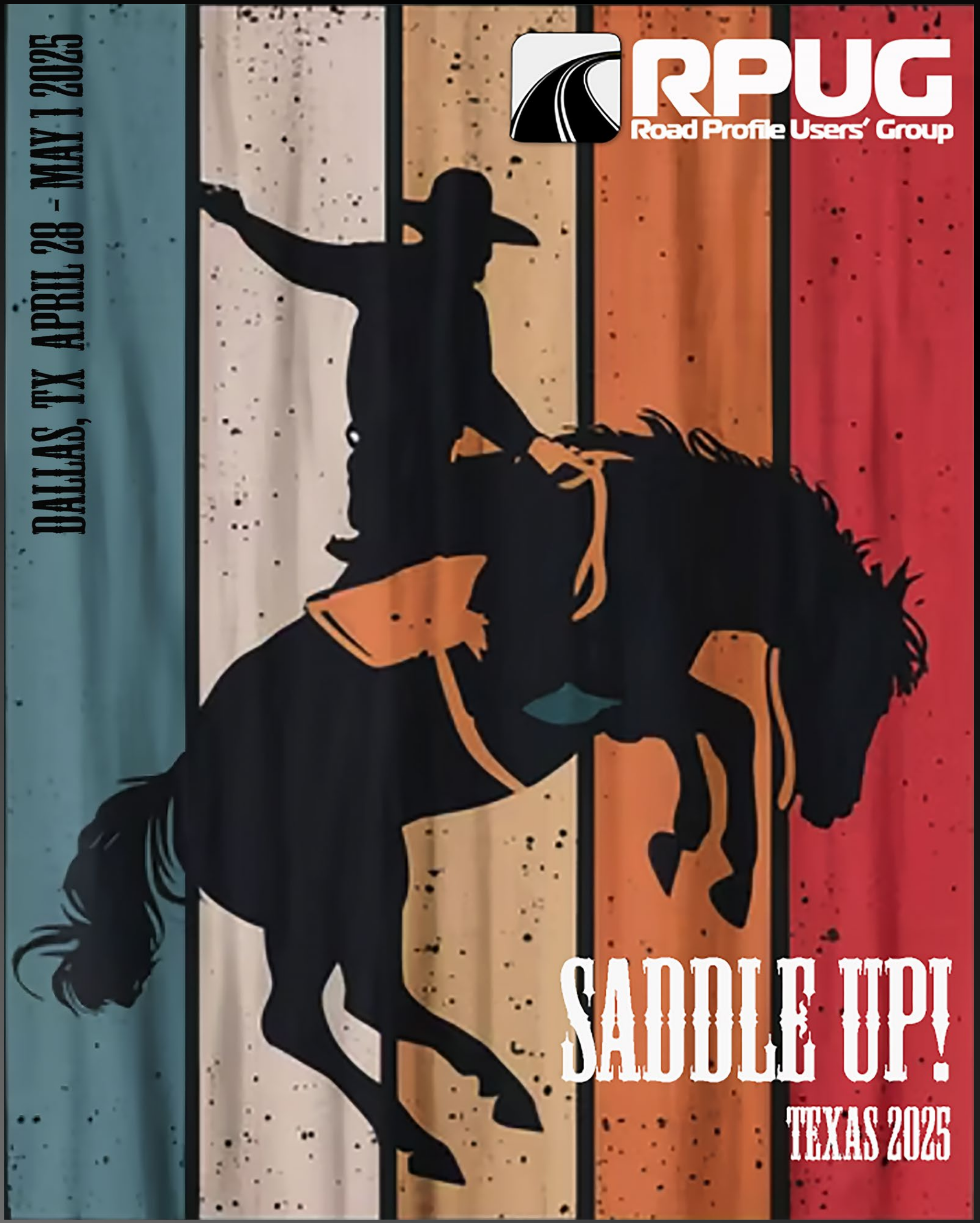

AUTOMATED PROJECT-LEVEL MAINTENANCE AND REHABILITATION PLANNING AND DESIGN FOR JOINTED PLAIN CONCRETE PAVEMENTS USING 3D PAVEMENT SURFACE DATA

Ryan Salameh, PhD
Project Engineer, ICC-IMS

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Research Assistant, Georgia Tech

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Professor, Georgia Tech

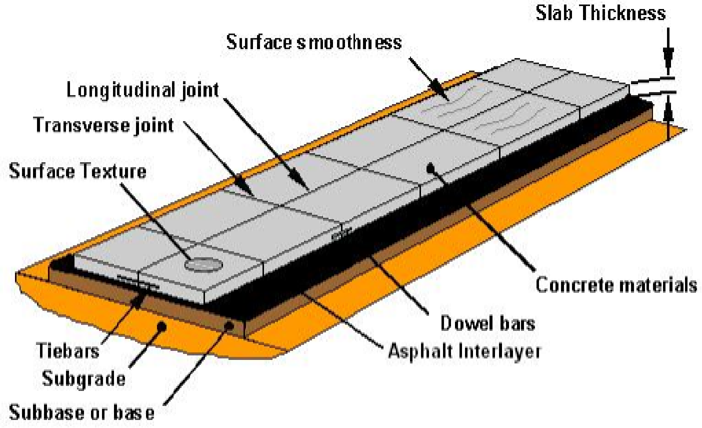
OUTLINE

- Background & Challenges of Current Practices
- Research Objectives
- Methodology & Case Study
- Conclusion

JOINTED PLAIN CONCRETE PAVEMENTS, A CRITICAL INFRASTRUCTURE

- **LIMITED MILES, HIGH IMPACT**
  - SMALL PORTION OF THE ROAD NETWORK
  - PREDOMINANTLY INSTALLED ON CRITICAL ROUTES (INTERSTATES, FREIGHT CORRIDORS)
    - 24% OF THE 47,684 MI OF US INTERSTATES
    - 4.36% OF GEORGIA'S 17,959 MI OF STATE ROUTES → 20% OF TRUCK TRAFFIC

- **DURABILITY AND LONG SERVICE LIFE**
  - DESIGNED TO SUPPORT HEAVY TRAFFIC FOR 40–50+ YEARS WITH PROPER PRESERVATION



INCREASING MAINTENANCE AND REHABILITATION (M&R) NEEDS FOR AGING JPCP

- **As JPCPs age, their maintenance and rehabilitation (M&R) needs grow affecting**
  - Functional performance
  - Structural integrity

- **Major distresses:**
  - Slab cracking
  - Joint and crack faulting
  - Joint and crack spalling

Slab cracking

Joint faulting

Joint spalling

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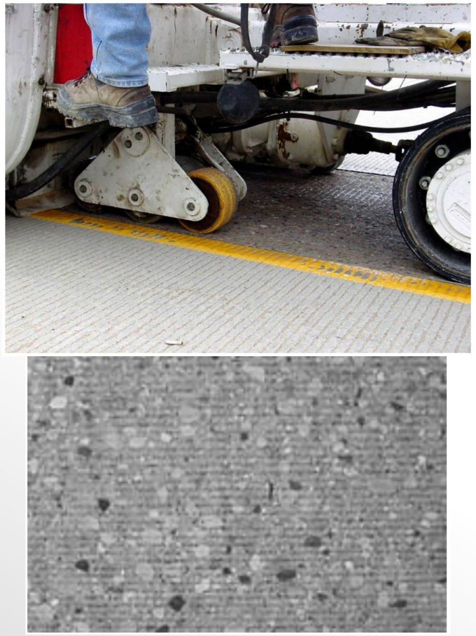
JPCP M&R ALTERNATIVES

Concrete Pavement Restoration (CPR)

- Extend pavement life and delay major rehabilitation

Slab Replacement (Full-depth repair)

Joint and Crack Sealing



Diamond Grinding

Lane Reconstruction (LR)

- New pavement with long design life (40+ years)

JPCP Construction using Slipform Paver

CPR PROJECT PLANNING & DESIGN

- **MOST JPCPS ARE LOCATED ON HIGH-TRAFFIC VOLUME ROUTES, THUS M&R ACTIVITIES MUST BE:**
  - **TIMELY** TO MAINTAIN GOOD CONDITION AND PREVENT FURTHER DETERIORATION
  - **EFFECTIVE** TO ADDRESS DISTRESSES, EXTEND PAVEMENT LIFE, AND DELAY FUTURE INTERVENTIONS
  - **CONDUCTED WITH MINIMAL TRAFFIC INTERRUPTIONS**

CPR Design and Planning Process

Identify specific slabs and joints that require repair based on surface distresses

↓

Select the appropriate treatment (e.g., crack sealing, replacement)

↓

Design the application of those treatments (e.g., partial vs full-length slab replacement)

↓

Estimate the project cost

↓

Develop traffic control plans

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CONVENTIONAL CPR PROJECT DESIGN PRACTICE

CPR DESIGN IS MOSTLY BASED ON SURFACE DISTRESS CONDITIONS

- LIMITED STRUCTURAL ASSESSMENT

Low-speed windshield surveys

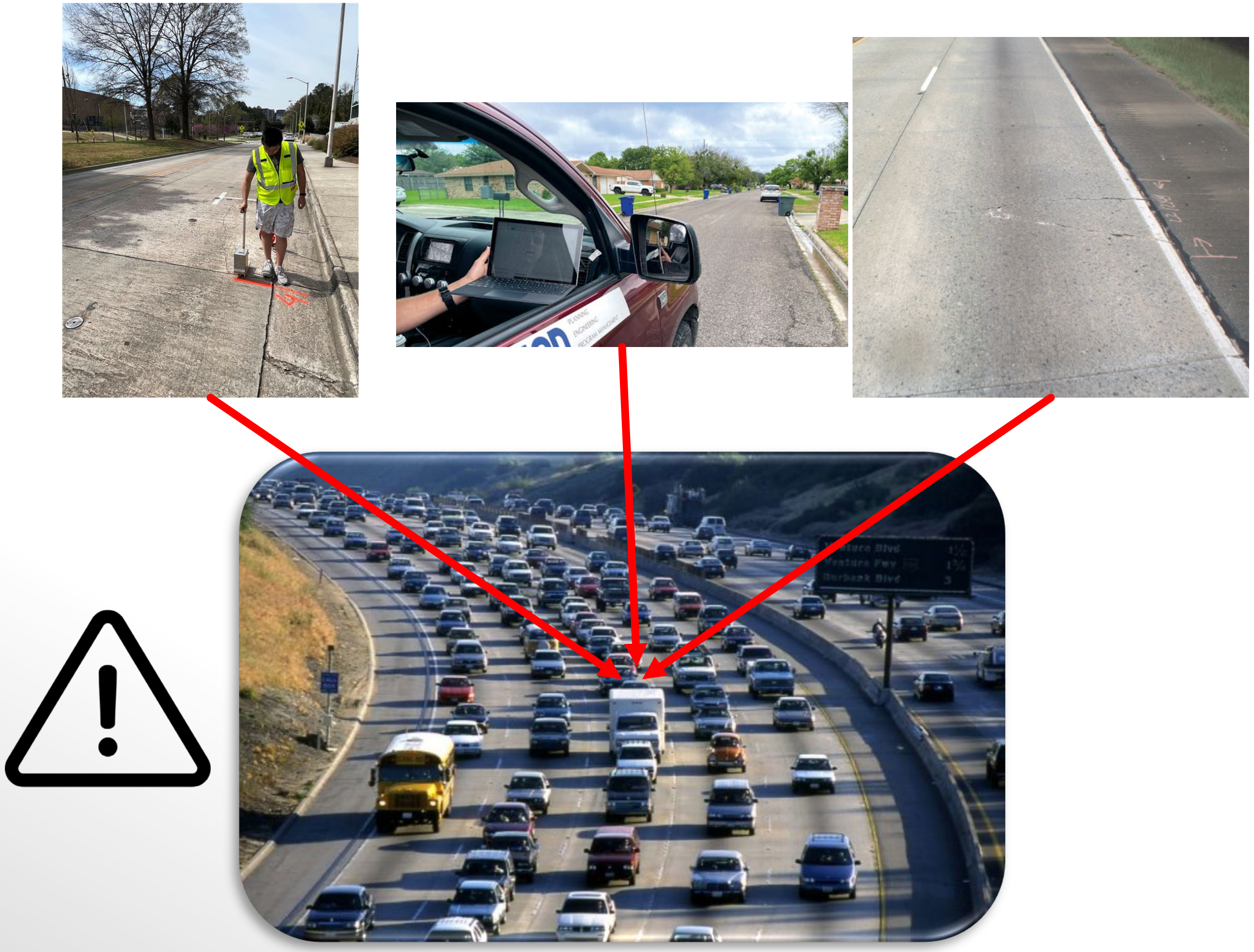
Field assessment (shoulder/median) and marking

Limited field measurements (e.g., joint faulting)

CHALLENGES WITH CURRENT CPR PROJECT DESIGN PRACTICE

- **Inability to perform detailed slab-level condition assessment and distress measurements**
  - High Cost for Traffic Control

- **Challenges:**
  - Safety Risks
  - Time-Consuming and Tedious Process
  - Prone to Inaccuracies
  - Limitations in Design Optimization
  - Distress deterioration outdating design



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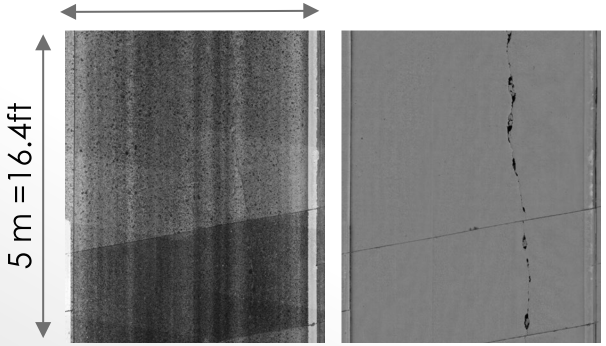
ADOPTION OF 3D LASER IMAGING SYSTEMS

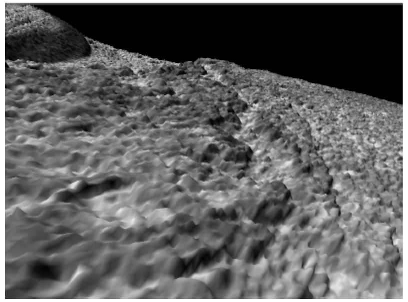
- **MAINSTREAM TECHNOLOGY AMONG STATE DOTs FOR AUTOMATED PAVEMENT SURVEYING AND CONDITION ASSESSMENT**
- SYSTEM OF 3D LASER SENSORS CAPTURING THE HIGH-RESOLUTION 3D PAVEMENT SURFACE DATA WITH FULL LANE COVERAGE AT HIGHWAY SPEED
- EXTRACT PAVEMENT SURFACE INDICATORS AND DISTRESSES USING IMAGE PROCESSING AND AI METHODS
  - E.G., CRACKING, RUTTING, FAULTING, IRI, POTHOLES

Georgia Tech Sensing Van with an installed 3D laser imaging system



Intensity (2D) Range (3D)

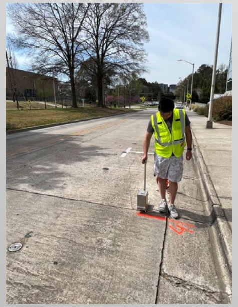
Sample Pavement Image

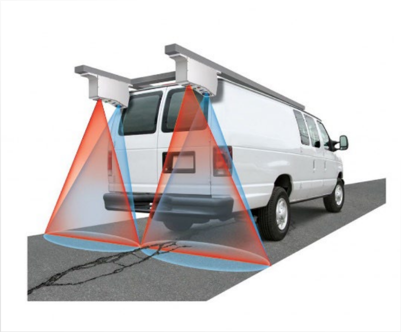
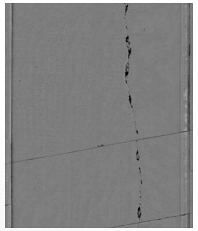


3D pavement surface texture data visualization

MANUAL VS AUTOMATED JPCP DISTRESS SURVEYS

Manual Surveys	Automated Surveys using 3D Laser Systems
Inaccurate: Subjective and prone to human error	**Accurate:** Objective, based on high-resolution pavement images and automation
Sampled: E.g., GDOT faulting measured every 8th joint at right edge)	**Full lane coverage:** Distress information for entire scanned pavement segment
Rough distress measurements: E.g., Count of slabs with transverse cracks	**High-resolution distress measurements:** E.g., Crack map and its measurements (length, width, orientation)
Lack of distress spatial information: Aggregated quantities recorded for long segments (e.g., 1-mi)	**Spatially-referenced distress information:** Ability to spatially locate high-resolution distresses along scanned segment

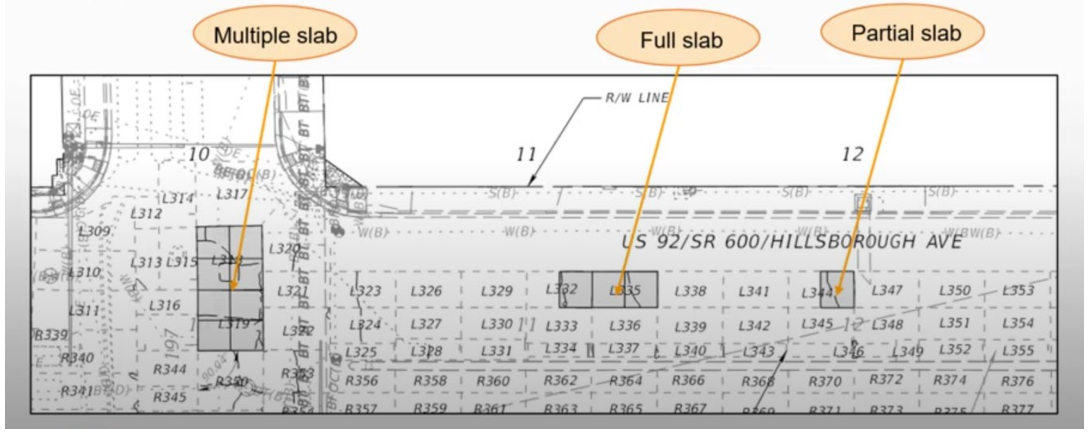


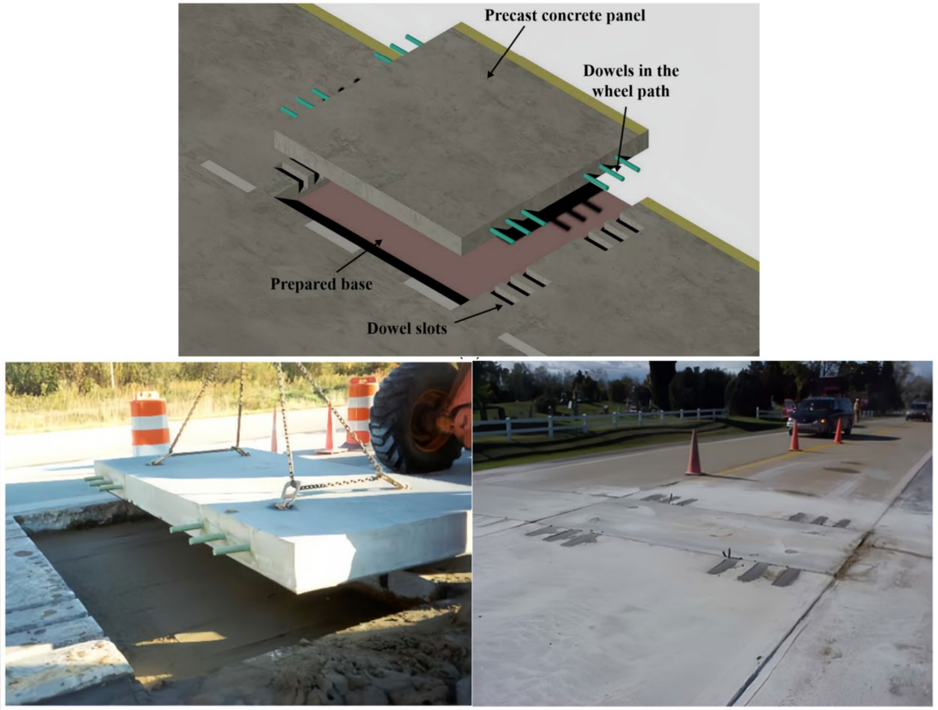
RESEARCH NEED

- **NEED TO LEVERAGE HIGH-RESOLUTION 3D PAVEMENT SURFACE DATA TO ENHANCE AND AUTOMATE THE DESIGN PROCESS FOR CPR PROJECTS**
  - GENERATE ACCURATE SLAB REPLACEMENT DESIGN PLANS

- **BENEFITS:**
  - STREAMLINE DESIGN PROCESS, IMPROVE ACCURACY, AND RESULT IN MORE EFFECTIVE REHABILITATION PLANS
  - REDUCE SAFETY RISKS WHILE MINIMIZING DISRUPTIONS TO TRAFFIC
  - SUPPORT EMERGING PRECAST CONCRETE PAVEMENT FOR SLAB REPLACEMENT: DETAILED DIMENSIONS



Sample Slab Replacement Design Layout (FDOT, 2022)



Precast Slab Replacement (Tan et al., 2024)

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RESEARCH OBJECTIVE

- **Develop a methodology to automate the CPR Preconstruction design and planning process using 3D pavement surface data**

- **The cornerstone of the methodology is a slab-based condition monitoring system, which includes:**
  - Slab layout inventory
  - Slab-based High-resolution distress condition data

- **Conduct a case study on a 10-mile project along I-16 near Macon, GA using 3D pavement surface data collected by GTSV in 2018**

CPR PROJECT DESIGN METHODOLOGY

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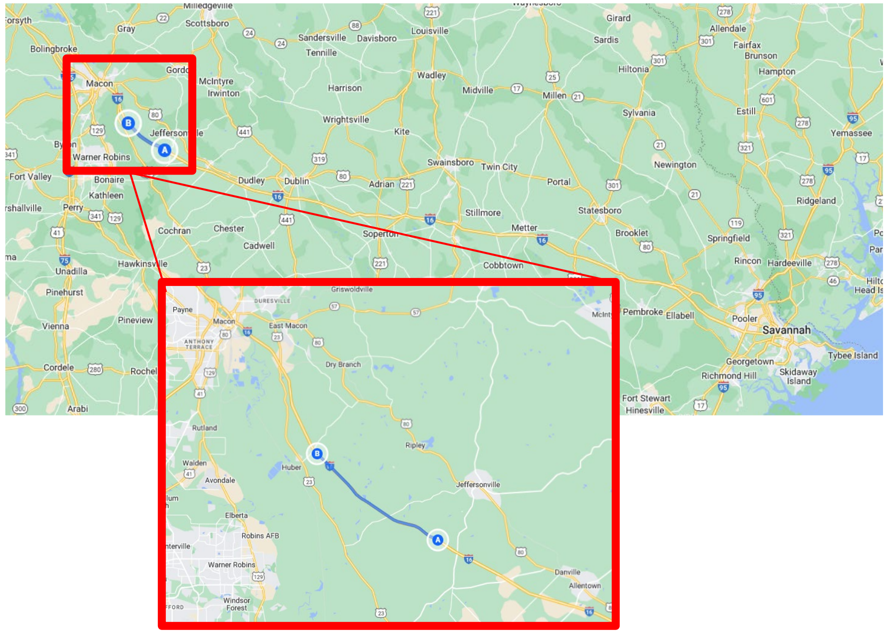
Case Study on I-16 WB using 2018 survey data

CASE STUDY

- 10-MILE SECTION ON INTERSTATE 16 FROM MP22 TO MP12 IN WESTBOUND DIRECTION
- TRAFFIC
  - AADT: 23,900 VEH/DAY
  - TRUCK PERCENTAGE: 24%
- BUILT IN 1972
- SLAB THICKNESS: 9-INCH
- JOINT DESIGN: UNDOWELED, SKEWED JOINTS, 16-23 FT SPACING
- BASE: CEMENT SOIL
- SHOULDER: ASPHALT PAVEMENT
- 3D PAVEMENT DATA SURVEYS: 2013 – 2018



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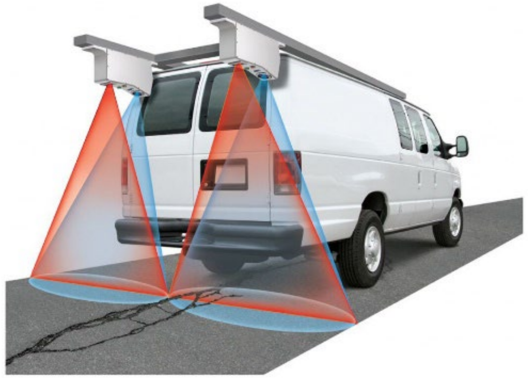
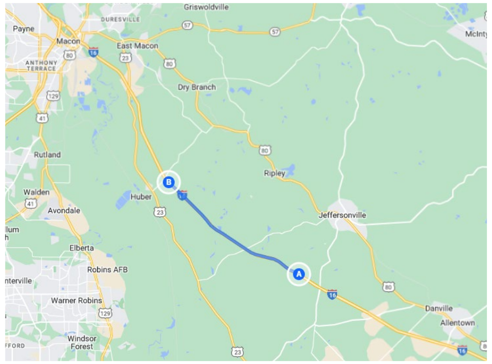


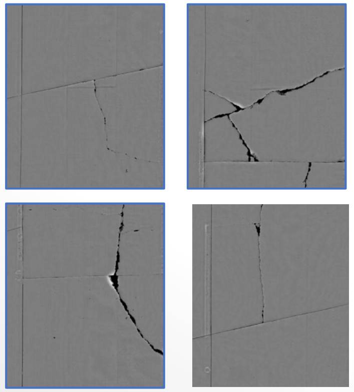
GTSV



I-16 WB
MP 22-12

High-resolution Pavement Images

…



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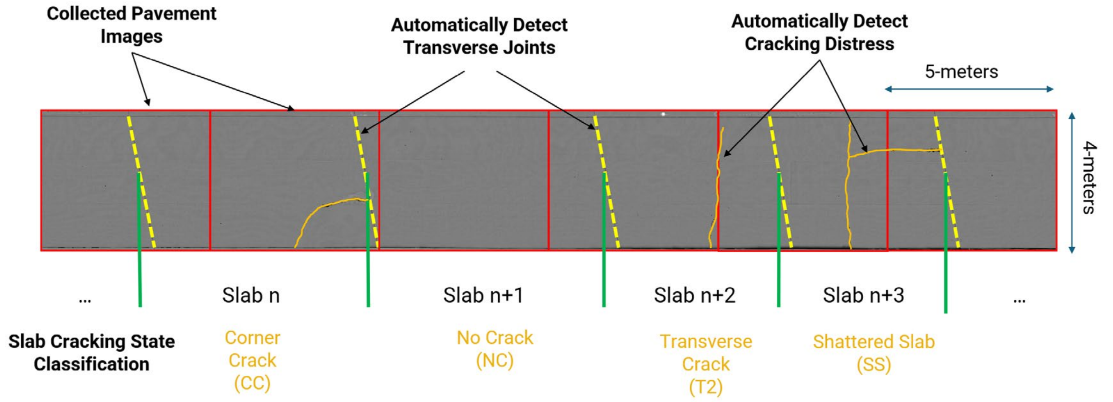
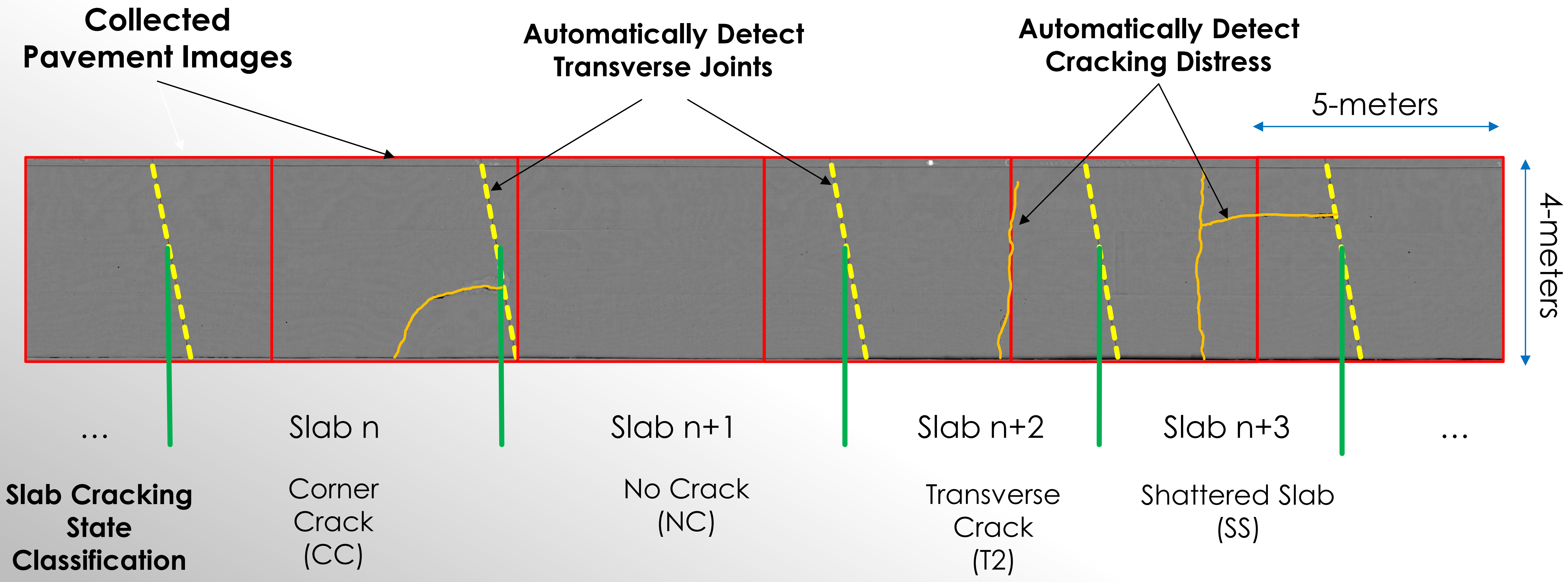
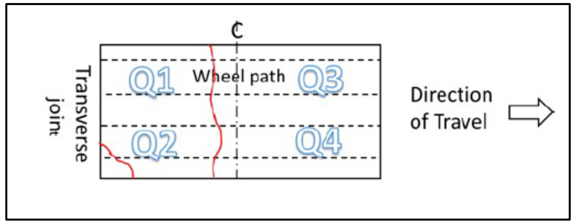


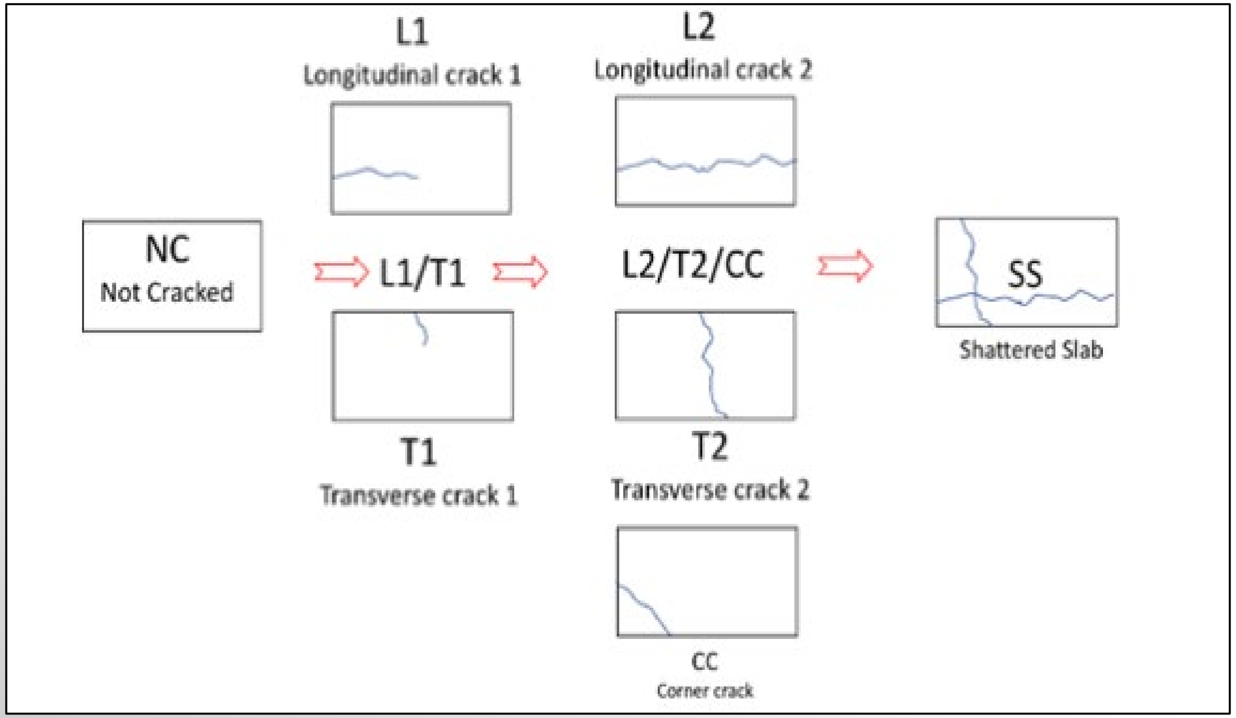
- **Cracking:**
  - Crack map illustrating the extent of cracking across the slab area
  - Crack length, crack width (95th percentile), and the slab's crack state classification (e.g., L1, T2, SS)
- **Joint Condition:**
  - Faulting measurements (median)
  - Spalling condition
  - Patching condition

SLAB-BASED DATA PREPARATION



CRACKING SLAB STATE PROGRESSION

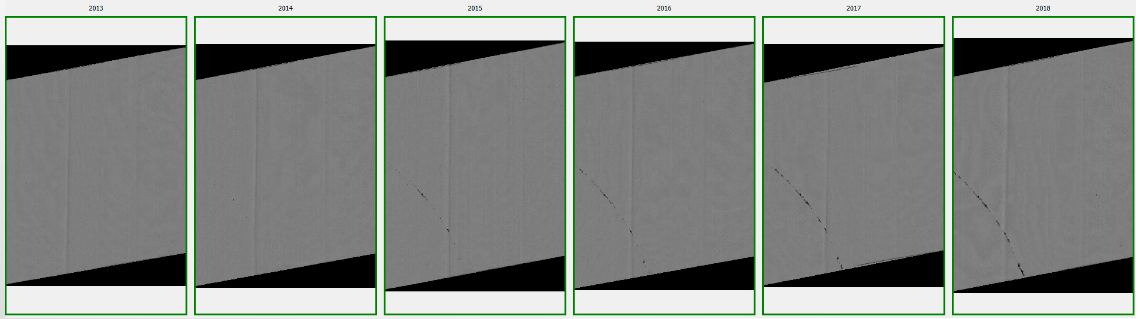




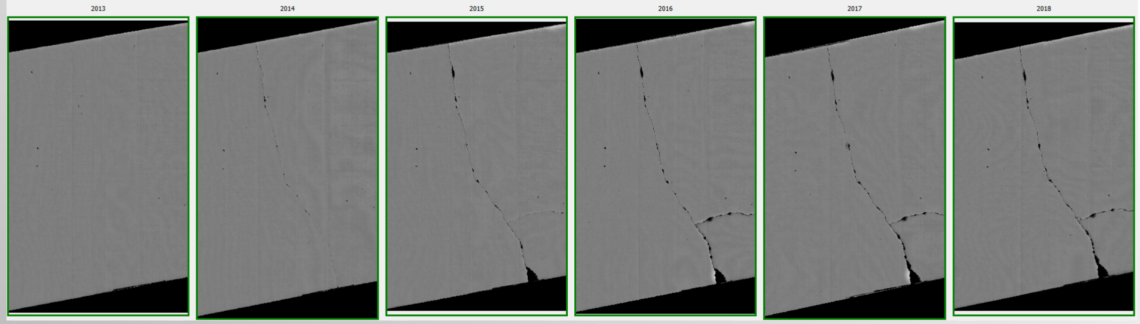
3D Slab-based State Progression (Geary, 2019)

SLAB CRACKING PROGRESSION (2013 – 2018)

2013	2014	2015	2016	2017	2018

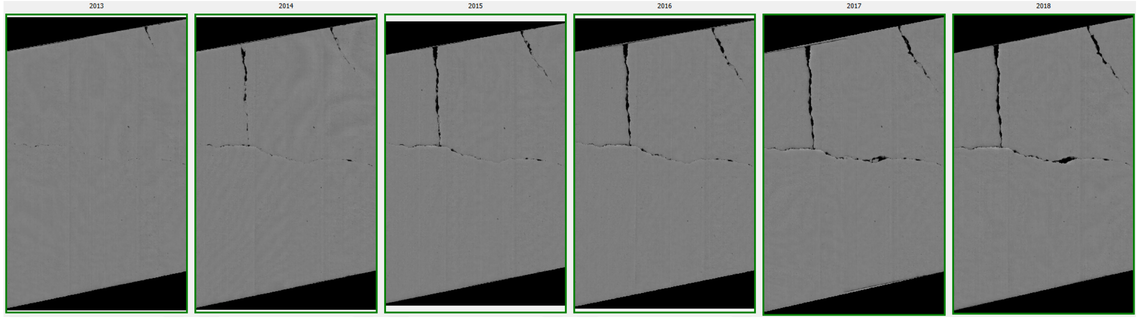


NC	NC	CC	CC	CC	CC

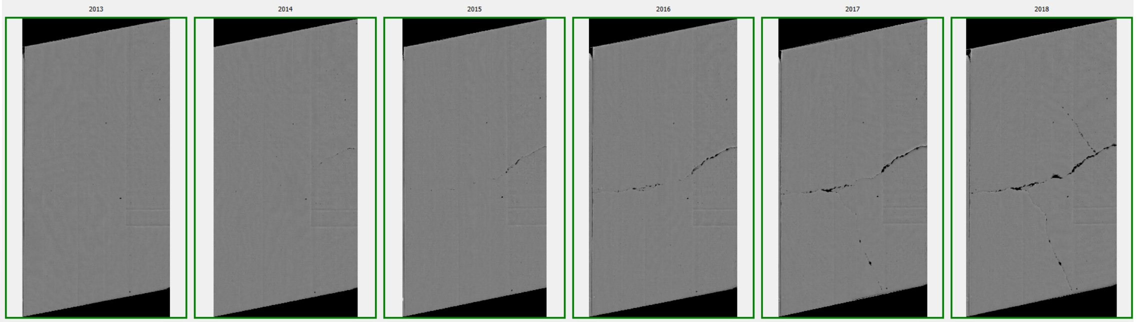


L1	L2	SS	SS	SS	SS

2013	2014	2015	2016	2017	2018



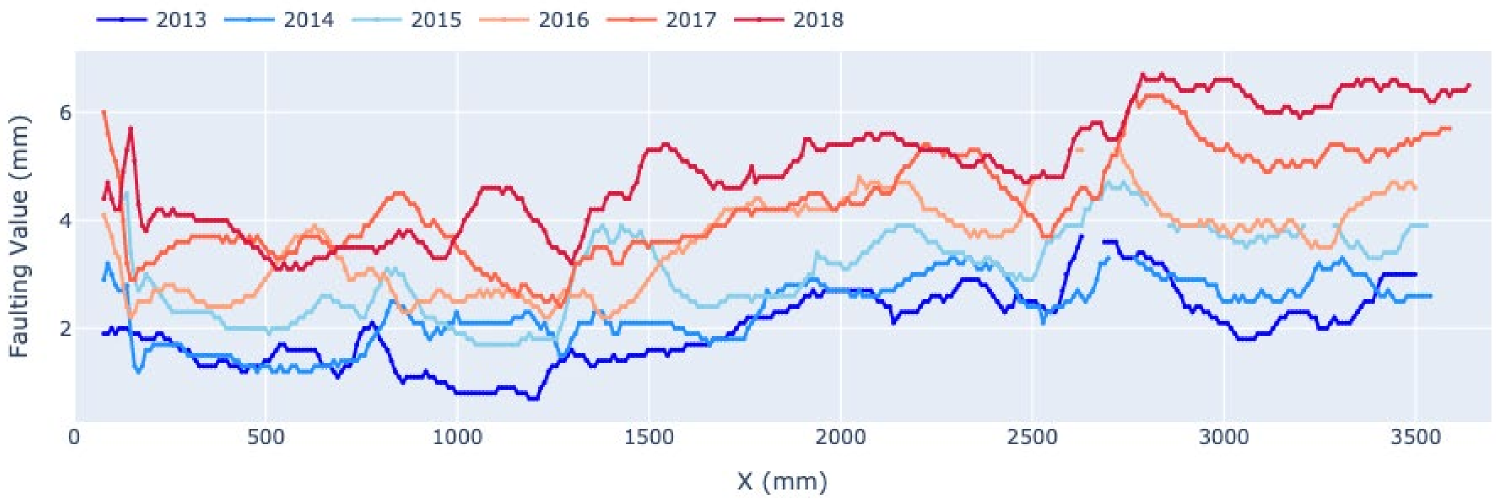
T2	SS	SS	SS	SS	SS

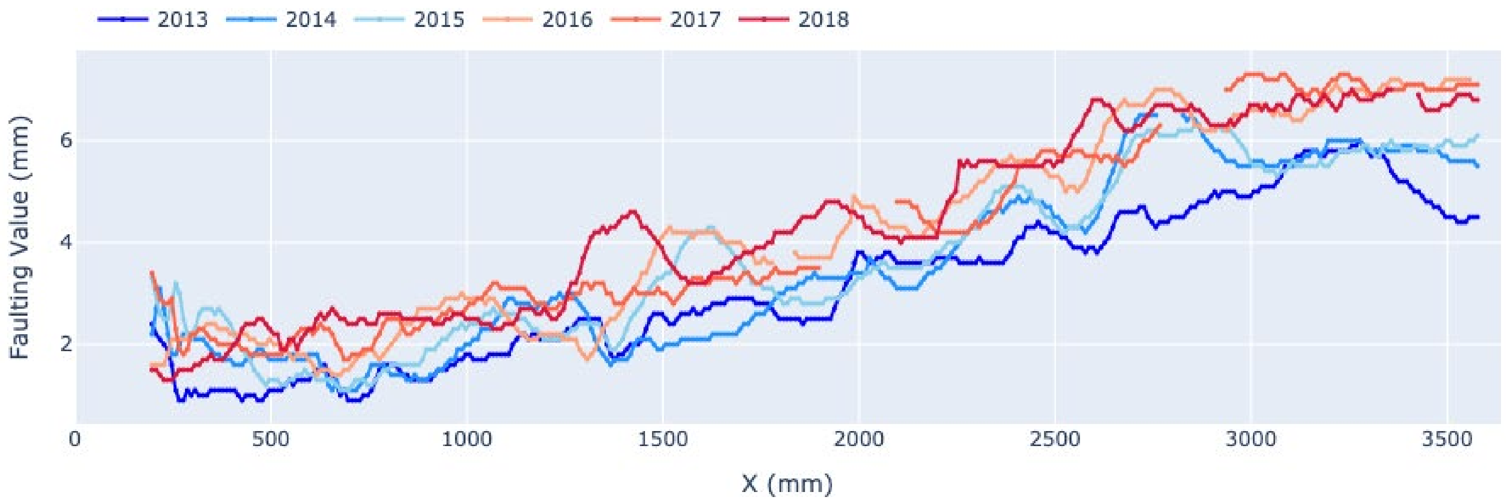


NC	T1	T2	T2	SS	SS

Data Collected by Georgia Tech Sensing Van on I-16 Westbound (2013 – 2018)

JOINT FAULTING MEASUREMENT PROFILE PROGRESSION (2013 – 2018)





CPR PROJECT DESIGN METHODOLOGY

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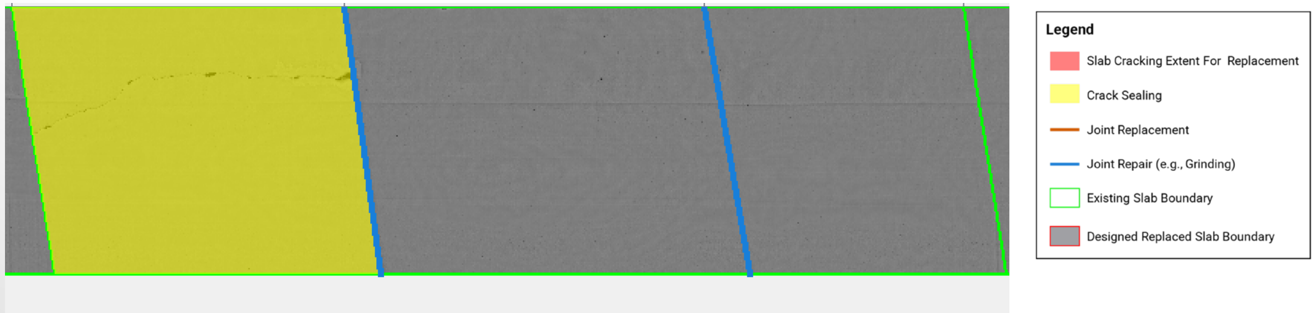
M&R Treatments	Criteria		
Cracking Related	**Slab State**	**Crack Width**	
Crack Sealing	L1, T1, L2	3mm - 12.7mm	
Slab Replacement (Full-depth Repair)	L1, T1, L2	> 12.7mm	
	T2, CC, SS	Any width	
	Criteria		
Joint Related	**Faulting**	**Spalling**	**Failed Patching**
Joint Repair (e.g., Diamond Grinding, Dowel Bar Retrofitting, etc.)	2.54mm – 12.7mm	✕	✕
Joint Replacement (Partial or Full-depth repair)	> 12.7mm	✓	✓

ID: 214
L2
L: 21.3ft
P95 Crack Width: 10.5mm
Crack Length: 23.9 ft (7.3m)

ID: 215
NC
L: 23.4ft
Fault: 3.5mm

ID: 216
NC
L: 16.7ft
Fault: 2.6mm



Crack Sealing and Joint Repair Examples

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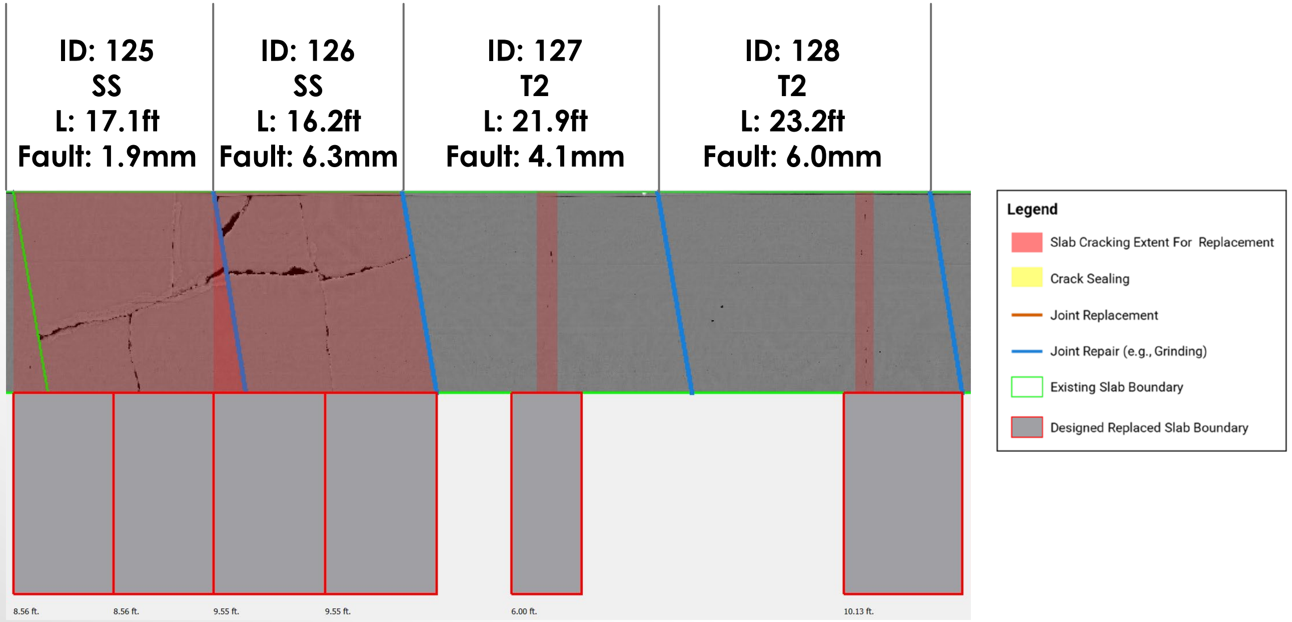
- **Minimum slab length for replaced slabs and residual original slabs:** 6 ft
- **Maximum replaced slab length:** 15 ft
- **Base Scenario:** Limit slab replacement within boundaries of existing slabs



Slab Replacement & Joint Repair Examples

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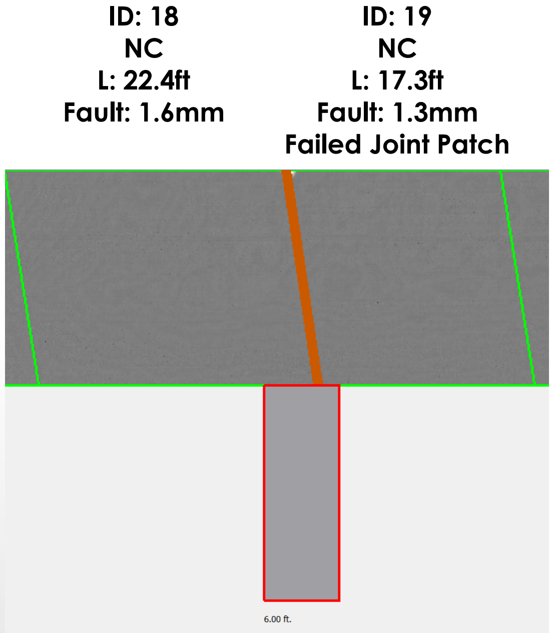

Legend
- Slab Cracking Extent For Replacement
- Crack Sealing
- Joint Replacement
- Joint Repair (e.g., Grinding)
- Existing Slab Boundary
- Designed Replaced Slab Boundary

Joint Replacement Example

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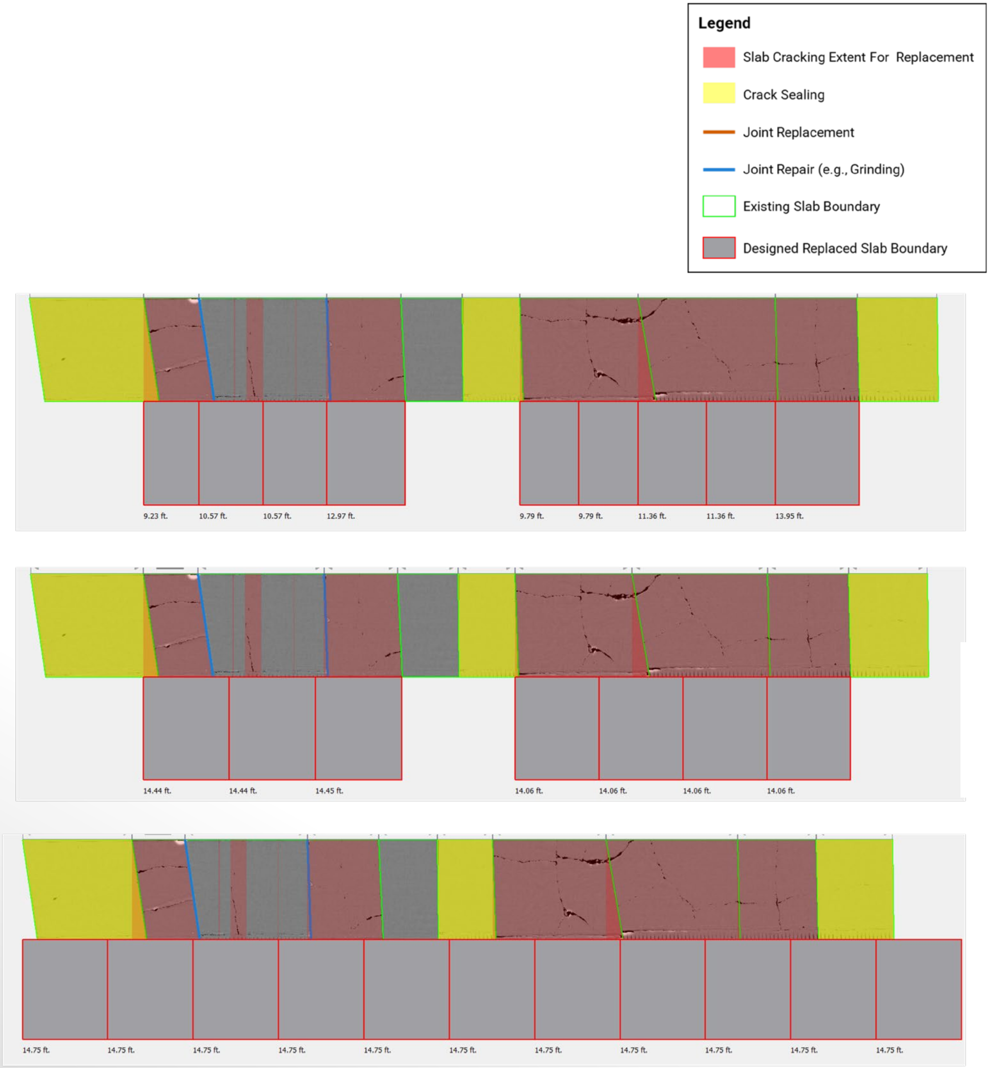

Baseline Scenario

Reduce Number of Joints

Constructability Optimization

Optimization Scenarios

CPR PROJECT DESIGN METHODOLOGY

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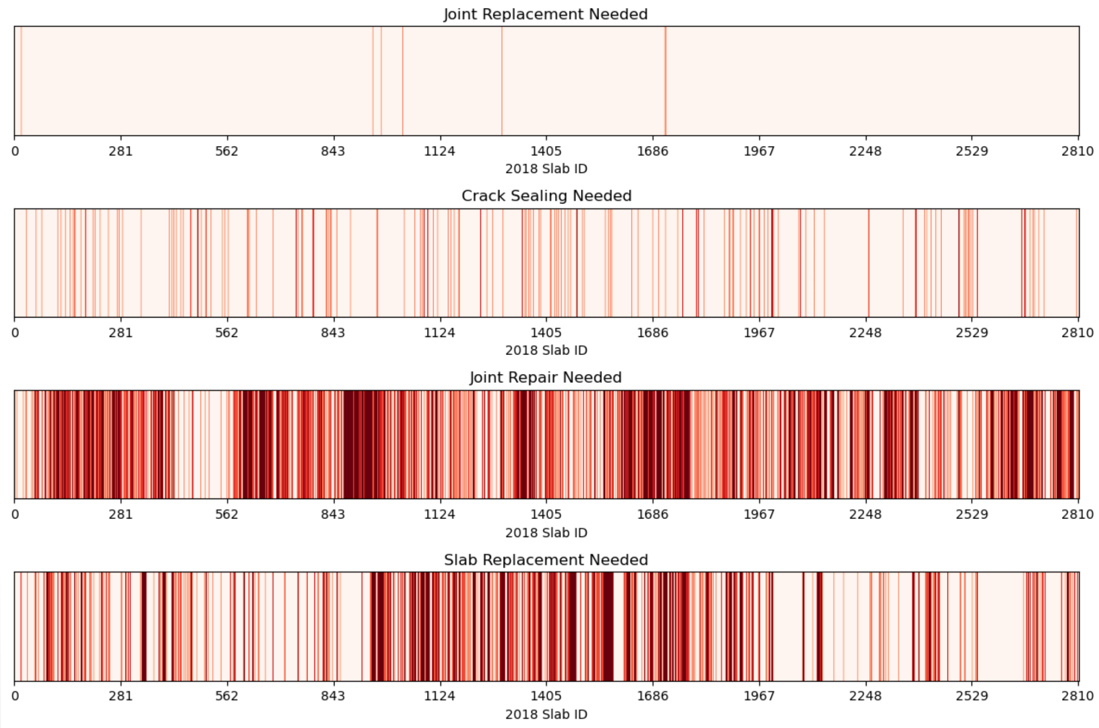


Mapped Repairs by Slab ID

SPATIALLY REFERENCED REPAIR DESIGN PLANS

- **Slab Replacement Report**
  - Slab Removal Locations
  - New Slab Joint Locations
- **Joint Replacement Report**
- **Crack Sealing Report**
- **Joint Repair Report**

Slab Replacement Report	
Part 1: Slab Removal Design Output	
OID	Unique ID for removal area
From MP	Precise start and end location of removal area
To MP	
From Station	
To Station	
From Slab ID	Target Existing Slab IDs and Joint Alignment Type of Slabs on Extremities of Removal Area
To Slab ID	
First Joint Alignment Type	
Last Joint Alignment Type	
Total Removal Length	Sum of existing slab lengths removed
Part 2: Replaced Slabs Design Output	
Replaced Slab ID	Unique ID for replaced slab
MP From	Precise start and end location of replaced slabs (new joints)
MP To	
From Station	
To Station	
From Slab ID	Target Existing Slab IDs and Joint Alignment Type of Slabs on Extremities of Replaced Slab
To Slab ID	
First Joint Alignment Type	
Second Joint Alignment Type	
Replaced Slab Length (ft)	New slab length

Joint Replacement Report	Crack Sealing Report	Joint Repair Report
Slab ID	Slab ID	Slab ID
MP	MP From	MP
Station	MP To	Station
Spalling Condition	From Station	Faulting Value (mm)
Patching Condition	To Station	
Faulting Value (mm)	Total Crack Length in Slab (mm)	
Replaced Slab ID	P95 Crack Width (mm)	
	Median Crack Width (mm)	

SAMPLE SLAB REPLACEMENT REPORT

Slab Removal Locations *(After clustering)*

OID	From Slab ID	To Slab ID	First Joint Aligned	Last Joint Aligned	From Station	To Station	From MM	To MM	Total Removal Length (ft)
24	138	140	FALSE	TRUE	24+13	24+50	21.543	21.536	37.313
25	142	144	TRUE	TRUE	24+65	25+29	21.533	21.521	63.911
26	149	149	TRUE	TRUE	26+04	26+24	21.507	21.503	20.066
27	160	160	TRUE	TRUE	27+93	28+18	21.471	21.466	24.501
28	165	165	TRUE	TRUE	28+94	29+20	21.452	21.447	26.339
29	169	169	TRUE	TRUE	29+72	29+98	21.437	21.432	25.971

New Slab Joint Locations

Replaced Slab ID	From Slab ID	To Slab ID	First Joint Aligned	Last Joint Aligned	From Station	To Station	From MM	To MM	Length (ft)
14	88	88	TRUE	FALSE	14+38	14+46	21.727	21.726	7.992
15	89	89	TRUE	FALSE	14+46	14+52	21.726	21.725	6.01
16	90	90	TRUE	FALSE	14+52	14+61	21.725	21.723	9.042
17	91	91	TRUE	FALSE	14+61	14+71	21.723	21.721	9.967
18	91	91	FALSE	TRUE	14+71	14+81	21.721	21.719	9.967
19	93	93	TRUE	FALSE	15+00	15+06	21.716	21.715	6.001

SAMPLE OF OTHER REPORTS

Crack Sealing Report

Slab ID	MP From	MP To	From Station	To Station	Total Crack Length (mm)	Median Crack Width (mm)	P95 Crack Width (mm)
176	21.415	21.413	30+90	30+99	2315.156	4.5	10.5
188	21.381	21.376	32+68	32+94	2178.42	2.5	6.5
189	21.376	21.373	32+91	33+11	6891.123	2	5.5

Joint Repair Report (e.g., Diamond Grinding)

Slab ID	MP	Station	Median Faulting (mm)	P95 Faulting (mm)
54	21.835	8+72	4.8	6.2
55	21.832	8+85	5.9	17.725
56	21.831	8+94	4.2	6.6

Joint Replacement Report

Slab ID	MP	Station	Replaced Slab ID
19	21.938	3+26	1
947	18.704	173+96	268
969	18.625	178+14	296

SAMPLE OF OTHER REPORTS

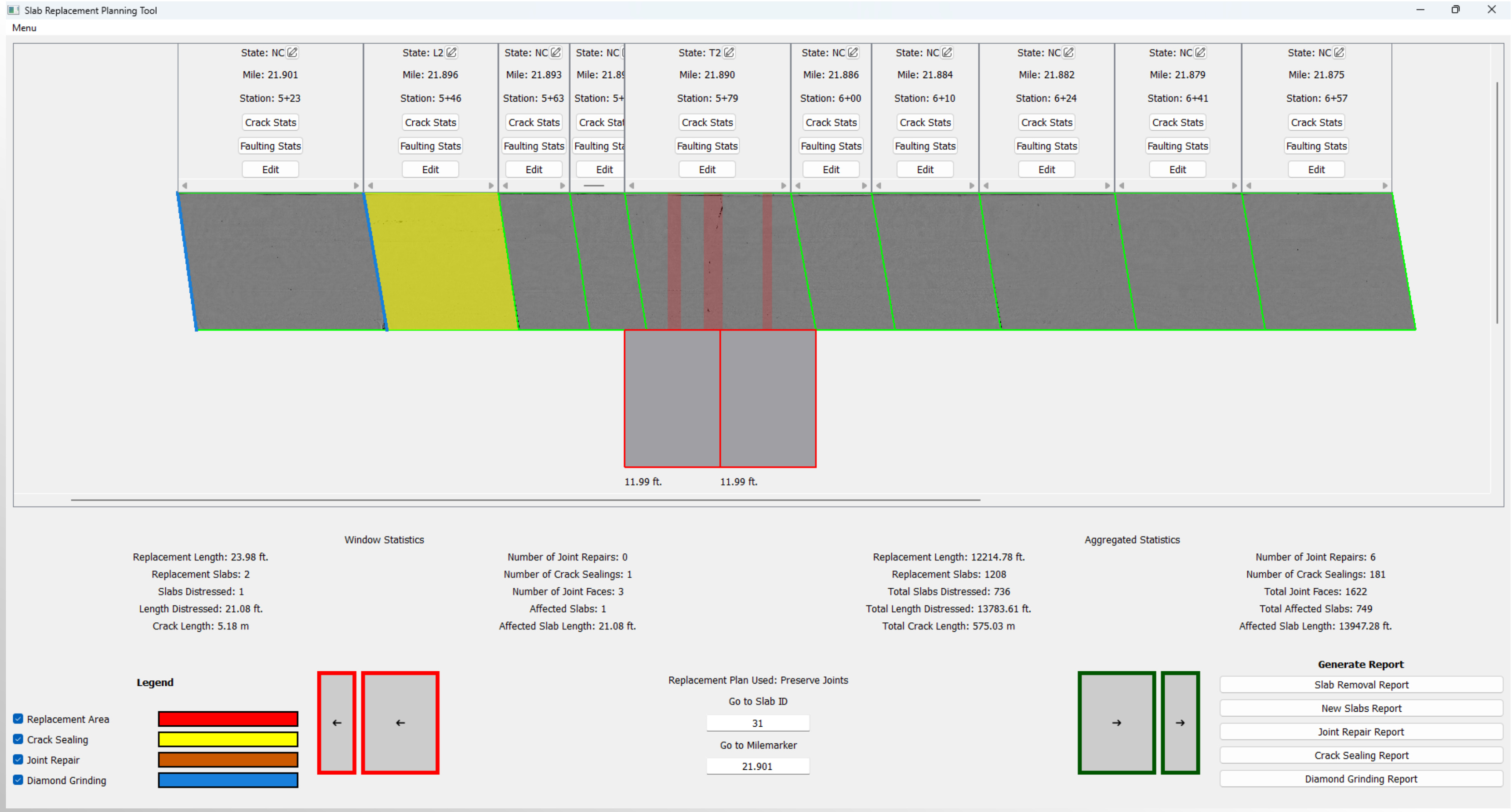
Reported Quantities	Scenario		
	Preserve Joints	Reduce Slabs	Optimize Constructability
Number of Distressed Slabs	736		
Length of Distressed Slabs (ft.)	13783.61		
Number of Affected Slabs	749	749	852
Length of Affected Slabs (ft.)	13,947.28	13,947.28	15,528.43
Number of Replaced Slabs	1,209	1,006	1,101
Length of Replaced Slabs (ft.)	12,225.84	12,225.84	14,362.26
Number of Joint Faces for Dowel Bar Quantity Estimation	1,624	1,421	1,415
Number of Slabs that Need Crack Sealing	181		
Total Crack Length of Slabs that Need Crack Sealing (m)	575.3		
Number of Affected Joints (Joint Repair)	1398		

4,788 cubic yards of concrete

15,565 dowel bars

CPR DESIGN TOOL

- Implementation of Automated CPR Design Methodology
- QC Tool (e.g., crack map detection errors)



CONCLUSION

- **THE DEVELOPED METHOD AUTOMATES THE CPR DESIGN PROCESS WORKFLOW USING 3D PAVEMENT IMAGE-DERIVED SLAB-LEVEL DATA TO GENERATE OPTIMAL REPLACEMENT DESIGNS.**
  - IMPROVES PROCESS EFFICIENCY & ACCURACY, AND THE TREATMENT EFFECTIVENESS.
  - PRODUCES SCALABLE AND REPRODUCIBLE OUTPUTS.
  - ENABLES RAPID RE-ANALYSIS AND DESIGN UPDATES IMMEDIATELY AFTER NEW CONDITION SURVEY DATA IS COLLECTED.

FUTURE RESEARCH RECOMMENDATIONS

- **Pilot Study for Automated CPR Design Methodology:** Conduct a pilot study to validate the practical feasibility of the developed automated CPR preconstruction design methodology and assess its potential to improve efficiency and accuracy.

- **Incorporate other factors into the design process**
  - Distress deterioration rate
  - Structural data at the slab-level using FWD/TSD
  - Adjacent lane condition based on multi-lane survey

REFERENCES

- ACPA (1995). Concrete Paving Technology: Guidelines for Full-Depth Repair, American Concrete Pavement Association.
- Caltrans (2015). Concrete Pavement Guide, State of California Department of Transportation, Division of Maintenance, Pavement Program.
- FDOT. (2022). Module 9: Concrete rehabilitation (FDOT Training) [Video]. YouTube., Florida Department of Transportation.
- Geary, G., 2019. A Spatial and Temporal 3D Slab-Based Methodology for Optimized Concrete Pavement Management. Thesis (PhD). Georgia Institute of Technology.
- NPCA (2021). Manual for Jointed Precast Concrete Pavement: 3rd Edition. National Precast Concrete Association.
- Smith, K., Grogg, M., Ram, P., Smith, K., & Harrington, D. (2022). Concrete Pavement Preservation Guide. National Concrete Pavement Technology Center, Federal Highway Administration.
- Tan, Q., Zhu, H., Yang, S., Yang, X., & Ou, L. (2024). Precast Assembled Road Paving Technology: Progress and Prospects. Materials, 17(10), 2245. https://doi.org/10.3390/ma17102245

THANK YOU !

Q/A

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