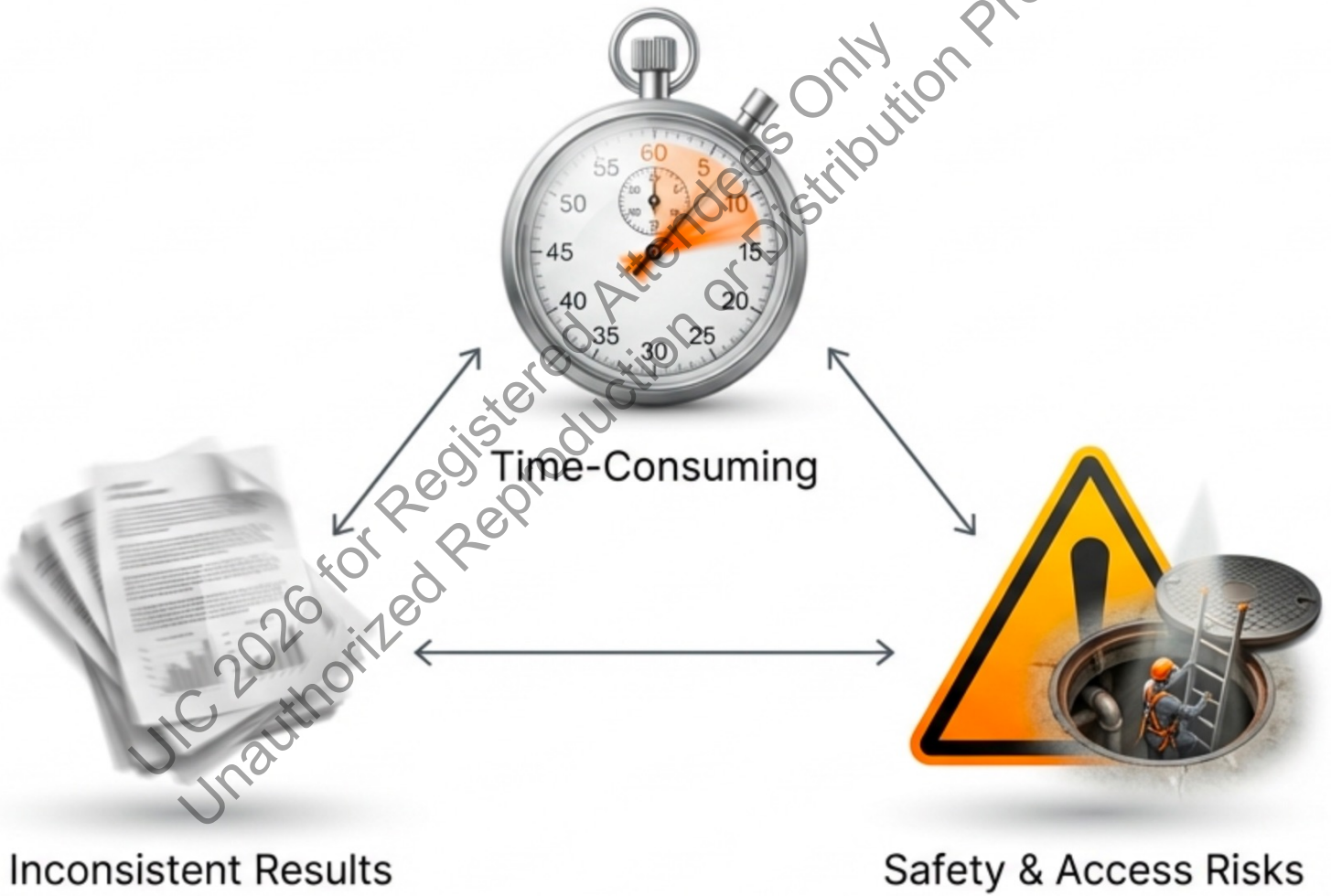
AI-Powered Rapid Manhole Inspection

Combining 360° Scanning with AI for Automated Asset Assessment

Jinwu Xiao, Wei Liao, Tom Iseley
Purdue University

The Inspection Bottleneck

Current infrastructure management is compromised by a Triangle of Inefficiency.



Traditional Methods Across the Three Levels

Level 1	Level 2	Level 3
Snapshot /Quick Video	Full CCTV review	Extended Recording

- 3D Reconstruction
- Heavy processing

Bridging the Gap Between Screening and Assessment

Delivering Level 3 detail at Level 1 speed.

What the Industry Needs

Speed

Fast field capture

Coverage

Complete coverage

Consistency

Standardized interpretation

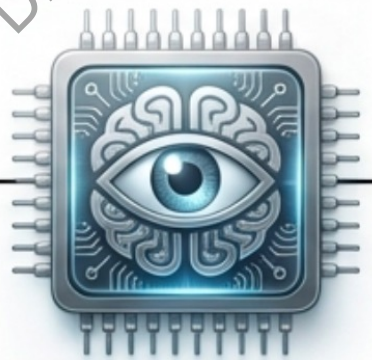
Records

Actionable records

The Core Concept: From Chaos to Structured Data

1. Rapid Capture

2. Unfold



3. Interpret

4. Report

Rapid 360° Data Capture

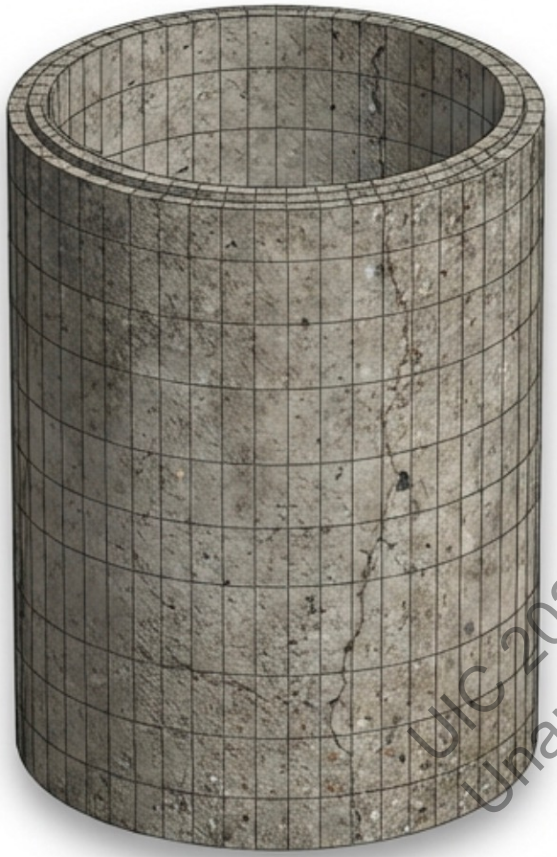
~15 SECONDS

Per manhole capture time.

- Handheld Operation: No tripods.
- Motion Robustness: Stabilized capture.
- Minimal Setup: Open and deploy.

The Digital Transformation: 3D to 2D

Unfolding the geometry for standardized analysis.



Geometric Transformation

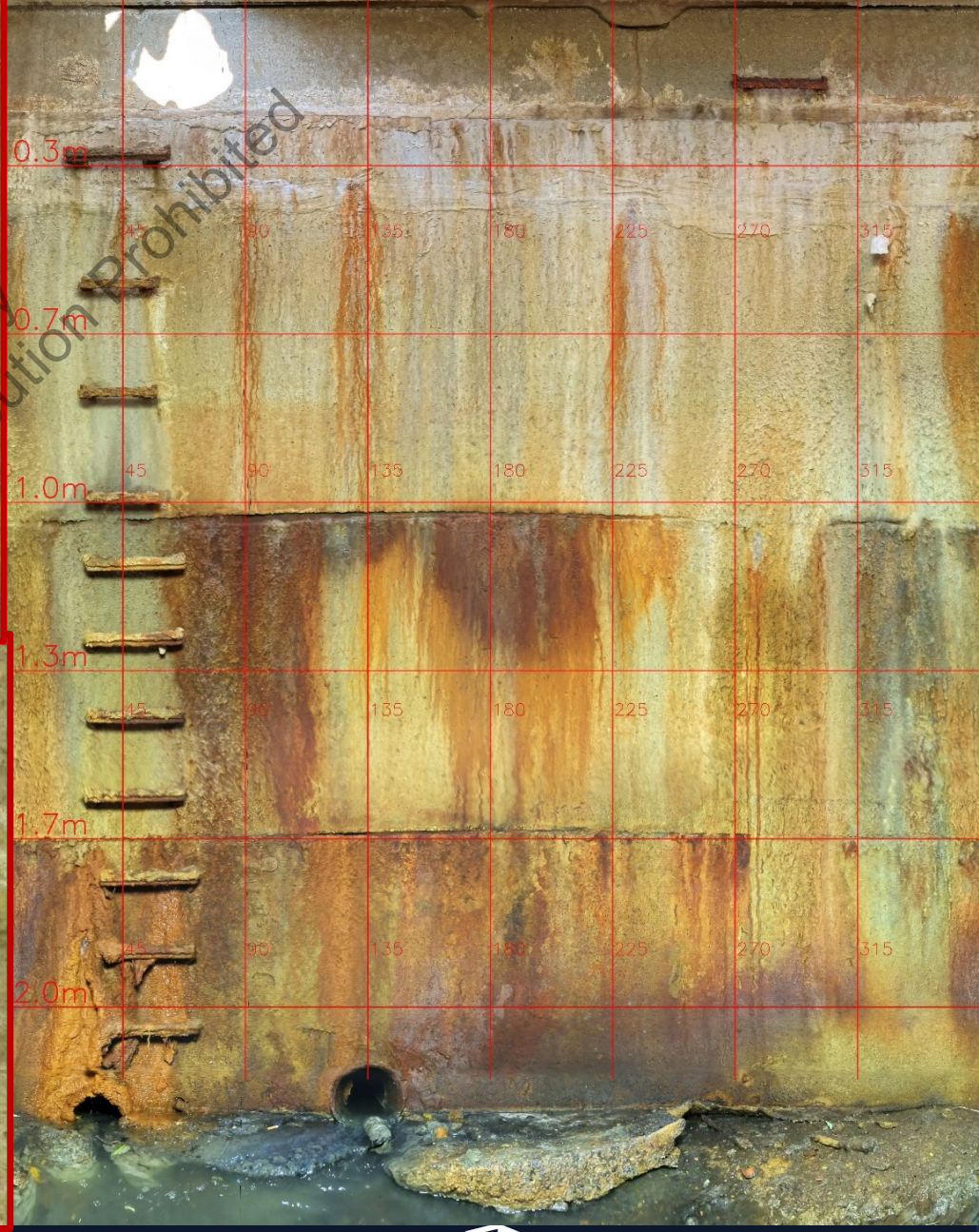
Why Unfolded Images Unlock AI Potential

VS.

Raw Video Frames (Fragmented & Variable)

Unfolded Image (Structured & Consistent)

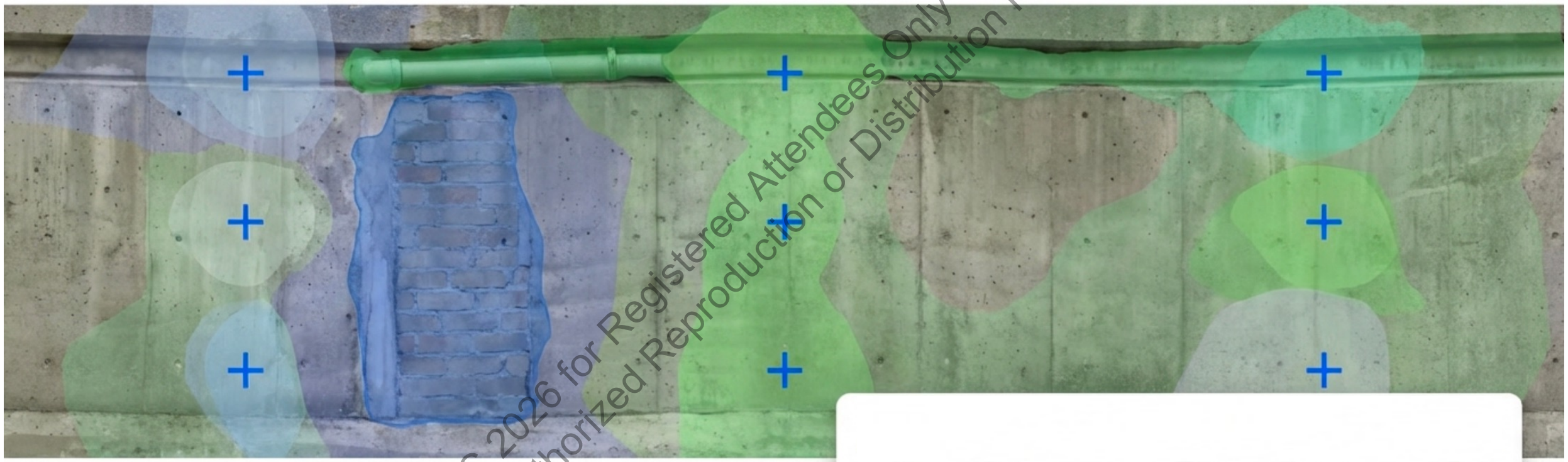
Standardization eliminates variability, creating the perfect dataset for Large Language Models.



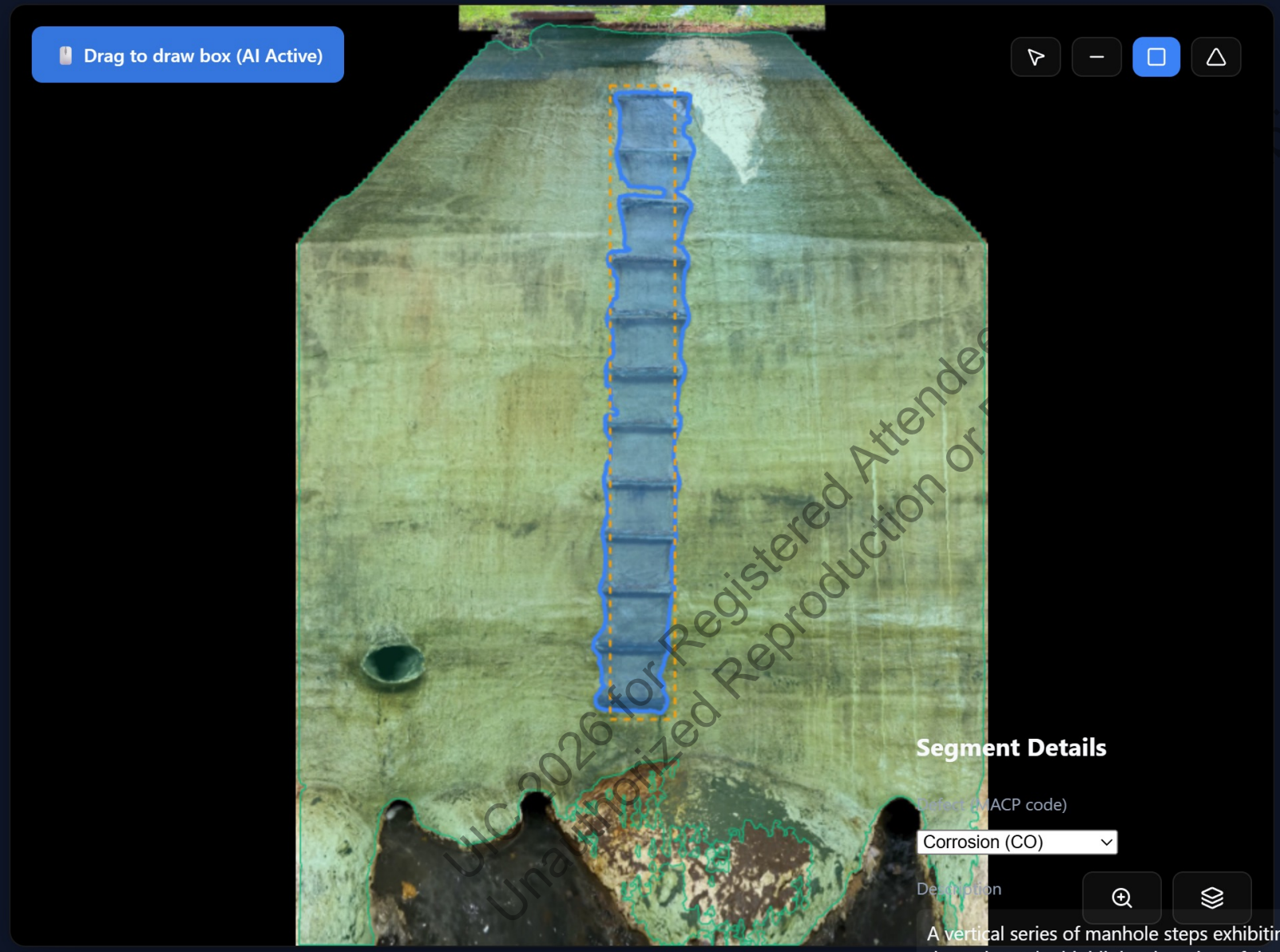
The AI Analysis Layer

Automated detection of defects, components, and conditions.

Step 1: Segmentation



- Method: Automatic 3x3 grid point prompts
- Process: Mask generation → Polygon contouring → Filter <50px areas



Detected Segments

2 areas • 1620273 px²

Clustered | Individual

- **Wall Interior (WI)** 1
  CO • Avg: 1498396 px²
- **Wall Interior (WI)** 1
  CO • Avg: 121877 px²

Close

Component (structure)

Wall Interior (WI)

Detected Segments

7 areas • 1608976 px²

Clustered | Individual

CO - Corrosion 1
Avg: 1498396 px²

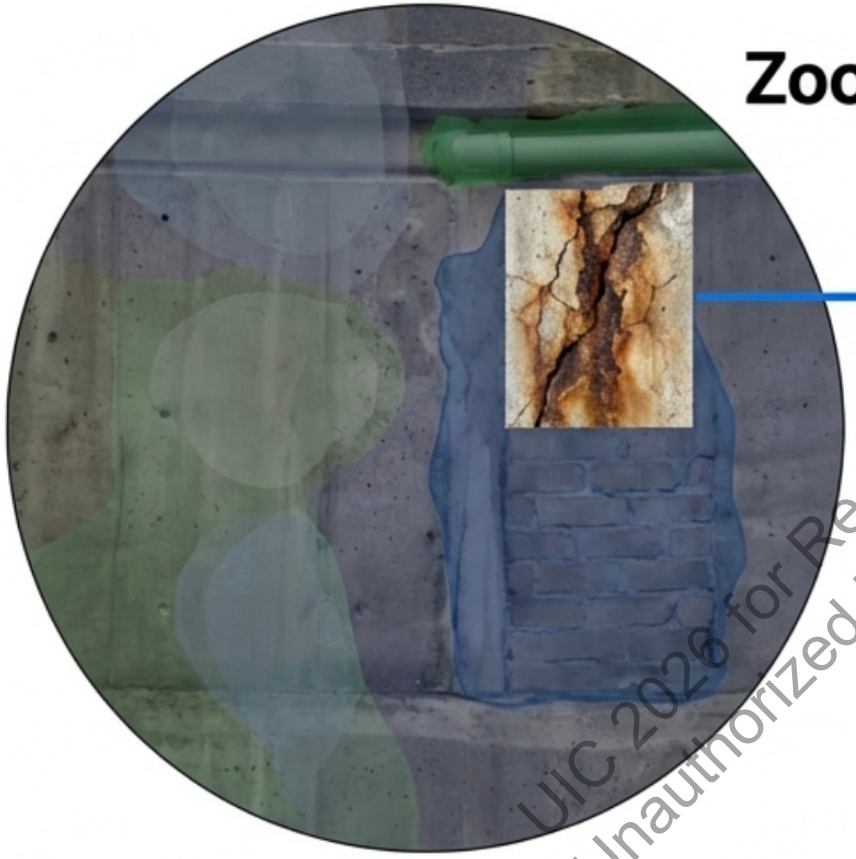
HL - Hole 6
Avg: 18430 px²

Close

Description

The highlighted manhole step shows significant surface corrosion with heavy rust accumulation across its entire visible width.

Step 2: The Brain (Gemini Vision Analysis)



Context View

Zoom and Analyze

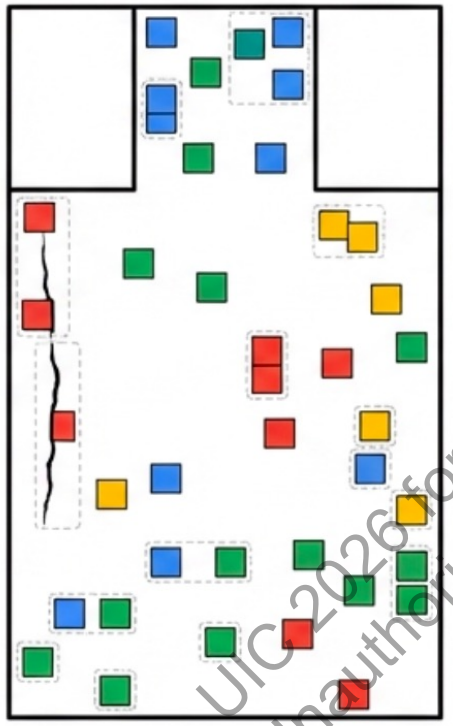
Crop View

Input: Crop + Context
Model: Gemini 3.0 Flash
Output: "Corrosion, Grade 3, Wall Interior"

The Loop: Intelligent Clustering & Merging

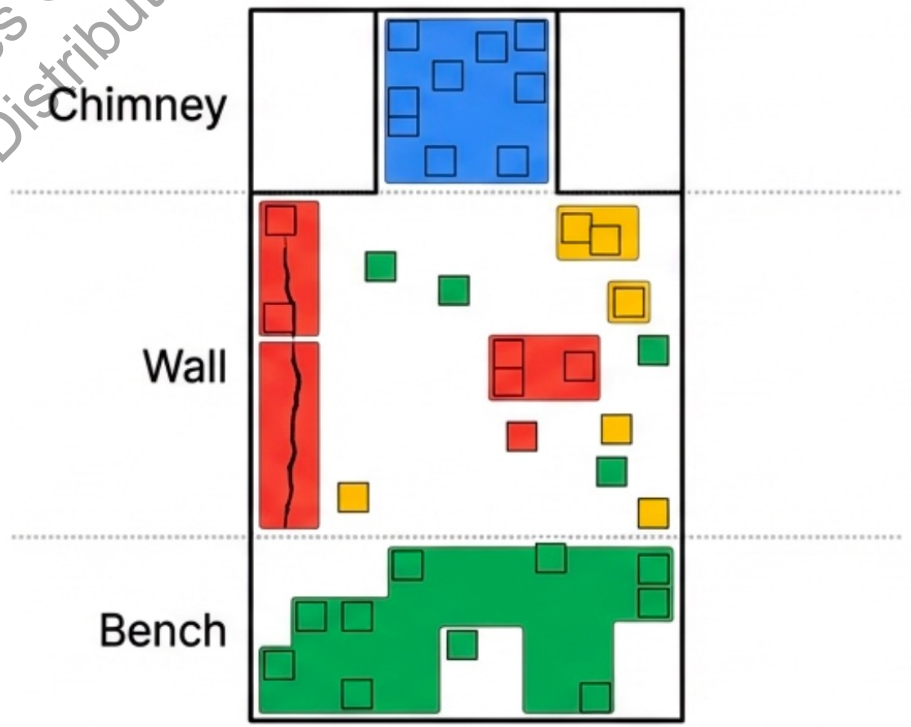
Before and After

Phase 1: Visual Clustering (Pre-AI)

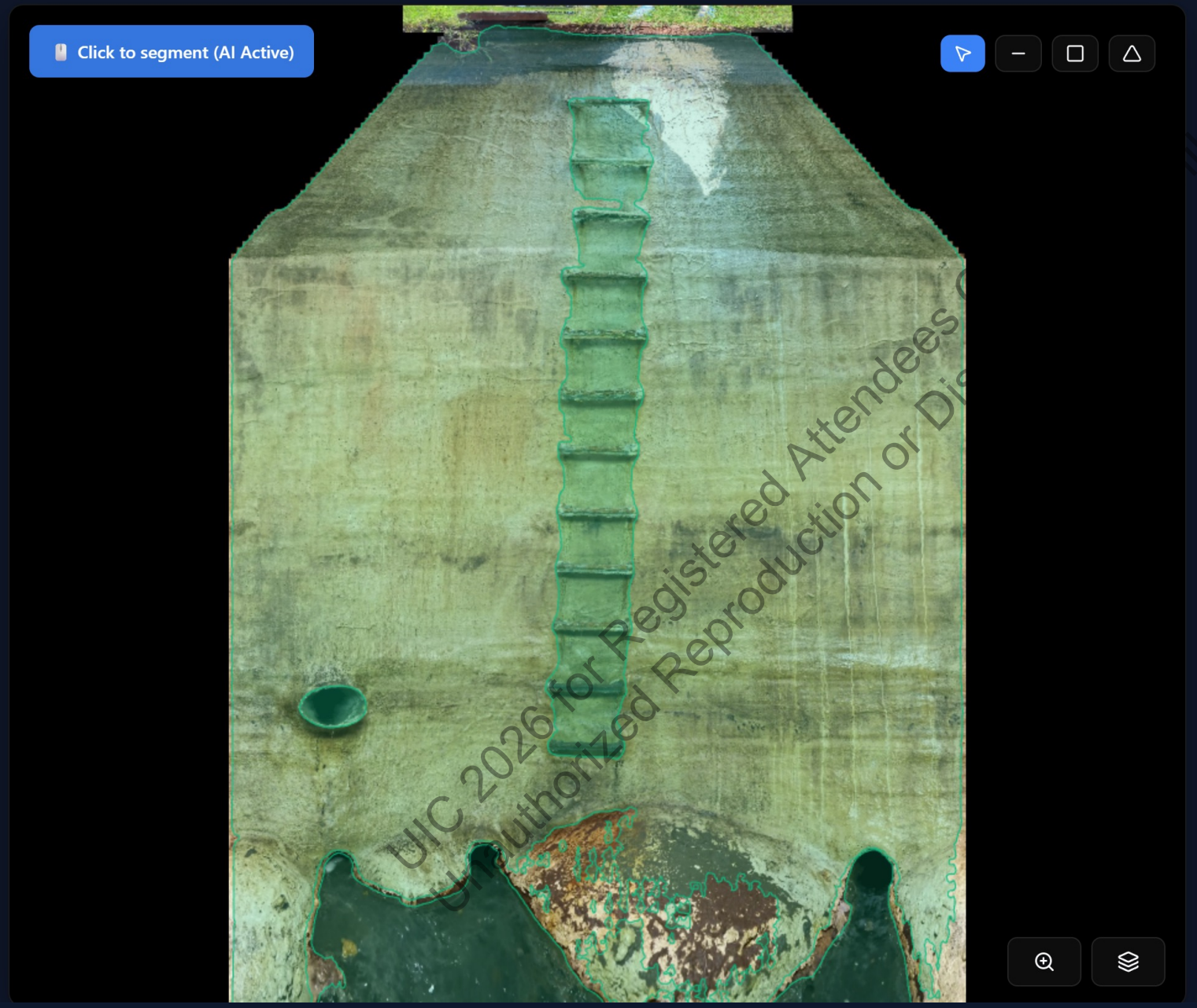


Grouped by proximity
(DBSCAN)

Phase 2: Component Clustering (Post-AI)



Grouped by Structure (Union-Find)
& Merged Split Defects



Detected Segments

5 areas • 1726850 px²

Clustered | Individual

CO Sev: 2
Area: 1498396 px² • 99.8% AI: 95%
The interior concrete surfaces exhibit widespread moderate surface corrosion with significant discoloration and exposed aggregate across the wall and cone sections.

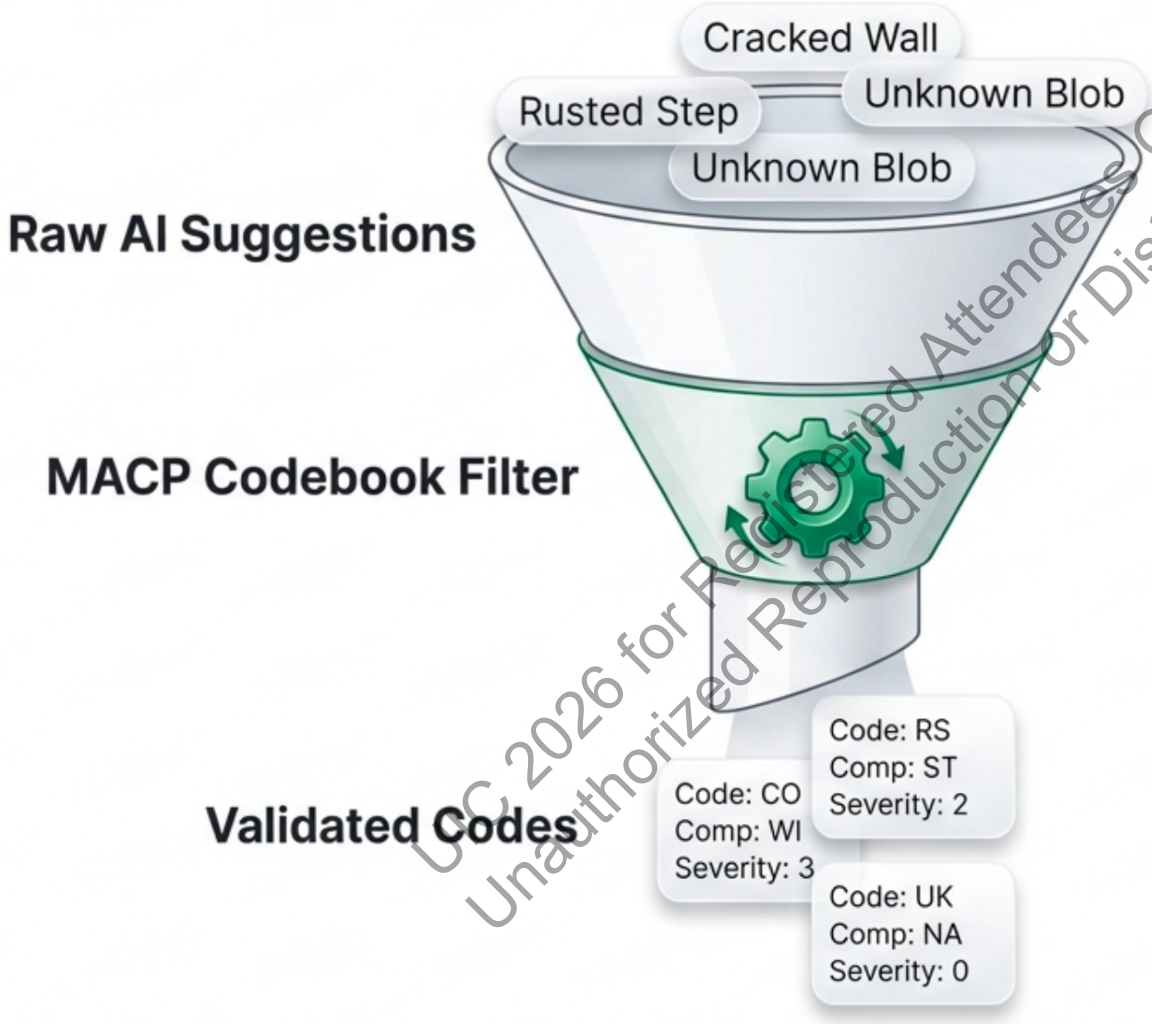
CO Sev: 3
Area: 121877 px² • 91.6% AI: 95% Step
A vertical series of manhole steps exhibiting advanced surface corrosion and oxidation throughout the highlighted section of the wall.

HL Sev: 4
Area: 5572 px² • 97.0% AI: 90%
A circular hole is visible in the wall interior, representing a significant breach where wall material is missing or a pipe is recessed.

HL Sev: 3
Area: 74371 px² • 99.6% AI: 85%
Significant surface corrosion and mineral deposits are visible on the bench area, characterized by rough texture and white encrustation near the channel.

HL Sev: 3
Area: 26635 px² • 98.1% AI: 85%
The interior wall area surrounding the pipe penetration shows significant corrosion with substantial surface material loss and exposed aggregate.

Step 3: The Law (MACP Rules Engine)



- **Closed-Set Classification:** Invalid codes auto-corrected to "UK" (Unknown).
- **Logic:** Enforces NASSCO standards. A frame defect cannot exist on a bench.

MACP Inspection Report

Generated by Gemini AI Assessor

Print

Inspection Summary

MACP Assessment concluded with 5 defects identified. Major defects include Hole. 5 visual clusters were analyzed.

Component Inventory

Overall condition of MACP structure components detected in this section.

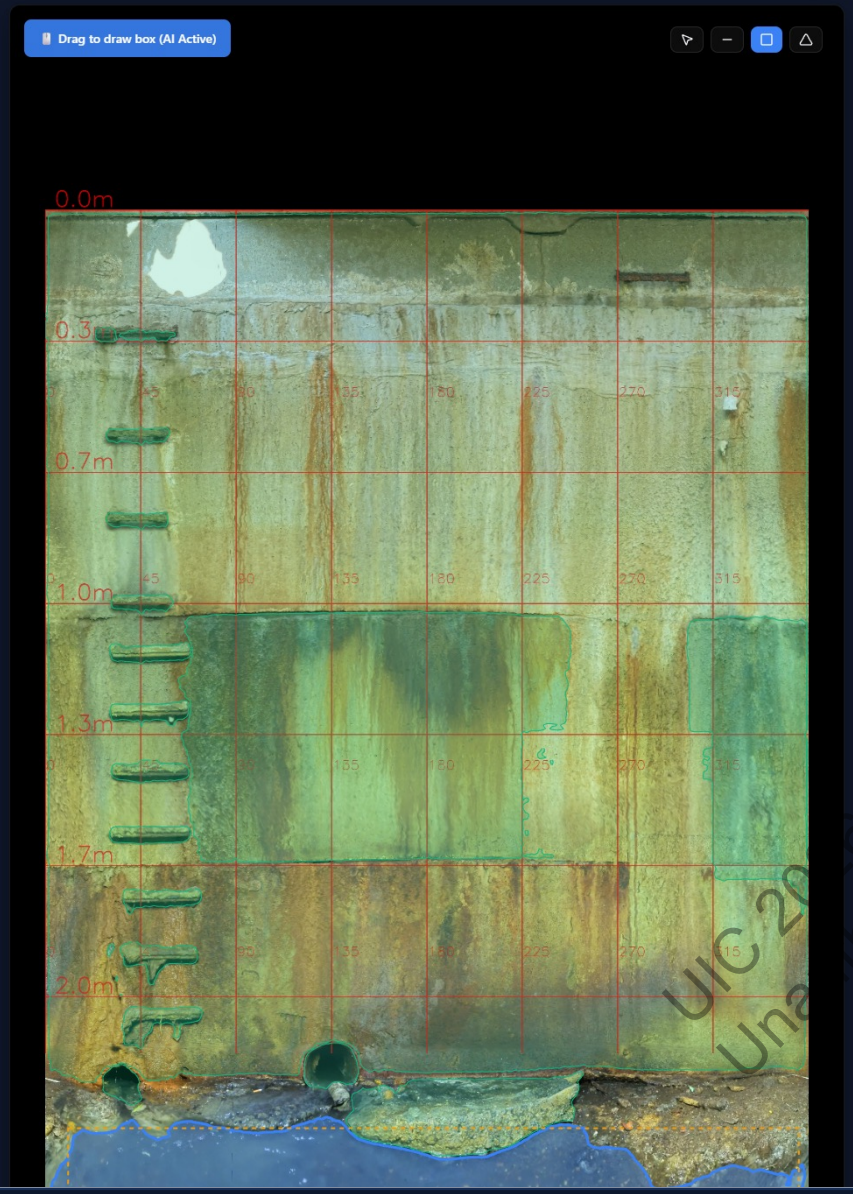
Component	Span (Relative)	Condition Grade	Notes
Chimney Interior (CMI)	0% - 6%	Grade 2	Top concrete section near frame, some minor surface wear and debris.
Cone Interior (COI)	6% - 26%	Grade 3	Tapered section of the manhole. Ladder rungs show visible corrosion and staining on the walls.
Wall Interior (WI)	26% - 83%	Grade 3	Main vertical shaft. Significant corrosion on ladder rungs with rust streaking. Small lateral/pipe penetration visible around y=0.7.
Bench (B)	83% - 96%	Grade 3	Benching area showing surface erosion, aggregate exposure, and some discoloration/buildup.
Channel (C)	92% - 100%	Grade 2	Active flow visible in the bottom channel; appears functional with some turbulent flow.

Defect Detail

Code	Comp	Description	Loc/Clock	Sev/Flag
CO	Wall Interior	The interior concrete surfaces exhibit widespread moderate surface corrosion with significant discoloration and exposed aggregate across the wall and cone sections.		Sev: 2
CO	Wall Interior	A vertical series of manhole steps exhibiting advanced surface corrosion and oxidation throughout the highlighted section of the wall.	2.0-8.0 ft @ 12:00	Sev: 3 S
HL	Wall Interior	A circular hole is visible in the wall interior, representing a significant breach where wall material is missing or a pipe is recessed.	10.5 ft @ 09:00	Sev: 4
HL	Bench	Significant surface corrosion and mineral deposits are visible on the bench area, characterized by rough texture and white encrustation near the channel.	14.0 ft @ 08:00	Sev: 3
HL	Wall Interior	The interior wall area surrounding the pipe penetration shows significant corrosion with substantial surface material loss and exposed aggregate.	14.5 ft @ 04:00	Sev: 3

ManholeAI
Advanced Inspection & Segmentation Portal

Automatic | Interactive | AI-Enhanced (Gemini) | Reset | Finalize Report



Detected Segments
8 areas • 24821556 px²

Clustered | Individual

- **SF** Sev: 3 — Area: 18650929 px² • 99.3% AI: 85% — *Significant surface deterioration and loss of material is visible near the top access ladder, characterized by a large spalled area exposing the underlying substrate.*
- **CO** Sev: 3 — Area: 374175 px² • 72.5% AI: 90% Step — *Extensive surface corrosion and heavy oxidation staining are visible on the interior wall surface, primarily concentrated around the vertical alignment of the manhole steps.*
- **CO** Sev: 2 — Area: 797900 px² • 96.1% AI: 85% — *The interior wall exhibits extensive surface corrosion with heavy reddish-brown staining and visible degradation of the concrete matrix.*
- **CO** Sev: 3 — Area: 2516696 px² • 96.7% AI: 95% Step — *Extensive surface corrosion and heavy iron staining on the interior wall, showing moderate surface degradation and overlapping with several steps.*
- **IS** Sev: 3 — Area: 31105 px² • 88.7% AI: 95% Step — *Active water infiltration is visible as a dripper entering through a void in the lower wall section near the bench interface.*
- **CO** Sev: 3 — Area: 56240 px² • 94.0% AI: 85% — *The pipe penetration exhibits significant corrosion and surface degradation, with visible iron oxide staining and an accumulation of sediment at the invert.*
- **RB** Sev: 3 — Area: 401131 px² • 96.3% AI: 90% — *A large, heavy accumulation of solidified deposits or encrustation is present on the bench area near the channel.*
- **DP** Sev: 3 — Area: 1993331 px² • 99.7% AI: 85% — *A significant accumulation of attached or settled deposits is visible on the bench, encroaching into the channel flow area.*

MACP Inspection Report

Generated by Gemini AI Assessor

Close | Print

Inspection Summary

MACP Assessment concluded with 8 defects identified. Major defects include none. 8 visual clusters were analyzed.

Component Inventory

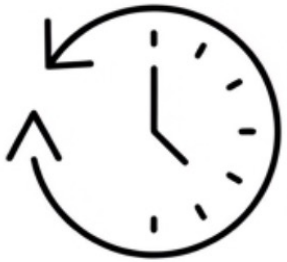
Overall condition of MACP structure components detected in this section.

Component	Span (Relative)	Condition Grade	Notes
Chimney Interior (CMI)	0% - 5%	Grade 2	Top concrete adjustment ring visible with surface staining and minor mortar joint wear.
Wall Interior (WI)	5% - 88%	Grade 4	Severe iron staining and corrosion throughout the shaft; manhole steps (rungs) show significant degradation and material loss.
Bench (B)	88% - 96%	Grade 3	Bench shows heavy accumulation of debris and silt; surface appears rough and potentially eroded.
Channel (C)	96% - 100%	Grade 3	Flow channel contains significant sediment and standing water, obstructing full view of the invert.

Defect Detail

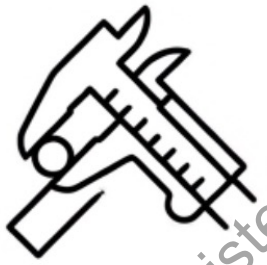
Code	Comp	Description	Loc/Clock	Sev/Flag
SF	Wall Interior	Significant surface deterioration and loss of material is visible near the top access ladder, characterized by a large spalled area exposing the underlying substrate.		Sev: 3
CO	Wall Interior	Extensive surface corrosion and heavy oxidation staining are visible on the interior wall surface, primarily concentrated around the vertical alignment of the manhole steps.	4.0 ft @ 01:30	Sev: 3 S
CO	Wall Interior	The interior wall exhibits extensive surface corrosion with heavy reddish-brown staining and visible degradation of the concrete matrix.	4.9 ft @ 10:30	Sev: 2
CO	Wall Interior	Extensive surface corrosion and heavy iron staining on the interior wall, showing moderate surface degradation and overlapping with several steps.	4.4 ft @ 05:15	Sev: 3 S

Executive Summary



Automated

Reduces inspection time by ~70%.



Standardized

Enforces MACP closed-set rules.

Auditable

Every pixel and decision is logged.

Scalable

Stateless API ready for high volume.

Built on State-of-the-Art Foundations

Robust, maintainable stack designed for horizontal scalability and GPU acceleration.

Thank you!