

# Cold-spray Additive Repair of Corroded Steel Bridge Beams

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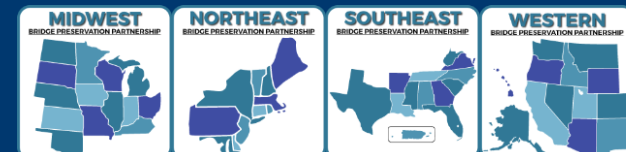
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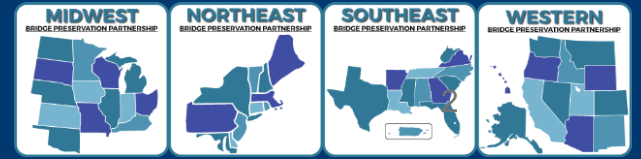


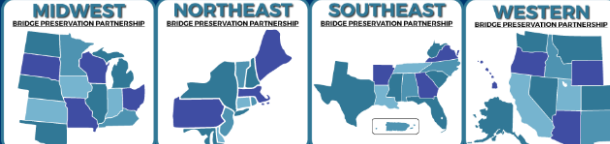
UMassAmherst  
College of Engineering





**nbppc** NATIONAL BRIDGE PRESERVATION CONFERENCE 2024  
*Innovation for Infrastructure Resiliency*





# Outline

**Part 1: UMass Bridge program**  
2015-present

**Part 2: 3D scanning for bridge inspection**  
hardware, data acquisition and processing

**Part 3: Corrosion Repair**  
Cold spray AM

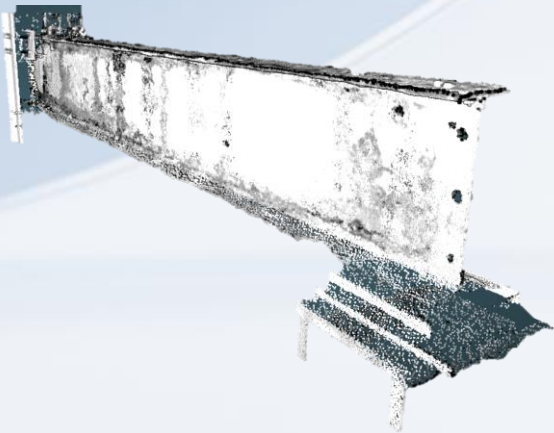
Bridge Experiments



Scanning



Cold-spray AM



# Part I Bridge program



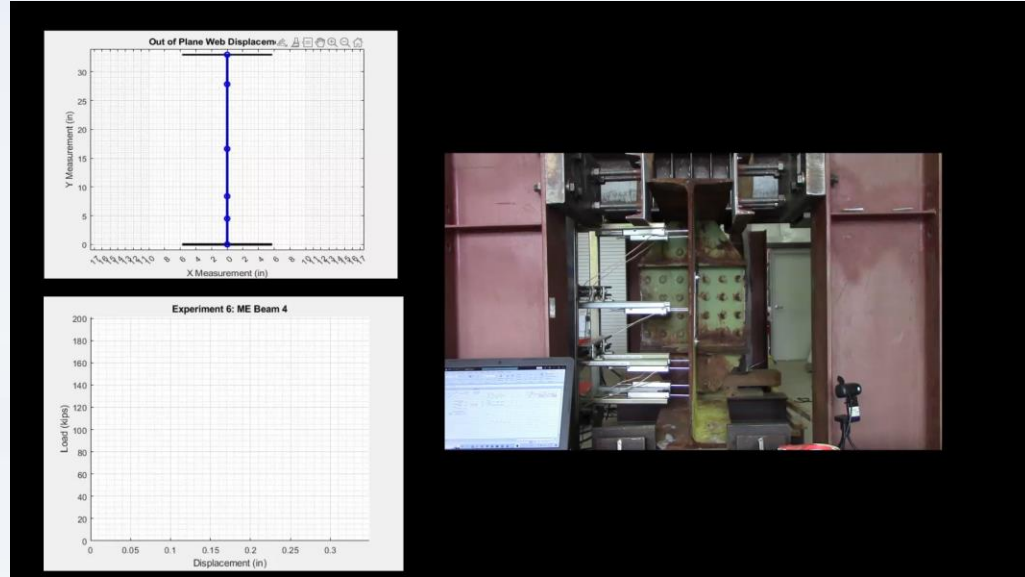
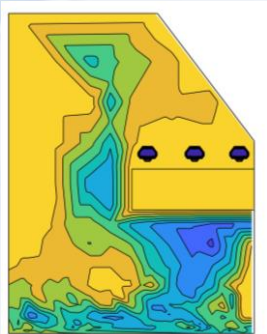
# Bridge Program



First research group to our knowledge to pack a bridge and bring it to the lab and test it



Since 2019 we have tested 17 beam ends from New England



## Inspection Reports

### Massachusetts

- Reports: 123
- Corroded Ends: 1045

### New England

- Reports: 132
- Corroded Ends: 915

Total > 1960

## Experimental Work

### Massachusetts

- Bridges: 3
- Tested Ends: 9

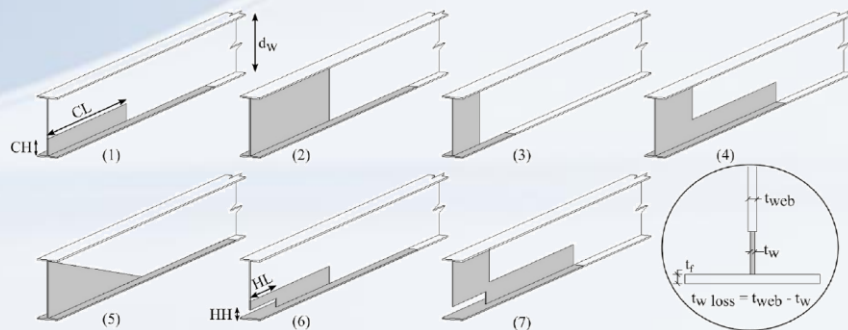
### New England

- Bridges: 7
- Corroded Ends: 29

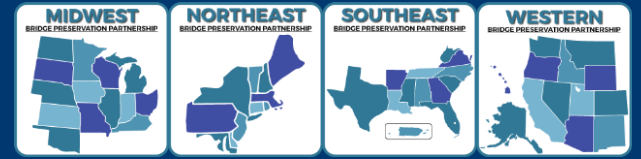
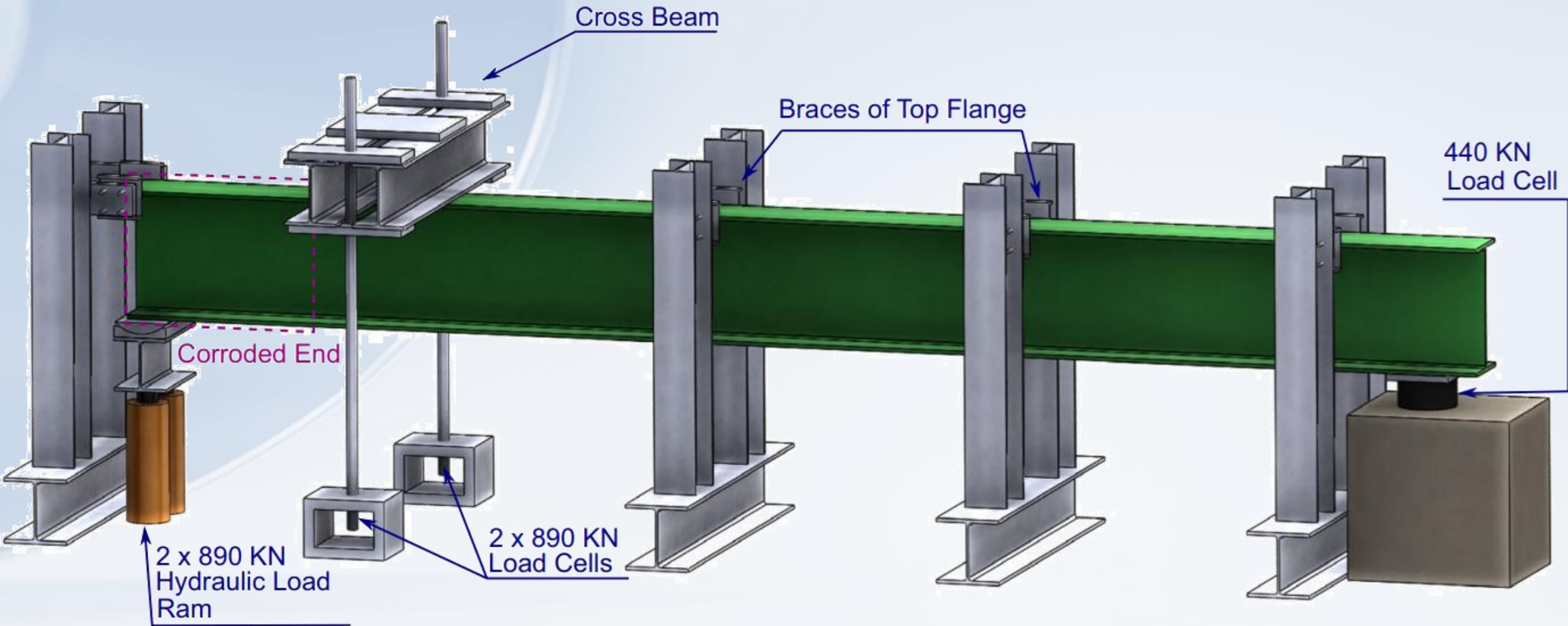
Total: Beams from 10 bridges

## Numerical Work

More than 5000 simulated scenarios (FEM and statistics to produce guidelines)

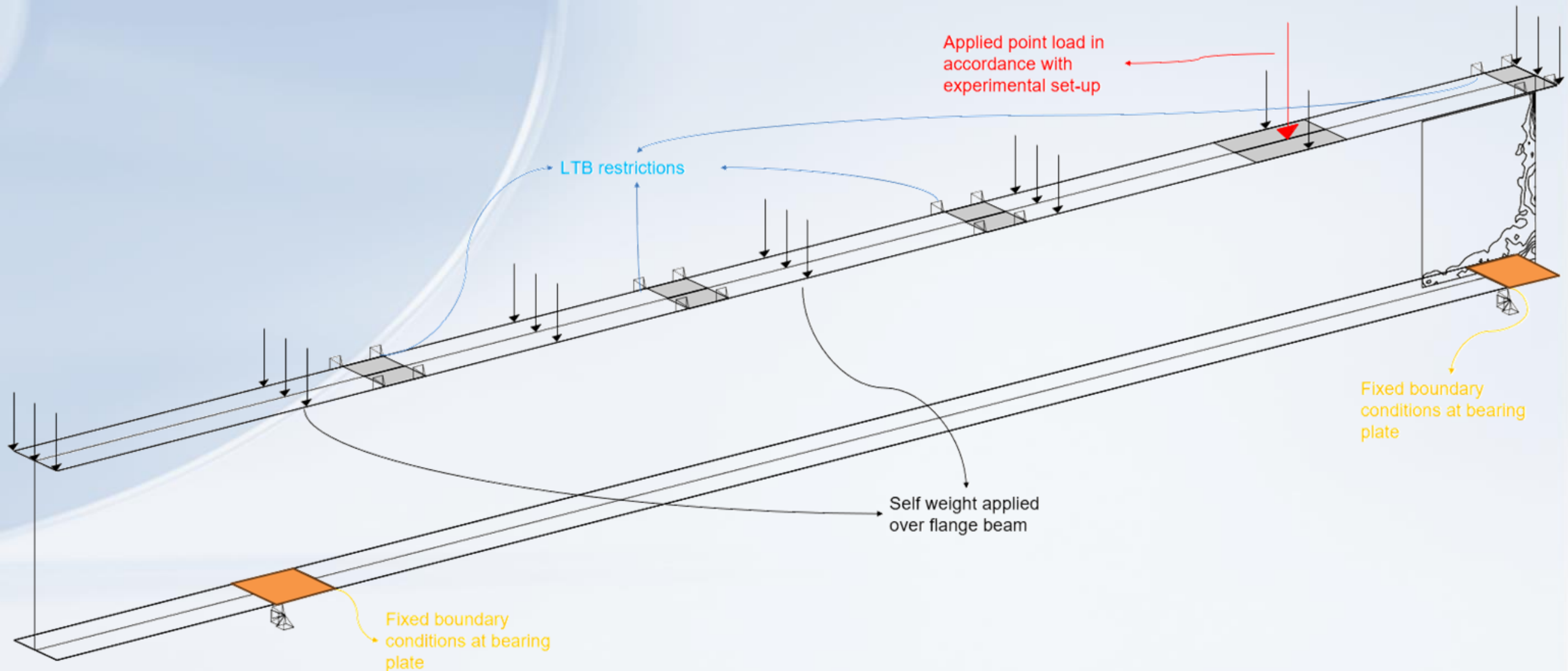


# Experimental study






# Bridge beam model



# Bridge Program

**September 2019**  
Report No. 19-008

Charles D. Baker  
Governor  
Karyn E. Polito  
Lieutenant Governor  
Stephanie Pollack  
MassDOT Secretary & CEO



## Development of Load Rating Procedures for Deteriorated Steel Beam Ends

Principal Investigator:  
Dr. Srey  
University of MA

**September 2021**  
Report No. 21-024

Charles D. Baker  
Governor  
Karyn E. Polito  
Lieutenant Governor  
Janey Tesler  
MassDOT Secretary & CEO



Principal Investigator:  
Dr. Srey  
University of MA



## Improved Load Rating Procedures for Deteriorated Steel Beam Ends with Deteriorated Stiffeners

Principal Investigator (s)  
Georgios Tzortzis, Graduate Researcher  
Dr. Sergio F. Brena  
Dr. Simos Gerassimidis  
University of Massachusetts At

Research and Technology Transfer Section  
MassDOT Office of Transportation Planning

**September 2021**  
Report No. 21-024

Charles D. Baker  
Governor  
Karyn E. Polito  
Lieutenant Governor  
Janey Tesler  
MassDOT Secretary & CEO

Goals/Objectives

Research and Technology Transfer Section  
MassDOT Office of Transportation Planning  
Planning.Research@dot.state.ma.us



Research and Technology Transfer Section  
MassDOT Office of Transportation Planning

**March 2022**  
Report No. 21-028

Charles D. Baker  
Governor  
Karyn E. Polito  
Lieutenant Governor  
Janey Tesler  
MassDOT Secretary & CEO



## Development of Comprehensive Inspection Protocols for Deteriorated Steel Beam Ends

Principal Investigator (s)  
Georgios Tzortzis, Graduate Researcher  
Dr. Sergio F. Brena  
Dr. Simos Gerassimidis



**May 2022**  
Report No. 22-029

Charles D. Baker  
Governor  
Karyn E. Polito  
Lieutenant Governor  
Janey Tesler  
MassDOT Secretary & CEO

## Feasibility of 3D Printing Applications for Highway Infrastructure Construction and Maintenance

Principal Investigator (s)  
Dr. John A. Hart  
Dr. Wens Chen  
Hadden Quindaris  
Dr. Simos Gerassimidis



Research and Technology Transfer Section  
MassDOT Office of Transportation Planning

U.S. Department of Transportation  
Federal Highway Administration

## Research in Progress

### BIM for Transit Infrastructure: A Feasibility and Gap Assessment with Current Practices and Systems at the MBTA

**Research Need**  
Research is needed on the importance of data governance and integration. MBTA management of new projects and ongoing operations can be improved by implementing the Building Information Modeling (BIM) delivery methodology in the Capital Delivery department.

**Goals/Objectives**  
BIM is a very powerful software for integrating many different concepts and models into a single platform. It can include coordination of information between trades, contractors, and designers during the design and construction process. This results in a very efficient process of identifying and resolving interference, incorporating design or part changes, and visualizing assets both in their final condition and at different stages of construction. The goals of the project are the following:  
o Collect and present information on effective BIM strategies based on practices of comparable agencies and a literature review.

o Provide recommendations on where BIM has the most promise for effective integration into MBTA practice  
o Highlight pitfalls to avoid when implementing BIM

Research and Technology Transfer Section  
MassDOT Office of Transportation Planning  
Planning.Research@dot.state.ma.us

### Project Information

This project is being conducted as part of the Massachusetts Department of Transportation (MassDOT) Research Program with funding from Federal Highway Administration (FHWA), State Planning and Research (SPR) funds.  
**Principal Investigator:**  
Simon Gerassimidis, Scott Cogan  
**Performing Organization:**

## Research in Progress

### Development of Improved Inspection Techniques using LIDAR for Deteriorated Steel Beam Ends

**Research Need**  
There is an emerging need for MassDOT to leverage the strength of LIDAR point cloud data and incorporate such a promising technology into their bridge inspection practices if it is deemed feasible.

### Goals/Objectives

1. To evaluate the accuracy and repeatability of LIDAR in quantifying key parameters for evaluating the residual capacity of the bridge, including the out-of-plane imperfection of the beam web, the surface area of corrosion, through hole requirements.  
2. To develop and validate automated or semi-automated point cloud processing methods, e.g., reduction of surface corrosion areas and measurement of the corresponding surface distortion.  
3. To develop practical and yet effective operational on-site procedures for collecting critical data from service steel beam ends using LIDAR, including pre/post inspection setup, digital sensor parameters and scanning configurations, etc., through lab and field experiments.

Research and Technology Transfer Section  
MassDOT Office of Transportation Planning  
Planning.Research@dot.state.ma.us

### Project Information

This project is being conducted as part of the Massachusetts Department of Transportation (MassDOT) Research Program with funding from Federal Highway Administration (FHWA), State Planning and Research (SPR) funds.  
**Principal Investigator:**  
Simon Gerassimidis, Changho Ai, Sergio Brena  
**Performing Organization:**  
University of Massachusetts Amherst  
**Project Champion:**  
Joan Markowski

## Research in Progress

### Revised Load Rating Procedures for Deteriorated Prestressed Concrete Beams

**Research Need**  
A number of precast, prestressed concrete bridges in Massachusetts (MA) have exhibited corrosion induced deterioration over the years, so development of new rating methods that include deterioration are needed.

### Goals/Objectives

This project seeks to accomplish the following objectives:  
1. Categorize the severity of deterioration of precast, prestressed concrete bridges as it relates to their safety.  
2. Develop engineering procedures to estimate the remaining capacity of deteriorated precast, prestressed concrete beams based on severity of the deterioration encountered. These procedures will be based on solid engineering principles verified by calibrated finite element analyses using laboratory testing of existing deteriorated components extracted from bridges scheduled for replacement.  
3. Develop a reliable rating methodology that results in safe predictions of existing capacity applicable to the range of deterioration encountered in existing precast, prestressed concrete bridges in MA.

Research and Technology Transfer Section  
MassDOT Office of Transportation Planning  
Planning.Research@dot.state.ma.us

### Project Information

This project is being conducted as part of the Massachusetts Department of Transportation (MassDOT) Research Program with funding from Federal Highway Administration (FHWA), State Planning and Research (SPR) funds.  
**Principal Investigator:**  
S. Breda, J. Bostaj, S. Cogan, S. Gerassimidis  
**Performing Organization:**  
University of Massachusetts Amherst  
**Project Champion:**

## Research in Progress

### 3D-Printed Lattice-Based Structures for Next Generation Bridge Bearings and Bridge Isolation Bearings

**Research Need**  
Bridge bearings are installed between the bridge substructure and the superstructure to transfer loads and allow controlled translations to reduce stresses in the structure. In deteriorated and aging bridges, the old bearing system commonly needs to be replaced, and these replacements are currently very costly. Recent progress in 3D printing applications through a recent Phase 1 MassDOT research project examined a new promising, customizable design for typical bridge bearings and isolation bearings. The current project will develop a prototype bearing system using concepts from architected lattice materials and apply to manufacture and test the 3D printing bearing systems.

### Goals/Objectives

The objectives of the proposed research include computational and experimental work to develop a new architected material bridge bearing product and test it for vertical, transverse, and other load conditions. In addition, the proposed research will aim to develop recommendations regarding the technoeconomic decision-making process (including cost models) informing how to apply the new prototype and identify the technical capabilities to achieve a cost-effective solution that can be implemented in the field.

Research and Technology Transfer Section  
MassDOT Office of Transportation Planning  
Planning.Research@dot.state.ma.us

### Project Information

This project is being conducted as part of the Massachusetts Department of Transportation (MassDOT) Research Program with funding from Federal Highway Administration (FHWA), State Planning and Research (SPR) funds.  
**Principal Investigator:**  
Prof. Gerassimidis, Prof. Chen, Prof. Hart  
**Performing Organization:**  
University of Massachusetts, Amherst  
**Project Champion:**  
Catherine Hong  
**Project Start Date:**  
April 2022  
**Expected Project Completion Date:**

## Research in Progress

### Feasibility of 3D Printing Applications for Highway Infrastructure Construction and Maintenance - Phase II

**Research Need**  
In recent years there has been a significant increase in interest in additive manufacturing, yet AM is largely unexplored within infrastructure projects, although it can provide unprecedented new design capabilities.

### Goals/Objectives

D.1. Explore the feasibility of additive repair technologies for steel corroded steel beams ends. Different additive manufacturing solutions and repair technologies will be examined in the lab and on-site. Repaired beams will be tested for their strength, fatigue, and corrosion resistance.  
D.2. Research the key factors related to the different repair technologies and equipment investigated that can impact the success of an attempted repair (Example: velocity of material being deposited). Use the research to develop a list of suggested options for equipment and facilities that seem well suited for handling 3D printing applications and the associated qualifications testing of 3D printing repaired steel bridge beams.

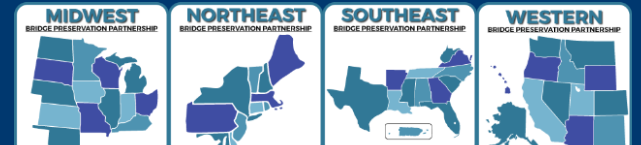
Research and Technology Transfer Section  
MassDOT Office of Transportation Planning  
Planning.Research@dot.state.ma.us

### Project Information

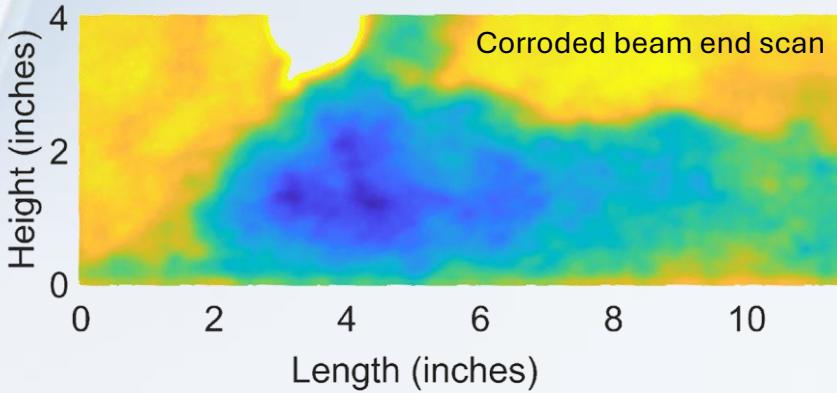
This project is being conducted as part of the Massachusetts Department of Transportation (MassDOT) Research Program with funding from Federal Highway Administration (FHWA), State Planning and Research (SPR) funds.  
**Principal Investigator:**  
Dr. S. Gerassimidis, Dr. J. Hart, Dr. W. Chen  
**Performing Organization:**  
UMass and MIT  
**Project Champion:**  
Paul Yokos and Catherine H Chen  
**Project Start Date:**  
April 22, 2022  
**Expected Project Completion Date:**  
November 30, 2023

### Methodology

1. Recommended methods for improving repair techniques of deteriorated transportation infrastructure elements, including deteriorated bridge ends, using 3D printing technologies.
2. Analyze and recommendations of cost effectiveness practices within 3D printing solutions, including in the field.
3. Scheduled services to disseminate the 3D printing findings to MassDOT personnel.
4. Final Presentation.
5. Final Report summarizing research activities, results, and recommendations.

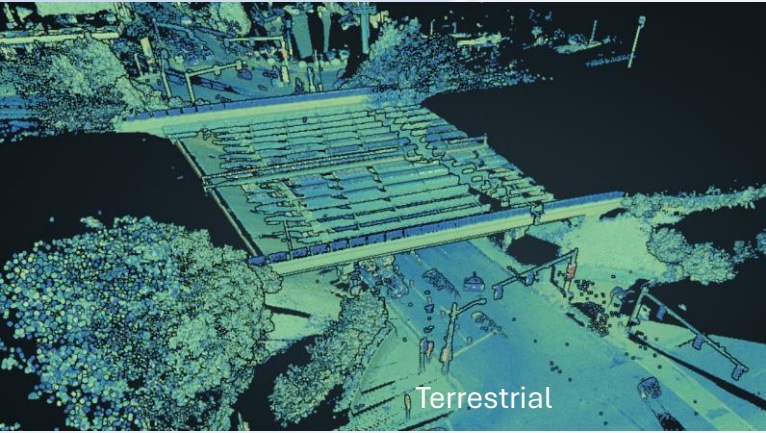
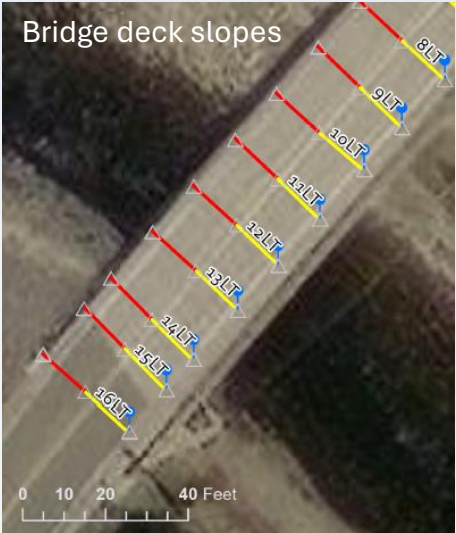
# Part II: 3D scanning for bridge inspection



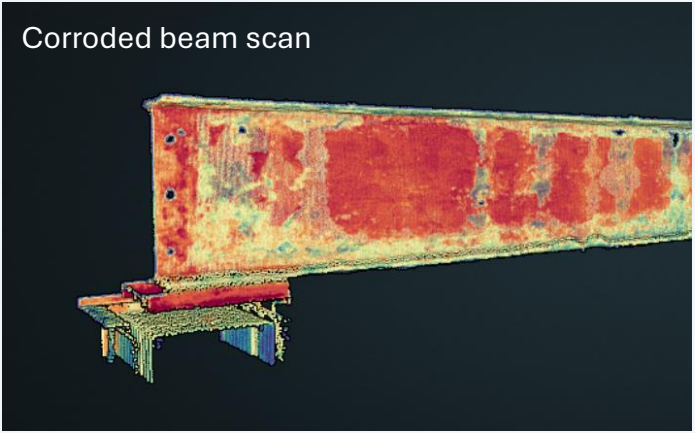
Concrete spalling



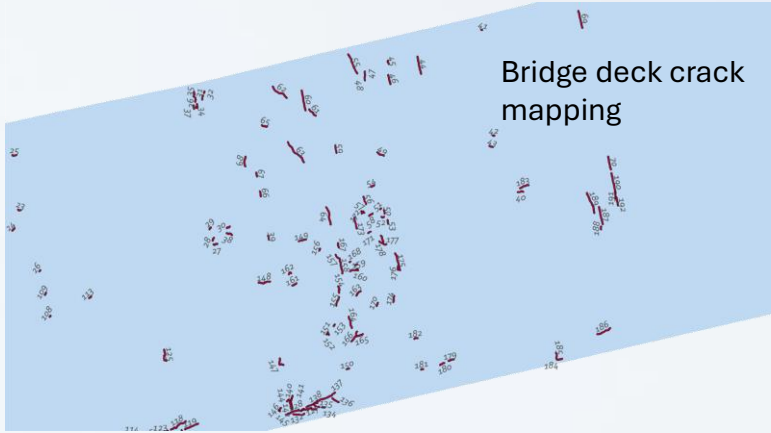
Bridge deck slopes



Corroded beam scan



Bridge deck crack mapping



# Corroded beam ends – Current State-of-Practice

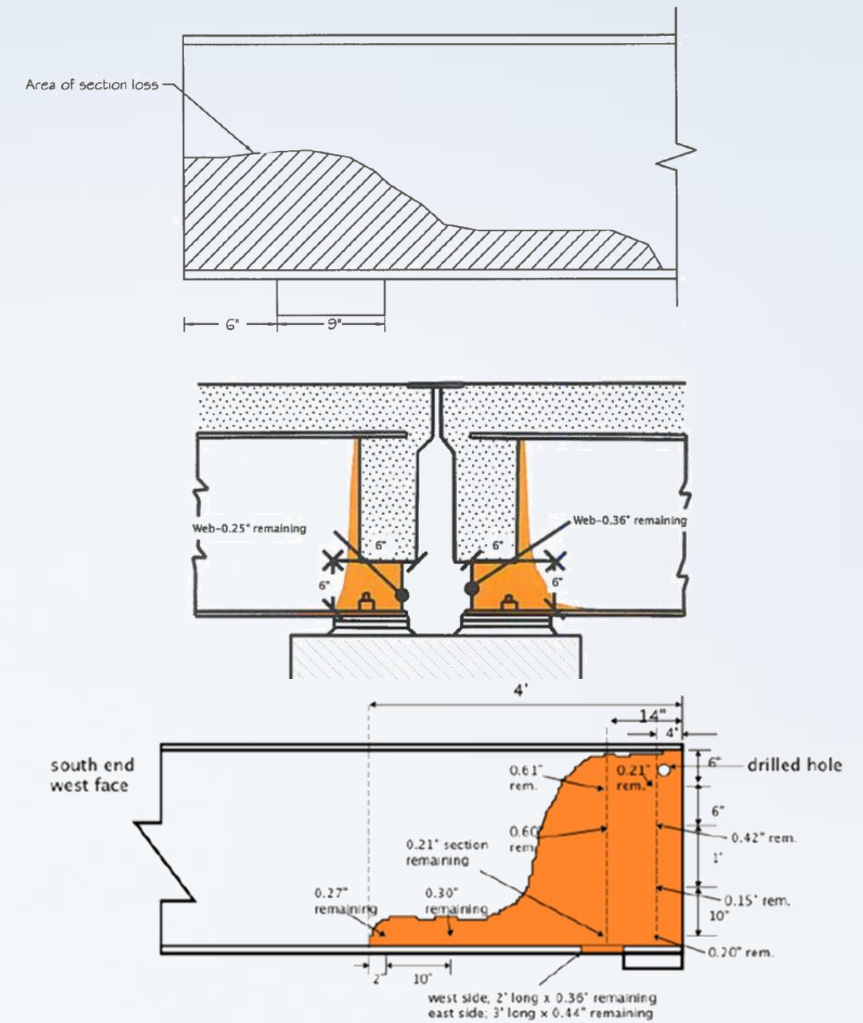
In the field



Taking Measurements

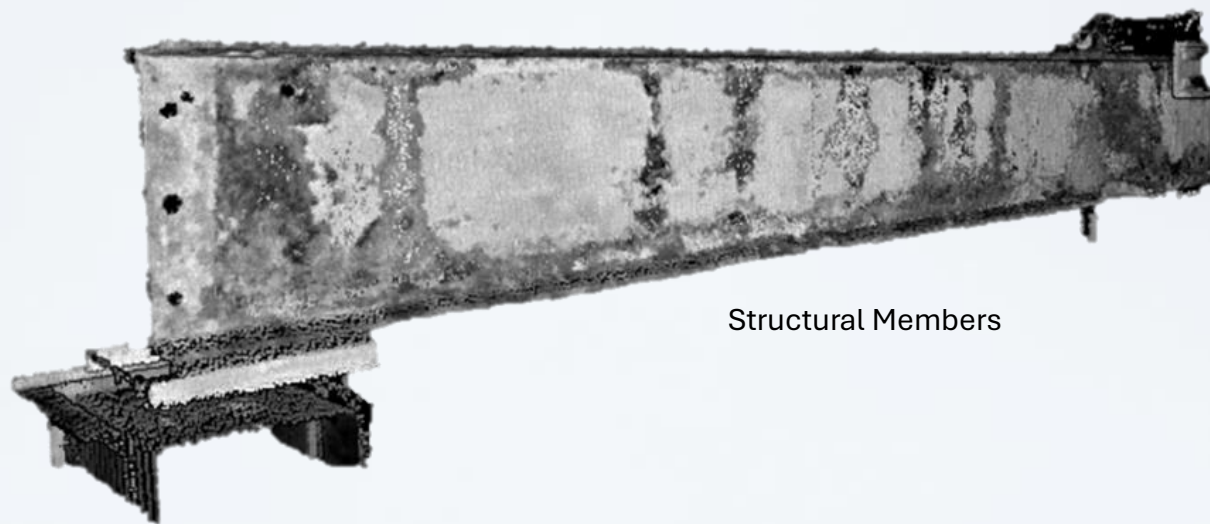
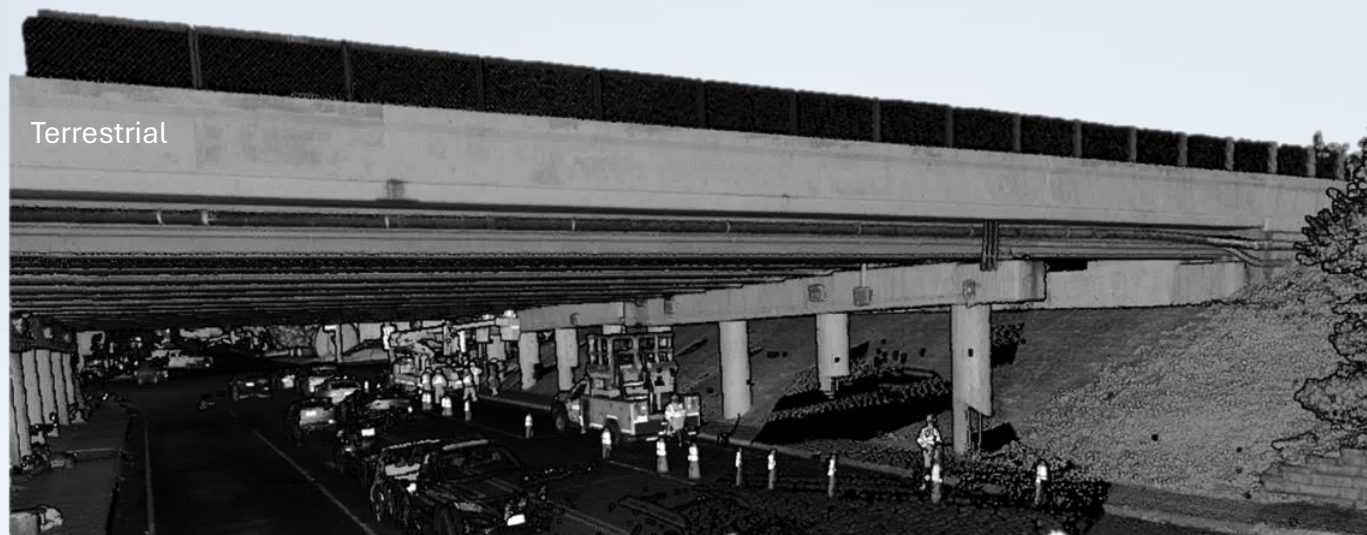


Corrosion Sketches

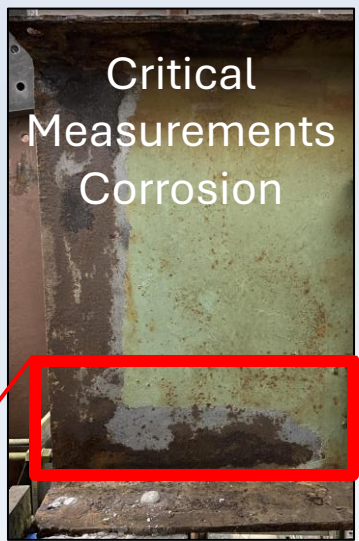


Source: GE

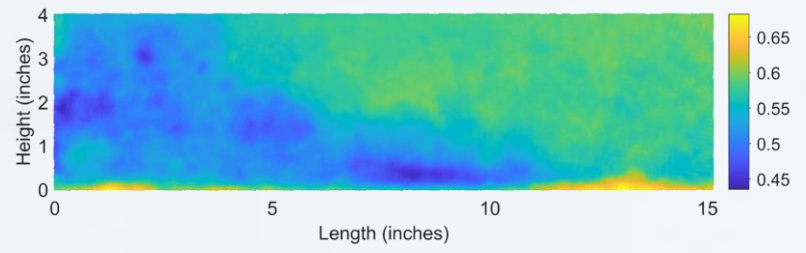
# 3D Scanning for Bridge Inspection - Terrestrial



# 3D Scanning for Bridge Inspection - Local



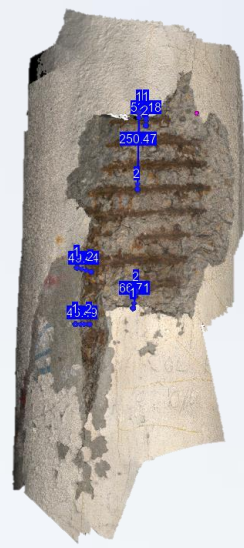
Critical Measurements  
Corrosion



Visuals



Geometry



Depth

Critical Measurements  
Spalling

# 3D Scanning for Bridge Inspection - Process

## 1. Component Identification



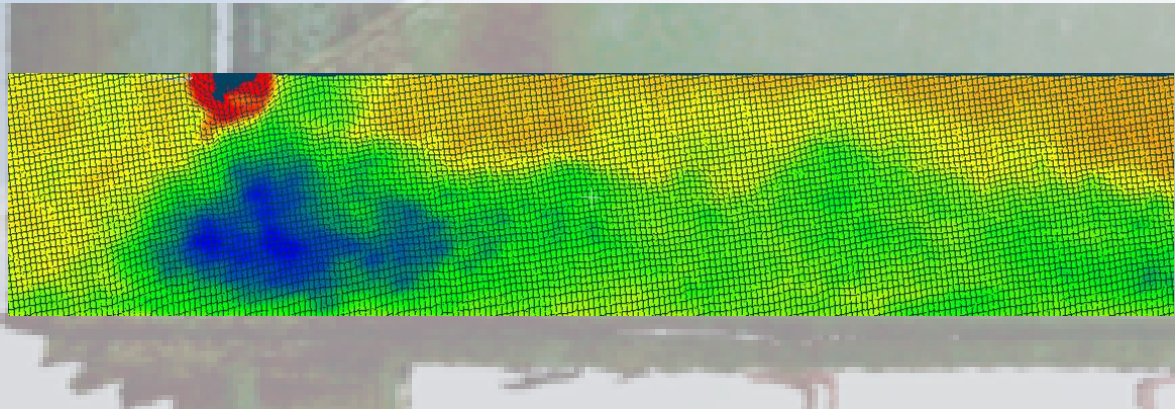
## 2. Scanning



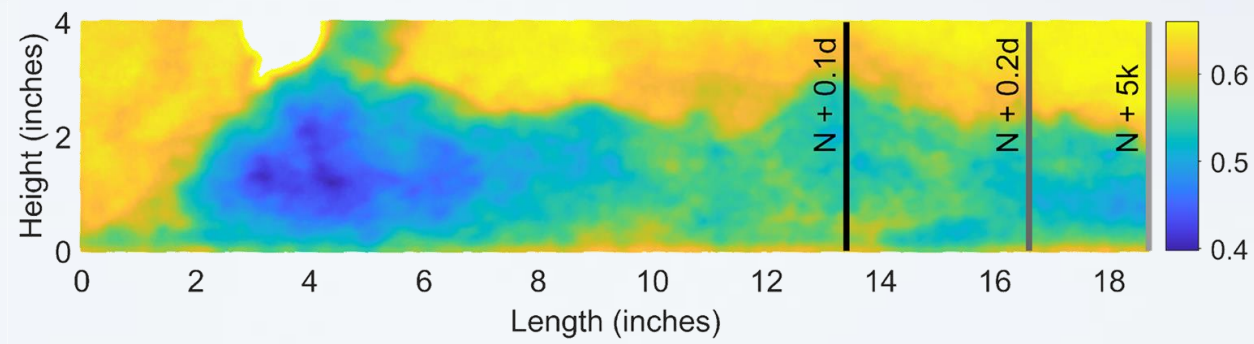
## 3. Model Processing



## 4. Post-Processing



## 5. Output map generation



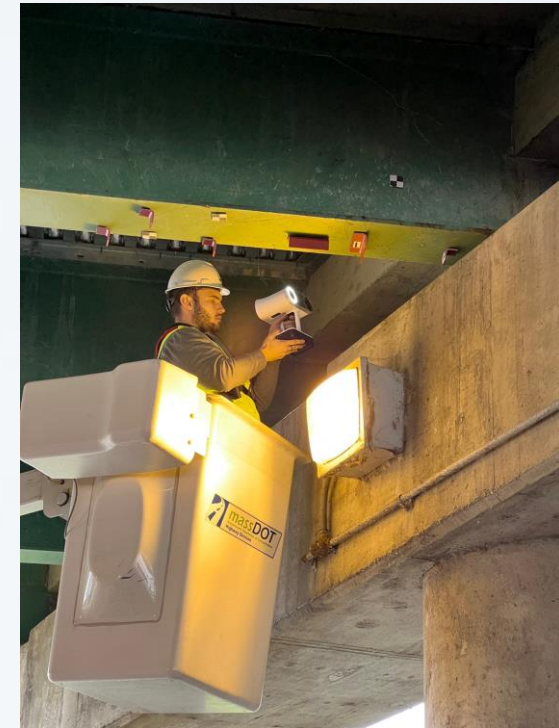
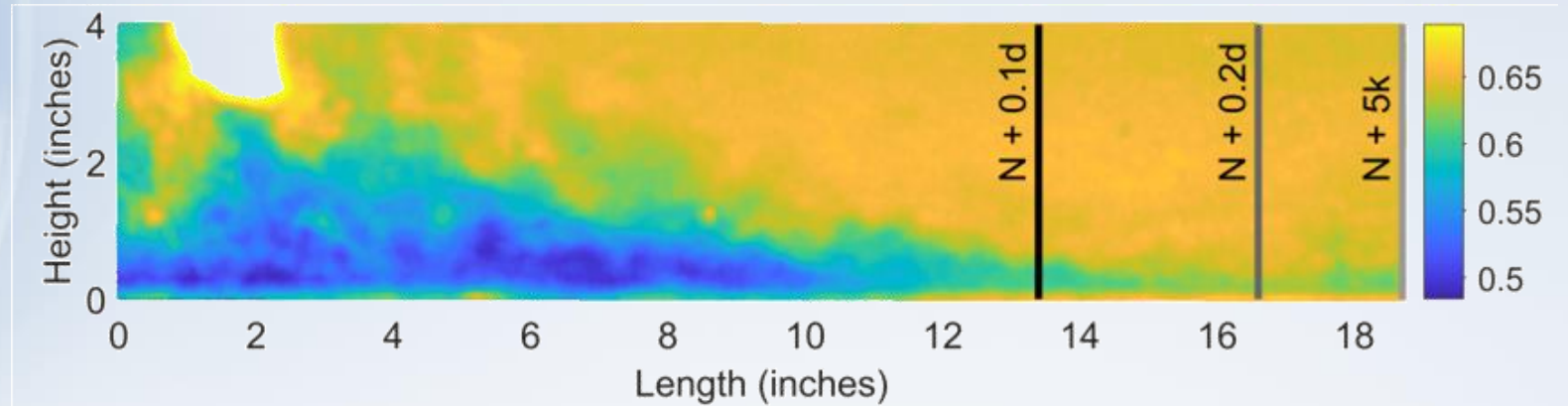
# 3D Scanning for Bridge Inspection - Summary

## Higher Cloud Density, detail, and accuracy:

- Around 400,000 points in the selected area to the right and millions of points in the full web height area
- Captures difficult to measure components like pitting and section loss at the edge of the web

## Portability and maneuverability:

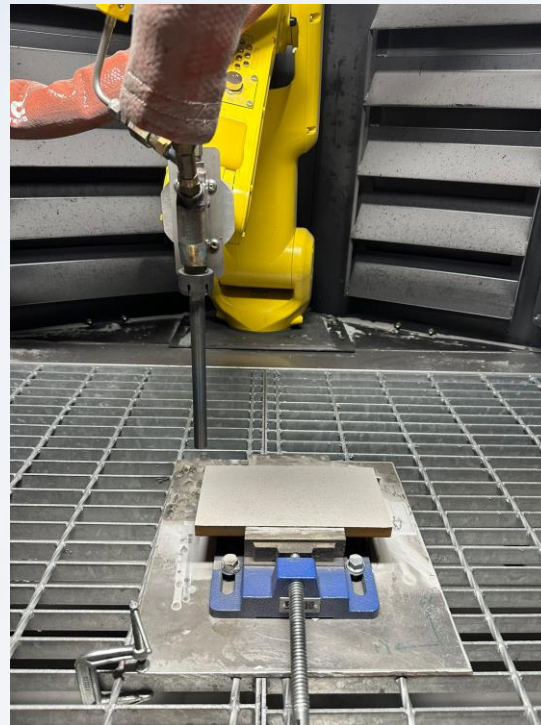
- Roughly 5 minutes per scan
- Easy to train and learn the scanning process
- Handheld and relatively lightweight machinery allows for easy on-site scanning

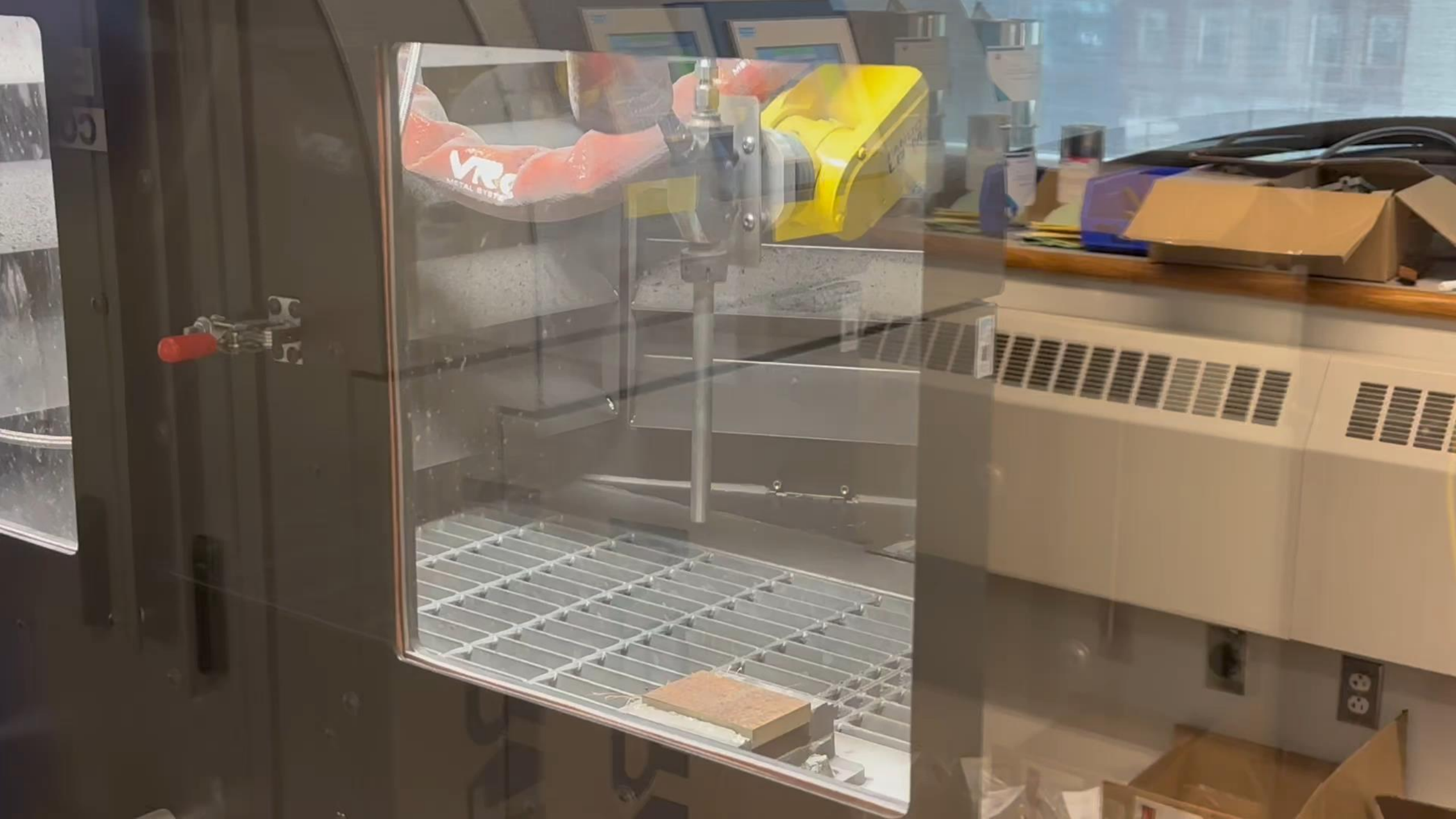




# Part III

## Cold-spray additive manufacturing

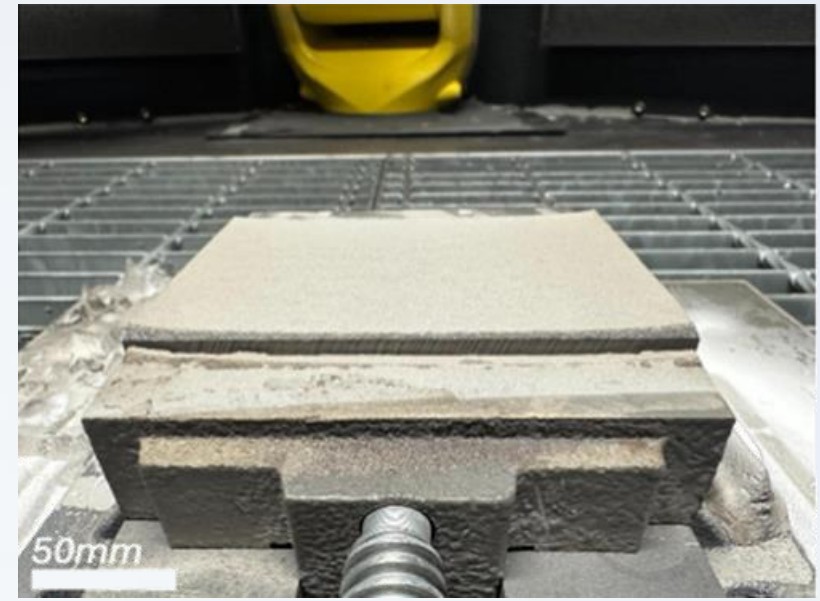
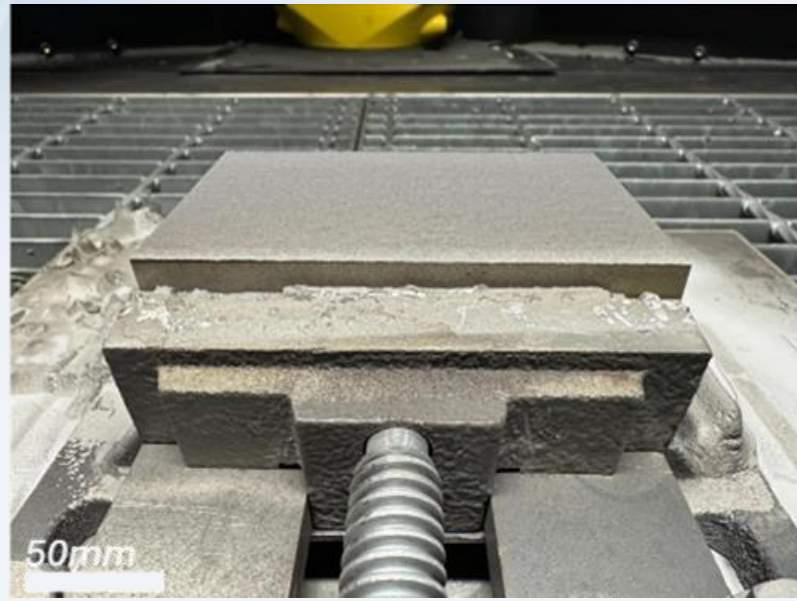




# Cold-Spray built up layers

150 seconds

1200 seconds



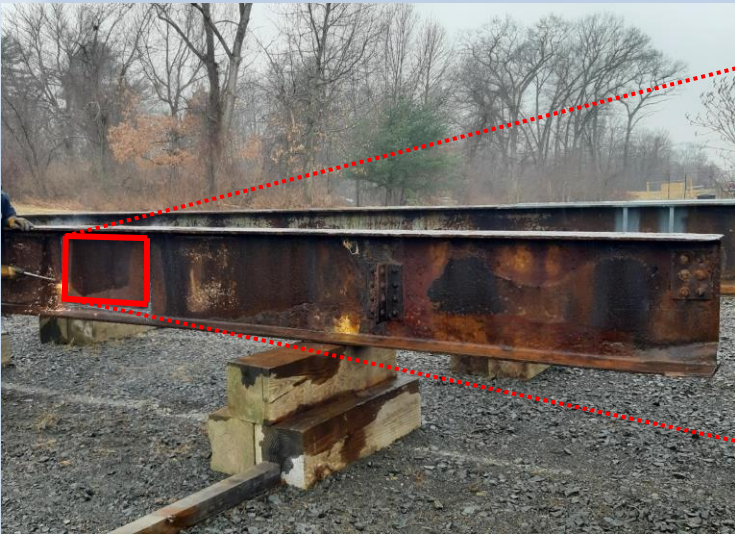
A36

A36 + intermediate layer

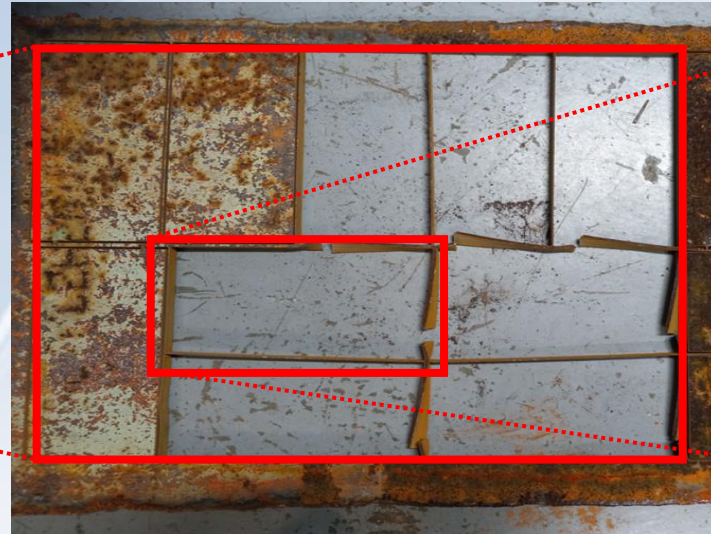
A36 + intermediate layer +  
built up layers

# Methodology

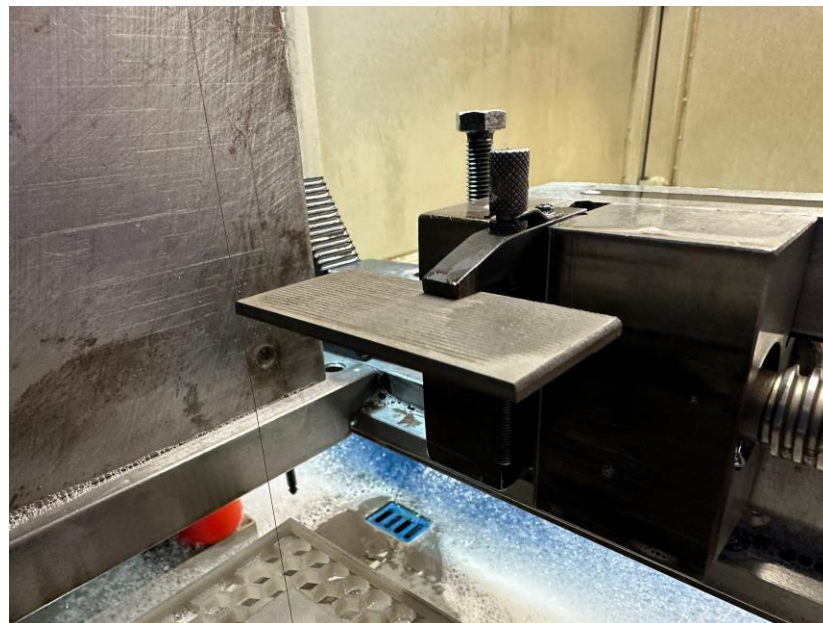
1. Obtain corroded substrates from real naturally-corroded steel beams from bridges in New England



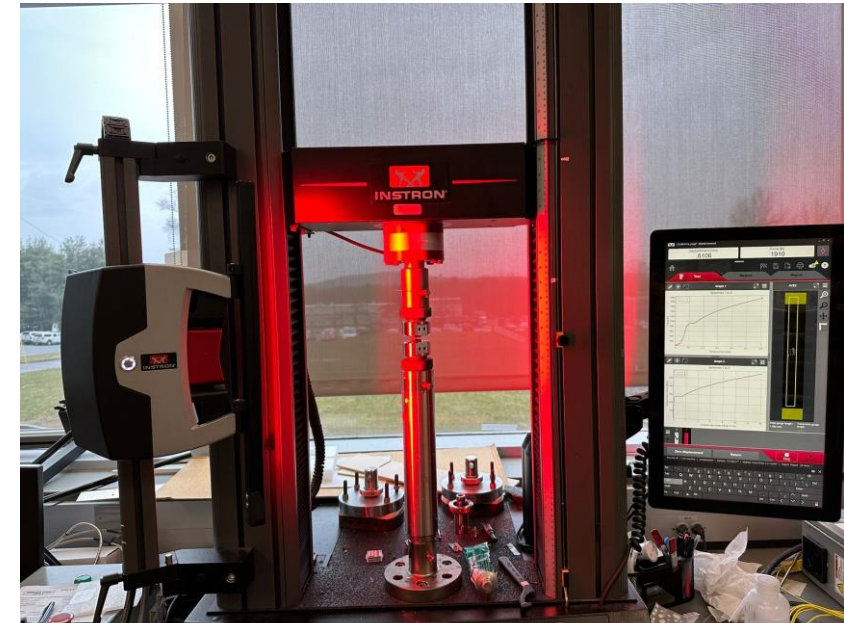
2. Cold Spray AM



3. Coupons of composite steel

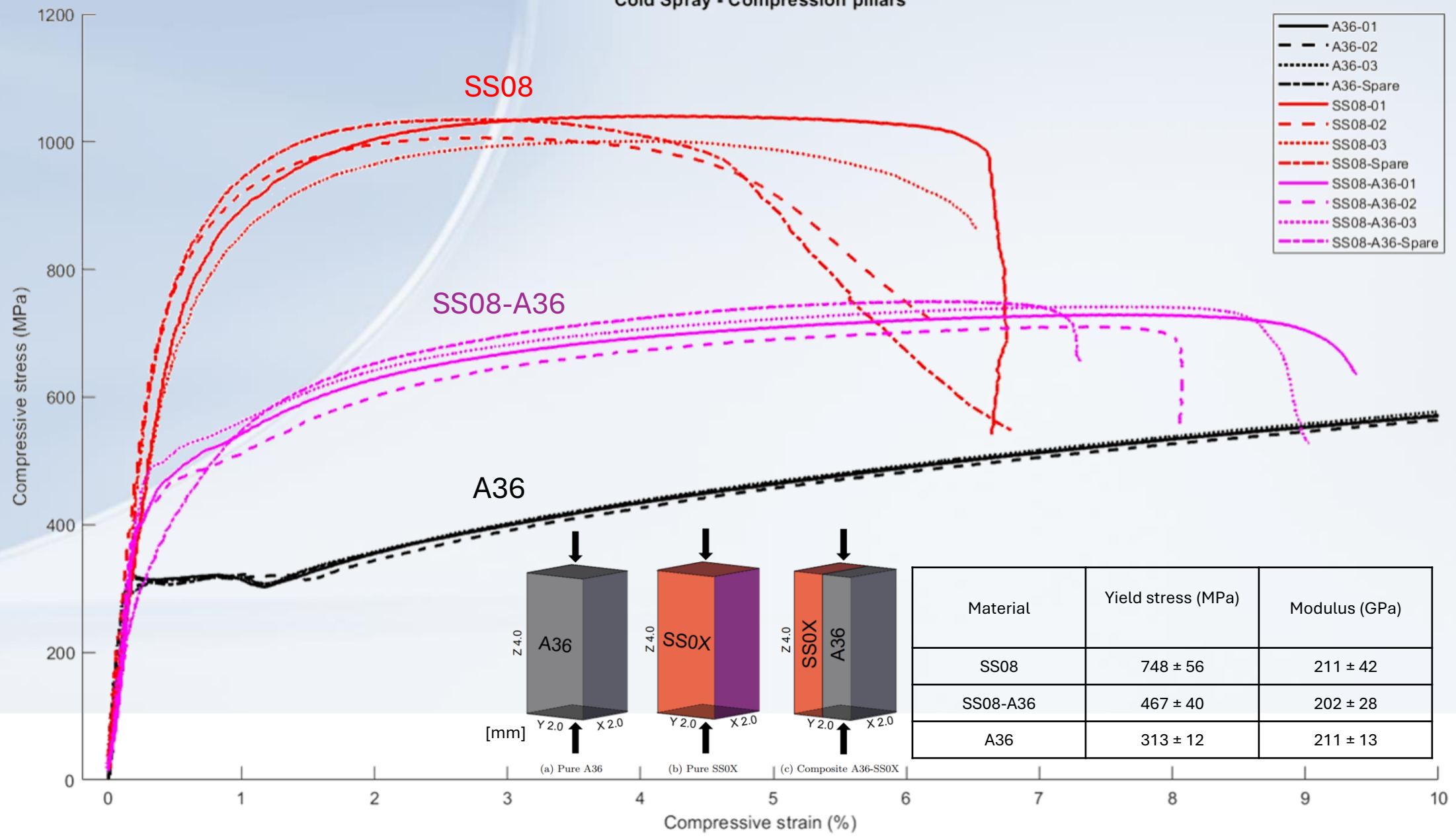


4. Coupon testing for mechanical properties

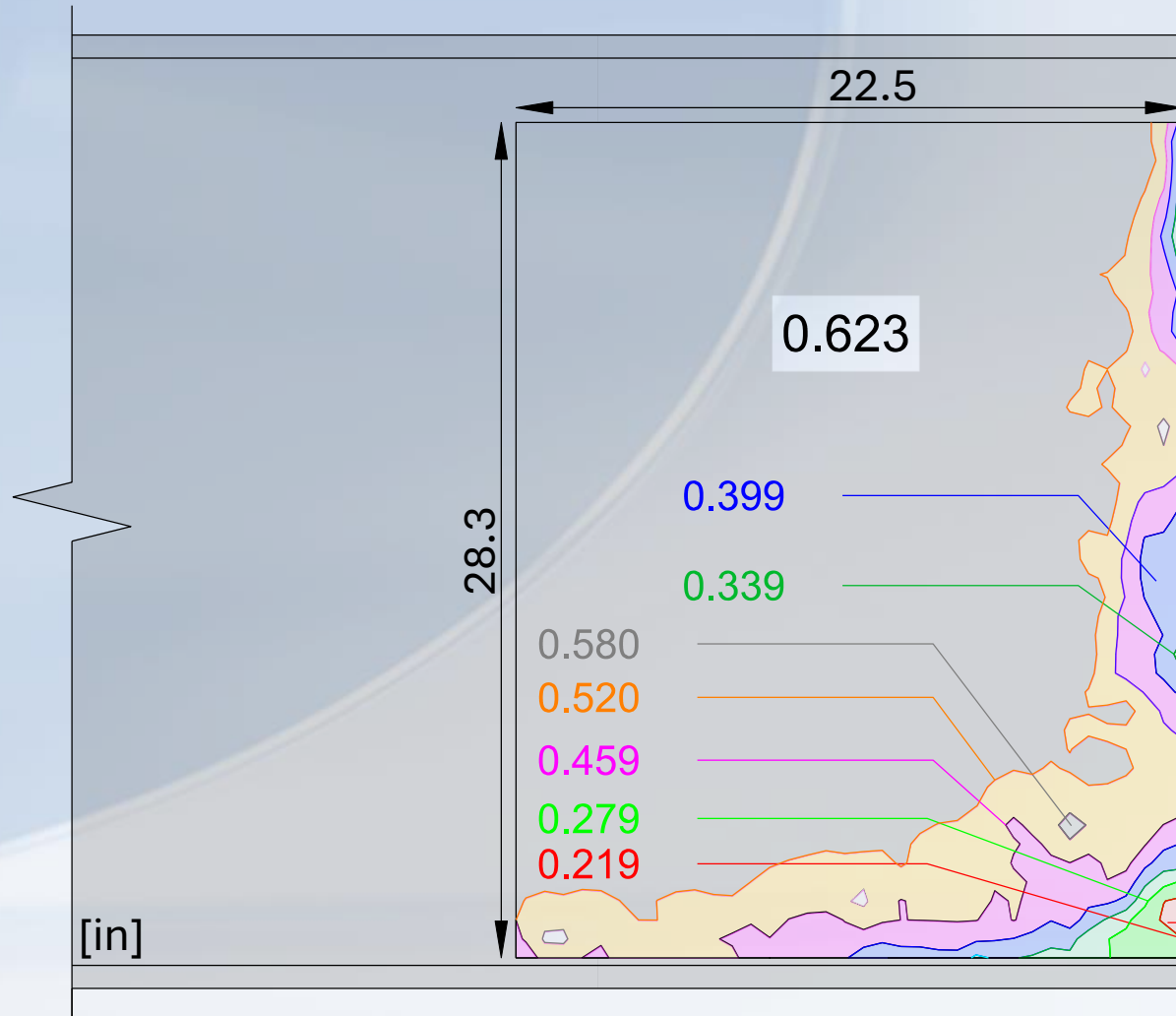


# Mechanical properties

Cold Spray - Compression pillars

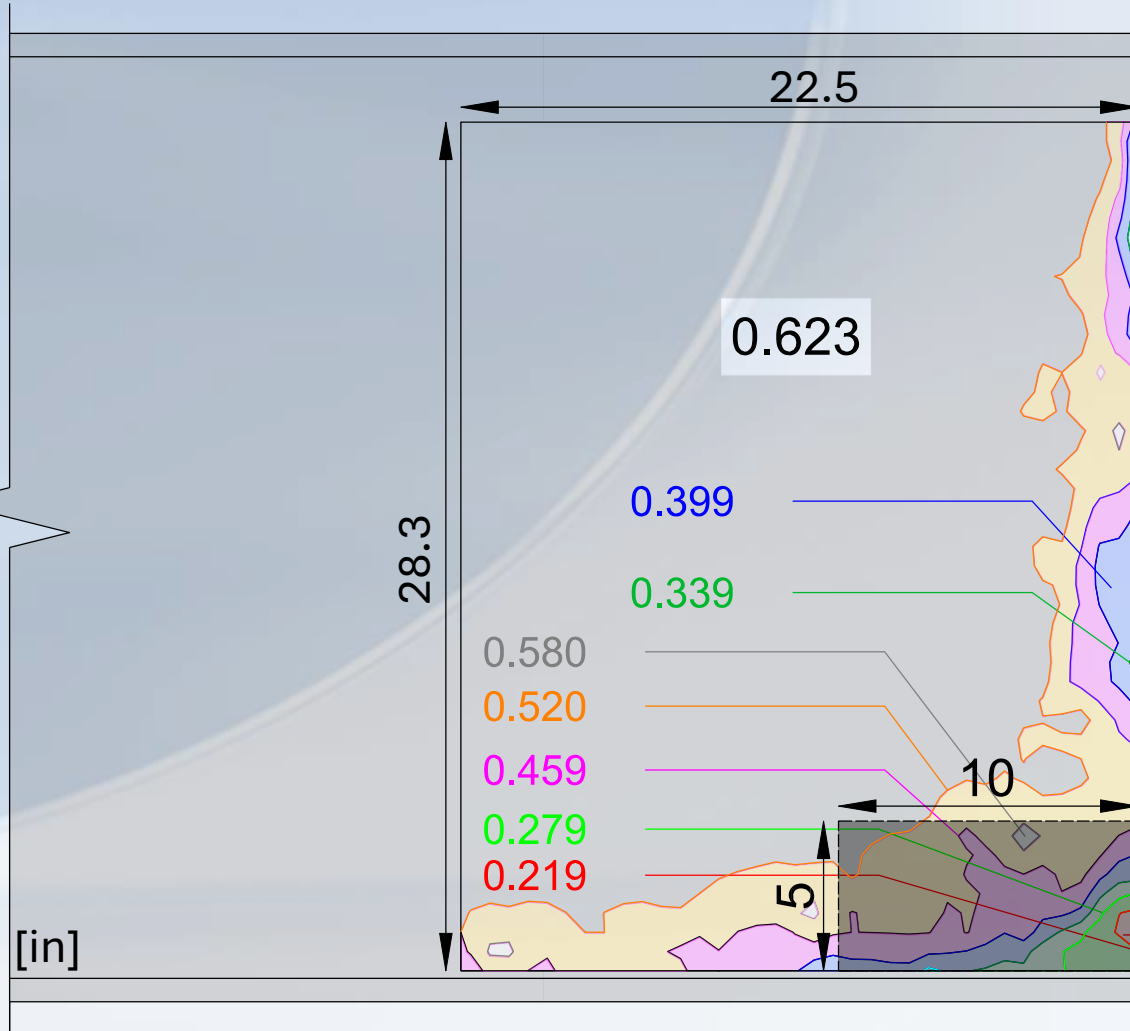


# Maine Bridge Beam

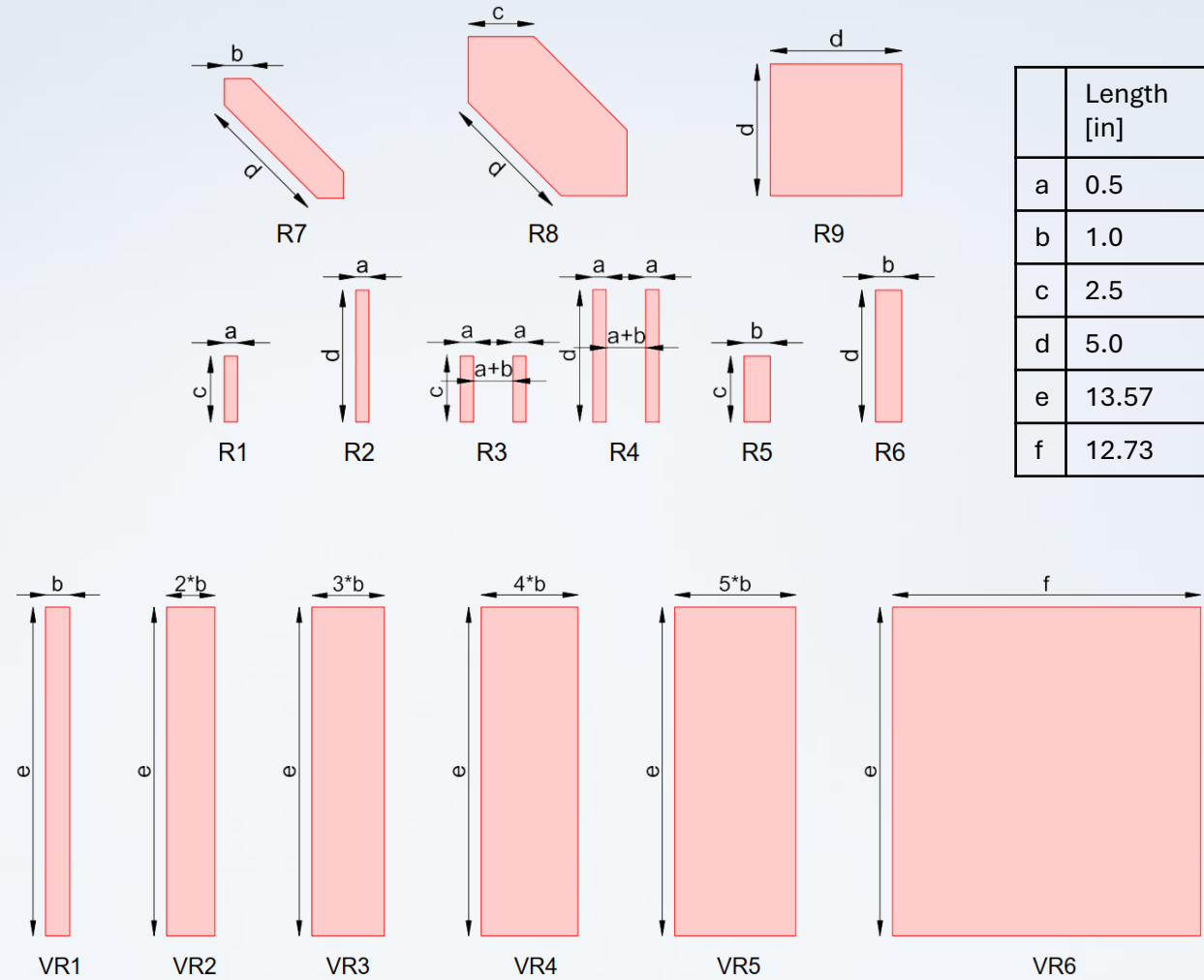


# Case Study 1 – Maine Bridge

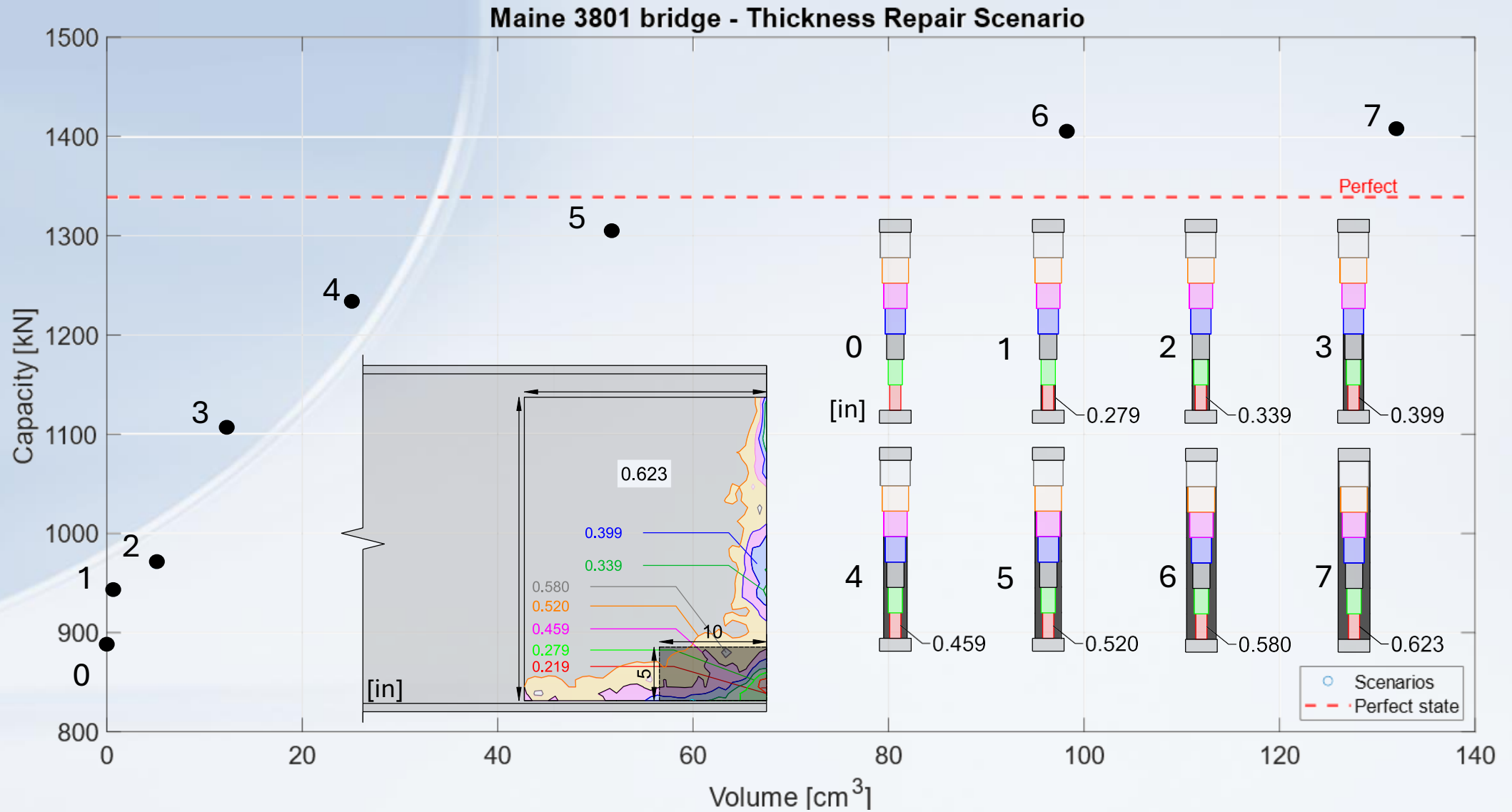
## Thickness repair scenario



## Line repair scenarios

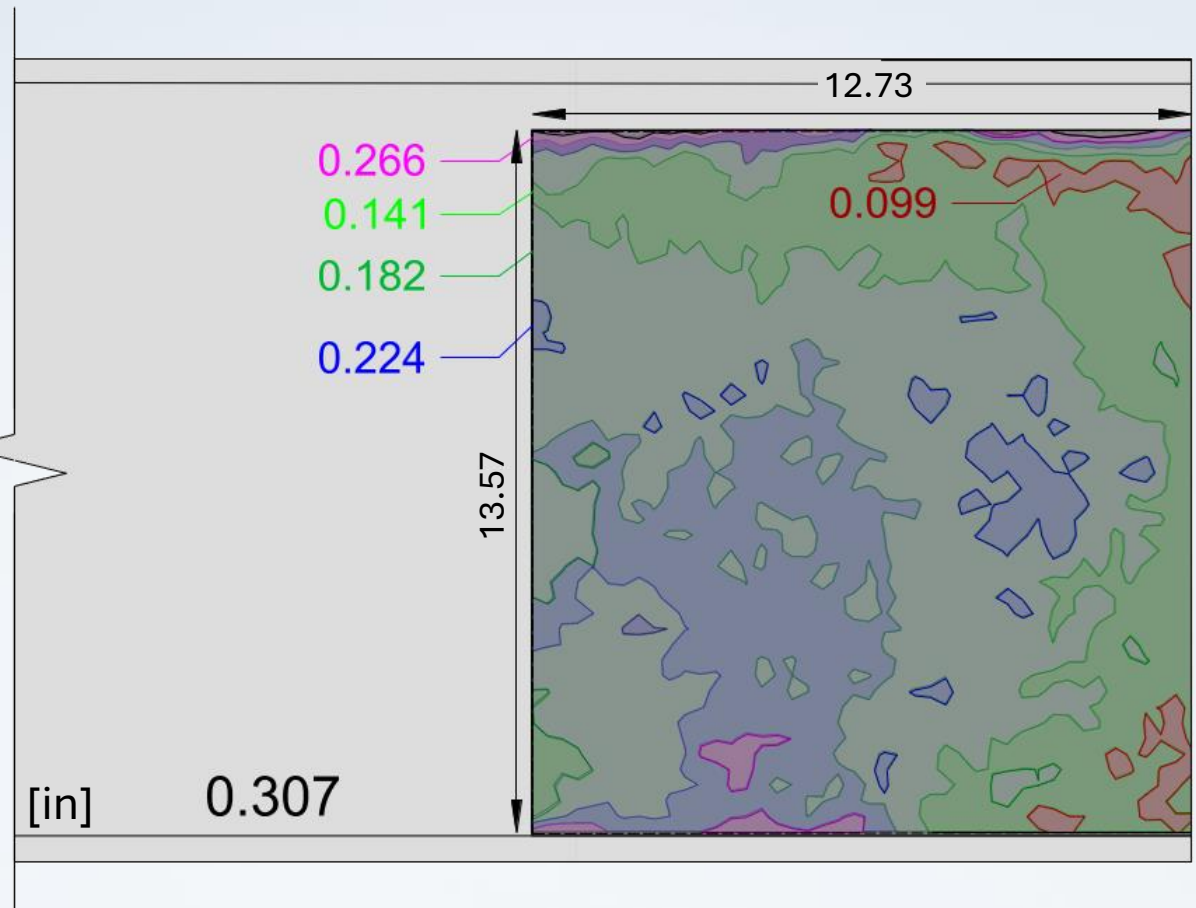
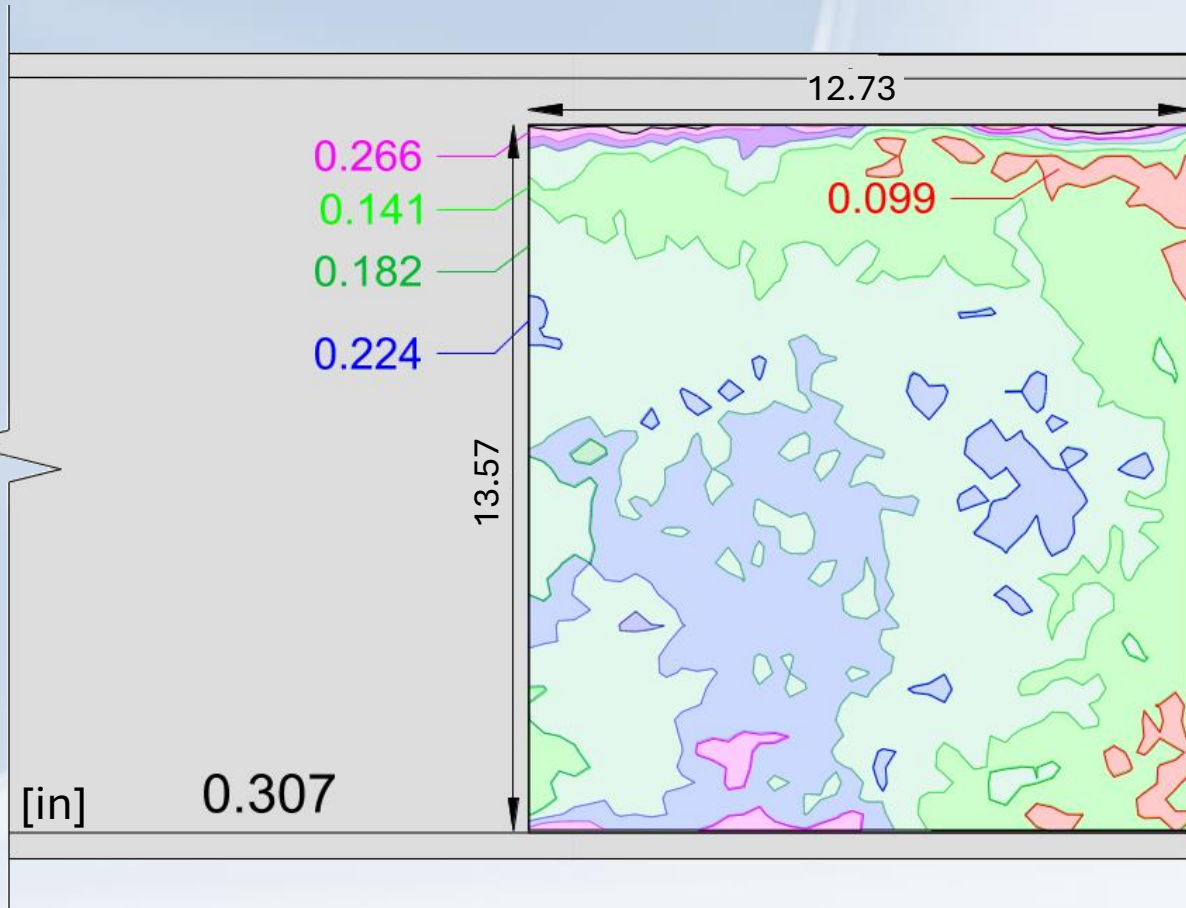


# Case Study 1 – Maine Bridge



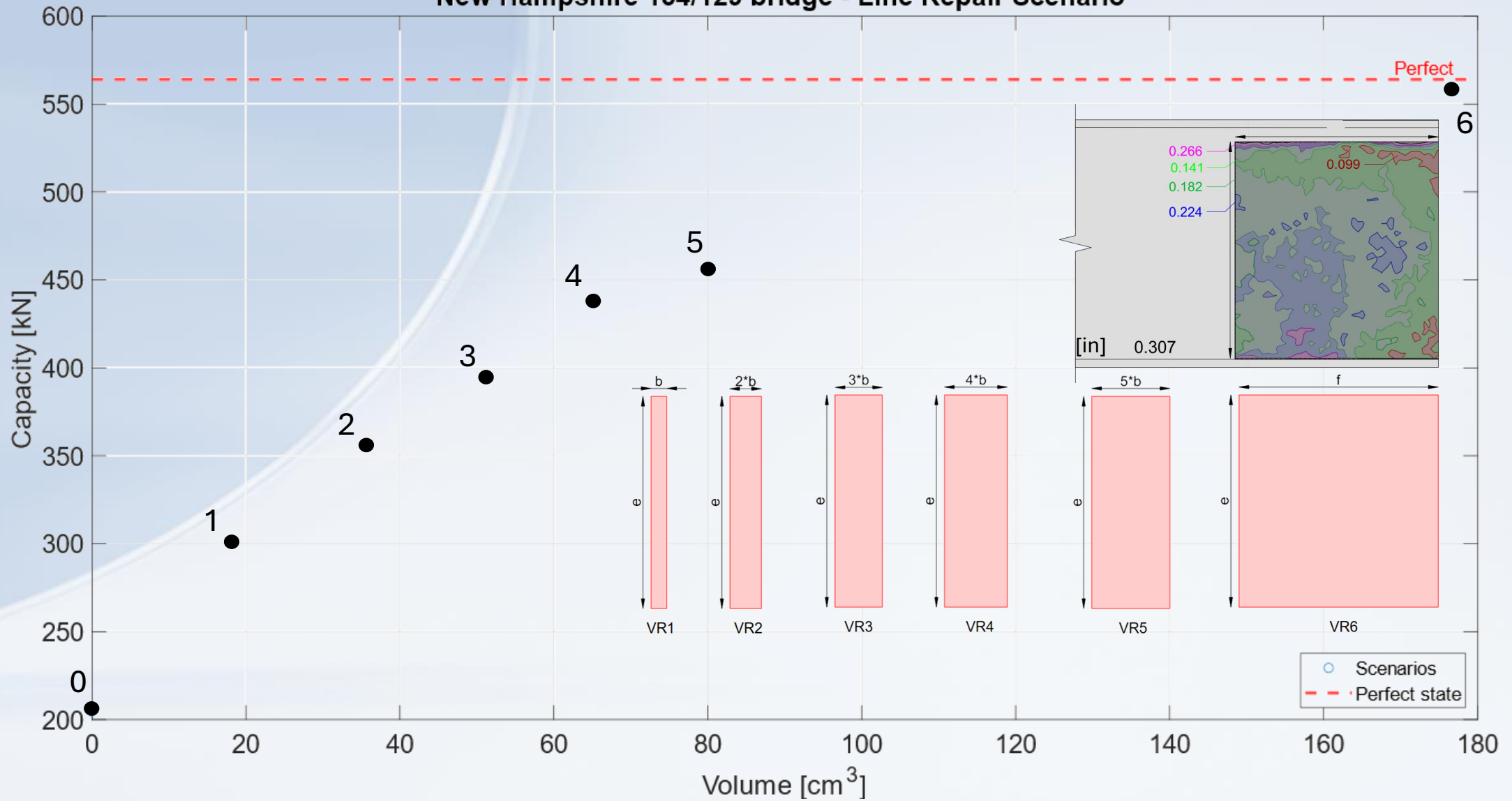


# Case Study 2 – New Hampshire bridge

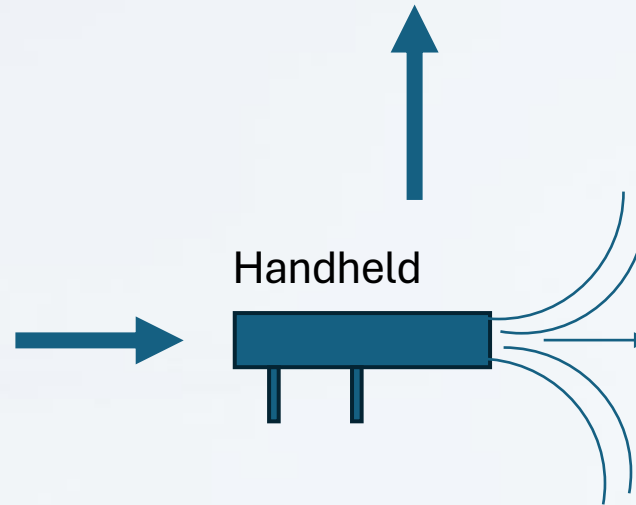


# Case Study 2 – New Hampshire bridge

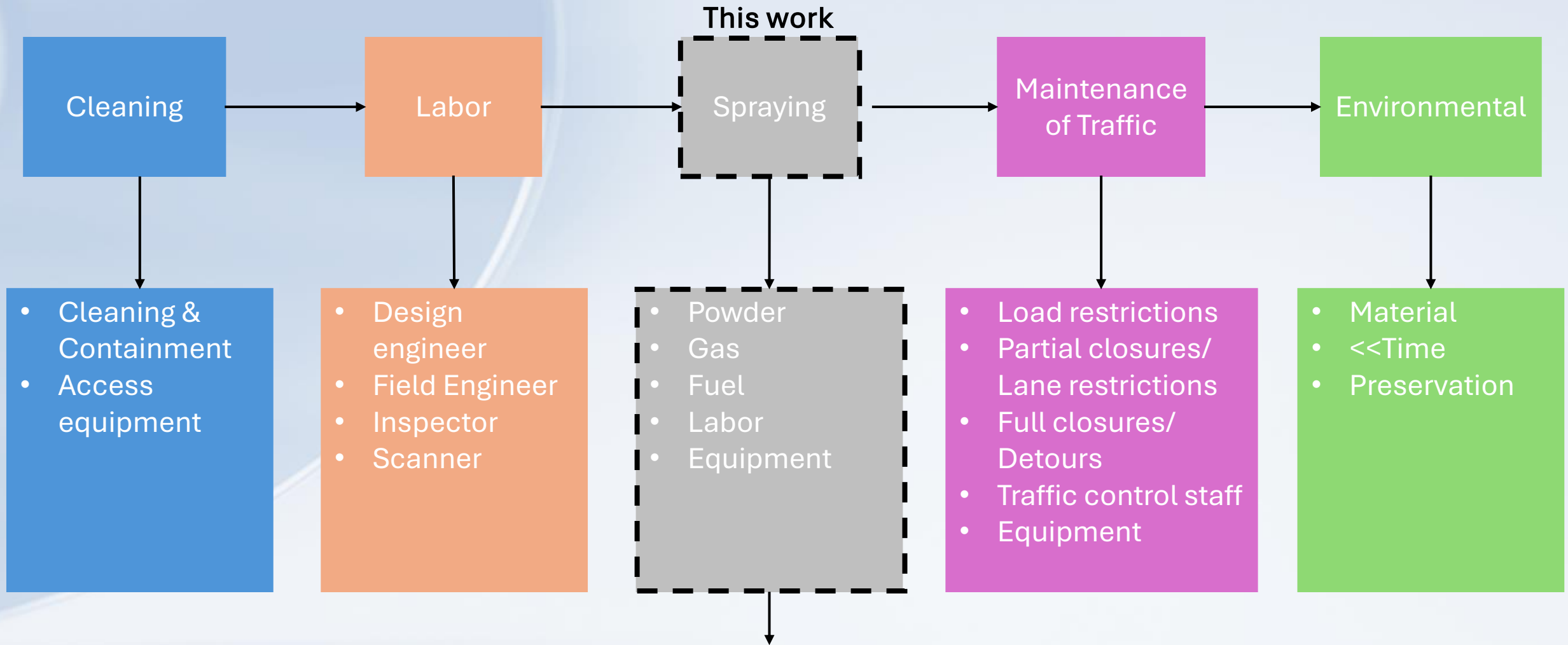
## New Hampshire 154/129 bridge - Line Repair Scenario



# Outlook

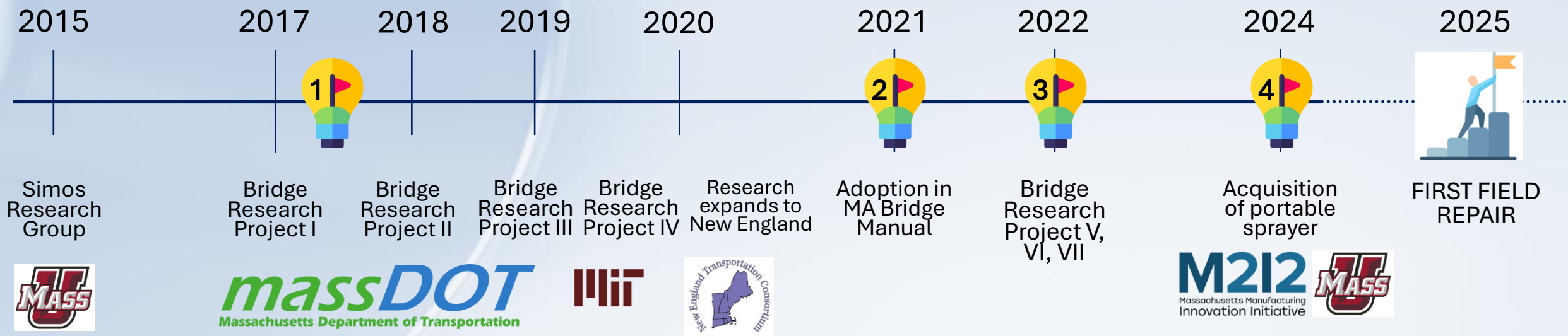


# Costs



**Total cost per mass of CSAM process < 500 \$/lb**

# Summary



**2017**

1<sup>st</sup> in the country to test naturally – real - corroded bridges in the lab

**2022**

1<sup>st</sup> in the country to successfully test cold spray repair on real naturally corroded plates from real bridges in the lab

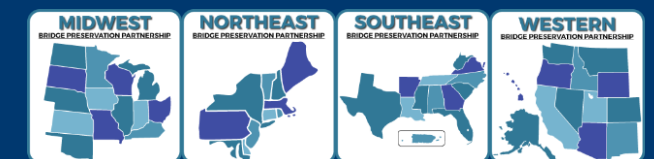
**2021**

New Bridge Load rating methods adopted in MA Bridge Manual

AASHTO proposal for national adoption 2025-2026

**2024**

Acquisition of portable cold sprayer (UMass)



# Thank you!

Questions?



**Brian Schagen**

Visiting PhD candidate at MIT | PhD candidate at UMass Amherst | MSc. Structural Enginee...



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UMassAmherst  
College of Engineering

