Case Studies and Recommendations for Repeatable NDE Surface and Subsurface Bridge Deck Condition Assessment

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Brief Company Info

NEXCO-West USA, Inc.

- Visual and Infrared Scanning Experience: 23+ years
- GPR Analysis Experience: 11+ years

iSee, LLC

- Roadway and Civil Infrastructure Experience: 37+ years
- GPR Experience: 11+ years

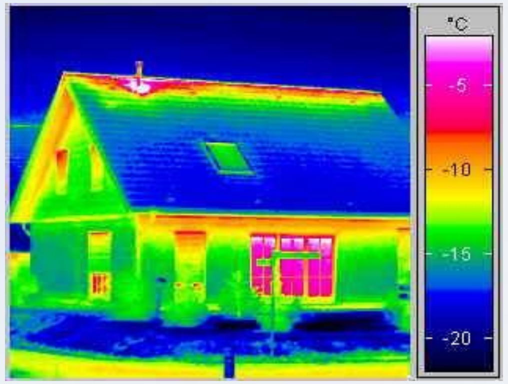
A Bit of NDT History

Ultrasonics (UT)

- Invented in 1920s
- Materials testing device patented in 1940s
- Consumer models available in 1970s

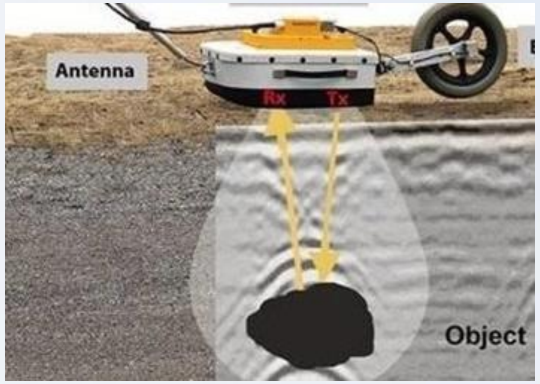
Infrared Thermography (IRT)

- Invented in 1870s
- Development during WWII for threat detection
- Consumer cameras available in 1960s



Ground-Penetrating Radar (GPR)

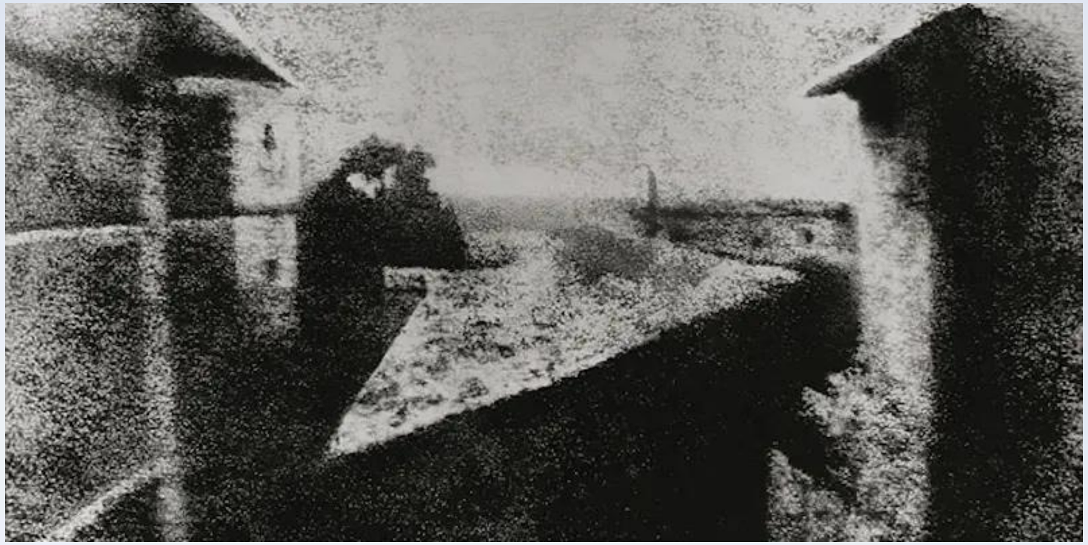
- Invented in 1930s
- Glacier depth measurement applications set stage for further development
- Consumer antennas available 1970s



Even Before Then… Photography!

- Invented in 1820s
- Consumer digital cameras released in 1980s

The first photograph: *View from the Window at Le Gras*



Gap Between Availability in the Market and Regular Use in Civil Industry

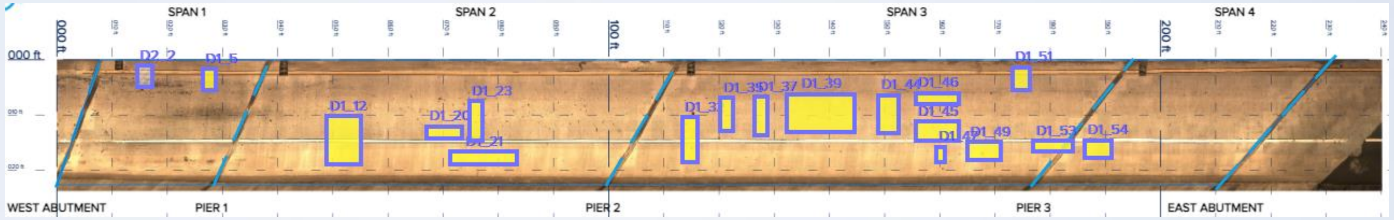
Ultrasonics	2024 – 1970 = 54 years
IRT	2024 – 1980 = 44 years
GPR	2024 – 1970 = 54 years
Visual	2024 – 1980 = 44 years

= About 50 years of visual or NDT-based record-keeping not fully utilized!

One Clarification

Individual photos represent typical findings.

A complete “stitched” surface (or recently full scaled model)



On-foot Applications and Direct Contact Methods

- Limited collection potential for large areas

- Advantageous for small-scale or follow-up investigations

Ultrasonic

Half-cell Potential

Vehicular, UAV, Aerial-Mounted Methods

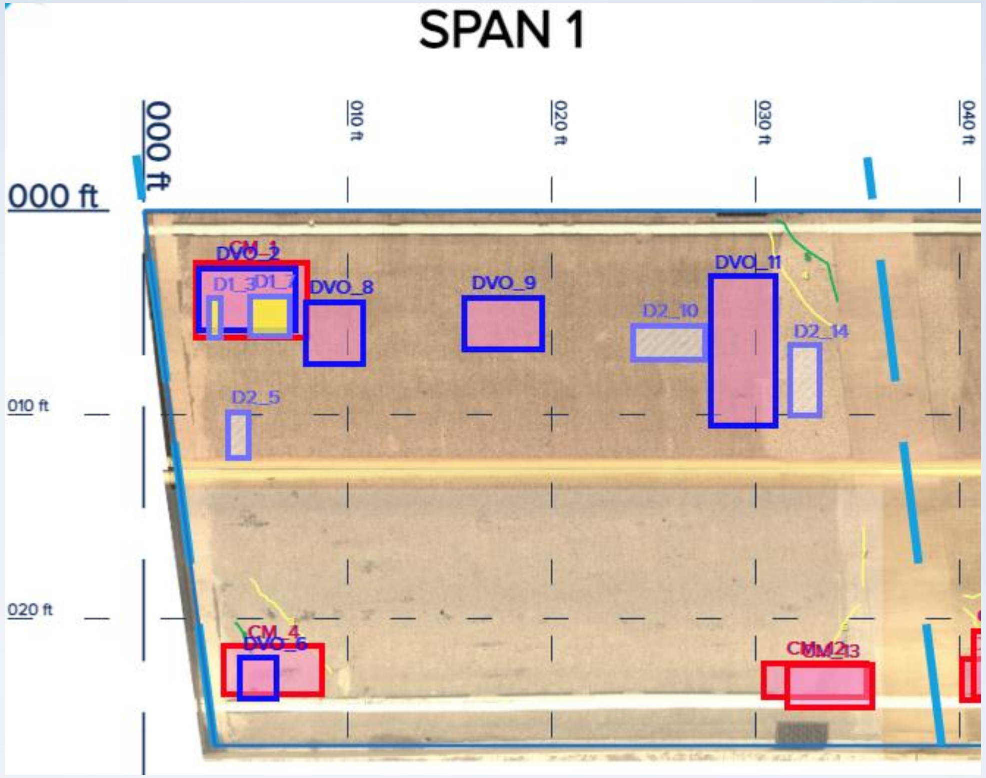
- Greatly enhanced collection potential for large areas

- May or may not provide 100% definitive results, but that's *not the primary intent*.
  - It's to get a reasonable assessment of <u>full-deck area condition state</u>.
  - Note: the rest of the presentation will refer to these rapid acquisition types

How Can Visual and NDT Methods Be Put to Use?

Typical Goals of NDT/E Investigation

1. Detect deficient features in concrete, asphalt, steel
2. Locate/map reinforcement, utilities, structural layers
3. Measure subsurface depths (incl cover depth)

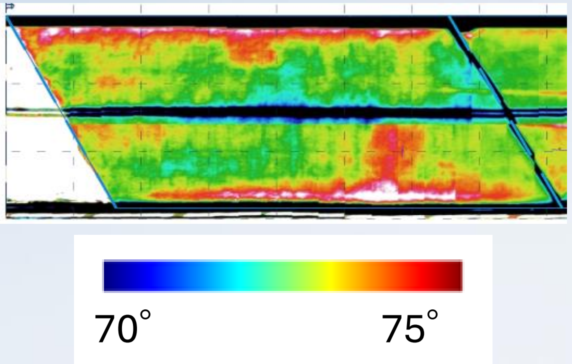


Reception (from 2010 to present)

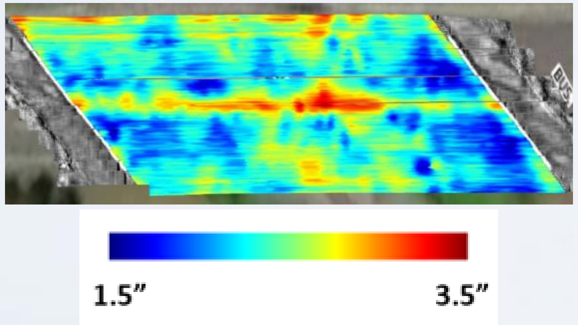
- Still skeptical. Few explanations for this:
- 100% detection confidence issue: the reality is, perfectly collected results are historically 80-90%. This is not a terrible thing, mainly for two reasons:
    1. NDT data advises further action and does not provide a complete, holistic inspection report diagnosing all factors contributing to structural health. But it introduces an efficiency in quantifying deficient findings that should not be ignored.
    2. Remember the other widely used applications? Military, medical, materials. The same issue exists, but acceptance levels of NDT use are higher.

Reception (from 2010 to present)

- Results from differing NDT methods take some time to understand.
  - Reporting on a complex structure warrants equally complex reporting.
  - “Red” doesn’t always mean “bad”. “Green” doesn’t always mean “good”.



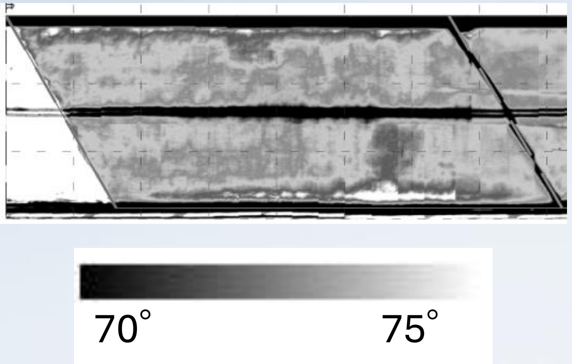
This map measures temperature.



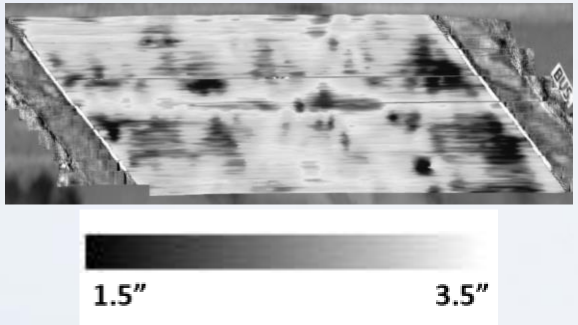
This map measures depth.

Reception (from 2010 to present)

- There's always the option to report everything in grayscale!



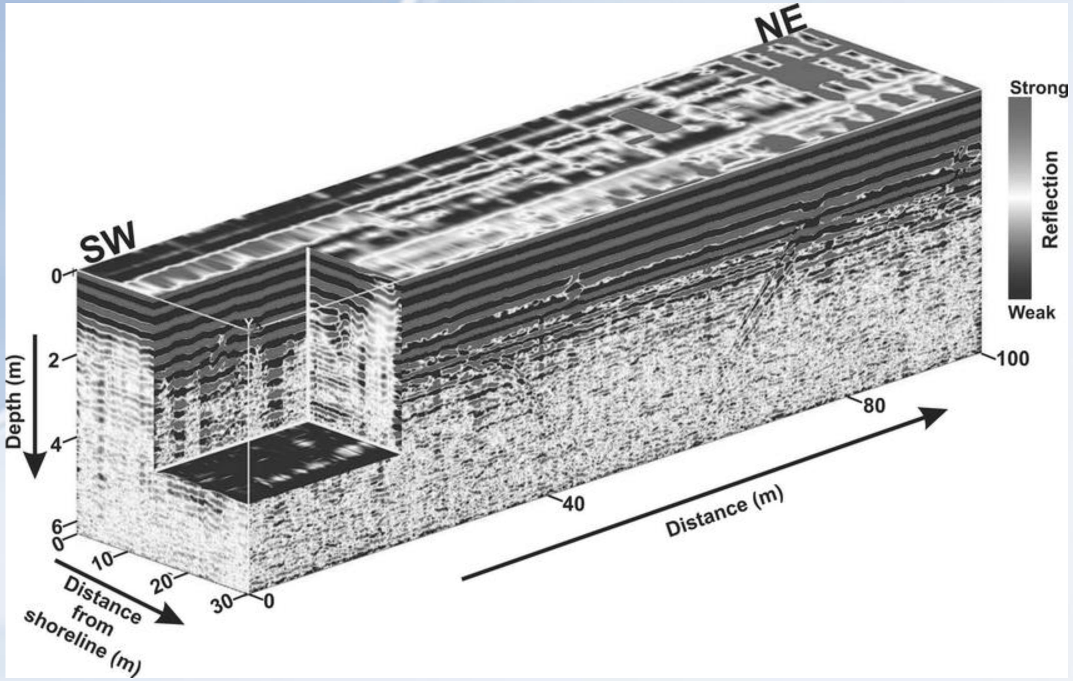
This map measures temperature.



This map measures depth.

Reception (from 2010 to present)

- Showing 3D analysis inside a 2D PDF file.



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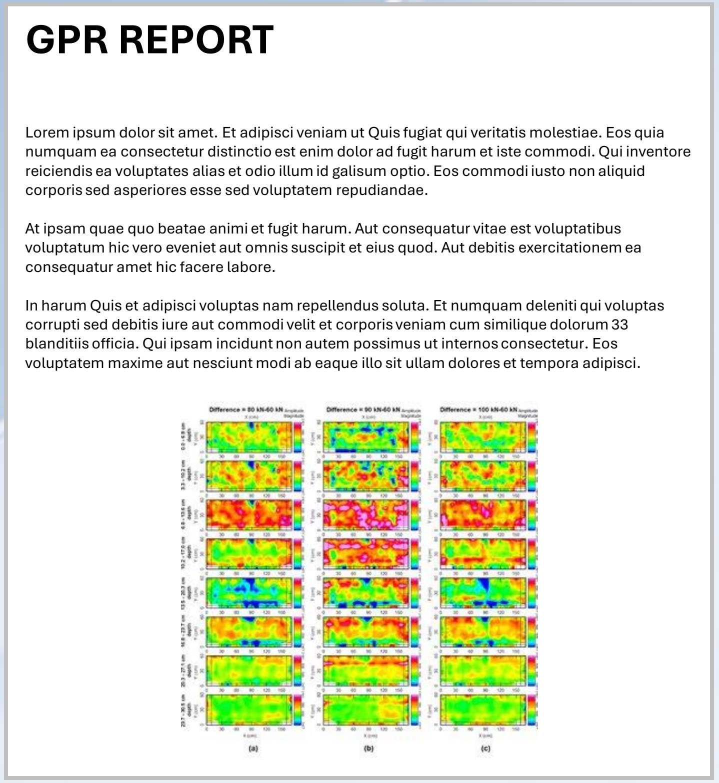

GPR REPORT

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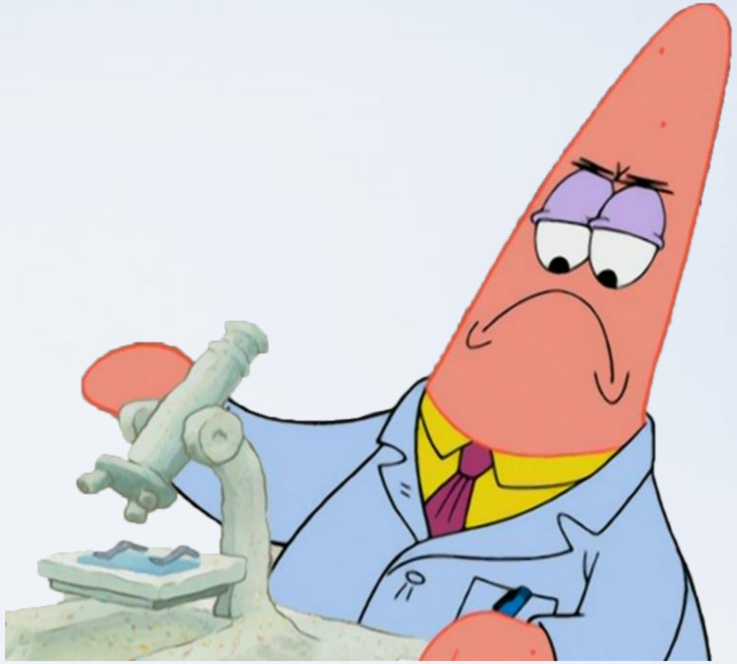


Reception (from 2010 to present)

- ASTM, AASHTO, NBIS do not consider reporting 3D quantities (volume).
  - It is somewhat unrealistic to generate accurate volume quantities anyhow, you'd need to run the bridge deck through something like an MRI machine…

…there are alternatives!

What can we do going forward?

- Lack of standard practices for presenting analysis results.
  - Civil applications have standards for data collection, but they still lack standards of practice when it comes to analysis and representation of findings.
  - Perhaps a more structured, routinized approach would increase confidence and acceptance levels.

☆ So how do we add to the current standards?

Review of Organizations Upholding NDT Standards

1. American Society for Nondestructive Testing (ASNT)

- SNT-TC-1A: A recommended practice for the qualification and certification of NDT personnel.
- CP-189: A standard for the qualification and certification of NDT personnel.

ASNT NDT Level II and III Programs: Certification program for NDT Level III personnel.

2. American Society for Testing and Materials (ASTM)

- Various Standards

3. American Society of Mechanical Engineers (ASME)

- ASME Section V: For boilers, pressure vessels, nuclear power plants.

4. Federal Aviation Administration (FAA)

- FAA Advisory Circulars (AC): Various ACs cover the use of NDT in the aviation industry, such as AC 43.13-1B for acceptable methods, techniques, and practices in aircraft inspection.

5. International Organization for Standardization (ISO)

- ISO 9712: International standards for the qualification and certification of NDT personnel, which is often referenced in the US alongside other standards.

6. NACE International

- NACE SP0194: Standard practice for field monitoring of galvanic anode systems.
- NACE MR0175/ISO 15156: Materials for use in H2S-containing environments in oil and gas production, which includes NDT methods for ensuring compliance.

ASNT

- Geared toward materials testing, doesn't consider vehicle-mounted or UAV-mounted collection methods.
- No GPR category offered

- Both NDT and direct visual confirmation courses offered in certain fields, Level II and III

ASTM

- Current standards for IRT, GPR specify minimum quality requirements for equipment and data collection, but are lacking in terms of presenting analysis results, understandably so to allow for advances in technology and customization.

- ASTM D4788-03: Standard Test Method for Detecting Delaminations in Bridge Decks Using Infrared Thermography
- ASTM D6087-22: Standard Test Method for Evaluating Asphalt-Covered Concrete Bridge Decks Using Ground Penetrating Radar

Just 9 sentences of guidance...

7. Interpretation and Plotting of Results

7.1 Plot the delaminations on a scaled plan of the bridge deck using either a manual or a computerized process.

7.2 Total the delaminated areas and present as a percentage of the total deck area in square feet (square metres).

8. Report

8.1 The report shall include the following information:

8.1.1 Bridge location and description,

8.1.2 Survey methods used and description thereof, including equipment used and the operators' names,

8.1.3 Data of test and environmental conditions,

8.1.4 Scaled plan of the bridge deck showing the areas of delamination and debonding,

8.1.5 Area of the bridge deck, ft^2 (m^2) and the percentage of the area delaminated or debonded, and

8.1.6 Location and condition of any cores taken.

AASHTO

- Prescribes how to classify and quantify findings following a visual or hands-on inspection.
- The result is typically a table which looks something like the following slide…

Element 12: Reinforced Concrete Deck

Defects	CS 1 GOOD	CS 2 FAIR	CS 3 POOR	CS 4 SEVERE
Delamination/Spall/ Patched Area (1080)	None.	Delaminated. Spall 1 in. or less deep or 6 in. or less in diameter. Patched area that is sound.	Spall greater than 1 in. deep or greater than 6 in. diameter. Patched area that is unsound or showing distress. Does not warrant structural review.	The condition warrants a structural review to determine the effect on strength or serviceability of the element or bridge; OR a structural review has been completed and the defects impact strength or serviceability of the element or bridge.
Exposed Rebar (1090)	None.	Present without measurable section loss.	Present with measurable section loss but does not warrant structural review.	
Efflorescence/Rust Staining (1120)	None.	Surface white without build-up or leaching without rust staining.	Heavy build-up with rust staining.	
Cracking (RC) (1130)	Insignificant cracks or moderate-width cracks that have been sealed.	Unsealed moderate-width cracks, or unsealed moderate pattern (map) cracking.	Wide cracks or heavy pattern (map) cracking.	
Abrasion/Wear (PSC/RC) (1190)	No abrasion or wearing.	Abrasion or wearing has exposed coarse aggregate but the aggregate remains secure in the concrete.	Coarse aggregate is loose or has popped out of the concrete matrix due to abrasion or wear.	
Settlement (4000)	None.	Exists within tolerable limits or arrested with no observed structural distress.	Exceeds tolerable limits but does not warrant structural review.	
Scour (6000)	None.	Exists within tolerable limits or has been arrested with effective countermeasures.	Exceeds tolerable limits but is less than the critical limits determined by scour evaluation and does not warrant structural review.	
Damage (7000)	Not applicable.	The element has impact damage. The specific damage caused by the impact has been captured in CS 2 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in CS 3 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in CS 4 under the appropriate material defect entry.

AASHTO

- Surface area covered by deficient findings are summed into CS categories 1-4.
- This becomes a guesstimate for needed repair quantities.

Span: ALL							
Element Number	Element Description	Unit of Measure	Total Quantity	Condition State 1	Condition State 2	Condition State 3	Condition State 4
12	Reinforced Concrete Deck (SF)	SF	7938	7554	350	34	0

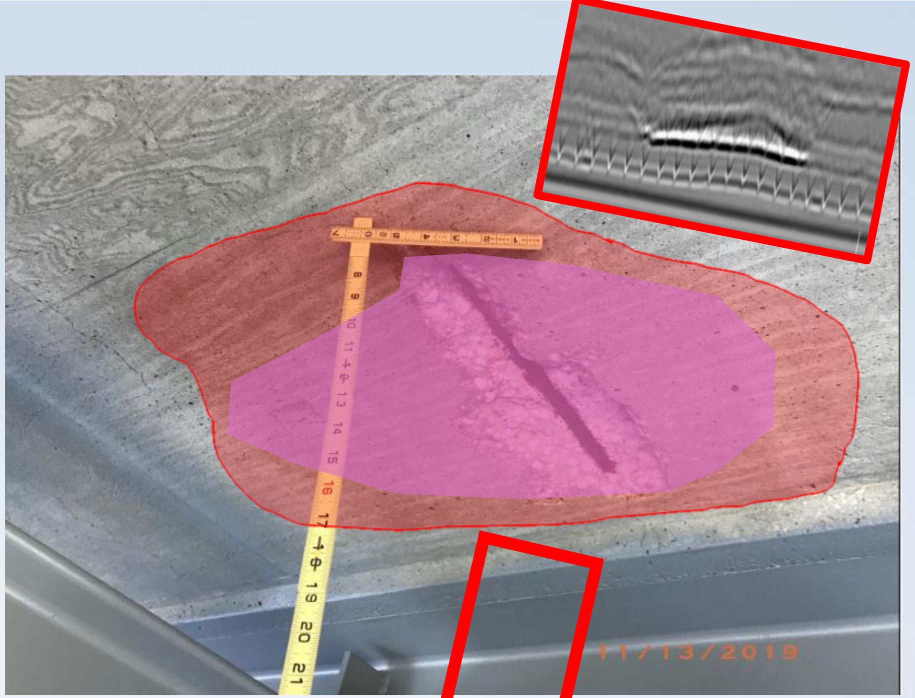
AASHTO

- Let's suppose we scan this deck underside with an IRT camera, and find that a wider area is affected. This offers us a more realistic repair quantity. It may not be the exact repair size needed, but potentially closer than the visual inspection.

Span: ALL							
Element Number	Element Description	Unit of Measure	Total Quantity	Condition State 1	Condition State 2	Condition State 3	Condition State 4
12	Reinforced Concrete Deck (SF)	SF	7938	7554	350	45	0

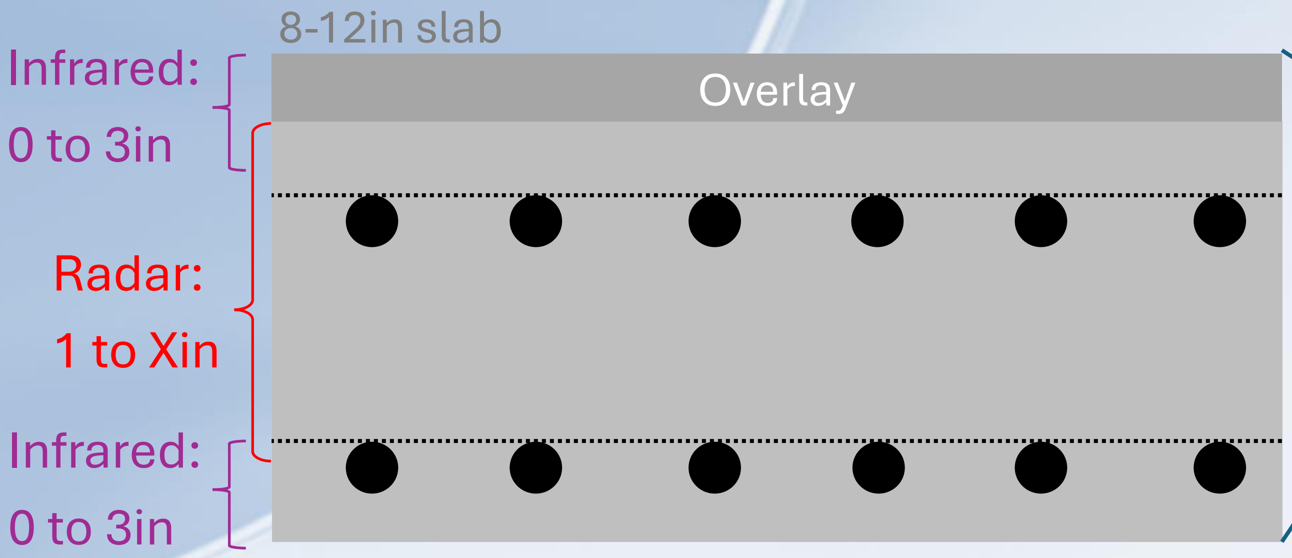
AASHTO

- Now let’s suppose we noticed in a GPR scan evidence of further delamination or corrosion above this area. This is where things get difficult to report, and where I think some discussions need to take place.



Span: ALL							
Element Number	**Element Description**	**Unit of Measure**	**Total Quantity**	**Condition State 1**	**Condition State 2**	**Condition State 3**	**Condition State 4**
12	Reinforced Concrete Deck (SF)	SF	7938	7554	350	**50**	0

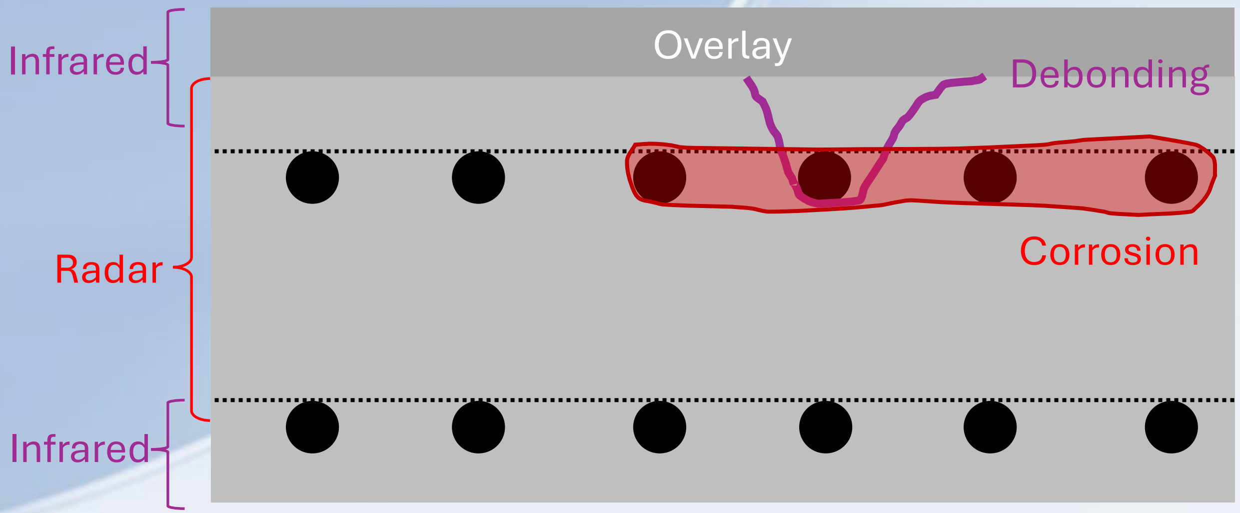
Typical Effective Ranges of Mobile NDE Methods

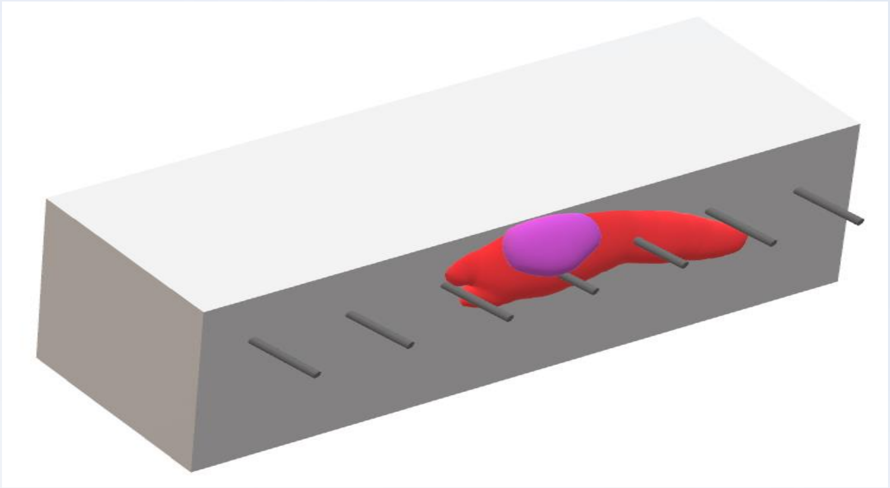


Elevation View

Quantifying This Volumetric Deficiency

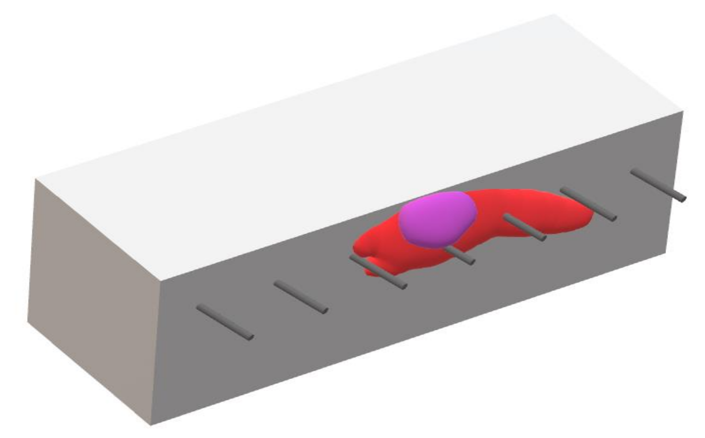
- This hypothetical xample shows two typical findings near rebar depth: evidence of corrosion from GPR signal attenuation and evidence of debonding from IRT hotspot.





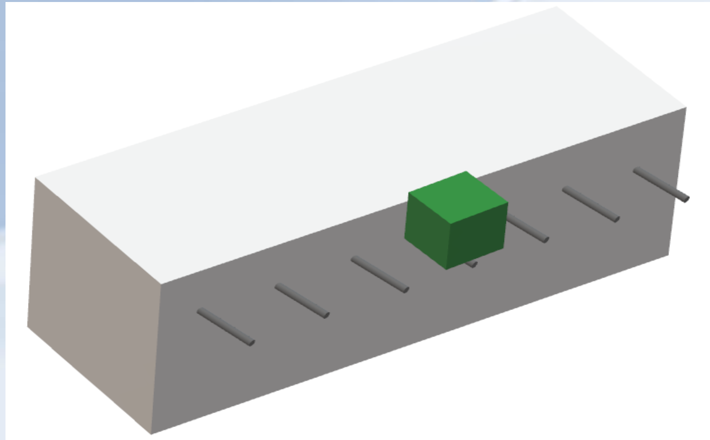
Quantifying This Volumetric Deficiency

Affected Area

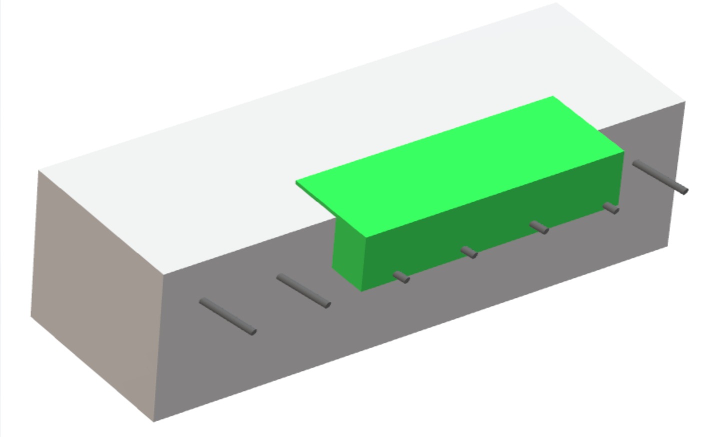


- If the owner decides to repair, the target repair area becomes something like the green areas below, with a choice of addressing potential issues like corrosion or only physically compromised areas which feature cracking, spalling, or debonding.

Repair Area Based on Sounding or IRT



Repair Area Based on GPR



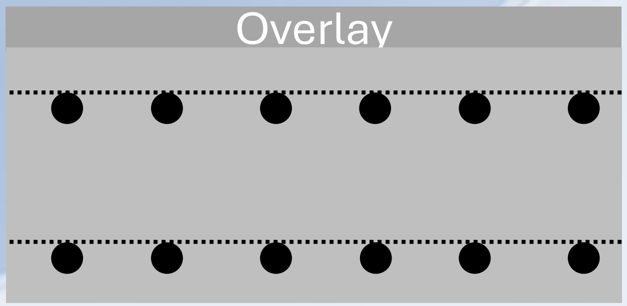
(Note: If low detection confidence levels come into play for whatever reason, coring of representative areas can help this decision making)

Ideas for Standardization

- Divide quantities into relevant depth ranges, then follow AASHTO as closely as possible.

Visual Results

Span 1: Surface Level (0in)					
Deficiency Type	Total Quantity (ft^2)	CS1	CS2	CS3	CS4
Delam/Spall/Patch (1080)	1000	800	150	50	0
Exposed Rebar (1090)	1000	750	150	100	0
Cracking (1130)	1000	950	40	10	0

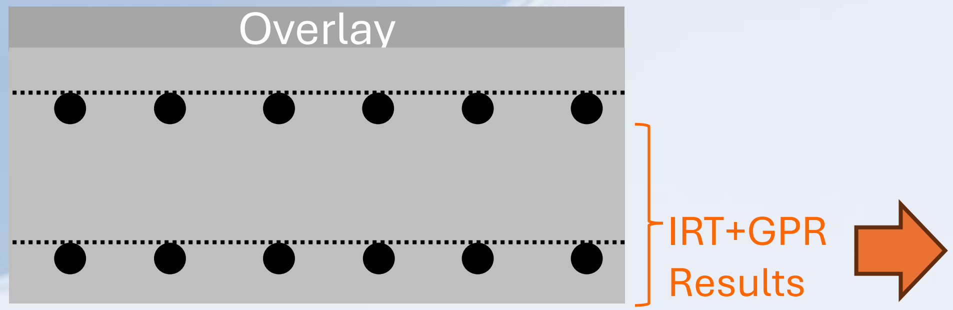


IRT+GPR Results

Span 1: Surface to Top Rebar Depth (0in to 3in)					
Deficiency Type	Total Quantity (ft^2)	CS1	CS2	CS3	CS4
Delam/Spall/Patch (1080)	1000	900	50	50	0
Corroded Rebar (NA) ???	1000	950	10	40	0
Cracking (1130)	1000	1000	0	0	0

Ideas for Standardization

- Continued

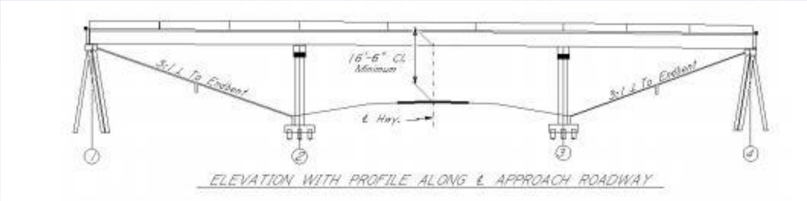


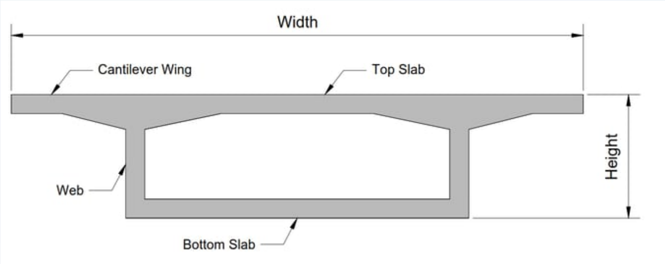
Span 1: Below Top Rebar Depth to End of Slab					
Deficiency Type	Total Quantity (ft^2)	CS1	CS2	CS3	CS4
Delam/Spall/Patch (1080)	1000	800	150	50	0
Corroded Rebar (NA)	1000	750	150	100	0
Cracking (1130)	1000	950	40	10	0

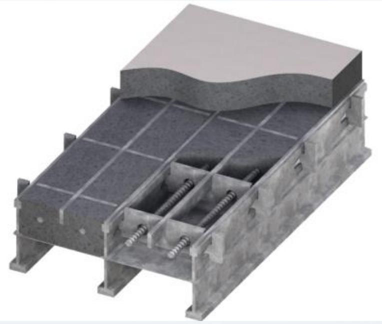
How a Maryland Agency has Structured their Approach

Successful Case Studies for Three Bridge Design Types

- Case Study A: Bread and Butter
- Case Study B: Box Girder
- Case Study C: Concrete Overfilled Steel Grid







Project Workflow (1/3)

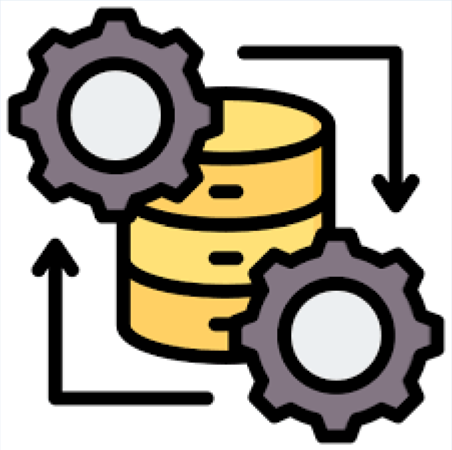
Create list of target bridges to be scanned considering next 2yr inspection cycle.

Discuss and clarify the deliverable formatting with vendor. This is vital, yet often left to end of project. It can create substantial delays.

Data collection and backup.

Project Workflow (2/3)

Data preprocessing and analysis



Deliverable generation

Review and quality checking of deliverables

Project Workflow (3/3)

Hand off results to term contract prime consultant (on-call A/E firm) or relevant structures group at agency

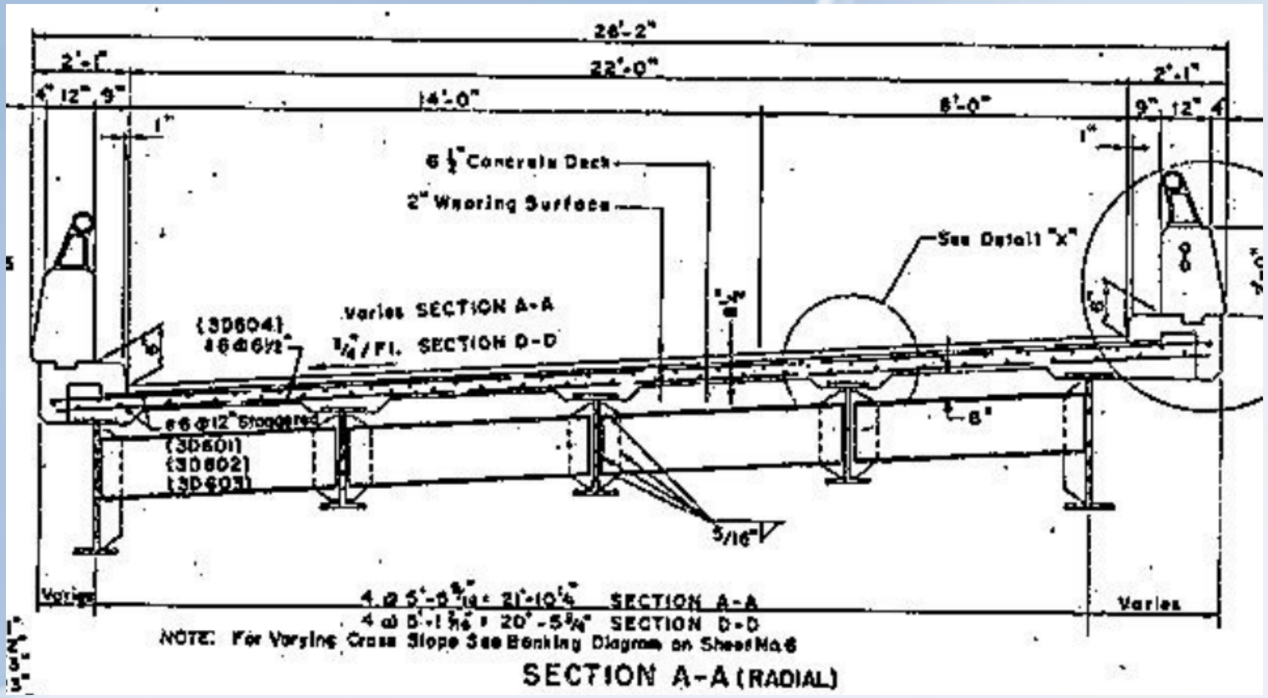
Hand off to maintenance firm or relevant maintenance group at agency

Retain results of 20XX inspection to compare to 20XX+2 inspection

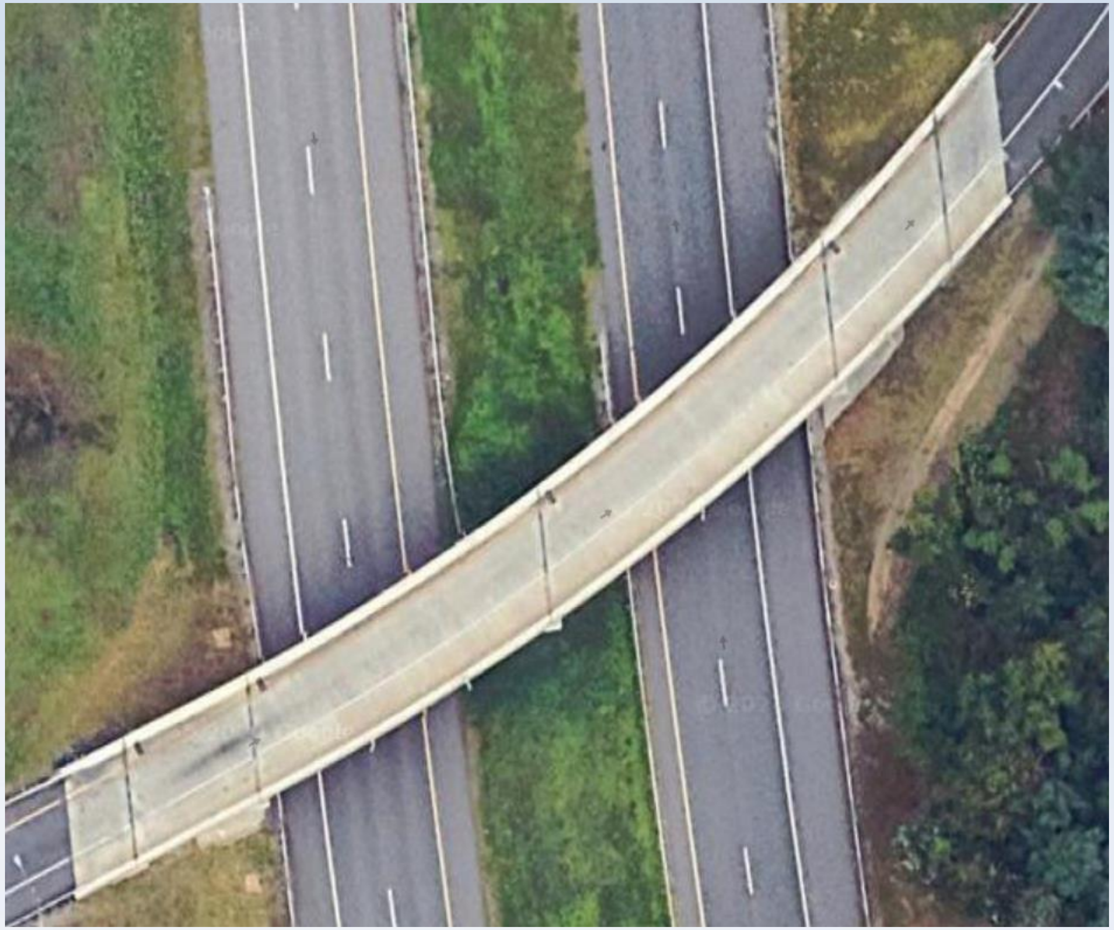
Legend Development

CONCRETE DECK				GPR	
CONDITION STATE 2		CONDITION STATE 3			[CM] - Corrosion/Moisture
	[MnS] - CS2 Minor Spall		[MjS] - CS3 Major Spall		[DVO] - Debonding/Void/Object
	[SP] - CS2 Sound Patch		[UP] - CS3 Unsound Patch	DELAMINATION	
	[ER] - CS2 Exposed Rebar		[ERSL] - CS3 Exposed Rebar Section ...		[D1] - Rebar Depth
	[MPC] - CS2 Moderate Pattern Crackl...		[HPC] - CS3 Heavy Pattern Cracking		[D2] - Within Overlay

Case Study A: Reinforced Concrete

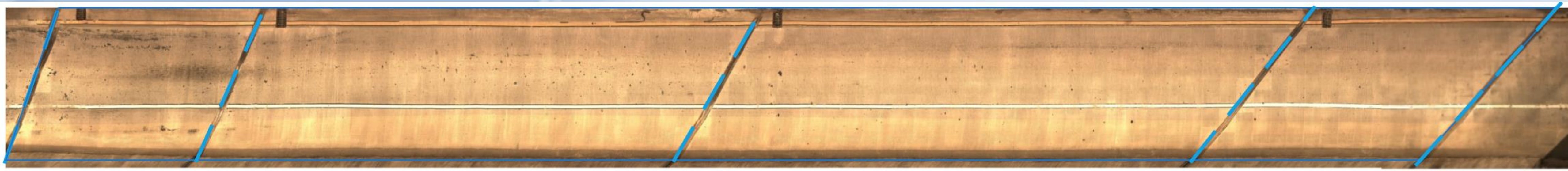


Cross Section

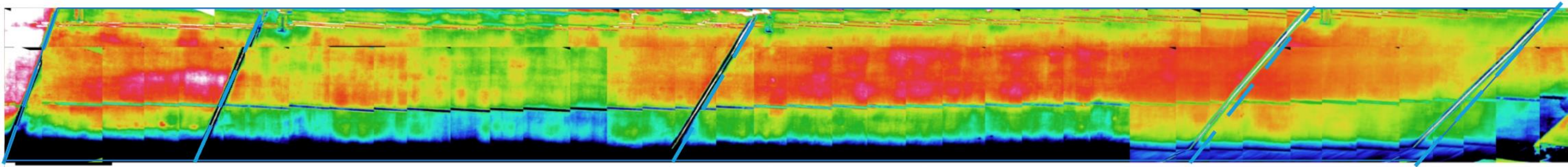


Case Study A: Reinforced Concrete

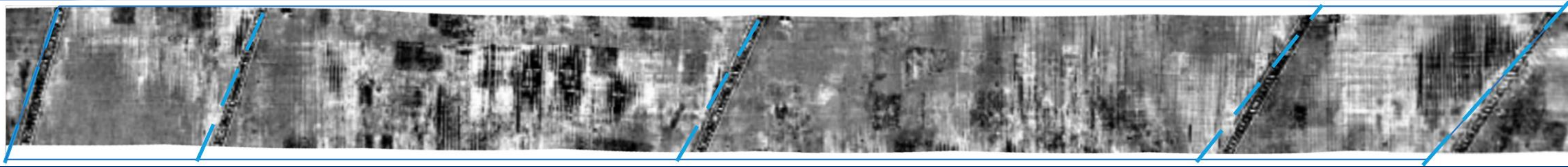
Visual Imagery



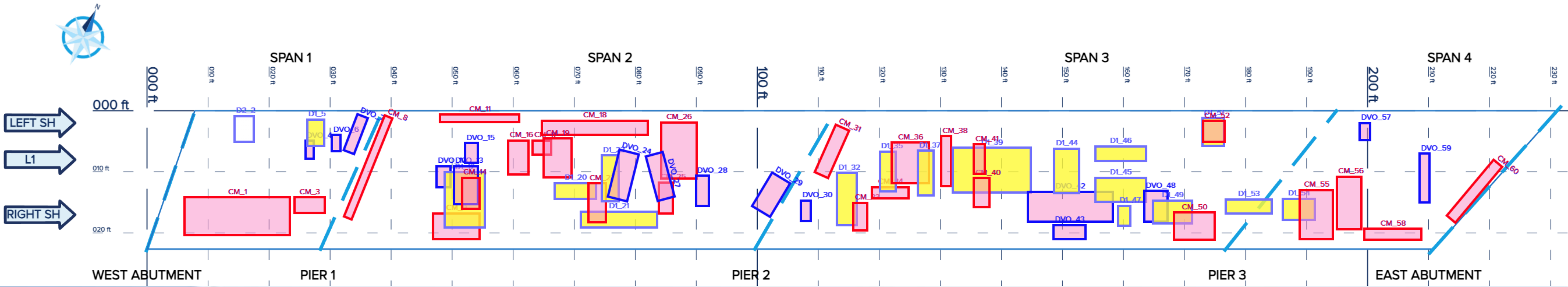
Infrared



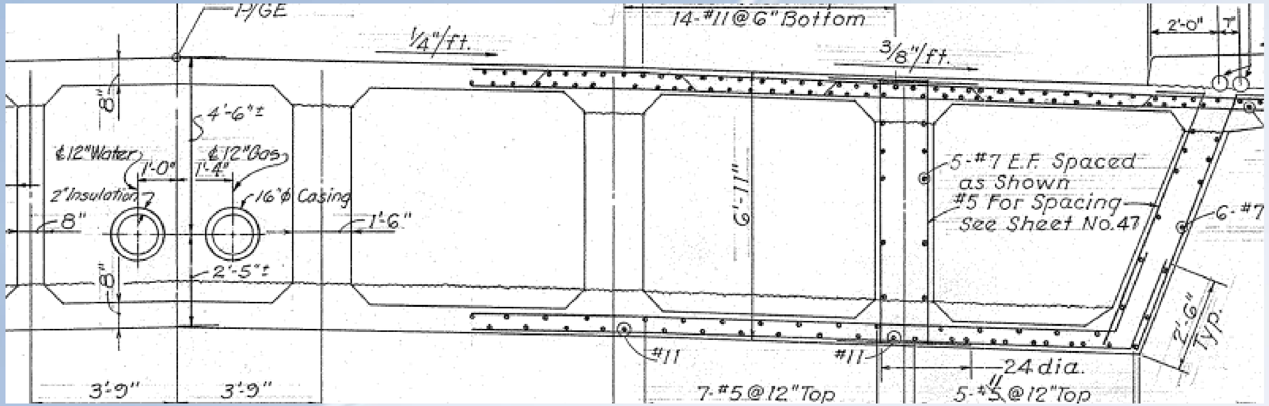
GPR Slice near Top Rebar



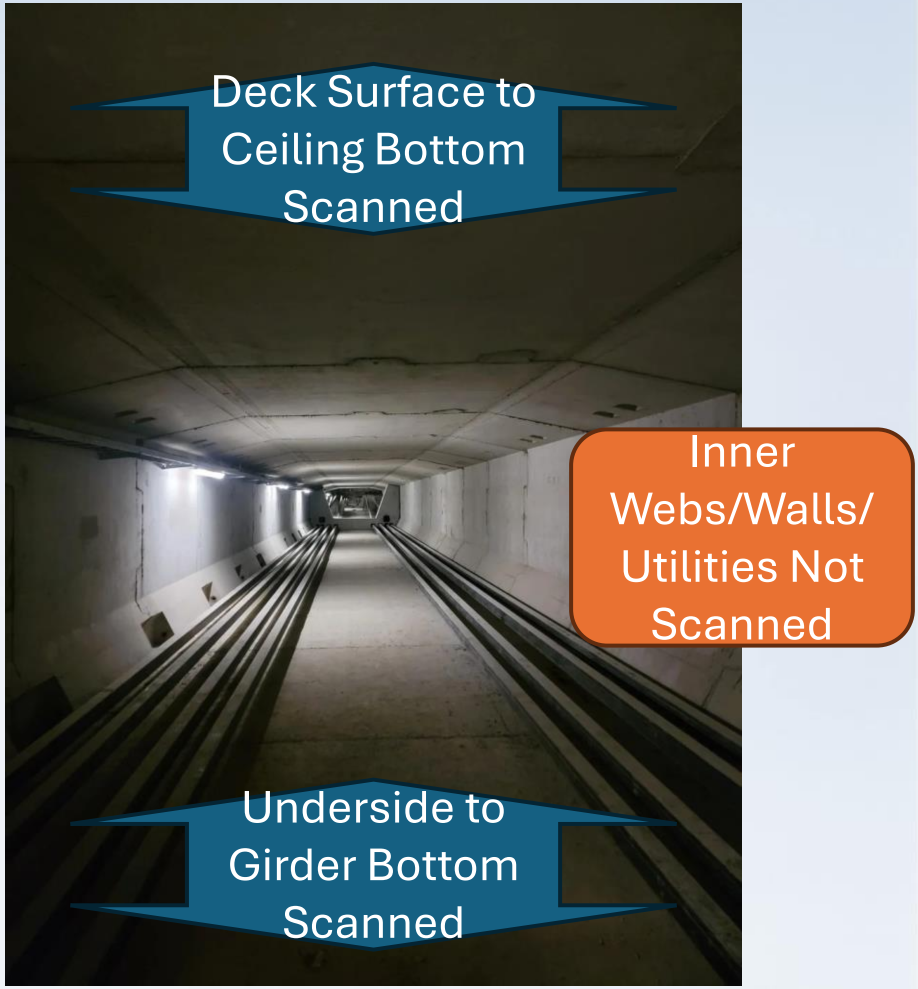
Case Study A


SPAN 1
SPAN 2
SPAN 3
SPAN 4
000 ft
100 ft
200 ft
010 ft
020 ft
LEFT SH
L1
RIGHT SH
CM_1
CM_3
D1_5
CM_8
CM_11
DVO_15
CM_18
CM_26
DVO_28
DVO_30
CM_31
D1_32
CM_36
CM_38
D1_44
D1_45
D1_46
DVO_48
CM_50
D1_53
CM_55
CM_56
DVO_57
CM_58
DVO_59
WEST ABUTMENT
PIER 1
PIER 2
PIER 3
EAST ABUTMENT

Case Study B: Box Girder

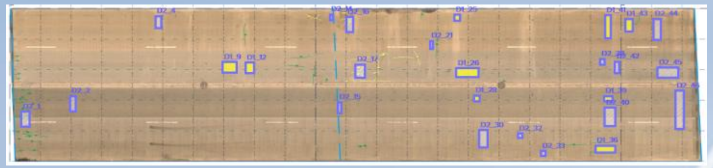


Cross Section

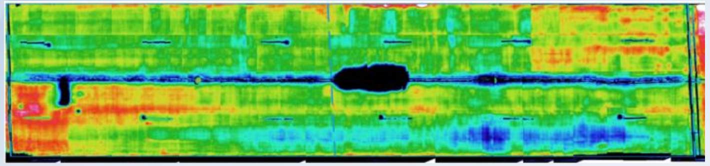


Case Study B: Deck Top

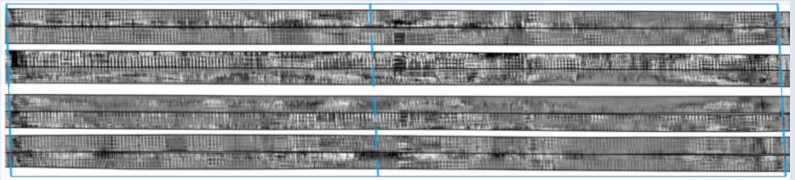
Visual Imagery



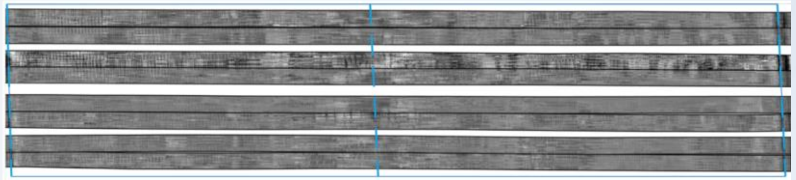
Infrared



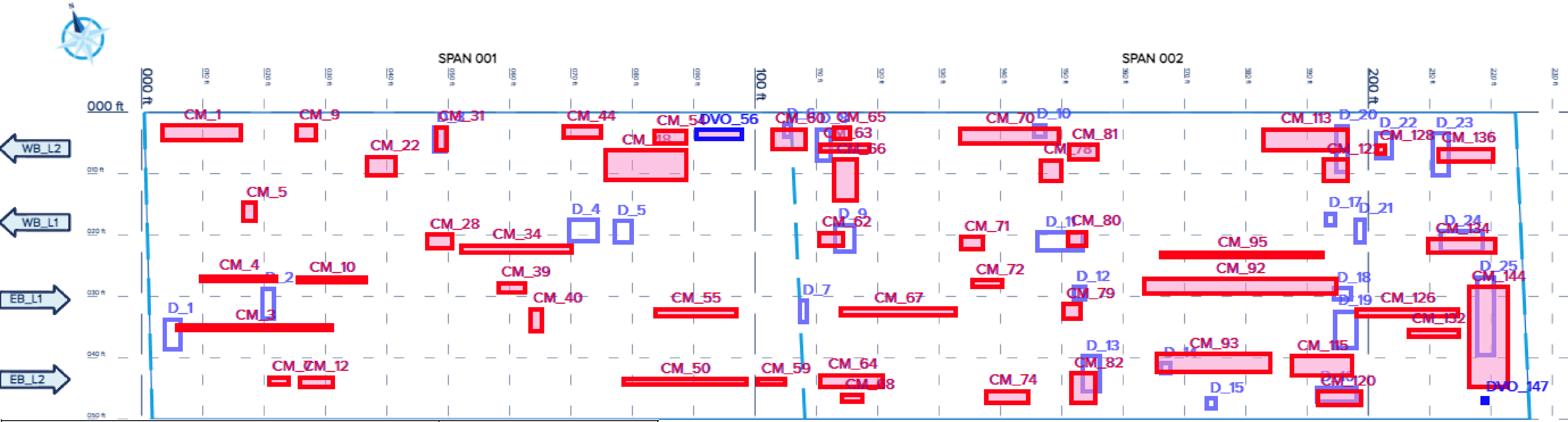
GPR Slice near Top Rebar



GPR Slice near Bottom Rebar

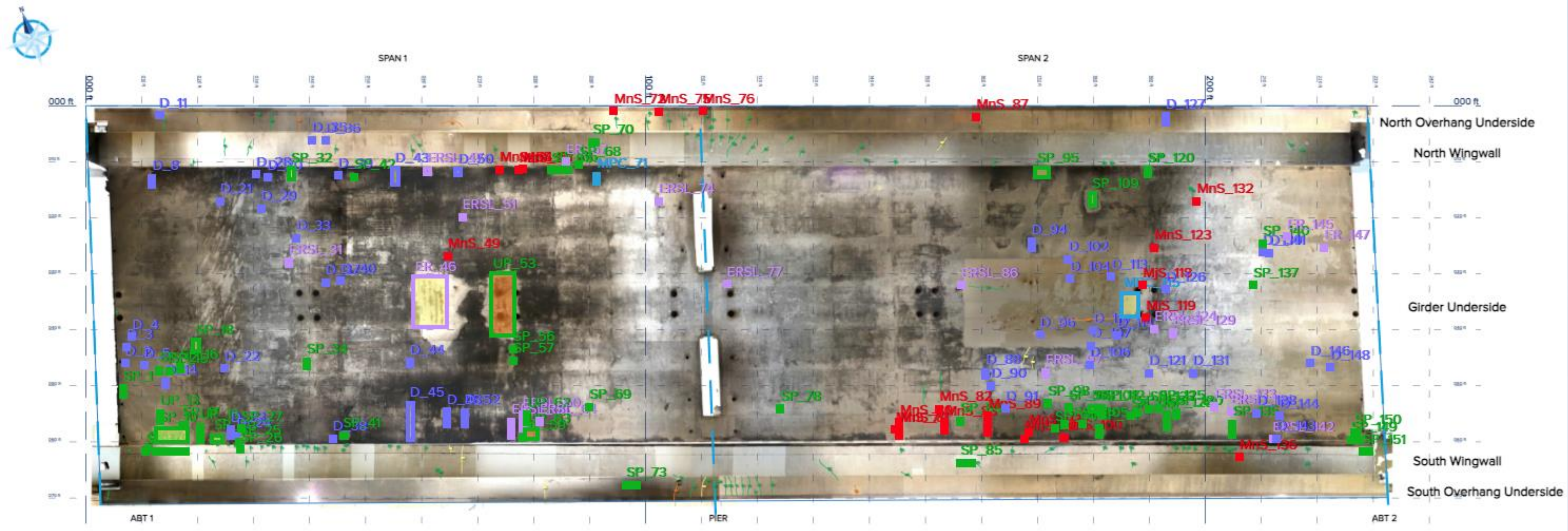


Case Study B: Deck Top



CONCRETE DECK		GPR
CONDITION STATE 2	CONDITION STATE 3	[CM] - Corrosion/Moisture
[MnS] - CS2 Minor Spall	[MjS] - CS3 Major Spall	[DVO] - Debonding/Void/Object
[SP] - CS2 Sound Patch	[UP] - CS3 Unsound Patch	DELAMINATION
[ER] - CS2 Exposed Rebar	[ERSL] - CS3 Exposed Rebar Section ...	[D1] - Rebar Depth
[MPC] - CS2 Moderate Pattern Crackl...	[HPC] - CS3 Heavy Pattern Cracking	[D2] - Within Overlay

Case Study B: Deck Underside

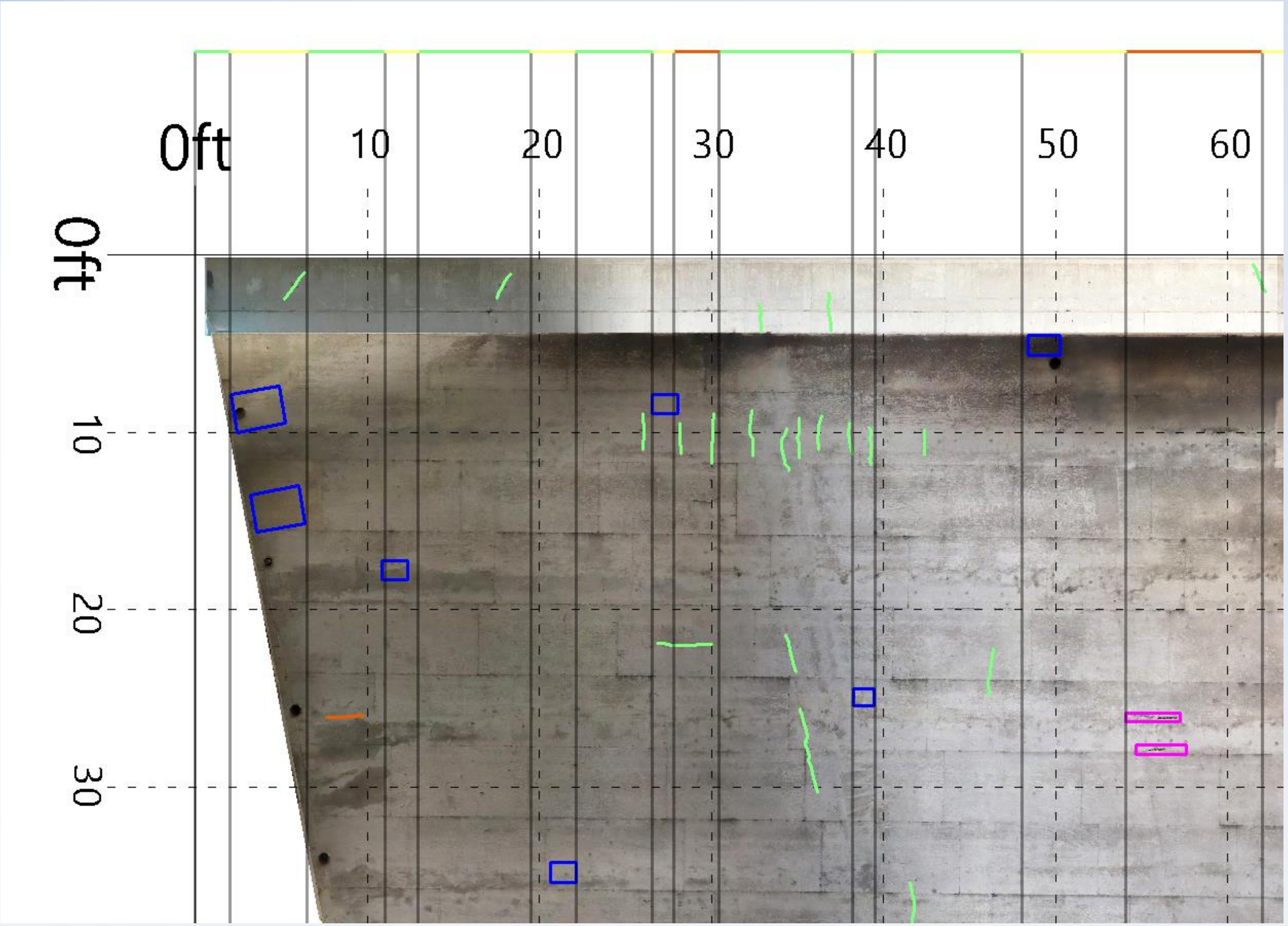


CONCRETE DECK				GPR	
CONDITION STATE 2		CONDITION STATE 3			[CM] - Corrosion/Moisture
	[MnS] - CS2 Minor Spall		[MJS] - CS3 Major Spall		[DVO] - Debonding/Void/Object
	[SP] - CS2 Sound Patch		[UP] - CS3 Unsound Patch	DELAMINATION	
	[ER] - CS2 Exposed Rebar		[ERSL] - CS3 Exposed Rebar Section ...		[D1] - Rebar Depth
	[MPC] - CS2 Moderate Pattern Crackl...		[HPC] - CS3 Heavy Pattern Cracking		[D2] - Within Overlay

Deck Underside Reporting

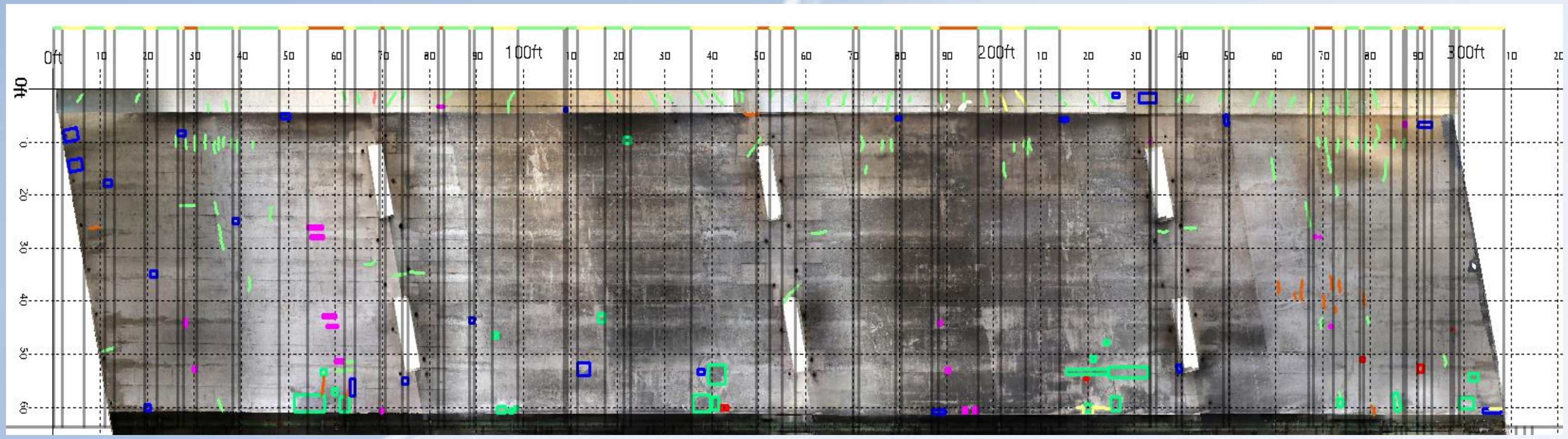
Green=CS1, Yellow=CS2, Red=CS3

- Typically, underside findings are quantified by square feet as part of AASHTO element #12, but for a box girder bridge, elements #105 (RC Closed Web/Box Girder) and #16 (RC Top Flange) are quantified in linear feet.
- We generated a few different maps/tables for the client to reference, and went with the following method.



Deck Underside Reporting

Green=CS1, Yellow=CS2, Red=CS3



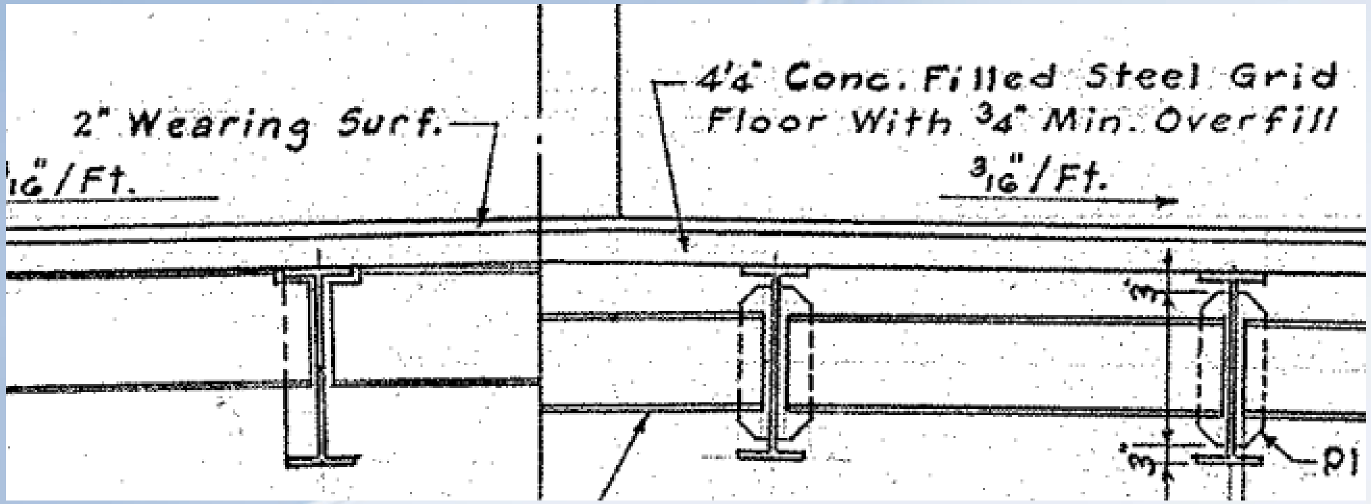
Element 105 (Reinforced Concrete Closed Web/Box Girder) Visual and IRT Findings Numerical Condition State Summary

Element #	Element Description	Span	Unit of Measure	Condition State Quantity [linear ft]								Total Quantity [linear ft]
				CS1		CS2		CS3		CS4		
105	RC Closed Web/Box Girder	SB_1	LF	39	56%	20	28%	13	19%	0	0%	70
105	RC Closed Web/Box Girder	SB_2	LF	49	59%	33	40%	3	4%	0	0%	83
105	RC Closed Web/Box Girder	SB_3	LF	43	51%	30	36%	13	16%	0	0%	83
105	RC Closed Web/Box Girder	SB_4	LF	43	61%	20	28%	7	9%	0	0%	70
105	RC Closed Web/Box Girder	NB_1	LF	39	56%	30	42%	10	14%	0	0%	70
105	RC Closed Web/Box Girder	NB_2	LF	26	32%	39	47%	13	16%	0	0%	83
105	RC Closed Web/Box Girder	NB_3	LF	33	40%	23	28%	23	28%	0	0%	83
105	RC Closed Web/Box Girder	NB_4	LF	39	56%	20	28%	13	19%	0	0%	70
105	RC Closed Web/Box Girder	Total	LF	312	51%	213	35%	95	16%	0	0%	612

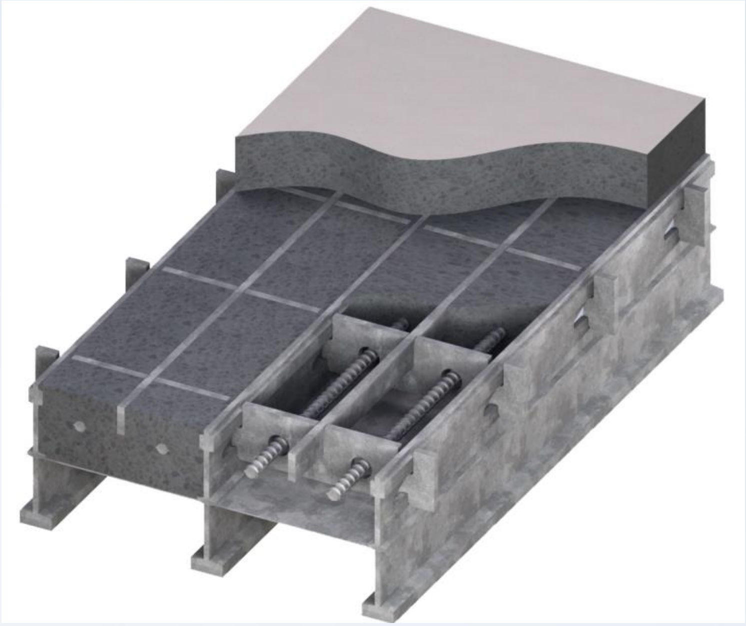
Element 105 Individual Deficiencies

Deficiency ID	Span	Deficiency Type	X Position [ft]	Y Position [ft]	Length [inch]	Width [inch]	Size [Sqft]
D_1	SPAN001	CS2 Delamination	5.0 - 7.0	7.0 - 10.0	34.0	26.0	6.1
D_2	SPAN001	CS2 Delamination	6.0 - 8.0	13.0 - 16.0	34.0	26.0	6.1
D_3	SPAN001	CS2 Delamination	11.0 - 12.0	17.0 - 18.0	13.3	18.0	1.7
D_4	SPAN001	CS2 Delamination	16.0 - 18.0	80.0 - 82.0	26.1	23.9	4.3
D_5	SPAN001	CS2 Delamination	17.0 - 19.0	74.0 - 75.0	13.3	23.9	2.2
D_6	SPAN001	CS2 Delamination	19.0 - 21.0	93.0 - 94.0	14.9	16.2	1.7
SP_7	SPAN001	CS2 Sound Patch	19.0 - 24.0	97.0 - 99.0	25.4	48.4	8.6
D_8	SPAN001	CS2 Delamination	20.0 - 21.0	60.0 - 61.0	13.3	12.8	1.2
D_9	SPAN001	CS2 Delamination	21.0 - 22.0	34.0 - 35.0	13.3	18.0	1.7
D_10	SPAN001	CS2 Delamination	21.0 - 22.0	107.0 - 108.0	9.1	11.2	0.7
UP_11 - 1	SPAN001	CS3 Unsound Patch	21.0 - 23.0	109.0 - 112.0	32.1	16.2	3.2
UP_11 - 2	APPROACH SLAB	CS3 Unsound Patch	21.0 - 23.0	109.0 - 112.0	32.1	16.2	0.4
UP_12 - 1	SPAN001	CS3 Unsound Patch	22.0 - 23.0	112.0 - 114.0	26.4	16.2	2.7
UP_12 - 2	APPROACH SLAB	CS3 Unsound Patch	22.0 - 23.0	112.0 - 114.0	26.4	16.2	0.3
D_13	SPAN001	CS2 Delamination	22.0 - 23.0	105.0 - 106.0	9.1	10.2	0.7
D_14	SPAN001	CS2 Delamination	23.0 - 25.0	110.0 - 112.0	22.9	23.1	3.7
UP_15 - 1	SPAN001	CS3 Unsound Patch	23.0 - 26.0	117.0 - 120.0	31.9	38.1	8.0
UP_15 - 2	APPROACH SLAB	CS3 Unsound Patch	23.0 - 26.0	117.0 - 120.0	31.9	38.1	0.5
UP_16	SPAN001	CS3 Unsound Patch	23.0 - 25.0	114.0 - 117.0	34.6	24.2	5.8
UP_17 - 1	SPAN001	CS3 Unsound Patch	23.0 - 27.0	120.0 - 122.0	21.4	42.9	5.8
UP_17 - 2	APPROACH SLAB	CS3 Unsound Patch	23.0 - 27.0	120.0 - 122.0	21.4	42.9	0.5

Case Study C: Concrete Overfilled Steel Grid Deck

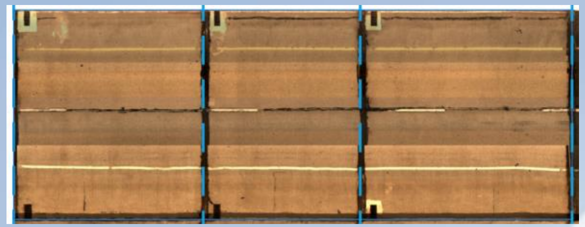


Cross Section

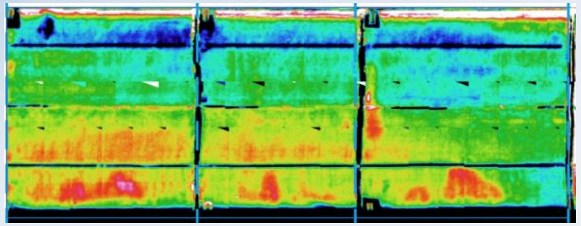


Case Study C

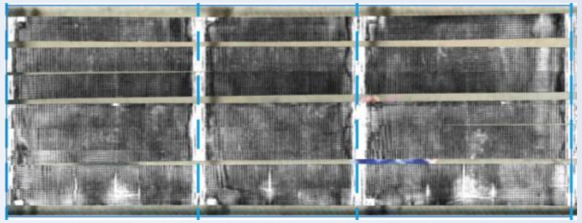
Visual Imagery



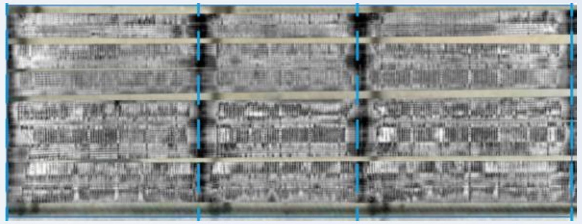
Infrared



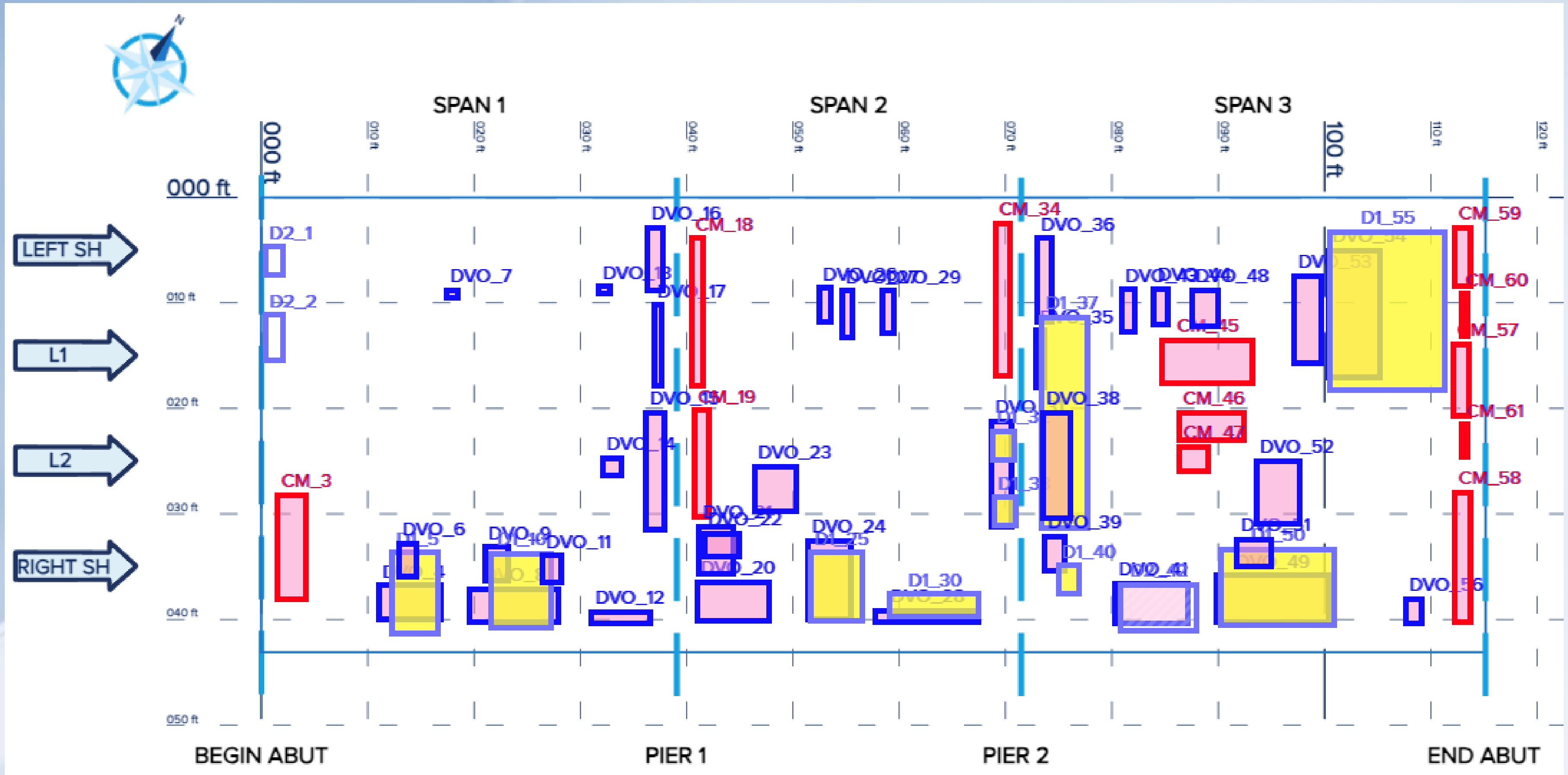
GPR Slice near Top Rebar



GPR Slice near Bottom Rebar



Case Study C



CONCRETE DECK		GPR
CONDITION STATE 2	CONDITION STATE 3	[CM] - Corrosion/Moisture
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More Ideas for Deliverable Standardization

- Human Analysis
  - There are people who have decades of experience detecting deficiencies with certain methods. There is a steep difference between first-time users and 4 to 5+ year veterans.
  - There are cases when tedious crack drawing, etc. really does warrant an automated tool.
- AI Analysis
  - Like in other fields, if AI is used as a tool, great. If it is being used as a full replacement…
    - Mistakes will occur, sometimes to the point where a manual redo is faster.
    - But models can become much more experienced in a few years' time.

More Ideas for Deliverable Standardization

- Key things to be mindful of whether analyzed by human or AI:
  - What can python use?
  - What is most accessible, practical?
  - What can be picked up and used by another vendor or software platform?

  - Some answers to all of these:
    - CSVs
    - KMZs
    - Raw images/data…? Kind of.

Some Final Observations

1. Clarity in crafting of deliverables
   - Become familiar with and ask for file types that can be used in the future.
   - Might be painful at first, but take the time to sit down with vendors to hash out details.
2. Pilots are good windows into a company's capabilities, but they can't starve on $0 net profit projects forever.
   - Barrier to entry can get better without much effort.
   - If current prime has extra budget, consider supplementation of both good and poor condition bridges.
3. New standards shouldn't limit technological developments or current practice, rather offer a platform to stand on for agencies to set up repeatable use.

Questions

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