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A THREE-LEVEL CRACK PROTOCOL FOR PAVEMENT CRACK REPORTING

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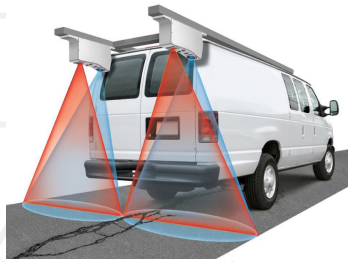
OUTLINE

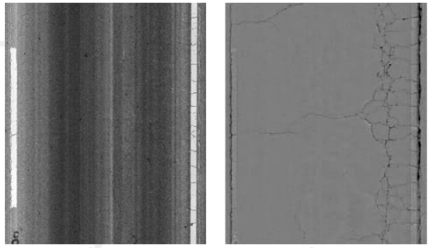
- Needs for a crack protocol to standardize:
  - Comparable crack information, such as HPMS reporting
  - Agencies' crack reporting needs (e.g., crack type classification)
- Proposed three-level protocol
- Case studies

What Were We Lacking? – Comparable Crack Protocol

Automated Data Collection



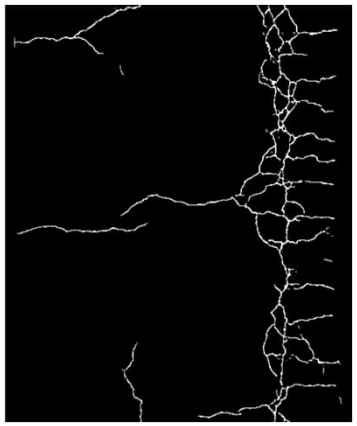
3D Imaging System



2D 3D

Pavement Image

Automated Crack Detection



Crack Map

Lacking a Comparable Crack Protocol (Fundamental **Crack Map Representation** & Customizable **Definitions)**

Lacking:

a) **Crack fundamental elements** to represent crack maps with engineering significance.

b) Standard digitized format to **model and store crack information** to make it comparable.

c) **Detailed definitions and procedures** with clear, repeatable execution guidance, with the ability to customize to different agencies' practices.

SHA Application

Agencies Application (PMS)

a) Performance Monitoring

b) Treatment Decision-making

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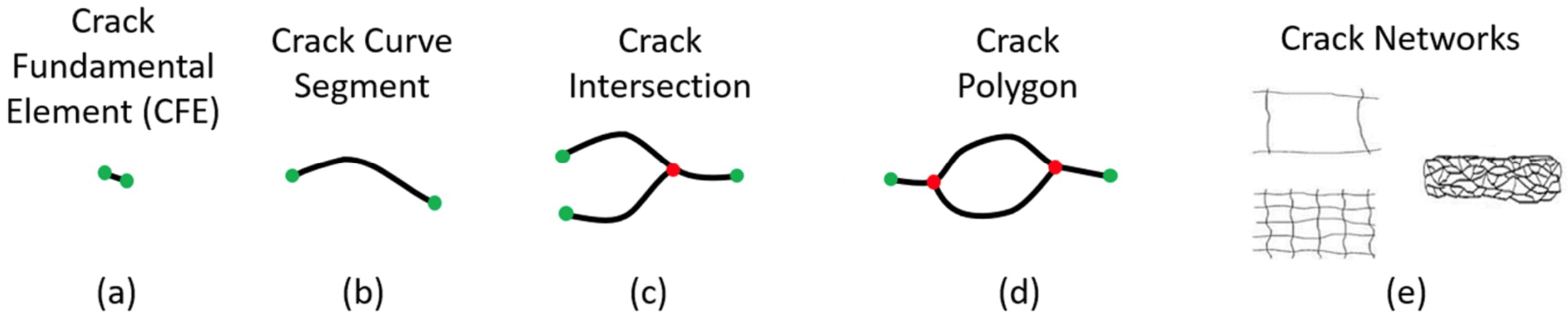
Crack Fundamental Element

- The concept of the crack fundamental element (CFE) was originally proposed by Dr. Tsai in 2014:
  1. Using fundamental geometry elements, like node and link, to represent crack geometry.
  2. Similar to roadway networks, existing GIS knowledge is leveraged.
- CFE serves as the basis of the digital twin of cracking data to perform the measurement and reporting in a digitized format.



Crack Fundamental Element

Tsai, Y., Jiang, C., Huang, Y. (2014) "A Multi-scale Crack Fundamental Element Model for Real World Pavement Crack Classification", ASCE Journal of Computing in Civil Engineering, vol. 28, no. 4, 2014

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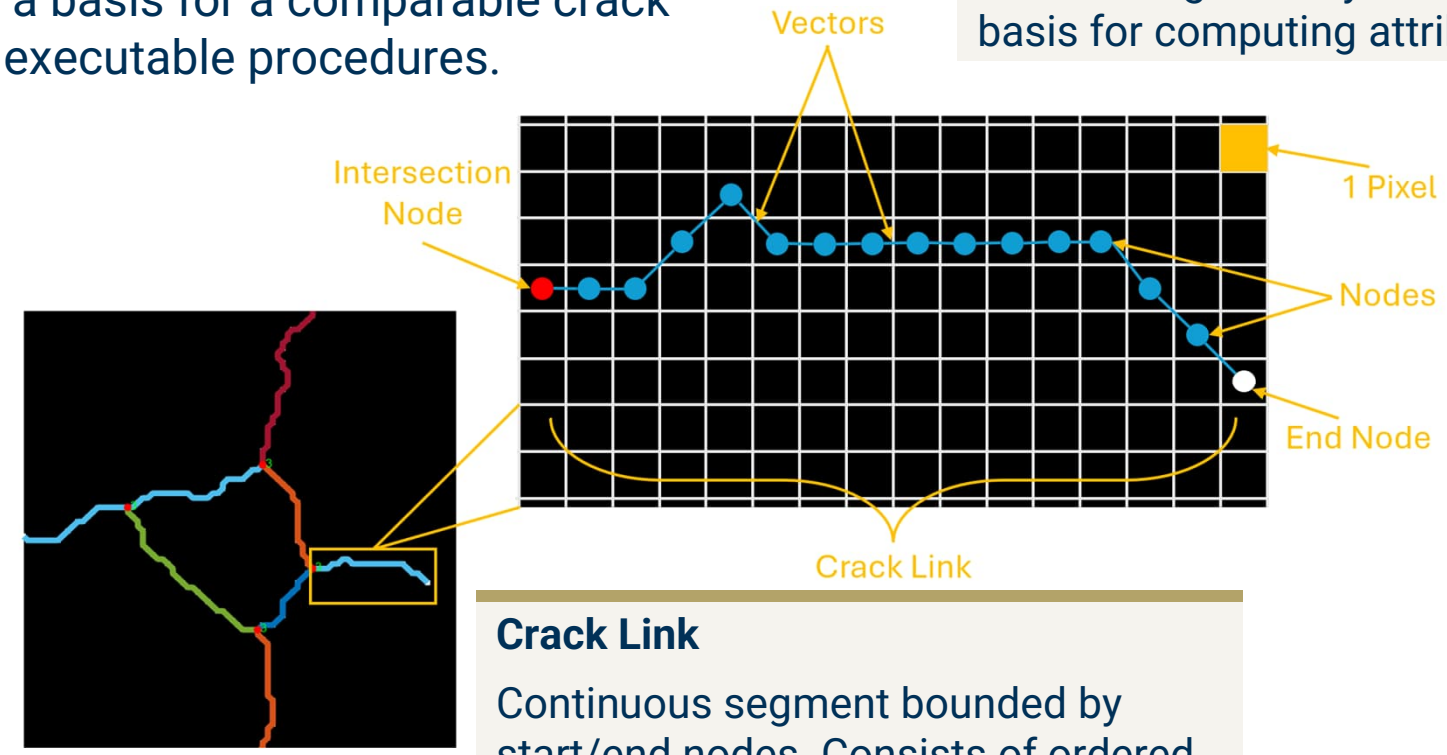
Crack Vector Model (CVM) as Fundamental Data Layer

CVM (Yang, 2024), developed on the concept of the **crack fundamental element** (Tsai, 2014), is introduced to provide the fundamental crack information as a basis for a comparable crack definition with executable procedures.

Crack Vector

Straight-line segment between two adjacent nodes. Vectors collectively define link geometry and serve as a basis for computing attributes.



Crack Node

Discrete digitized point describing geometry. Includes start, end, and intermediate nodes capturing curvature. Default spacing: 1 pixel.

Crack Link

Continuous segment bounded by start/end nodes. Consists of ordered crack nodes connected by vectors. The fundamental analytical unit.

Yang, Z. (2024). Crack propagation analysis using pavement image registration and crack vector model for predictive and precision pavement maintenance. Georgia Institute of Technology.

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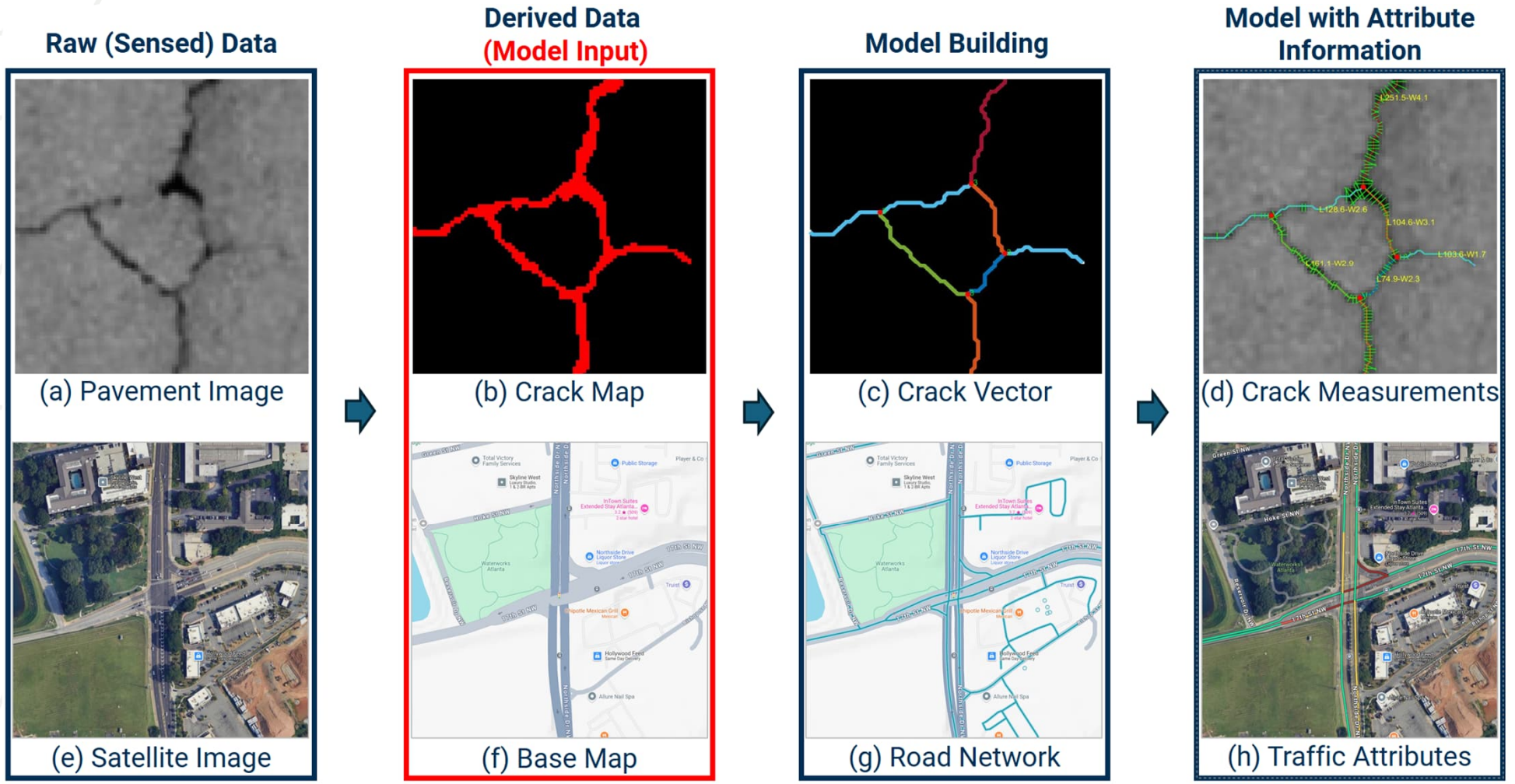
Analogy Between CFE/CVM and GIS

Leveraging GIS concepts that represent roads as network links with traffic attributes, **CFE and CVM represent cracks as links with geometric attributes and provide a practical way to quantify crack elements for fundamental, invariant information.**



CVM	→	GIS
Crack Link	→	Road Segment
Crack Node	→	Intersection / Endpoint
Crack Vector	→	Path between nodes

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Data Processing Advantages of CVM

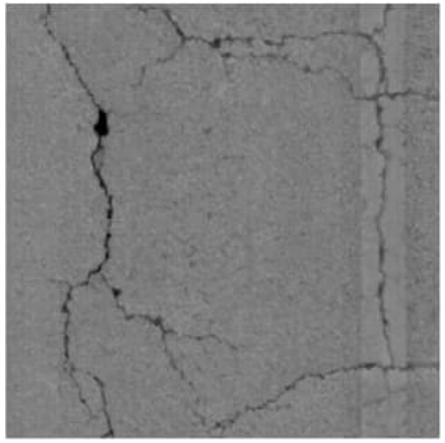
Compared to pavement images and crack maps, CVM:

1. Reduces data size: ~2 MB to ~200 KB per image
2. Expedite data processing: crack information immediately queryable — no repeated extraction is needed, saving time.

Larger Data Size
~2 MB
(5m long image)

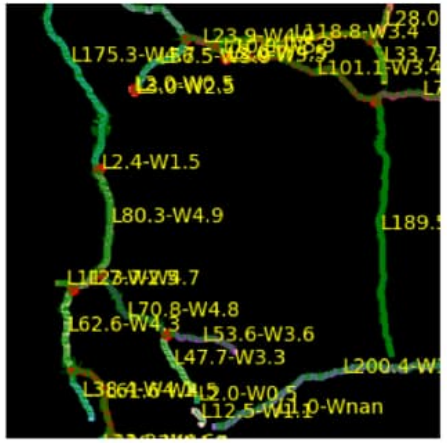
1m

Need to Extract Crack Information



Pavement Image

Crack Map



CVM

Smaller Data Size
~200 KB

Crack Information Ready

Yang, Z. (2024). Crack propagation analysis using pavement image registration and crack vector model for predictive and precision pavement maintenance. Georgia Institute of Technology.

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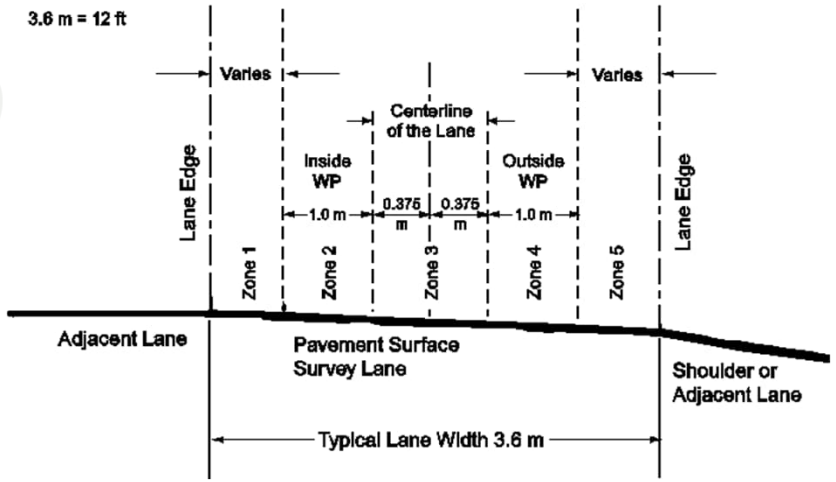
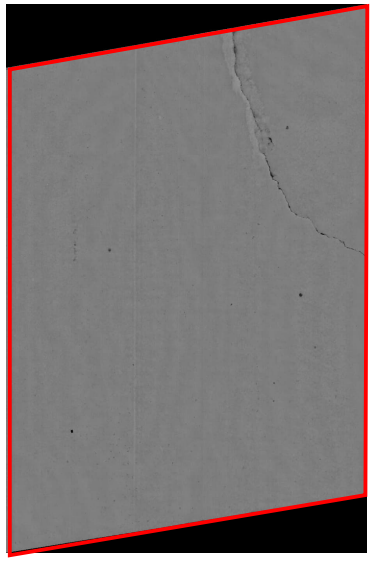
Level 1 Link-wise Crack Reporting Using CVM

Data:	Image ID	Zone Boundary	Link ID	Node Coordinates	Width (mm or in.)	Sealed Crack (0/1)	Representative Width (mm or in.)		Length (mm or in.)	Orientation (degree)	Position (zone, ratio)	Density (mm/m^2 or in/ft^2)	Alligator Crack (0/1)
	L-x1*	**L-x2**	**L-x3**	**L-x4**	**L-x5**	**L-x6**	**L-x7**	**L-x8**	**L-x9**	**L-x10**	**L-x11**	**L-x12**	**L-x13**
Definitions	-	Position location (lane markings or slab #)	Crack link (n)	[(x_1, y_1), (x_2, y_2), ...(x_n, y_n)]	(w_1, w_2, ... w_n)	Yes/ No	Average or representative width		Sqroot [$(y_n-y_1)^2 + (x_n-x_1)^2$]	atan2 (yn-y1, xn-x1)	-		
Asphalt specific	*(*x*=A) L-A1	Zone Position for lane marking zone1_left_px=z1 zone2_left_px=z2 zone3_left_px=z3l zone3_right_px=z3r zone4_left_px=z4 zone5_left_px=z5					Ave of w_2 to w_{n-1} shown in example	Severity Level (L/M/H)				indicator of adj. cracks	Yes/ No Defined by density of adj. cracks
JPCP specific	*(*x*=J) L-J1	Slab ID, 1 to n					Same as asphalt	Future			N/A	N/A	N/A

Level 1 Reporting Items



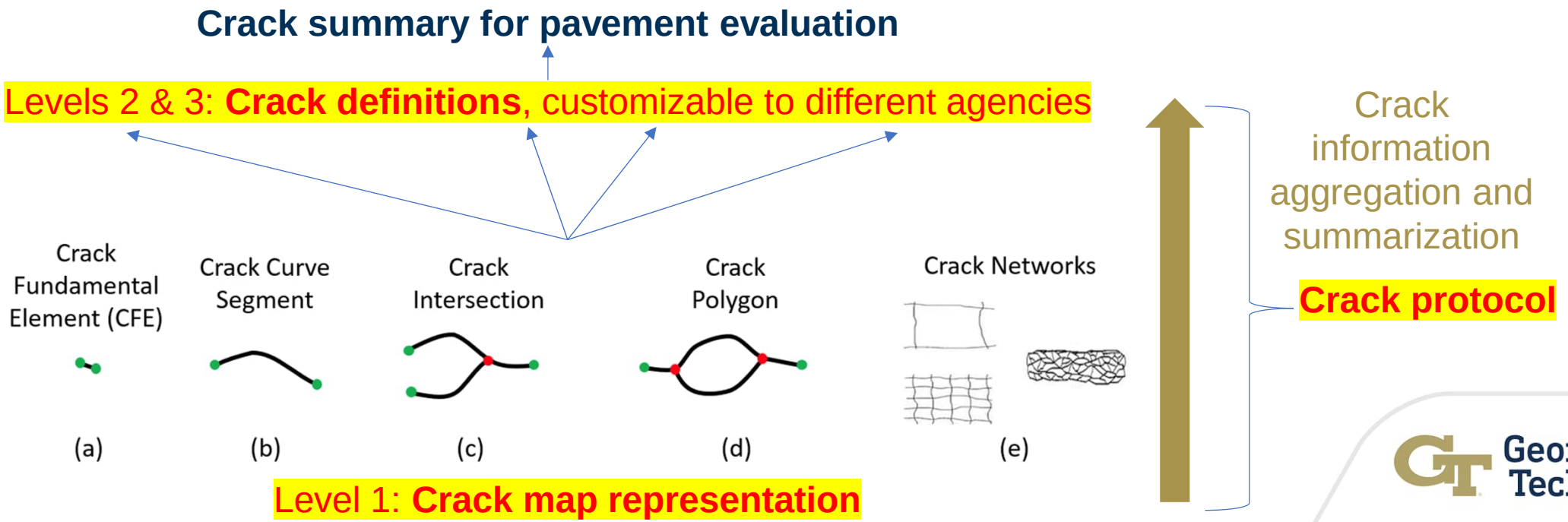
Zone Layout (Asphalt/CRCP)



Slab Layout (JPCP/JRCP)

Proposed Three-Level Hierarchy

- **Level 1** serves as the **crack map representation** because it captures the fundamental and invariant information extracted directly from crack maps.
- **Levels 2 and 3** are **definitions**, as they depend on the specific interpretations, criteria, and reporting needs of different agencies and can therefore be customized.
- Accordingly, the overall procedure that transforms the Level 1 crack map representation into the Level 2 and Level 3 definitions is referred to as a **protocol**.



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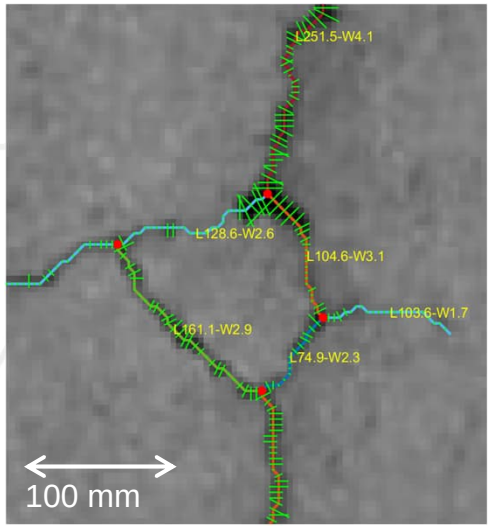
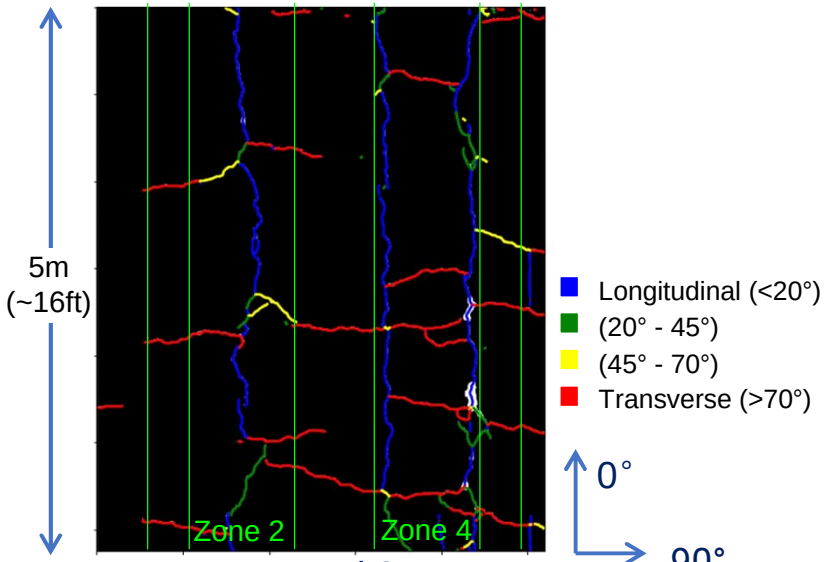
Detailed Crack Protocol (Asphalt & CRCP)

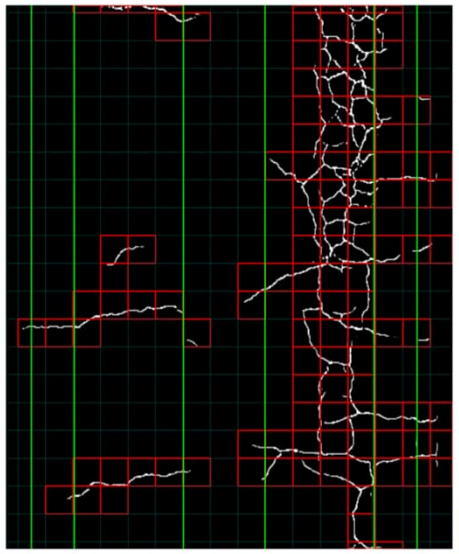
- **Level-1 Link-wise** cracking information: Store and report fundamental cracking information at the crack link level.
- **Level-2 Aggregated** cracking information: Aggregate by mutually exclusive crack types. Report by severity and zones.
- **Level-3 Grid-based** cracking information: Report cracking percentage by severity level, zone, and overall section by grid measurement.



Level-1



Level-2


Level-3

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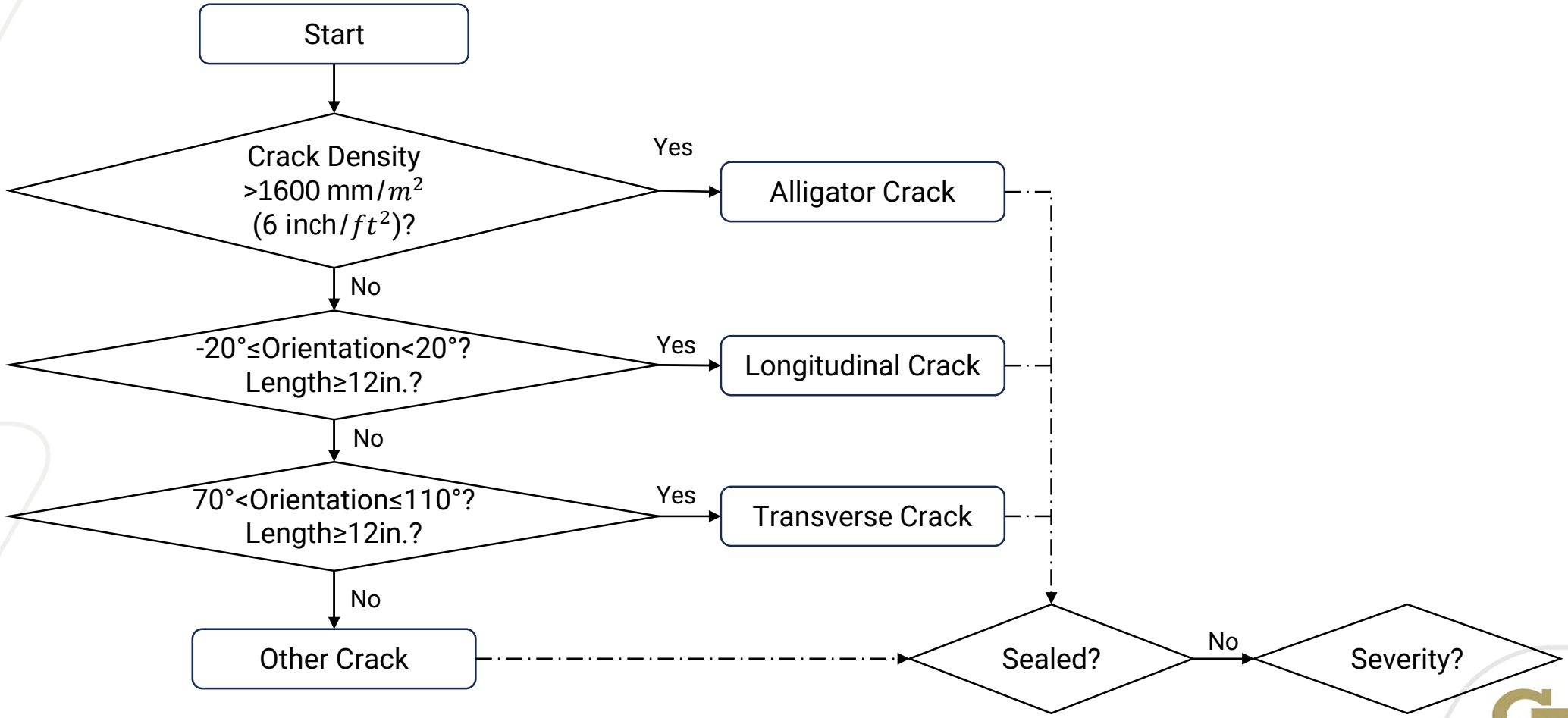
Level 2 Classification Using Drop-out Method

Developed the drop-out method for mutually exclusive crack type classification sequence.



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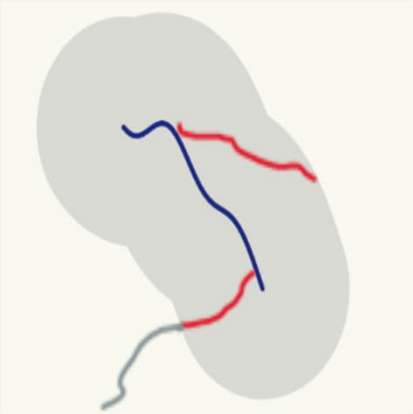
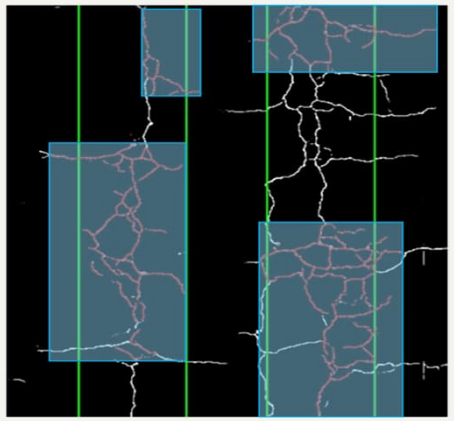
Customizable Level 2 Classification Criteria

1 First: Alligator Crack Identification using Crack Density (Asphalt only)



Density Buffer Method



Alligator Crack Area

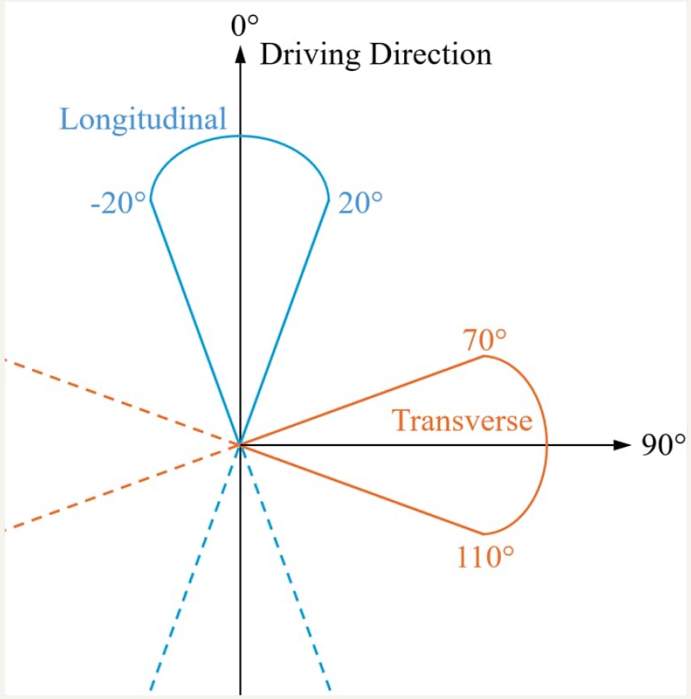
For each crack link, construct a 450mm (1.5 ft) circular buffer.

Compute density = surrounding crack length / buffer area.

Links exceeding 1,600 mm/m² (6 in/ft²) → alligator.

Excluded before orientation-based classification.

2 Then: Orientation-Based Types



Longitudinal: -20° to 20° (min. 12 in.)

Transverse: 70° to 110° (min. 12 in.)

Other: all remaining crack links

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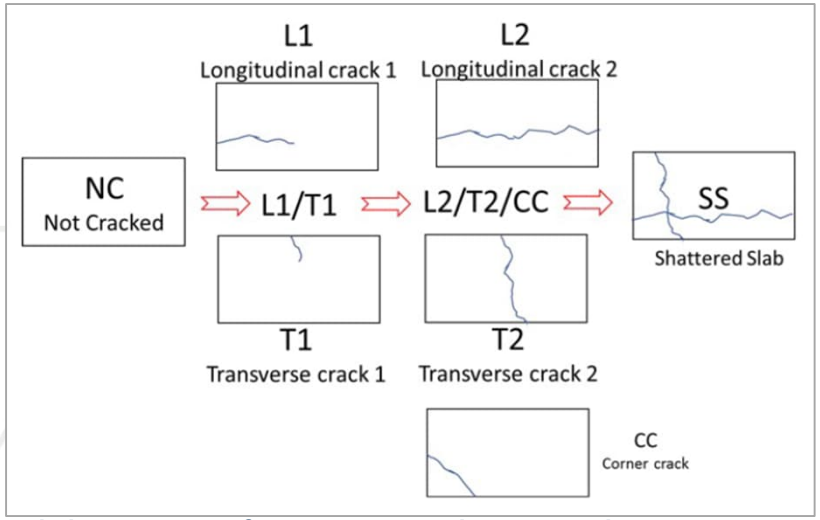
Detailed Crack Definitions (JPCP/JRCP)

- **Level 1 Link-wise**
  Similar to asphalt, but each crack link is associated with a Slab ID.
- **Level 2 Aggregated (Slab-wise)**
  Report aggregated information per slab.
- **Level 3 Grid-based (Slab as Grid and Reporting Slab State)**
  Classify slabs into different states. And report the proportion in each state.



Slab State Definition Based on Cracking Pattern (Geary, 2021)

Key Design for JPCP/JRCP:

Treats each slab as an adaptive grid unit to directly support slab replacement planning and end-of-life estimation.

Geary, G. M. and Y. Tsai (2021). A 3D Slab-Based Methodology to predict end of life for concrete pavements, in International Journal of Pavement Engineering.

Recommended Implementation Process

Comparable Fondation

Customizable Reporting

1	2	3	4	5	6
Data Collection	**Preprocessing**	**CVM Processing**	**Level 1 Report**	**Level 2 Report**	**Level 3 Report**
Collect 3D pavement images per AASHTO standards	Generate binary crack maps; identify zones (1–5)	Vectorize crack map into link-node model with attributes	Link-wise attributes: geometry, width, sealed status	Aggregate by crack type, severity, and zone	Grid-based % (asphalt/CRCP) or slab state % (JPCP/JRCP)

Bottom-Up Structure: Measurement → Aggregation → Reporting

Users can trace any reported statistic back to its underlying measurements.

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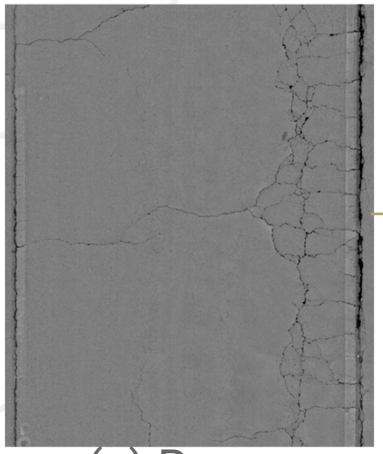
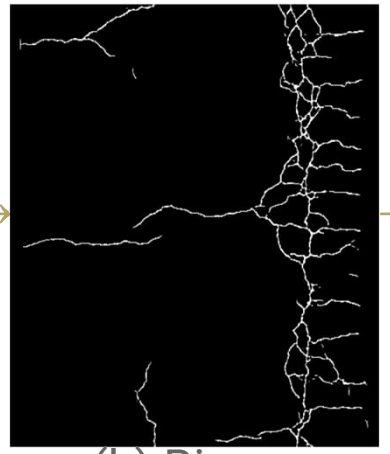
Asphalt Case Study

Collection & Processing

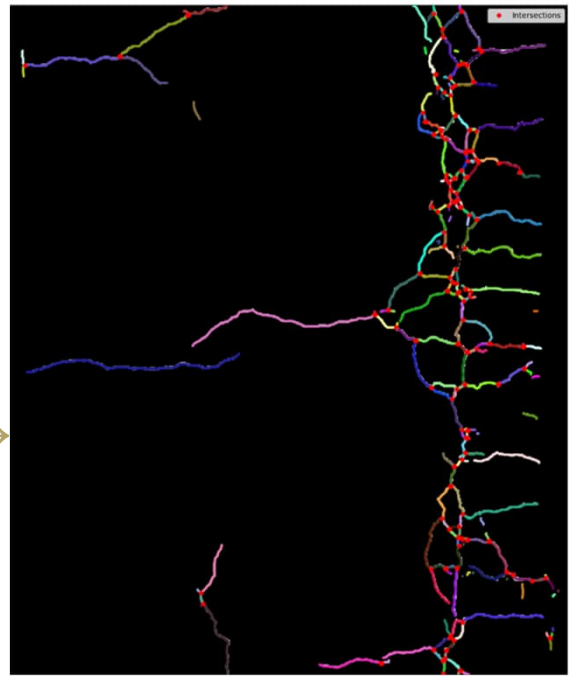


(a) Range Image



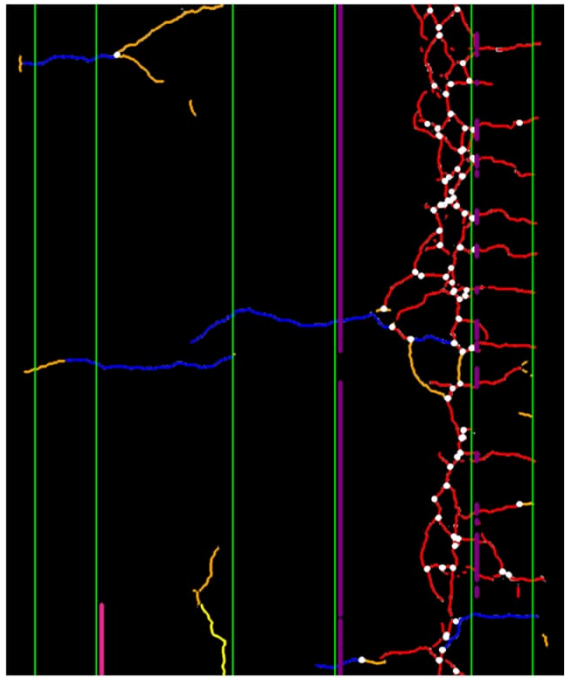
(b) Binary Crack Map

Level 1



(c) CVM (colored links)

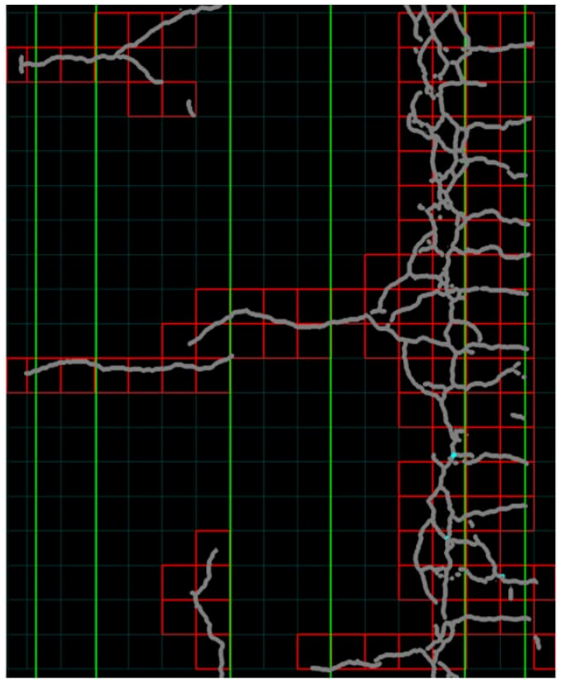
Level 2



(d) Aggregated Crack Information

- Alligator
- Longitudinal
- Transverse
- Other

Level 3



(e) Grid Percentage

- Low severity
  26.35%
- Medium
  0.63% (Zone 4),
  0.32% (Zone 5)
- High
  0%

JPCP Case Study

0.1-mile section with 40 slabs demonstrating slab-based reporting.

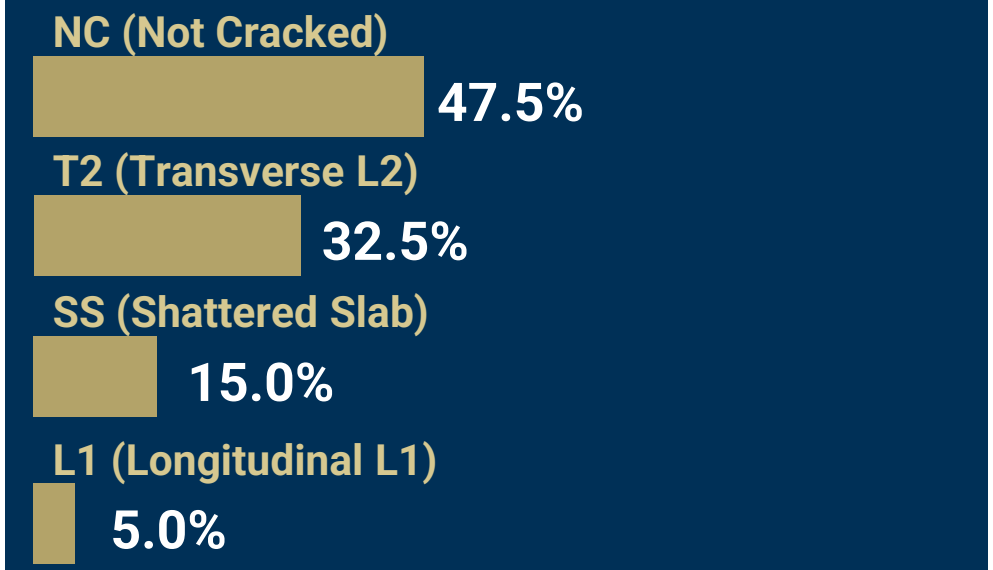
Level 1: Link-wise (Slab-based)

Each crack link is associated with the Slab ID for traceability. A single slab may span adjacent images.

Level 2: Slab-wise Aggregation

	Cracked Slabs	Total Length
Slabs	21 of 40	—
Longitudinal	—	19,823 mm
Transverse	—	54,302 mm
Other	—	25,697 mm

Level 3: Slab State Classification



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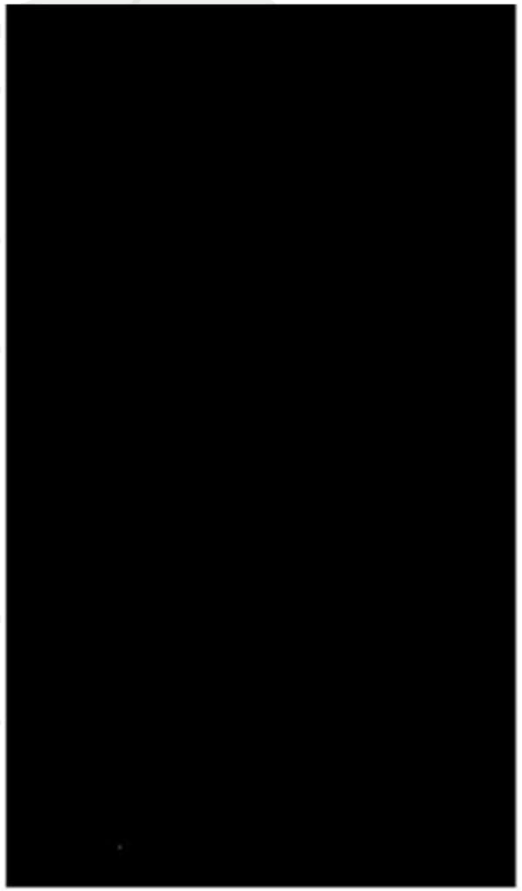
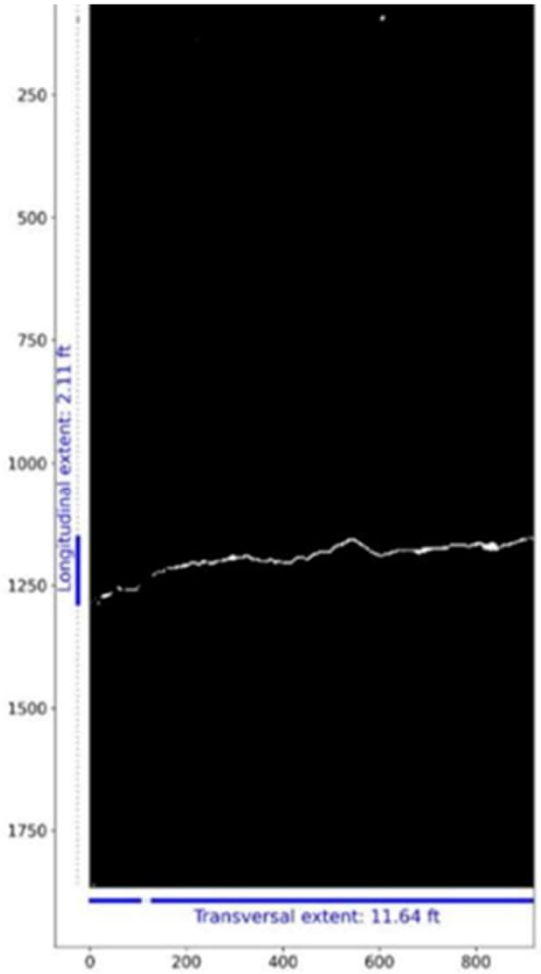
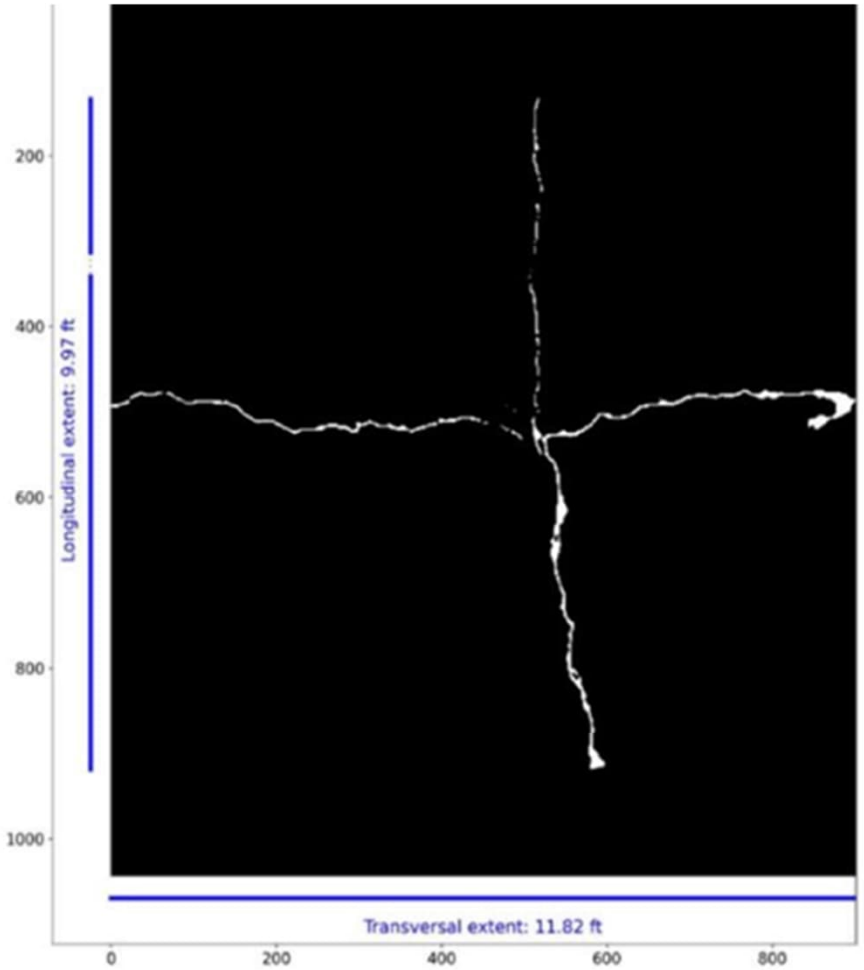
JPCP Case Study – Slab State Examples



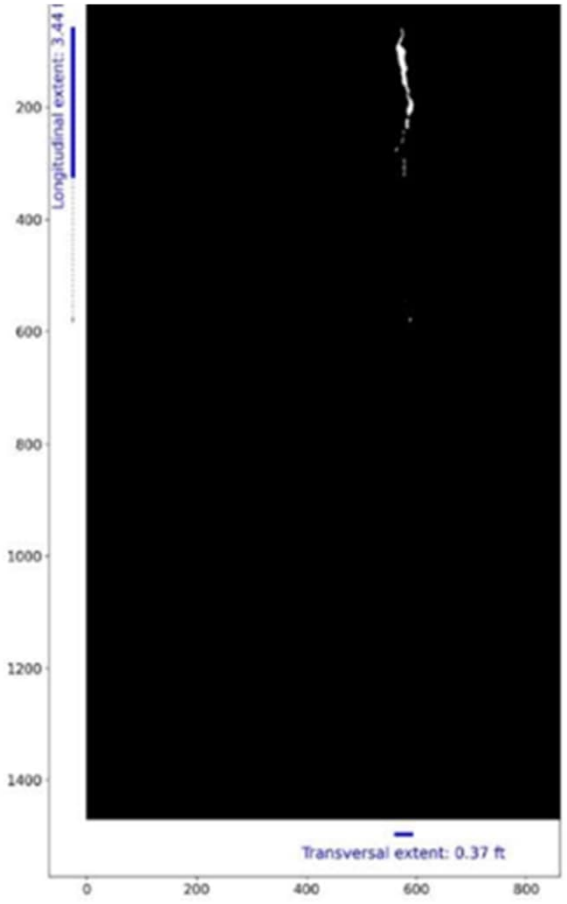
Not Cracked (NC)



Transverse Level 2



Shattered Slab



Longitudinal Level 1

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Conclusions

Proposed **comparable crack protocol**, including: **Crack map representation** for fundamental and comparable crack information modeling and storing, and **crack definition** for executable and customizable crack reporting for pavement management.

1. Introduced **CFE/CVM as a foundational data layer** for comparability and flexibility.
2. Illustrated customizable **crack definitions** to aggregate and report fundamental crack information for pavement evaluation.
3. Designed a **bottom-up 3-level hierarchy** (link-wise → aggregated → percentage) for practicality and traceability.

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THANK YOU!

QUESTIONS?

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2026 RPUG CONFERENCE ★ PITTSBURGH, PA ★ APRIL 28 - MAY 1