RPUG
Road Profile Users' Group

A THREE-LEVEL CRACK PROTOCOL FOR PAVEMENT CRACK REPORTING

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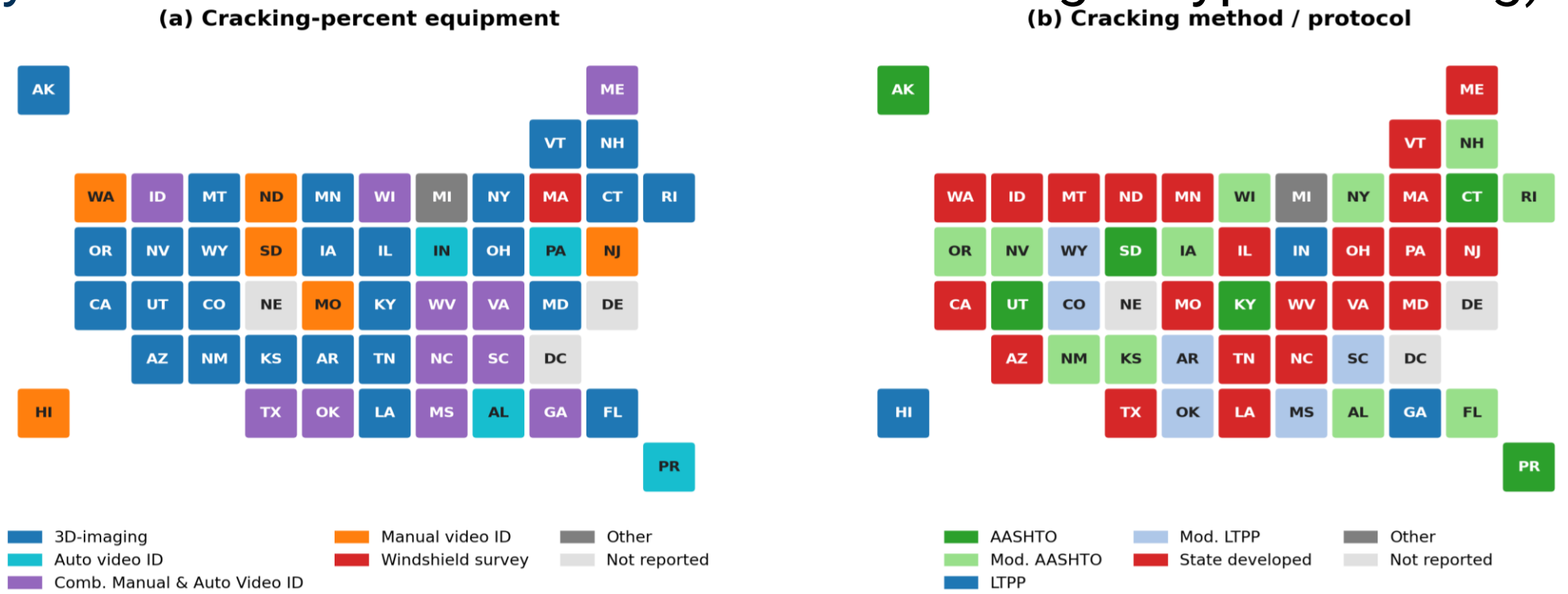
OUTLINE

- 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

The issue: Lack of Consistent Way to Report HPMS Cracking

1. HPMS cracking reports define an indicator for comparison.
2. Most agencies are using 3D imaging system
3. However, the calculation methods vary (e.g., without a consistent way to measure/calculate the extent of fatigue-type cracking).



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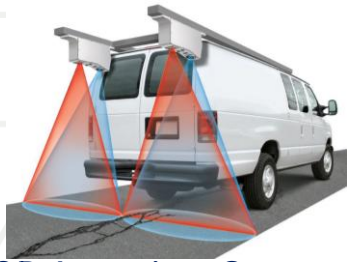
Source: FHWA Highway Statistics, Table HM-66 (2024). Each tile = one state/territory; color = the equipment (a) or protocol (b) the state DOT predominately uses.

The Issues We Are Facing – No Standard Crack Map Representation (CMR)

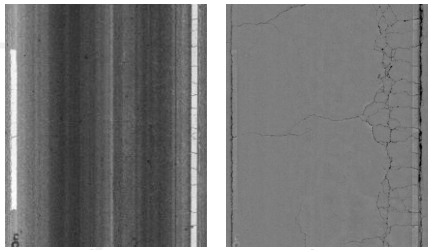
1. **Inconsistent representation and reporting** (e.g., HPMS) **across agencies**.
2. **Weak year-to-year comparability**
   No standard CMR disrupts consistent multi-year performance tracking.
3. **Lack of methods to store important Crack Map information (limited usability of 3D pavement surface image data)**
   Lack of methods to effectively model, store, visualize, analyze and report important Crack Map Info extracted from pavement images.
4. **M&R Effectiveness is difficult to measure**
   Treatment outcomes are difficult to evaluate objectively without using detailed Crack Map Info.

What Were We Lacking? – Comparable Crack Protocol

Automated Data Collection



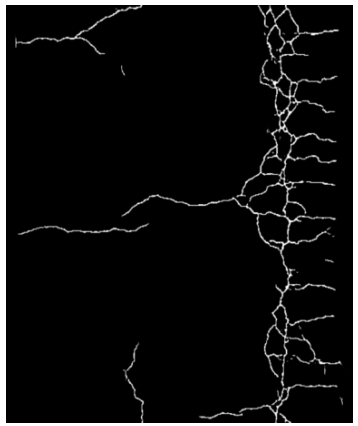
3D Imaging System



2D 3D

Pavement Image

Automated Crack Detection



Crack Map

Crack Map Representation & Definitions

That can:

a) Represent crack maps with engineering significance, not just sets of pixels.

b) Provide standard, simple, repeatable execution guidance to model, store, visualize, analyze, and report crack map info.

SHA Application

Agencies Application (PMS)

a) Performance Monitoring

b) Treatment Decision-making

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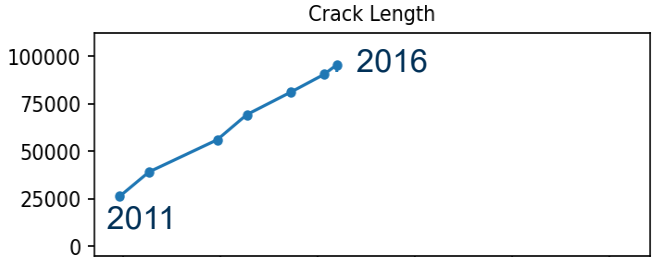
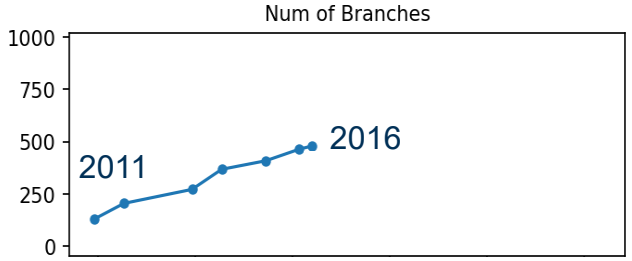
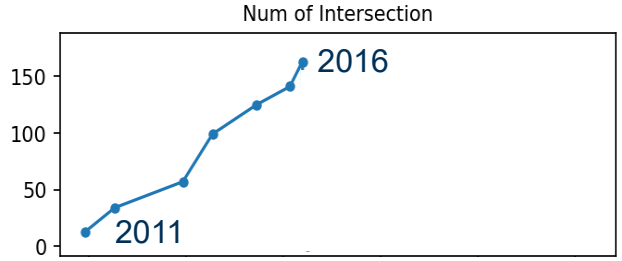
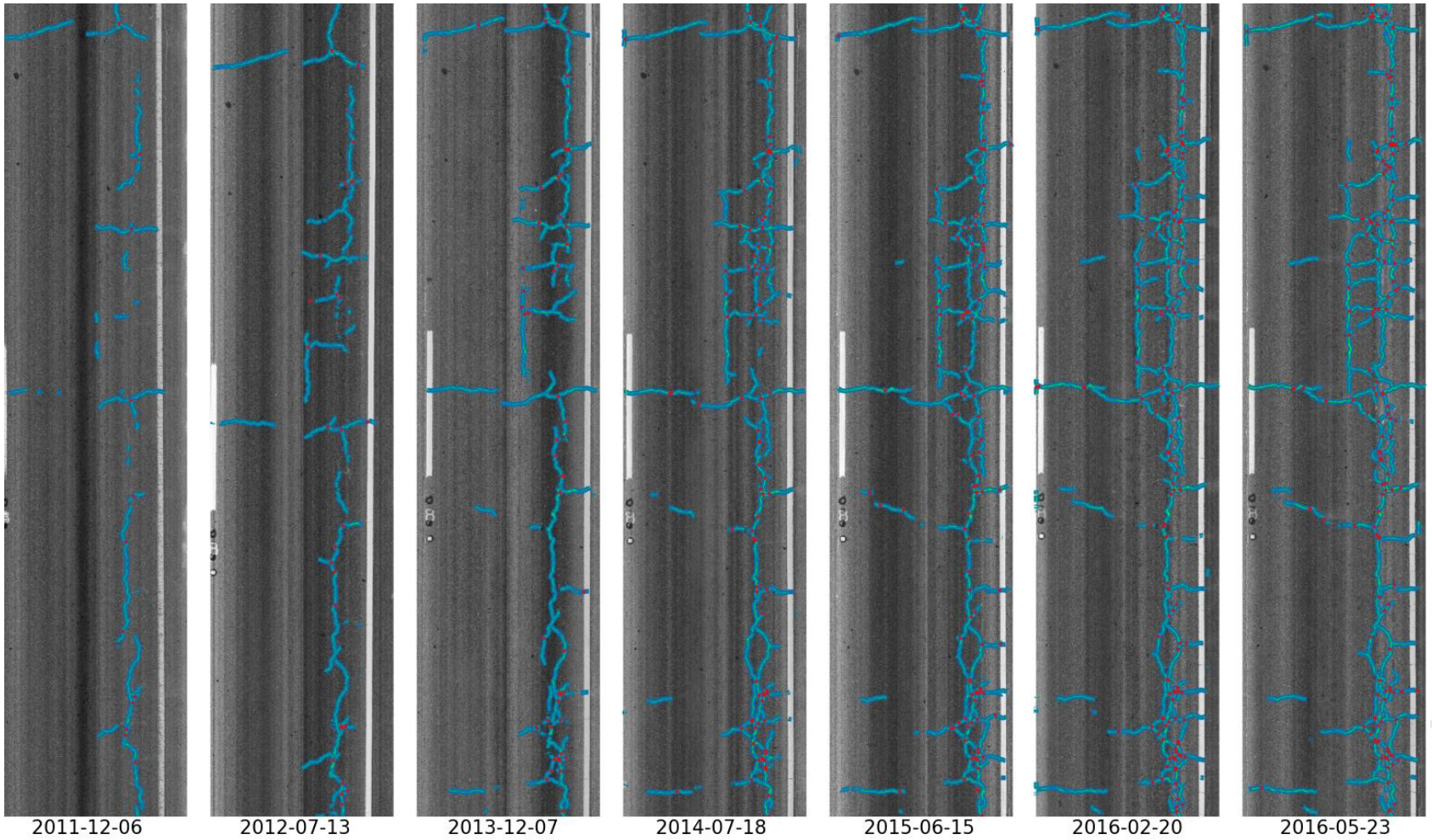
Potential use of Crack Map Info – Go Beyond Statistics







Use fundamental crack geometries to add values on engineering interpretation and utilization



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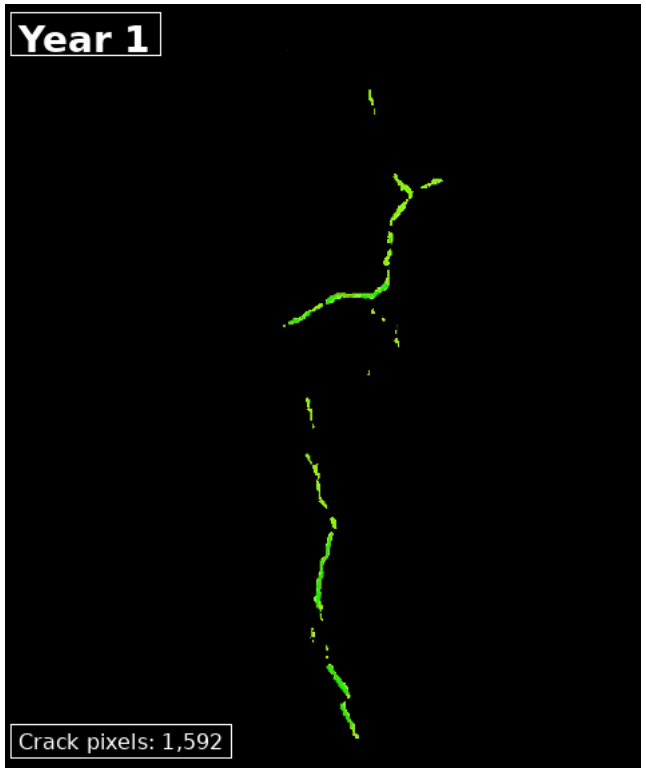
Potential use of Crack Map Info – Go Beyond Statistics to Crack Pattern

Use fundamental crack geometries to add values on engineering interpretation and utilization

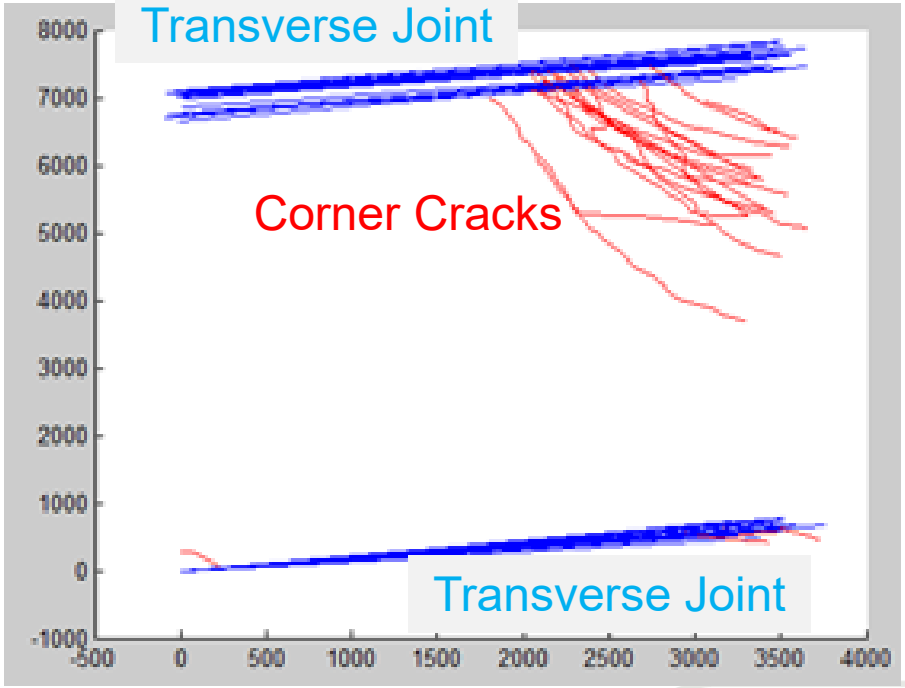
Crack Growth Pattern on Asphalt Pavement
(How would longitudinal cracks deteriorate to alligator cracks)



Year 1: Green
Last Year: Red
Middle Years: Yellow and Orange

Travel Direction

Crack Spatial Pattern on JPCP for Treatment
(What are the spatial characteristics of corner cracks: cases of 20-25 ft slabs)



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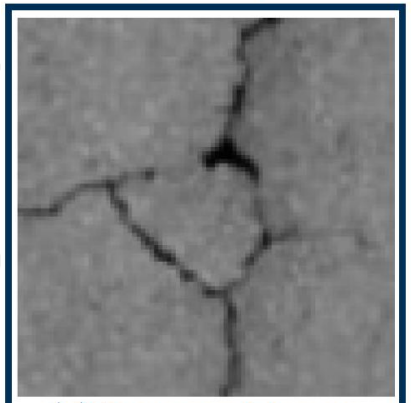
A Crack Map Representation - Leverage from GIS/Google Map

Leveraging GIS concepts that represent roads as network links with traffic attributes, define a method to **model, store, visualize, analyze and report crack geometric attributes** so **fundamental crack geometries and patterns can be utilized and analyzed quantitatively**.

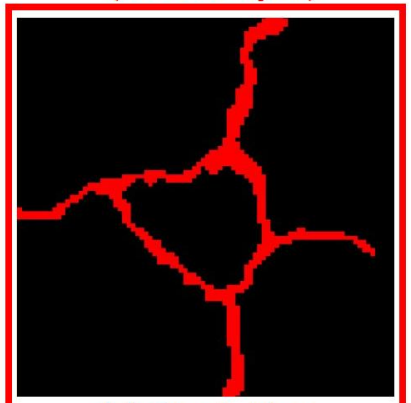
Raw (Sensed) Data



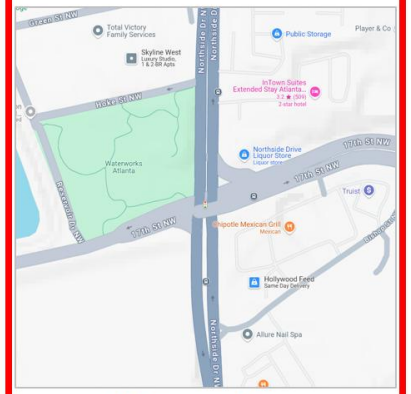
(a) Pavement Image

(e) Satellite Image

Derived Data (Model Input)

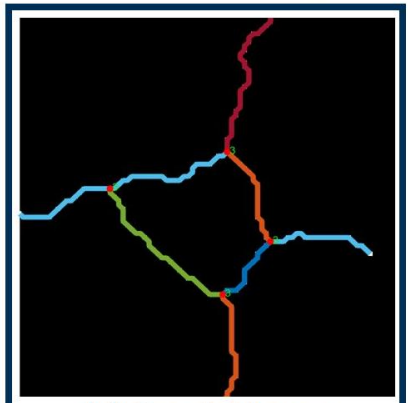


(b) Crack Map



(f) Base Map

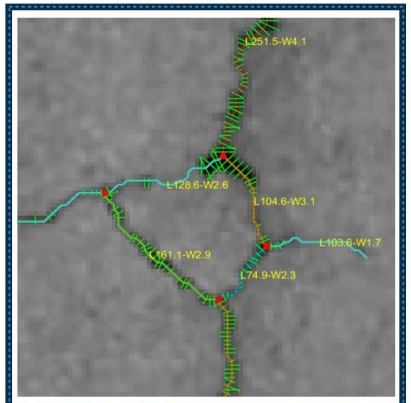
Model Building



(c) Crack Vector

(g) Road Network

Model with Attribute Information



(d) Crack Measurements

(h) Traffic Attributes

Vectorized Crack → **GIS**

Crack Link → Road Segment

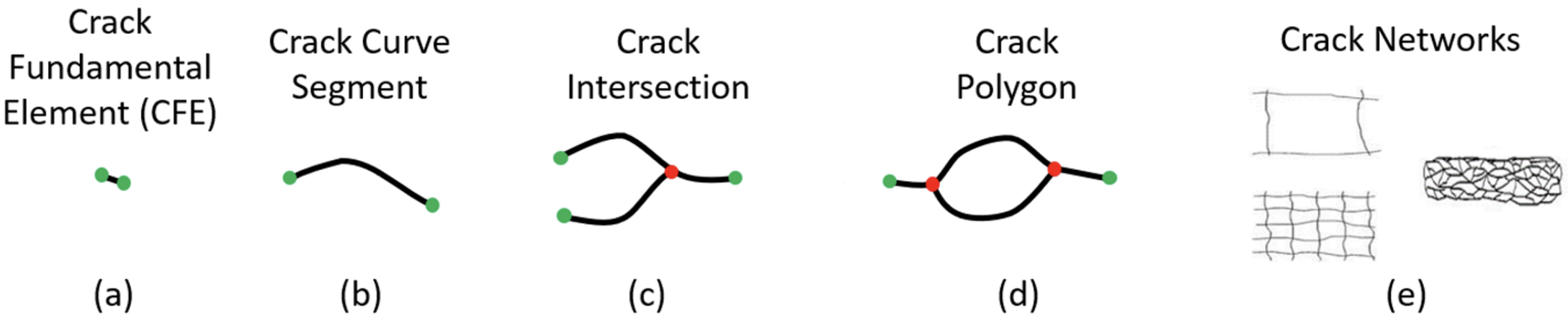
Crack Node → Intersection / Endpoint

Crack Vector → Path between nodes

Crack Fundamental Element

The crack fundamental elements:

1. Use **fundamental geometry (e.g., node and link)** to represent the important crack patterns.
2. Similar to roadway networks, existing GIS knowledge is leveraged.



Crack Fundamental Element

A consistent way to model, store, visualize, analyze and report crack map info

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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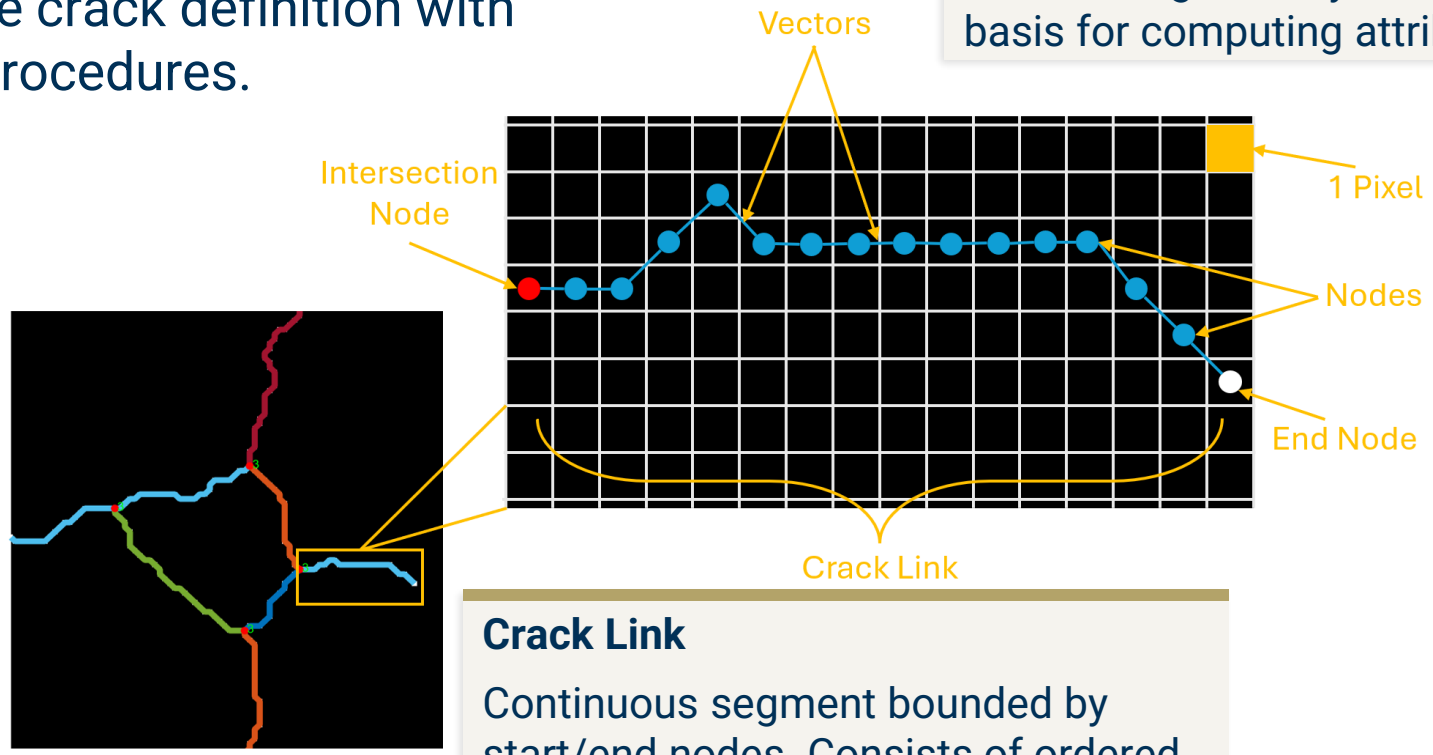
Vectorize Cracking Data as Fundamental Data Layer

Vectorize the cracking data under a uniform format (**Crack Vector Model**) 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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Data Processing Advantages of Vectorized Cracking Data

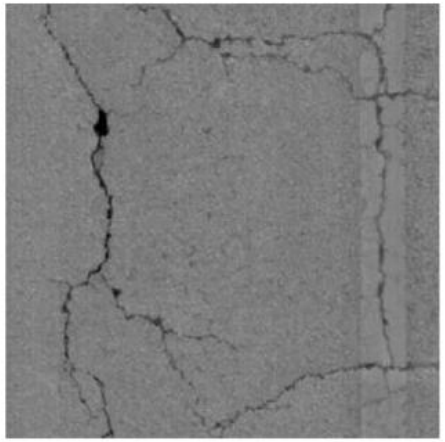
Compared to pavement images and crack maps, vectorized cracking data:

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)

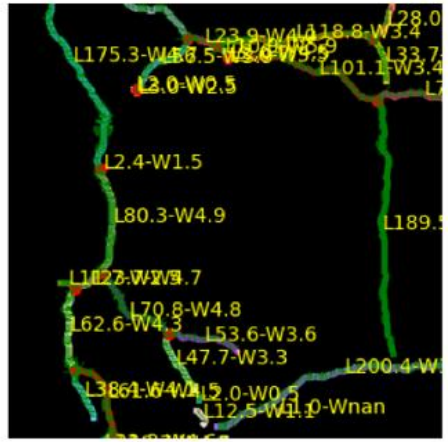
1m

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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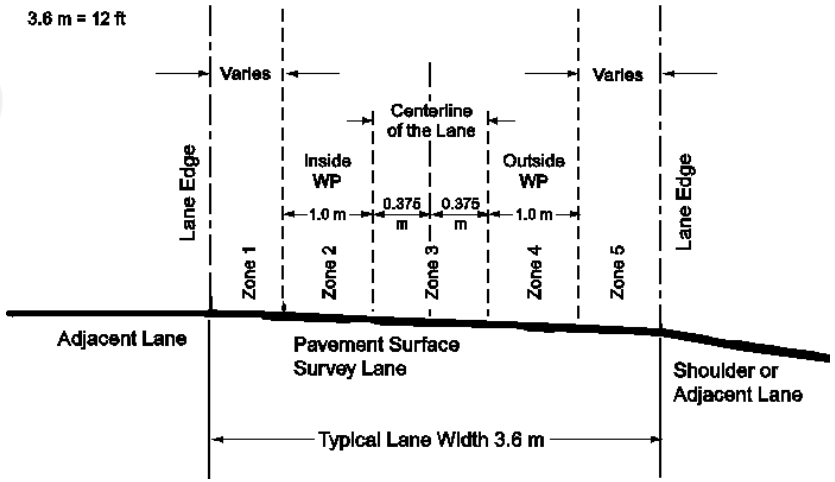
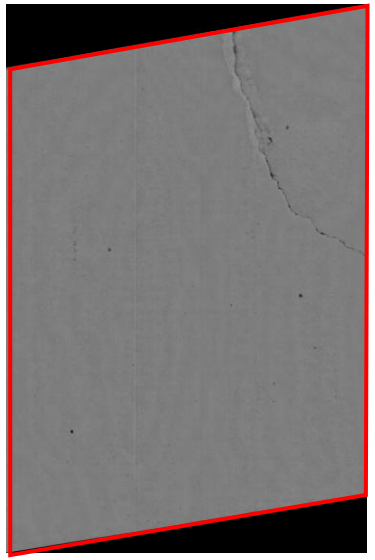
Level 1 Link-wise Crack Reporting Using Vectorized Data

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



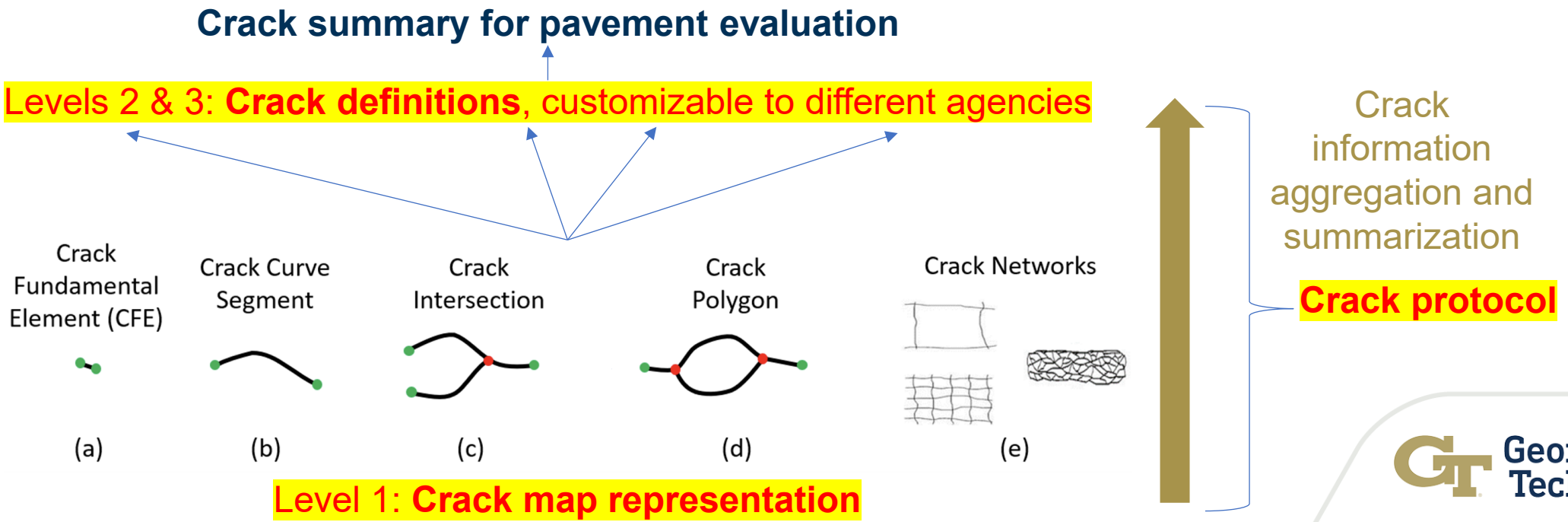
Zone Layout (Asphalt/CRCP)



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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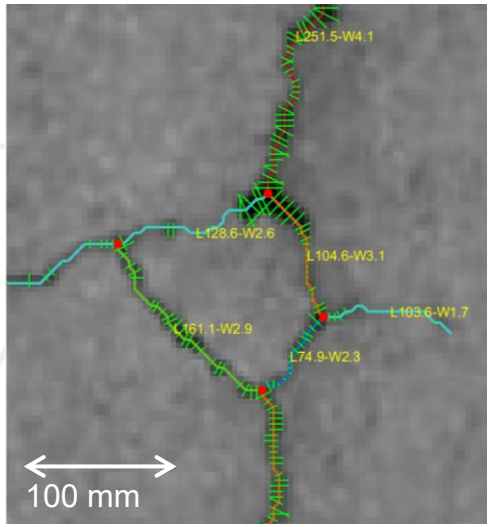
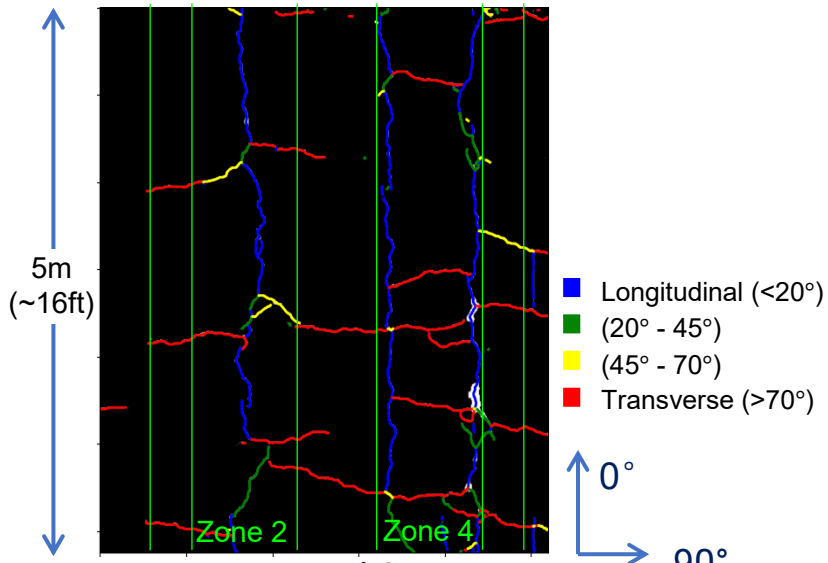
Detailed Crack Protocol (Asphalt & CRCP)

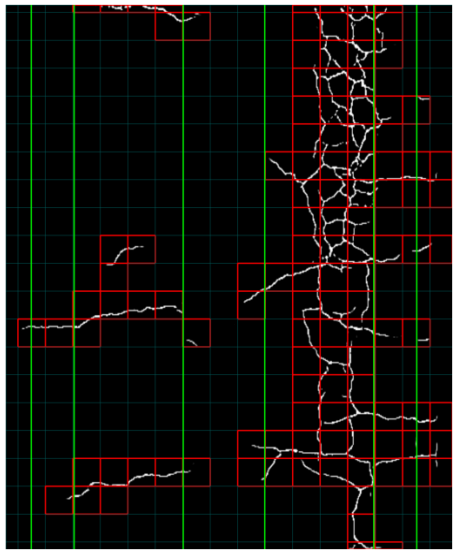
- **Level-1 Link-wise** cracking information: Store and report fundamental cracking information at the crack link level.
- **Level-2 Aggregated** cracking information: Aggregate by mutually exclusive crack types. Report by severity and zones.
- **Level-3 Grid-based** cracking information: Report cracking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



Level-1



Level-2


Level-3

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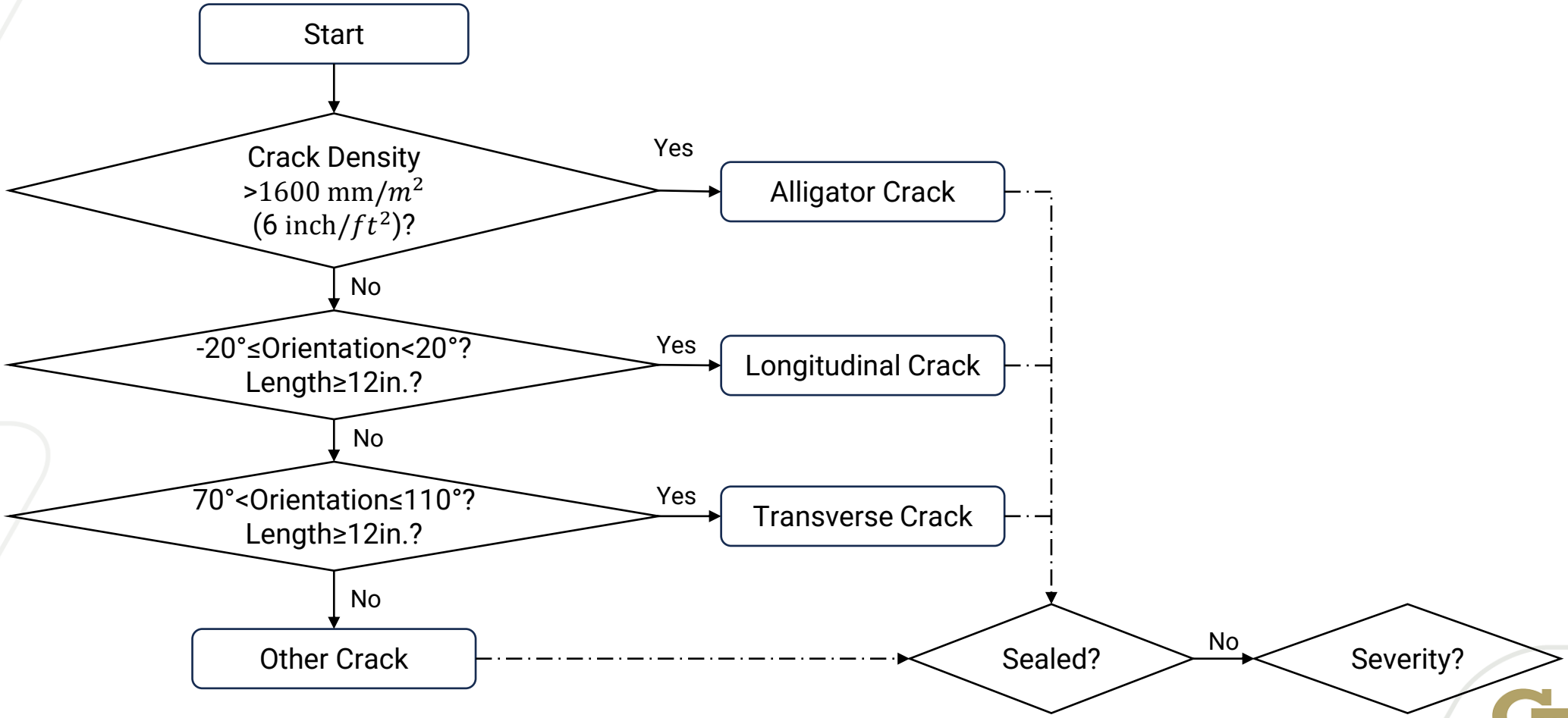
Level 2 Classification Using Drop-out Method

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



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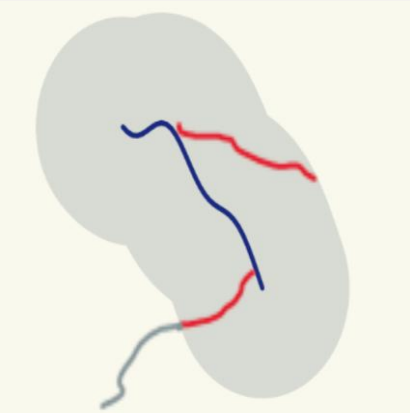
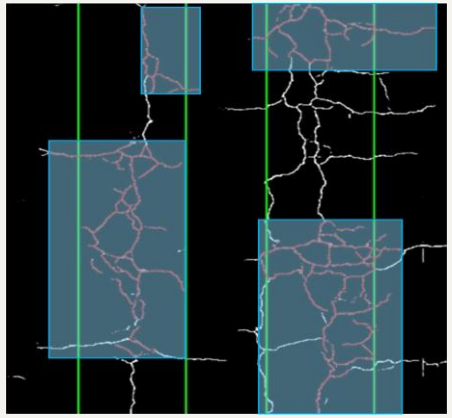
Customizable Level 2 Classification Criteria

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



Density Buffer Method



Alligator Crack Area

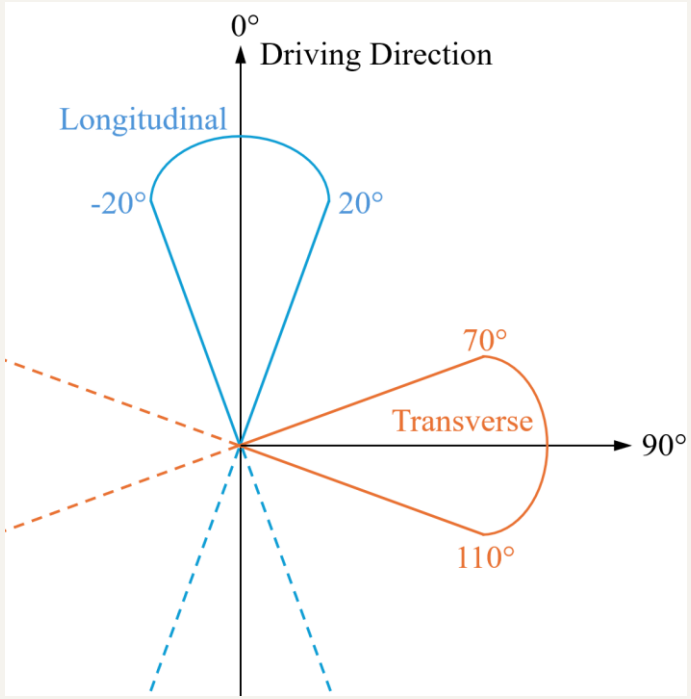
For each crack link, construct a 450mm (1.5 ft) circular buffer.

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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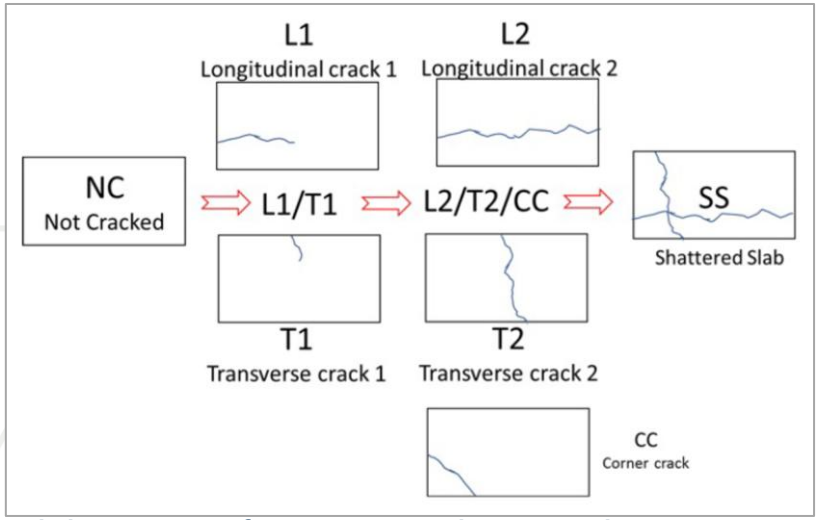
Detailed Crack Definitions (JPCP/JRCP)

- **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)

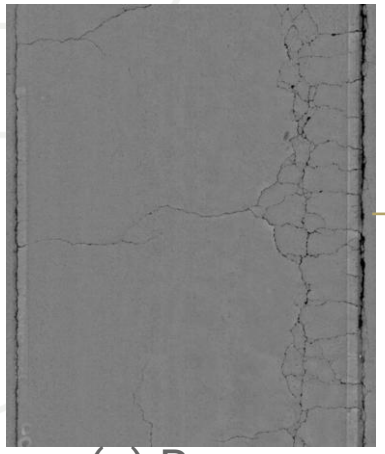
Key Design for JPCP/JRCP:

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

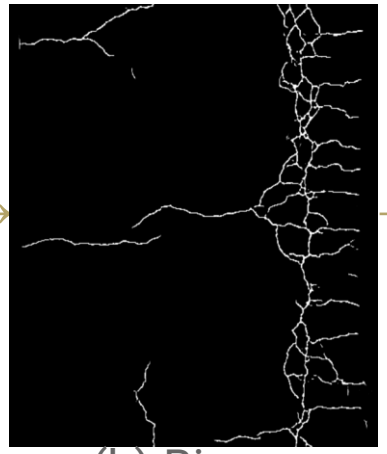
Geary, G. M. and Y. Tsai (2021). A 3D Slab-Based Methodology to predict end of life for concrete pavements, in International Journal of Pavement Engineering.

Asphalt Case Study

Collection & Processing

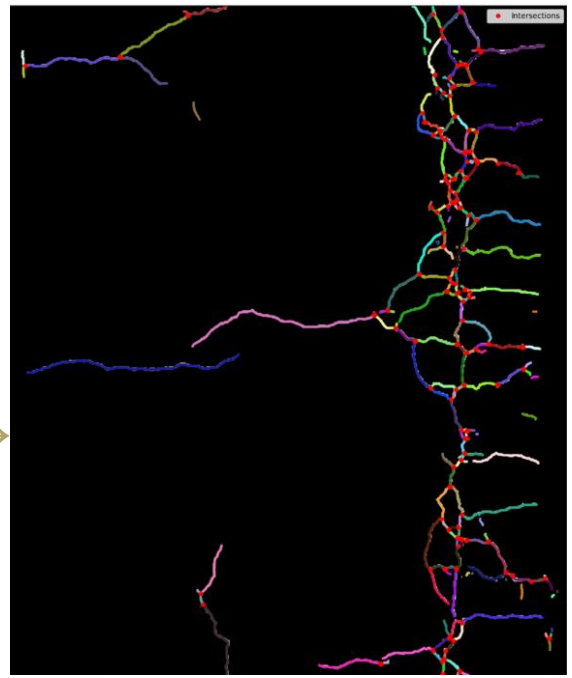


(a) Range Image



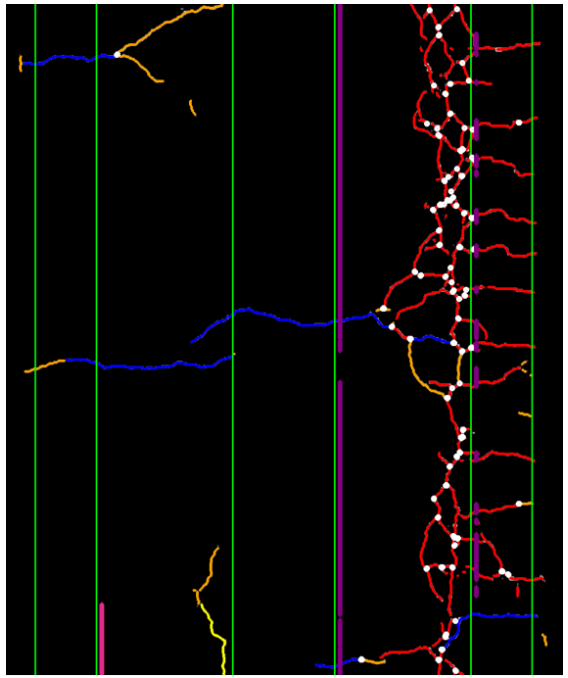
(b) Binary Crack Map

Level 1



(c) Vectorized Cracking (colored links)

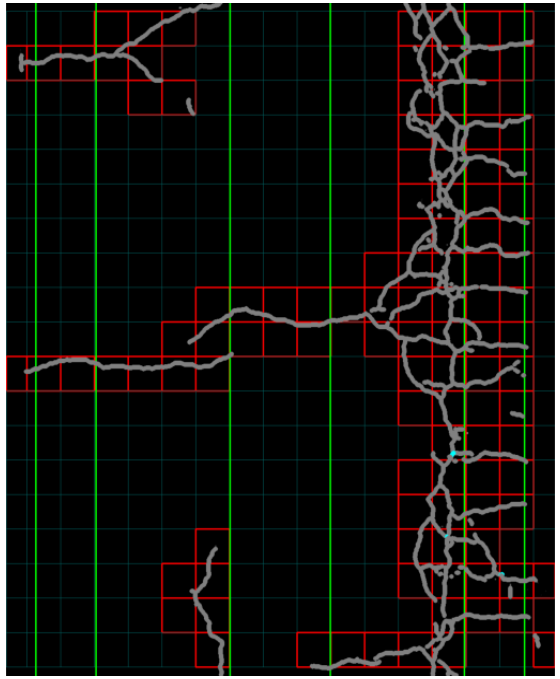
Level 2



(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

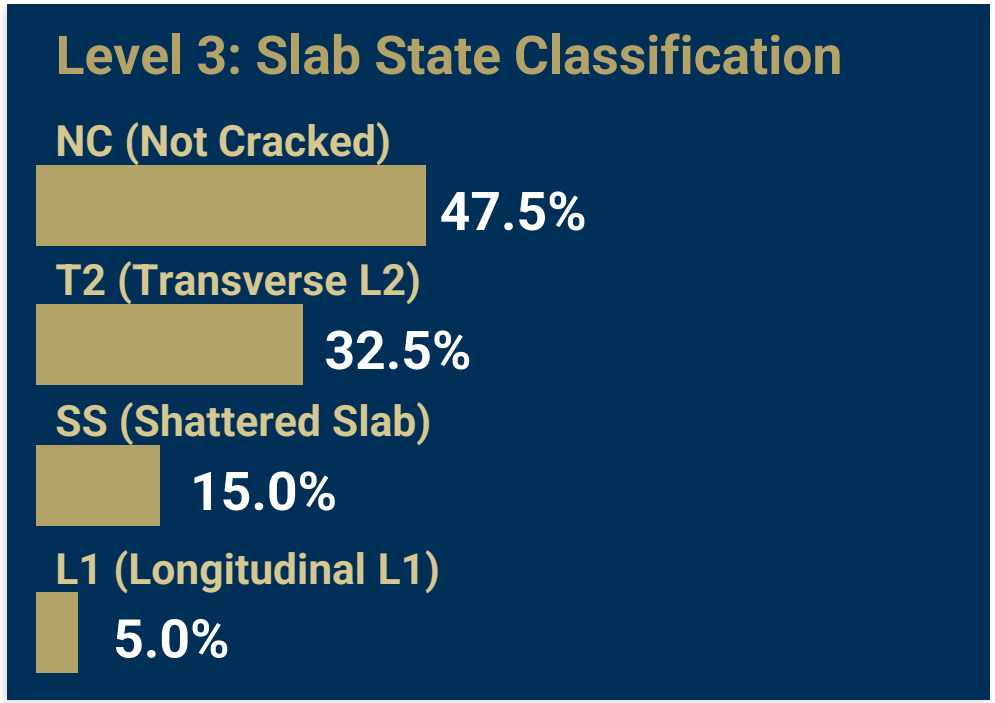
0.1-mile section with 40 slabs demonstrating slab-based reporting.

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



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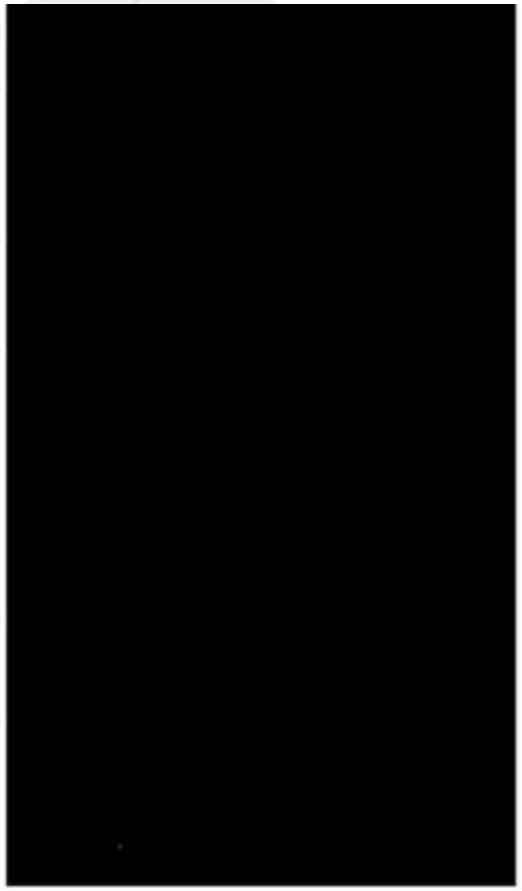
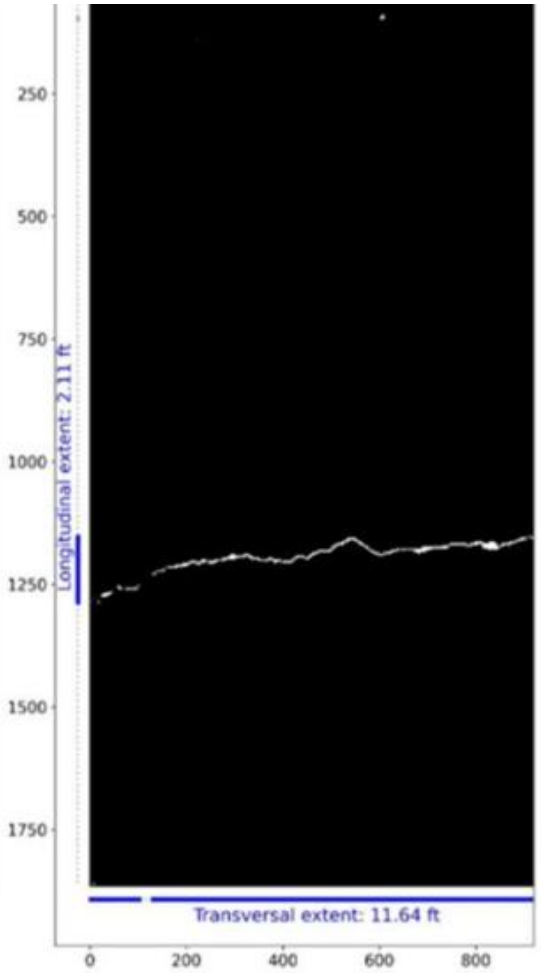
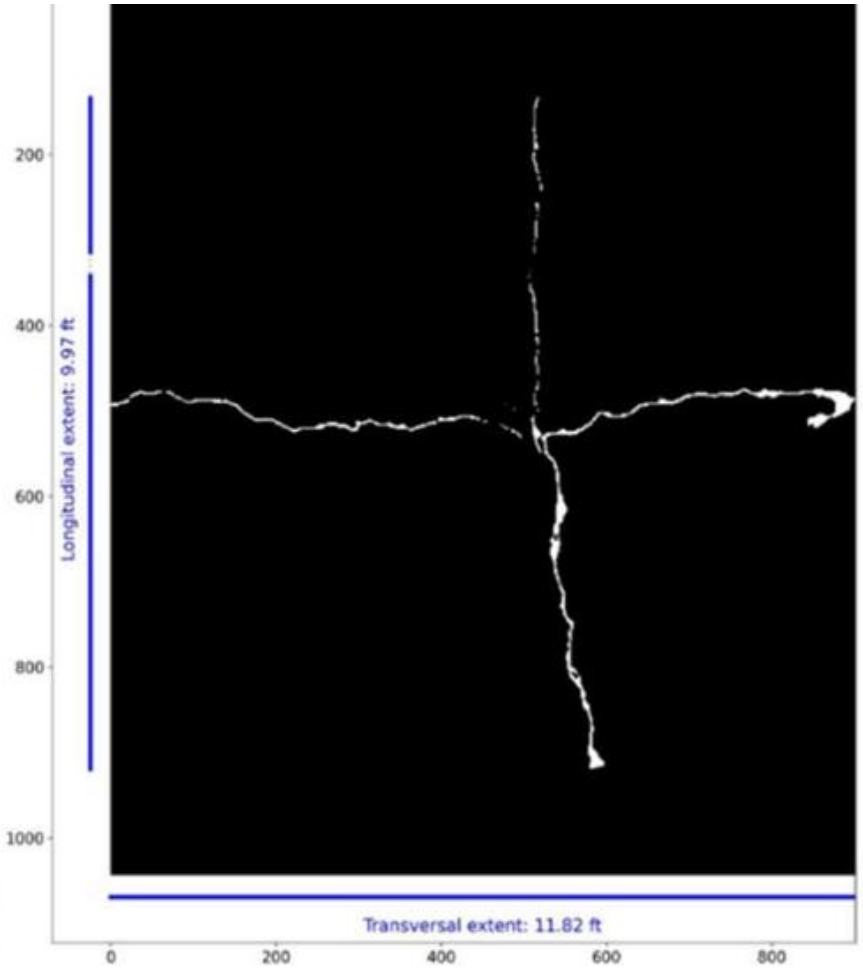
JPCP Case Study – Slab State Examples



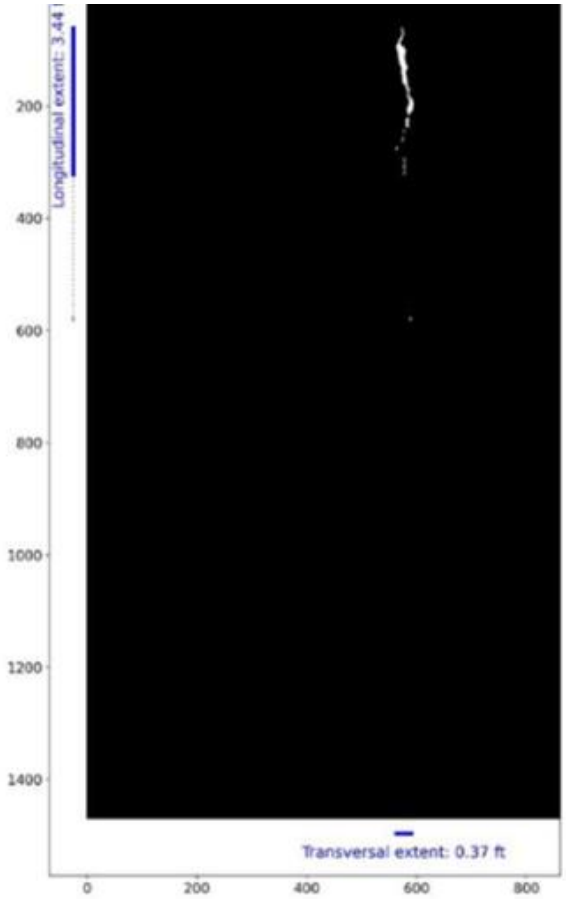
Not Cracked (NC)



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. **Vectorize cracking data** **as the 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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