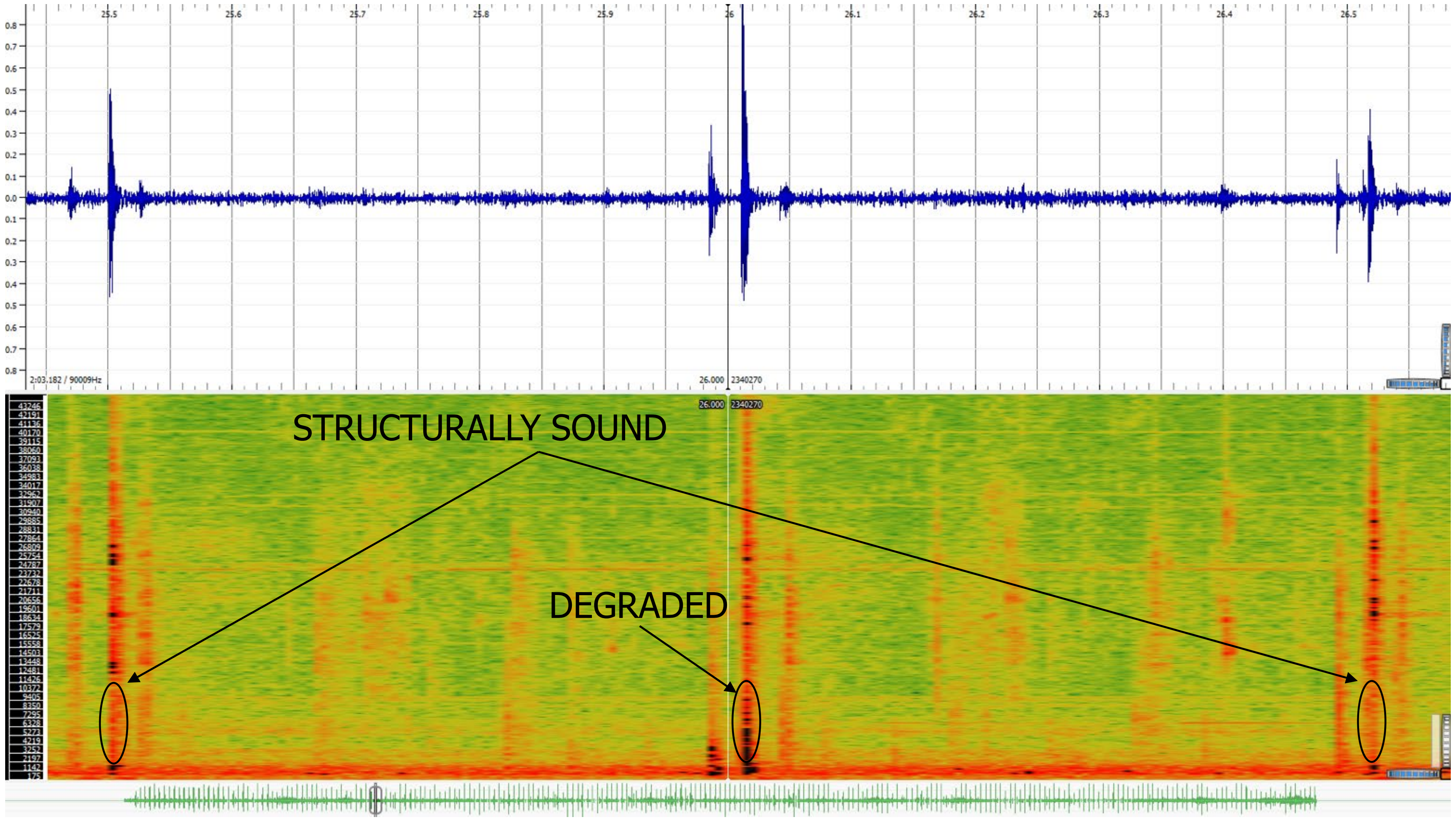
FILTERED DATA



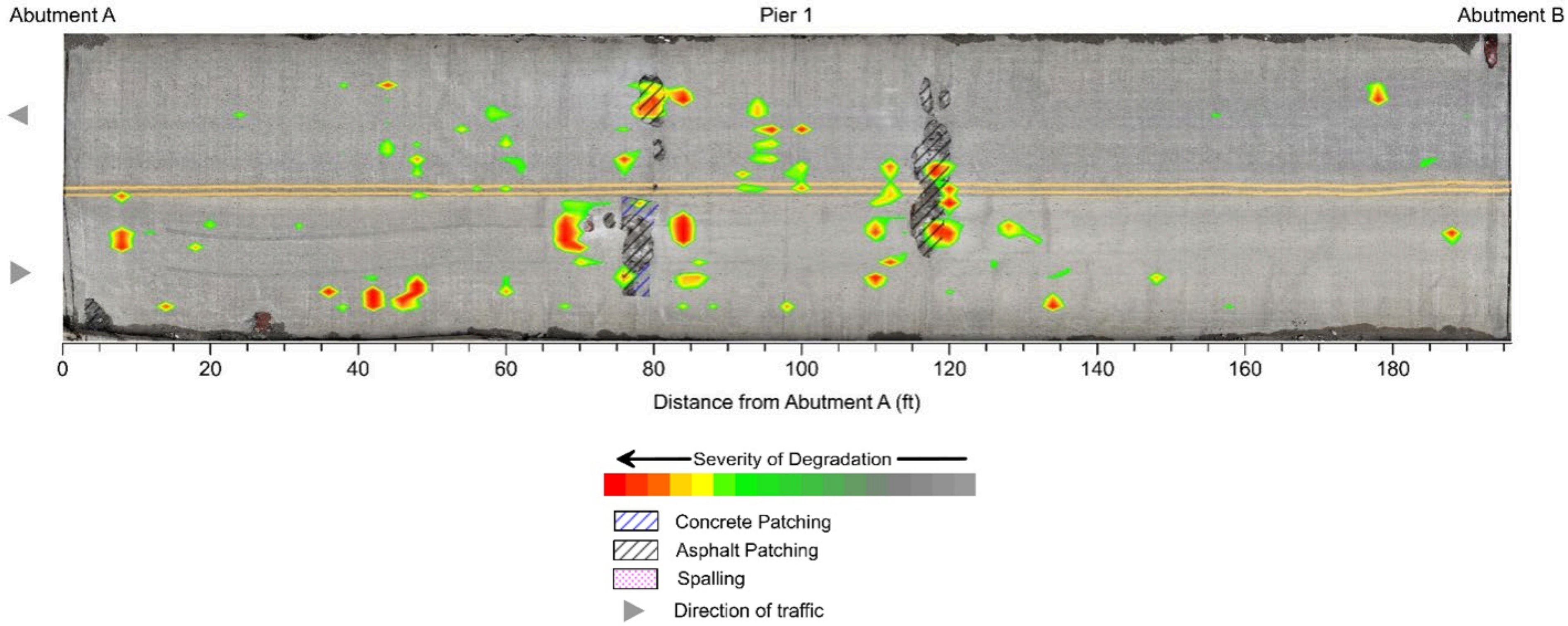
SPECTROGRAM OF FILTERED DATA



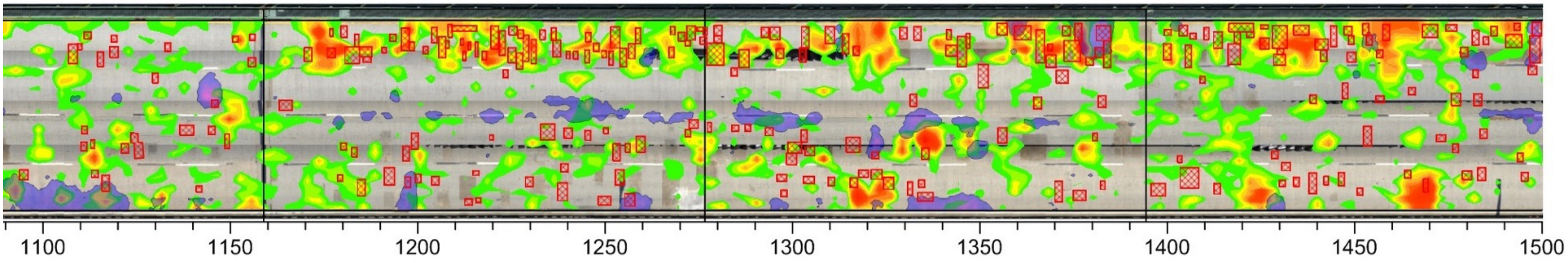
SounDAR ANALYSIS AUTOMATION

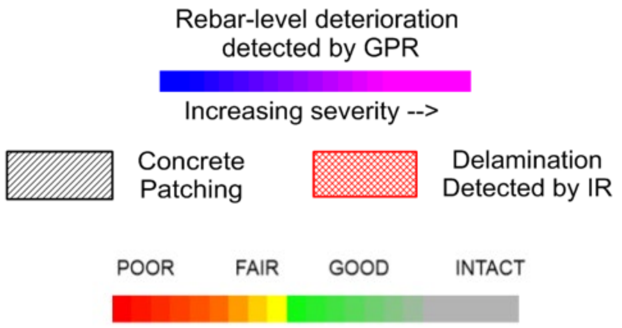
SounDAR RESULTS

- 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.





RAW DATA.
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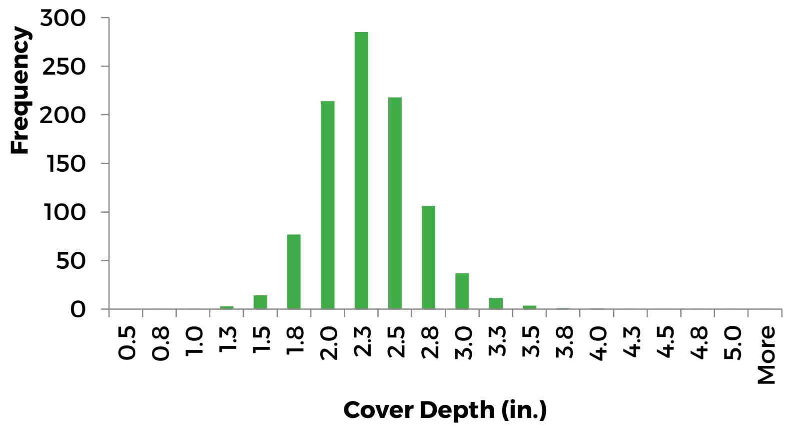
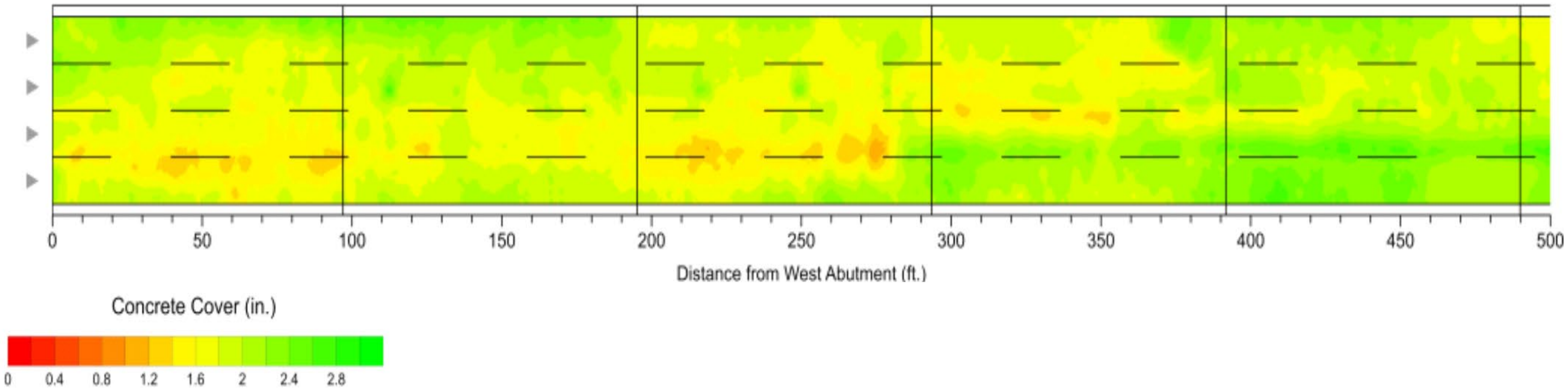
Cover depth

- Distribution of clear cover indicates which top mat bars will be affected earliest
- Statistical sampling can be derived from GPR linescans

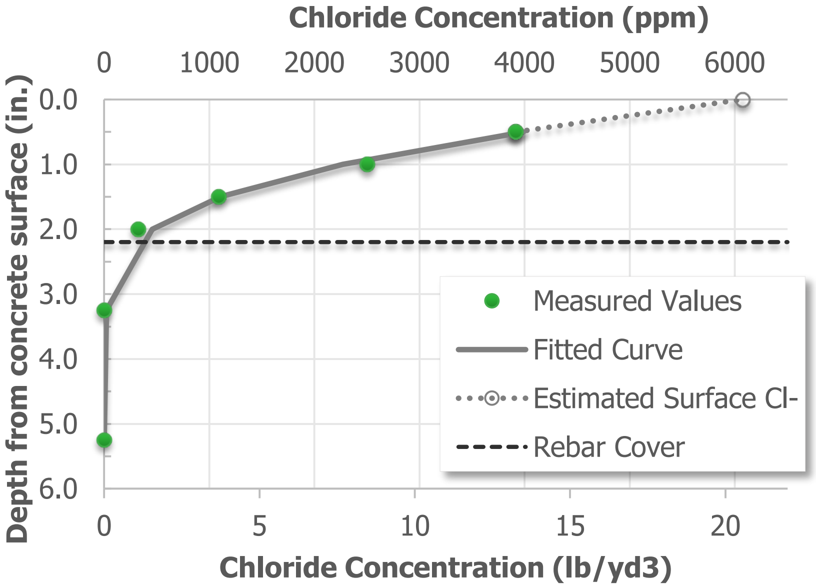




Corrosion-based service life

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



Corrosion-based service life

Basic diffusion model

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

where:

$C_{x,t}$ = Concentration of species (Cl^-) at specified depth and time (lb Cl^-/yd^3 concrete)

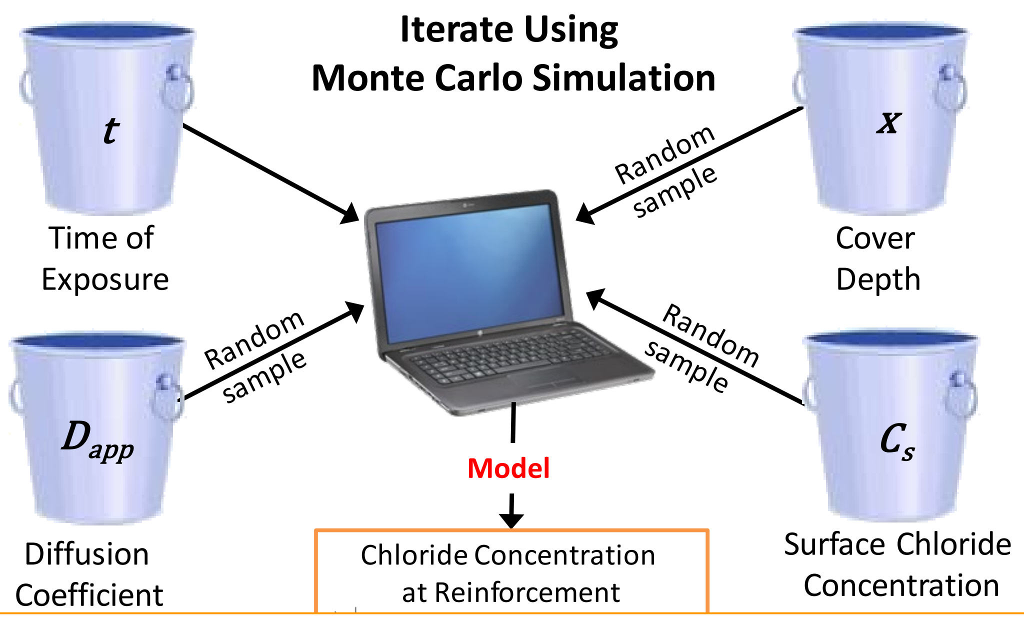
C_o = Concentration of species (Cl^-) at/near surface that drives diffusion (lb Cl^-/yd^3 concrete)

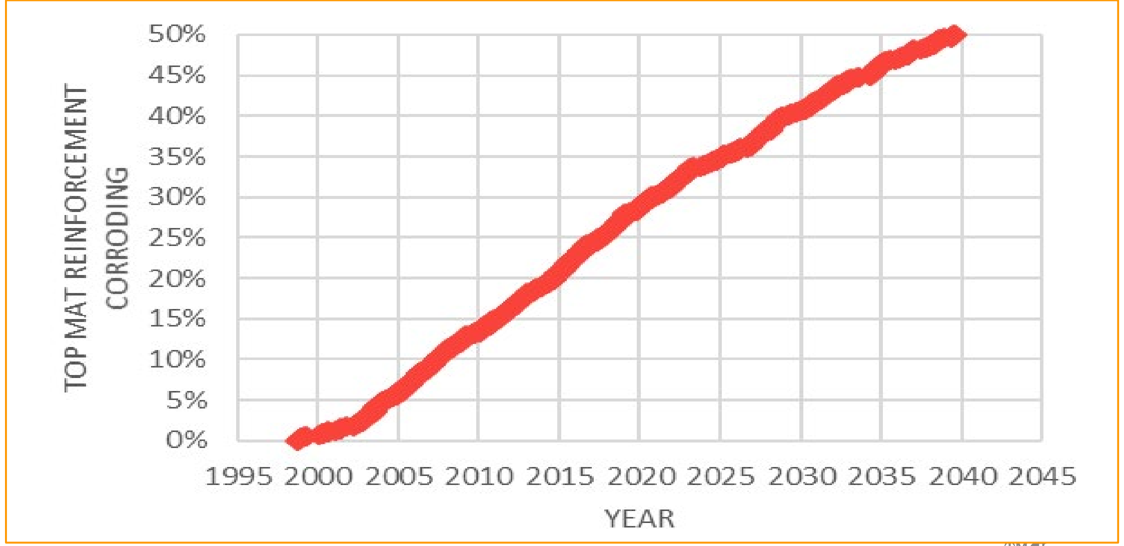
D_c = Coefficient that describes diffusion rate of species through the medium (in^2/yr)

x = Depth from the surface (in)

t = time over which diffusion occurs (yrs)

erf = mathematical error function





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Synthesis of Conventional and NDE results

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

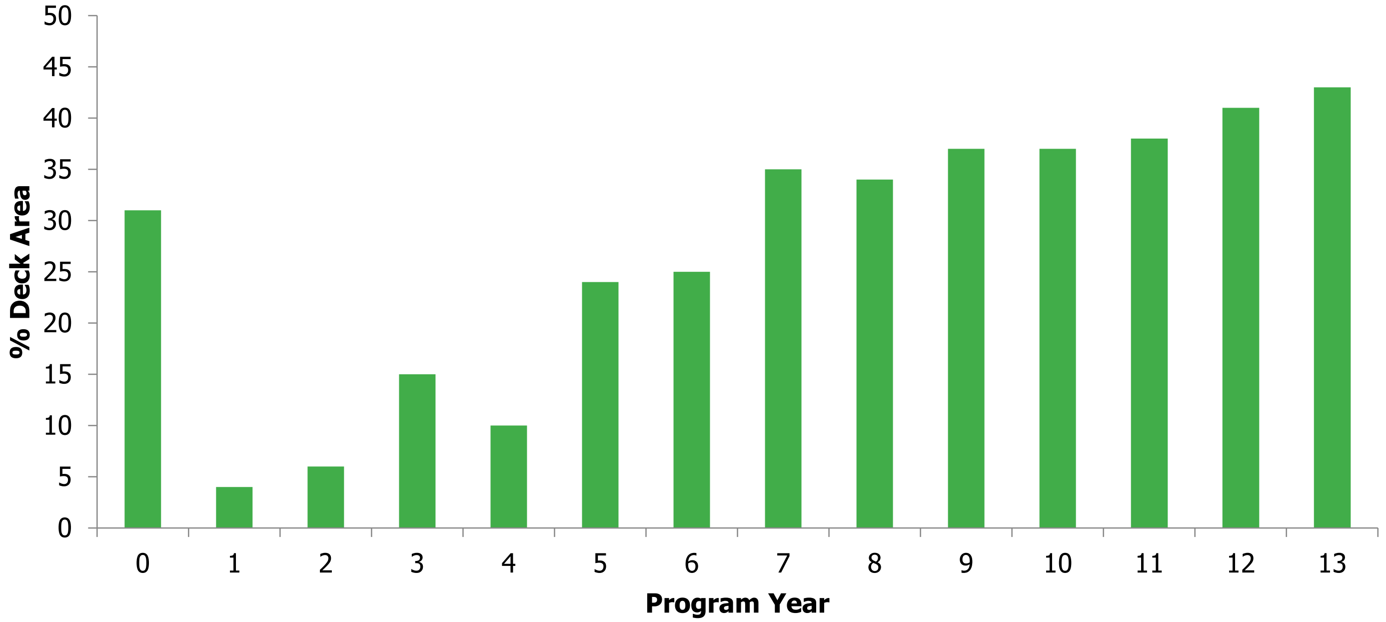
$$\boldsymbol{CI}\% = k_1 \times \boldsymbol{SL}\% + k_2 \times \boldsymbol{GPR}\% + k_3 \times \boldsymbol{IR}\% + k_4 \times \boldsymbol{DAR}\% + k_1 \times \boldsymbol{HVR}\%$$

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
k1, k2, k3, k4, k5 = weighting coefficients chosen by engineering judgement;
$n = 1$ to 5, $kn < 1$; $\sum(k1, k2, k3, k4, k5) = 1$

Current and Future Condition Assessment

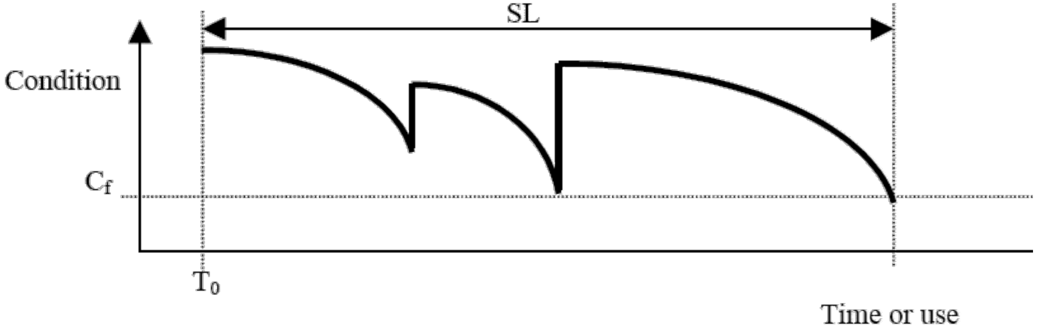
- Emphasize DAR, IR and HRV for current damage assessment to define expected repair quantities for near-term repair
- Emphasize corrosion service life (SL) and GPR components to predict future needs



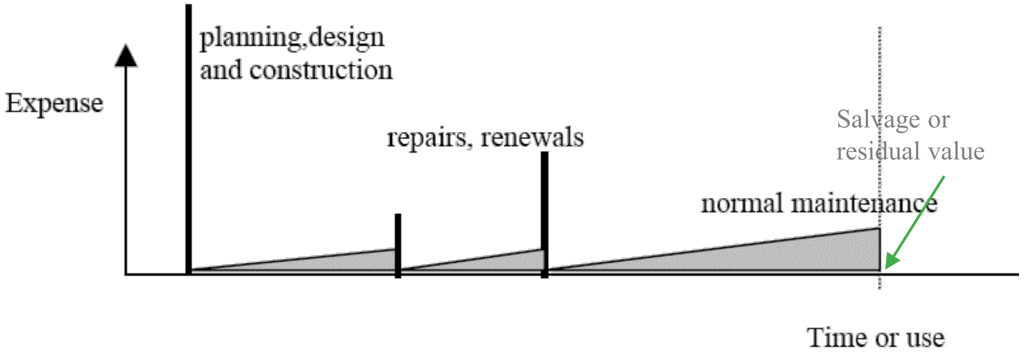
Trend in Patching Needs Based on Current Condition and Deterioration

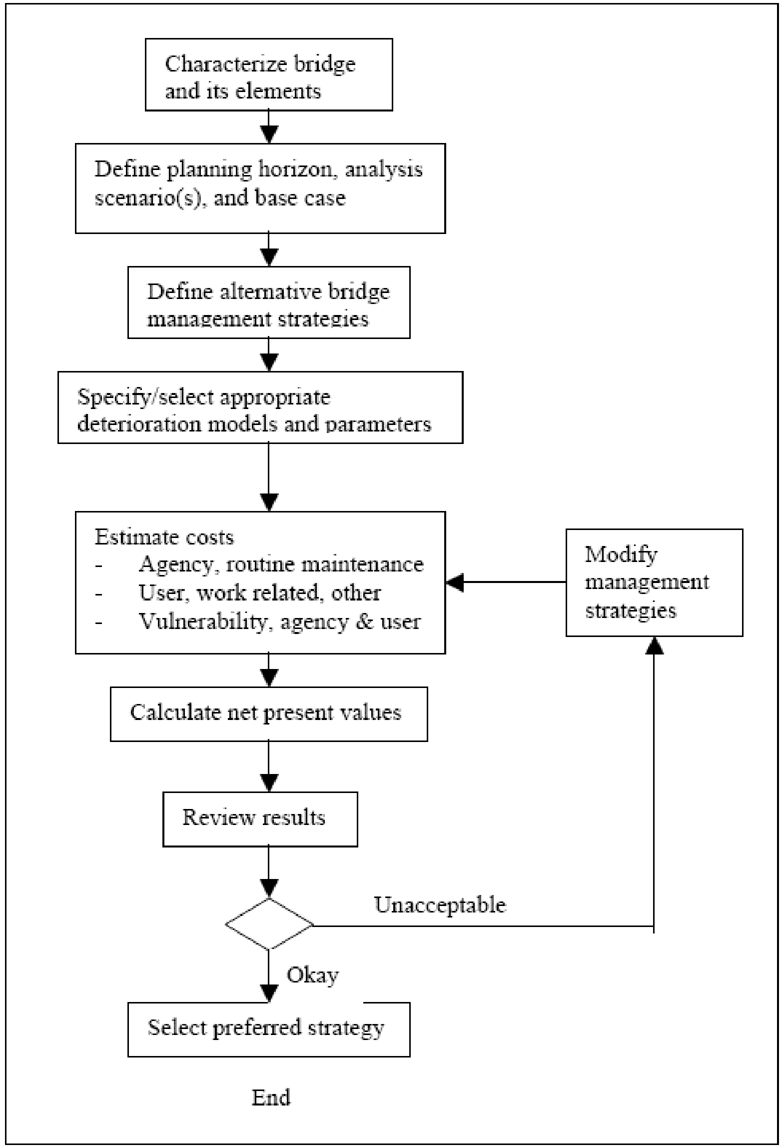
Life-Cycle Cost Analysis

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

Life Cycle Cost Analysis

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.

HAVE WE ACHIEVED OUR GOALS?

- 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.

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