RABIT: Automated Condition Assessment of Concrete Bridge Decks by Robotic System

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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.
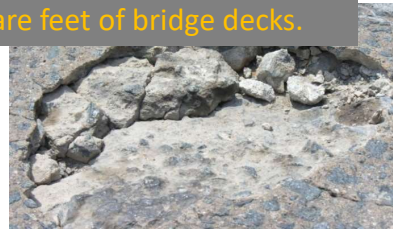
Outline

- 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?

- 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.
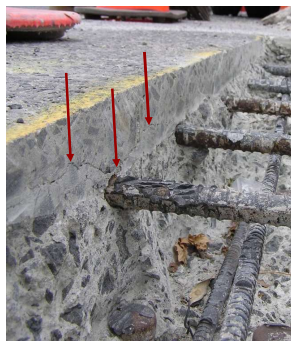
Reinforced Concrete Deterioration Types of Primary Interest
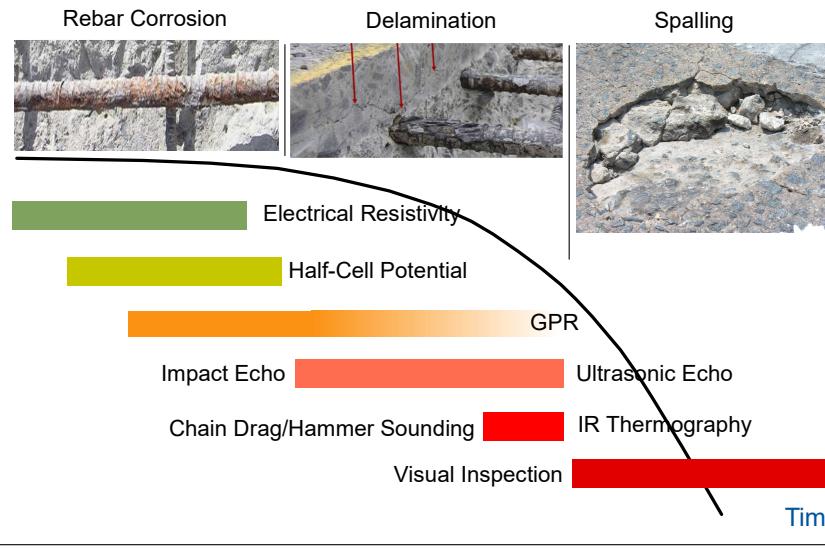
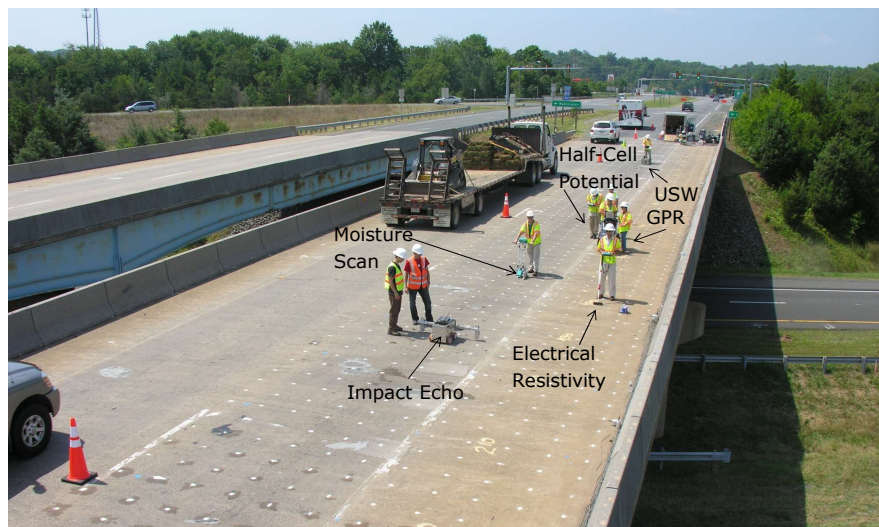Corrosion   Delamination   Concrete Degradation
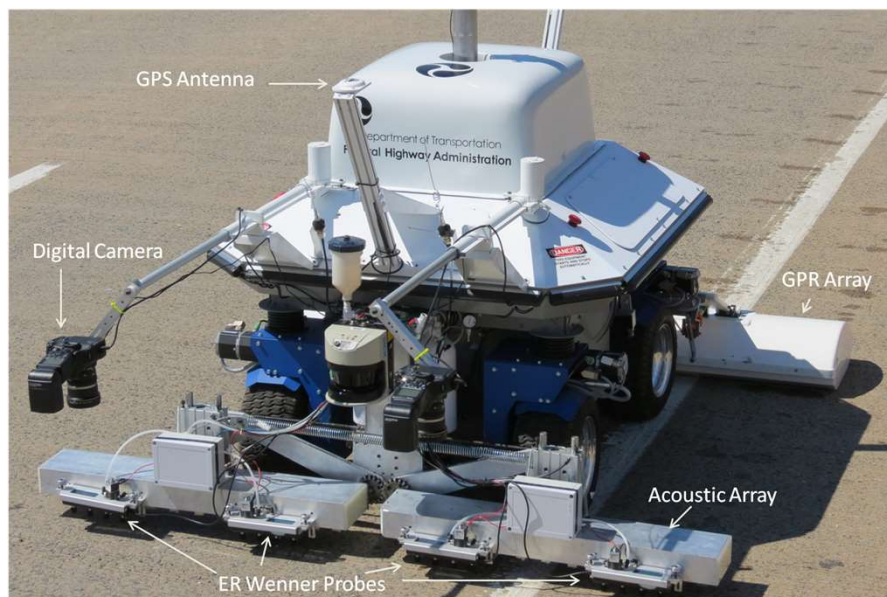
Deck Condition Assessment Vs. NDE Method

Haymarket Bridge NDE Data Collection

NDE Surveys Using Manual NDE Technologies

RABIT Components

GPS Antenna

Digital Camera

GPR Array

Acoustic Array

ER Wenner Probes

RABIT Components

Panoramic Camera

GPR Arrays

RABIT Transportation by Command Van
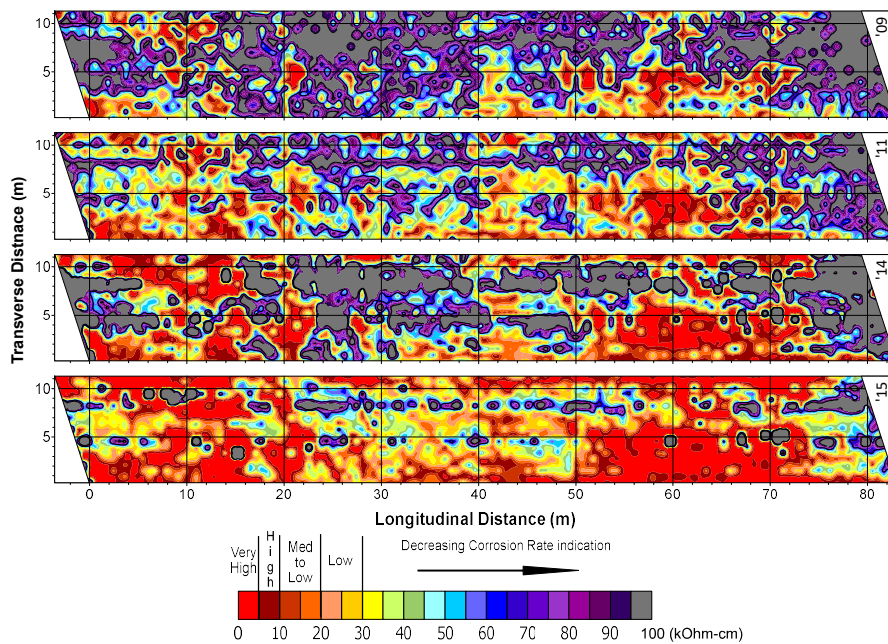
Command Van Displays

Illustration of Benefits from NDE Surveys

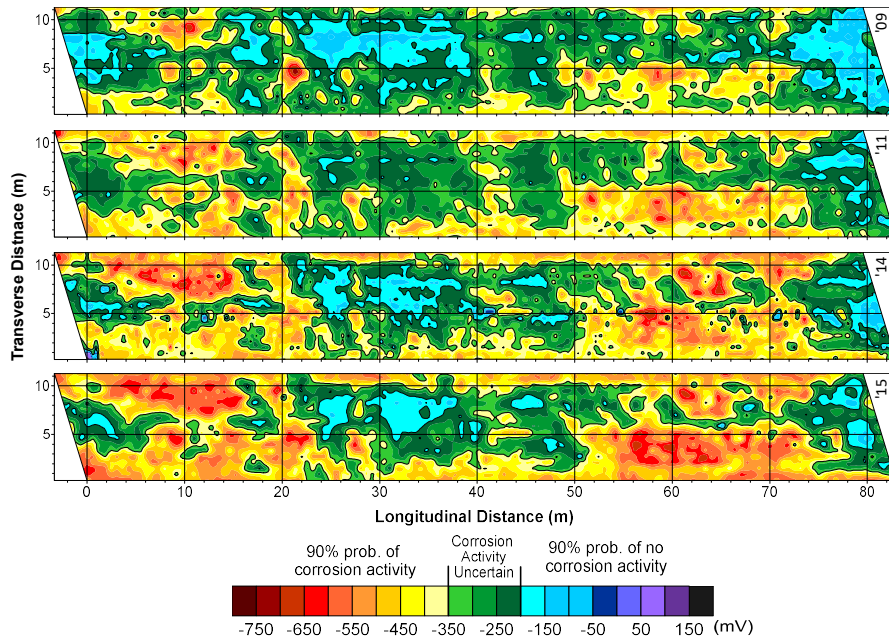Accurate Description of Internal Deterioration
and Defects

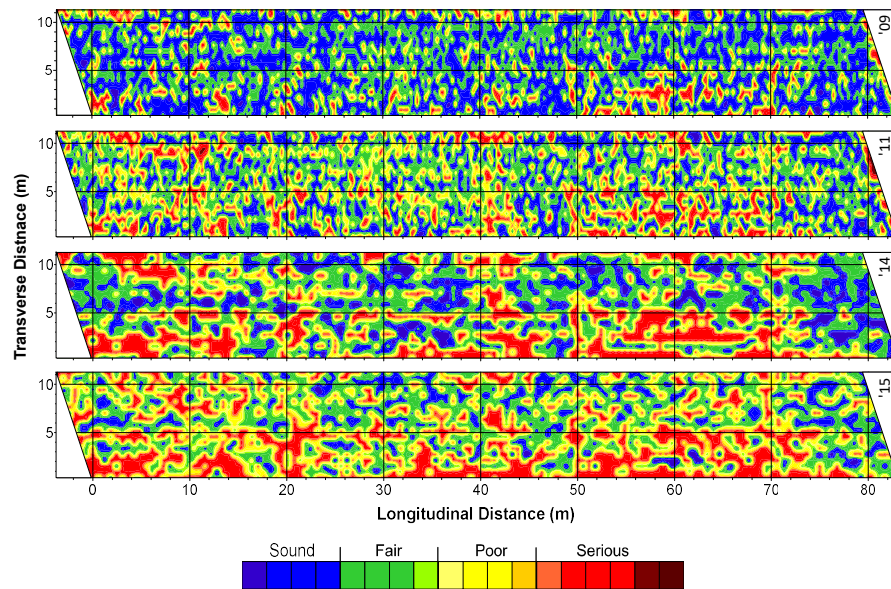# FHWA's LTBP Program - Rt.15 over I-66 Bridge, Haymarket, VA
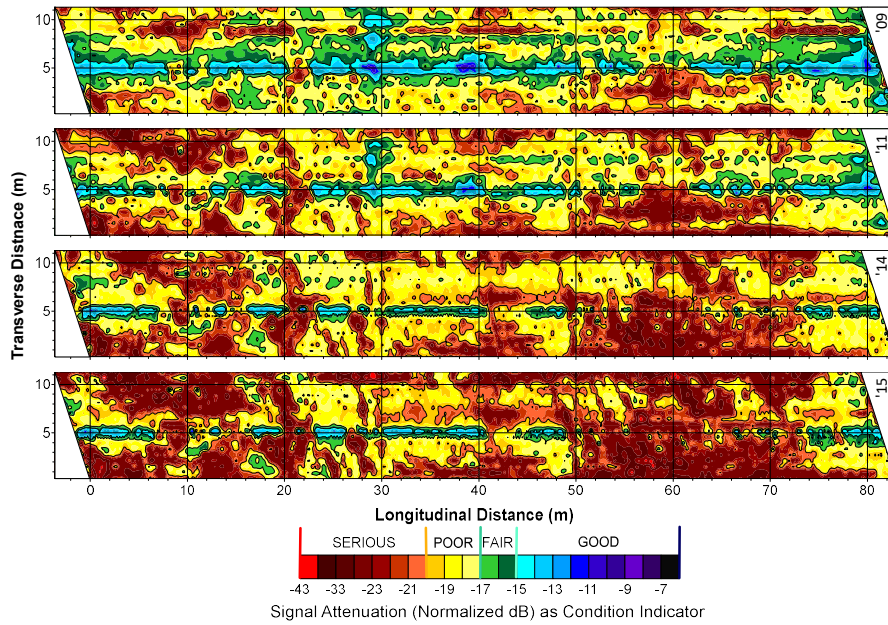

ER Maps for Haymarket Bridge 2009-2015
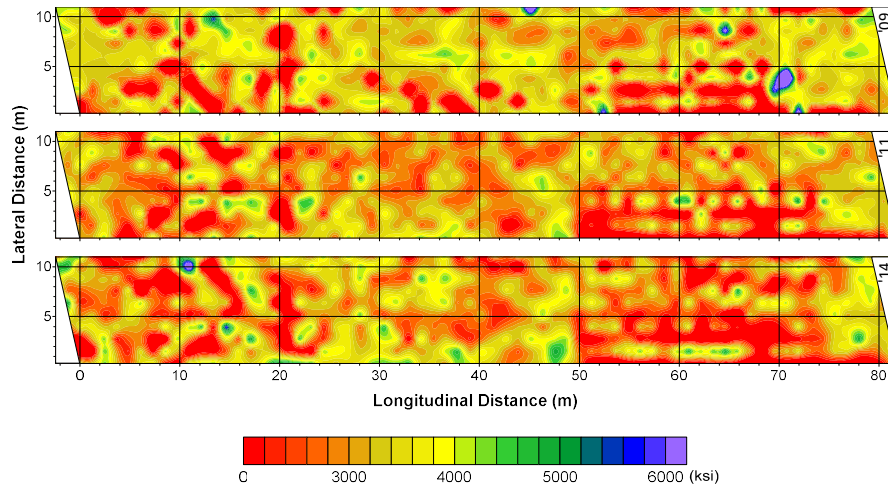
HCP Maps for Haymarket Bridge 2009-2015

Delamination Maps for Haymarket Bridge 2009-2015

9

GPR Maps for Haymarket Bridge 2009-2015

Transverse Distnace (m)

'09

'11

'14

'15

Longitudinal Distance (m)

SERIOUS			POOR	FAIR	GOOD		
-43	-33	-23	-21	-19	-17	-15	-13	-11	-9	-7

Signal Attenuation (Normalized dB) as Condition Indicator

Concrete Modulus Maps for Haymarket Bridge 2011-15

Lateral Distance (m)

'09

'11

'14

Longitudinal Distance (m)

0   3000   4000   5000   6000 (ksi)

Comparison of NDE Technology Results for 2015
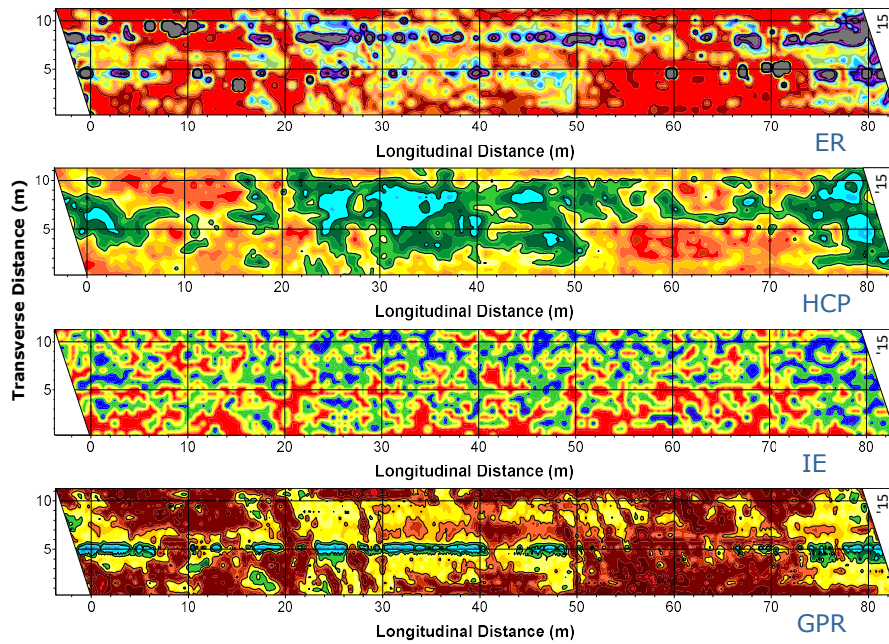
Comparison of NDE Technology Results for O1 Bridge

Illustration of Benefits from NDE Surveys
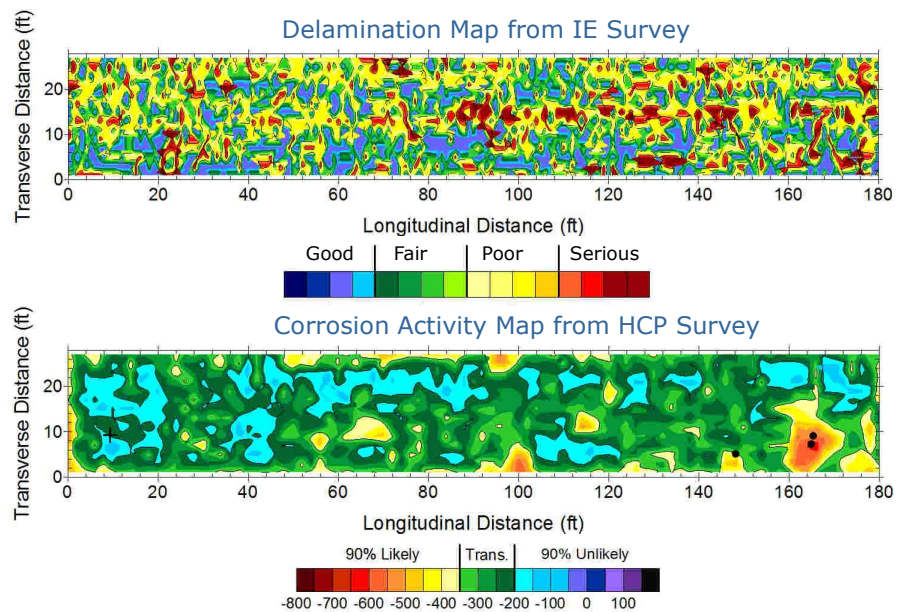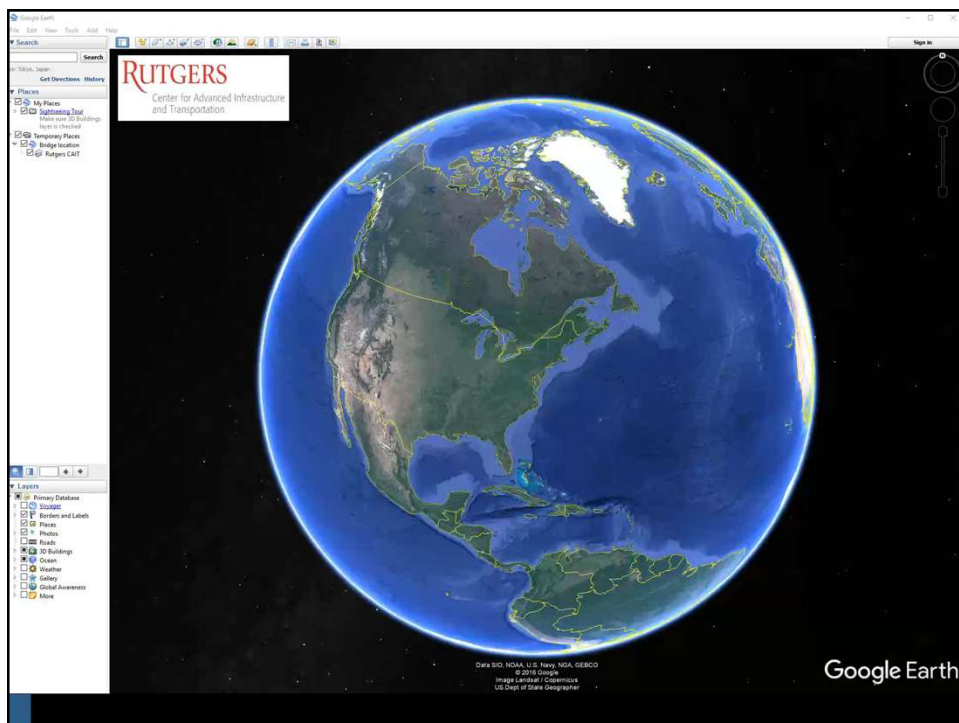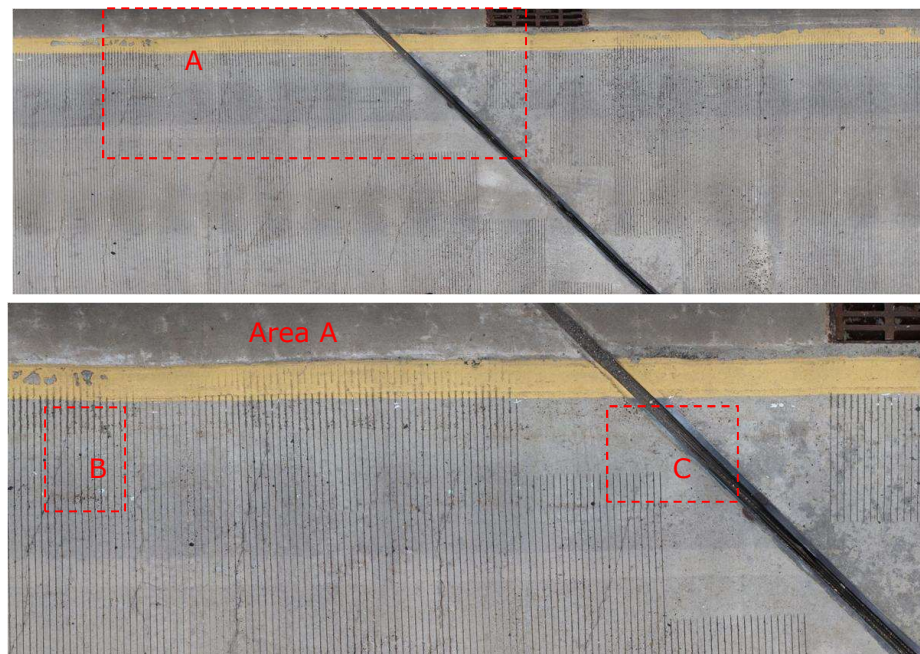
Intuitive Presentation of Deterioration and Defects

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

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

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

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

Condition Indices and Percentages of Deck Area for ER and HCP

NDE Technology	Year	Condition Index	Percentage of Deck Area		
			90% Probability of Corrosion	Transition	90% Probability of No Corrosion
Half-Cell Potential	2009	45.4	30	49	21
	2011	26.1	51	46	3
	2014	25.8	57	34	9
	2015	23.7	60	32	8
			Medium to High Corrosion Rates	Low Corrosion Rates	Very Low Corrosion Rates
Electrical Resistivity	2009	52.2	28	39	33
	2011	41.6	40	38	23
	2014	39.7	52	17	31
	2015	14.7	78	14	8

$$Active\ Corrosion\ (HCP) Condition\ Index = \frac{A_{90\%\ Sound} \times 100 + A_{Transition} \times 50 + A_{90\%\ Corrosion} \times 0}{A_{Total}}$$

$$ER\ Condition\ Index = \frac{A_{Very\ Low} \times 100 + A_{Low} \times 50 + A_{High} \times 0}{A_{Total}}$$

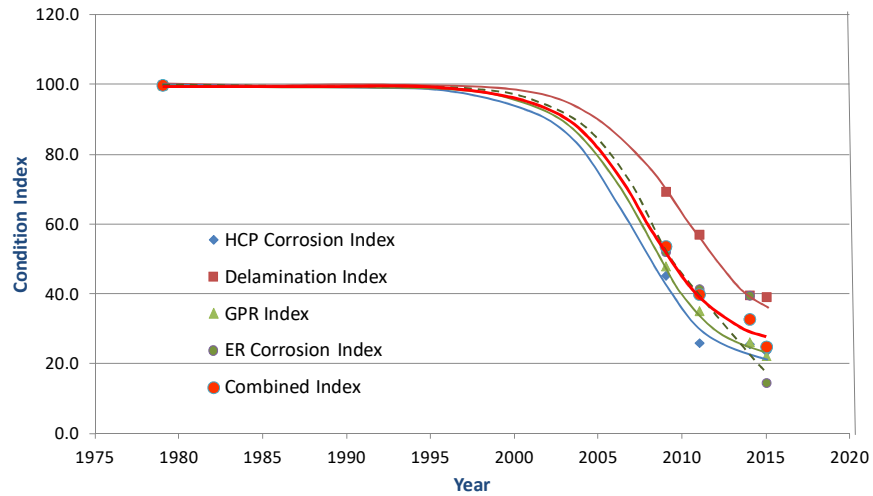## Comparison of 2009 to 2015 Condition Indices of the Haymarket Bridge

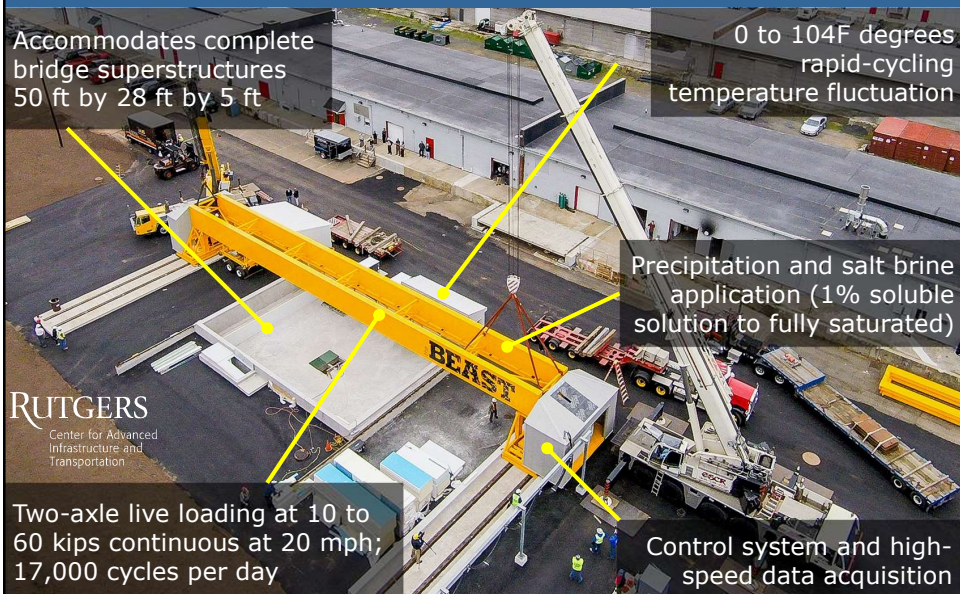| NDE Condition Assessment	2009	2011	2014	2015
Active Corrosion	39.4	28.1	25.8	23.7
Corrosive Environment	52.2	41.6	39.7	14.7
Delamination Assessment	70.0	57.2	39.8	39.3
GPR Assessment	48.1	35.3	26.4	22.4
Combined NDE Index	52.4	40.6	32.9	25.0
NBI Rating (Visual)	6	6	6	6

Condition Deterioration Progression Between 2009-2015
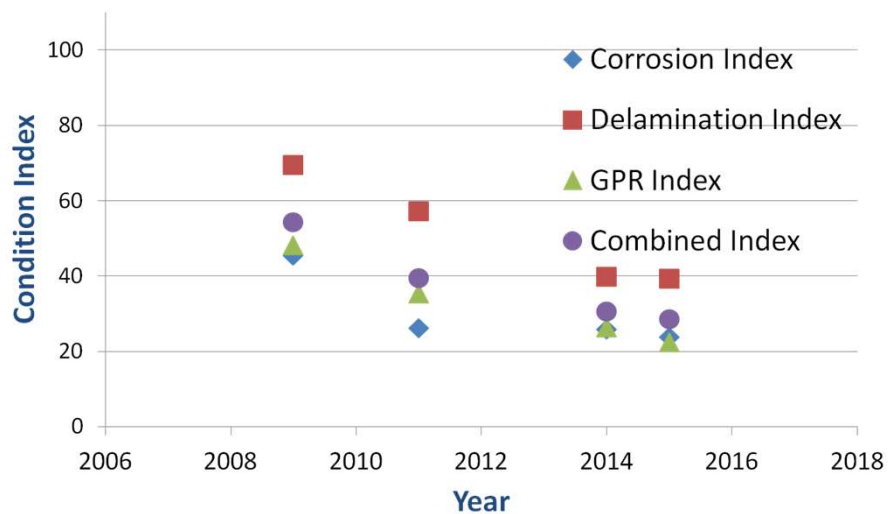
Condition Index Degradation Curves for Four NDE Technologies

The BEAST – Bridge Evaluation and Accelerated Structural Testing

Accommodates complete bridge superstructures 50 ft by 28 ft by 5 ft

0 to 104F degrees rapid-cycling temperature fluctuation

Precipitation and salt brine application (1% soluble solution to fully saturated)

Two-axle live loading at 10 to 60 kips continuous at 20 mph; 17,000 cycles per day

Control system and high-speed data acquisition

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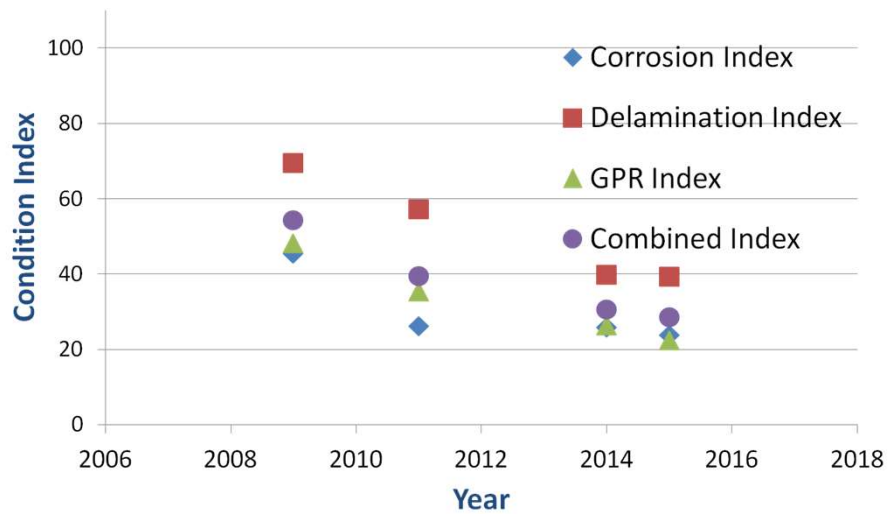## BEAST - Bridge Evaluation and Accelerated Structural Testing

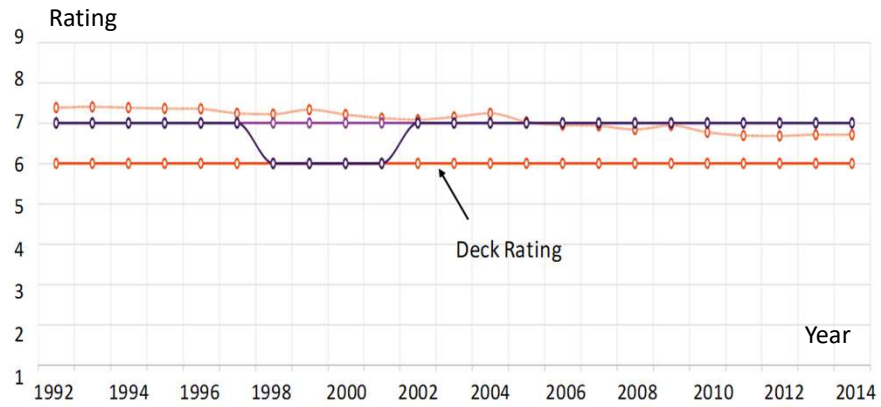## BEAST - Bridge Evaluation and Accelerated Structural Testing

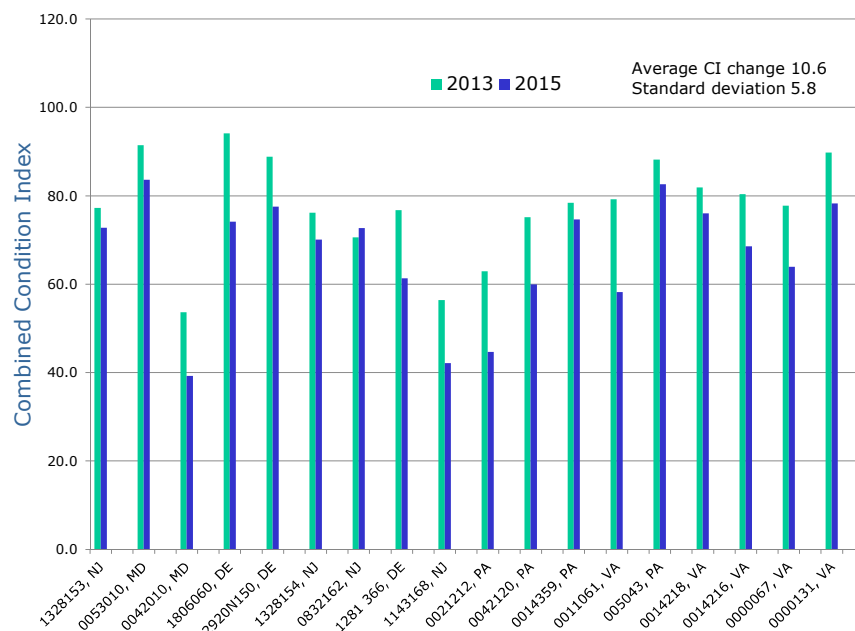BEAST - Bridge Evaluation and Accelerated Structural Testing
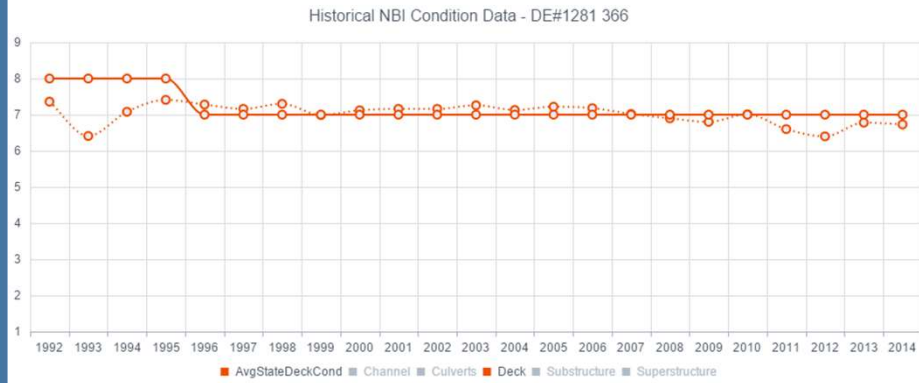

Condition Deterioration Progression Between 2009-2015

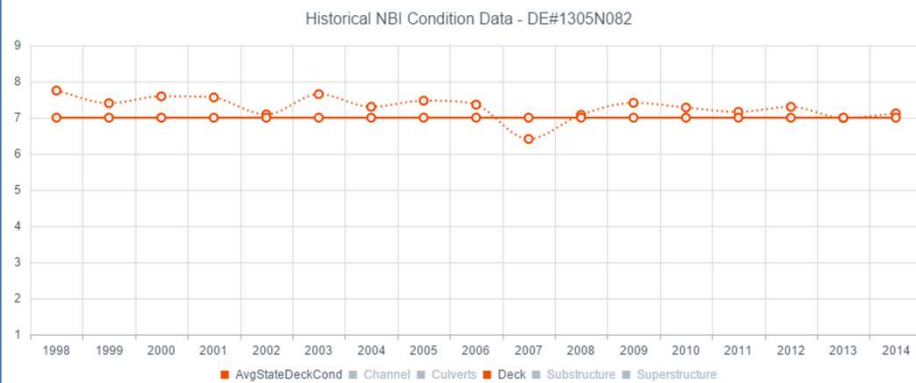NBI Deck Condition Rating of Haymarket Bridge

Combined Condition Index for 18 Cluster Bridges

Sample NBI Condition Rating
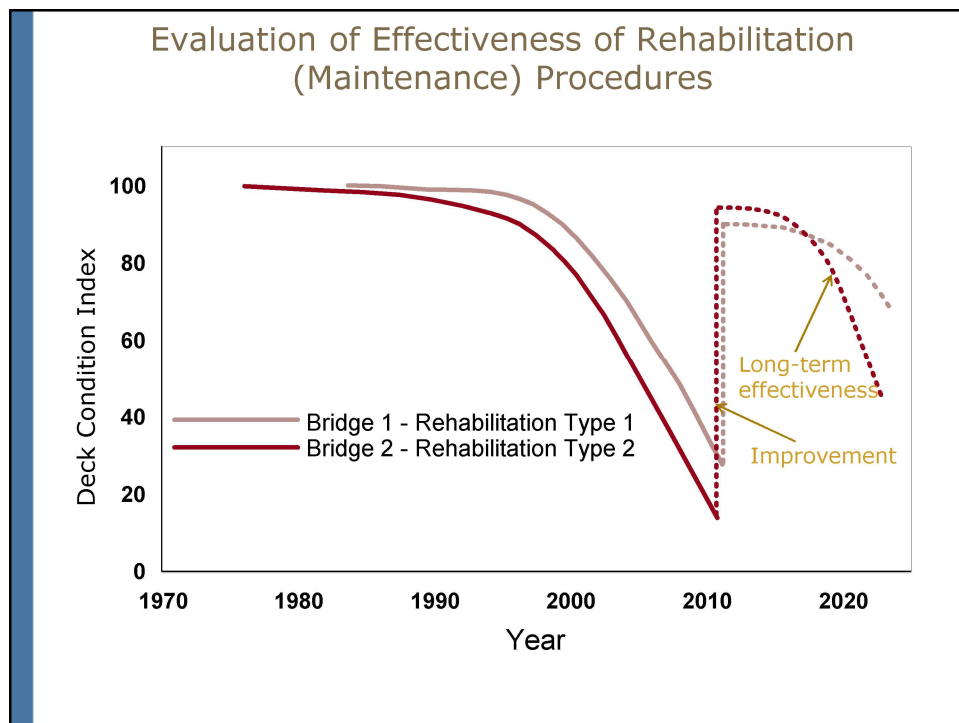
Historical NBI Condition Data - DE#1281 366

Sample NBI Condition Rating

Historical NBI Condition Data - DE#1305N082

NBI Condition Rating Vs. NDE Condition Index

Evaluation of Effectiveness of Rehabilitation (Maintenance) Procedures
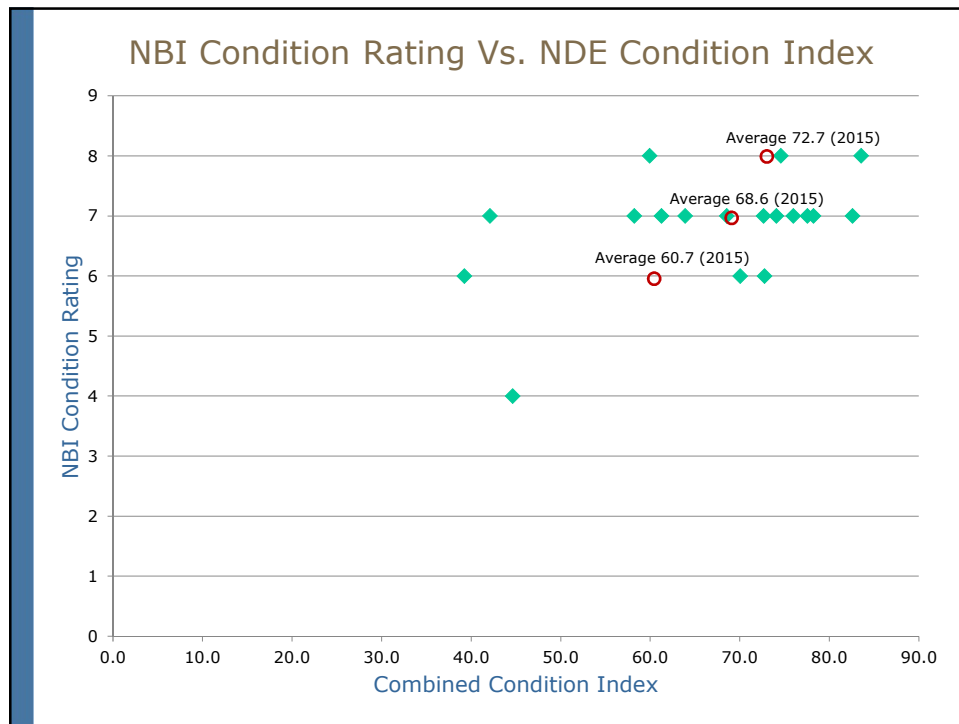
Life Cycle Cost Analysis

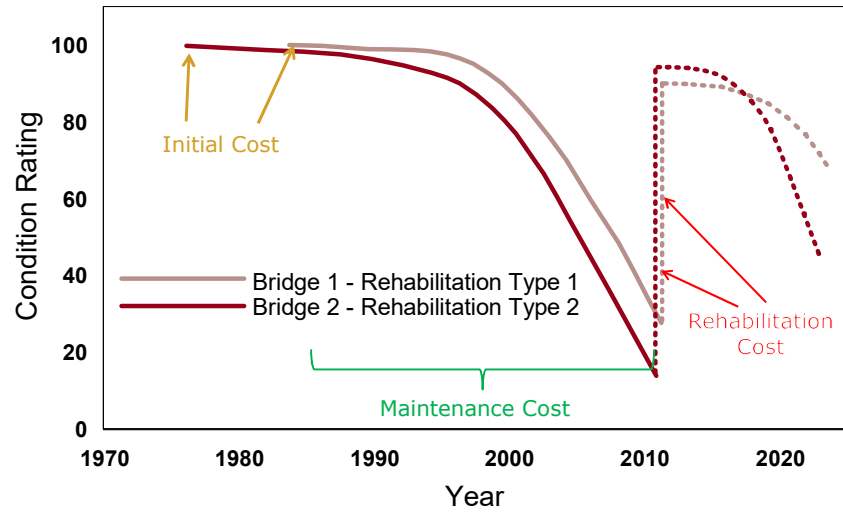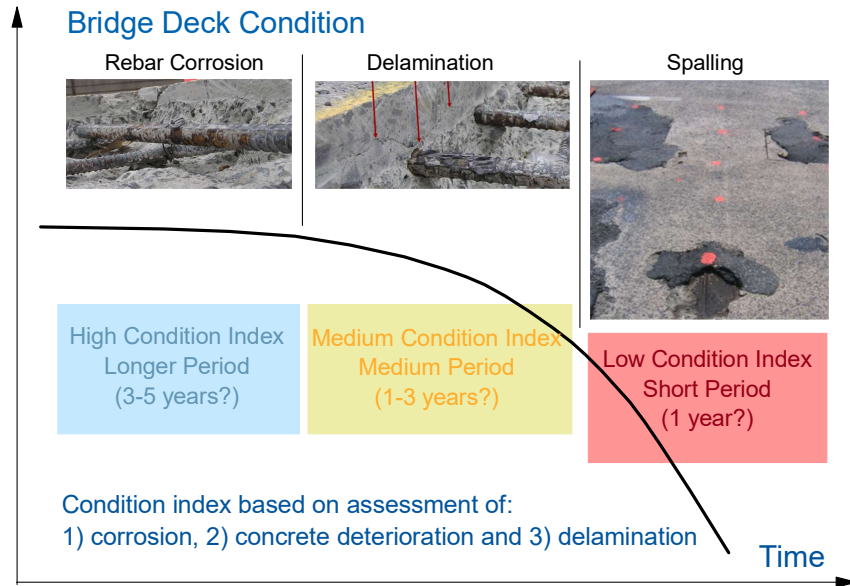# Illustration of Benefits from NDE Surveys

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
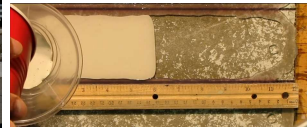
State of Practice in Rehabilitation

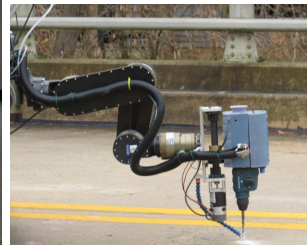## State of Practice in Rehabilitation

Minimally Invasive and Autonomous Rehabilitation

Material Development

Material Delivery Development

Deck Delamination

Deck Delamination
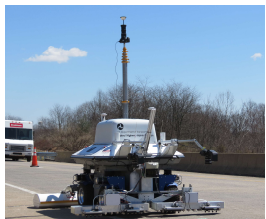
Filling of a Delamination

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.

Acknowledgments

- Federal Highway Administration – LTBP Program
  - Dr. Hamid Ghasemi, Dr. Rob Zobel, Dr. Hoda Azari
- National Institute of Standards and Technology – NIST-TIP – Dr. Felix Wu
- Rutgers University
  - Faculty (Dr. Basily Basily, Dr. Jingang Yi, Dr. Ali Maher, Dr. Kristin Dana, Dr. Bala Balaguru, Dr. Husam Najm)
  - Post-Docs (Dr. Hung La, Dr. Seong-Hoon Kee, Dr. Jinyoung Kim, Dr. Trung Duong, Dr. Kien Dinh, Dr. Giri Venkiteela)
  - Research Engineers (Ronny Lim, Hooman Parvardeh)
  - Graduate Students (Michael Klein, Parneet Kaur, Prateek Prasanna, Fei Liu, Mitja Trkov)
- IDS, Italy
  - Guido Manacorda, Giorgio Barsacchi, Alessandro Simi
- Geomedia Research and Development, El Paso, Texas
  - Dr. Mark Baker

Thank You!