# Improving Bridge Assessment through integration on Visual Inspection and Non-destruction Evaluation Data

Amir H. Alavi, PhD

IRISE ANNUAL MEETING

MAY 25, 2022

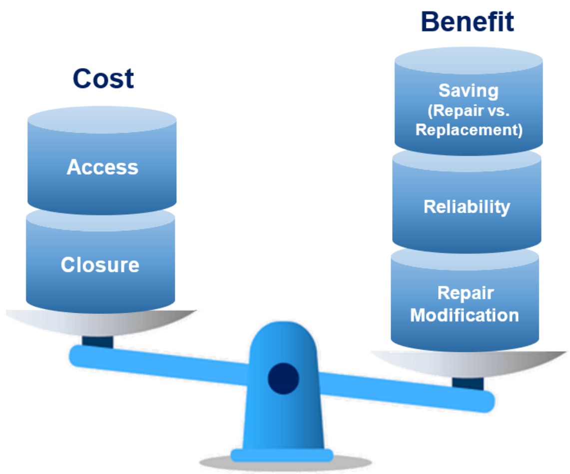
# The Background

www.washingtonpost.com

The US Federal Reserve Board:

- **Reduction of the national GDP due to failure of civil infrastructure** **1%**

- **The America's aging infrastructure** **D+**




**Cost-effective, continuous, and user-centered assessment and safety evaluation of civil infrastructure are on demand**

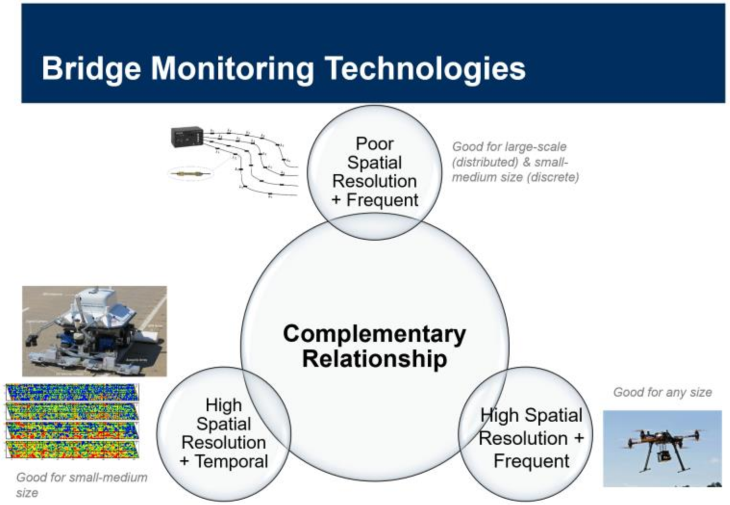
PITT | IRISE

# The Problem

- Large costs and relatively long intervals between inspections for large structures

- Current assessment approaches are generally subjective in nature and provide only qualitative data reflective of surface or near-surface condition

- Huge gap exists in:
  - Reliability/consistency/implementation of the UAVs over the service life of bridges
  - Effective approaches to fuse the collected massive NDE data




PITT | IRISE

# Project Objectives

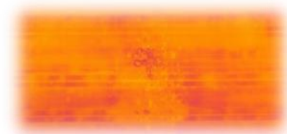
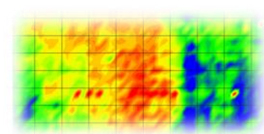
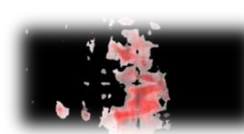
- Establish a framework capable of leveraging the data provided by emerging UAV-based and NDE techniques
- Addressing the principal challenges associated with studying the service life of bridge structures:
  - Long-time scales (which requires accelerated aging)
  - The diverse outputs related to bridge condition (in terms of data collected through UAV, NDE, and visual inspection)
- Identifying the synergies among bridge degradation, remaining service life, and the results taken from the multimodal sensing technologies (NDE, and UAV-based)

# Project Approach

**Tasks:**

- **Development of Automated Vision-Based Inspection**
  - **Collection of high-resolution and high-temporal data from the BEAST facility**
  - **Advanced data interpretation for UAV data**
  - **UAV data collection strategy**
- **Improvement of Multi-resource NDE Data Interpretation**
  - **Individual NDE data interpretation**
  - **Multi-resource NDE data fusion**



**Deliverables:**

- **Final Report**
- **Technical Articles**
- **Technical Events (TRB, NEBPP)**

# Application of Results

**The BEAST**

Bridge Evaluation and Accelerated Structural Testing Lab (BEAST):

- **Full-scale Bridge Systems**
- **Accelerated Deterioration**
- **Speed up 30 times**


➢ **NDE Data Collected from the BEAST:**

- **Electrical Resistance (ER)**
- **Ultrasonic Surface Wave (USW)**
- **Ground Penetrating Radar (GPR)**
- **Half Cell Potential (HCP)**

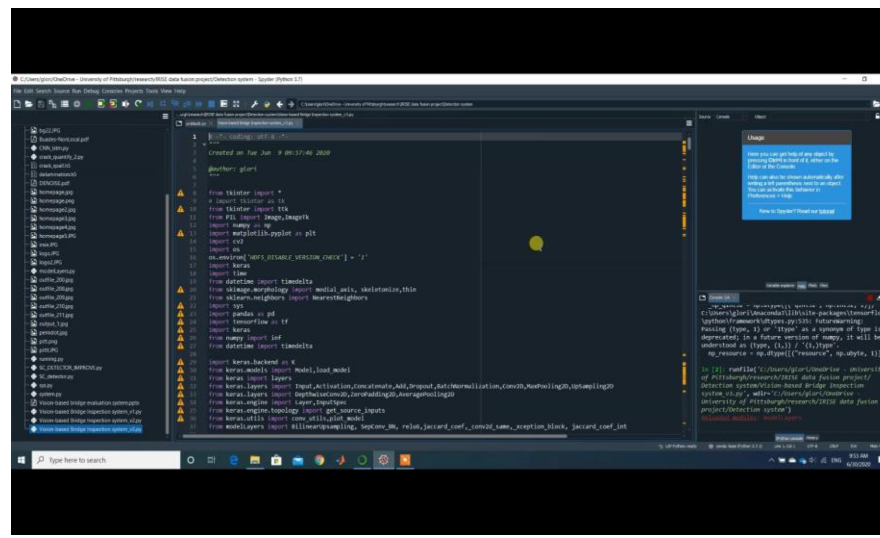
➢ **UAV Data Collected from the BEAST:**

- **HD Images (UAV/Hand-held)**
- **Infrared Images (UAV/Hand-held)**

# Application of Results

**Automated Vision-Based Inspection**

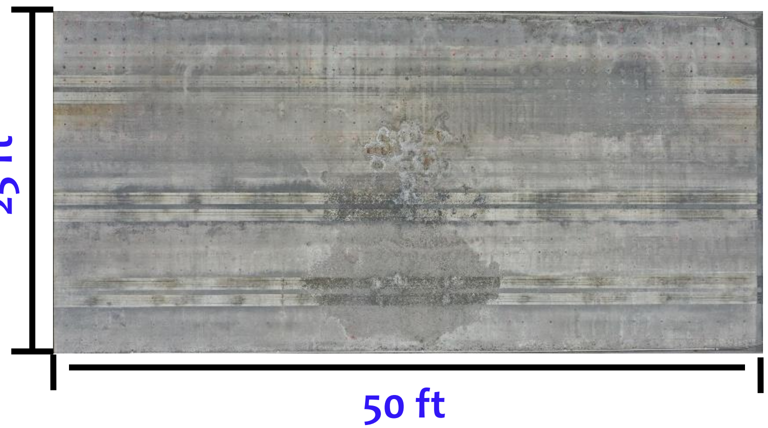
An easy-to-use tool is developed based on the presented methodologies for surface and subsurface damage evaluation

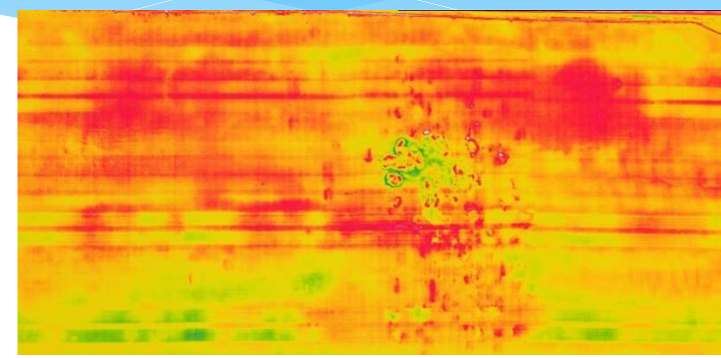



# Application of Results

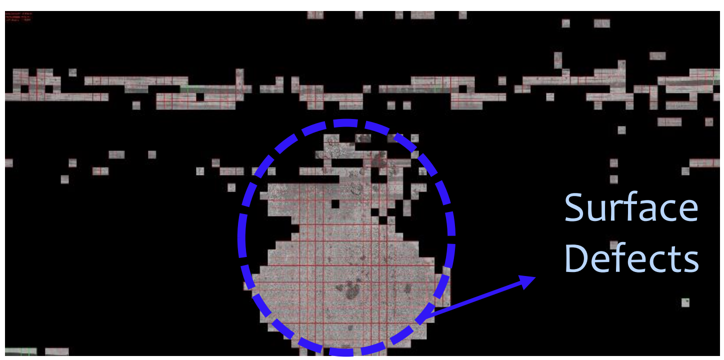
**Implementation and Validation on BEAST**

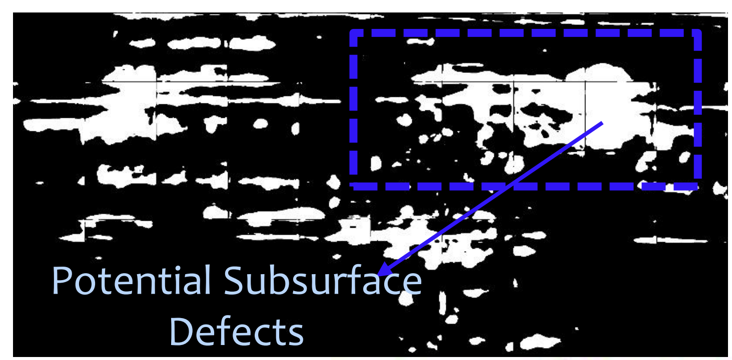
**Input**



**Output**



# Application of Results

## UAV Data Collection Strategy


### Challenges:

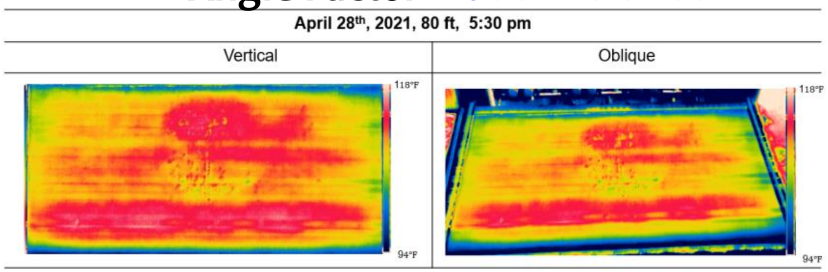
- IR image quality can be **affected** by **many factors**
- Investigation in UAV IR data **collection strategy** is necessary

| | Collection #1 | Collection #2 | Collection #3 |
|---|---|---|---|
| **Time** | Morning (10 am - noon) | Afternoon (3-5 pm) | Evening |
| **Distance from Deck (feet)*** | 30/40/50/60/70/80 | 30/40/50/60/70/80 | 30/40/50/60/70/80 |
| **Camera angles** | Vertical/Oblique | Vertical/Oblique | Vertical/Oblique |
| **Overlap** | 75% | 75% | 75% |
| **Deck condition** | Dry | Dry | Dry |
| | | | |
| **HD Images** | Same setting as IR image (only before sunset) | | |

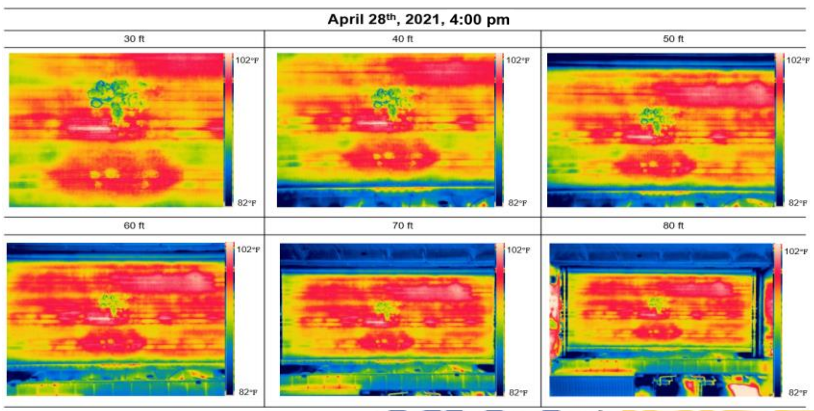
# Application of Results

- The necessary temperature change for IRT under passive conditions is **at least 8.2° C**.
- The temperature changes were **11.1° C** at the closest climatological substation to the BEAST facility on **April 28th, 2021**

**Angle Factor** Moderate effect

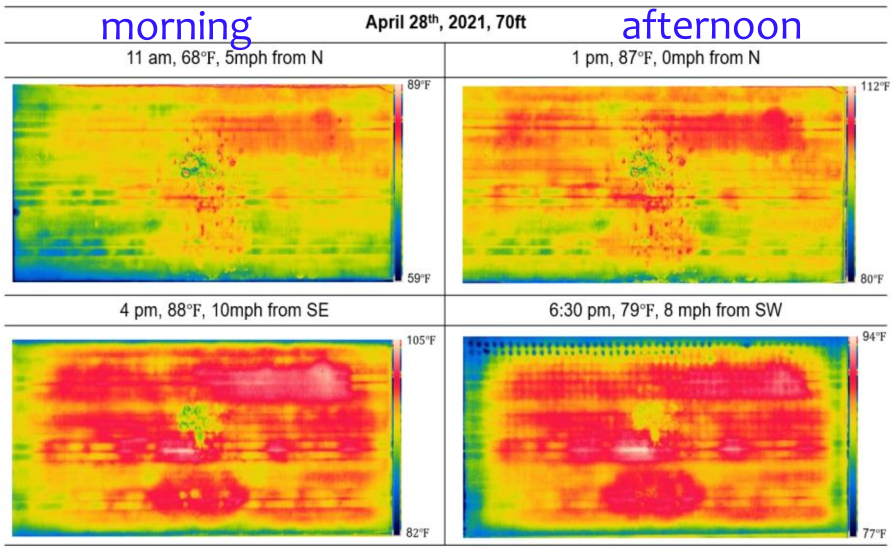



**Distance Factor** No significant effect




**Time Factor** Significant effect

morning afternoon



# Application of Results

**Multi-resource Data Collected from the BEAST**

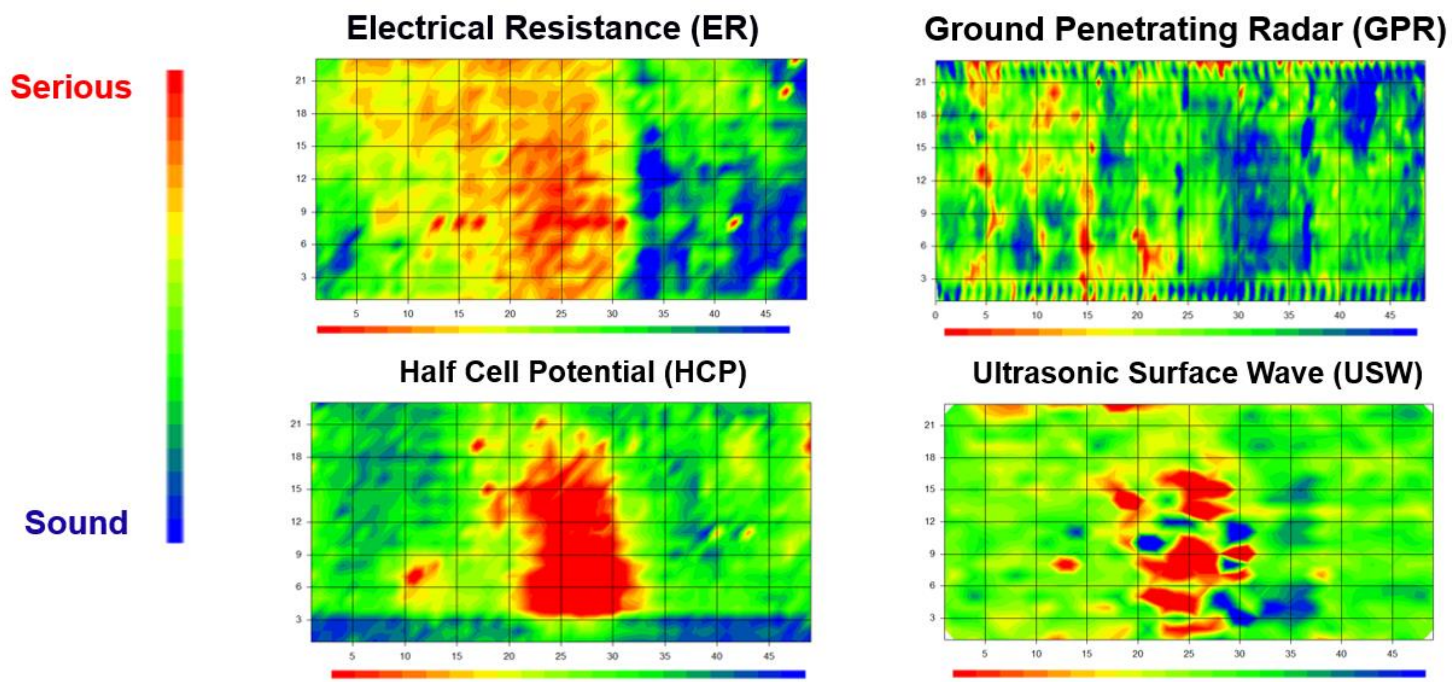
**10 rounds of NDE data collection have been conducted**

| Data Collection Date | Cumulative Live Load Cycles | Cumulative Freeze-thaw Cycles | Deck Condition Rating (Visual Inspection) | NDE Data Collection (IE/ USW/ER/GPR/HCP) |
|---|---|---|---|---|
| **11/2019** | 185000 | 8 | - | X |
| **01/2020** | 385000 | 24 | - | X |
| **02/2020** | 572000 | 35 | X | X |
| **06/2020** | 717000 | 39 | - | X |
| **11/2020** | 914000 | 48 | X | X |
| **12/2020** | 1114000 | 56 | - | X |
| **03/2021** | 1323270 | 70 | X | X |
| **04/2021** | 1374876 | 73 | X | X |
| **06/2021** | 1671506 | 85 | X | X |
| **07/2021** | 1866006 | 85 | X | X |

# Application of Results

**Statistical Analysis for Individual NDE Data**

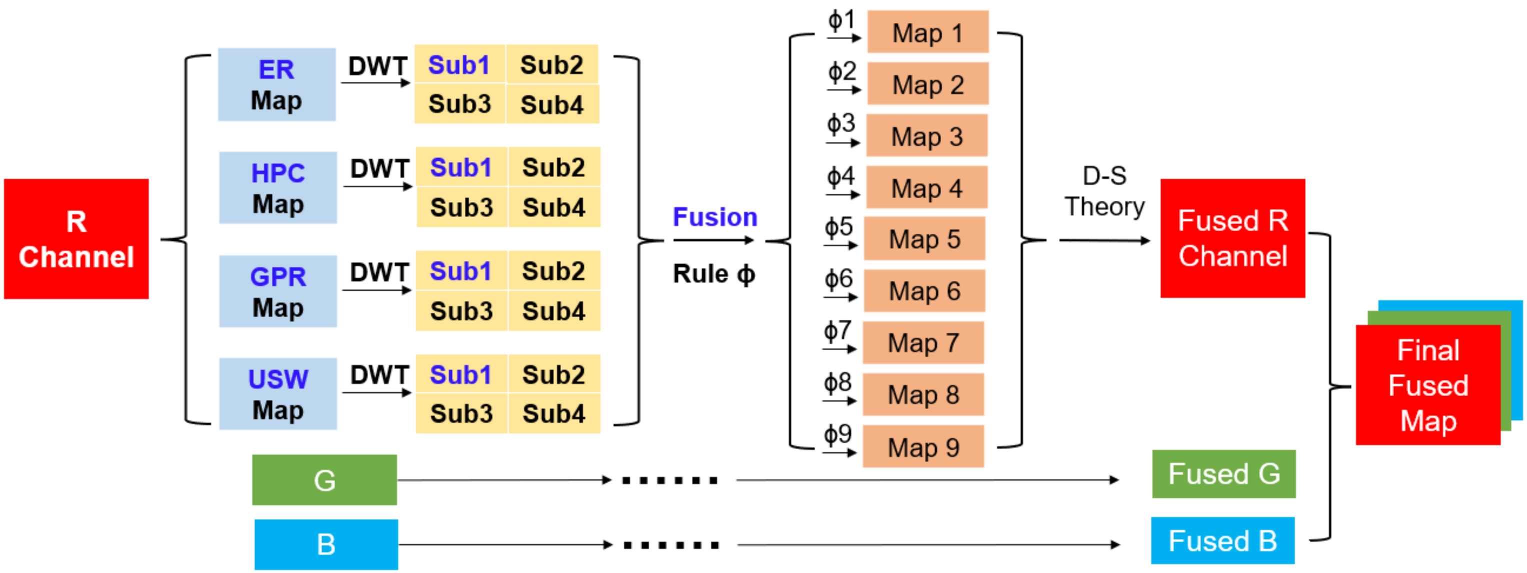
**Condition maps** (April 2021)



# Application of Results

**Multi-resource NDE Data Fusion**

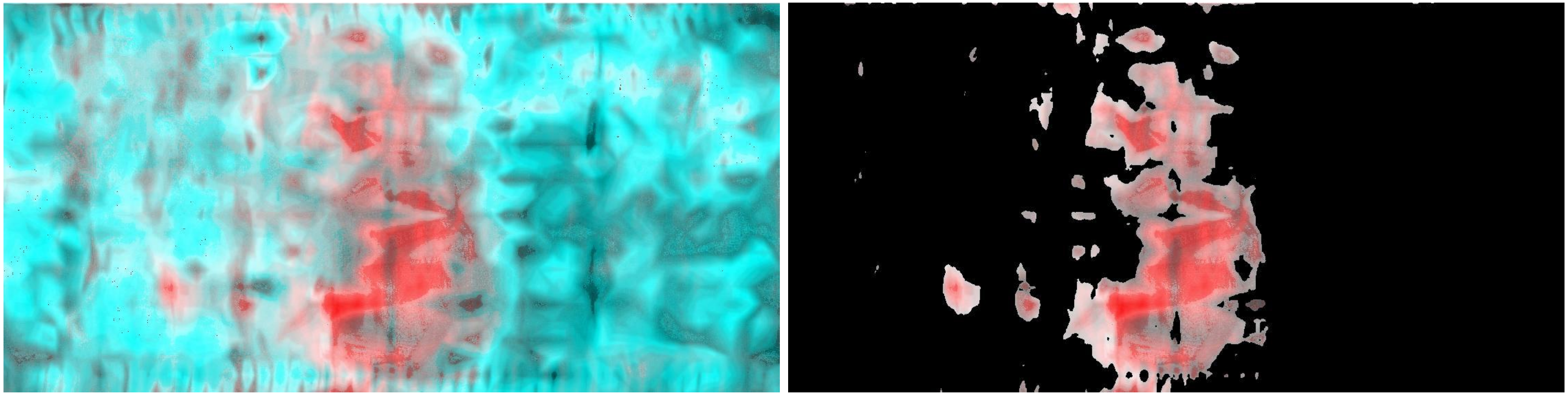
Discrete Wavelet Transforms (DWT) + Improved Dempster-Shafer (DS) Evidence Combination Theory



# Application of Results

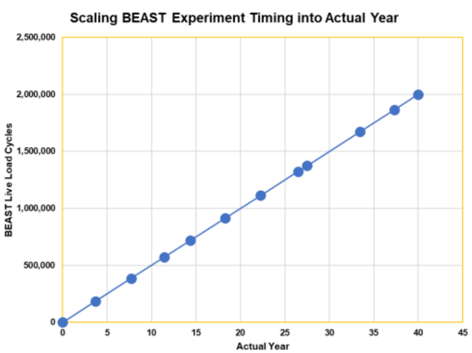
**Multi-resource NDE Data Fusion**

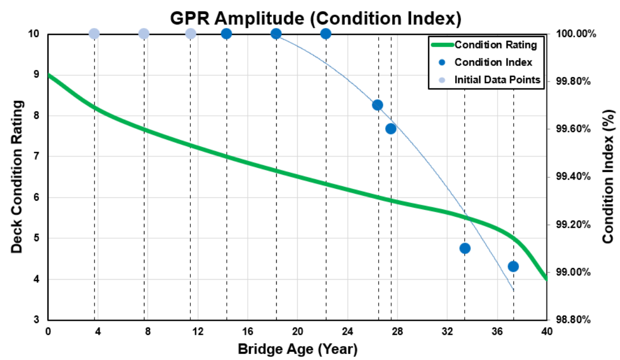
Since **red** color means high probability of existing **damages**, red parts are segmented out

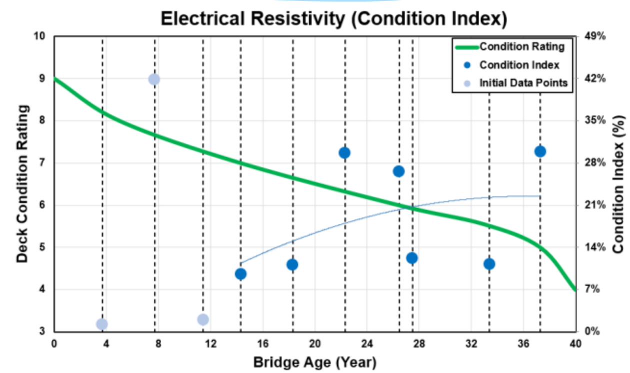


# Application of Results

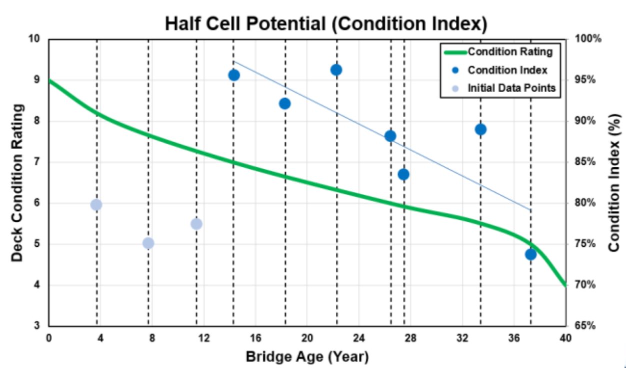
## Comparison Between Individual NDE Results and Fused Results




**Individual NDE result does NOT match the trend well**

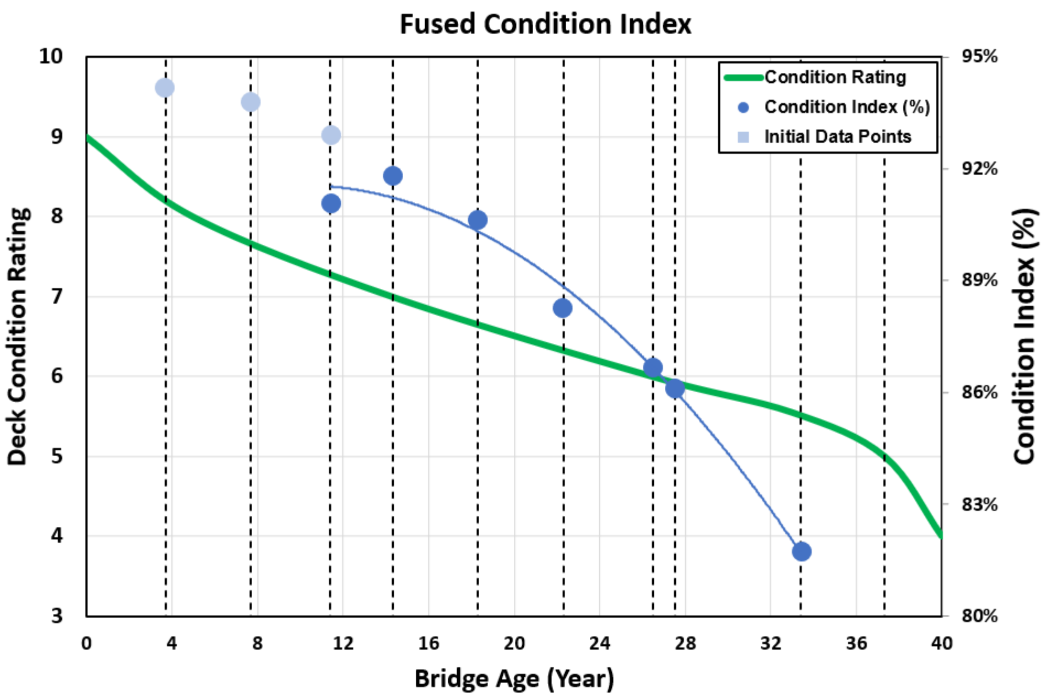



PITT | IRISE

# Application of Results

**Comparison Between Individual NDE Results and Fused Results**

**Individual NDE result does match the trend well**



# Summary

- **Automated Vision-based Evaluation**
  - Surface and subsurface defects detection methodologies
  - An easy-to-use tool for DOTs and large–scale implementation
  - UAV data collection strategy
- **Multi-resource NDE Data Interpretation**
  - Individual analysis of NDE data collected from BEAST
  - Multi-resource NDE data fusion method
  - Comparison of individual NDE results and fused results

# Acknowledgement

The project is sponsored by PennDOT.

**Project Panel**

Tom Macioce, PennDOT
Keith Cornelius, PennDOT
Rich Runyen, PennDOT
Brian Rampulla, PennDOT
Shelley Scott, PennDOT

Jonathan Buck, FHWA
Mike Burdelsky, Allegheny Co
Mike Pichura, MBI

**Students**

Gloria Zhang

PITT | IRISE
CENTER FOR IMPACTFUL RESILIENT INFRASTRUCTURE SCIENCE & ENGINEERING

pennsylvania
DEPARTMENT OF TRANSPORTATION

RUTGERS
Center for Advanced Infrastructure and Transportation

WJE
ENGINEERS ARCHITECTS MATERIALS SCIENTISTS
Wiss, Janney, Elstner Associates, Inc.

PITT | IRISE

# Thank you

Amir H. Alavi, PhD
Assistant Professor
Department of Civil and Environmental Engineering
University of Pittsburgh
E-mail: alavi@pitt.edu

# Early Opening of Concrete Pavements to Traffic

Lev Khazanovich, Katelyn Kosar, Lucio Salles,
Alex Stevanovic

IRISE ANNUAL MEETING

MAY 25, 2022

# The Research Problem

- The current empirical methods for determining traffic-opening criteria are overly conservative.

- An innovative mechanistic-based procedure for quantifying the risk of premature failure and long-term damage caused by traffic opening will facilitate reduction of unnecessary construction delays, construction and user costs.

# Project Approach

- ❑Task A: Literature review
- ❑Task B: Laboratory and field testing
- ❑Task C: Develop mechanistic-empirical model
- ❑Task D: Conduct traffic simulation
- ❑Task E: Final Report

# PennDOT Strength Criteria (2021)

| Slab Thickness, in | Strength for Opening to Traffic, psi | | | |
|---|---|---|---|---|
| | Slab Length < 10 ft | | Slab Length ≥ 10 ft | |
| | $f'_c$ | MR (3rd point loading) | $f'_c$ | MR (3rd point loading) |
| 6.0 | 3000 | 490 | 3600 | 540 |
| 7.0 | 2400 | 370 | 2700 | 410 |
| 8.0 | 2150 | 340 | 2150 | 340 |
| 9.0 | 2000 | 275 | 2000 | 300 |
| 10.0 + | 2000 | 250 | 2000 | 300 |

# Laboratory and Field Testing

**❑ Two concrete mixtures:**

1. Long-Life Conventional
2. High Early Strength (7 hours)

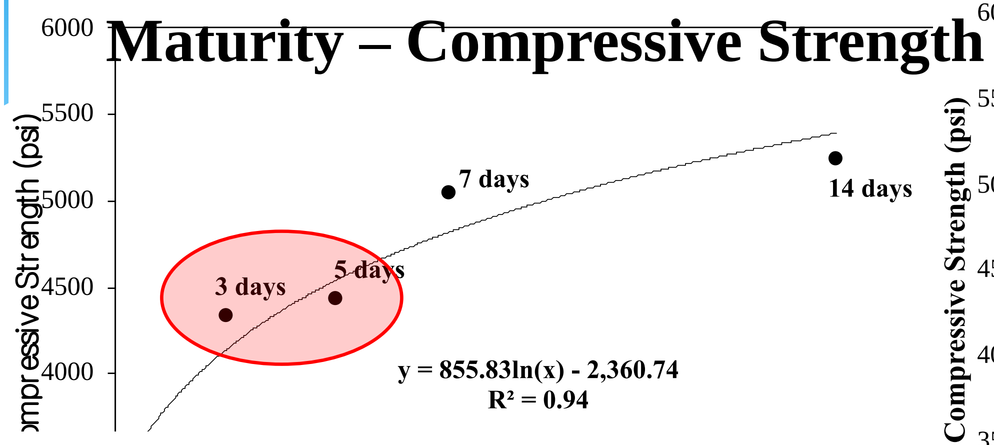
**❑ Three tests:**

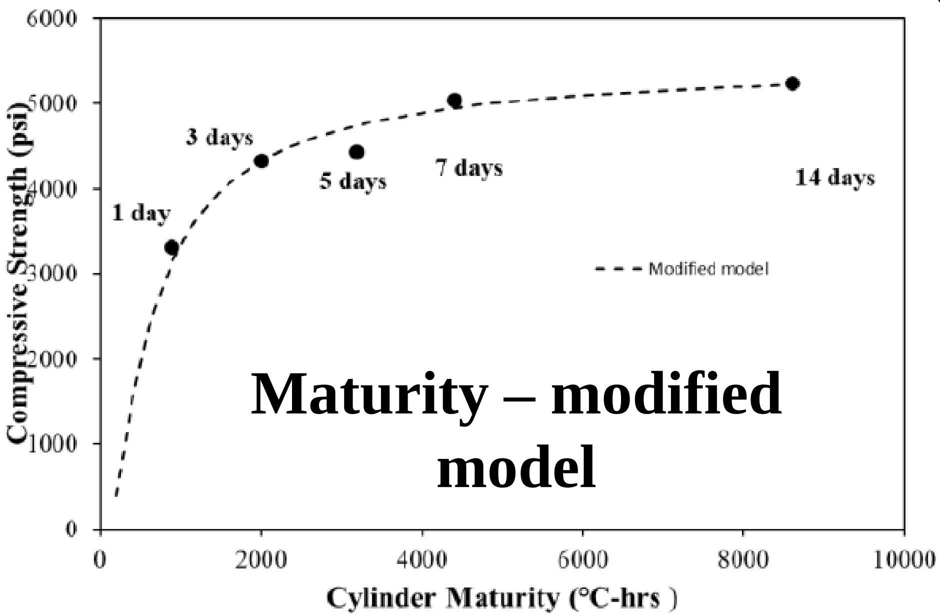
1. Laboratory: Compressive and flexural strength
2. Maturity: Lab and Field
3. Ultrasound: Lab and Field

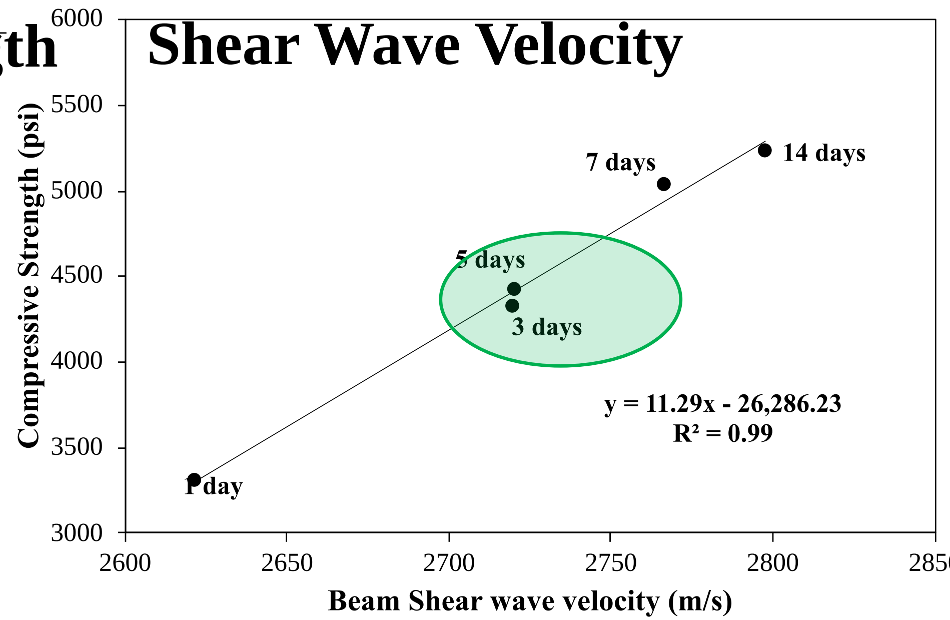
PITT | IRISE

# Laboratory Testing

- Long-Life Conventional Mix Compressive Strength Development

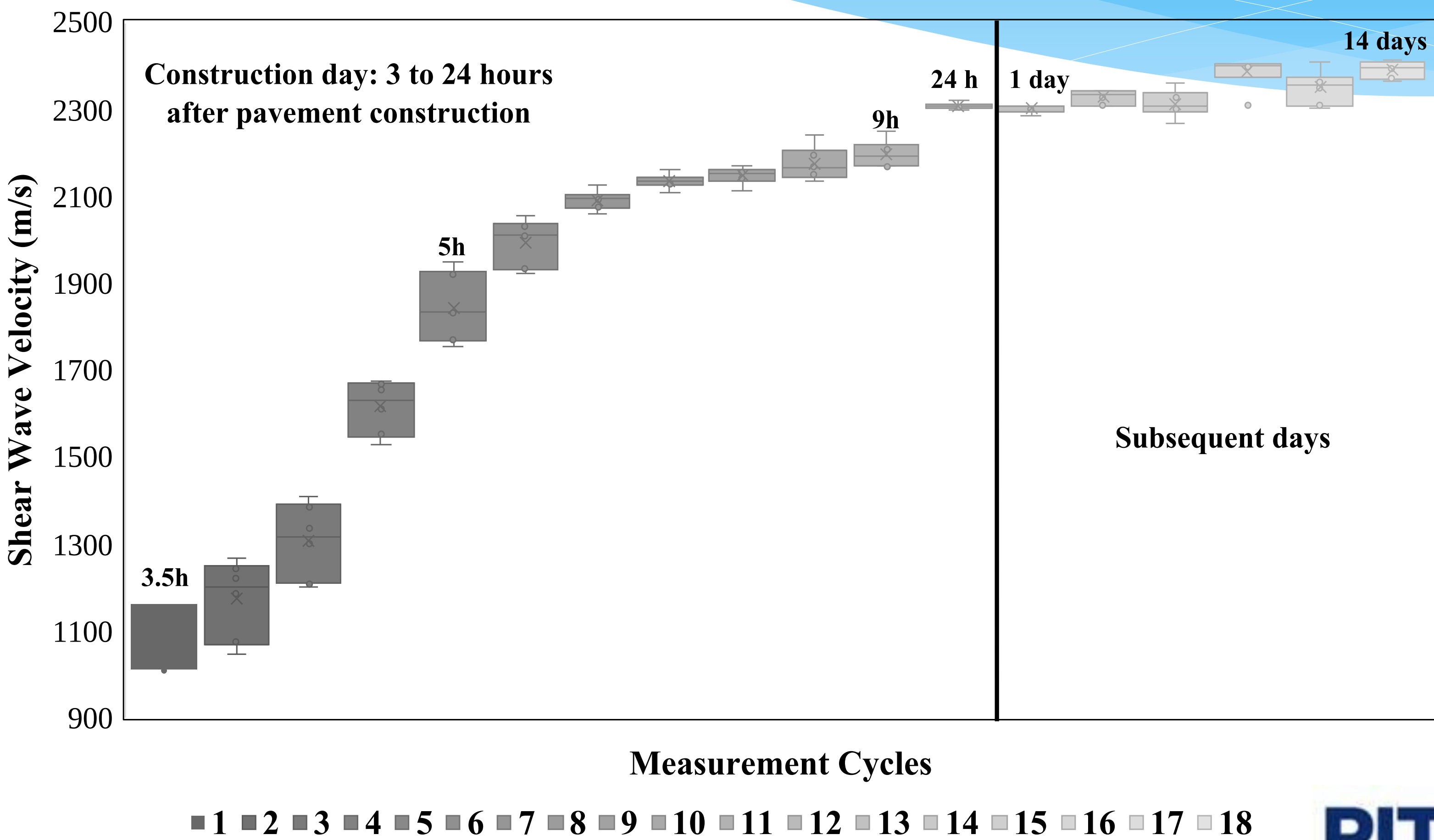


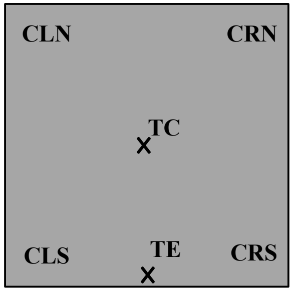



# Field Testing

- Variability of concrete properties




PITT | IRISE

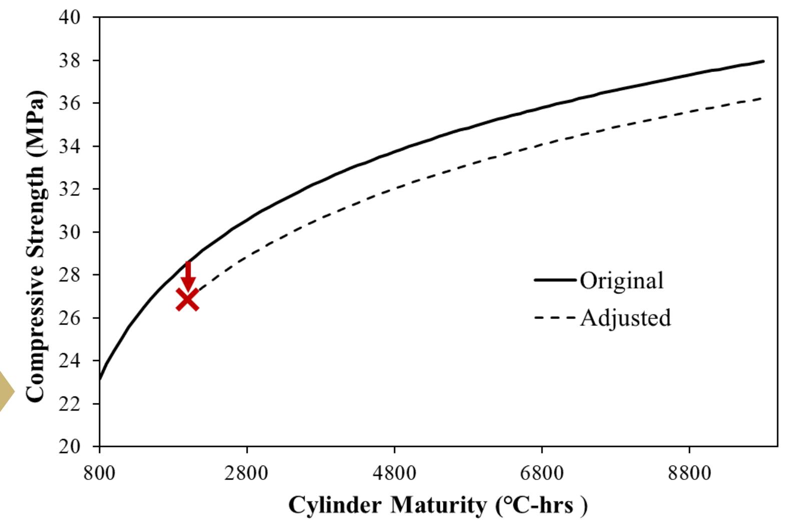
# Early Age Strength Prediction

**Strength Forecasting** using Maturity

+

**Strength Correlation** using Ultrasonic Tomography

Adjusting strength prediction using in-situ strength estimated by wave velocity

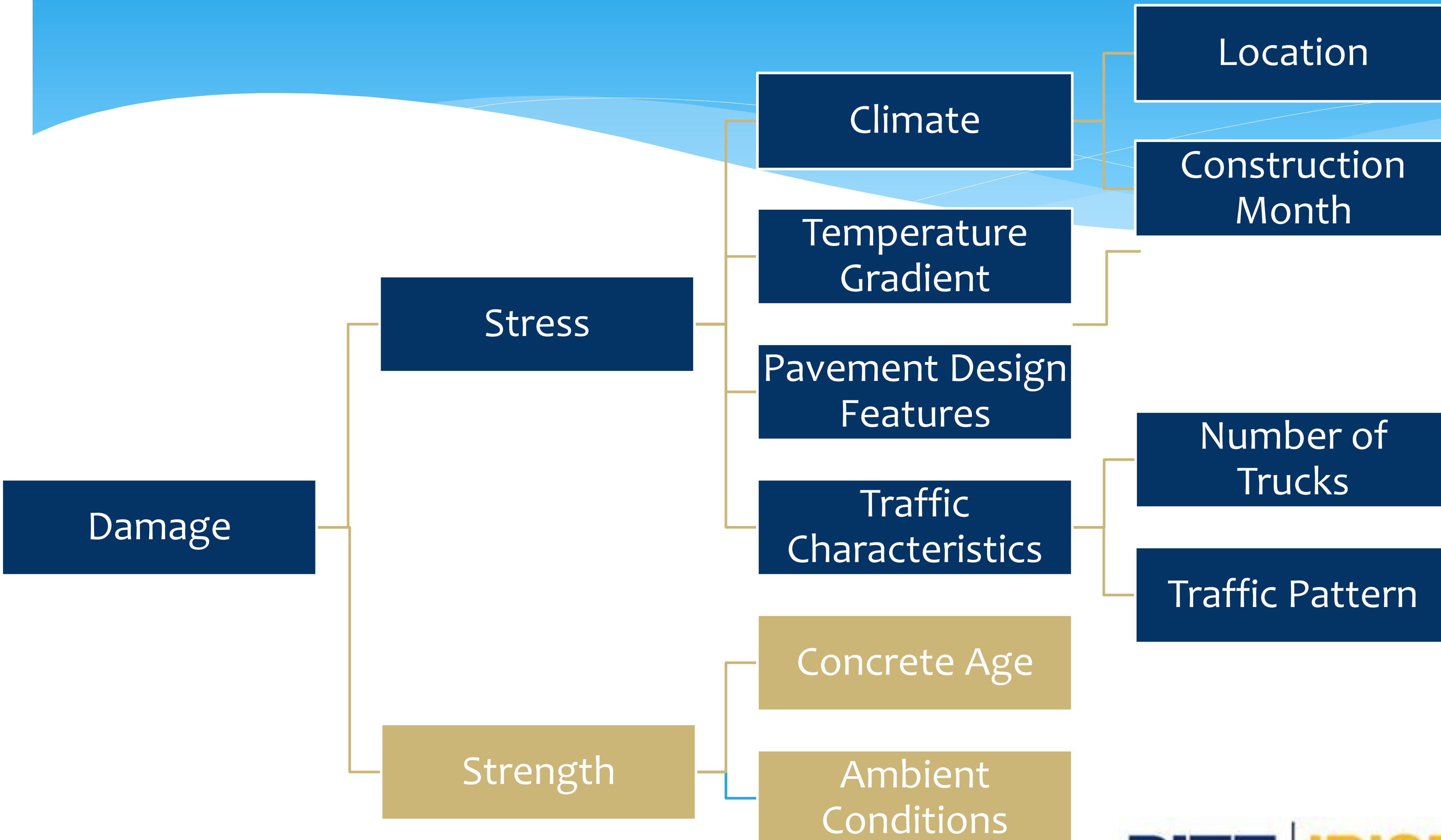



Reduces risk of over- or underpredicting strength which can lead to mistimed early age construction practices.



PITT | IRISE

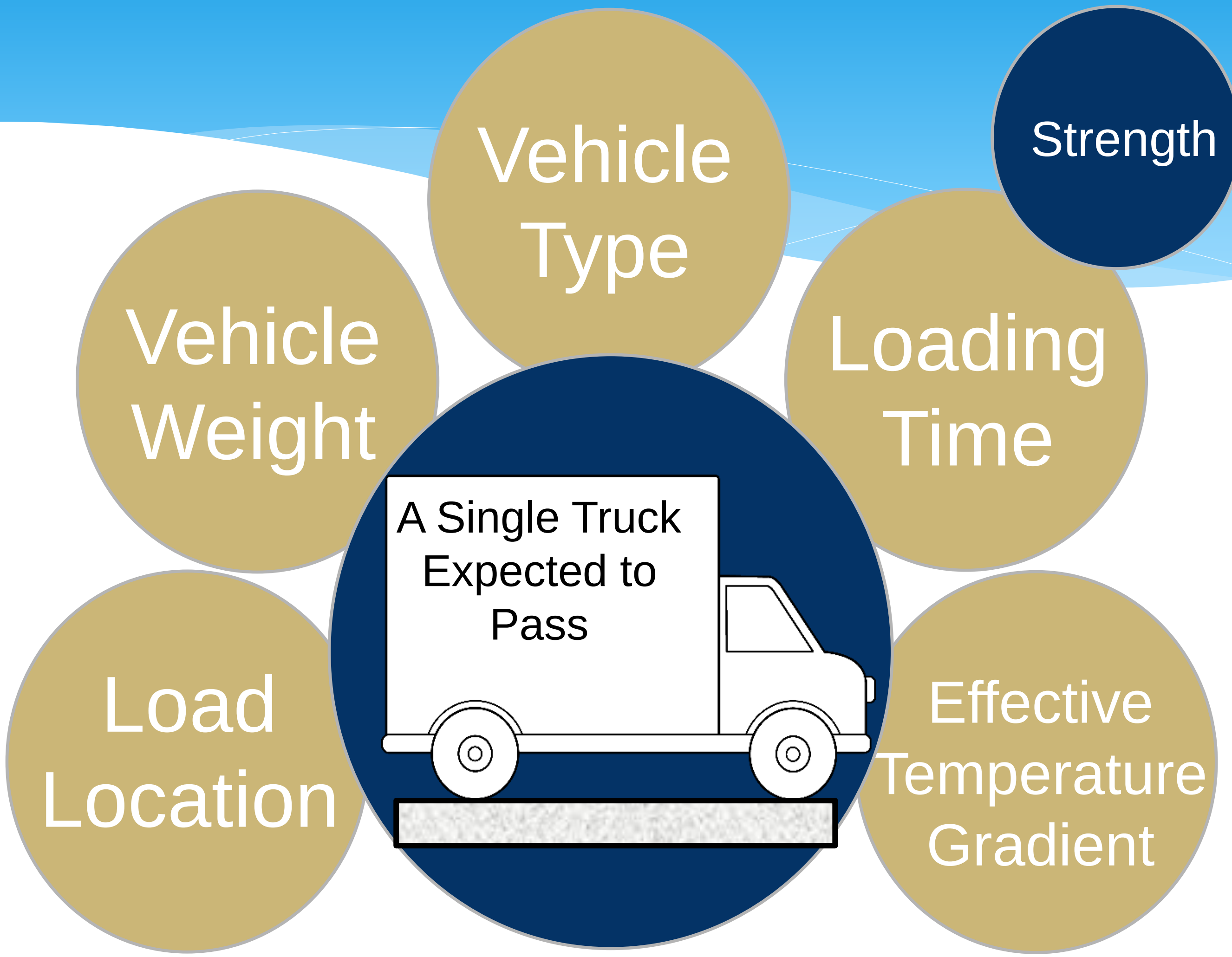
# Factors Affecting Concrete Damage



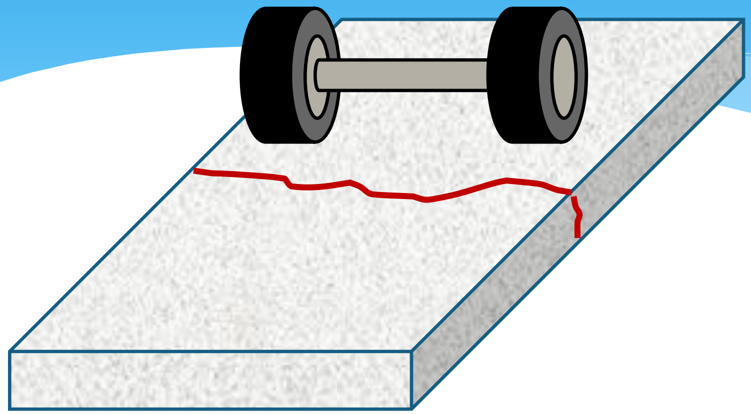



PITT | IRISE

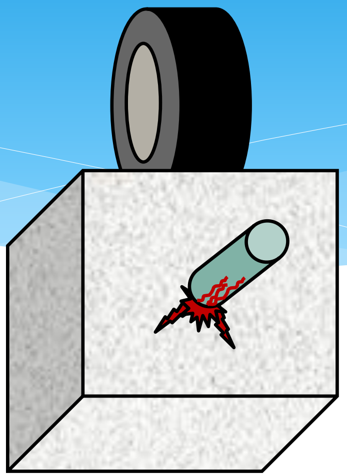
# Risk Assessment



# Risk Assessment



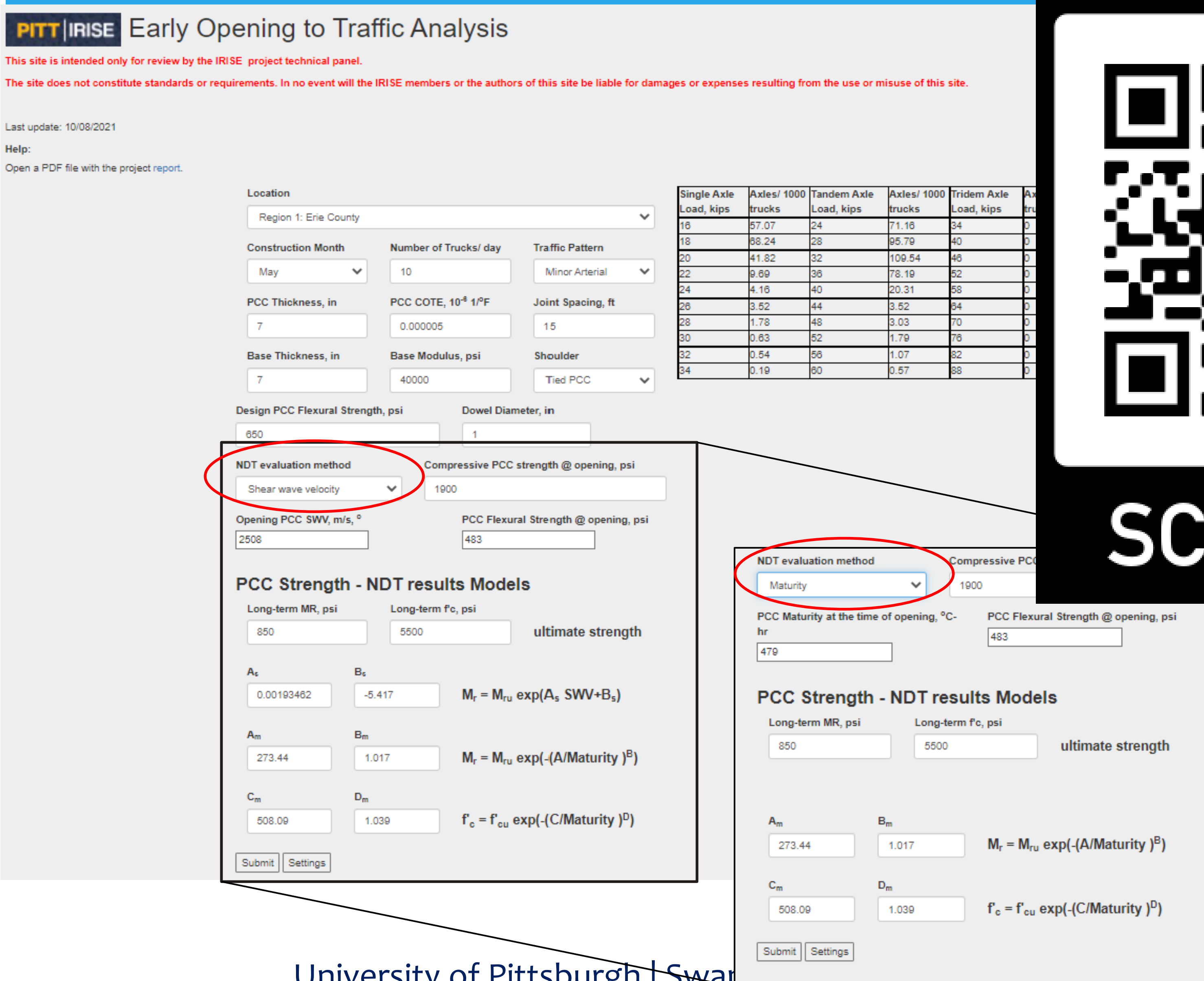
Transverse Cracking
(bending stress exceeds flexural strength)



Dowel Bar Damage
(concrete bearing stress exceeds compressive strength)

$$Reliability = 100\% - \frac{1}{Number\ of\ Simulations}\sum\left(\frac{Number\ of\ Failures}{Total\ Number\ of\ Trucks}\right)$$

# Web-Based Tool



PITT | IRISE Early Opening to Traffic Analysis

This site is intended only for review by the IRISE project technical panel.

The site does not constitute standards or requirements. In no event will the IRISE members or the authors of this site be liable for damages or expenses resulting from the use or misuse of this site.

Last update: 10/08/2021

Help:

Open a PDF file with the project report.

Location: Region 1: Erie County

Construction Month: May

Number of Trucks/ day: 10

Traffic Pattern: Minor Arterial

PCC Thickness, in: 7

PCC COTE, $10^{-6}$ 1/°F: 0.000005

Joint Spacing, ft: 15

Base Thickness, in: 7

Base Modulus, psi: 40000

Shoulder: Tied PCC

Design PCC Flexural Strength, psi: 650

Dowel Diameter, in: 1

| Single Axle Load, kips | Axles/ 1000 trucks | Tandem Axle Load, kips | Axles/ 1000 trucks | Tridem Axle Load, kips | Ax tru |
|---|---|---|---|---|---|
| 16 | 57.07 | 24 | 71.16 | 34 | 0 |
| 18 | 68.24 | 28 | 95.79 | 40 | 0 |
| 20 | 41.82 | 32 | 109.54 | 46 | 0 |
| 22 | 9.69 | 36 | 78.19 | 52 | 0 |
| 24 | 4.16 | 40 | 20.31 | 58 | 0 |
| 26 | 3.52 | 44 | 3.52 | 64 | 0 |
| 28 | 1.78 | 48 | 3.03 | 70 | 0 |
| 30 | 0.63 | 52 | 1.79 | 76 | 0 |
| 32 | 0.54 | 56 | 1.07 | 82 | 0 |
| 34 | 0.19 | 60 | 0.57 | 88 | 0 |

NDT evaluation method: Shear wave velocity

Compressive PCC strength @ opening, psi: 1900

Opening PCC SWV, m/s, °: 2508

PCC Flexural Strength @ opening, psi: 483

PCC Strength - NDT results Models

Long-term MR, psi: 850

Long-term f'c, psi: 5500

ultimate strength

$A_s$: 0.00193462

$B_s$: -5.417

$M_r = M_{ru} \exp(A_s\ SWV + B_s)$

$A_m$: 273.44

$B_m$: 1.017

$M_r = M_{ru} \exp(-(A/Maturity)^B)$

$C_m$: 508.09

$D_m$: 1.039

$f'_c = f'_{cu} \exp(-(C/Maturity)^D)$

Submit | Settings

NDT evaluation method: Maturity

Compressive PC[...]: 1900

PCC Maturity at the time of opening, °C-hr: 479

PCC Flexural Strength @ opening, psi: 483

PCC Strength - NDT results Models

Long-term MR, psi: 850

Long-term f'c, psi: 5500

ultimate strength

$A_m$: 273.44

$B_m$: 1.017

$M_r = M_{ru} \exp(-(A/Maturity)^B)$

$C_m$: 508.09

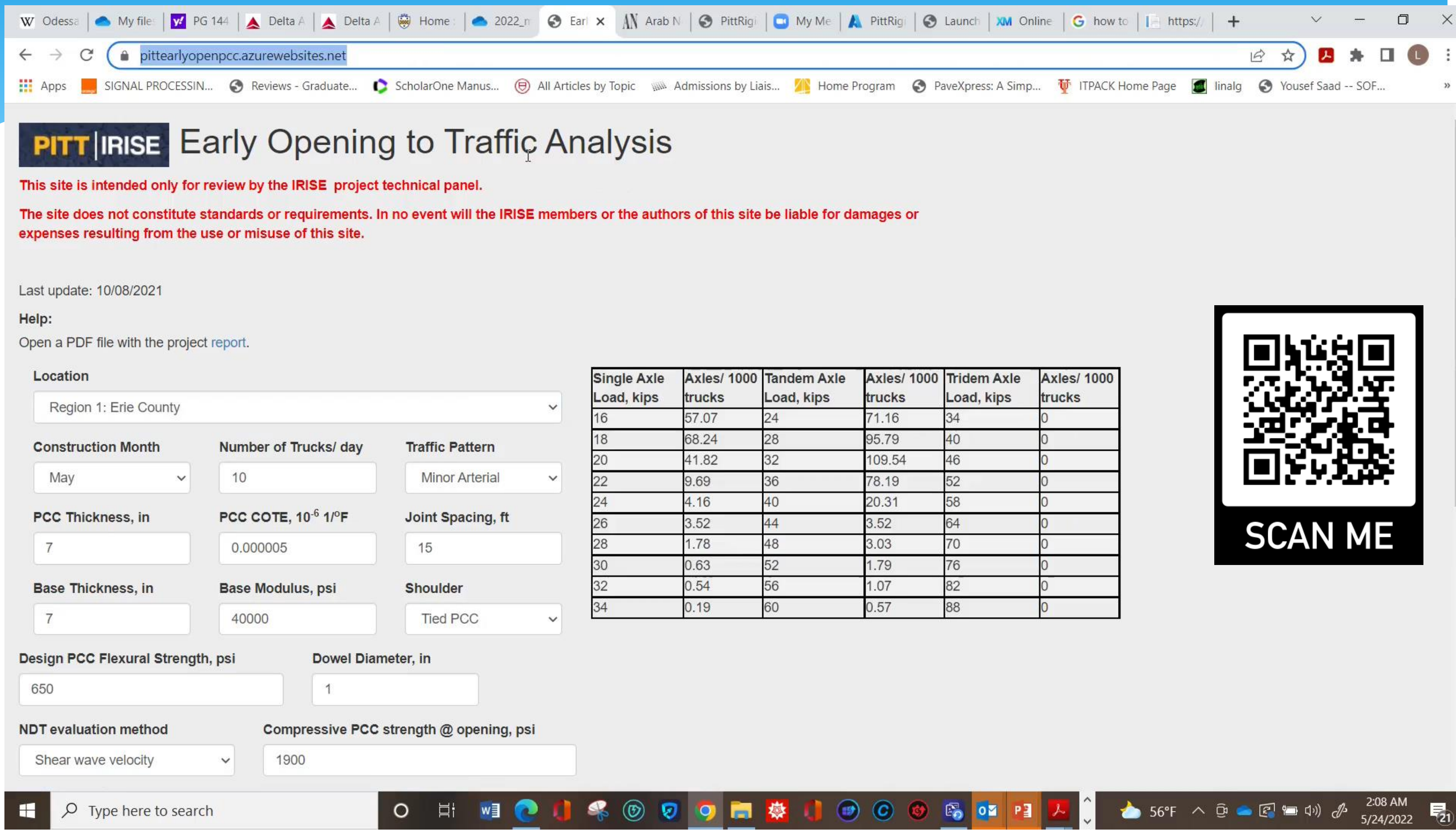
$D_m$: 1.039

$f'_c = f'_{cu} \exp(-(C/Maturity)^D)$

Submit | Settings

SCAN ME

# Web-Based Tool



pittearlyopenpcc.azurewebsites.net

## Early Opening to Traffic Analysis

**This site is intended only for review by the IRISE project technical panel.**

**The site does not constitute standards or requirements. In no event will the IRISE members or the authors of this site be liable for damages or expenses resulting from the use or misuse of this site.**

Last update: 10/08/2021

**Help:**

Open a PDF file with the project report.

**Location**: Region 1: Erie County

**Construction Month**: May

**Number of Trucks/ day**: 10

**Traffic Pattern**: Minor Arterial

**PCC Thickness, in**: 7

**PCC COTE, $10^{-6}$ 1/°F**: 0.000005

**Joint Spacing, ft**: 15

**Base Thickness, in**: 7

**Base Modulus, psi**: 40000

**Shoulder**: Tied PCC

**Design PCC Flexural Strength, psi**: 650

**Dowel Diameter, in**: 1

**NDT evaluation method**: Shear wave velocity

**Compressive PCC strength @ opening, psi**: 1900

| Single Axle Load, kips | Axles/ 1000 trucks | Tandem Axle Load, kips | Axles/ 1000 trucks | Tridem Axle Load, kips | Axles/ 1000 trucks |
|---|---|---|---|---|---|
| 16 | 57.07 | 24 | 71.16 | 34 | 0 |
| 18 | 68.24 | 28 | 95.79 | 40 | 0 |
| 20 | 41.82 | 32 | 109.54 | 46 | 0 |
| 22 | 9.69 | 36 | 78.19 | 52 | 0 |
| 24 | 4.16 | 40 | 20.31 | 58 | 0 |
| 26 | 3.52 | 44 | 3.52 | 64 | 0 |
| 28 | 1.78 | 48 | 3.03 | 70 | 0 |
| 30 | 0.63 | 52 | 1.79 | 76 | 0 |
| 32 | 0.54 | 56 | 1.07 | 82 | 0 |
| 34 | 0.19 | 60 | 0.57 | 88 | 0 |

SCAN ME

# Analysis of Work-Zone User Delay Costs

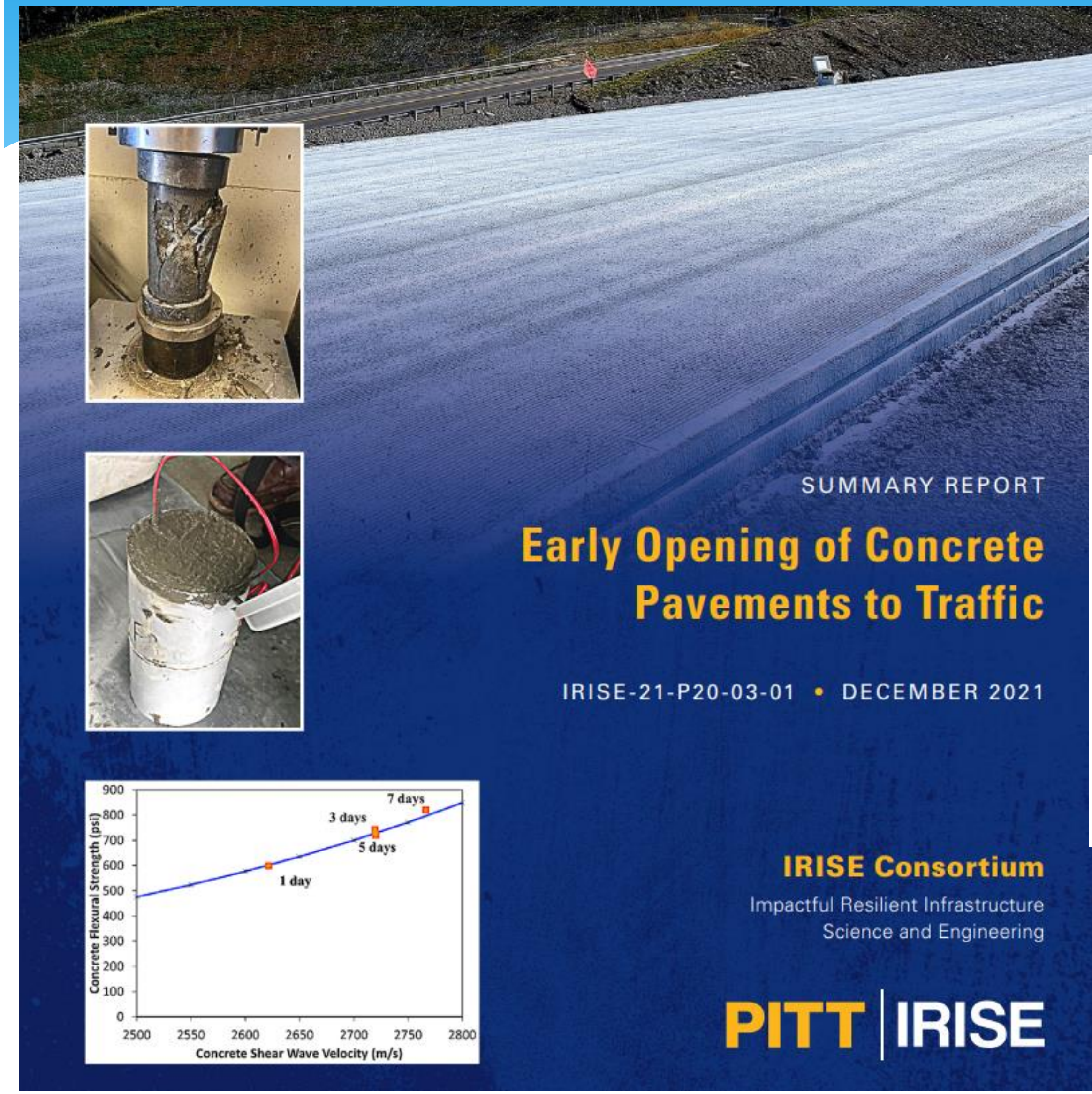
- Considered arterial and freeway networks
- Faster construction has a significant impact on user cost for arterial roads
- User delay costs for freeways must consider more factors to determine significance

Cost of Delay Caused by Work-Zone for Pittsburgh Downtown Network

| Time of day | Passenger Car Delay (h) | Heavy Vehicle Delay (h) | Bus Delay (h) | Total |
|---|---|---|---|---|
| AM peak | 287.6 | 1.9 | 2.0 | 291.5 |
| Mid-day | 581.7 | 4.1 | 4.1 | 589.8 |
| PM peak | 222.8 | 1.4 | 1.6 | 225.8 |
| Evening | 239.3 | 1.8 | 1.7 | 242.7 |
| Free Flow hours | 547.2 | 5.3 | 3.9 | 556.4 |
| Total Delay (h) | 1,878.5 | 14.4 | 13.2 | 1,906.2 |
| User Delay Cost ($) | 67,064.0 | 377.0 | 2,998.7 | 70,439.7 |
| Vehicle Operating Cost ($) | 49,217.9 | 2,297.8 | 1,689.7 | 53,205.4 |
| Total User Cost of Delay ($) | 116,281.9 | 2,674.7 | 4,688.4 | **123,645.1** |

PITT | IRISE

# Final Report




PITT | IRISE