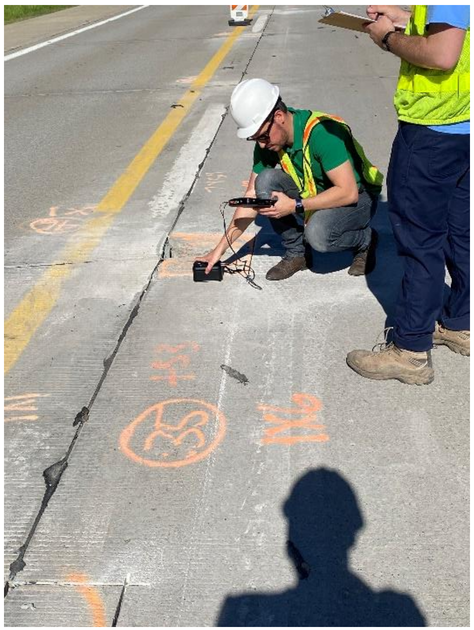
Material Compatible Repair Evaluation



Steve Sachs

IRISE ANNUAL MEETING

MAY 25, 2022

Research Problem

- Premature failures in partial depth repairs (PDRs)

- Incompatible thermal expansion
- Unequal deformation under traffic loads
- Excessive shrinkage
- Bond failure
- Compressive failure of repair material
- Insufficient consolidation
- Delayed curing

Project Objectives

- Assess PDR performance using results from previous IRISE study to develop material compatible repair (MCR) for field project
  - Use MCR and a standard repair material
  - Long-term field evaluations of repairs made

- Investigate the ability of ultrasonic tomography testing to provide:
  - reliable information for required partial depth repair dimensions
  - evaluate bond condition after repair placement

Performance Engineered Repair Mixture

- Two main steps toward developing a PERM:

1. Identifying the CTE of the in-situ concrete;

2. Using appropriate materials and proportioning so:
   - CTE of the PERM and the in-situ concrete are comparable,
   - Drying shrinkage of the PERM is minimized
   - Strength and durability requirements are met

Project Approach

- Task A: Project Selection and Evaluation
  - find suitable PCC rehab project where PDRs are to be performed
  - historical construction data and 4 cores from the roadway to evaluate CTE, E, and f'_c
  - develop a (Performance Engineered Repair Mixture) PERM for the project using the results from the year one MCR project

- Task B: Ultrasonic Tomography Testing of PCC Pavement Prior to PDR
  - Ultrasonic Tomography testing prior to the repair placement
  - Recommendations for repair dimensions (both horizontal and vertical) of the compared to conventional sounding methods
  - cores from Task A will be used to validate the testing

Project Approach

- Task C: Partial Depth Repair Construction
  - PERM specified for use on the project along with a standard repair material
  - Repairs placed using both mixtures w/ same placement and curing methods for both repairs
  - Companion specimens cast with both PERM and standard repair material to measure CTE, E, and f'c, ε_{repair}

Traditional Repair

»

Material Compatible Repair

- Applied load
- Change in temperature
- Drying shrinkage

» *Elastic modulus, $E_{repair} = E_{existing}$*
» *Thermal coefficient, $\alpha_{repair} = \alpha_{existing}$*
» *ε_{repair} reduced*

Project Approach

- Task D: Performance Monitoring
  - Repair performance monitored for a period of five-years at a frequency of one observation per year
- Task E: Ultrasonic Tomography Testing of Partial Depth Repairs
  - Ultrasonic tomography used to evaluate repair strength development and bond between PDR and existing PCC
  - Testing will be conducted in all repairs constructed under Task B
- Task F: Final Report
  - Summarize project activities, results, and recommendations

Schedule/Status and Application of Research Results

- Project started January 1st
  - Rehab project on SR 22 in Westmoreland Co selected
    - Section EB between 819 and Hannastown Rd
  - Cores obtained and tested, PERM developed
  - Ultrasonic tomography testing performed prior to PDR
  - PDRs placed this week

Results from year 1 MCR IRISE project being implemented in field trial to assess feasibility

Thanks!
PennDOT District 12 & Swank Construction

Developing Methodologies to Predict and Quantify the benefits of Research that Creates Durable and Longer Lasting Highway Infrastructure

Mark J. Magalotti P.E. Ph.D.

IRISE ANNUAL MEETING

MAY 25, 2022

The Research Problem

- The transfer of new technologies into practice is the ultimate goal of IRISE research
- More durable and longer lasting highway infrastructure creates benefits to extend the life of highways and bridges
- These benefits must be measured decades into the future
- The challenge is to quantify and predict benefits for many of these advancements

Project Objectives

- Benefits must be considered in the cost of design, construction and maintenance phases of highway infrastructure projects
- Environmental impacts and sustainability benefits are difficult to evaluate but need to be considered
- Methodologies have been developed that quantify and can extrapolate cost and user data available on an appropriate scale (national, state or project) for highway infrastructure and user costs or case studies

IRISE Projects to be Evaluated

- Landslide Best Practices – **11/1/22**
- Joint Design Optimization – **9/30/23**
- Preliminary Evaluation of Pavement Surface Distresses Related to Pavement Marking – **9/30/22**
- Remote-Controlled Technology Assessment for Safer Pavement Construction and QA/QC – **7/1/22**
- Development of Simplified Mechanistic-Empirical Design Tool for Pennsylvania Rigid Pavements - **Completed**
- Material Compatibility Repair - **Completed**

Project Approach/Deliverables Status/Schedule

- Task A Literature Review - **Complete**
- Task B Development of Methodologies - **Complete**
- Task C Application of Methodologies to Research Results – **In process due 11/1/22**
- Task D – Final Report – **12/21/22 due**

Application of Research Results

- **Preliminary Evaluation of Pavement Surface Distresses Related to Pavement Marking**
- When joints are repaired the reapplied pavement markings are a cost that could be eliminated if longer lasting joints were constructed
- The potential savings for reapplication of longitudinal pavement markings per year could be $1,937,772 for thermoplastic for the two case studies evaluated in Allegheny and Beaver County Interstate Highways

Application of Research Results

- **Remote-Controlled Technology Assessment for Safer Pavement Construction and QA/QC**

- Pennsylvania Highway Worker Injury Reports of Vehicles intruding into active work zones totaled 143 crashes from 2017-2020

Application of Research Results

- **Remote-Controlled Technology Assessment for Safer Pavement Construction and QA/QC**
- Value of Highway Worker Injury Reports of Vehicles intruding into active work zones totaled 23 that could be mitigated by technologies being investigated were determined

Year	Number of Injuries	Average Cost	Total	Inflation Factor	Present Value
2017	11	$20,227	$222,297	1.6	$355,995.20
2018	4	$20,227	$80,908	1.7	$137,543.60
2019	6	$20,227	$121,362	1.75	$212,383.50
2020	2	$20,227	$40,454	1.82	$73,626.28
Total					$779,548.58

Application of Research Results

- **Development of Simplified Mechanistic-Empirical Design Tool for Pennsylvania Rigid Pavements**
- Three case studies were identified to illustrate the benefits of using the ME design method that would result in less concrete pavement depth

Project	Original Design Total Costs	PittRigid ME Design Total Costs	Cost Reduction
Southern Beltway Plain Cement Concrete Pavement RPS	$44,025,986	$37,422,088	$6,603,898
US-119 Plain Cement Concrete Pavement RPS	$10,640,273	$9,044,232	$1,596,041
Ivory Avenue Plain Cement Concrete Pavement RPS	$210,375	$178,819	$31,556
		Total	$8,231,495

Application of Research Results

- **Material Compatibility Repair**
- A comparison of current and expected service life applied to the MCR improved method repair costs resulted in the following estimate of benefits

Pavement Repair Research Results Benefit Analysis Summary					
Repair Method and PennDOT Costs per Year	Total Repairs Cost	Adjustment for Increased Repair Costs (7%)	Average 2 Year Life Cycle Annual Replacement Costs - Current Method	Average 15 Year Annual Life Cycle Replacement Costs - New Method	Potential Savings over 15 Year Cycle of Repairs
Partial Depth Repairs (Material Comptable Repairs)					
2018	$121,506.38	$130,011.83	$143,359	$20,453	$1,843,597
2019	$479,791.26	$513,376.65			
2020	$237,516.92	$254,143.10			
2021	$308,057.76	$329,621.80			

Schedule/Status

- ❑ Complete analysis for Landslide and Joint Design Projects
- ❑ Provide one page summary Pavement Marking , MCR and Safer Pavement projects for review
- ❑ Complete the Task C report for review

Preliminary Evaluation of Pavement Surface Distresses Related to Pavement Markings

Click to add text

Lucio Salles, Lev Khazanovich

IRISE ANNUAL MEETING

MAY 25, 2022

The Problem

- Reports of pavement distresses, such as cracking and raveling, under or along pavement markings

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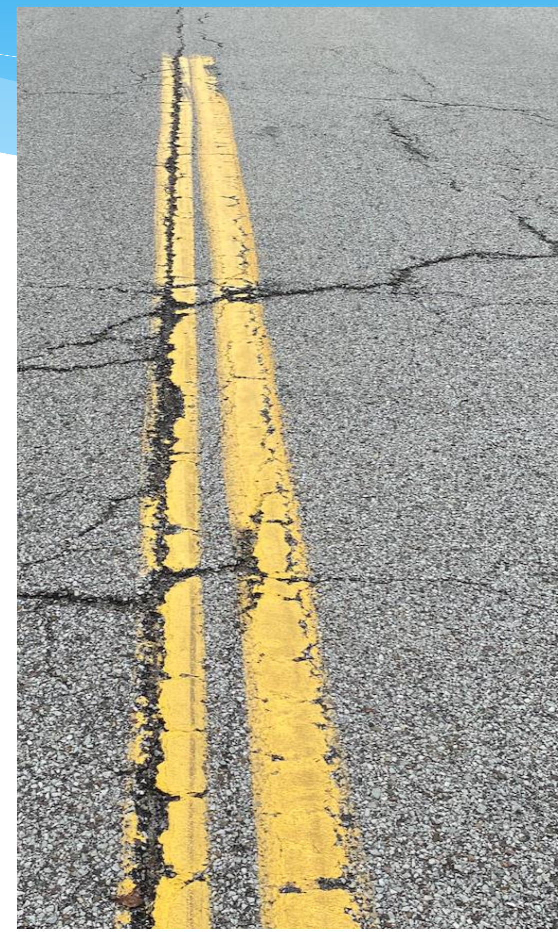
Project Objectives

- ❑ Investigate pavement surface deterioration related to pavement markings

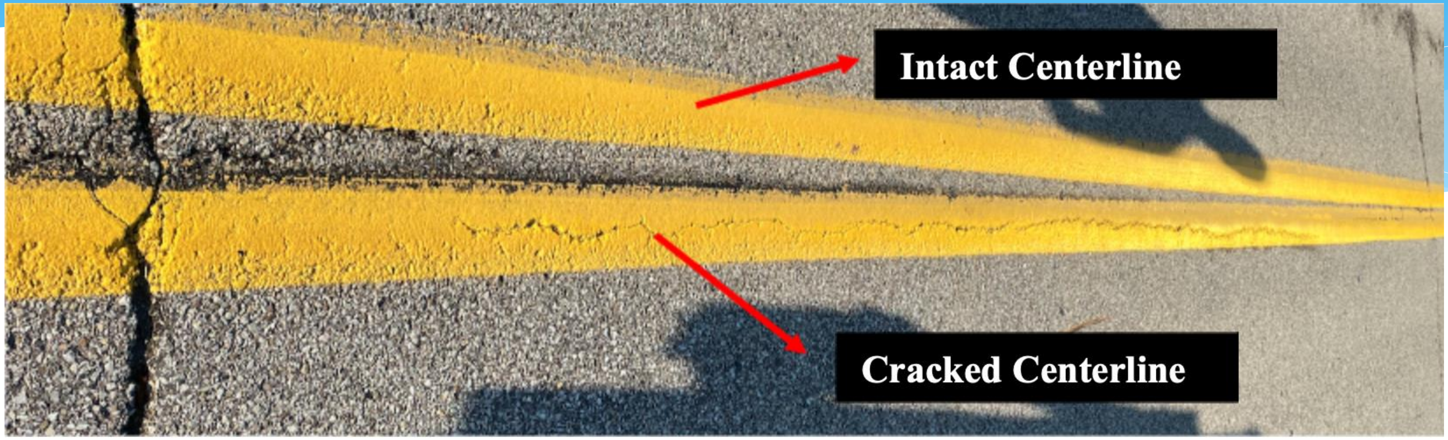
- ❑ Develop approaches to mitigate the issues

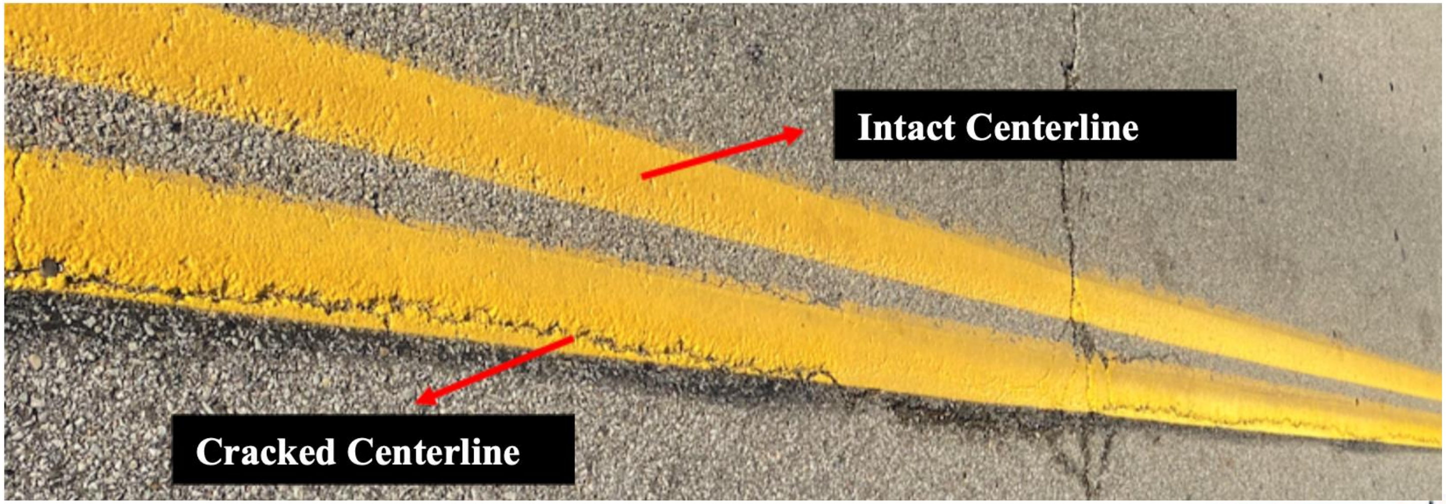
Visual Surveys

- PennDOT
- Allegheny County



Visual Surveys

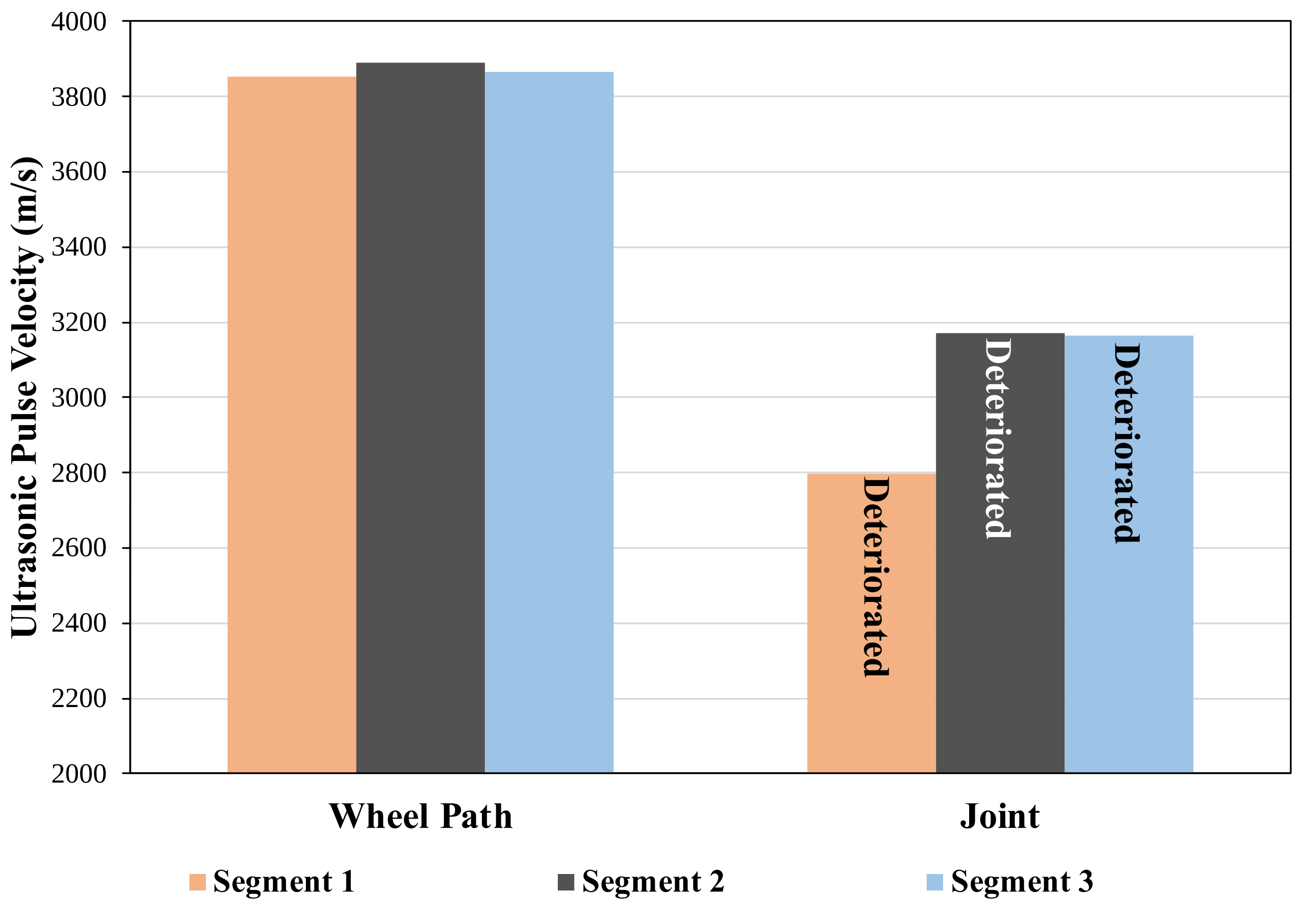




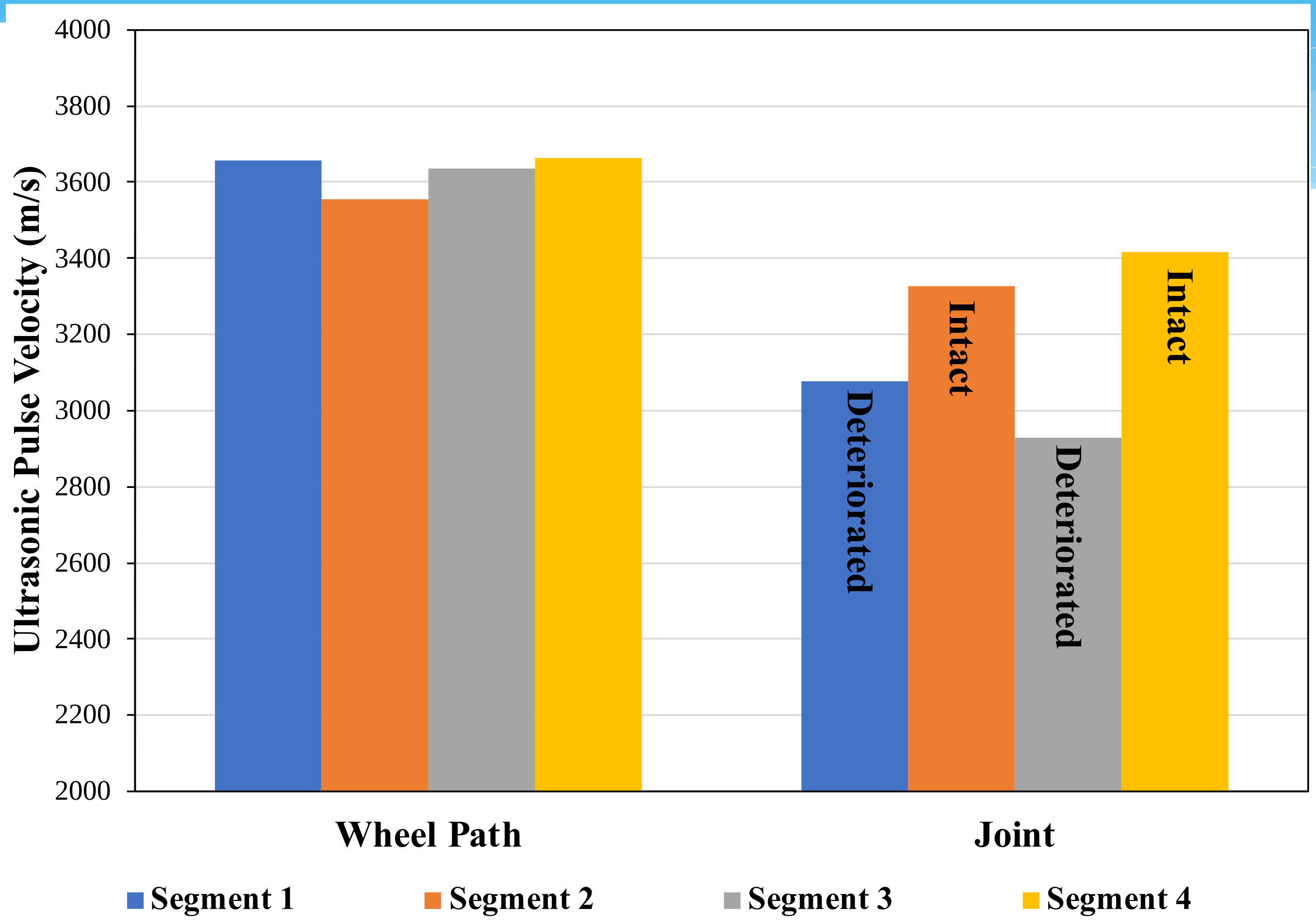
Non-Destructive Testing

- ❑Ultrasonic Testing
- ❑Measure Pulse Velocity
- ❑Related to stiffness, density

Non-Destructive Testing

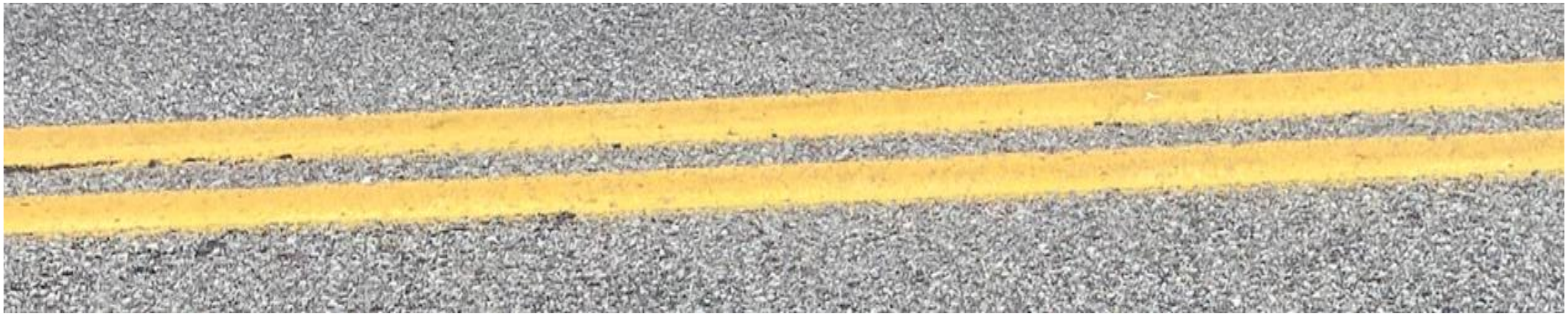


Non-Destructive Testing



Non-Destructive Testing

Deteriorated Joint



Intact Joint

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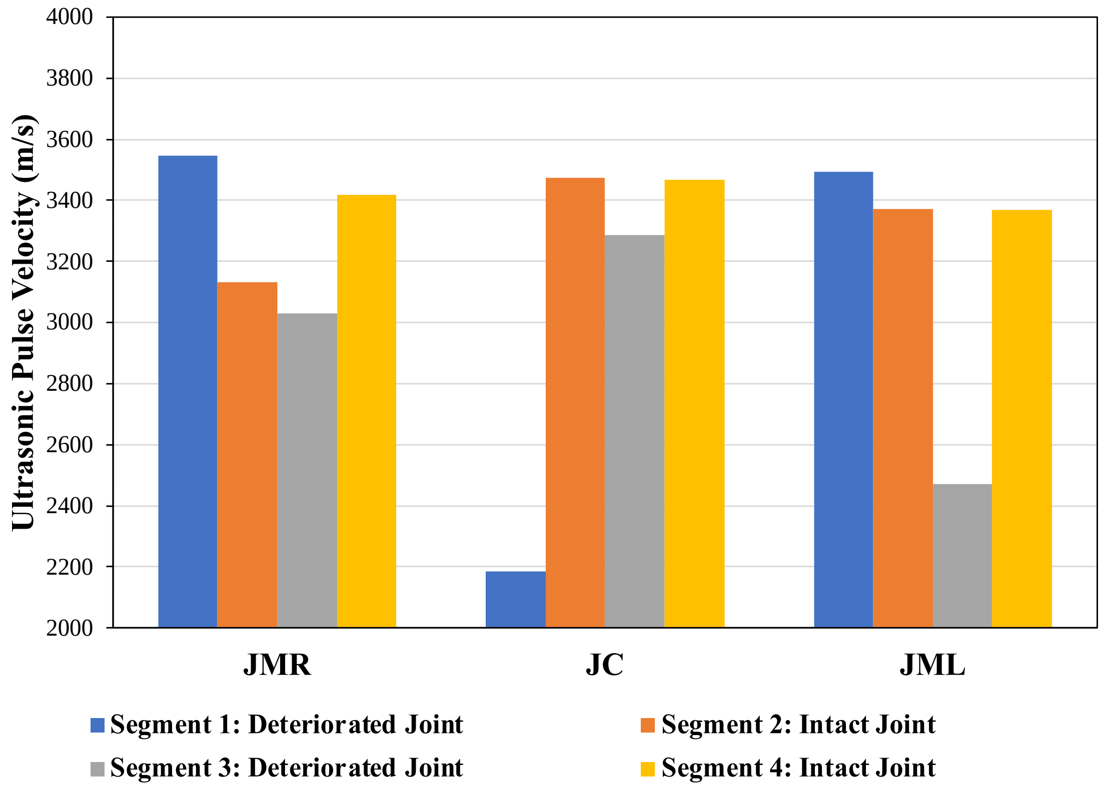
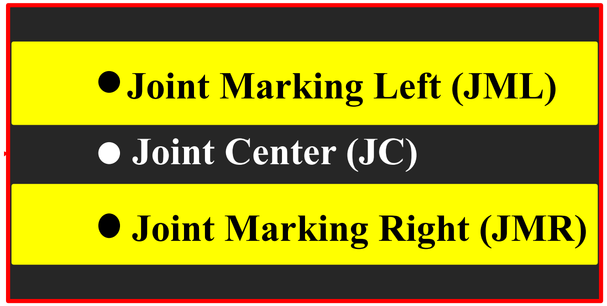
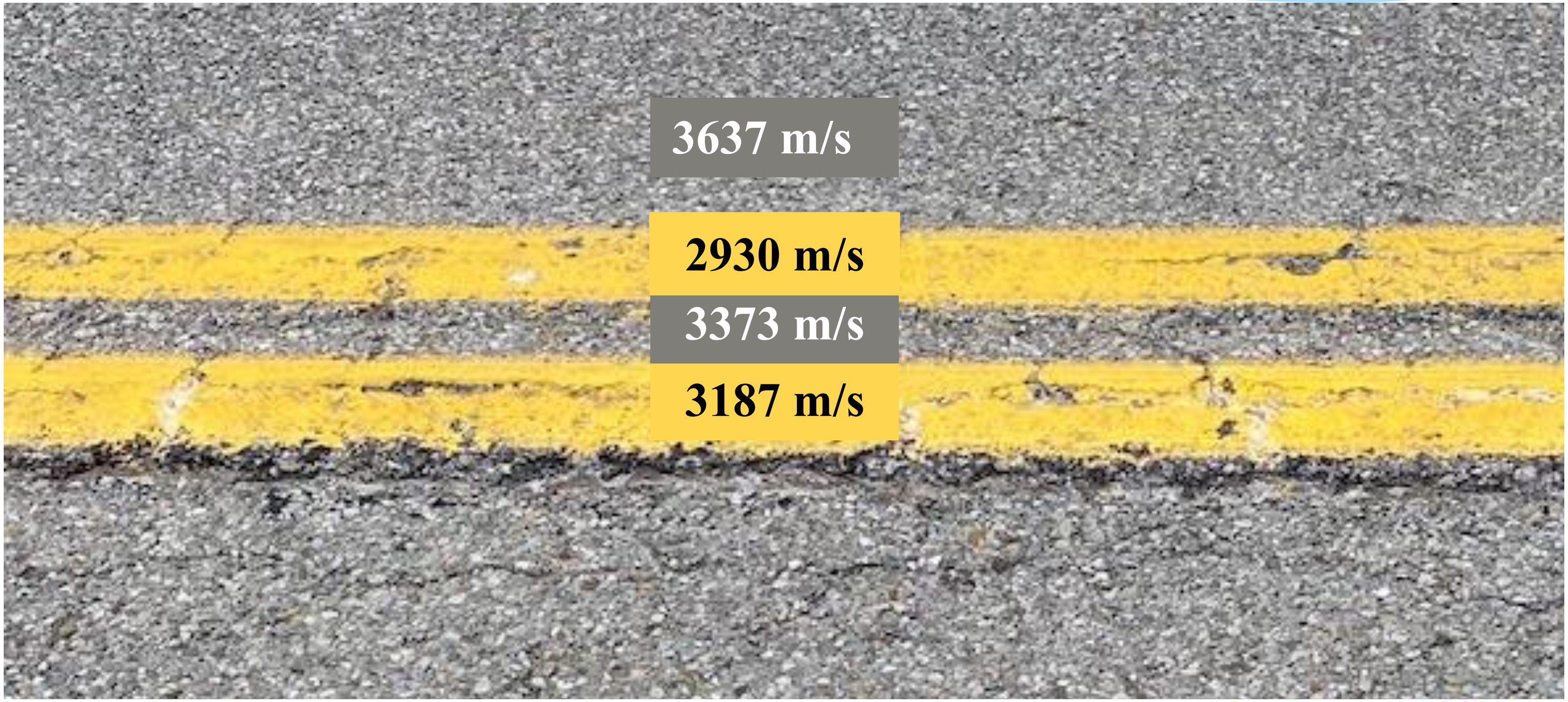
Non-Destructive Testing

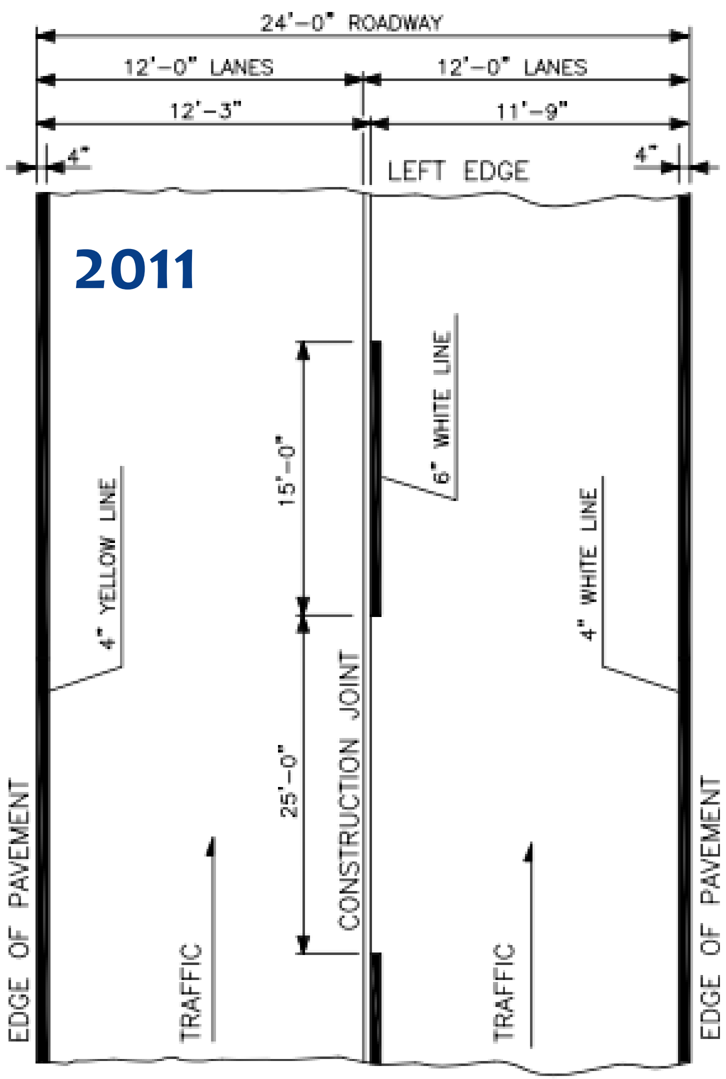


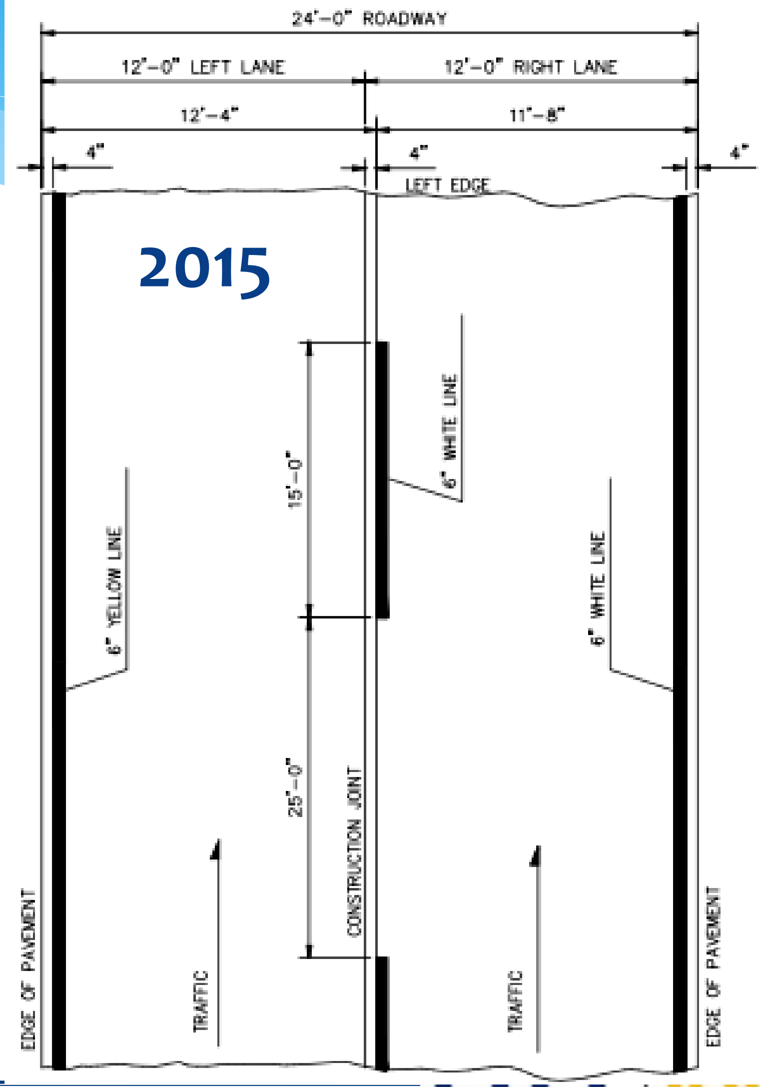


Non-Destructive Testing



Turnpike Commission





Project Status

- Task C (FE simulation of temperature differences effects)
- Task D (Mitigation Strategies)
- Final Report due September 2022

Remote-Controlled Technology Assessment for Safer Pavement Construction and QA/QC

Lucio Salles, Lev Khazanovich

IRISE ANNUAL MEETING

MAY 25, 2022

The Problem

- Pavement Construction, Inspection and Maintenance often require active workers' presence at the construction site

- Increases the potential for accidents due to traffic interaction

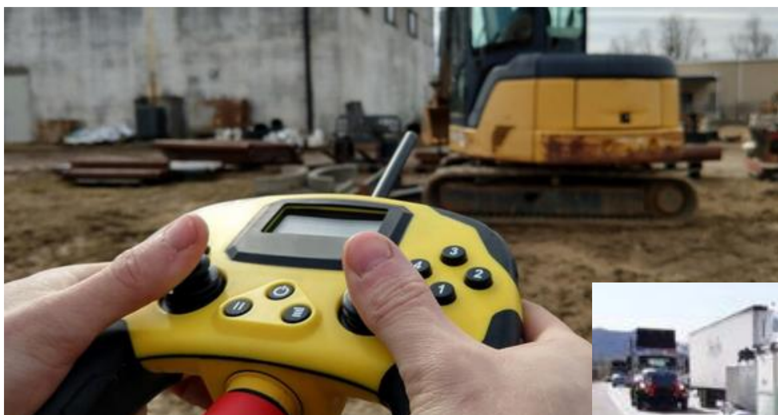
Project Objectives

- Recent developments in drones, robotics, artificial intelligence, and other remote-controlled related areas

- Identify and review new and emerging remote-controlled processes with focus on pavement construction and QA/QC

Tech Scan

- Over 20 potential technologies identified for pavement construction, inspection and maintenance



3 Selected Technologies

- #1 - Remote-Controlled GPR for Asphalt Density

3 Selected Technologies

- #2 - Automated Real-Time Thermal Profiling for Asphalt Paving

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3 Selected Technologies

- #3 - Work Zone safety: Autonomous Impact Protection Vehicle

Technology Transfer Workshops

- AIPV – April 2022

- DPS & Thermal Profiling – Yesterday!!

Project Status

- ❑Task C (Workshop)
- ❑Task D (Final Recommendations)
- ❑Final Report due July 2022

Investigating New Underground Utility Location Technologies and Novel Methods to Improve the Safety and Efficiency of Highway Construction

Lev Khazanovich

IRISE ANNUAL MEETING

MAY 25, 2022

The Problem

- Precise location of underground utilities is a major challenge for highway design and construction

- In many instances, position of the utilities is unknown or incompatible with existing records

Project Objectives

- To investigate emerging technologies that could more accurately determine lateral position and depth of both known and unknown utilities to improve safety and optimize schedules for highway construction

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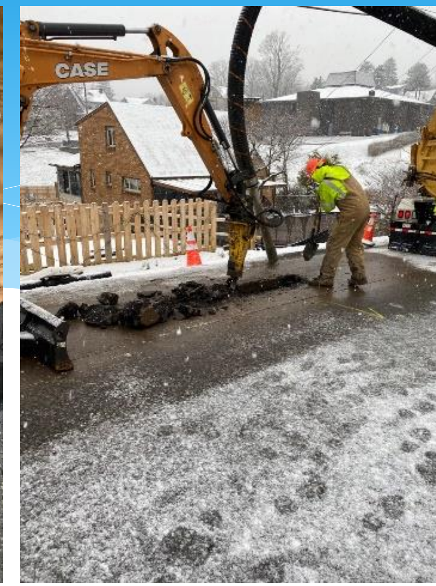
Current Practices

- Highly dependable on tracer wires and pavement marks

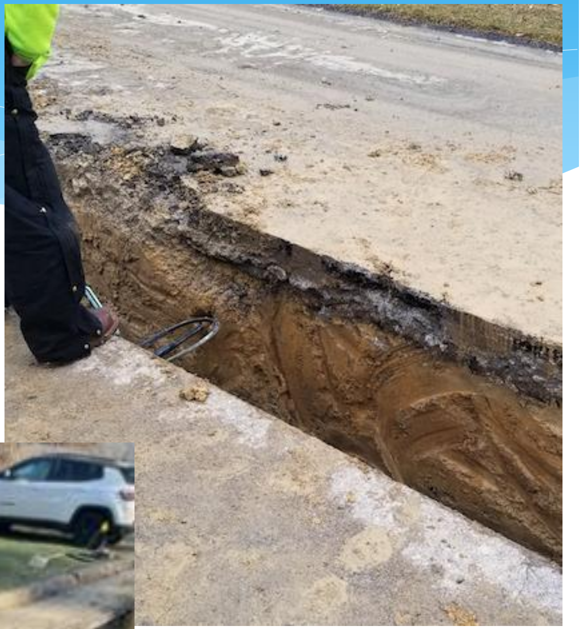
- Use expensive vacuum truck





Common & Challenging Scenarios

- Unmarked cables
- Abandoned lines
- Plastic conductors
- Unreliable depth data
- Utilities in various subgrade materials



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Technology Scanning

- Provide fast, accurate and easy to interpret results.
- Provide accurate lateral and depth information of underground utilities.
- Locate plastic pipes with and without tracer wires.
- Scan a whole project segment in case of potential unmarked or abandoned utilities.
- Present accurate results in various subgrade materials, especially considering Pennsylvania's "blue slab" subgrade.

Project Status

- Task B (scanning for promising technologies)
- Task C (side-by-side field testing of selected technologies)
- Final Report due in January 2023

Identifying the Major Causes of Work Zone Accidents and Health Hazards in the Highway Industry

Lev Khazanovich

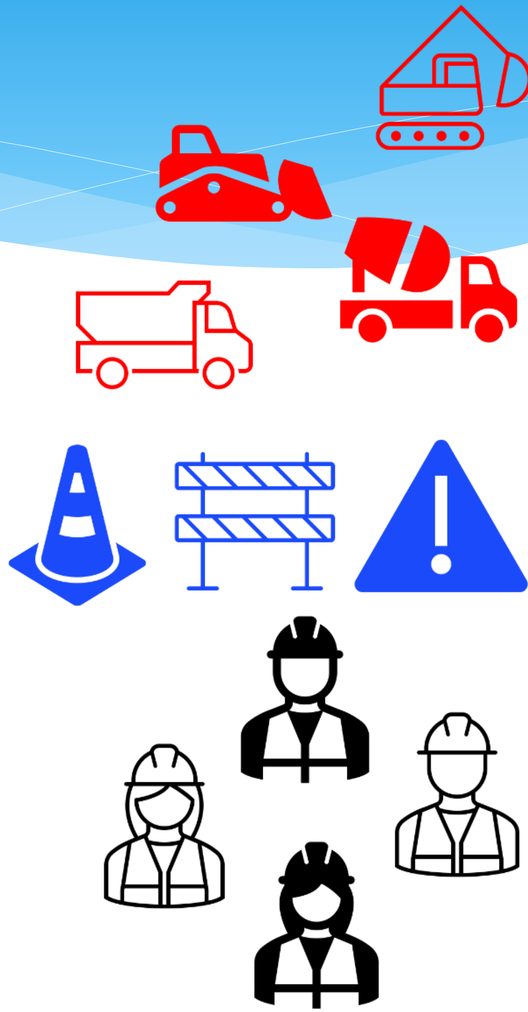
IRISE ANNUAL MEETING

MAY 25, 2022

The Problem

- Accidents, health hazards, and near-misses in construction work zones are complex events caused by a variety of issues

- Research is heavily focused on building construction



Project Objectives

- Identify the very specific activities and scenarios that cause accidents, health hazards and near-misses in the highway industry

- Develop safety database to inform safety-related actions

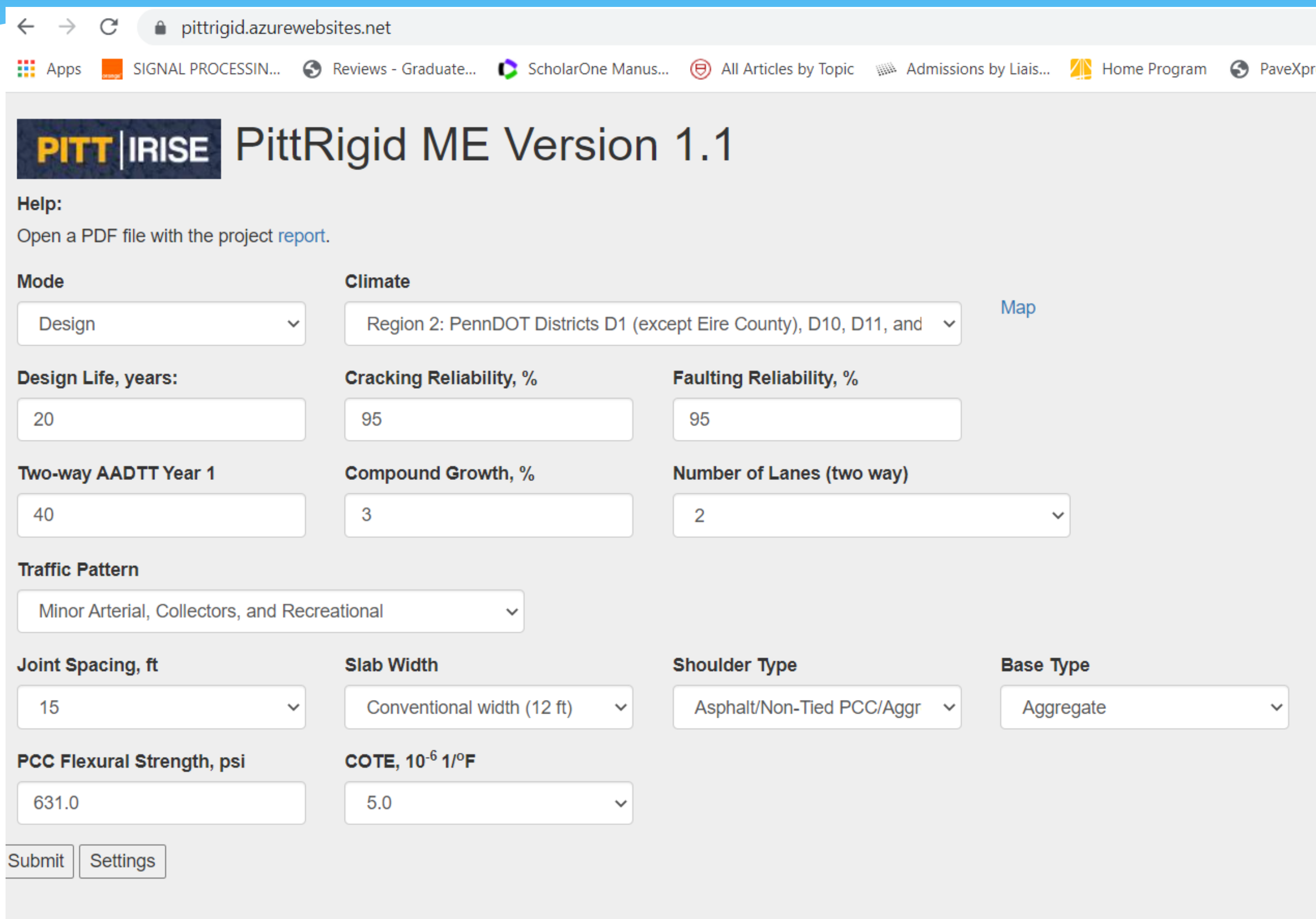
Data Collection

- National and State agencies
- Insurance companies
- Contractors
- Unions
- Construction associations

Project Status

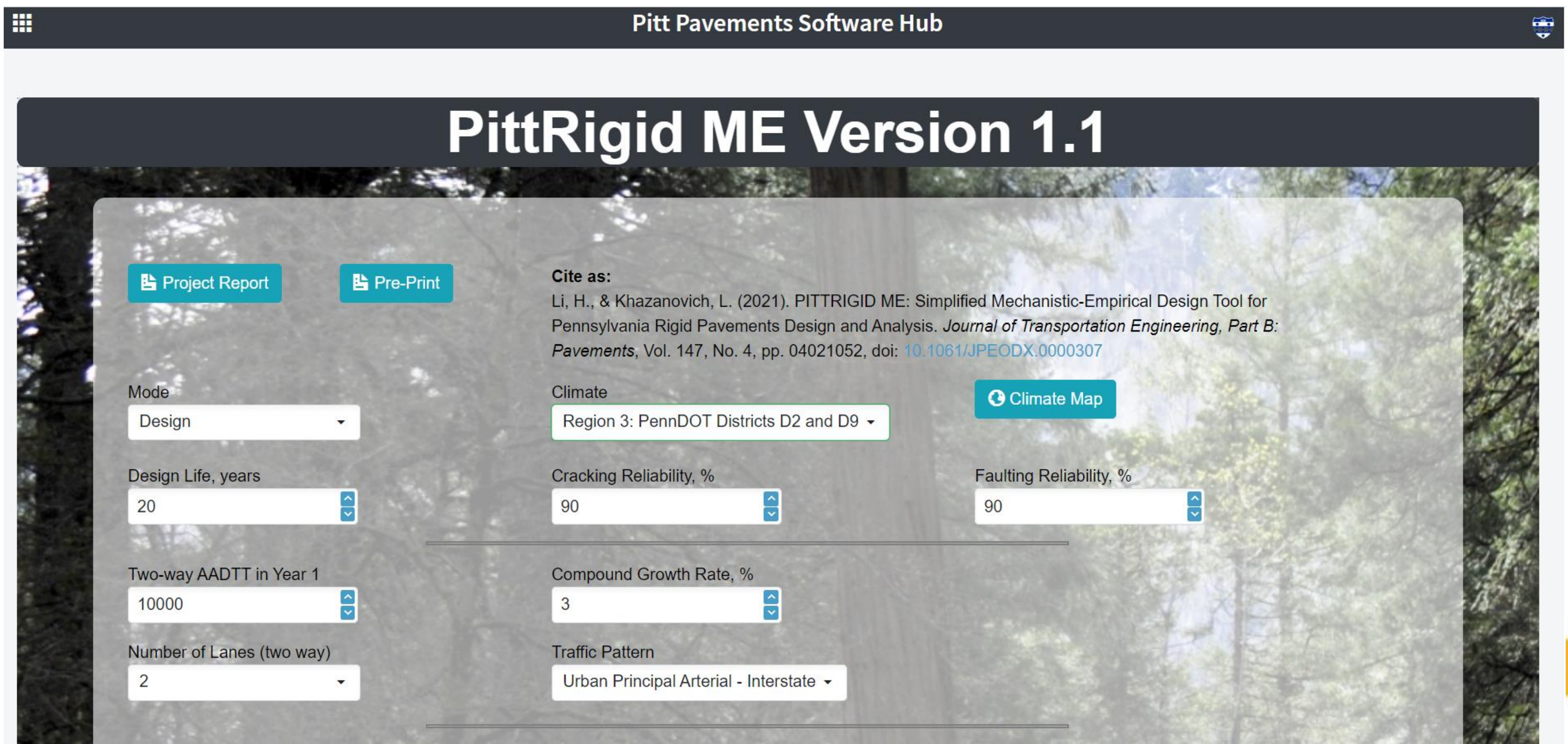
- Project just started
- Technical Panel kick-off meeting (nominations?)

Past IRISE Project: PittRIGID ME



PittRIGID ME Improvements

- ❑ Added a new faulting model
- ❑ Revised website



Landslides Best Practices

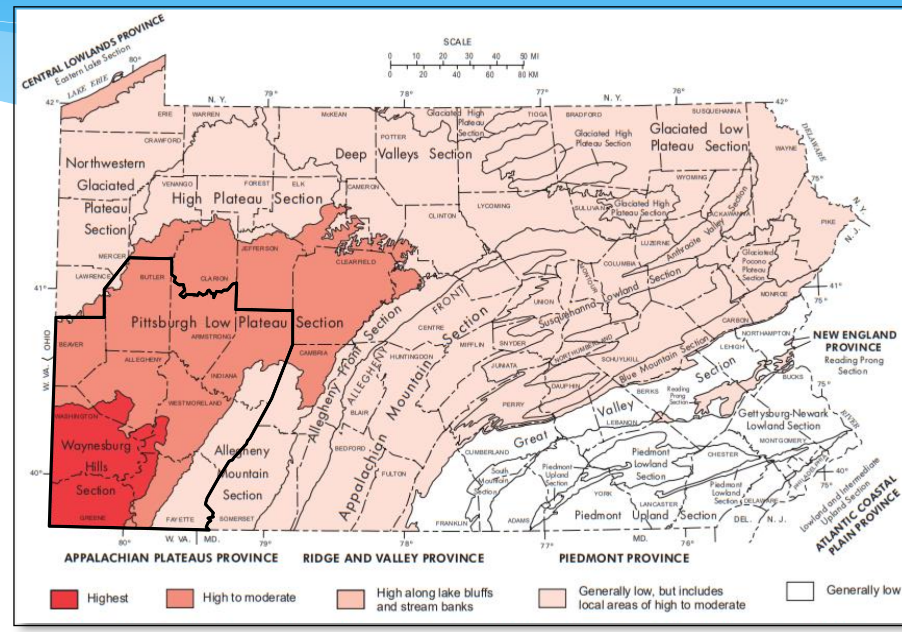
Fatma Ciloglu, Ph.D., P.E.

IRISE ANNUAL MEETING

MAY 25, 2022

Project Objectives

- Establish fundamental guidelines to characterize type and form of landslide impacting southwestern PA infrastructure, assess hazards and take corrective action within the framework of "best practices"
- Identify proven/long-term or reliable design approach(es) as well as innovative construction methods and materials that will provide a more resilient infrastructure system



(Delano and Wilshusen 2001)

- Bring forth emerging technology being used in other regions to mitigate landslides
- To identify challenges in design procedures and permitting processes and improvements needed in current design and permitting procedures and procurement practices.

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Project Approach/Deliverables

Produce Region-specific Best Practices document targeting Geotechnical practitioners and agencies who are familiar with the geologic setting in Southwestern Pennsylvania

- Establish fundamental guidelines to characterize type and form of landslide, assess hazards and take corrective action within the framework of "best practices"
- Identify proven/long-term or reliable design approach(es) as well as innovative construction methods and materials that will provide a more resilient infrastructure system
- Bring forth emerging technology being used in other regions to mitigate landslides
- Make distinction about acceptable consequences to tailor solutions to the target audience
- Final Best Practices Document and interim quarterly submission of the working material

Landslide Mitigation Flowchart

Unstable Slope is Identified – Time to Respond

Site Reconnaissance

CHAPTERS 2, 4 & 5

- Complete Field Checklist
- Identify scope and urgency of project
- Identify key geologic and topographic features
- Identify site constraints such as existing infrastructure, utilities, proximity to ROW/property line, etc.
- Determine likely mode of failure

Desktop Study

CHAPTERS 3, 4 & 5

- Review available geologic, historic, landslide, mining and topographic information
- Identify any presence of problematic geologic units (e.g., redbeds, etc.) or colluvium (historic slides)
- Review historic aerial photographs to document history of slope movement
- Request maintenance records if available
- Identify sensitive features in proximity to slide (e.g., utilities, structures, roadway, etc.)

Subsurface Investigation

CHAPTERS 4, 5, 6 & 7

- Prepare/execute an Exploration Plan
- Drill test borings and excavate test pits to characterize subsurface conditions and assess the extent of the slide
- Perform a laboratory investigation to aid in classification of soils encountered and determine engineering properties for analysis and design

Instrumentation and Monitoring

CHAPTER 6

- Depending on the urgency or impact of the unstable slope, this may be performed prior to the subsurface investigation
- Install instrumentation to monitor piezometric conditions and/or slope movement

Analysis and Design

CHAPTERS 5, 10, & 12

- Use data obtained to develop subsurface section(s), define the extent of the slide mass and mode of instability, and assess rate and magnitude of movement
- Perform engineering analyses and conduct a detailed alternatives analysis
- Complete design and prepare construction documents

Identify Preferred Solution(s)

CHAPTERS 10 & 11

- Select the preferred alternative to repair/stabilize the slope with the client considering:
  - Effectiveness;
  - Acceptable Risk;
  - Economic Constraints;
  - Impact to the public and environment; and
  - Time constraints (e.g., urgency)

Construction

CHAPTERS 6, 8, & 12

- Execute plans to mitigate/repair/ stabilize landslide
- Monitor the site closely to ensure construction activities are not triggering additional slope movement
- Ensure surface water and groundwater are managed during construction

Post Construction Monitoring

CHAPTER 6

- Use instrumentation and/or regular site visits to verify successful execution to stabilize slope
- Confirm implemented mitigation, stabilization or repair is performing as designed

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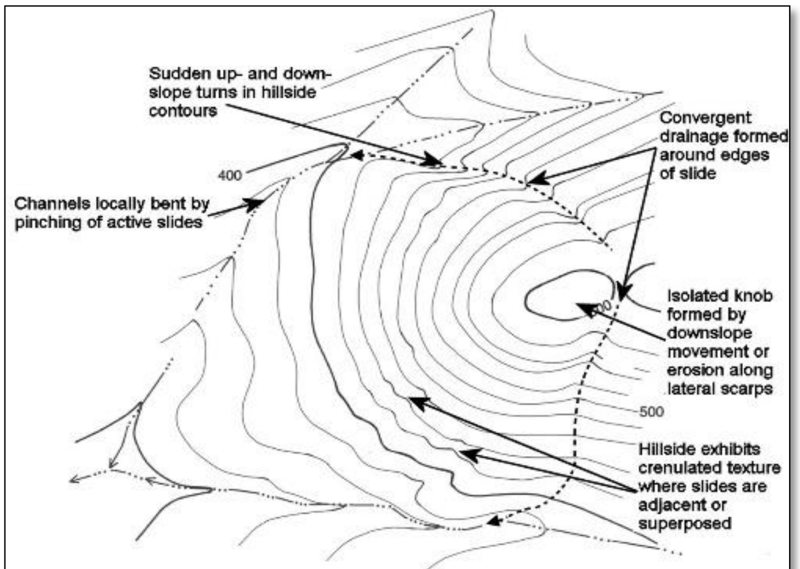
Desktop Study/Site Reconnaissance

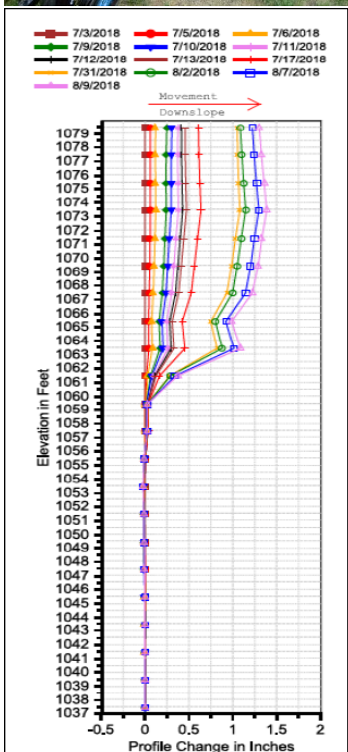


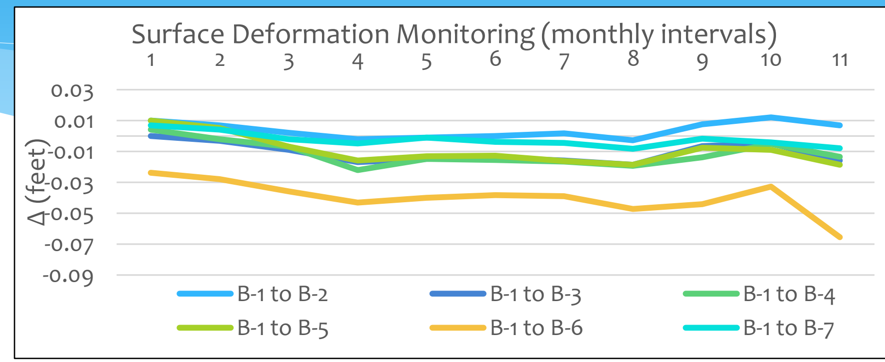
- Review of available data and mapping in the region to identify landslide prone areas
- Use data to develop potential triggers or modes of failure

Subsurface Investigation

- Use data obtained during desktop study to perform a purpose driven subsurface investigation; samples for laboratory testing, water level readings, and any instrumental will be installed during the investigation
- Once complete, detail subsurface sections will be derived to serve as the basis of design

Instrumentation & Monitoring

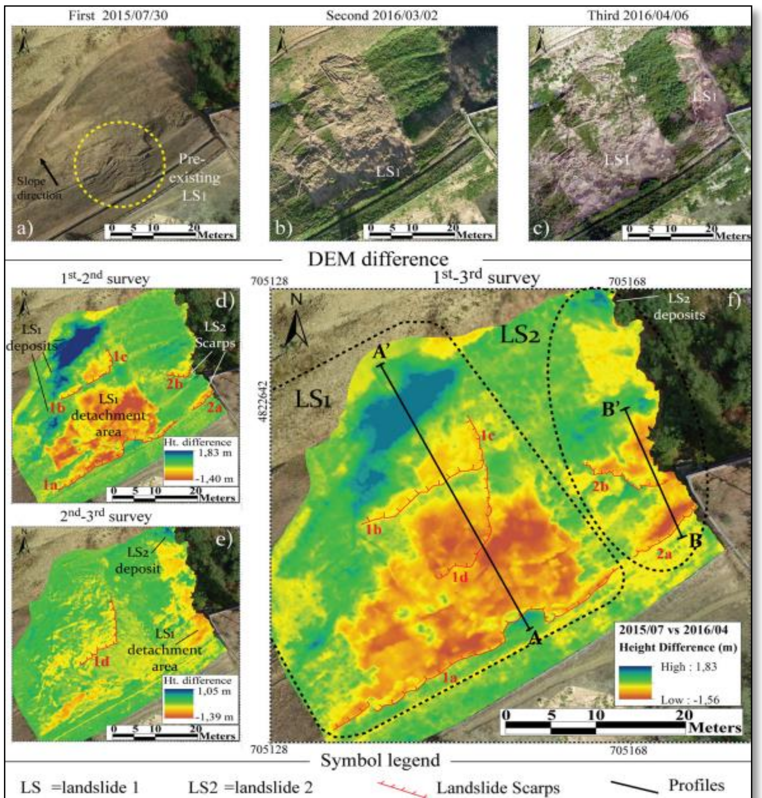


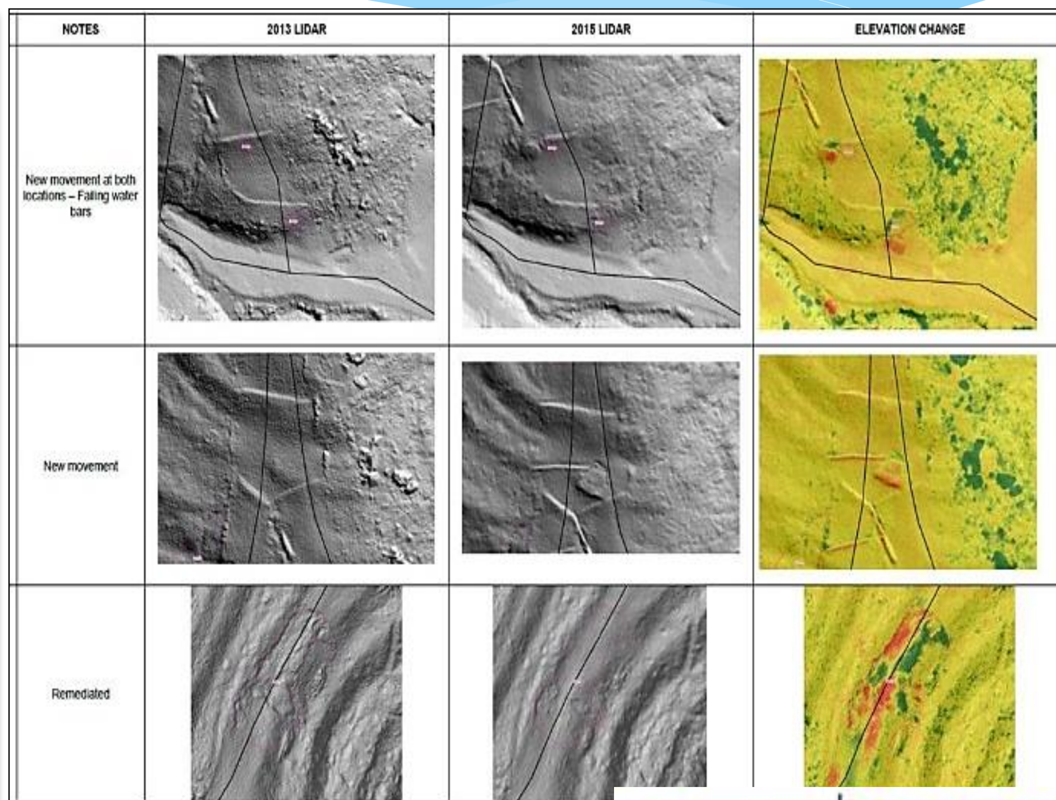


- ❑ Overview of common instrumentation for landslide monitoring including:
  - ❑ Surface Monitoring via conventional survey
  - ❑ Inclinometers
  - ❑ Tiltmeters
  - ❑ Crack Gauges
  - ❑ Piezometers
- ❑ Description, use, costs, and installation considerations
- ❑ Data Reduction and Forecasting

Instrumentation & Monitoring

- Emerging technology including LiDAR and UAV's





(Rossi, 2018)

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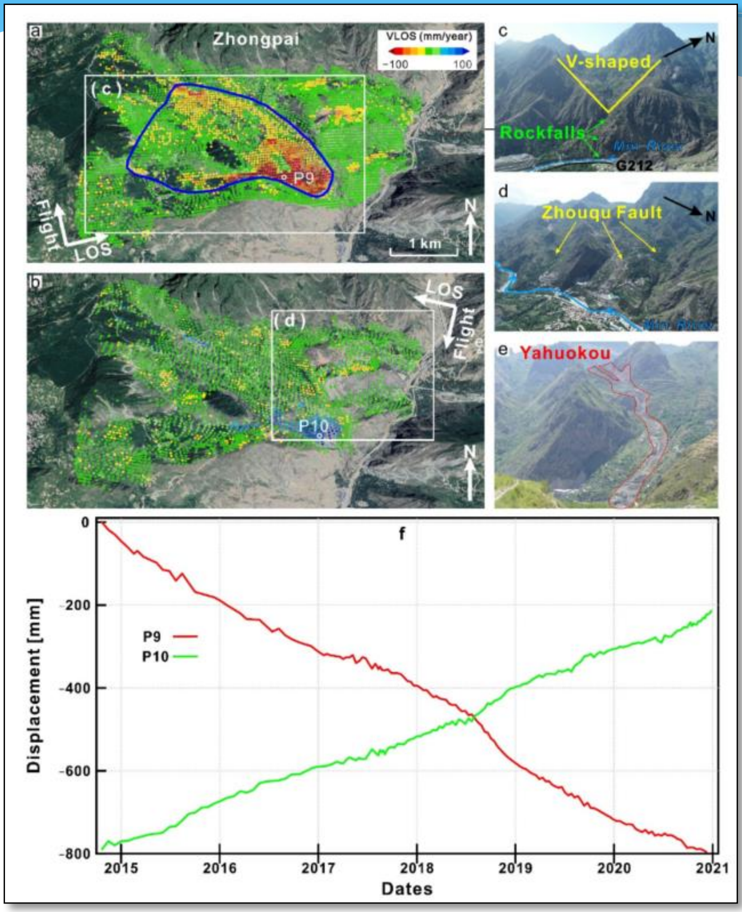
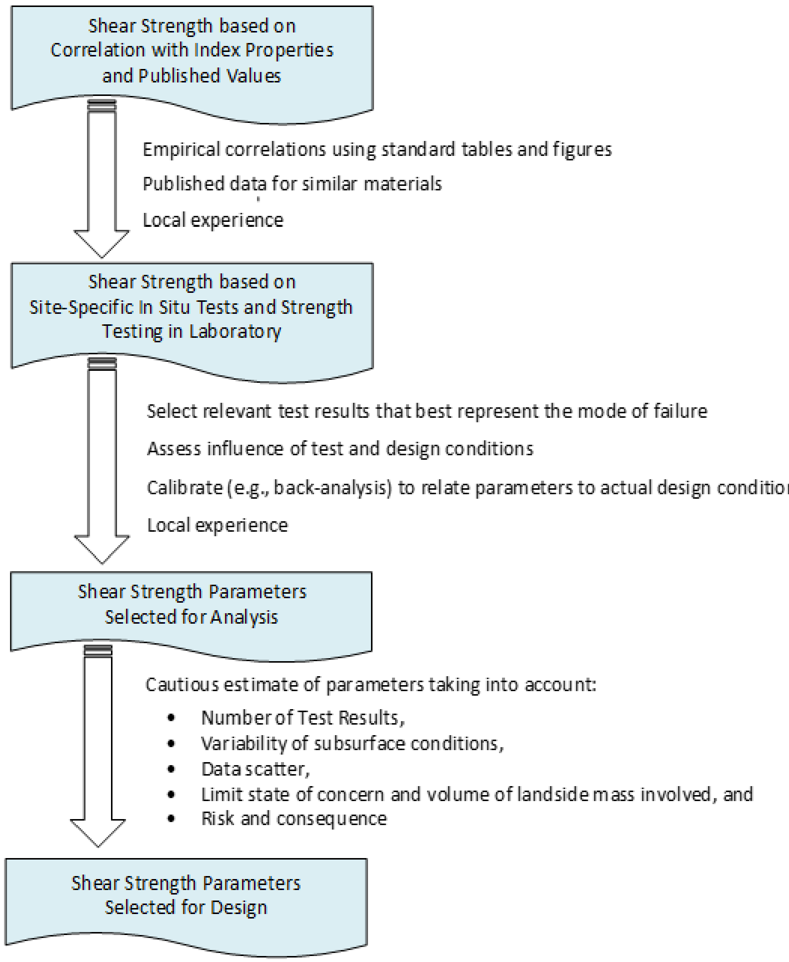
Instrumentation & Monitoring



(Liu et. al, 2022)

- Emerging technology for remote satellite monitoring including inSAR

Laboratory Testing



- Overview of index property and shear strength testing to inform parameter development
- Coworking relationship between practitioner and laboratory
- Data verification

Slope Maintenance

Category	Feature	Documentation Method	Documentation Effort
Surface Drainage	Drainage Channels	• Field survey • Drone Survey	• visual observations including measurements (size of cracks of surface depressions) • ground/air photos
Subsurface Drainage	Seeps	• Field survey • Drone Survey	• visual observations • measurements (size, flow rate) • sketches • ground/air photos
	Drainage Systems	• Field survey	• Visual observations • Downhole camera to document discontinuities
Surface Maintenance/ Erosion Control	Surface deformation and erosion	• Field survey • Drone Survey • LiDAR	• visual observations including • measurements (size of cracks or surface depressions, changes in grade) • sketches • ground/air photos
	Structural integrity of fences and homes	• Field survey	• visual observations • measurements (displacement, tilt, cracking) • ground photos
Surcharge Loading	Excess Loading at Slope Crest	• Field survey • Drone Survey • LiDAR	• visual observations including approximate size and type of loading • sketches • ground/air photos
Toe Support Loss	Erosion at toe from natural waterways or surface drainage	• Field survey • Drone Survey • LiDAR	• visual observations • measurements (approximate volume of toe loss) • sketches • ground/air photos

- ❑ Maintenance practices to record and remediate deficient surface
- ❑ Documentation effort to track at slopes

Overgrown Roadway Ditch with Ponded Water

Cleared Ditch to Maintain Positive Drainage

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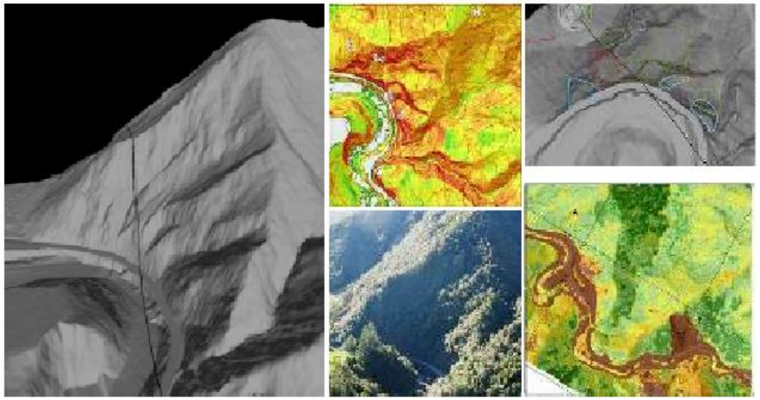
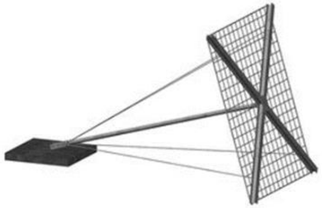
Next Steps
Slope (Asset) Management

- Avoidance – Land Use Planning
- Characterize Hazard, Vulnerability, & Risk
- Slope Hazard Rating
- Landslide Inventory(ies)
- Data Management
- Decision Making Matrix
- Risk Reduction (knowledge-based action)
- Emergency Response vs. Planned Improvement



Next Steps
Stabilization & Repair Methods



- ✓ Drainage Improvement
- ✓ Vegetation
- ✓ Earthwork: Buttressing, Slope Regrading, Unloading
- ✓ Physical Restraint: Retaining Walls, Soil Nailing, Soil Launcher
- ✓ Ground Improvement
- ✓ Emerging Technology: Micropile, Geosynthetics (Reinforced Soil Slopes), Wick Drains

Questions and Answers

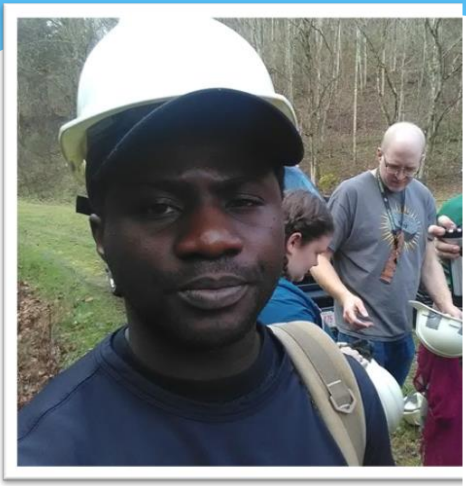
Development of a Roadway Landslide Inventory and Analytical Tool for Southwestern Pennsylvania

Presentation by: Daniel Bain

IRISE ANNUAL MEETING

MAY 25, 2022

Project Team



Abiodun Ayo-Bali

Tyler Rohan

Tony Iannacchione

Emrah Özpolat

Eitan Shelef

Regional Geology, Soils and Changing Climate Elevate Landslide Risk

- During wet years, landslide impacts require substantial funding to address (e.g., ~$127 million spent by PennDOT in 2018, more than 4x a typical year)
- Patterns in landslides are a challenge to recognize with fractured data

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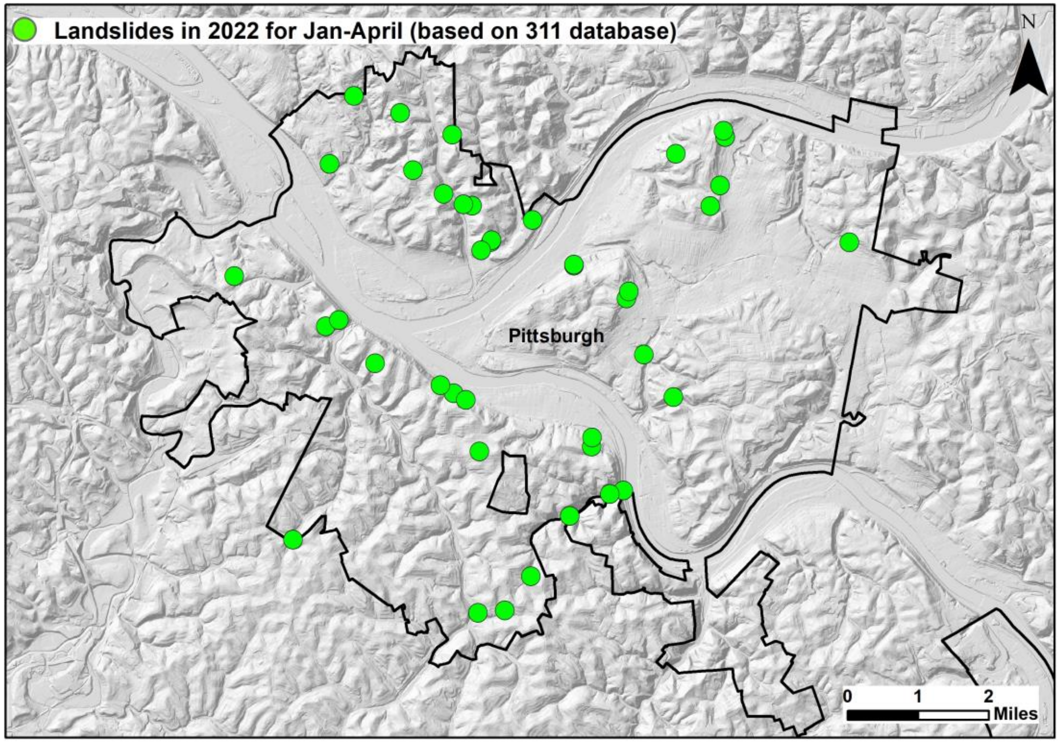
Our Project Aims to Produce an Inventory of Landslides that:

- Amalgamates data from multiple agencies
- Uses a systematic and standardized format
- Effectively addresses the data needs of the interested agencies.



Project Can Be Split Into ~3 phases

Data Discovery, Gathering, etc.

Data Organization & Refinement/ Database Development

Database Structures to IRISE Members

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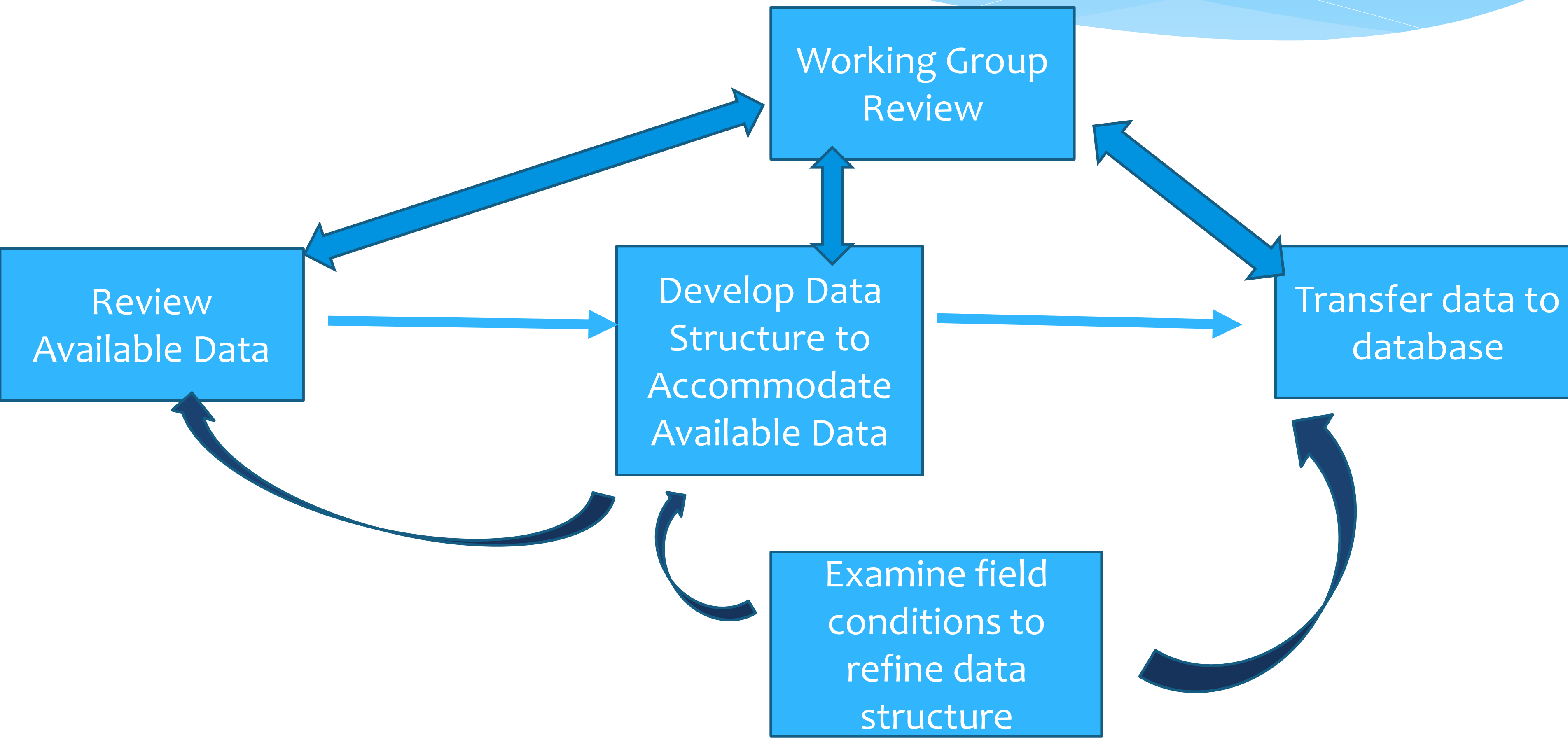
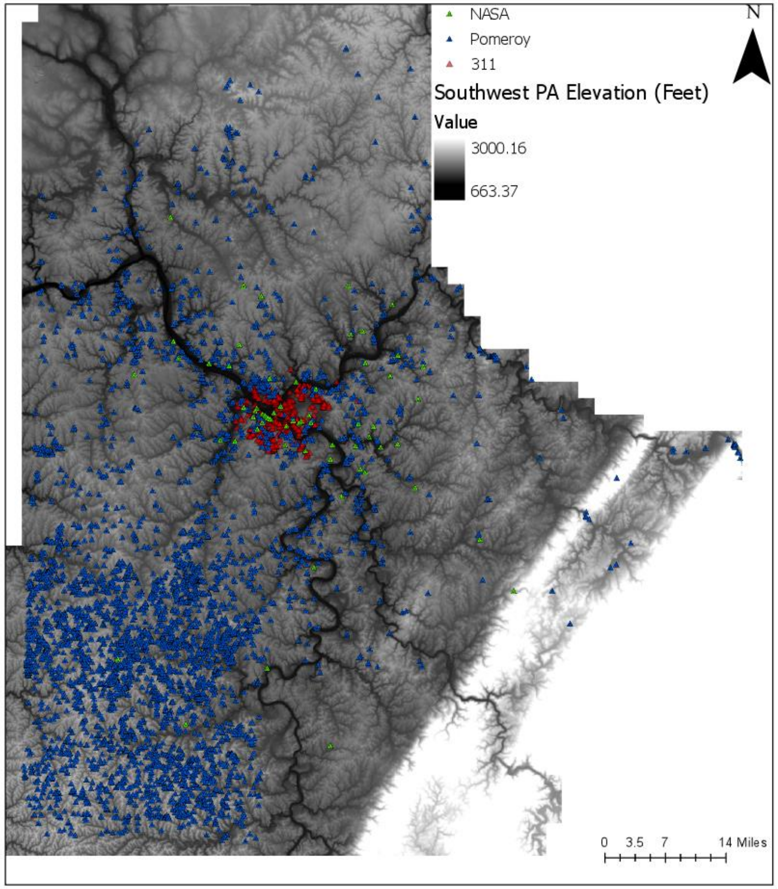
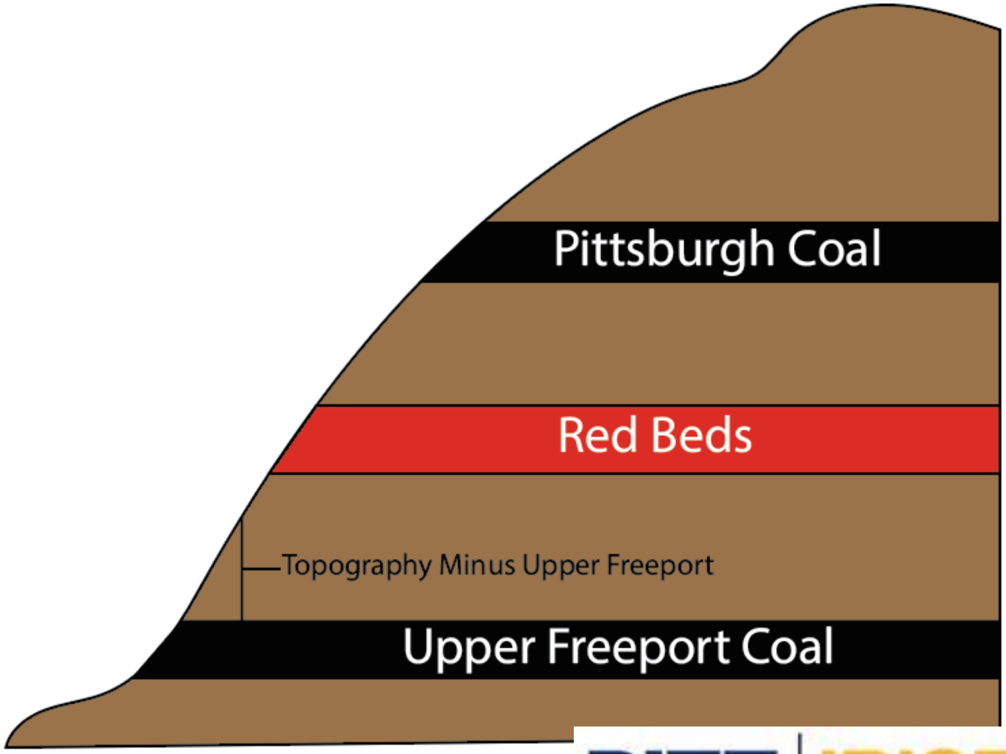
We Currently are in the Data Gathering Phase

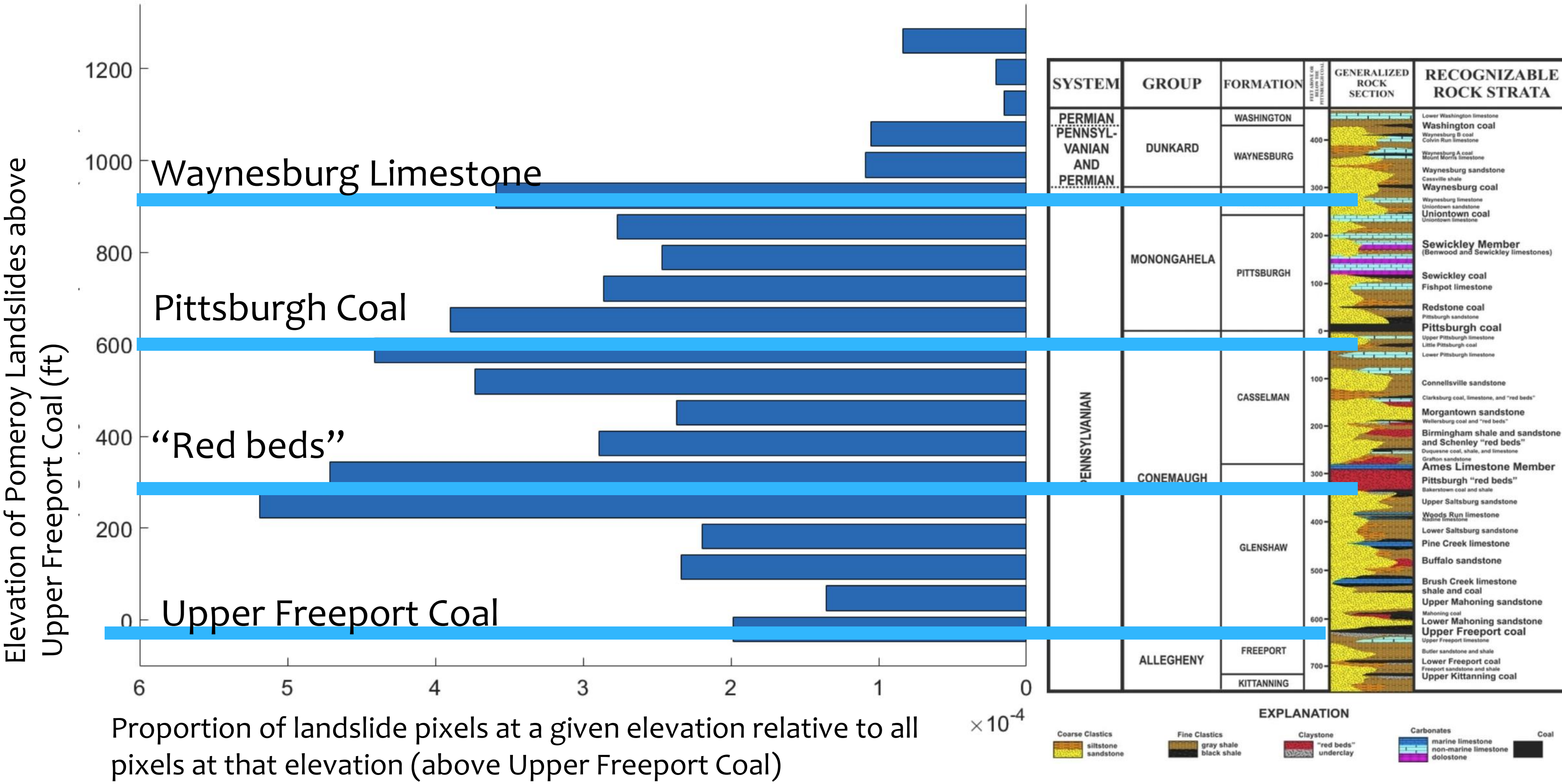


Early applications of our data – Focus on important geologic formations

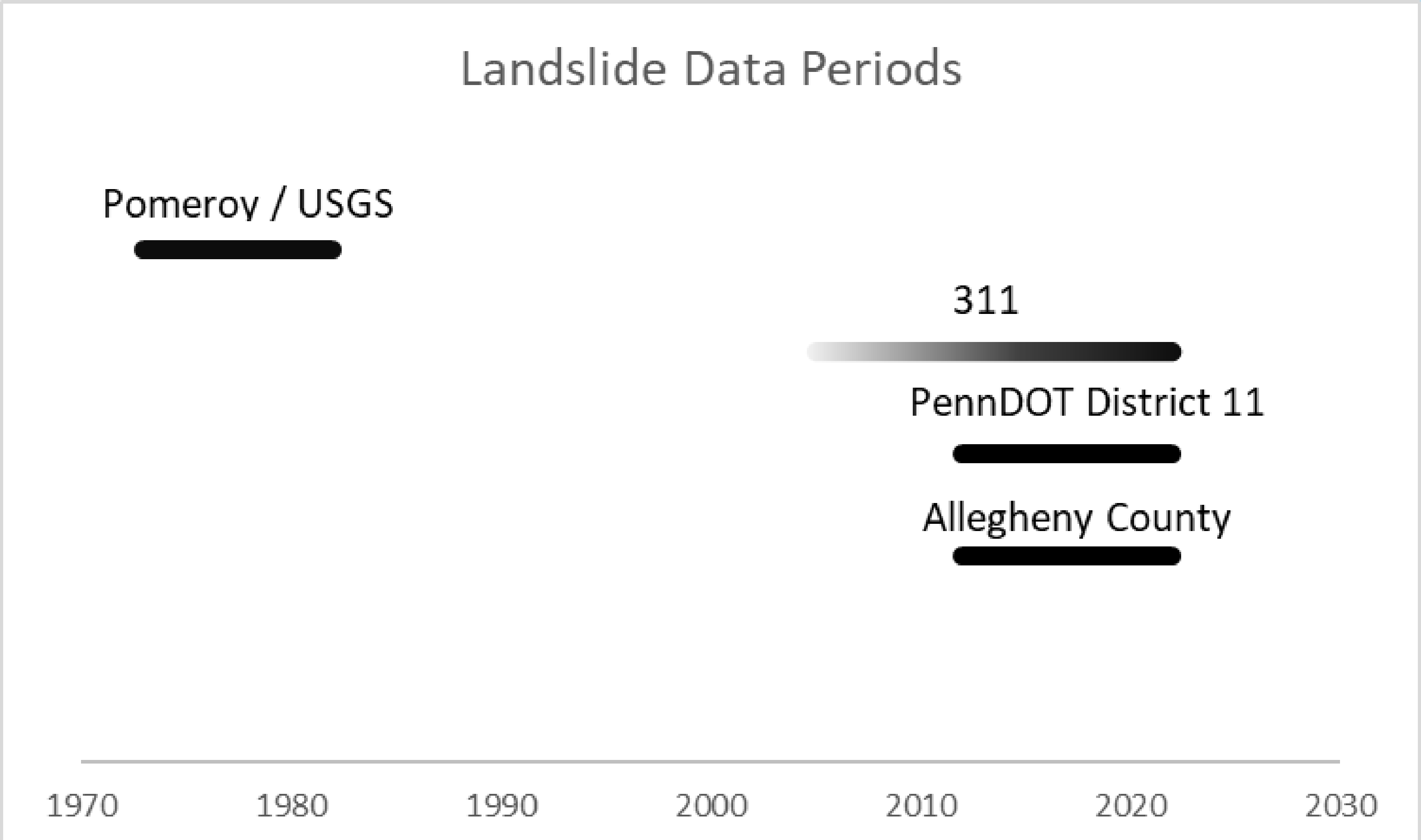




Using the data, we can evaluate the geology

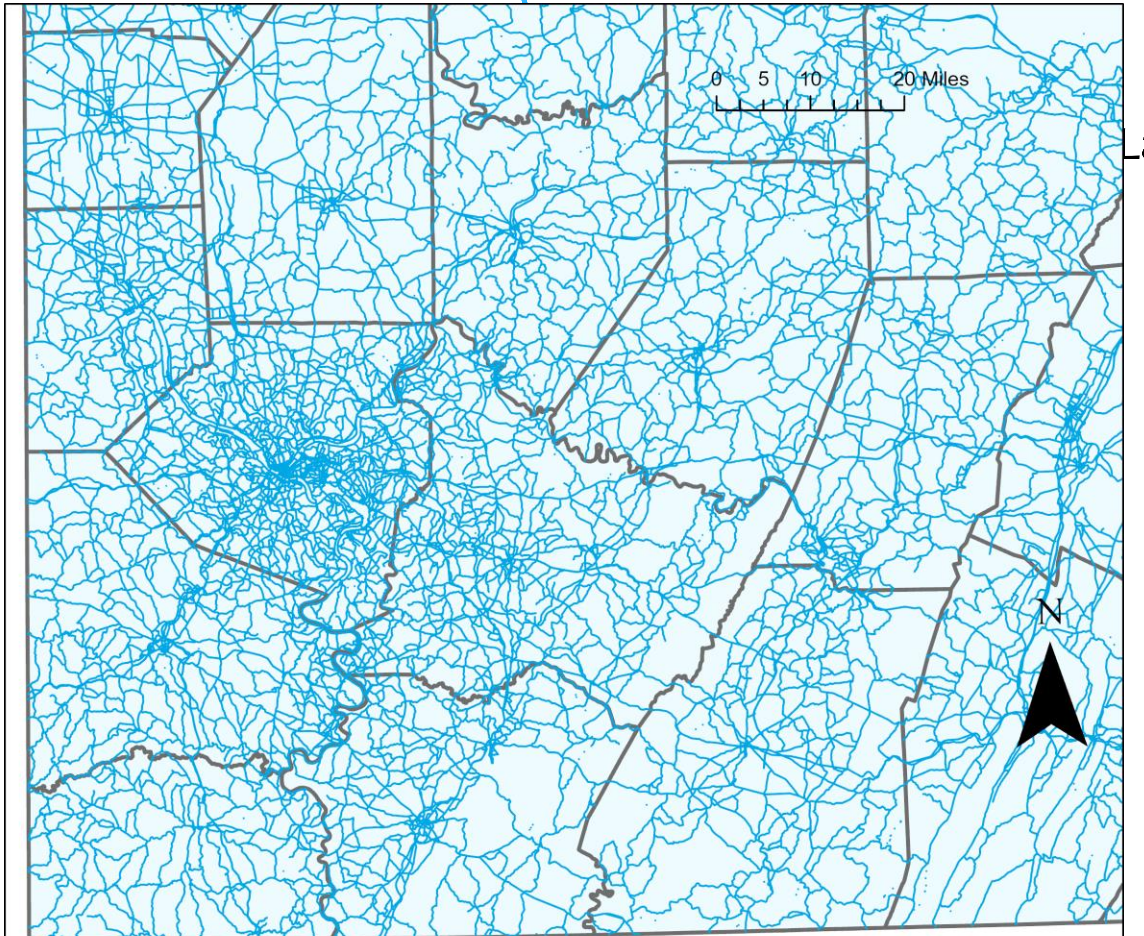


Interesting results, but need to continue to collect modern data



Modern data helps pinpoint road relevant data and focus data collection

Regions ~200-260 ft above Upper Freeport Coal



Landslide

Schedule/Status

Task	1/22 - 3/22	4/22 - 6/22	7/22 - 9/22	10/22 - 12/22	1/23- 3/23	4/23 - 6/23	7/23 - 9/23	10/23 - 12/23
1) Establish working group and convene monthly meetings								
2) Iteratively identify data sources								
3) Gather Data -- Field Visits								
4) Data Organization/Database Development								
5) Draft Database (and associated report)								
6) Final database (and associated report)								

Questions?

Integrating Additive Manufacturing with Accelerated Bridge Construction Techniques

Amir H. Alavi, PhD

IRISE ANNUAL MEETING

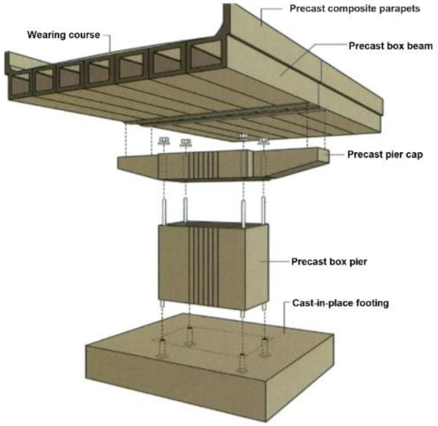
MAY 25, 2022

The Problem

Modular forms of bridge construction have been of continued interest in prefabricated bridge elements and systems (**PBES**)

The Limitations:

- High cost for developing modular forms
- Time consuming and labor intensive
- Construction safety concerns
- Limited customizability



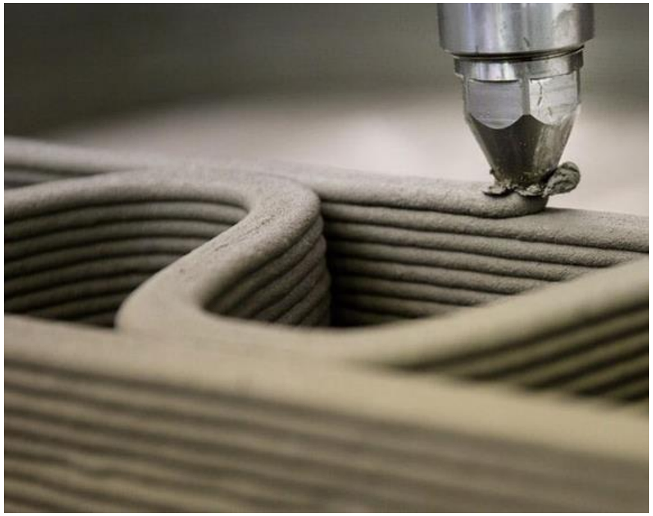
The Needs:

- **Increase the construction quality of PBES**
- **Reduce their construction time and labor cost**
- **Enhance the safety and reliability**
- **Minimize the environmental footprint of the PBES fabrication plants**
- **Produce structural elements with optimized topologies**
- **Enable in-situ repair of existing ABC elements via customizable design**

Project Objectives

Objectives:

- Explore the feasibility of integrating additive manufacturing with ABC techniques in Pennsylvania
- Identifying, fabricating and mechanical testing of a range of 3D printable prefabricated bridge elements currently used in ABC projects



Tasks and Deliverables

Tasks and Deliverables:

- **Task A – Review of the stat-of-the-art of 3D concrete printing research** ✓
- Task B – Identifying optimal 3DCP reinforcement and mixture designs for bridge prefabricated elements ✓
- Task C – 3D printing of prefabricated elements in ABC systems at small-scale
- Task D: Development of Recommendations
- Task E: Final Report

Project Approach

Comprehensive literature review for 3D printable concrete mixture developed has been conducted

Requirements for 3D Printable Concrete Mixture

- **Extrudability:**
  Extrudability is defined as the ability to transport the fresh concrete to a nozzle in the hopper of the extruder as a continuous filament
- **Buildability:**
  Buildability is used to evaluate the ability of fresh 3DPC to bear its own weight, as well as the load of concrete from above layers, without collapse during printing
- **Mechanical Properties:**
  Mechanical properties of 3DPC are also very important, since they determine the practical application of 3DPC in construction directly

Project Approach

Materials Selection for 3D Printable Concrete Mixture

- **Supplement cementitious materials:**
  SCMs like fly ash, silica fume, limestone filler, and blast furnace slag, are used to partially replacement
- **Admixtures:**
  Viscosity modified agent (VMA) was frequently used in 3DPC to enhance the viscosity and cohesion and then improve the shape stability after extrusion
- **Aggregates:**
  At present, only limited number of studies applied coarse aggregates in 3DPC, most of the researchers printed and studied 3D printed mortar without coarse aggregates

Project Approach

Some Example Mixture Designs

- Ma et al. [1] design
- Malaeb et al. [2] design
- Liu et al. [3] design
- Le et al. [4] design
- Rahul et al. [5] design
- Ivanova et al. [6] design
- Weng et al. [7] design

- Fine aggregate (maximum size of 2mm)
- Maximum size of an aggregate: 1/10 of the diameter of the printing nozzle
- Compressive strength: ~5000-8000 psi
- Fiber-reinforced concrete (12/0.18 mm length/diameter polypropylene micro fibers; Compressive strength: 14500 psi)

1. G. Ma, L. Wang and Y. Ju, "State-of-the-art of 3D printing technology of cementitious material—An emerging technique for construction," *Sci. China Technol,* vol. 61, no. 4, p. 475–495, 2018.
2. Z. Malaeb, H. Hachem, A. Tourbah, T. Maalouf and F. Hamzeh, "3D concrete printing: machine and mix design," *International Journal of Civil, Eng. Technol.,* vol. 6, no. 6, pp. 14-22, 2015.
3. Z. Liu, M. Li, Y. Weng, T. N. Wong and M. J. Tan, " Mixture design approach to optimize the rheological properties of the material used in 3D cementitious material printing," *Constr. Build Mater.,* vol. 198, p. 245–255, 2019.
4. T. Le, S. Austin, S. Lim, R. Buswell, A. Gibb and T. Thorpe, "Mix design and fresh properties for high-performance printing concrete," *Mater. Struct.,* vol. 45, pp. 1221-1232, 2012.
5. A. V. Rahul, M. Santhanam, H. Meena and Z. Ghani, "3D printable concrete: mixture design and test methods," *Cem. Concr. Compos.,* vol. 97, p. 13–23, 2019.
6. I. Ivanova and V. Mechtcherine, "Effects of volume fraction and surface area of aggregates on the static yield stress and structural build-up of fresh concrete," *Materials ,* vol. 13, no. 7, p. 1551, 2020.
7. Y. Weng, M. Li, M. J. Tan and S. Qian, "Design 3D printing cementitious materials via fuller thompson theory and marson-percy model," *Constr. Build Mater,* vol. 163, p. 600–610, 2018.

Project Approach

3D printed concrete

Compressive Strength	1 day	7 days	28 days
	~2900 psi	~5800 psi	~7250 psi
Flexural Strength	~1000 psi (28 days, 77 °F, 17% w/c ratio)		

Standard Concrete

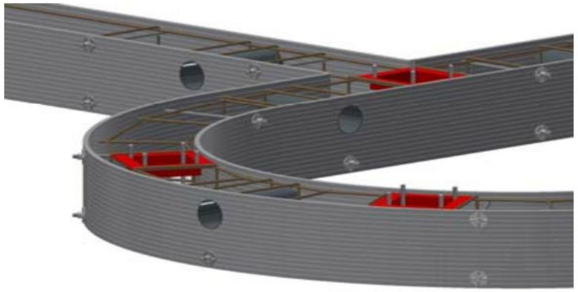
Compressive Strength	28 days
	4000-10000 psi
Flexural Strength	800~1200 psi

Project Approach

Comprehensive literature review for reinforcement strategies has been conducted

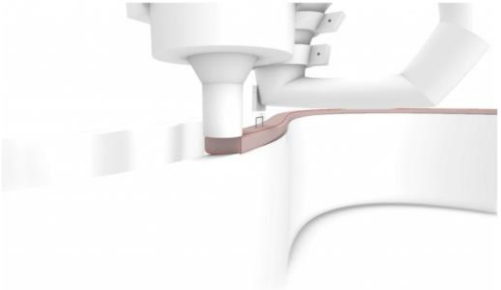
Placing steel reinforcement horizontally between 3d-printed concrete layers

Concrete floor slabs with add-on-printed reinforced ribs

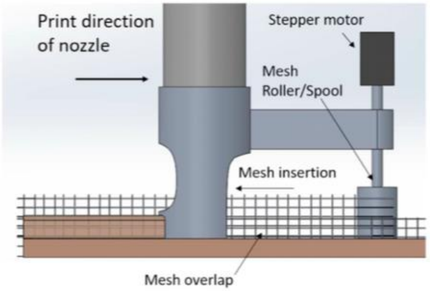


Placing vertical reinforcement in 3D printed formwork

Post-tensioning of steel reinforcement placed in 3D printed conduits



Staple reinforcement while printing



Mesh insertion and embedment using the custom-designed 3D printing nozzle

Project Approach

Machine Setup And Tests

Printer Manufacture: 3D Potter Scara Elite

- 68 inches in Z height and 112 inches in diameter
- Printing 360 degrees with continuous rotation

Pump Manufacture: IMER Small 50 Pump

- Pump up to 3.5 gallons of material per minute through 85 ft of 1″ hose
- Start pumping with the new variable flow rate from 1.7 to 30 cubic feet per hour

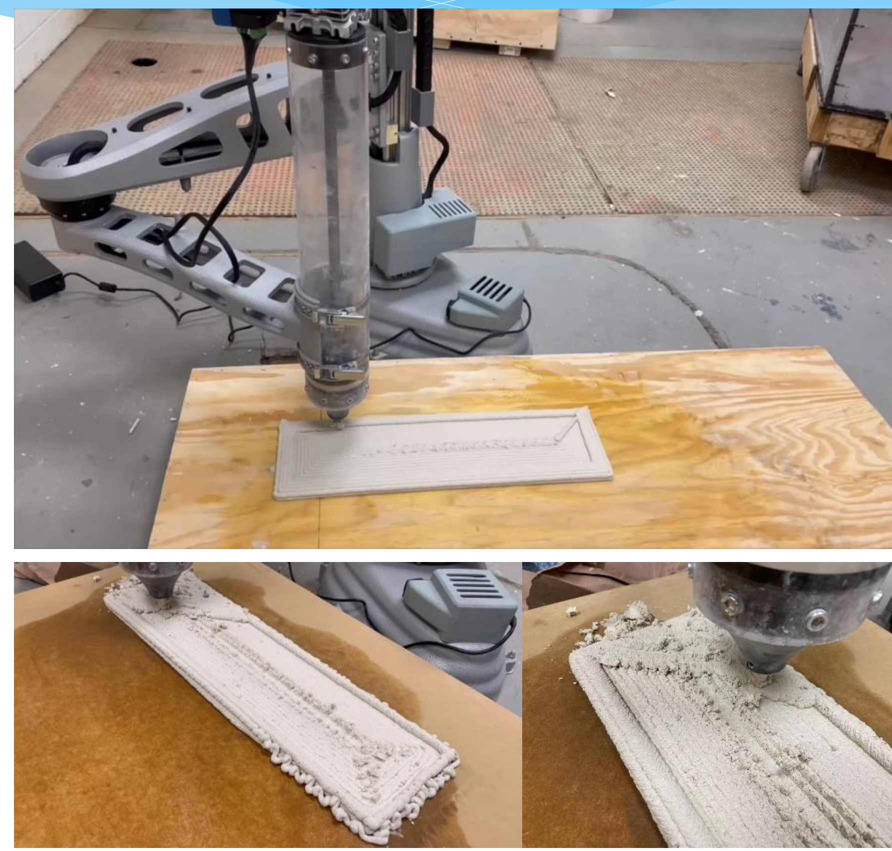
Project Approach

Current Printing Challenges:

- ➢ Printing orientation selection
- ➢ Printing speed tuning
- ➢ Nuzzle size selection
- ➢ Pumping speed tuning

Steps:

- Try different nuzzle sizes, printing and pumping speed, printing orientation
- 3D print beams with and without reinforcement
- Four-point flexural tests



Acknowledgement

The project is sponsored by PennDOT.

Project Panel

Jason Zang, PennDOT
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Jonathan Buck, FHWA
John Boyer, Pennsylvania Turnpike
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Thank you

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Concrete Pavement Vibration and Compaction

Alessandro Fascetti

IRISE ANNUAL MEETING

MAY 25, 2022

The Problem

- The quality of a paving process is influenced by:
  - environmental conditions (e.g., temperature and humidity)
  - the type of concrete mix,
  - layout of reinforcement, and
  - the manipulations performed during construction (i.e., vibration and compaction).
- The effect of each of the influencing factors needs to be accurately defined, to provide guidelines and operational control for the optimization of the process

Project Objectives

1) Build novel experimental tools to enable optimized design and construction of concrete pavements
2) Experimentally investigate the effect of vibration and compaction in paving processes under different conditions
3) Create novel computational tools to perform predictions and identify best practices for optimal paving processes
4) Develop guidelines to provide more efficient construction for new pavements

Project Approach

- **Task A:** compile a literature review of existing rules and guidelines from DOTs.

	Agency	Vibration frequency	Specification
1	MnDOT	3,600-6,000 vibrations per minute	MnDOT 2301
2	PennDOT	Not less than 100 vibrations per second (6,000 per minute)	PennDOT Pub 408
3	IDOT	Minimum of 3,500 vibrations per minute	IDOT Construction Manual
4	NYSDOT	Vibrators capable of 6,000-10,000 vibrations per minute	NYSDOT Section 500
5	Iowa DOT	4,000-8,000 vibrations per minute	Specification 2301

Project Approach

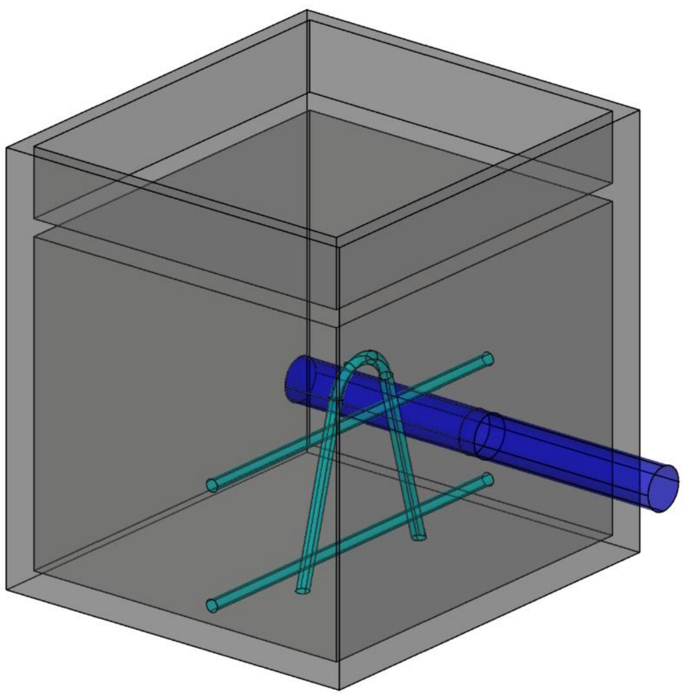
❑ **Task B:** design and conduct an experimental campaign on controlled specimens to evaluate micro-mechanical effects of vibration on the 3-dimensional arrangement of aggregate.

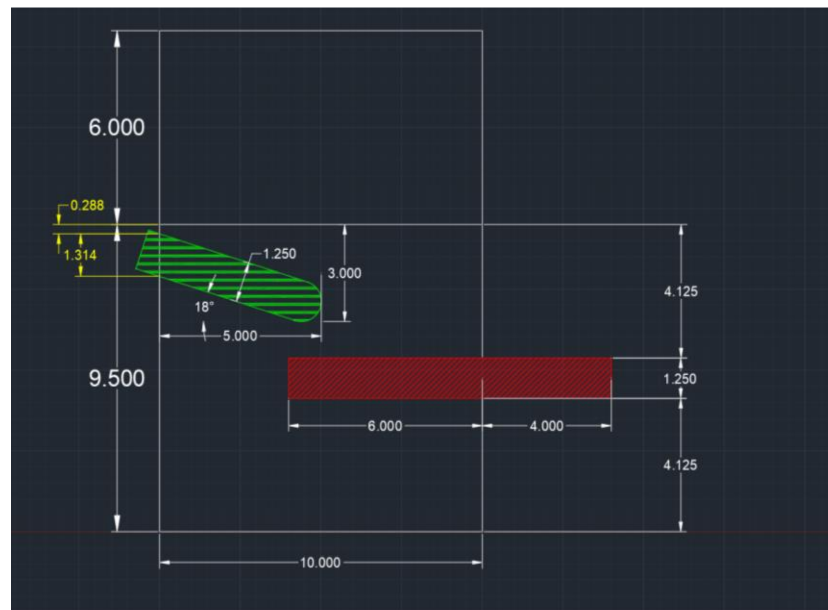
Taylor et al., 2018

Criticality: the precision of the test declines with the increasing size of coarse aggregate (Taylor et al. 2018).

Project Approach

- **Task B:** design and conduct an experimental campaign on controlled specimens to evaluate micro-mechanical effects of vibration on the 3-dimensional arrangement of aggregate.





Application of Results

- Experimental data can be used to predict the field conditions, and to inform the numerical simulations.

- Simplified mechanistic model can be used for fast predictions and model parametrization in paving jobs.

- Guidelines and recommendations based on both the experimental and numerical investigations.

Schedule/Status

- **Task A:** Completed
- **Task B:** Underway (40%)
- **Task C:** Planned
- **Task D:** Planned

PCC Pavement Joint Design Optimization

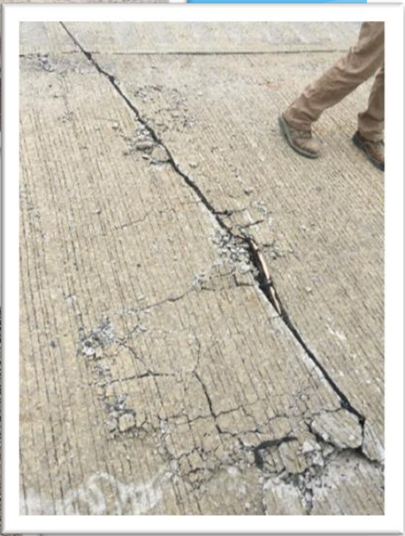
IRISE ANNUAL MEETING
MAY 25, 2022

Presenter: Julie Vandenbossche, PhD, PE
Zachary Brody

Panel members

- Jason Molinero – Allegheny County
- Mathew Blough – PA Turnpike
- Charles Buchanan – PA Turnpike
- Chuck Niederriter – Golden Triangle
- Lydia Peddicord - PennDOT

The Problem



Transverse Joints

- Effect initial and future costs
- Commonly define the life of the pavement

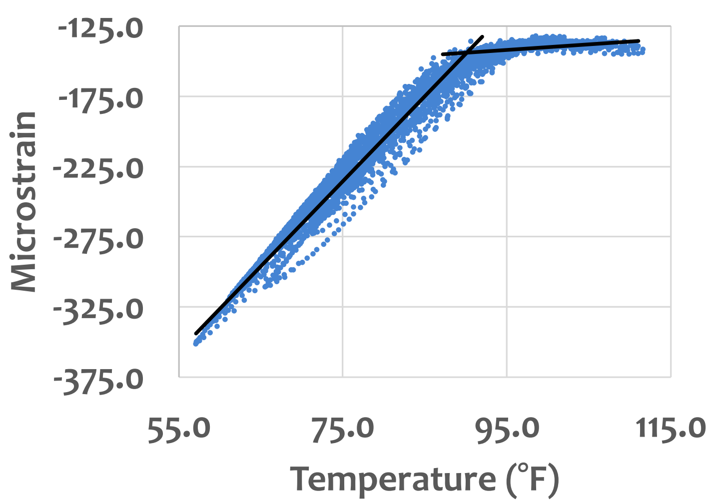
Joint performance is a function of…

- Sealant performance
- Joint spacing
- Load transfer
- Concrete durability
- Pavement design

Project Objectives

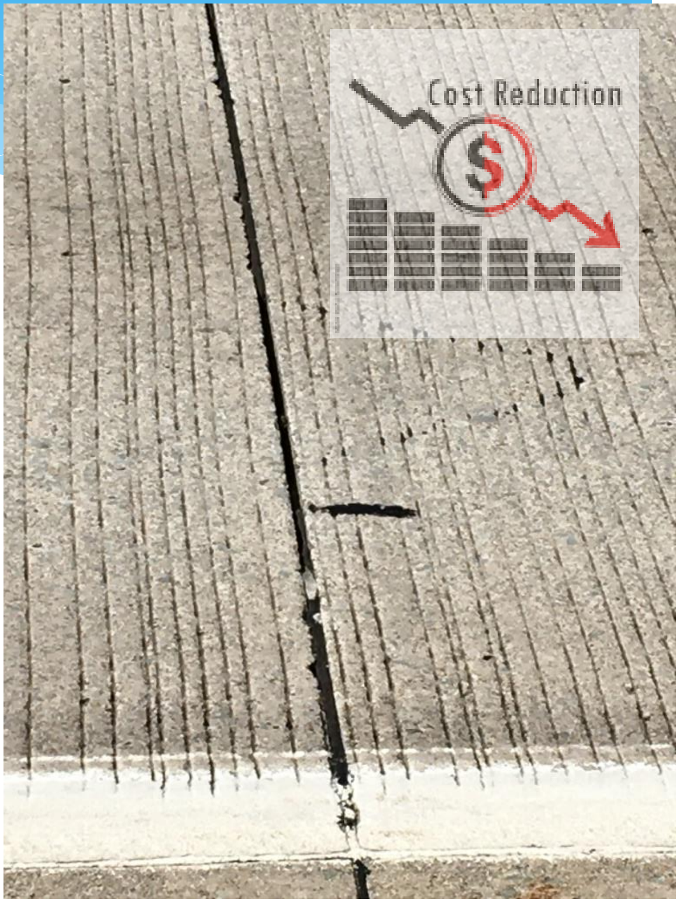
- Holistic review of jt performance
- Identify deficiencies
- Design strategies to minimize deficiencies

Project Approach



1. Establish current practices
2. Review current PA performance data
3. Work with CPQI Committee
4. Investigate jt width ranges (SR-22 Smart Pavement)
5. Develop joint design strategies to address deficiencies
6. Provide recommendations for enhanced jt performance

Application of Results



Recommendations that contribute to..

1. Increased jt performance
2. Reduce life cycle cost of JPCP

Schedule/Status

Task	2022												2023											
	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lit. Review																								
Jt & Pave. Perform. Data Review																								
Jt. Res. Design																								
Jt. Performance Deficiencies																								
Jt Design Strategies																								
Draft Final Report																								
Final Report																								