Extending Life of Bridges through Robotic Condition Assessment and Minimally Invasive Rehabilitation

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RUTGERS
THE STATE UNIVERSITY OF NEW JERSEY

Infrastructure Health Monitoring and Prevention

- Prevention
- Diagnostics
- Early intervention
- Overall health monitoring

- Better lives
- Longer lives
- Financially sounder lives

Nondestructive Evaluation and Minimally Invasive Rehabilitation

How Can We Improve Management of Our Bridges through Implementation of Robotic NDE and MIR?

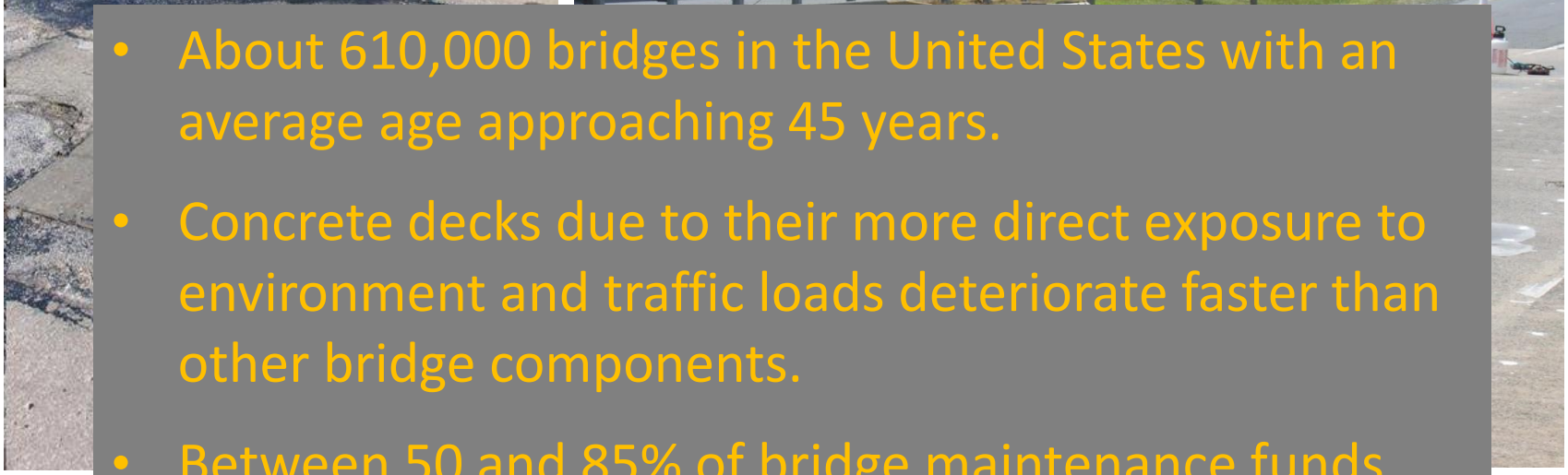
1. NDE technologies provide more detailed and accurate information about internal deterioration or defects, and information can be presented more intuitively.
2. NDE enables more accurate and quantifiable assessment of progression of deterioration.
3. The condition is described more objectively and enables objective comparison of bridges on the network level.
4. The data enable bridge owners to develop more realistic deterioration, predictive and life-cycle cost models for their bridge populations.
5. The speed and productivity of NDE surveys is rapidly improving due to automation and use of robotics.
6. A minimally invasive rehabilitation capability perfectly complements NDE's early problem detection capability.

Outline

- Automation of NDE data collection
- Illustration of benefits from NDE surveys
  - Accurate description of deterioration and defects
  - Intuitive presentation of the condition
  - More realistic deterioration and predictive modeling
  - Optimized use of resources in bridge inspections and maintenance
- Merging of robotic evaluation and rehabilitation
- Conclusions

Automation of NDE for Concrete Decks

Why Bridge Decks?



- About 610,000 bridges in the United States with an average age approaching 45 years.
- Concrete decks due to their more direct exposure to environment and traffic loads deteriorate faster than other bridge components.
- Between 50 and 85% of bridge maintenance funds are spent to maintain, repair or replace portions of the Nation's 3.2 billion square feet of bridge decks.

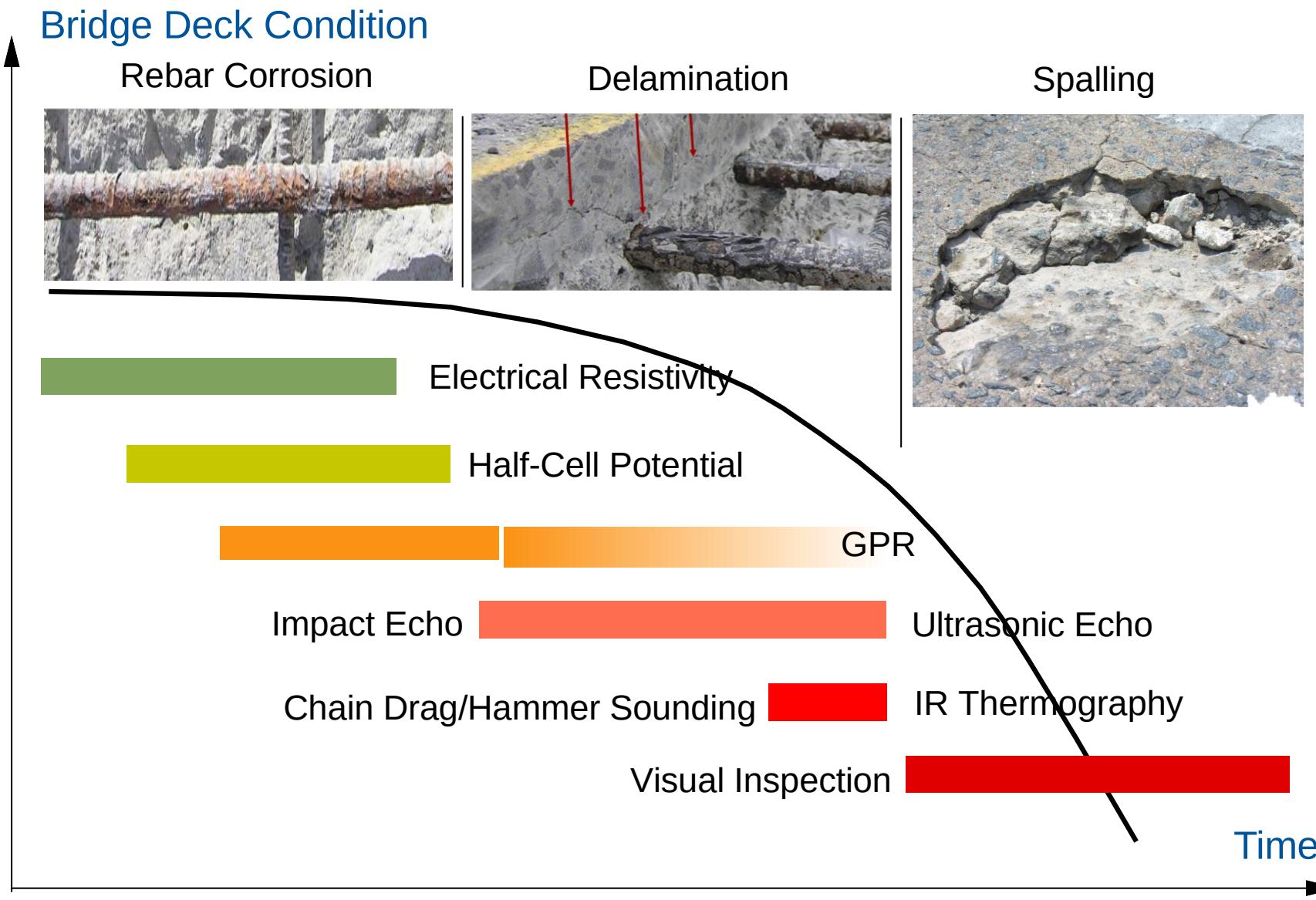
Reinforced Concrete Deterioration Types of Primary Interest

Corrosion

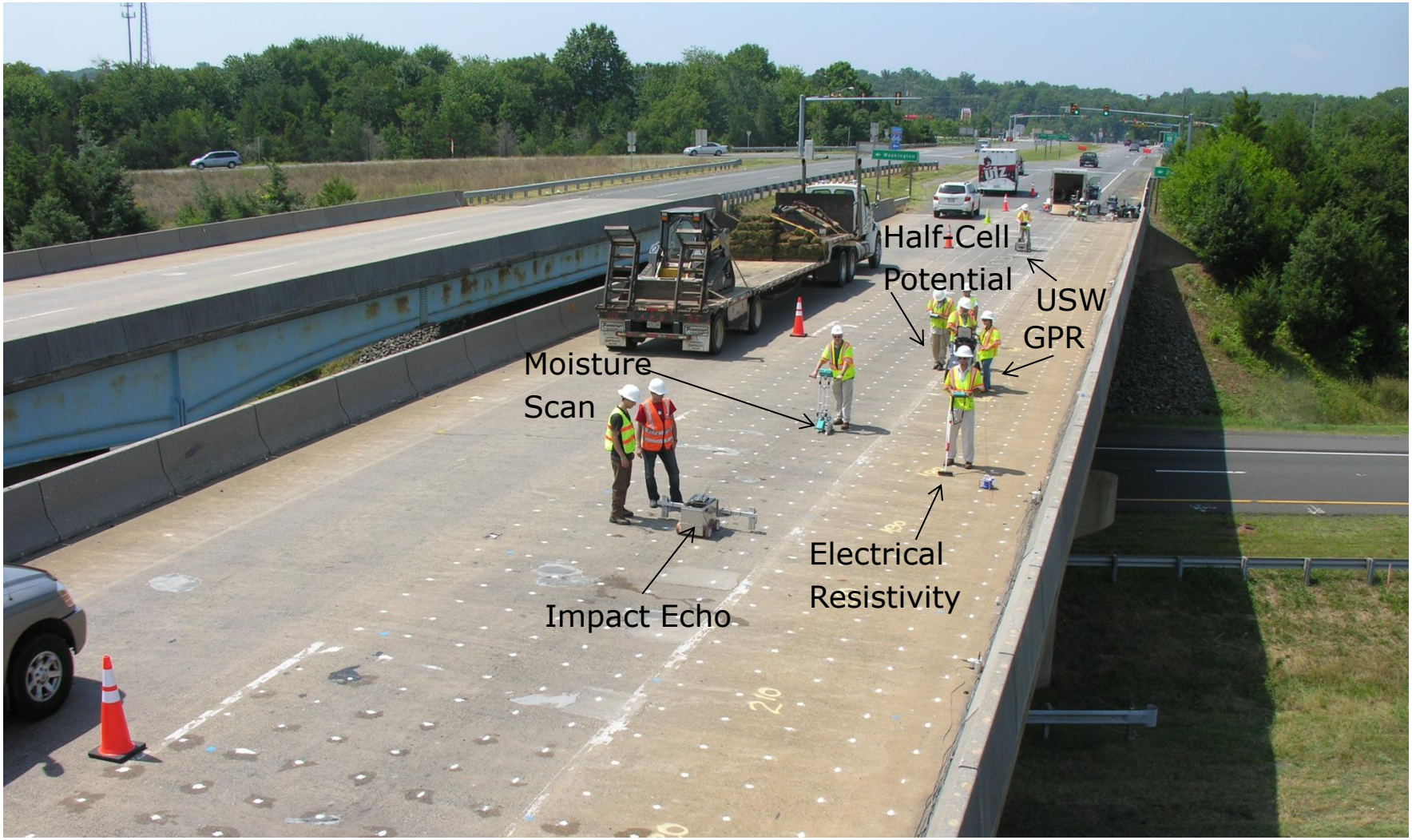
Delamination

Concrete Degradation

Deck Condition Assessment Vs. NDE Method

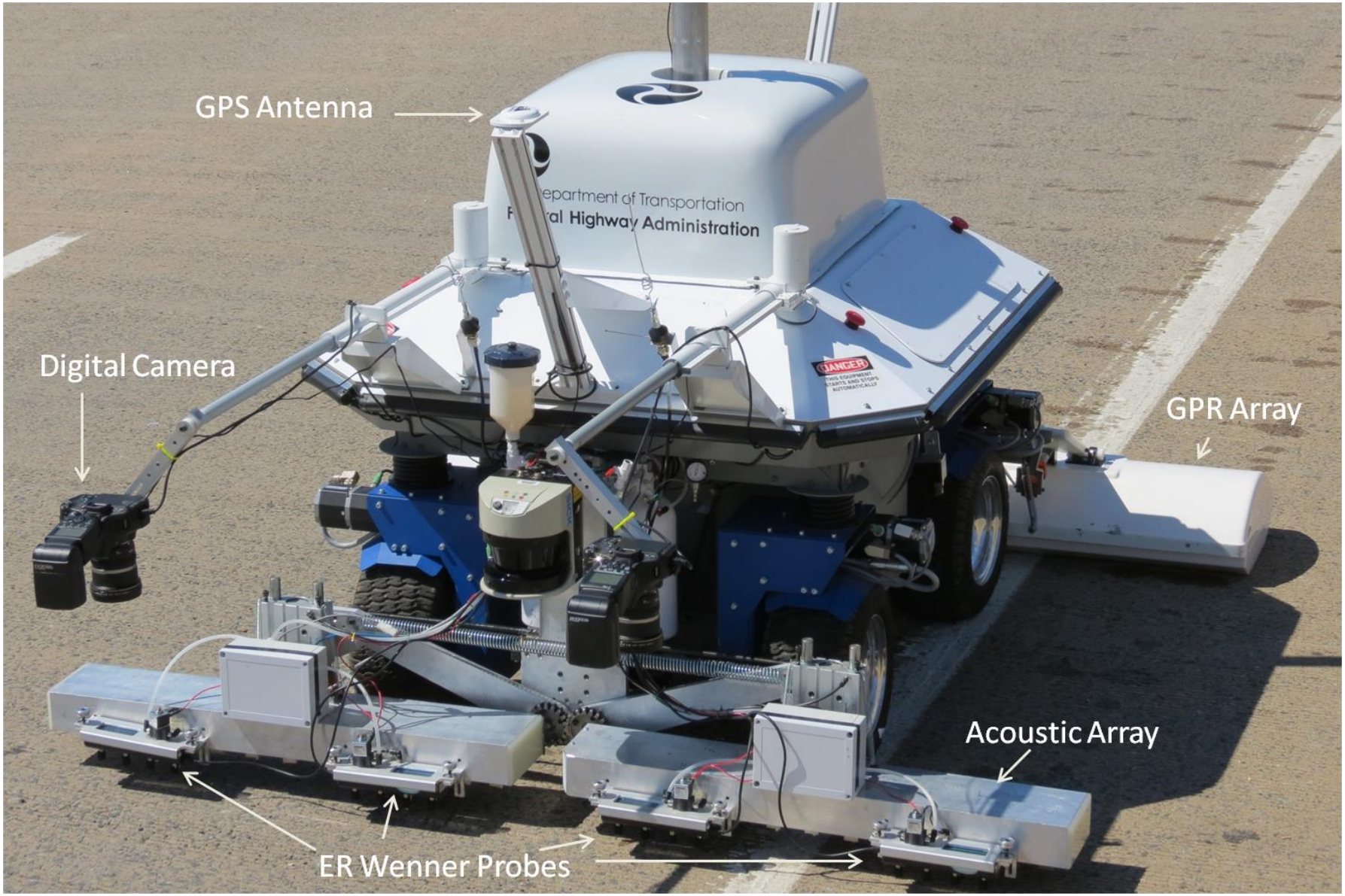


Haymarket Bridge NDE Data Collection



NDE Surveys Using Manual NDE Technologies

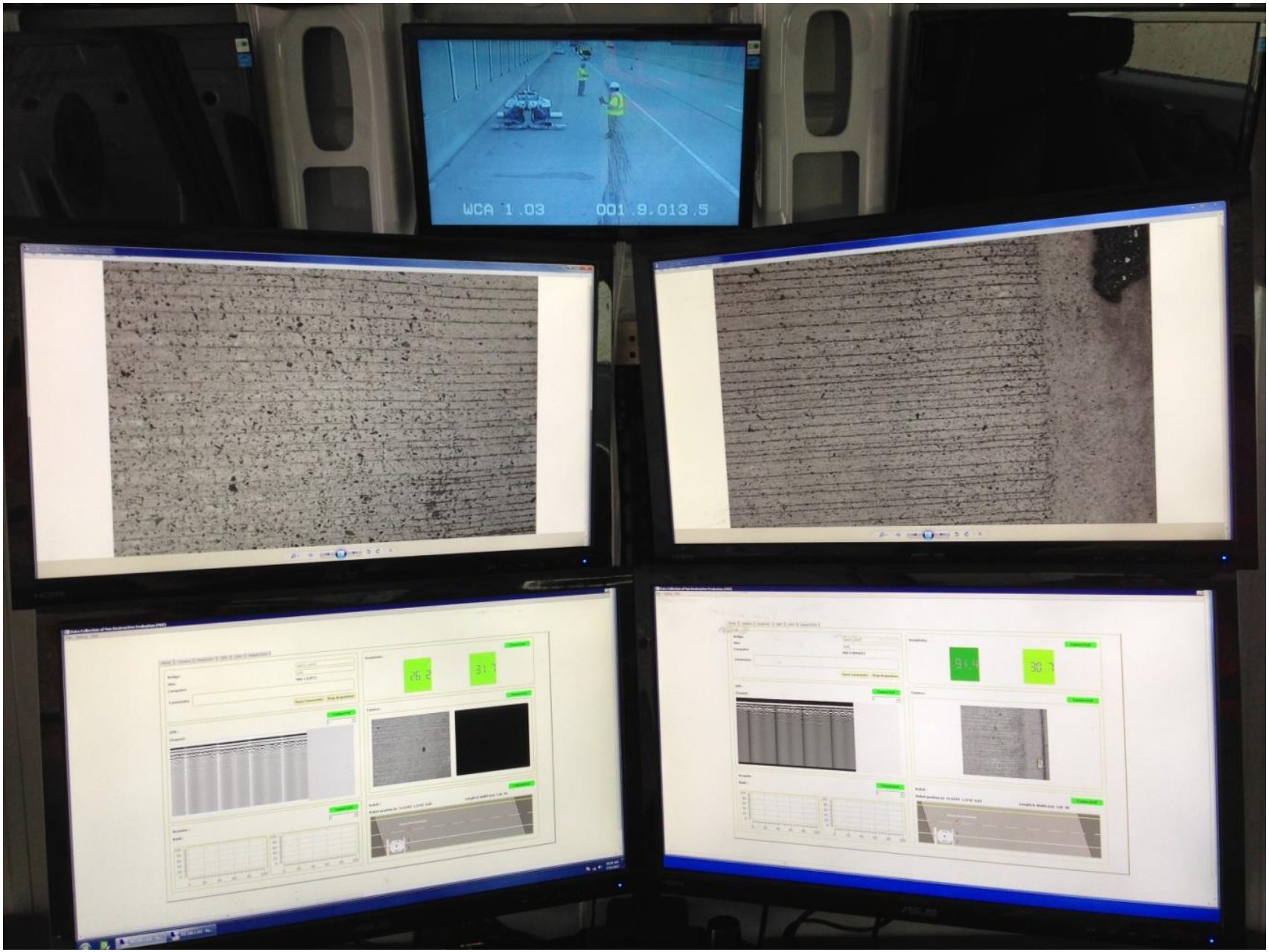
RABIT Components



RABIT Components

RABIT Transportation by Command Van

Command Van Displays



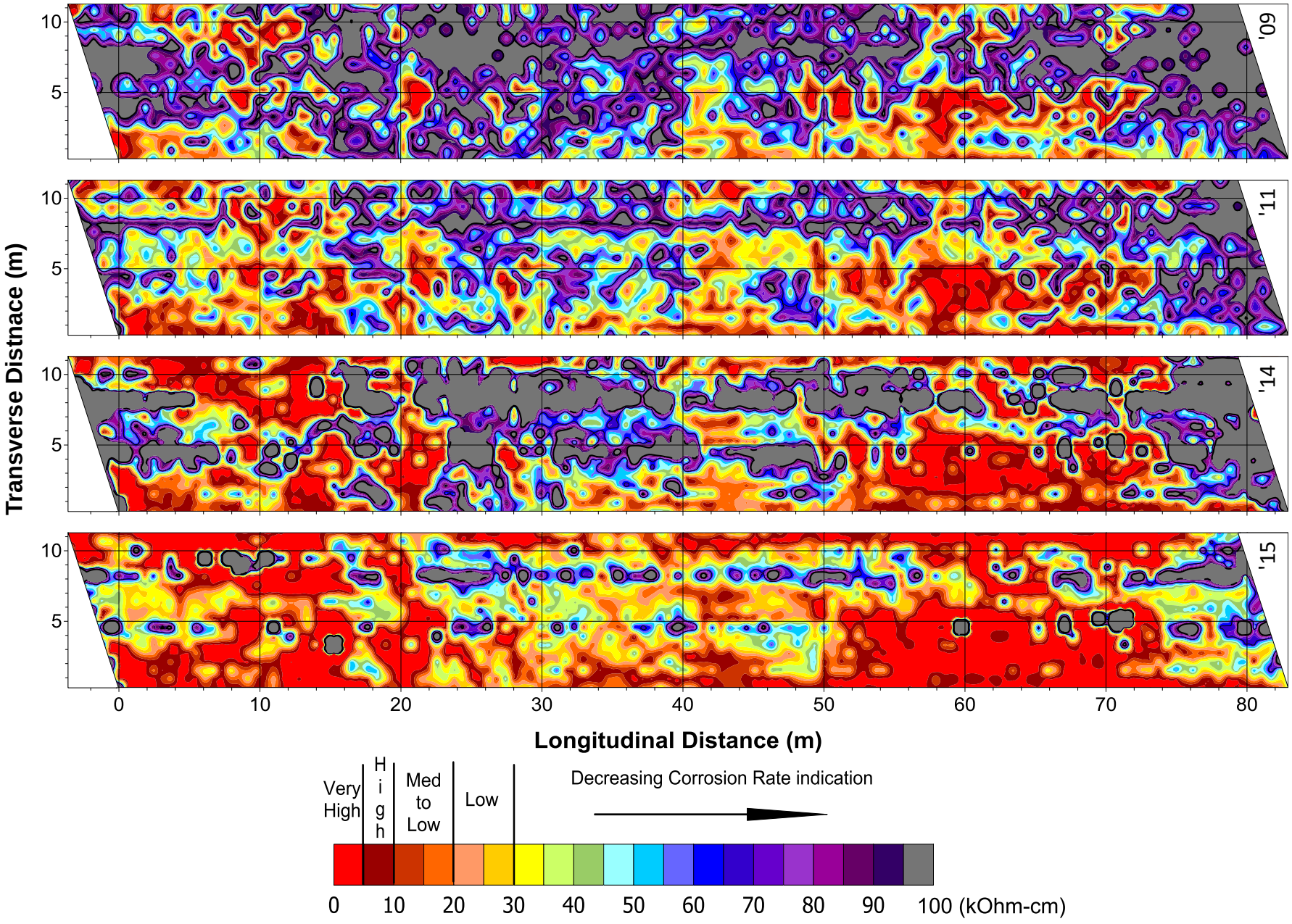
RABIT Data Collection

Illustration of Benefits from NDE Surveys

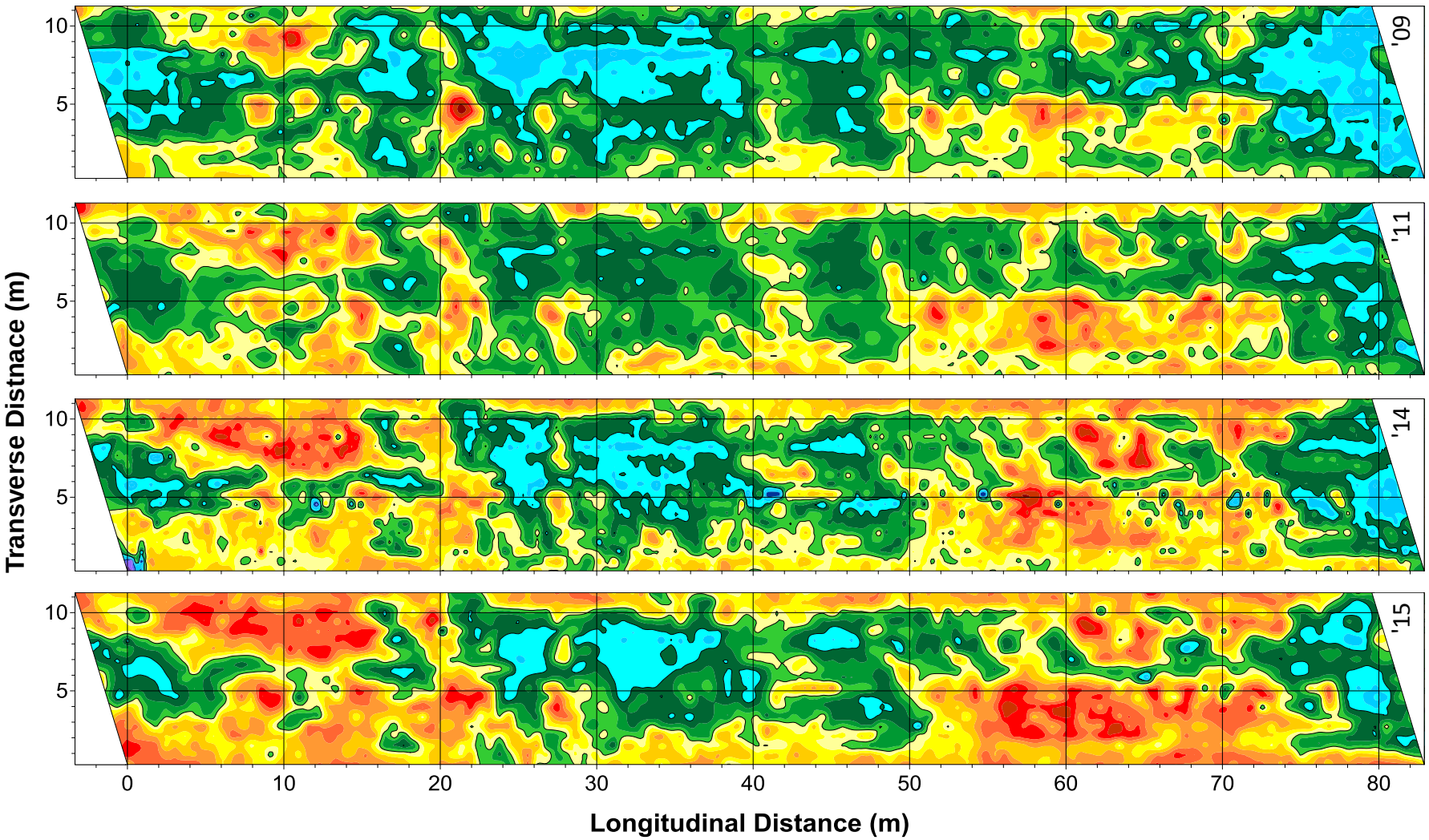
Accurate Description of Internal Deterioration and Defects

FHWA's LTBP Program - Rt.15 over I-66 Bridge, Haymarket, VA

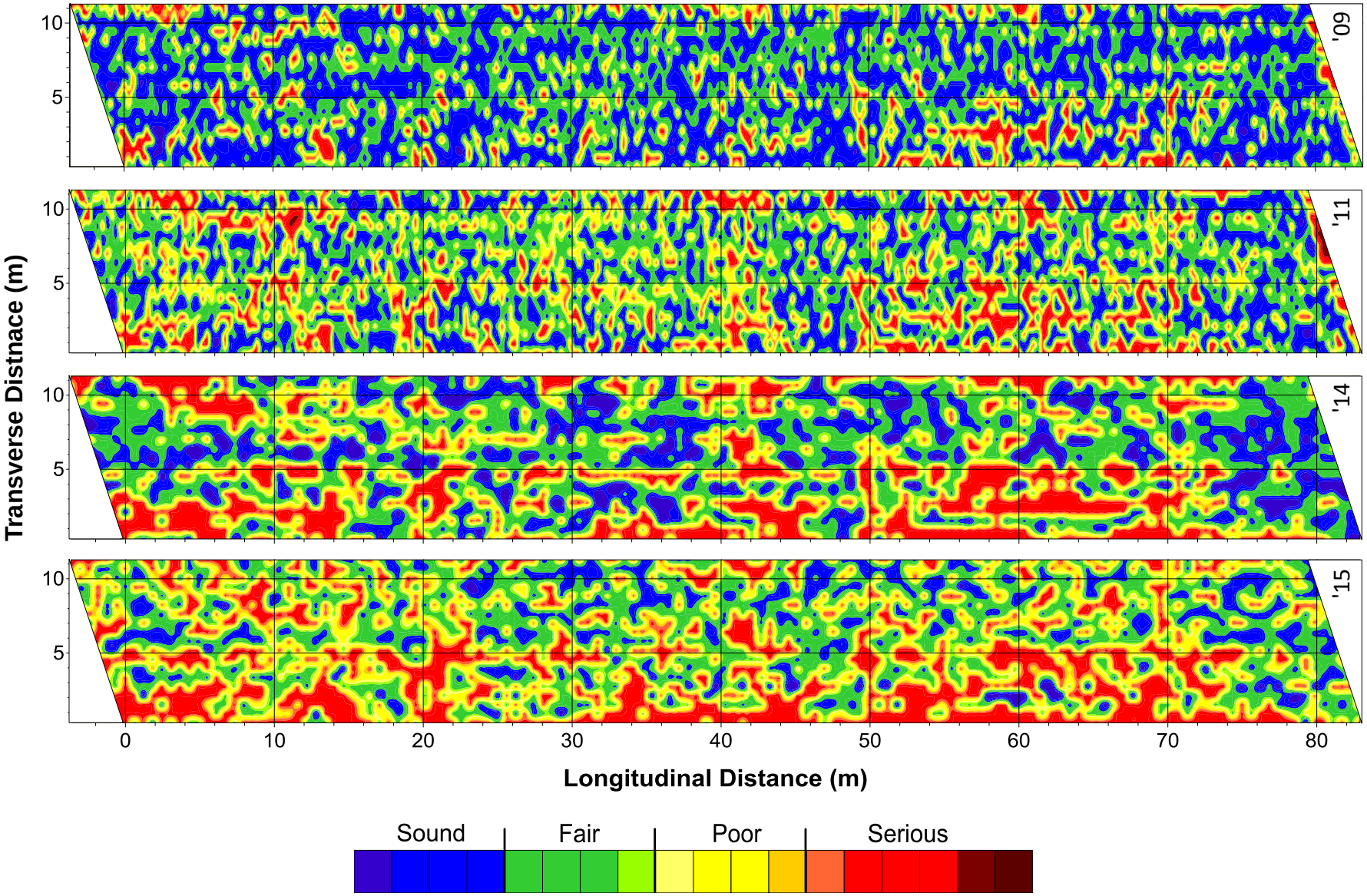
ER Maps for Haymarket Bridge 2009-2015



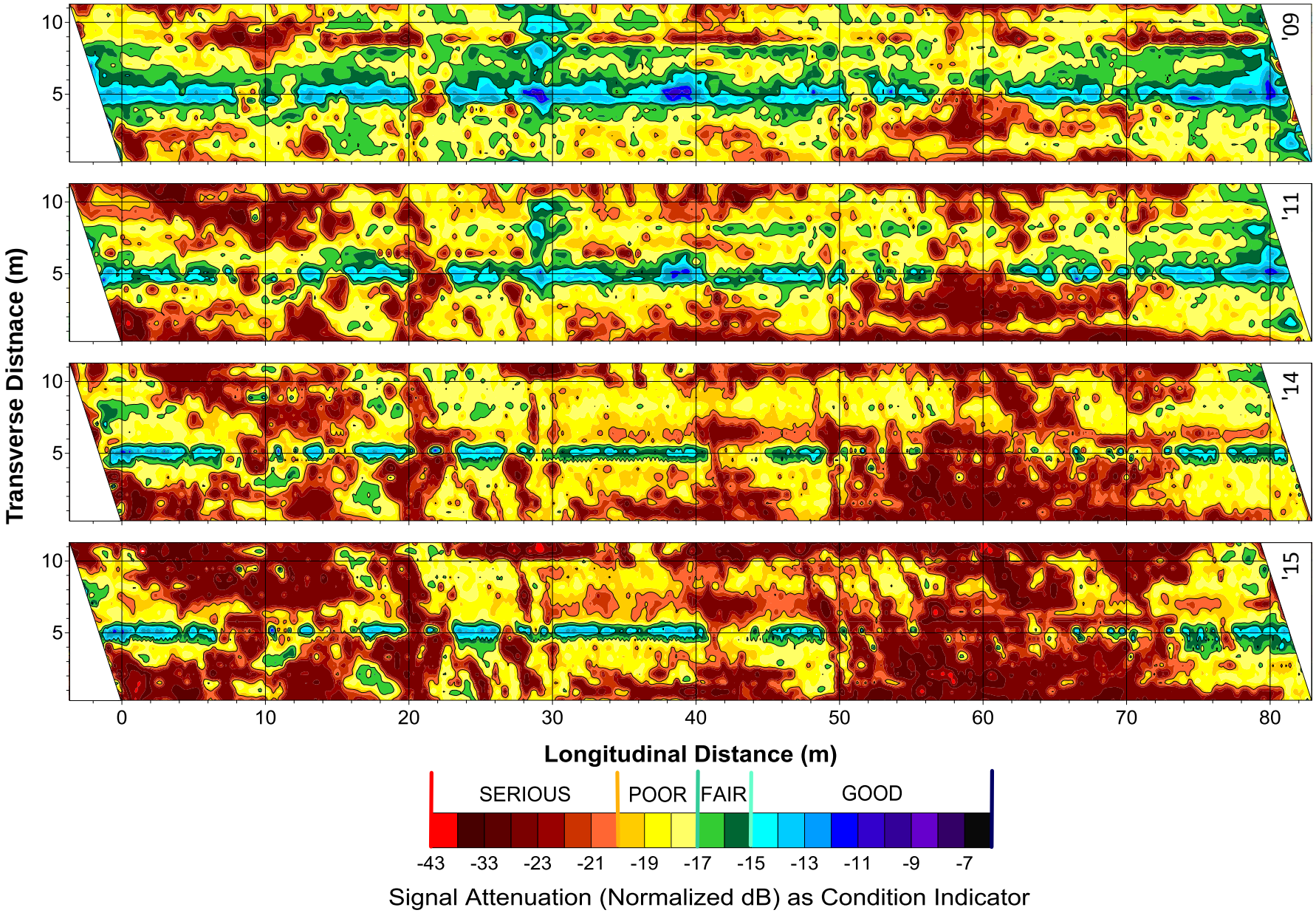
HCP Maps for Haymarket Bridge 2009-2015



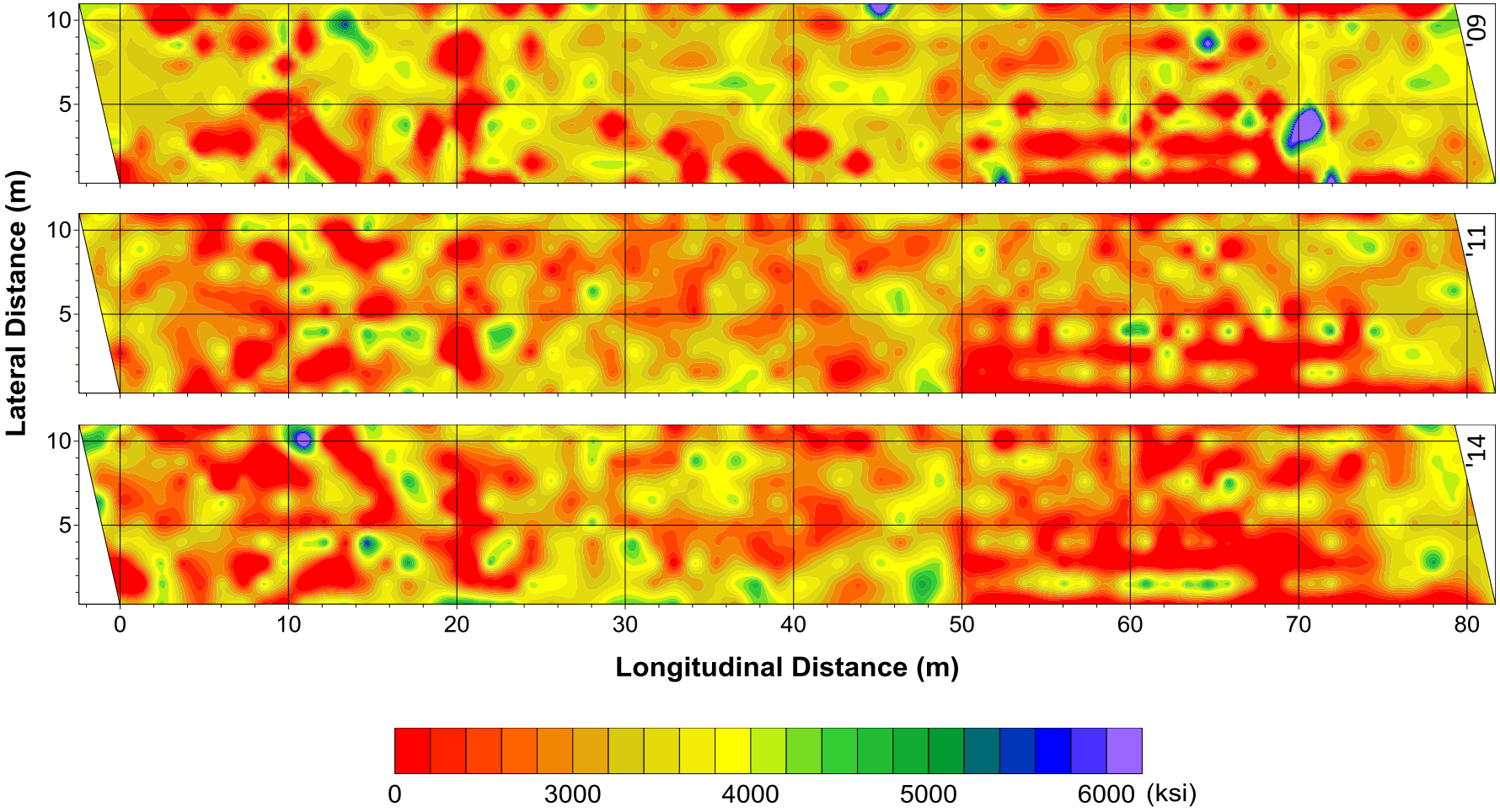
Delamination Maps for Haymarket Bridge 2009-2015



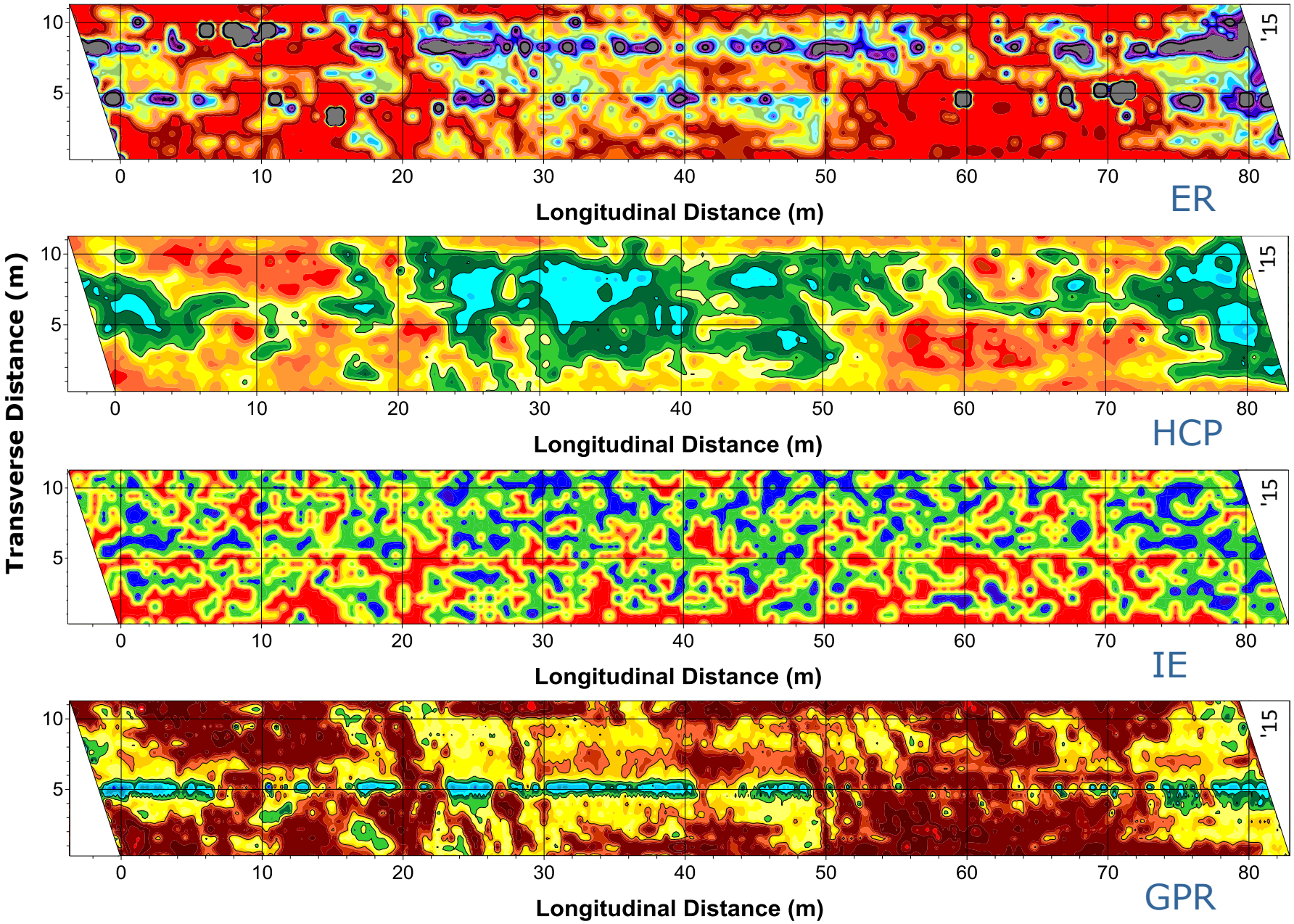
GPR Maps for Haymarket Bridge 2009-2015



Concrete Modulus Maps for Haymarket Bridge 2011-15



Comparison of NDE Technology Results for 2015



Comparison of NDE Technology Results for O1 Bridge

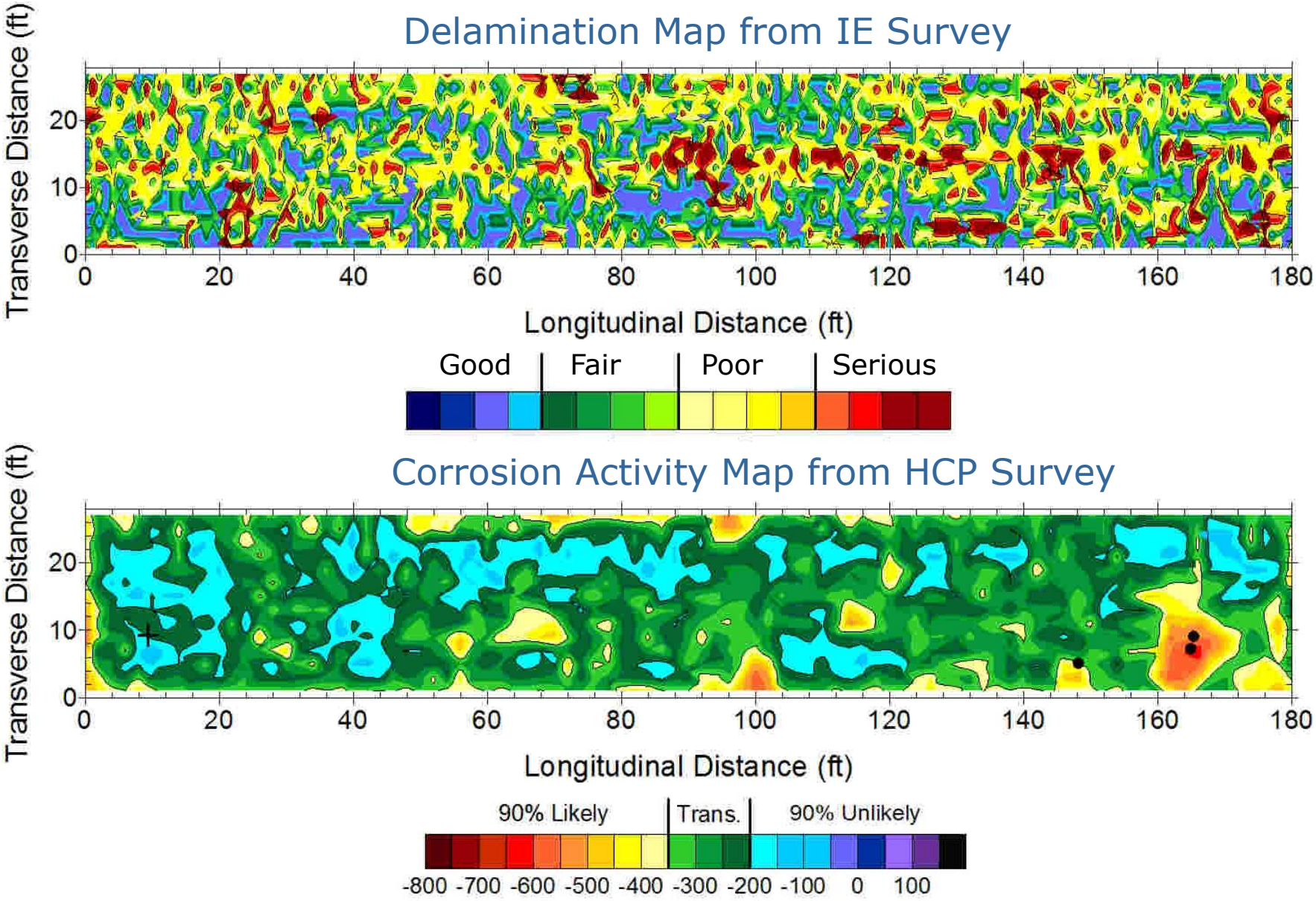
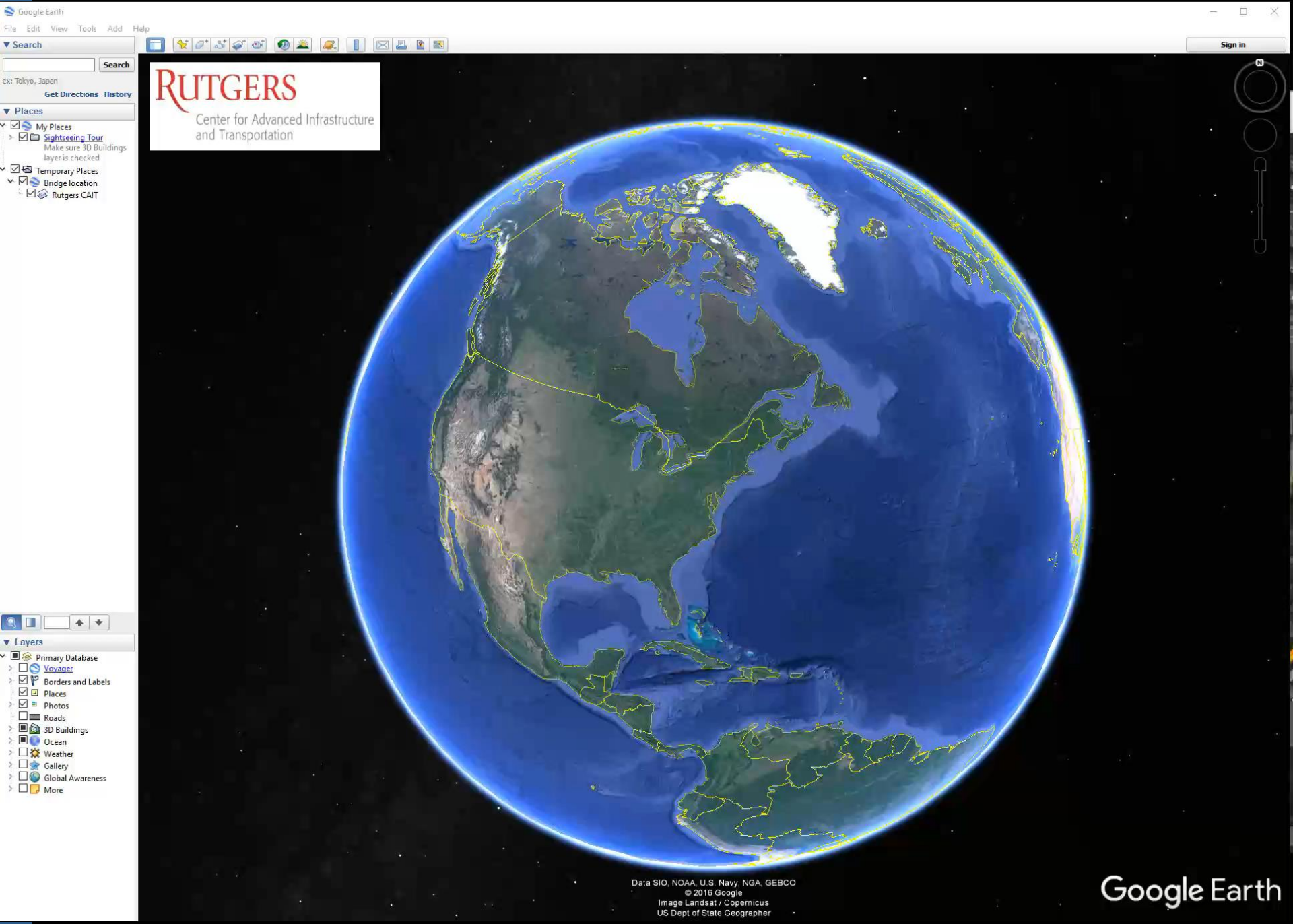


Illustration of Benefits from NDE Surveys

Intuitive Presentation of Deterioration and Defects


Google Earth
File Edit View Tools Add Help
Search
Search
ex: Tokyo, Japan
Get Directions History
Places
My Places
Sightseeing Tour
Make sure 3D Buildings layer is checked
Temporary Places
Bridge location
Rutgers CAIT
Sign in
RUTGERS
Center for Advanced Infrastructure and Transportation
Layers
Primary Database
Voyager
Borders and Labels
Places
Photos
Roads
3D Buildings
Ocean
Weather
Gallery
Global Awareness
More
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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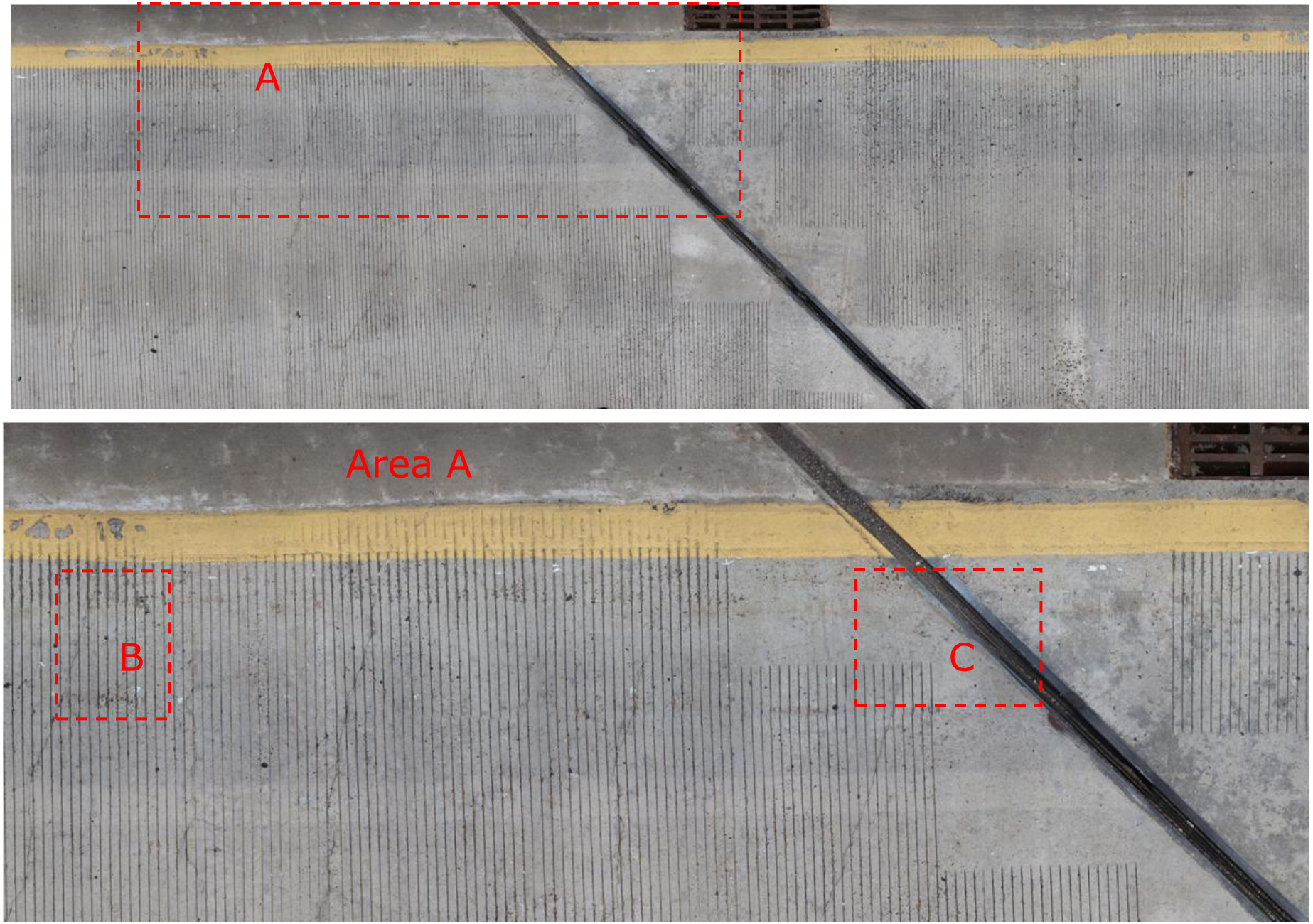
US Dept of State Geographer
Google Earth

Superimposed RABIT's Impact Echo Data on LiDAR Image of Arlington Memorial Bridge

Stitched Images of Bridge Deck

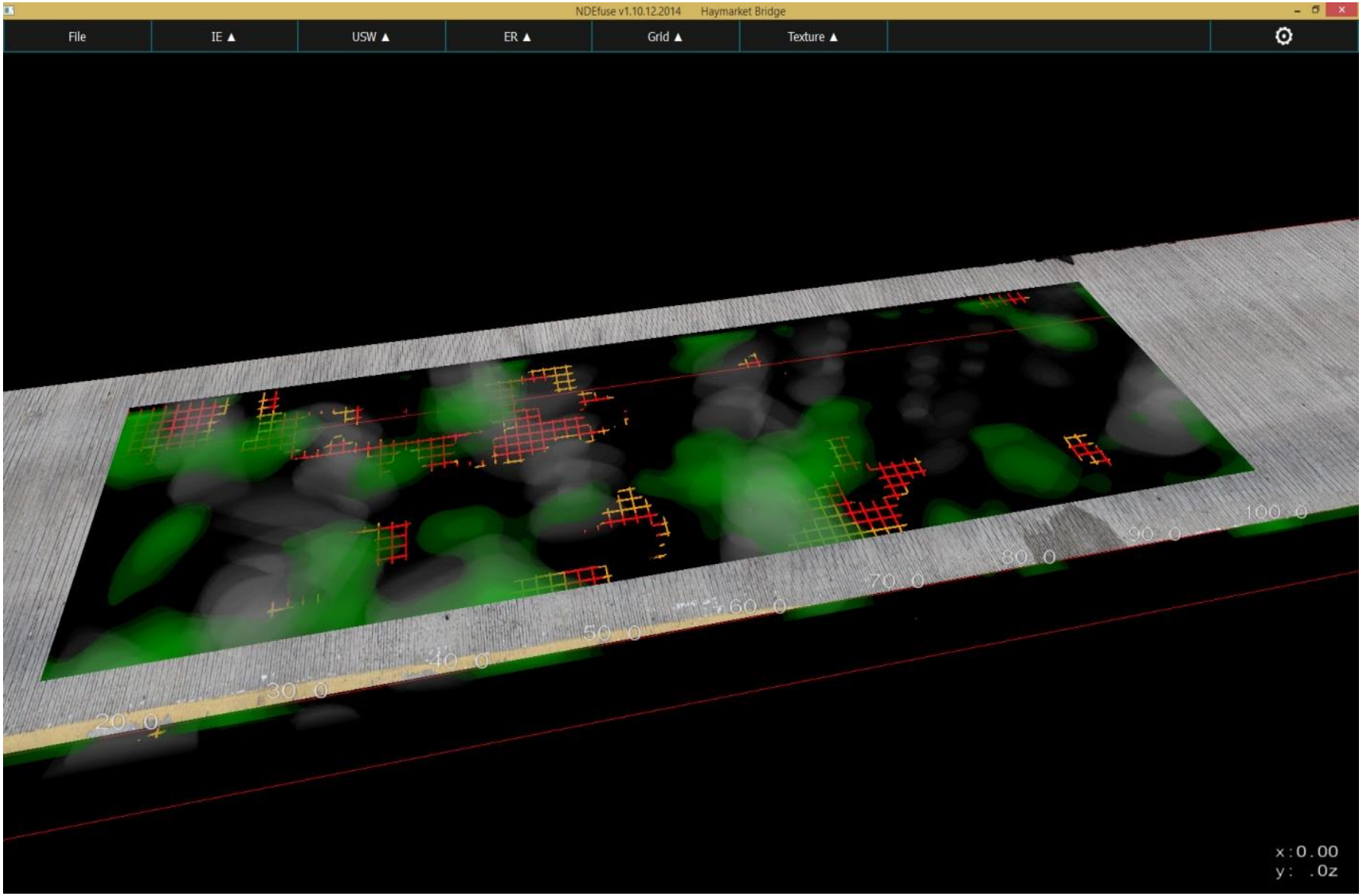


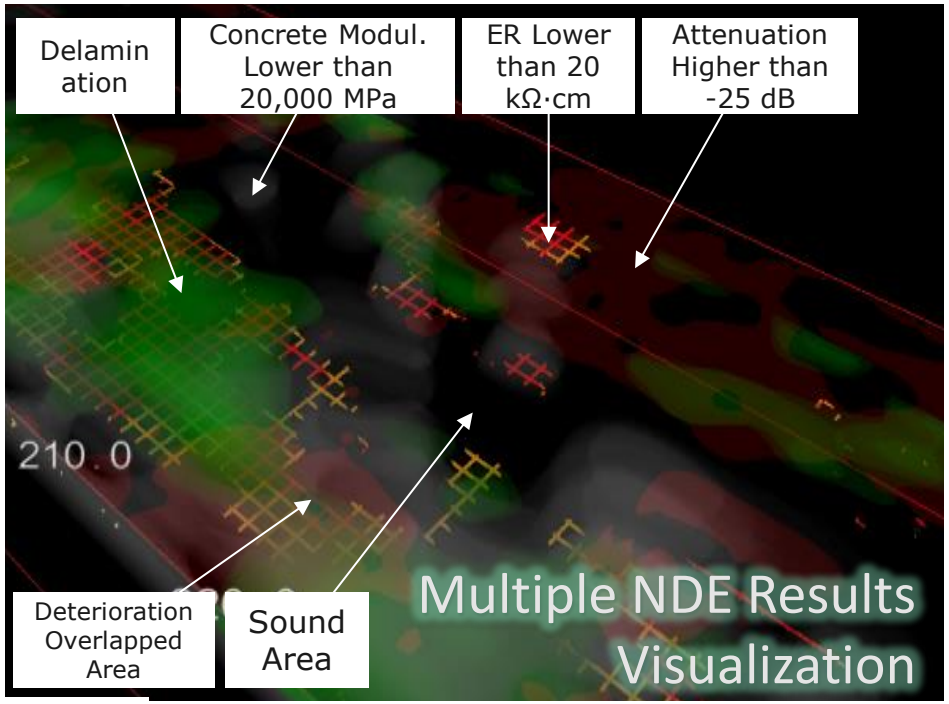
Zoomed Area B

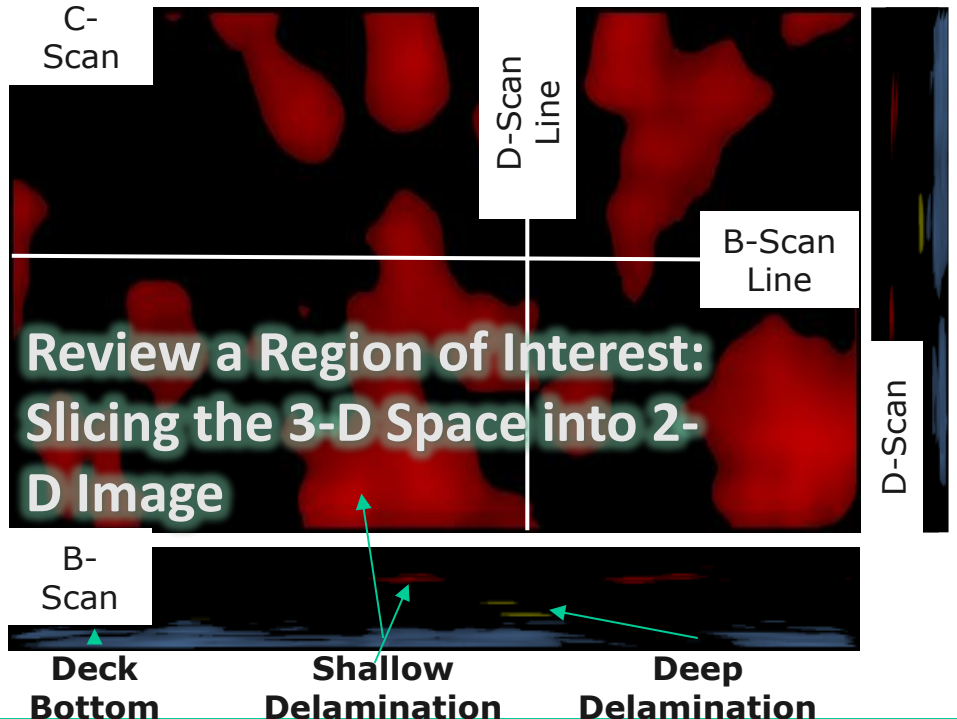
Zoomed Area B

Stitched Image of a Section of Haymarket Bridge Deck

3D Visualization of Extracted Features







Internal - External Deterioration Correlation

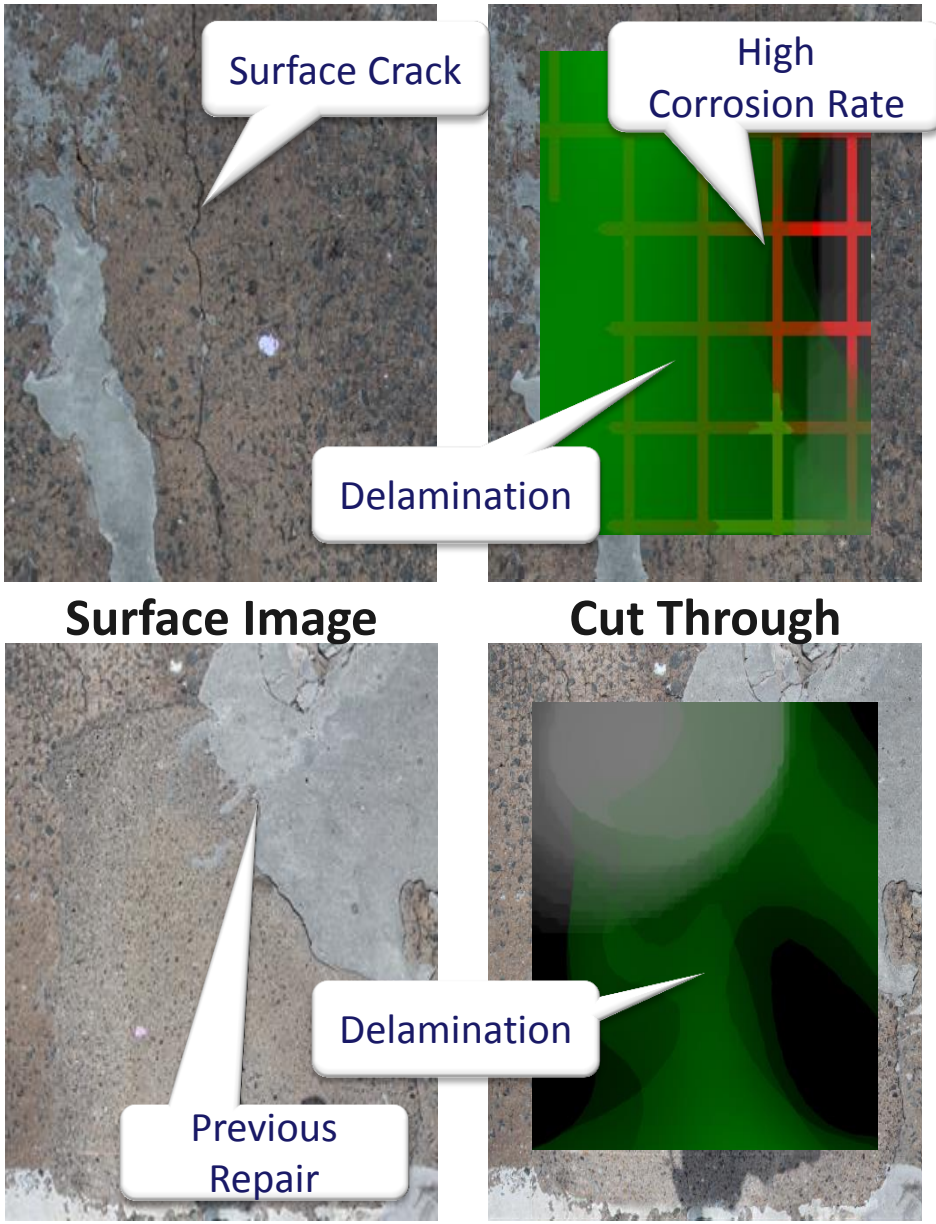


Illustration of Benefits from NDE Surveys

More Realistic Deterioration, Predictive and Life-Cycle Cost Modeling

Condition Indices and Percentages of Deck Area for IE and GPR

NDE Technology	Year	Condition Index	Percentage of Deck Area			
			Serious	Poor	Fair	Good
Impact Echo	2009	69.5	15	4	26	54
	2011	57.0	25	10	26	39
	2014	39.7	39	3	40	18
	2015	39.3	45	7	31	21
			Serious	Poor	Fair	Good
GPR	2009	48.1	21	41	24	14
	2011	35.3	33	43	16	8
	2014	26.4	45	45	6	4
	2015	22.4	55	35	5	5

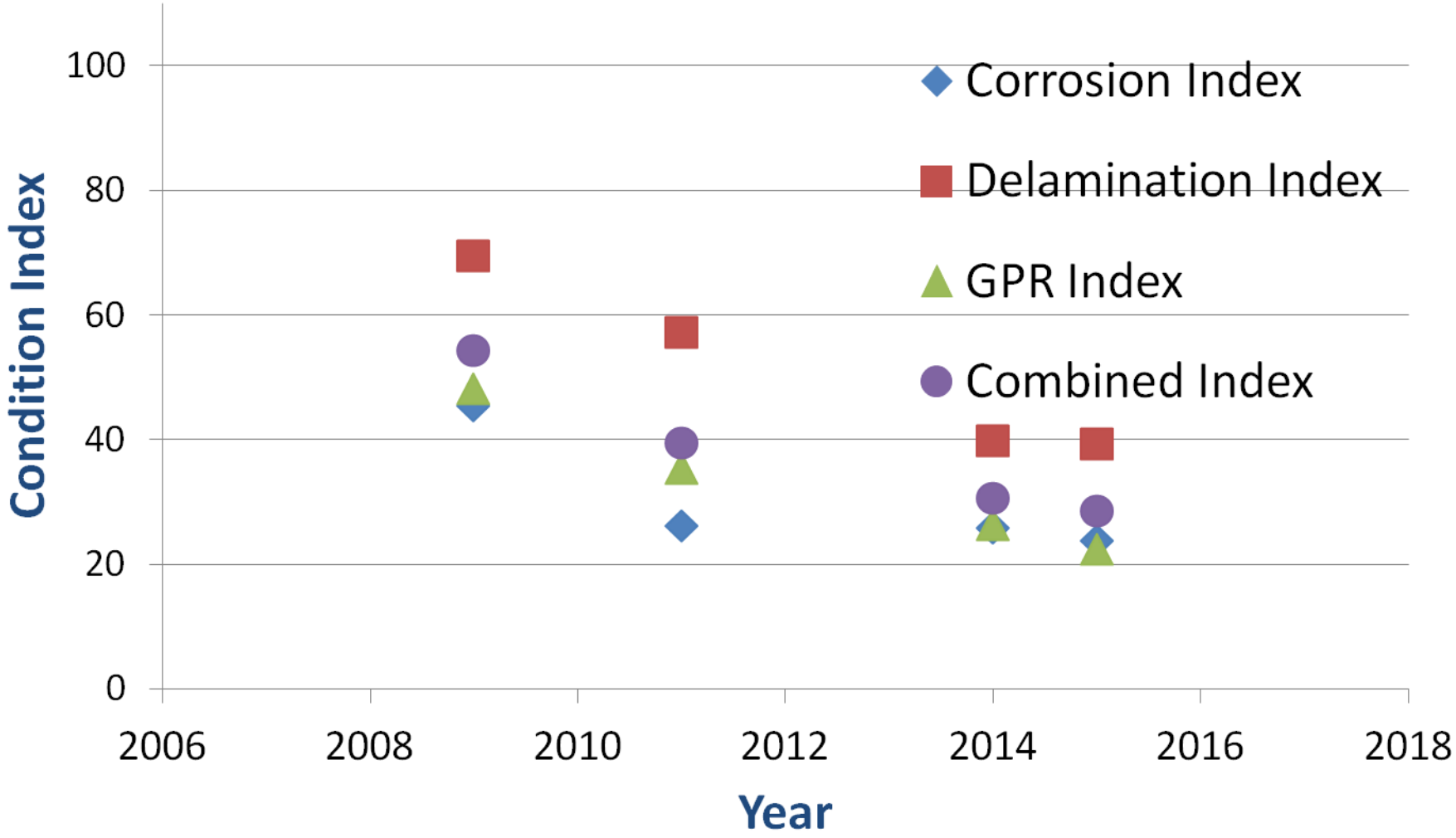
$$Delamination\ Index\ (IE) = \frac{A_{Good} \times 100 + A_{Fair} \times 50 + A_{Poor} \times 50 + A_{Serious} \times 0}{A_{Total}}$$

$$GPR\ Based\ Condition\ Index = \frac{A_G \times 100 + A_F \times 70 + A_P \times 40 + A_S \times 0}{A_{Total}}$$

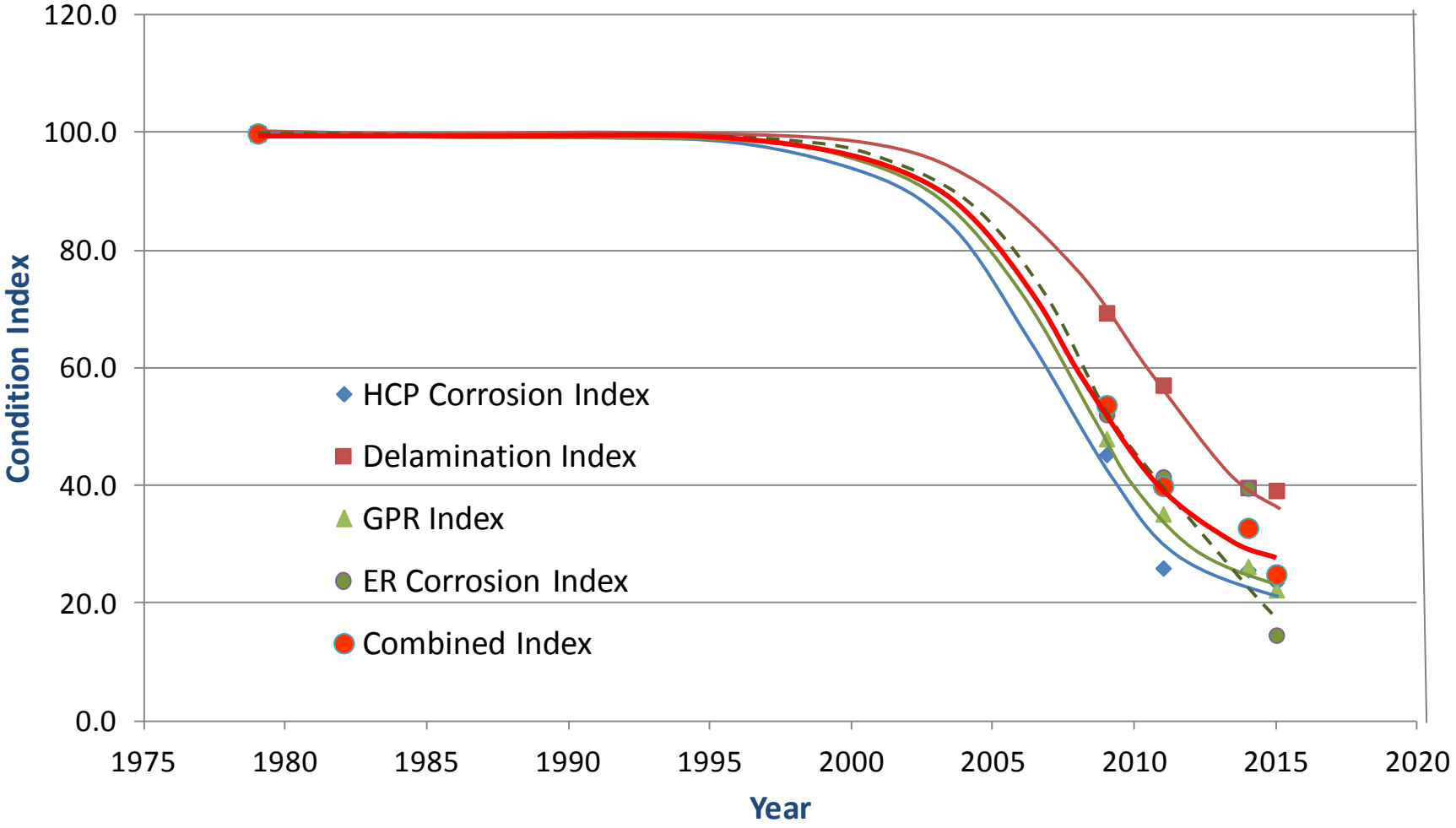
Comparison of 2009 to 2015 Condition Indices of the Haymarket Bridge

NDE Condition Assessment	2009	2011	2014	2015
Active Corrosion	39.4	28.1	25.8	23.7
Corrosive Environment	52.2	41.6	39.7	14.7
Delamination Assessment	70.0	57.2	39.8	39.3
GPR Assessment	48.1	35.3	26.4	22.4
Combined NDE Index	52.4	40.6	32.9	25.0
NBI Rating (Visual)	6	6	6	6

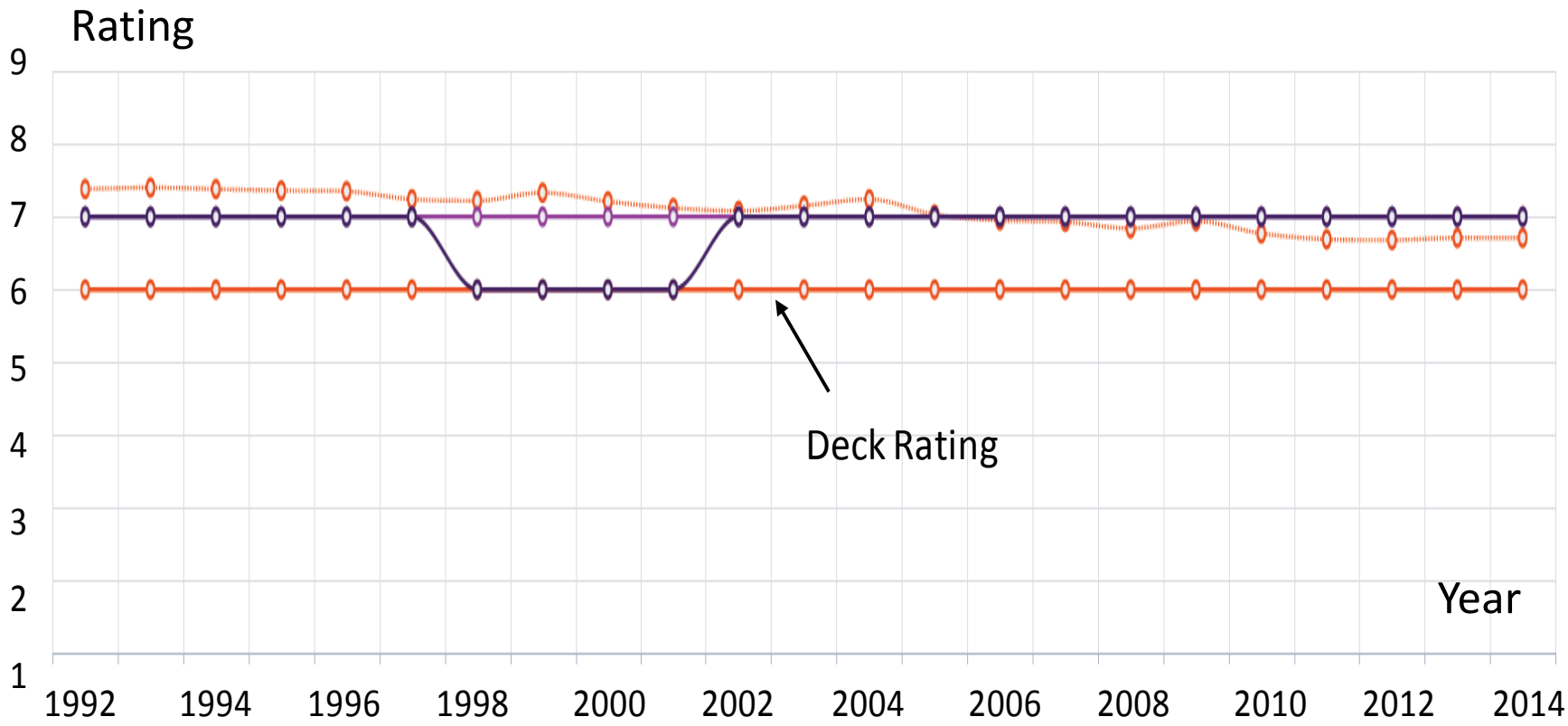
Condition Deterioration Progression Between 2009-2015



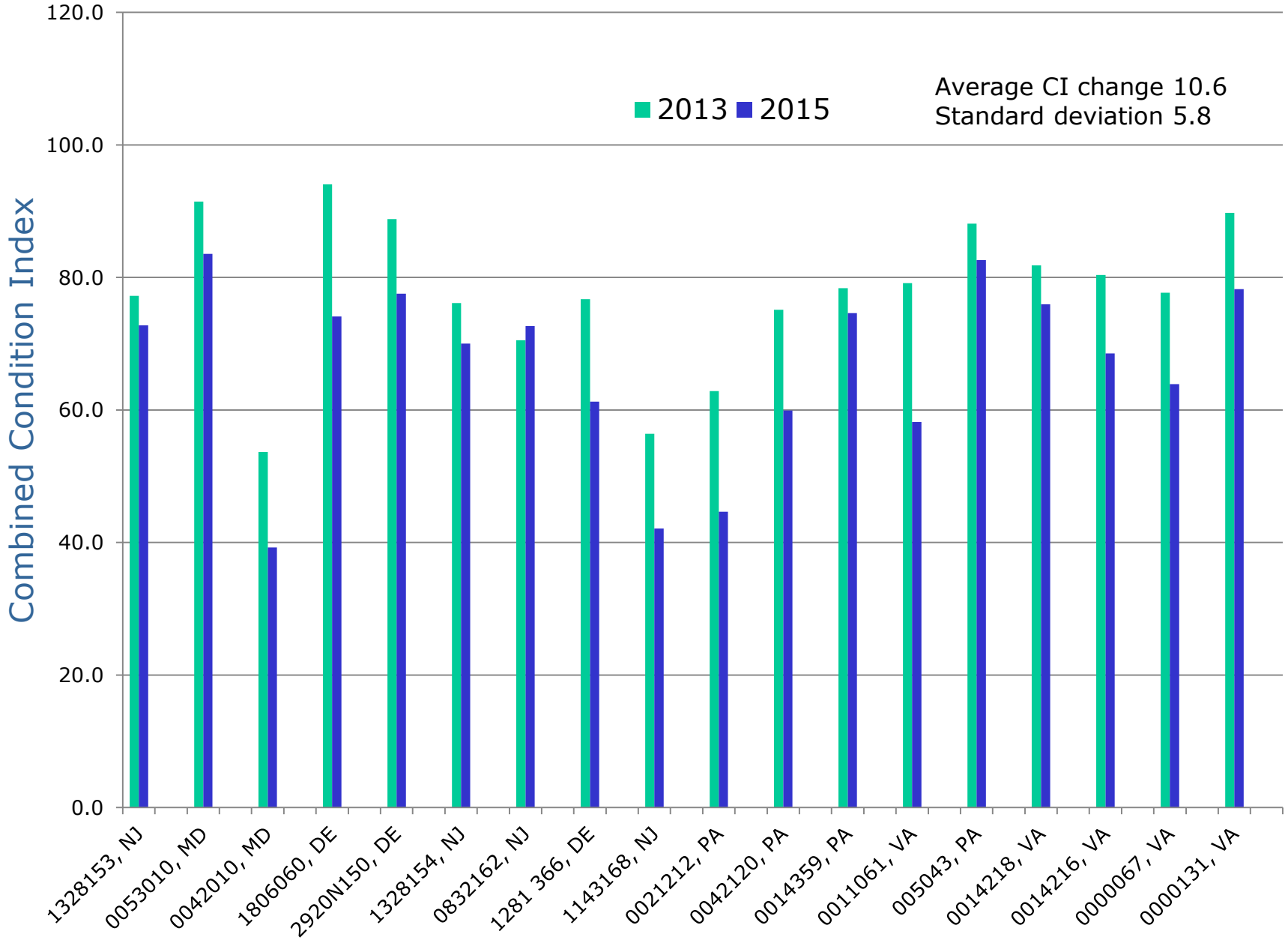
Condition Index Degradation Curves for Four NDE Technologies



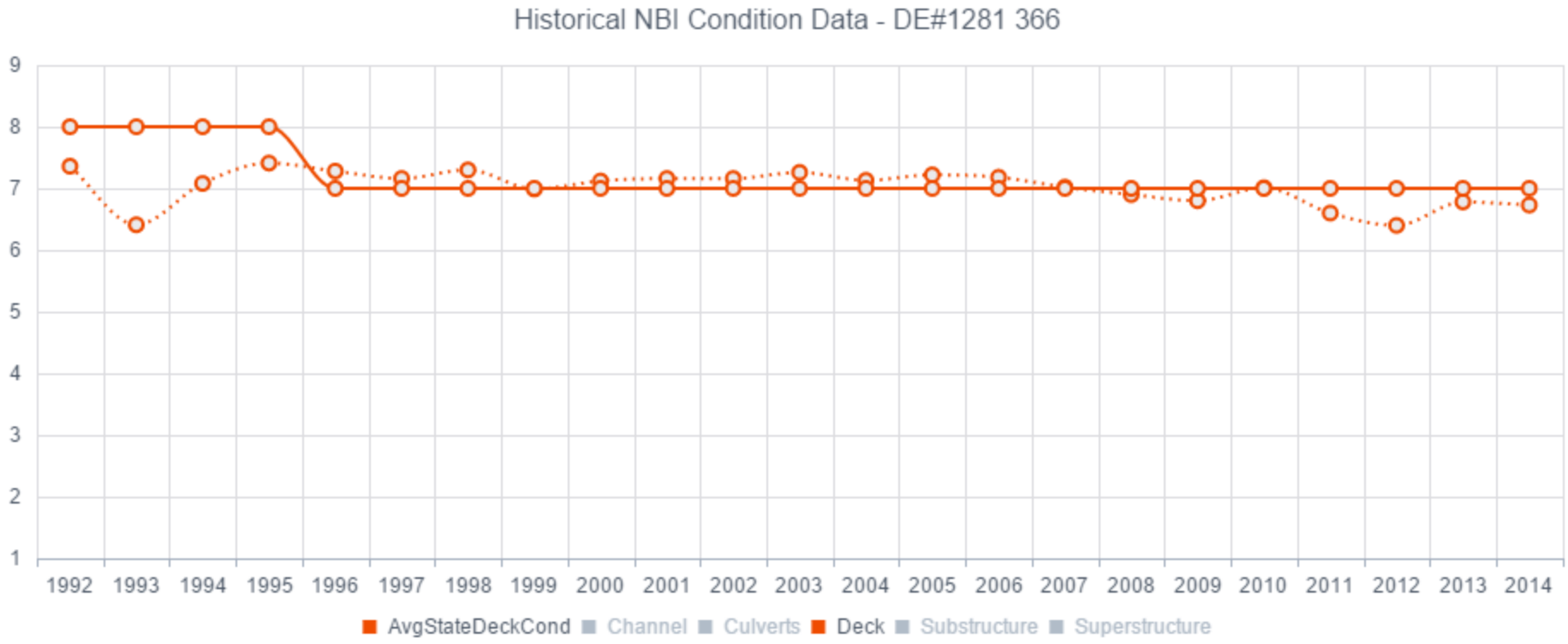
NBI Deck Condition Rating of Haymarket Bridge



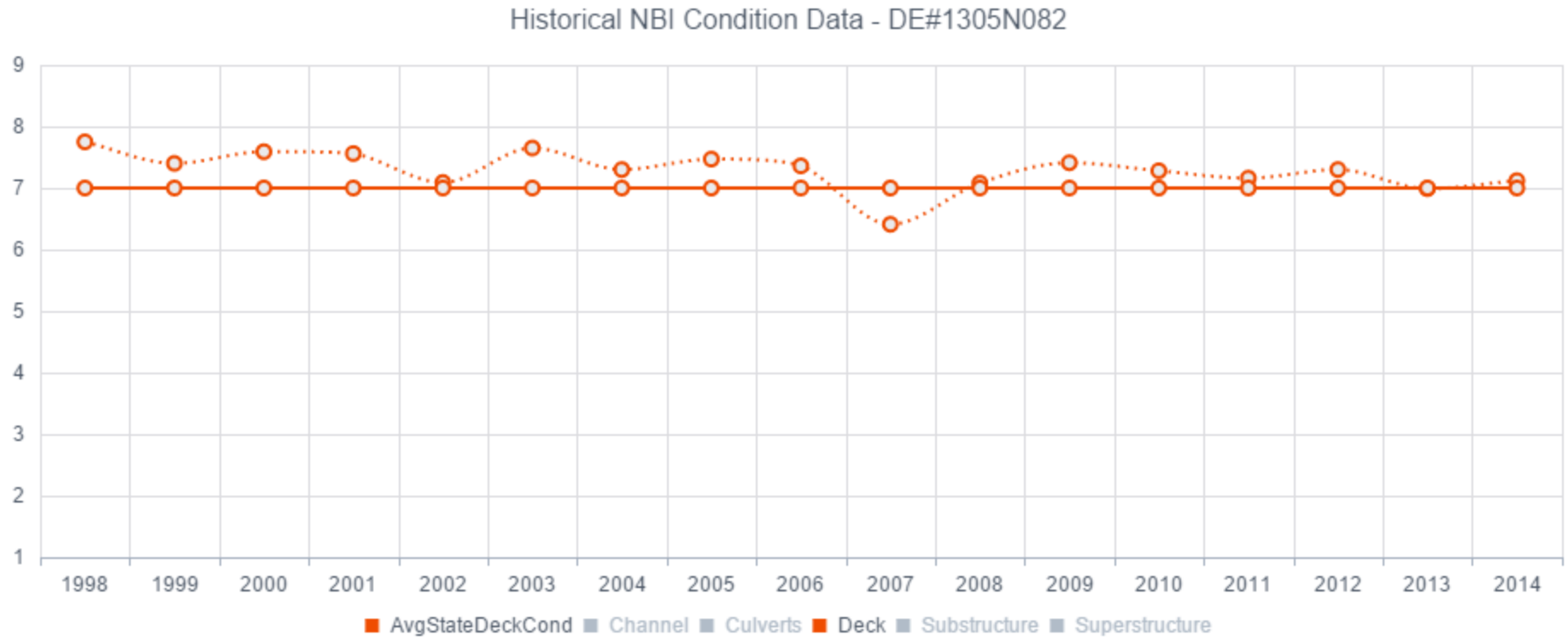
Combined Condition Index for 18 Cluster Bridges



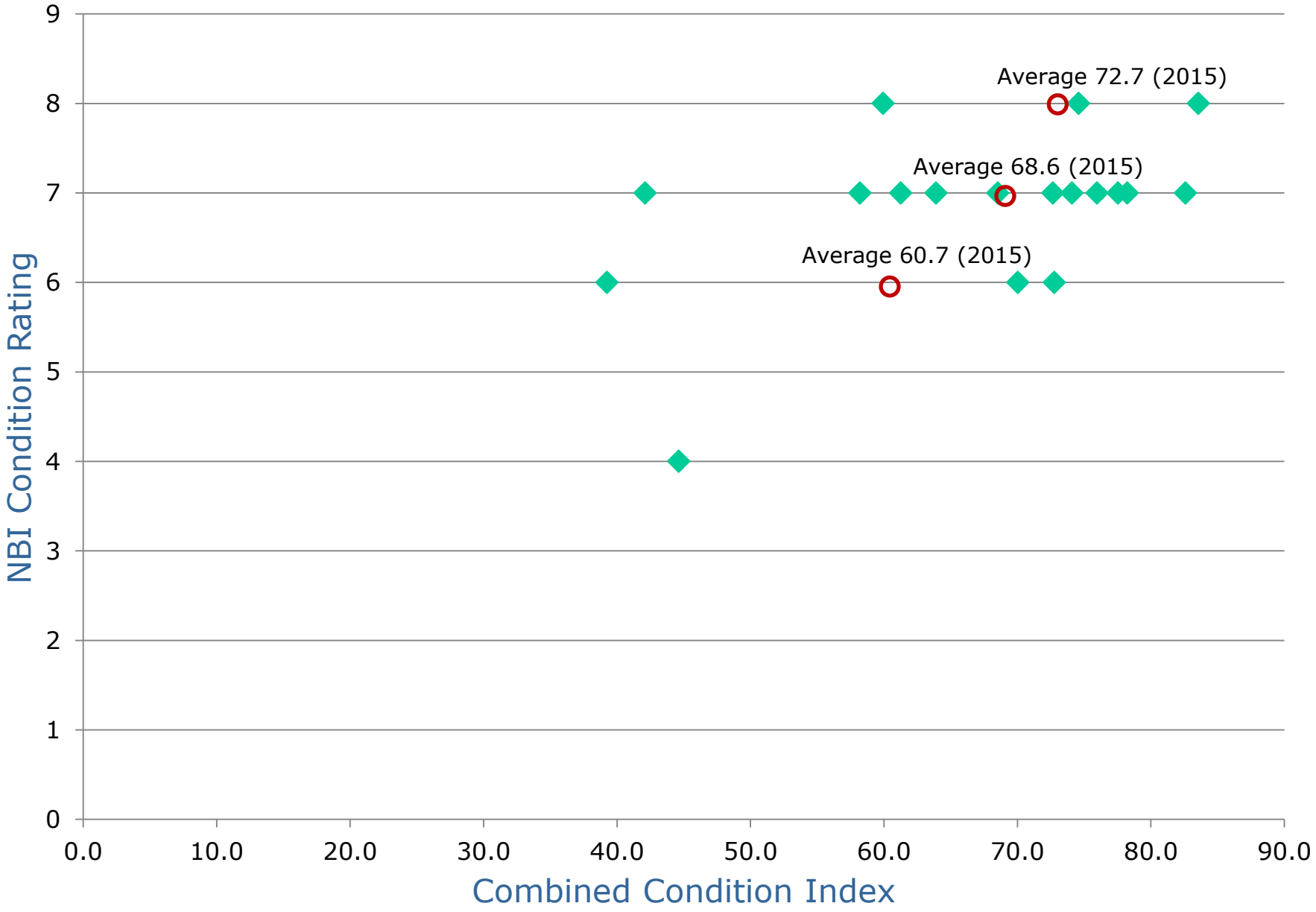
Sample NBI Condition Rating



Sample NBI Condition Rating



NBI Condition Rating Vs. NDE Condition Index



Life Cycle Cost Analysis

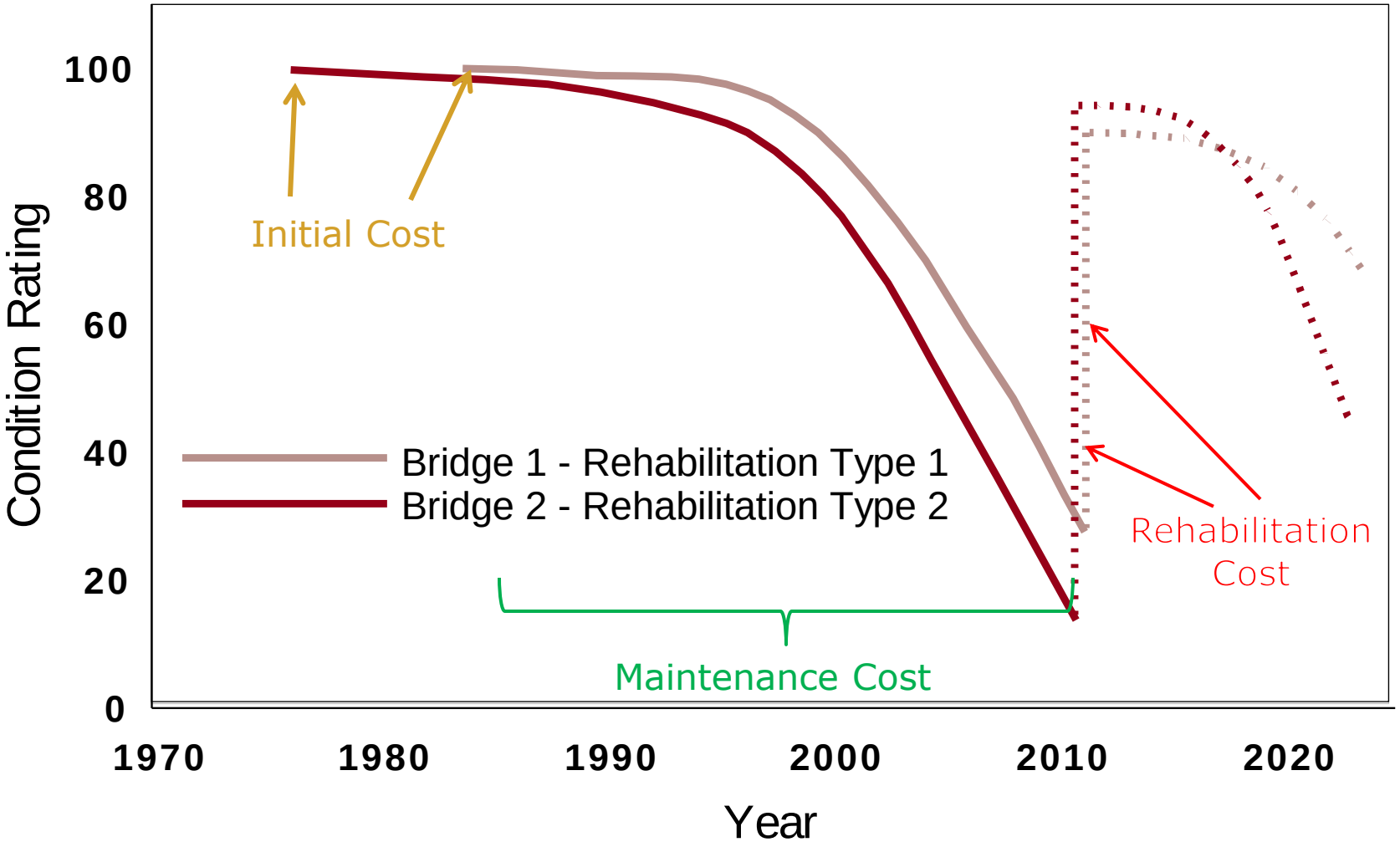


Illustration of Benefits from NDE Surveys

Optimized Use of Resources in Inspection and Maintenance

Protocols for Frequency of Testing

Bridge Deck Condition

Rebar Corrosion

Delamination

Spalling

High Condition Index
Longer Period
(3-5 years?)

Medium Condition Index
Medium Period
(1-3 years?)

Low Condition Index
Short Period
(1 year?)

Condition index based on assessment of:
1) corrosion, 2) concrete deterioration and 3) delamination

Time

Segmentation - Comparison of 2009 and 2011 Condition Indices for the Virginia Bridge Deck

	2009			2011		
	Left Lane	Right Lane	Shoulder	Left Lane	Right Lane	Shoulder
Active Corrosion	50	50	32	30	32	17
Delamination Assessment	70	72	66	58	59	54
Concrete Degradation	40	60	30	27	45	16
Combined Index	53.3	60.7	42.7	35	45.3	29

Merging of Robotic Evaluation and Rehabilitation

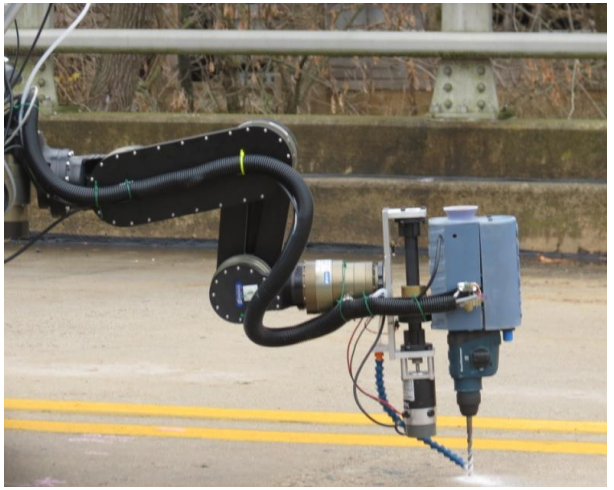
State of Practice in Rehabilitation

State of Practice in Rehabilitation

Minimally Invasive and Autonomous Rehabilitation

Material Development

Material Delivery Development



Filling of a Delamination

Rehabilitation Robot Demonstration

Current Practice Vs. Future of Evaluation and Rehabilitation

- Duration in days
- High cost
- Significant traffic interruptions
- Risks to transportation workers

- Duration in hours
- Moderate cost
- Early intervention
- Minimal traffic interruptions
- Low risks to transportation workers

Conclusions

- NDE technologies can provide detailed and accurate information about deterioration or defects.
- Comprehensive condition assessment of bridge decks can be achieved only through a complementary use of multiple technologies.
- NDE technologies enable more objective condition assessment, development of more reliable deterioration and predictive models, and ultimately better asset management.
- Automation of NDE will lead to:
  - Significantly improved speed of bridge NDE surveys,
  - Safer data collection, and
  - Effective multi NDE technology approach.
- Minimally invasive and automated early intervention will be an integral part of future management of highway bridges.

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Thank You!
IDS