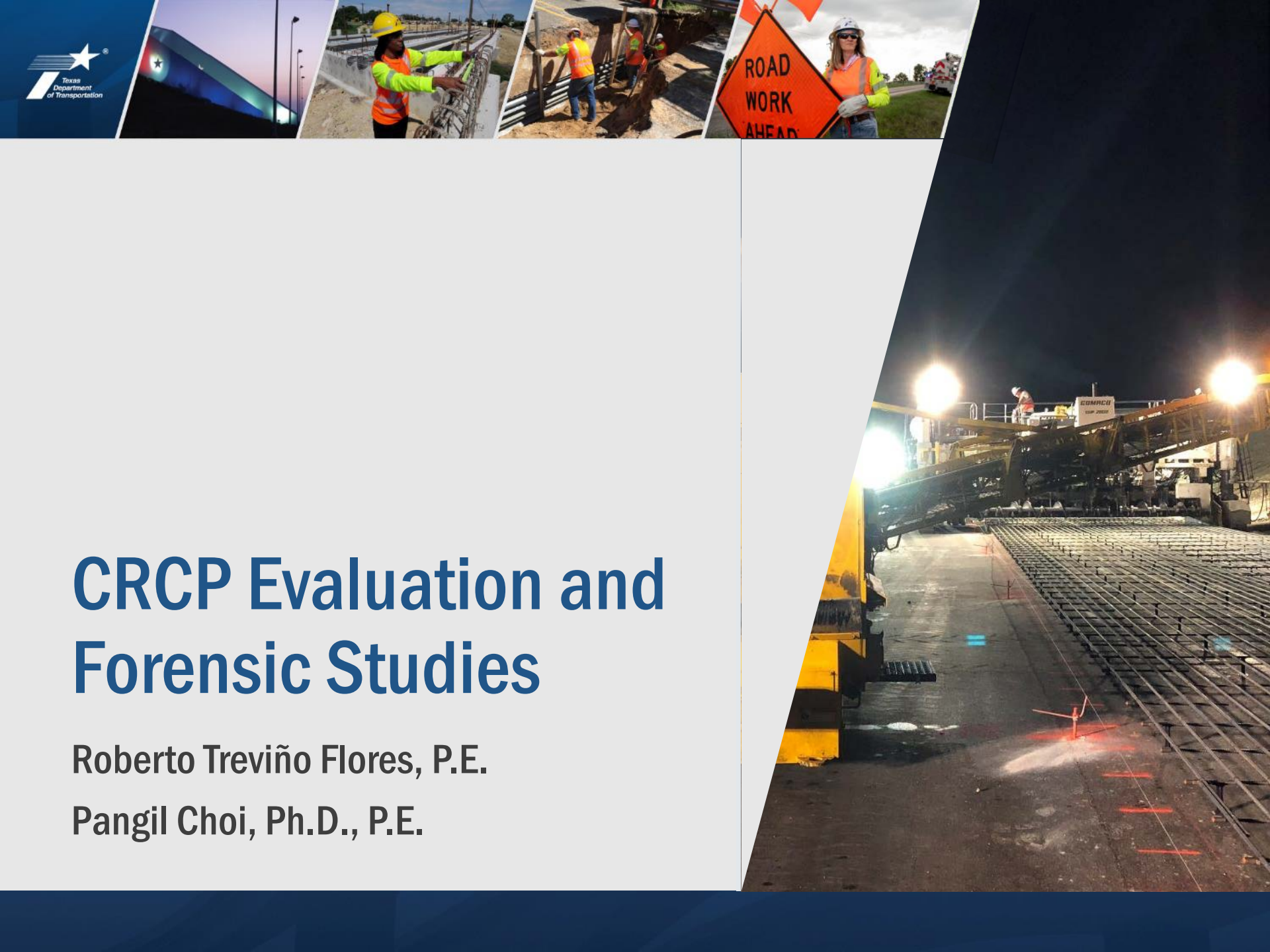


# CRCP Evaluation and Forensic Studies

Roberto Treviño Flores, P.E.

Pangil Choi, Ph.D., P.E.

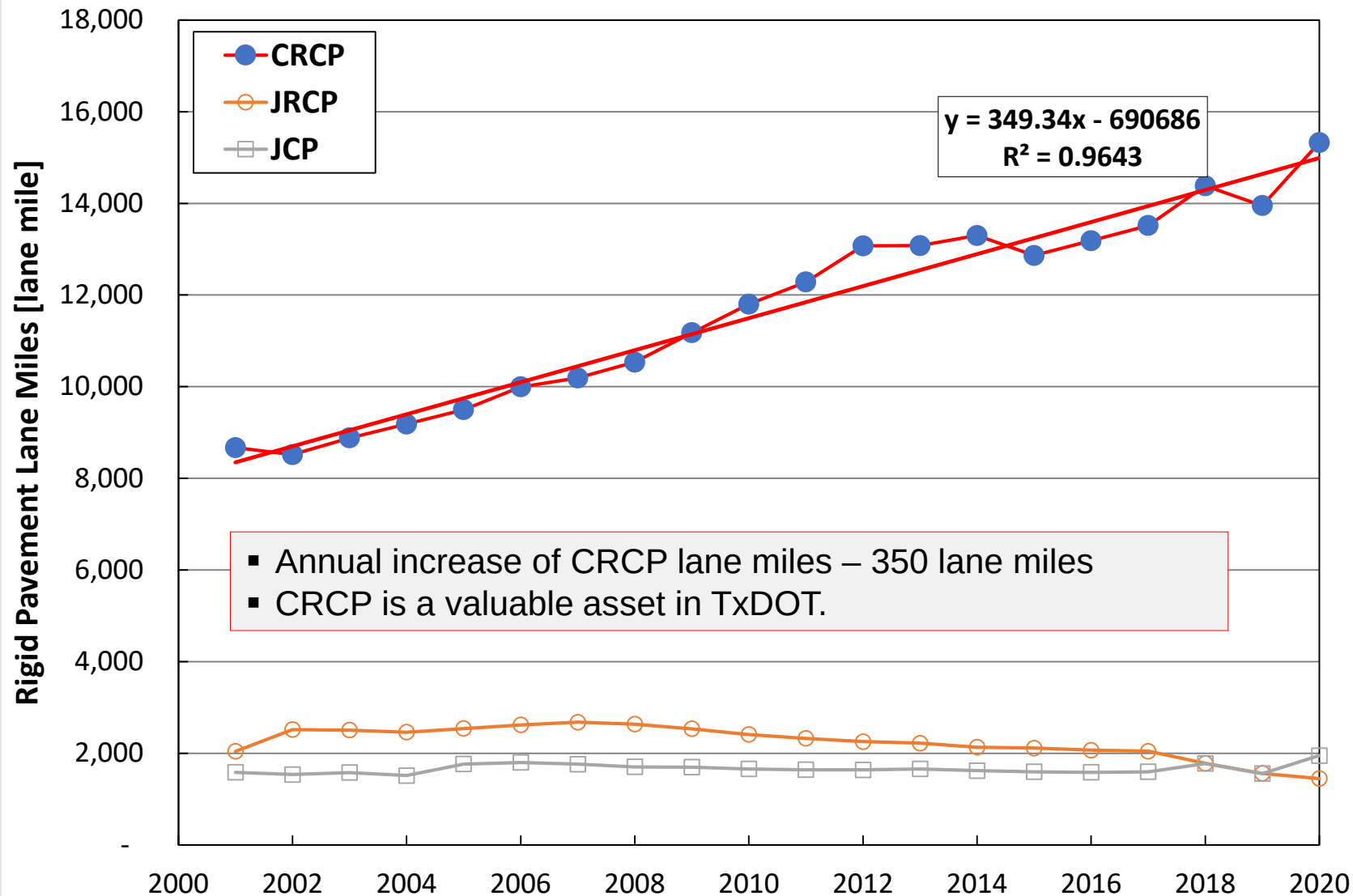


ROAD  
WORK  
AHEAD



- 1** TxDOT Rigid Pavement
- 2** Forensic Evaluation Process
- 3** Non-Destructive Testing Devices
- 4** Case Study 1 – Austin District
- 5** Case Study 2 – Ft. Worth District
- 6** Discussions

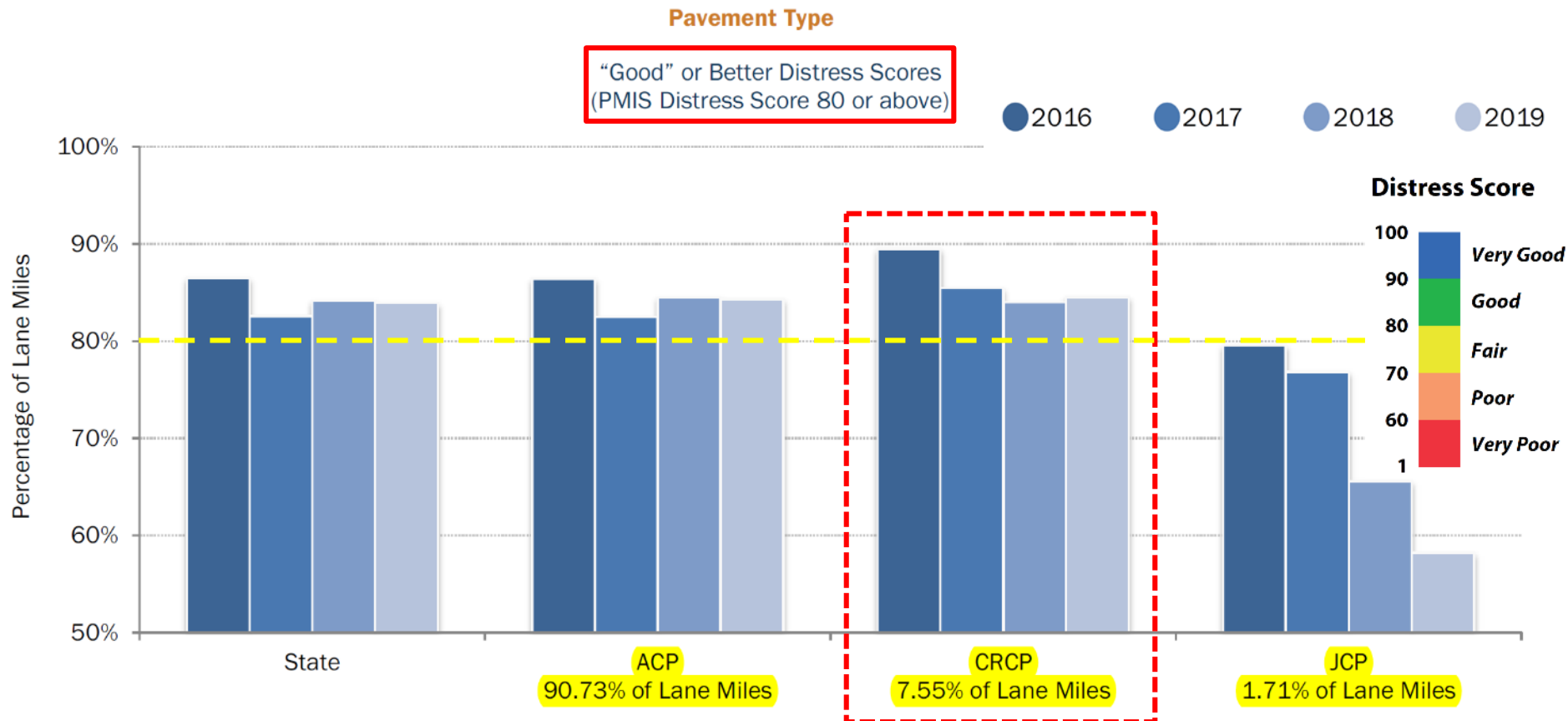
# 1. TxDOT Rigid Pavement



## PMIS Distress Score 80 or Above – better distress score in CRCP



- **Distress Score** combines all of the distress ratings into a single value that describes overall pavement distress.
- **Distress Score** ranges from 1 (very poor) to 100 (very good).

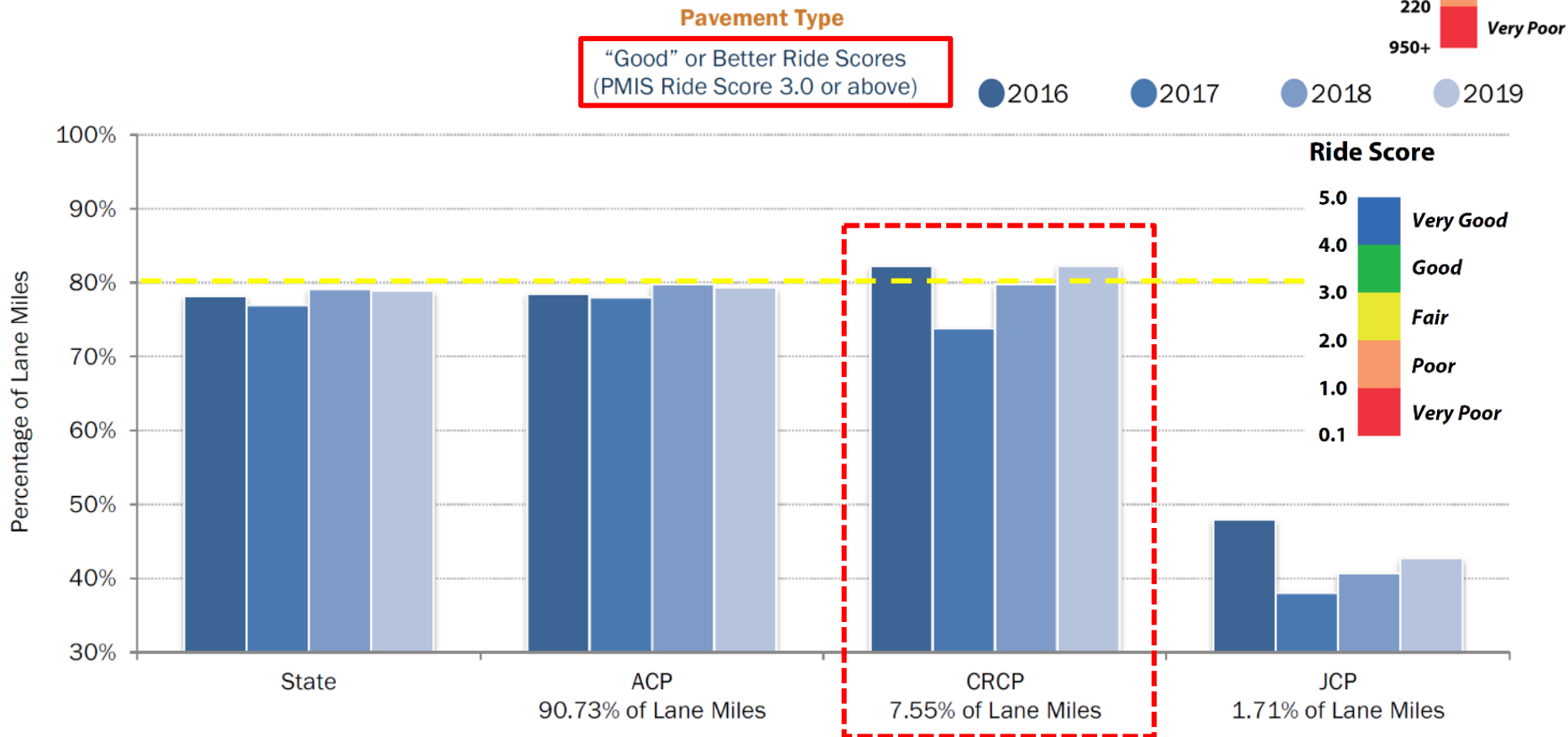
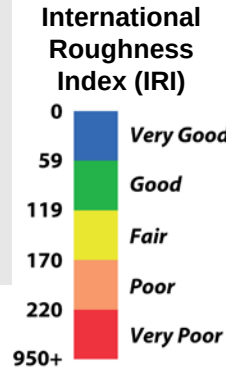




## PMIS Ride Score 3.0 or Above – better ride in CRCP



- **Ride Score** is an average of all 0.1 mile SI (Serviceability Index) measurements into a single value that describes overall pavement ride quality.
- **Ride Score** ranges from 0.1 (very poor) to 5.0 (very good).





<http://onlinemanuals.txdot.gov/txdotmanuals/pdm/pdm.pdf>

### 1.2 Selection of Rigid Pavement Type

CRCP provides excellent long-term performance requiring very low maintenance. The department policy is to utilize CRCP for new or reconstructed rigid pavements in Texas. Although CRCP is the preferred concrete pavement type, the department has expanded the applications where CPCD can be used as an acceptable alternative to CRCP. The following criteria list the applications where CPCD can be used instead of CRCP at the discretion of the district engineer:

- ◆ For roadways with design traffic of 40 million ESALs or less,
- ◆ For frontage roads where CRCP is difficult to construct due to numerous leave-out sections,
- ◆ For roadways controlled and maintained by another government entity,
- ◆ For parking areas or roadways with crosswalks, adjacent parking, or sidewalks,
- ◆ For railroad crossings, approaches to structures, or to widen existing jointed pavement, or
- ◆ For intersections and approaches in flexible pavement roadways that are associated with vehicle braking and acceleration which could cause shoving and rutting of an asphalt pavement.

## 2. Forensic Evaluation Process



- Pavement forensic evaluation, **WHY?**
  - Identify causes of pavement distress
  - Keep improving TxDOT design standards and specifications
  - Develop training materials/TxDOT inspector & contractor
  - **Minimize pavement distress and save tax payer's money**



# Forensic Evaluation Process



**Forensic Request  
From TxDOT  
Districts**

**Define the Scope  
and Potential  
Solutions**

**Compile project information  
Develop a field plan  
Conduct site investigation**

**Select a Repair Strategy**

**Evaluate  
Causes of  
Distress**

**Evaluate  
Pavement  
Structural  
Capacity**

**Evaluate Subgrade  
and Base Properties**

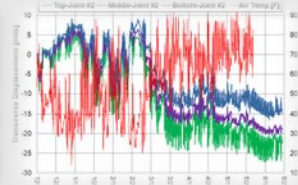
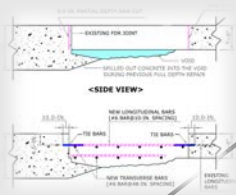
**Short-term  
& Long-term  
Monitoring**

**Perform NDT**

- Data Analysis
- Recommendations
- Design Details and Specifications/DMS

- Monitoring for Pavement Short-term/Long-term Behavior if needed

- FWD
- TPAD
- MIRA
- GPR
- LiDAR
- DCP
- ...







## Pre-evaluation (office)

- Historical data analysis
  - As-built plans
  - Maintenance
- Web soil survey
- Google earth survey
- PMIS data

## Evaluation strategy

- Pick the right tools:
  - GPR
  - FWD
  - TPAD
  - Coring/DCP
  - MIRA
  - LiDAR...

## Field evaluation

- PPE
- Traffic control
- Testing sequence
- Personnel
- Execute testing plan

- Data analysis
- Identify causes of distresses

- Develop a Report
- Provide Practical Recommendations
- Technical Support

### 3. Non-Destructive Testing Devices – Air-Launched GPR



- Frequency: 1 GHz
- Effective depth: ~2 ft.
- Can operate at highway speeds
  - 1 trace every 5 ft. @ 60mph
  - Can collect 1 trace per foot @ 25mph
- Collects Video & GPS



## ❑ Ground Coupled Penetrating Radar



- Antenna in contact w/ surface
- Push cart/handheld/trailer
  - 2.6 GHz ➔ ~1 ft.
  - 400 MHz ➔ ~12 ft.

400 MHz



2.6 GHz

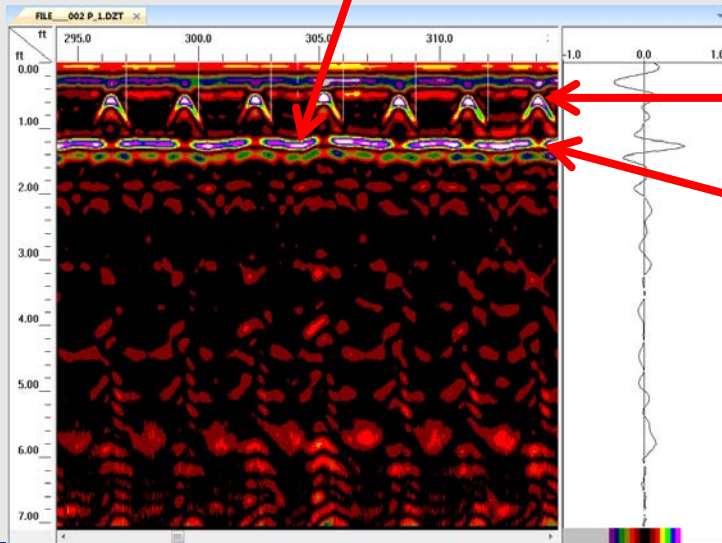




## □ Ground Coupled Penetrating Radar (400 MHz)

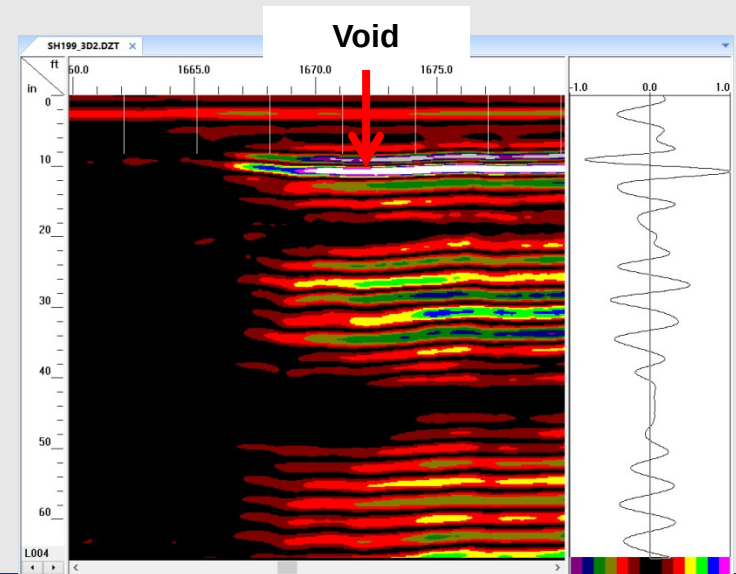


- GC-GPR data processing: continue to make progress



Rebar

HMA  
stripping



## ❑ Total Pavement Acceptance Device (TPAD)



- Collects:
  - Rolling Dynamic Deflectometer (RDD)
  - Video, GPR & GPS
- 2 mph data collection
- 3 geophones
- Deflection recorded every 0.1 ft.

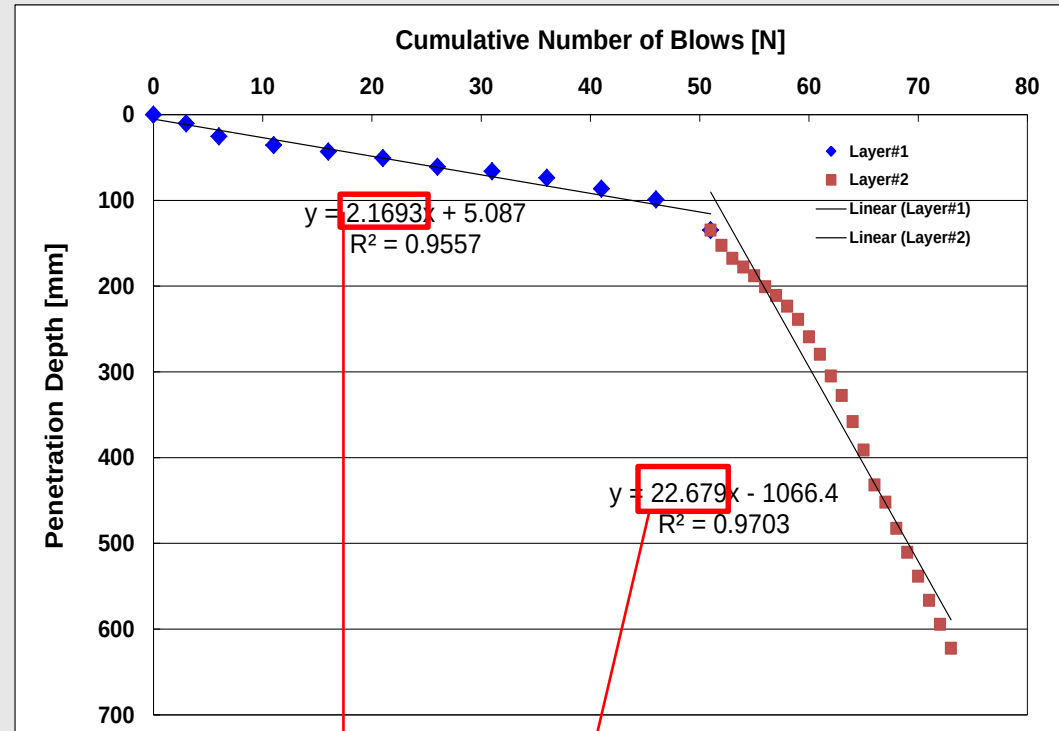
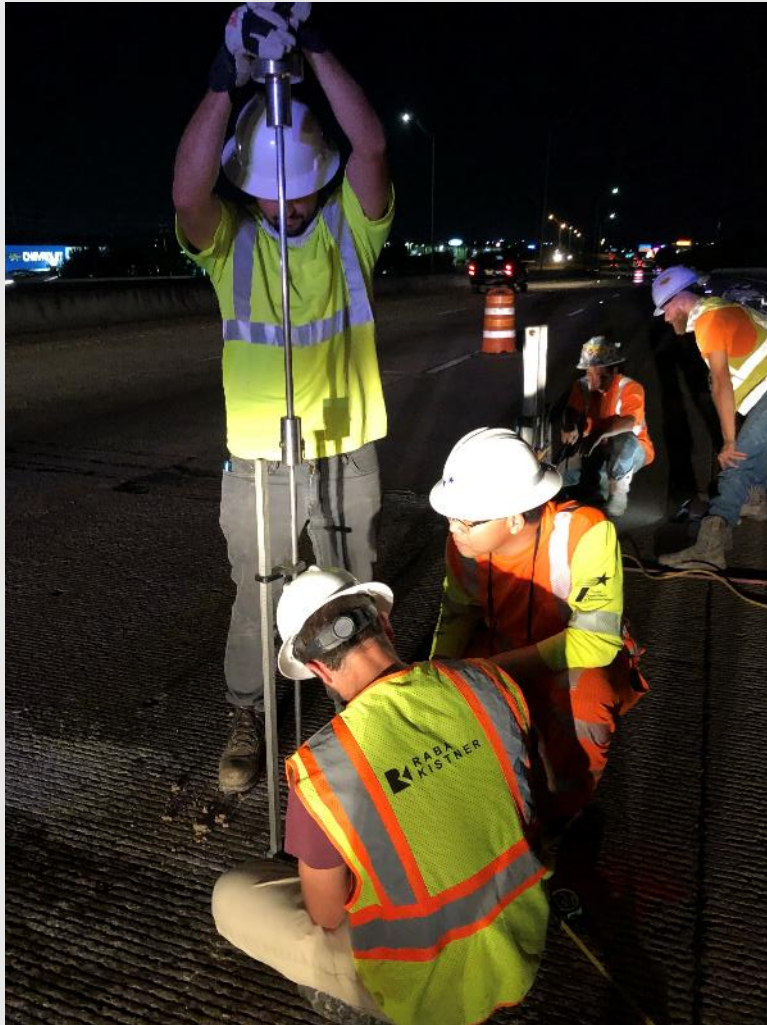


- Drops a load and pavement deflections are measured through 7 to 9 sensors.
- Used to estimate the pavement structural capacity
- Used to evaluate load transfer efficiency at the joints and cracks (rigid)
- Estimation of back-calculated  $k$ -value (rigid)





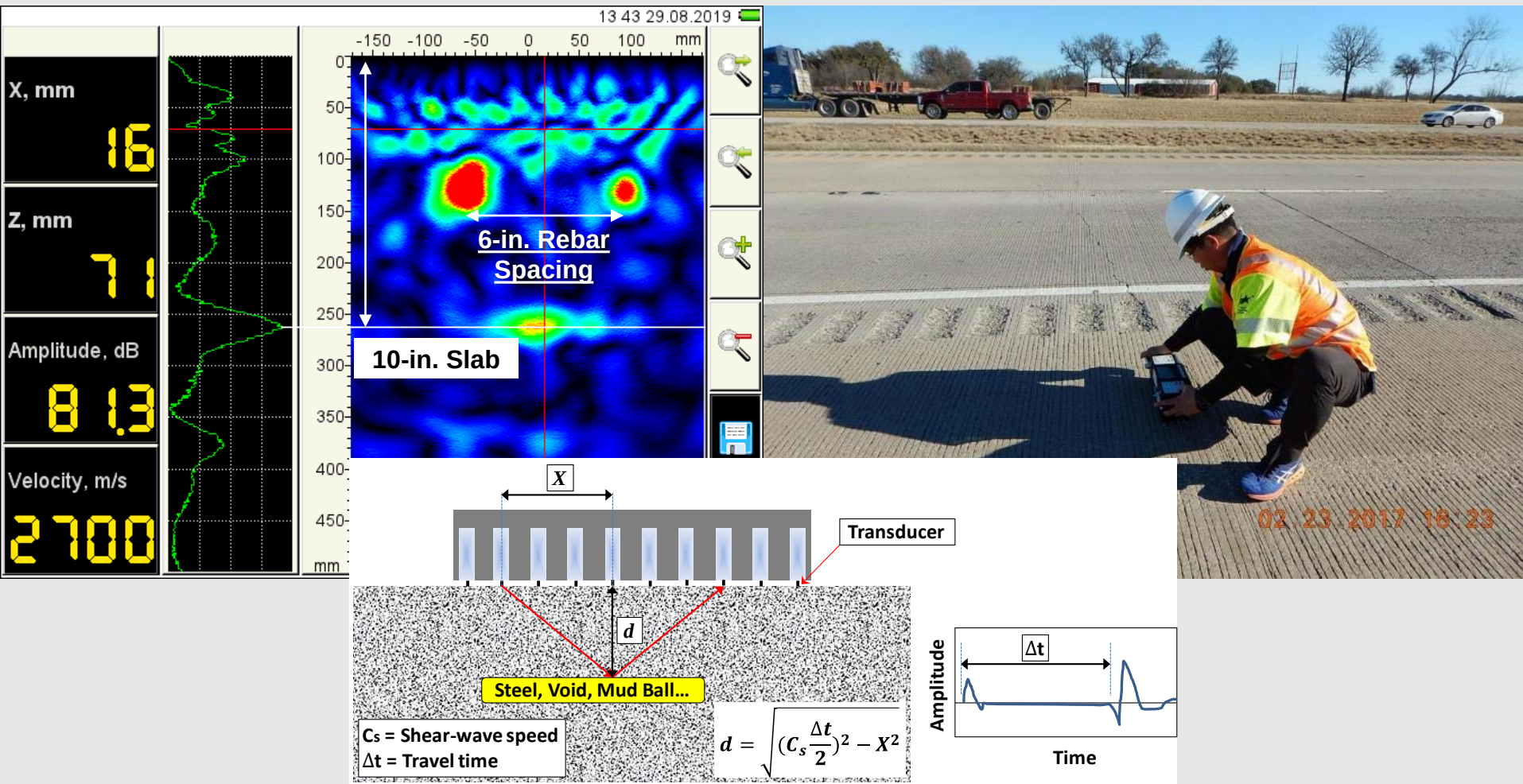
- Penetration rate to estimate the modulus of sub-base and subgrade

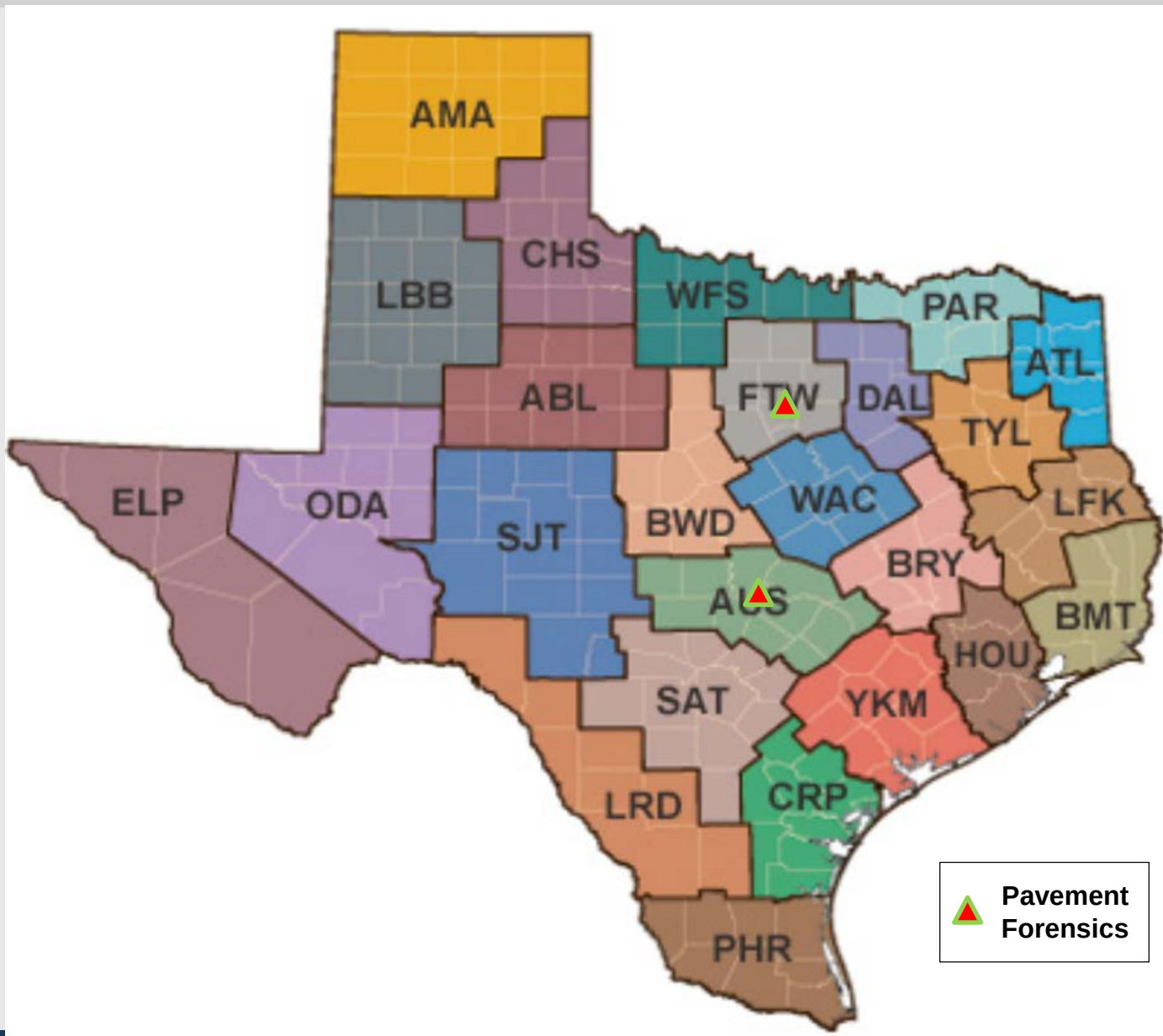


|               | Layer 1 | Layer 2 |                                    |
|---------------|---------|---------|------------------------------------|
| mm/blow       | 2.1963  | 22.679  | Gradient of graph (A)              |
| CBR           | 122.66  | 8.85    | $CBR = 292 / A^{1.12}$             |
| Modulus (ksi) | 55.37   | 10.03   | $Modulus = 2.55 \times CBR^{0.64}$ |



- Shear-wave ultrasonic testing
- Investigation of slab thickness, rebar location, and delamination

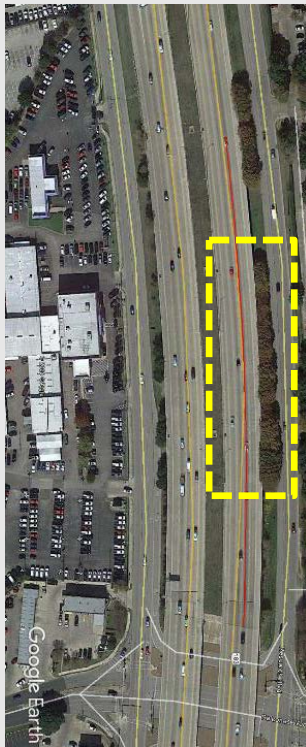




## 4. Case Study #1 – Austin District



- 11-in. CRCP has shown very **good performance over 25 years**.
- However, **large TPAD and FWD deflections** were detected on a 450' section of CRCP.
- District has a **concern** for the planned **widening project**.
- The request is to investigate the cause of large deflections.
  - Potential weak subgrade or voids under the CRCP



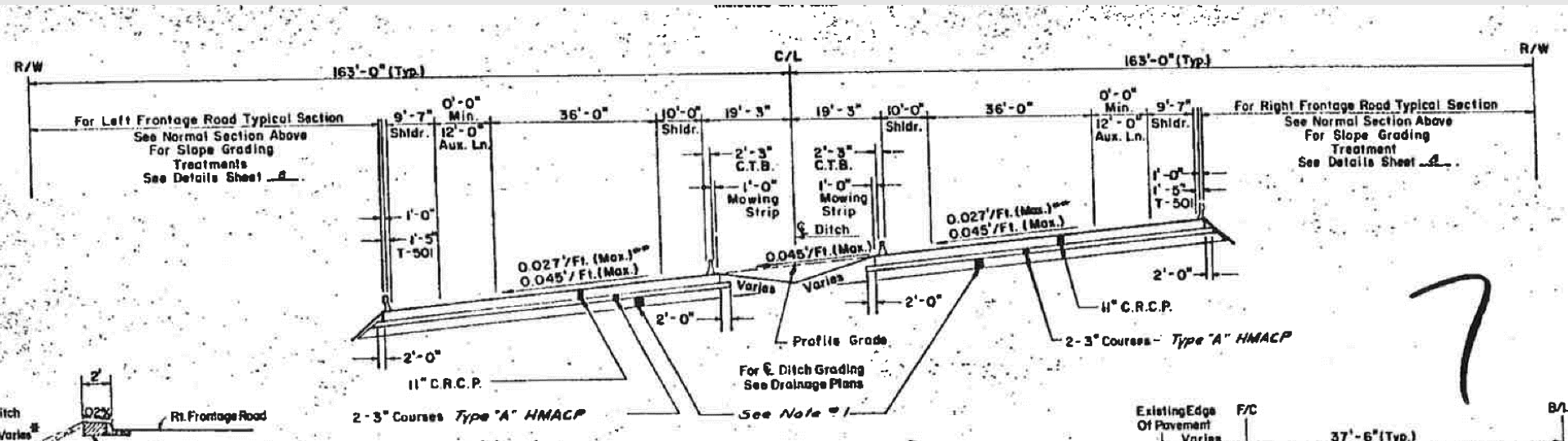
| Attribute       | Information                                                               | Notes               |
|-----------------|---------------------------------------------------------------------------|---------------------|
| Date Work Begin | July 1992 (Letting)                                                       |                     |
| Date Completed  | 04/28/1995                                                                | 25-year service     |
| Pavement Type   | Rigid – CRCP                                                              |                     |
| Slab thickness  | 11-in.                                                                    |                     |
| Shoulder Type   | Tied-Concrete                                                             |                     |
| Base Type       | 6.0-in. TY-A HMA                                                          | Limestone Aggregate |
| Subgrade Type   | Type C Embankment to be used as top 12-in. under CRCP (in fill area only) |                     |
| Drainage Type   | Traffic Barrier & Inlet                                                   |                     |



## □ Typical Section – Pavement Structure



- 11-in. CRCP + 6-in. TY-A HMA + 12-in. TY-C Embankment



### NOTE:

1. Ty. "C" Emb. To Be Used As Top 12" Under CRCP In Fill Areas Only.
2. All Unpaved Areas Are To Receive 4" Topsoil And Cellulose Fiber Mulch Seeding.
3. See CRCP Details For Longitudinal Joint Types And Locations.

11-in. CRCP

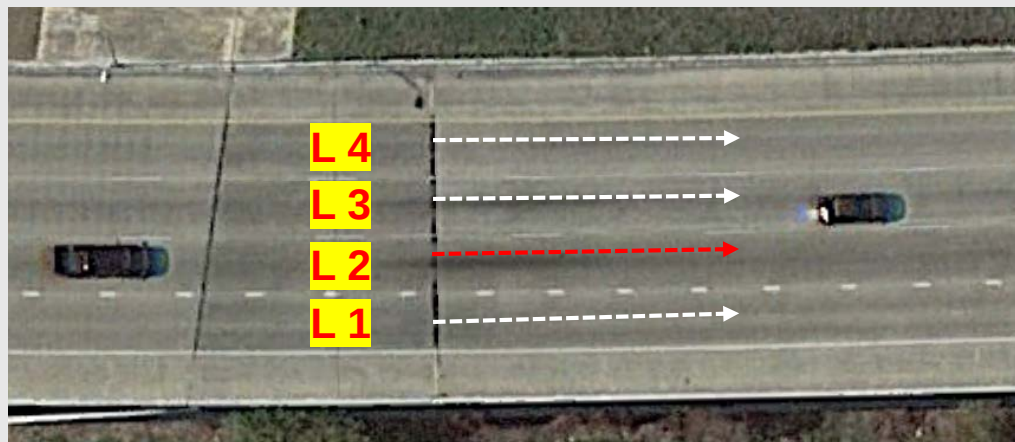
6-in. TY-A HMA

12-in. TY-C  
Embankment

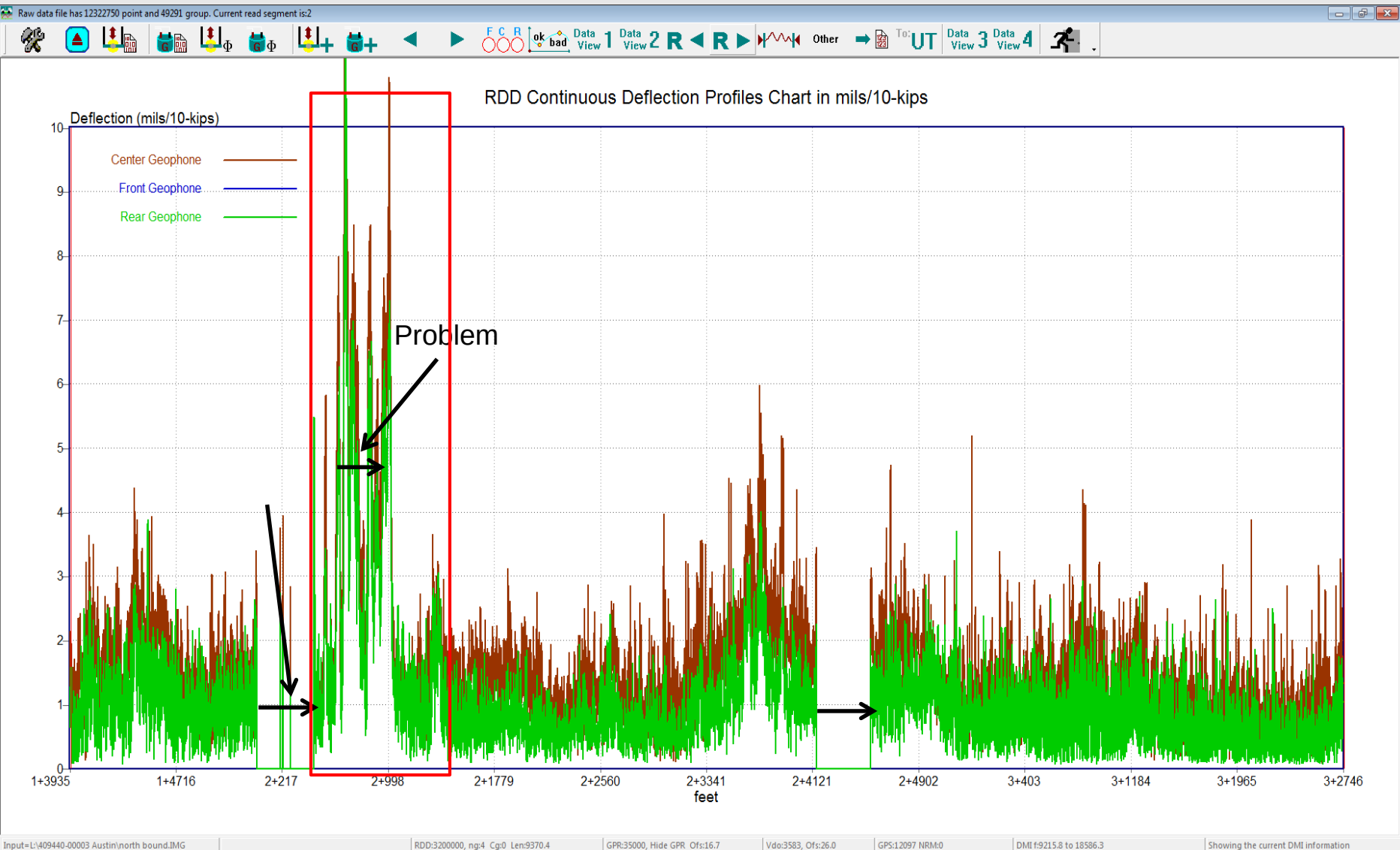
Embankment  
(Fill Section)



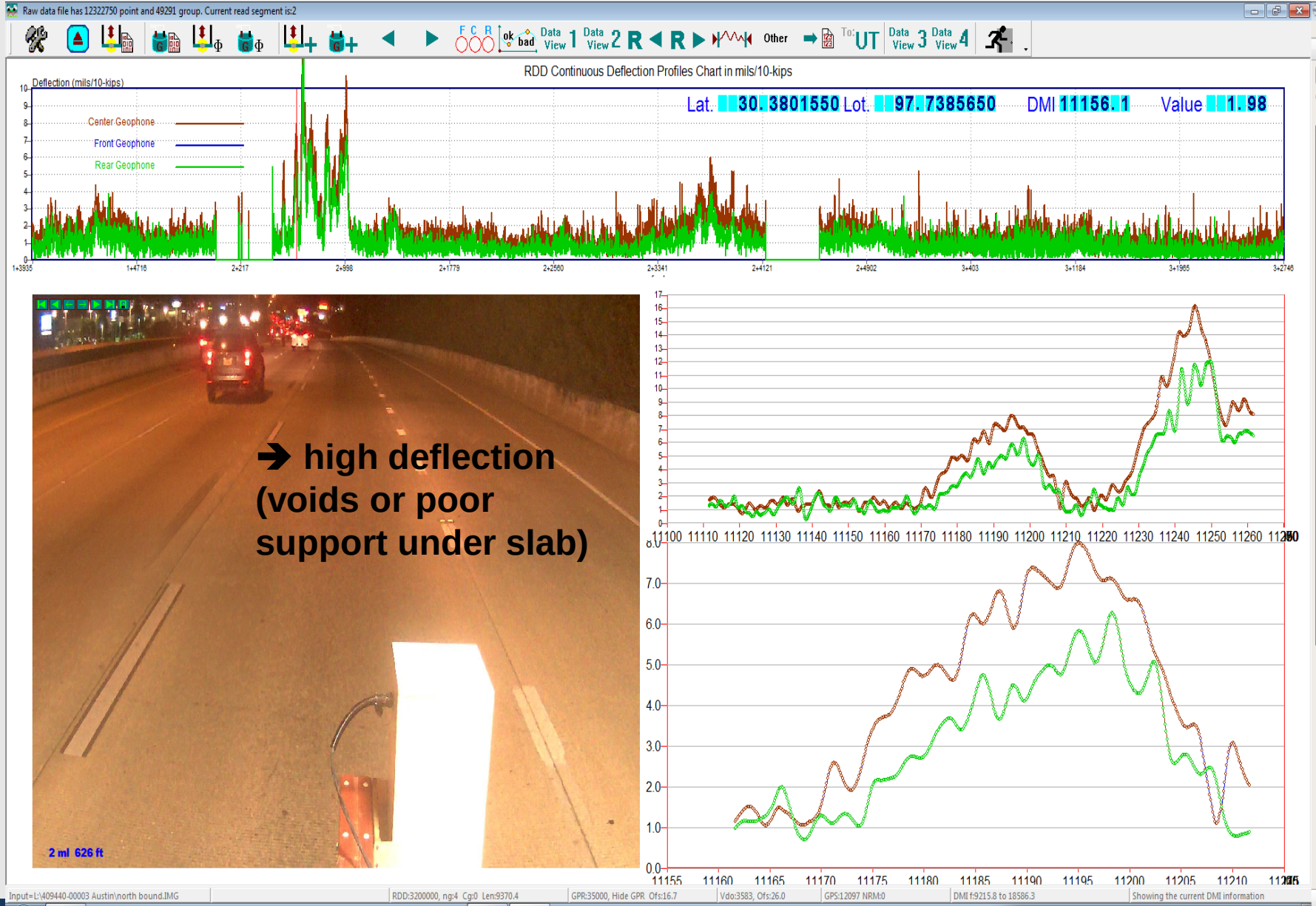
## □ Location of Test Section



## 4.1 District Data (12/2017 TPAD Data by TTI)



# Problem area – NB direction L2





## 4.2 Web Soil Survey and Google Earth Historical Imagery



### Plasticity Index

| Map unit symbol             | Map unit name                                  | Rating (percent) | Acres in AOI | Percent of AOI |
|-----------------------------|------------------------------------------------|------------------|--------------|----------------|
| TcA                         | Eckrant and Speck soils, 0 to 2 percent slopes | 34.0             | 10.7         | 100.0%         |
| Totals for Area of Interest |                                                |                  | 10.7         | 100.0%         |

PI = 34

### Organic Matter

| Map unit symbol             | Map unit name                                  | Rating (percent) | Acres in AOI | Percent of AOI |
|-----------------------------|------------------------------------------------|------------------|--------------|----------------|
| TcA                         | Eckrant and Speck soils, 0 to 2 percent slopes | 4.50             | 10.7         | 100.0%         |
| Totals for Area of Interest |                                                |                  | 10.7         | 100.0%         |

4.5%

### Gypsum

| Map unit symbol             | Map unit name                                  | Rating (percent) | Acres in AOI | Percent of AOI |
|-----------------------------|------------------------------------------------|------------------|--------------|----------------|
| TcA                         | Eckrant and Speck soils, 0 to 2 percent slopes | 0                | 10.7         | 100.0%         |
| Totals for Area of Interest |                                                |                  | 10.7         | 100.0%         |

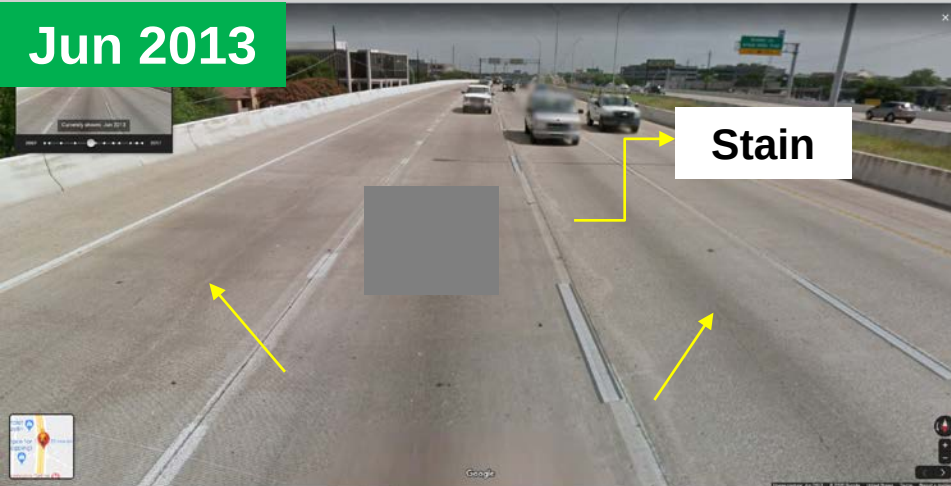
0.0%



# ❑ No Significant Progress of Longitudinal Crack (2013 to 2019)



**Jun 2013**



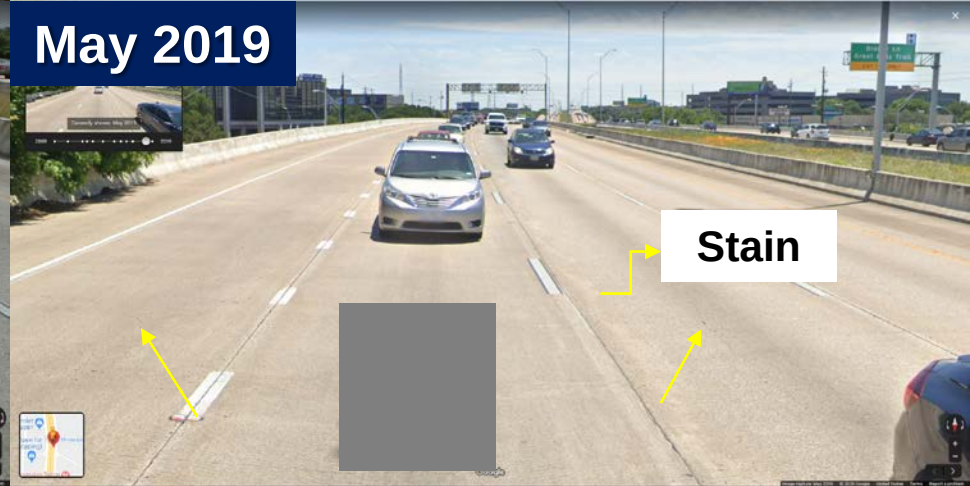
**Jul 2015**



**May 2017**



**May 2019**



- Pavement distress appears to be consistent over the years.
  - The pavement problem appears to occur before 2009 according to the Google Street View.



- **1) Visual Inspection**
  - Evaluate distress and crack progress
- **2) TPAD**
  - TPAD: Evaluate network level structural capacity
  - Select in-depth evaluation locations
- **3) FWD (GPS Coordinates)**
  - Overall structural capacity
  - Select coring locations in field according to the deflection (L – M – S deflections)
  - Determination of repair area
- **4) Coring and DCP (GPS coordinates)**
  - Pavement structure: layer thickness
  - Check for voids underneath CRCP slab
  - Check base and subgrade condition/modulus
- **5) Deflection vs. void thickness**



## □ Typical Distress – Localized CRCP Settlement at L2



o Pavement settlement at pavement surface = 0.25-in.

o No significant distress or settlement over the years (2009 to 2020)

## □ Typical Distress: Localized Longitudinal Crack at L1 & L3

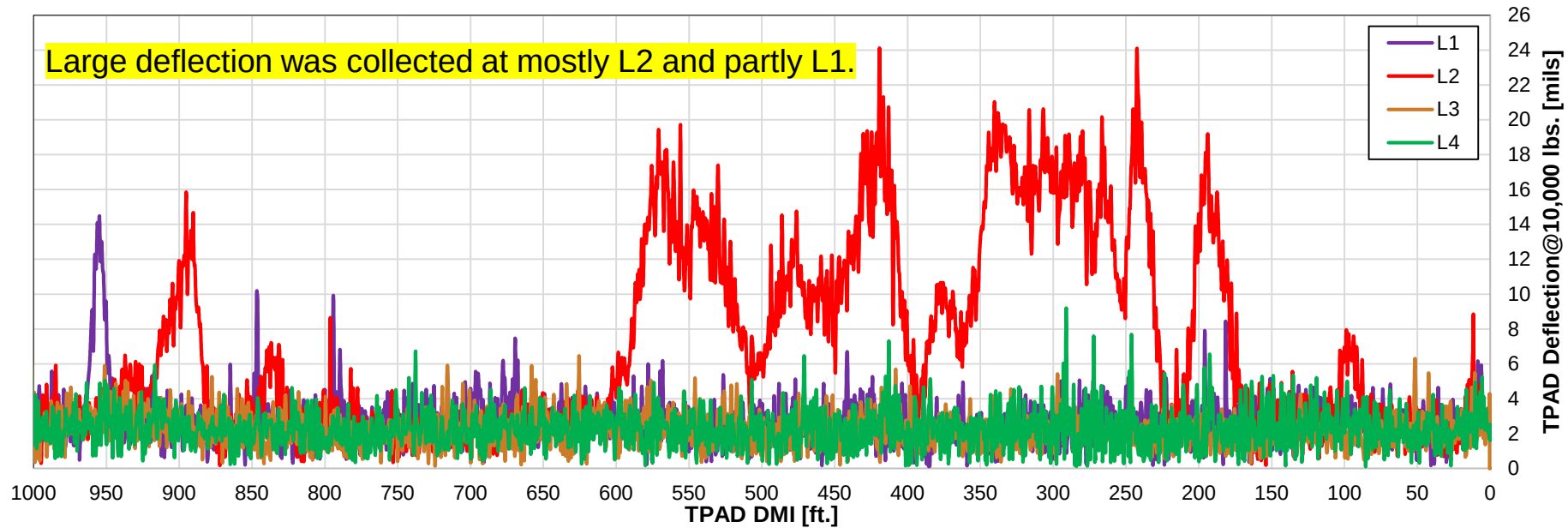


- No significant crack progress from April 2011 to June 2020





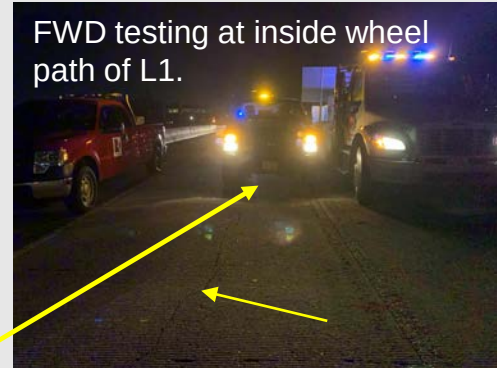
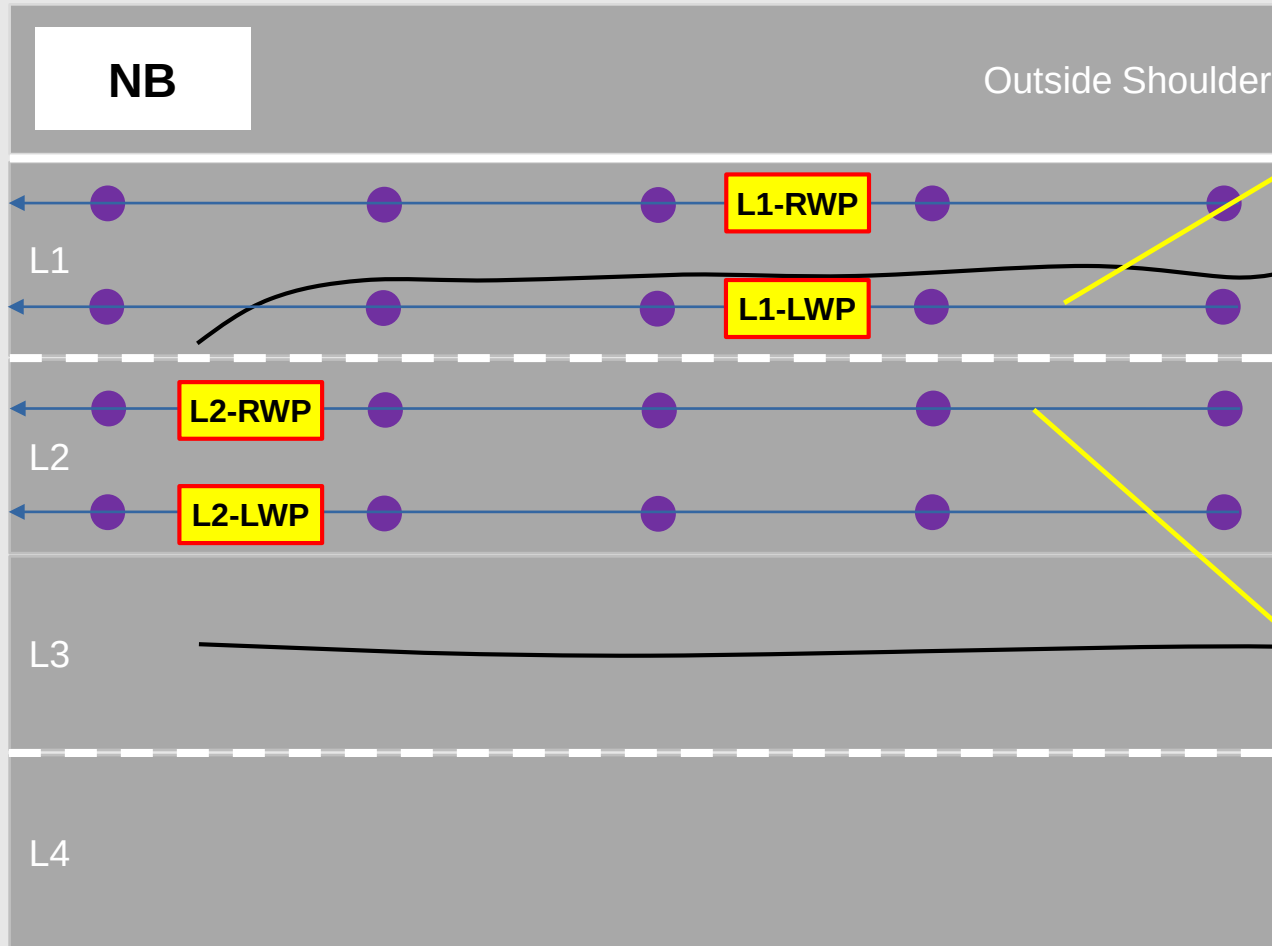
## 4.4 TPAD Testing Results (Testing on 05/27/2020)



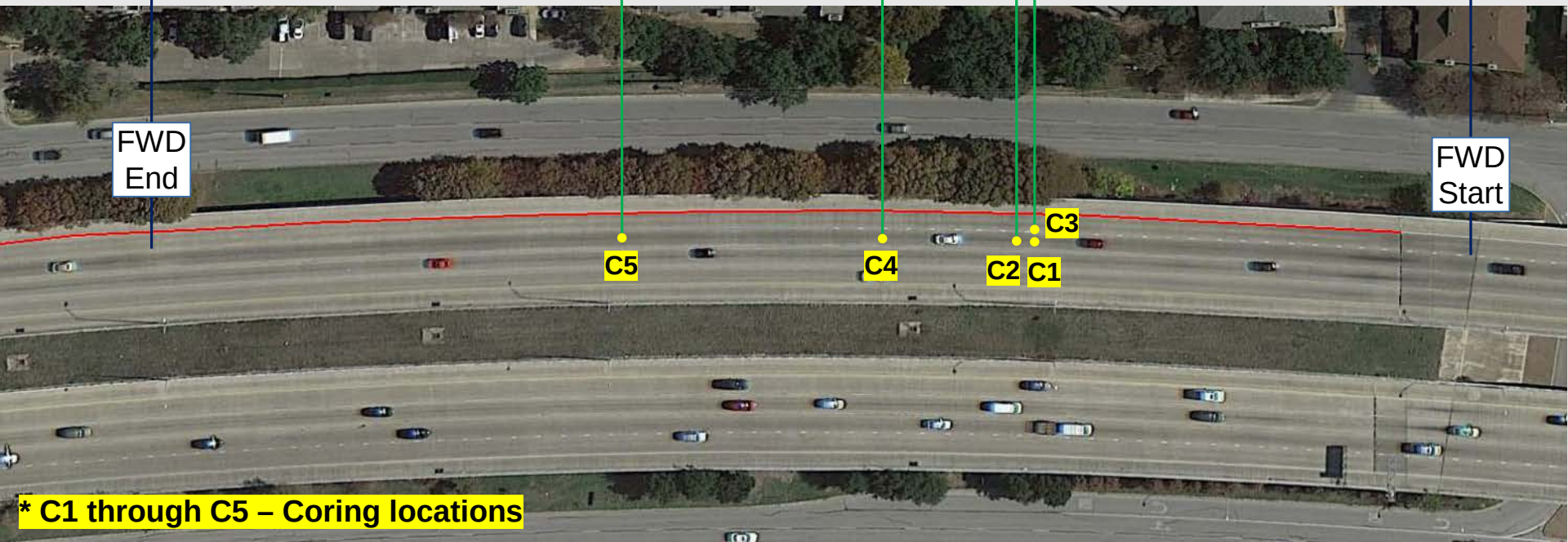
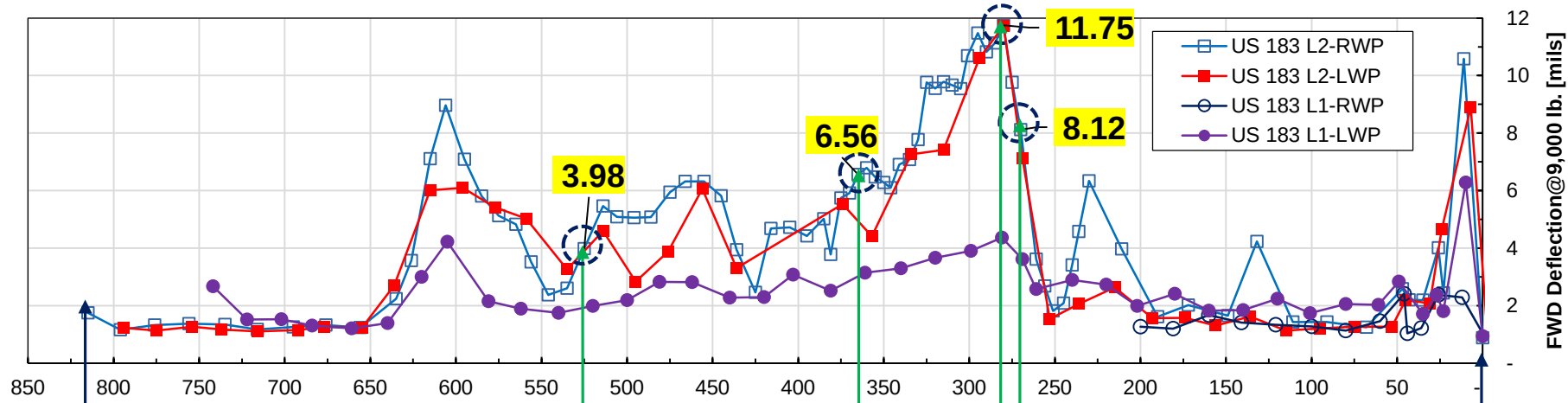
## 4.5 FWD Testing (Testing on 06/04/2020)



### ■ FWD testing detail

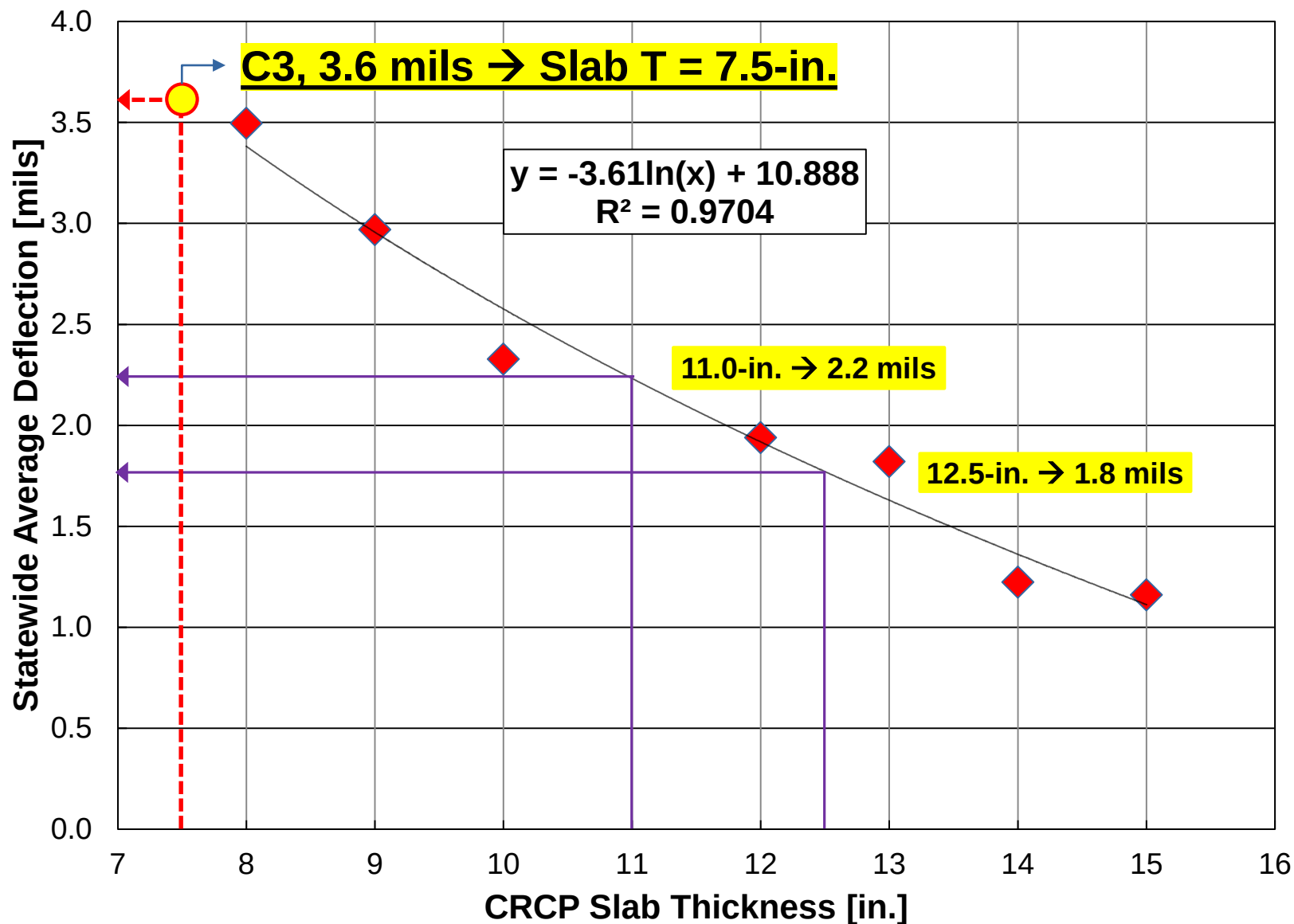


# □ FWD Deflection@9,000 lbs.

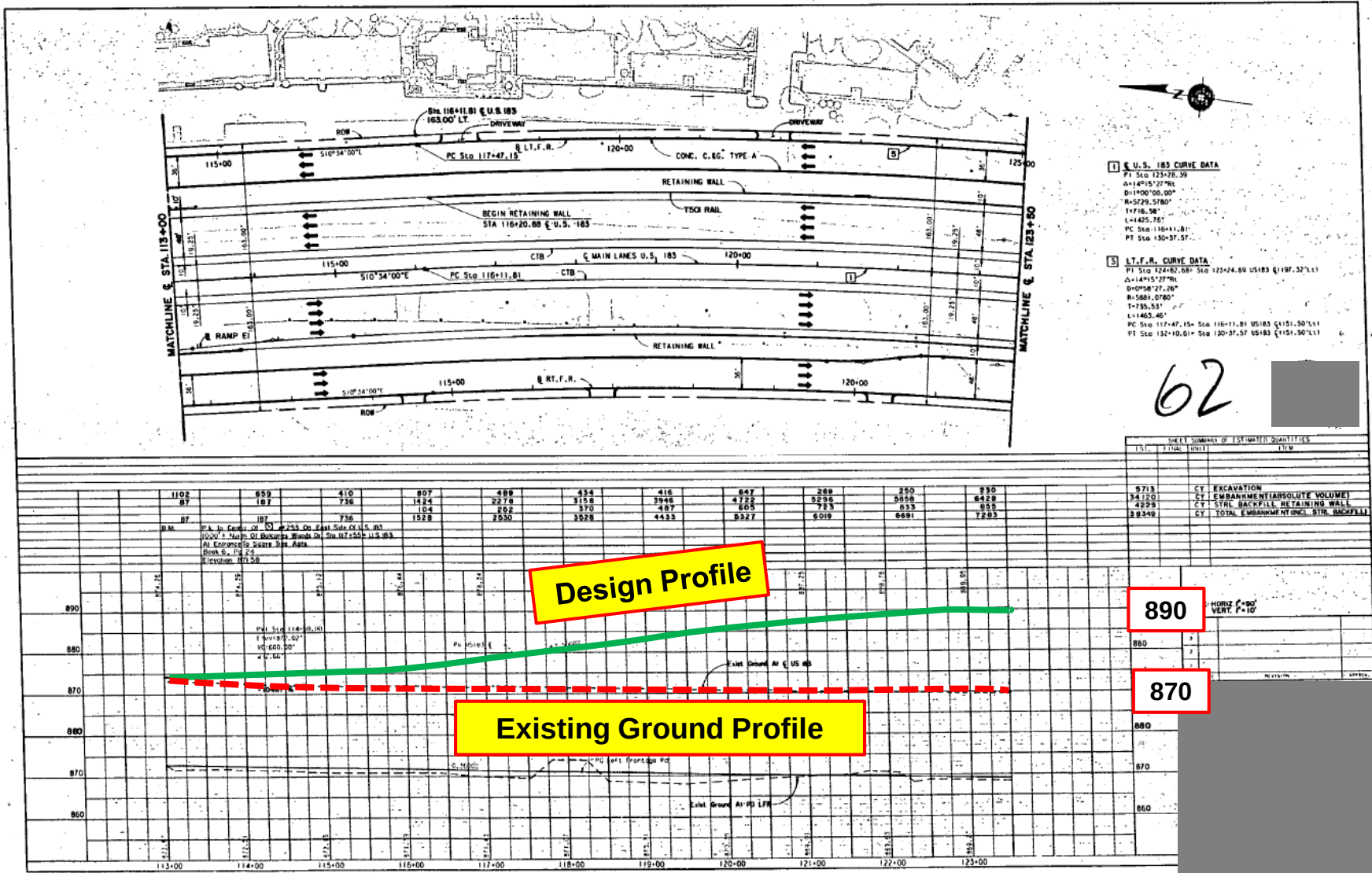


\* C1 through C5 – Coring locations

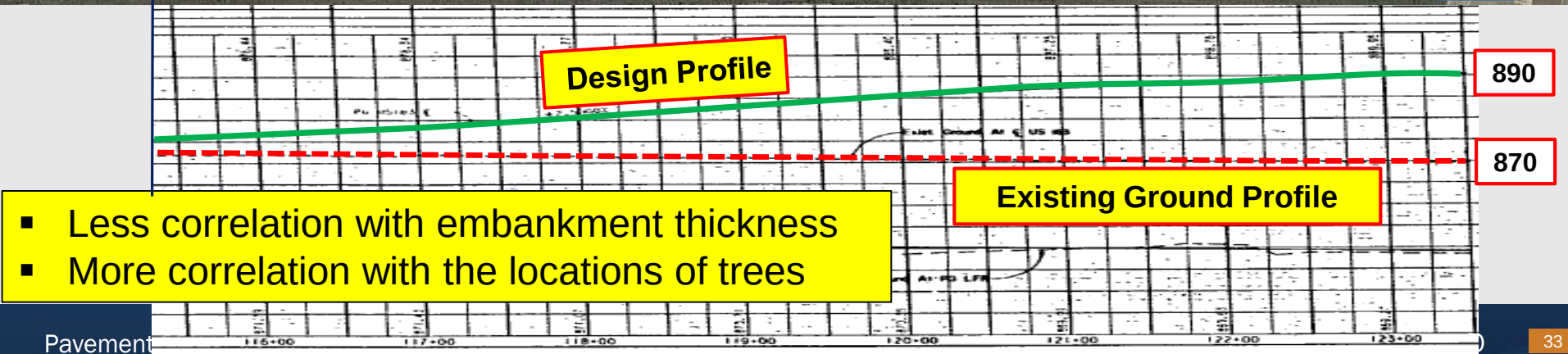
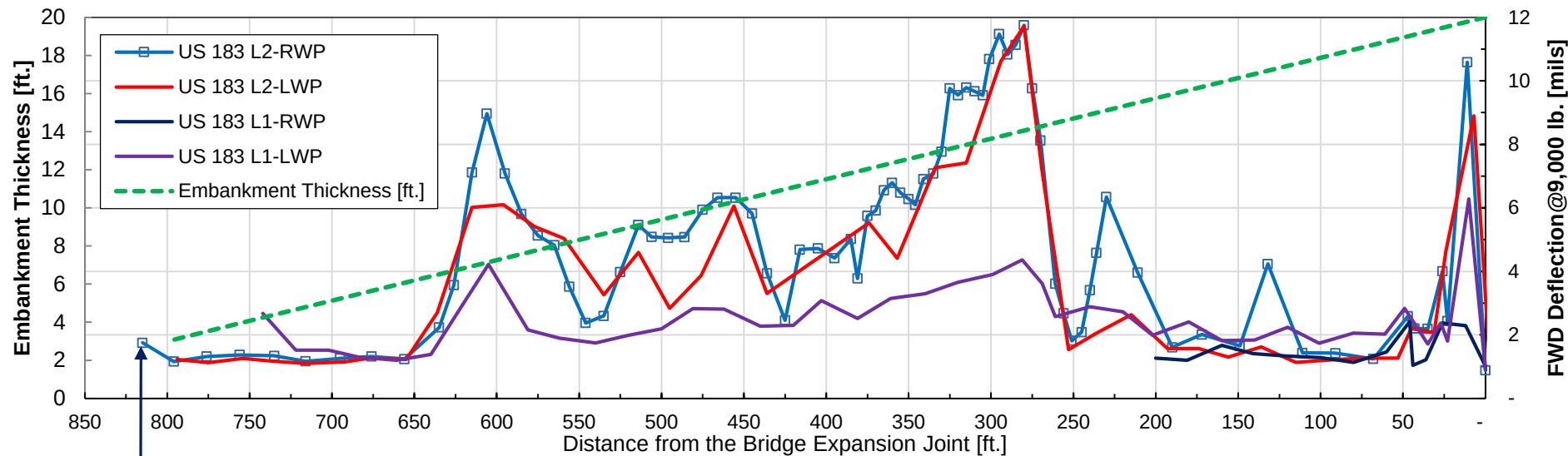




# Design Profile/Existing Ground Profile



# FWD Deflection vs. Embankment Thickness





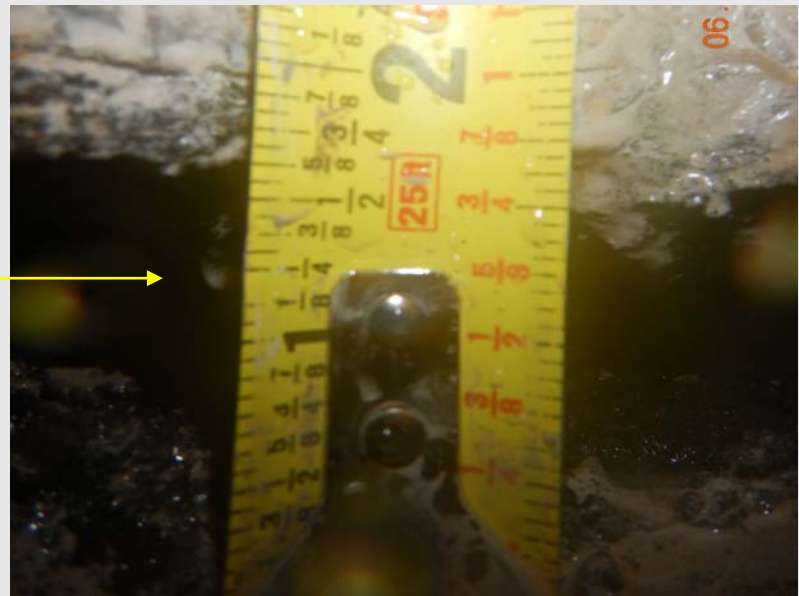
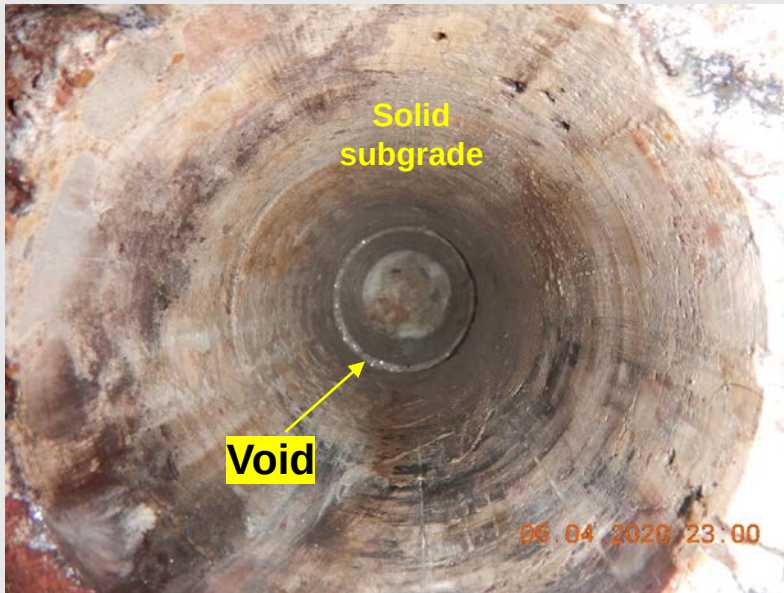
## 4.6 Coring and DCP Testing Results (Testing on 06/04/2020)

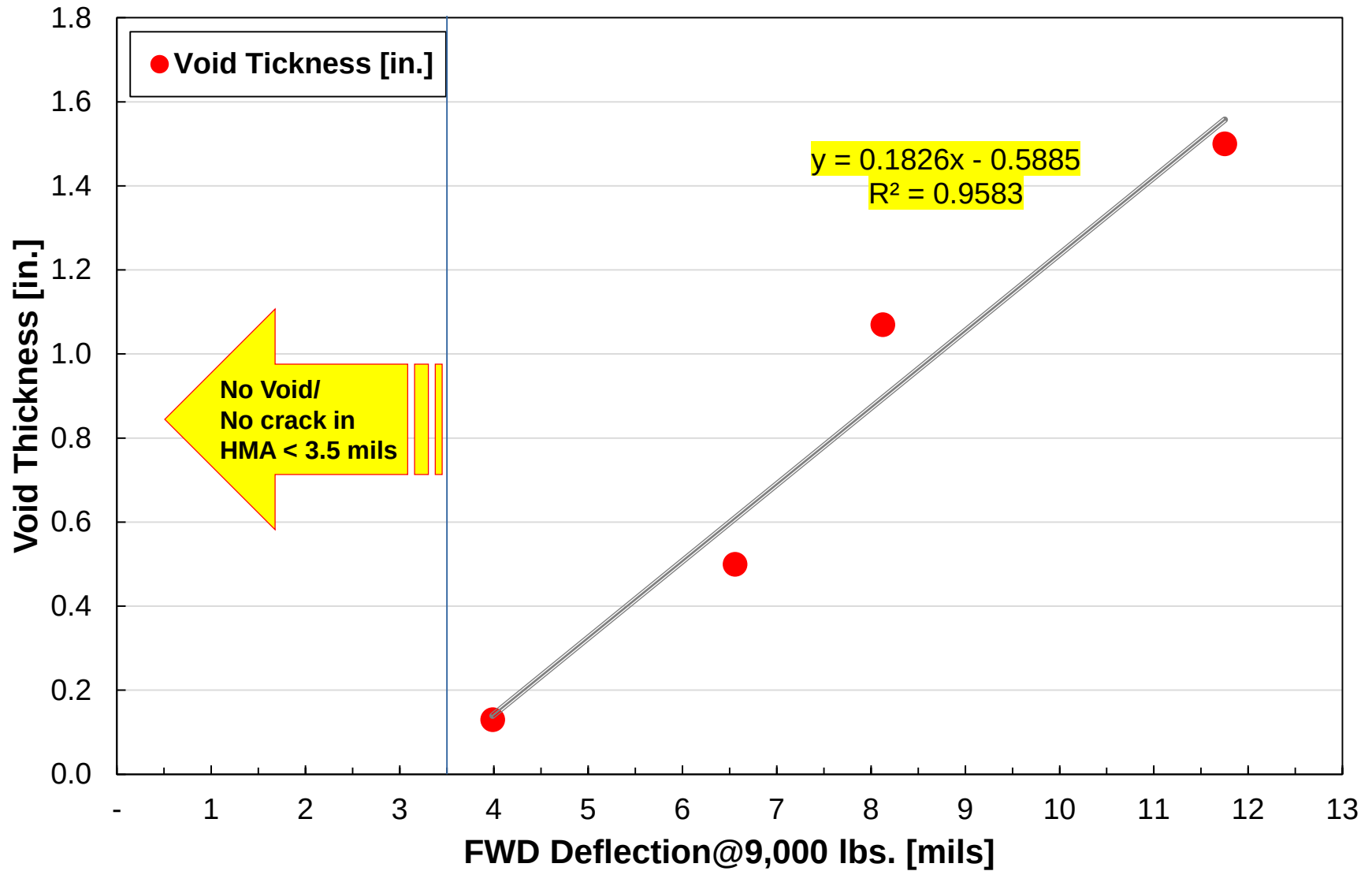


- Very stable and strong subgrade (12-in. TY-C embankment materials)

| Core # | FWD<br>DMI | CRCP<br>Slab<br>T<br>[in.] | HMA<br>Base<br>T<br>[in.] | Deflection<br>@9,000 lbs<br>[mils] | Void<br>T<br>[in.] | Pavement Layer<br>Information         | Modulus<br>[ksi] |                 |
|--------|------------|----------------------------|---------------------------|------------------------------------|--------------------|---------------------------------------|------------------|-----------------|
|        |            |                            |                           |                                    |                    |                                       | Subgrade         | Natural<br>Soil |
| C1     | 270        | 12.25                      | 6                         | 8.12                               | 1.07               | CRCP<br>12.0 – 13.0-in.               | 46.4             | -               |
| C2     | 280        | 12.75                      | 6                         | 11.75                              | 1.50               |                                       | 27.3             | -               |
| C3     | 269        | 12.50                      | 6                         | 3.60                               | 0.25               | HMA<br>6.0-in.                        | 36.7             | -               |
| C4     | 365        | 13.00                      | 6                         | 6.56                               | 0.50               | Subgrade<br>12-in. TY-C<br>Embankment | 28.9             | -               |
| C5     | 525        | 12.25                      | 6                         | 3.98                               | 0.13               | Embankment<br>Fill Section            | 34.3             | -               |

## □ Void Thickness Measurements



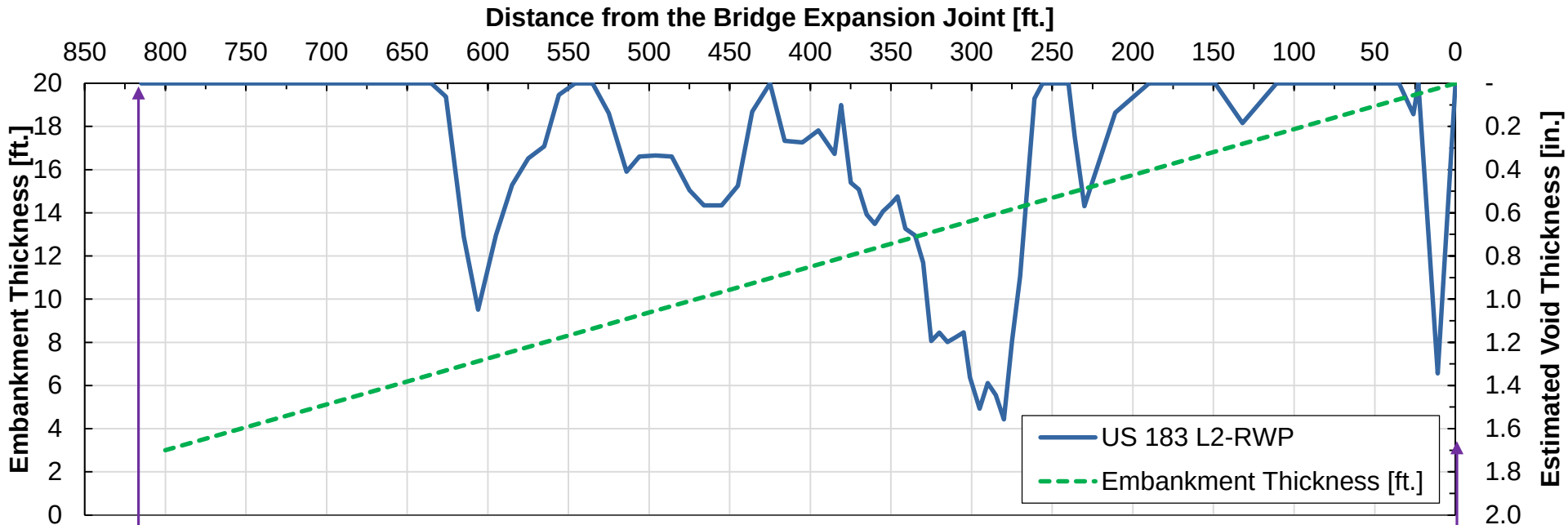




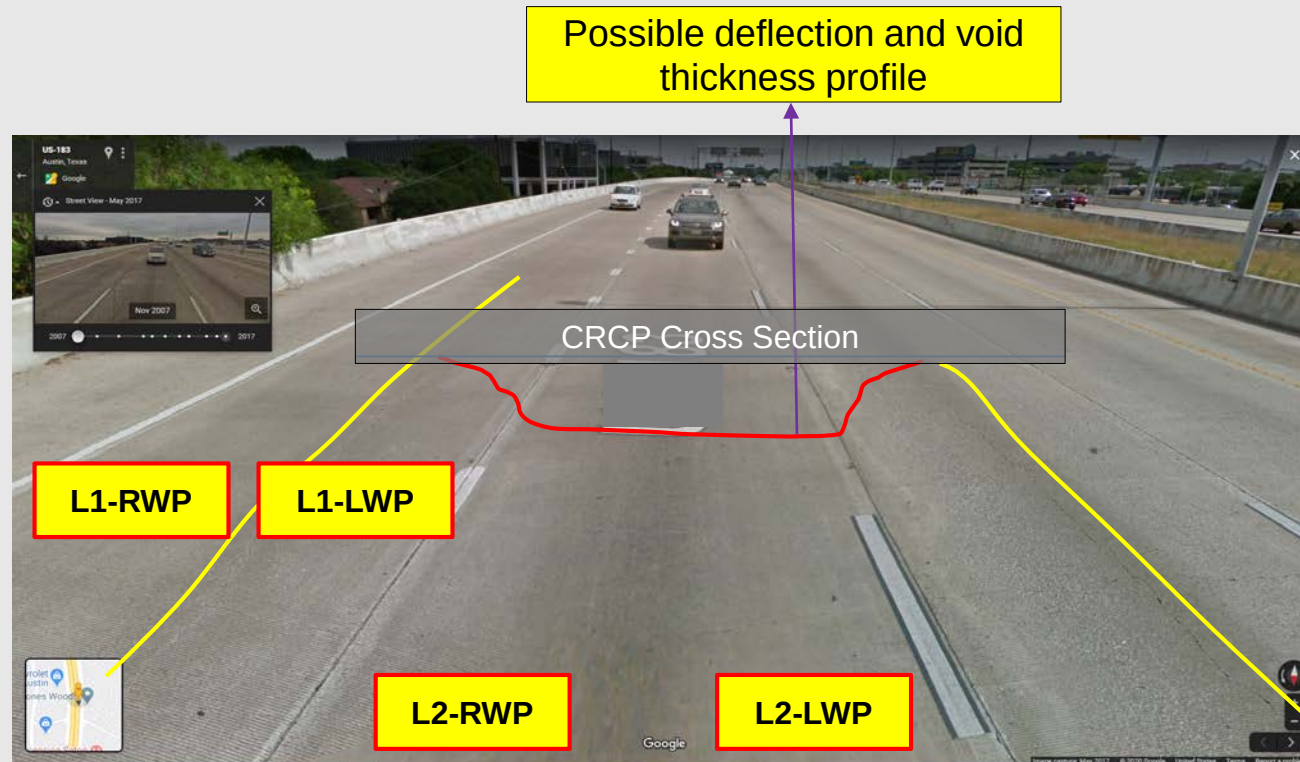
## Estimated Void Thickness Profile (L2 – RWP)



- Largest deflection profile is used to estimate the void profile.



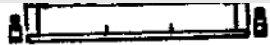
- Large deflections were measured in both wheel paths of L2
- Deflection in L1-LWP was slightly higher than statewide average (2.0-mil) due to settlement in L2, resulting in longitudinal crack.





- **Immediate settlement**
  - Related to construction/removal of temporary connector
  - Compaction between embankment and wall select fill
  - Issue during embankment construction of a lower layer
- **Issue related to the location of trees beside retaining wall.**
  - TxDOT Pavement Manual, “Trees create a greater chance of subgrade desiccation leading to soil shrinkage and possible cracking. This phenomenon is most evident in soils with higher plasticity index.”
  - $PI = 34$ , Organic matter = 4.5%
- **No correlation between pavement settlement and traffic**

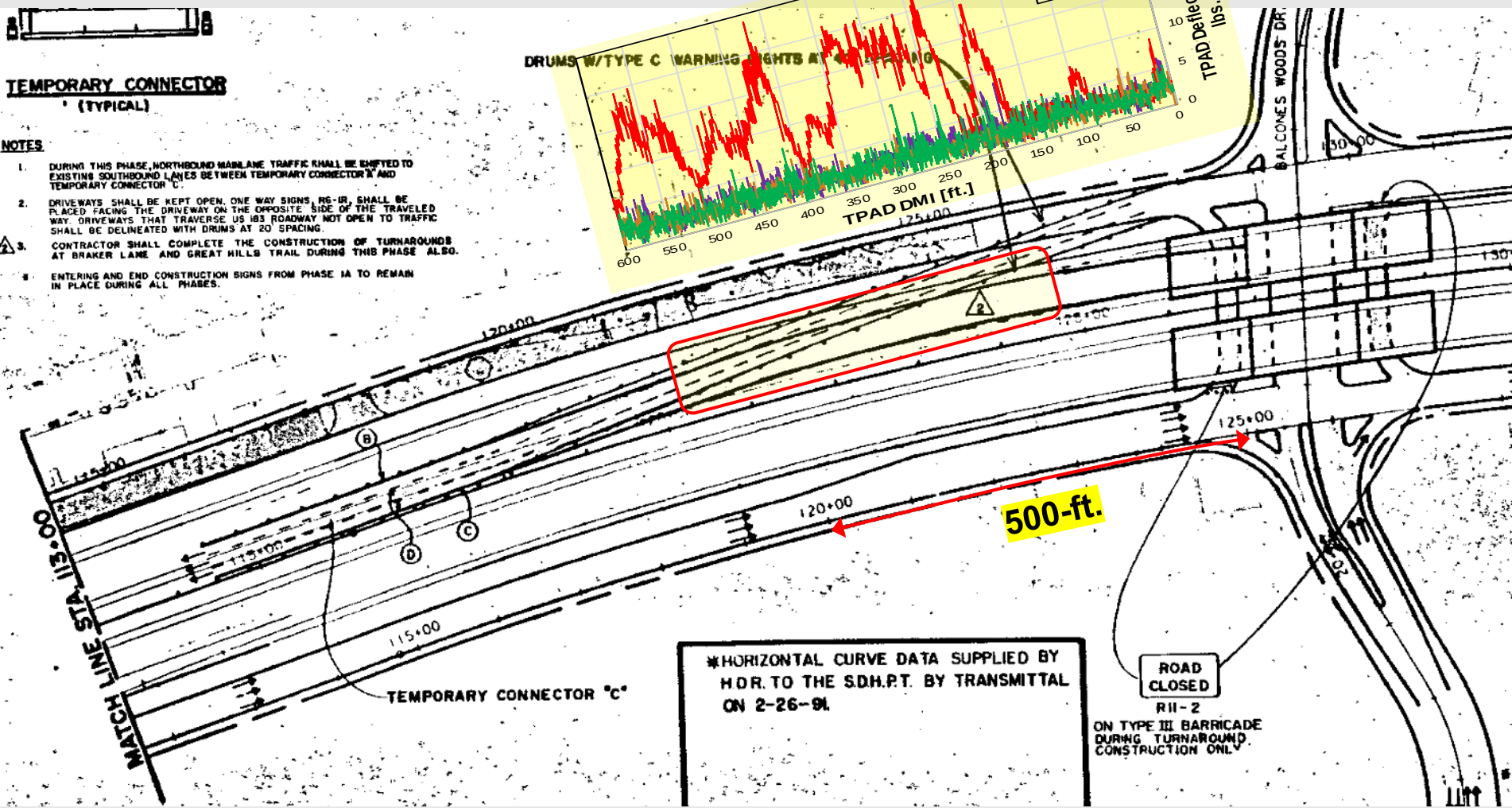
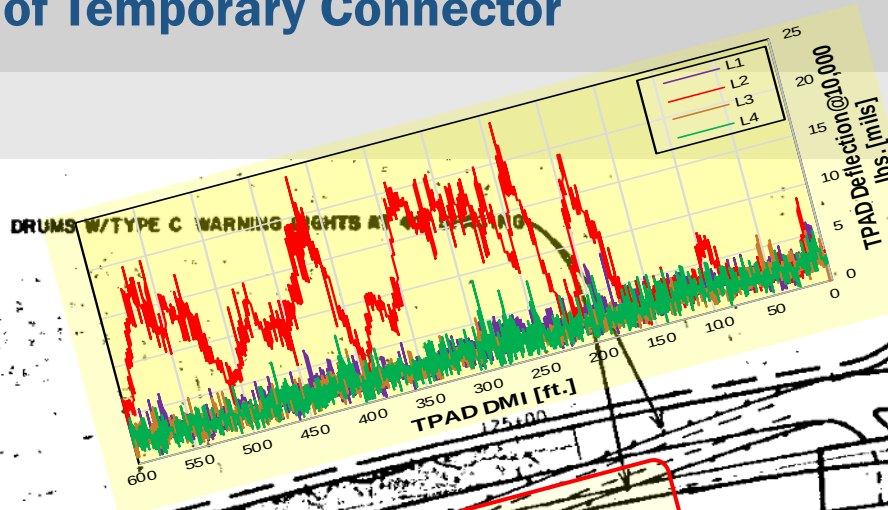
# Construction/Removal of Temporary Connector



## TEMPORARY CONNECTOR (TYPICAL)

### NOTES

1. DURING THIS PHASE, NORTHBOUND MAINLANE TRAFFIC SHALL BE SHIFTED TO EXISTING SOUTHBOUND LANES BETWEEN TEMPORARY CONNECTOR 'A' AND TEMPORARY CONNECTOR 'C'.
2. DRIVEWAYS SHALL BE KEPT OPEN. ONE WAY SIGNS, RS-10, SHALL BE PLACED FACING THE DRIVEWAY ON THE OPPOSITE SIDE OF THE TRAVELED WAY. DRIVEWAYS THAT TRAVERSE US 183 ROADWAY NOT OPEN TO TRAFFIC SHALL BE DELINEATED WITH DRUMS AT 20' SPACING.
3. CONTRACTOR SHALL COMPLETE THE CONSTRUCTION OF TURNAROUNDS AT BRAKER LANE AND GREAT HILLS TRAIL DURING THIS PHASE ALSO.
4. ENTERING AND END CONSTRUCTION SIGNS FROM PHASE 1A TO REMAIN IN PLACE DURING ALL PHASES.

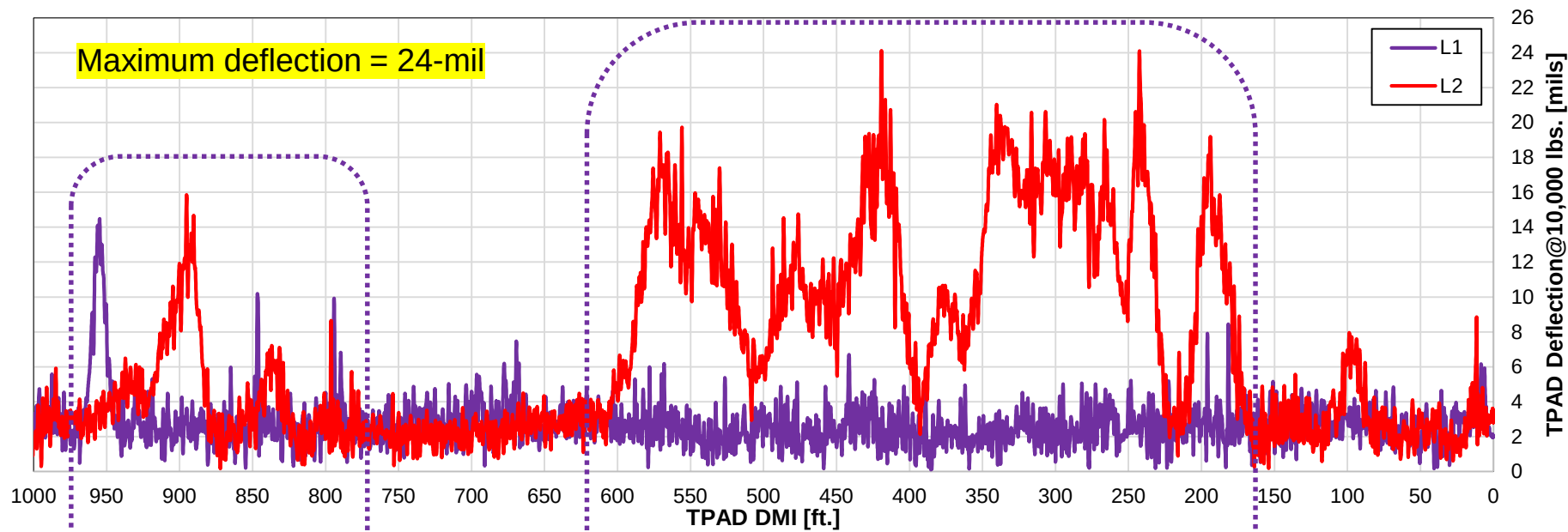




## ❑ Possible Cause of Large Deflection in Only L2



# □ L1 & L2 – Large deflection appears to be related to trees.



o Large deflection at L2 seems to be related to trees, but no evidence.

## 2.2.3.5 Vegetation

## Pavement Manual, page 3-8

- ◆ Although vegetation is normally beneficial, having large trees or other vegetation requiring a sustainable water supply close to the roadbed or roots that are close or under the roadbed are most likely detrimental. These conditions create a greater chance of subgrade desiccation leading to soil shrinkage and possible cracking. This phenomenon is most evident in soils with higher plasticity indexes (Tex-106-E, “Calculating the Plasticity Index of Soils”) and large shrinkage potential (Tex-107-E, “Determining the Bar Linear Shrinkage of Soils”).

OC = 4.5%

PI = 34

Jul 2015



Jan 2017

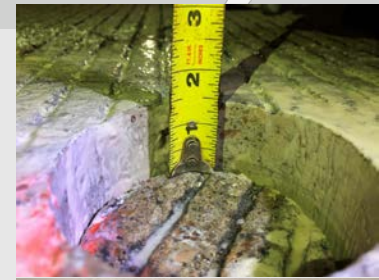
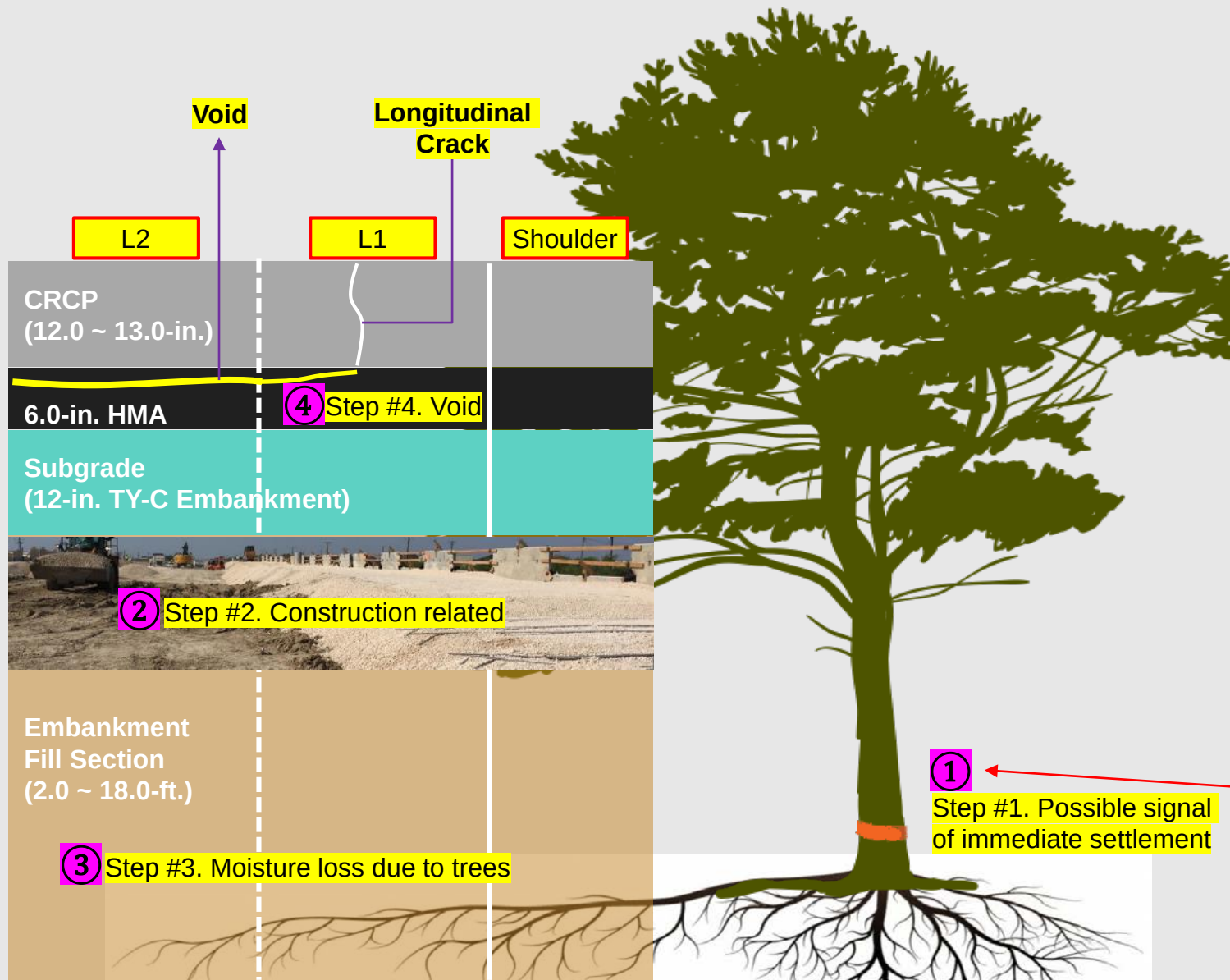


Jan 2018





# Void Mechanism







- No significant distress was observed along the test section – No significant distress
- No significant longitudinal crack progress from 2011 to 2020
- Although there is void, the current pavement structure continues to carry the design traffic volume – Very successful performance.
- The cause of settlement could be a combination of:
  - 1) construction and removal of temporary connector
  - 2) construction practices
  - 3) moisture loss due to trees.
- Subgrade conditions, which is 12-in. TY-C embankment, appears to be very stable and strong – Subgrade is very strong.
- No correlation between pavement settlement and traffic

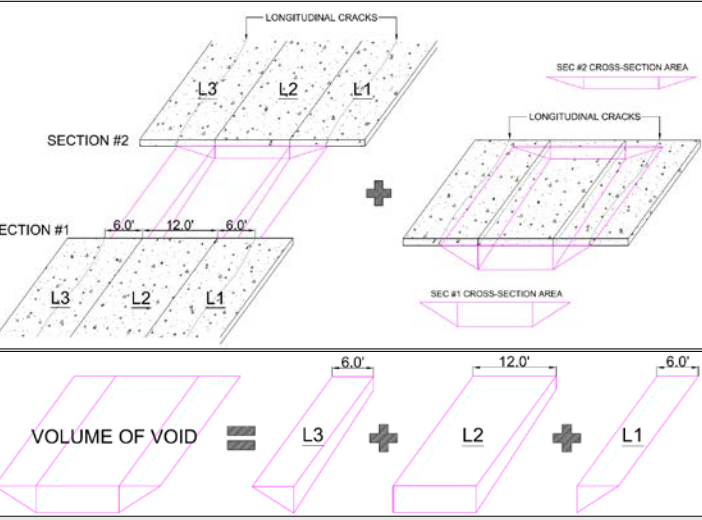


- **Option #1) Continue to monitor until a repair strategy can be scheduled**
  - Pros: No immediate cost
  - Cons: The void and settlement are not repaired
- **Option #2) Preventive maintenance concept – Pressure grouting (SS 3051)**
  - Repair limit:
    - Length = 450-ft. (200-ft to 650-ft from the BAS)
  - Pros: Moderate cost (\$\$) & void is filled
  - Cons: Void may not be filled 100%
- **Option #3) Full-depth repair**
  - Pros: Void and settlement are repaired
  - Cons: Increased cost (\$\$\$), involves lanes 1-3, traffic control impacts traveling public (close up to 3 lanes w/ positive barrier or full freeway closure) and construction challenges

# Option #2) Pressure Grouting (SS 3051) & DMS 4675



## Estimated Total Volume of the Void, 338.5 CF = 12.54 CY



<http://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/specs/2014/spec/ss3051.pdf>

**Special Specification 3051**  
**Pressure Grouting**

1. DESCRIPTION

Undersealing existing voids under the concrete pavement at locations shown on the plans or designated by the Engineer. This work includes drilling injection holes, placement of undersealing grout, testing to control fill of pavement, clean-up and other related work.

[https://ftp.dot.state.tx.us/pub/txdot-info/cst/DMS/4000\\_series/pdfs/4675.pdf](https://ftp.dot.state.tx.us/pub/txdot-info/cst/DMS/4000_series/pdfs/4675.pdf)

**DMS-4675**  
**Cementitious Grouts and Mortars for Miscellaneous Applications**

Effective Date: December 2014

1. DESCRIPTION

This Specification governs the pre-qualification procedure, packaging, and material properties of cementitious grouts and mortars used for miscellaneous applications. These applications include but are not limited to:

- grouting precast member connections,
- grouting anchor bolts and dowels,
- grouting lateral connectors for prestressed beams.

| DMI (ft.) | Section Length (ft.) | US 183 L2 RWP | Deflection (in.) | Void Thickness (in.) | Cross-Section Area(ft <sup>2</sup> ) |     |     | Void Volume (ft <sup>3</sup> ) |     |     |          |
|-----------|----------------------|---------------|------------------|----------------------|--------------------------------------|-----|-----|--------------------------------|-----|-----|----------|
|           |                      |               |                  |                      | L1                                   | L2  | L3  | L1                             | L2  | L3  | Subtotal |
| 0         | 0                    | L2-RWP        | 0.88             | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
| 11        | 11                   | L2-RWP        | 10.58            | 1.3                  | 0.3                                  | 1.3 | 0.3 | 1.8                            | 7.4 | 1.8 | 11.1     |
| 25        | 12                   | L2-RWP        | 2.44             | -                    | -                                    | -   | -   | 2.0                            | 8.1 | 2.0 | 12.1     |
| 26        | 3                    | L2-RWP        | 4.01             | 0.1                  | 0.0                                  | 0.1 | 0.0 | 0.1                            | 0.2 | 0.1 | 0.3      |
| 35        | 9                    | L2-RWP        | -                | -                    | -                                    | -   | -   | -                              | 0.6 | 0.2 | 1.0      |
| 43        | 8                    | L2-RWP        | -                | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
| 47        | 4                    | L2-RWP        | -                | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
| 68        | 21                   | L2-RWP        | 1.24             | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
| 91        | 23                   | L2-RWP        | 1.43             | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
| 111       | 20                   | L2-RWP        | 1.43             | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
| 132       | 21                   | L2-RWP        | 4.23             | 0.2                  | 0.0                                  | 0.2 | 0.0 | 0.5                            | 1.9 | 0.5 | 2.9      |
| 149       | 17                   | L2-RWP        | 1.65             | -                    | -                                    | -   | -   | 0.4                            | 1.6 | 0.4 | 2.4      |
| 172       | 23                   | L2-RWP        | 2.01             | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
| 189       | 18                   | L2-RWP        | 1.61             | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
| 211       | 21                   | L2-RWP        | 3.97             | 0.1                  | 0.0                                  | 0.1 | 0.0 | 0.4                            | 1.4 | 0.4 | 2.1      |
| 230       | 19                   | L2-RWP        | 6.34             | 0.6                  | 0.1                                  | 0.6 | 0.1 | 1.7                            | 6.7 | 1.7 | 10.0     |
| 236       | 6                    | L2-RWP        | 4.58             | 0.2                  | 0.1                                  | 0.2 | 0.1 | 0.6                            | 2.5 | 0.6 | 3.7      |
| 240       | 4                    | L2-RWP        | 3.41             | -                    | -                                    | -   | -   | 0.1                            | 0.5 | 0.1 | 0.7      |
| 245       | 5                    | L2-RWP        | 2.09             | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
| 251       | 6                    | L2-RWP        | 1.82             | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
| 256       | 5                    | L2-RWP        | 2.88             | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
| 261       | 5                    | L2-RWP        | 2.61             | 0.1                  | 0.0                                  | 0.1 | 0.0 | 0.0                            | 0.2 | 0.0 | 0.3      |
| 270       | 9                    | L2-RWP        | 8.12             | 0.9                  | 0.2                                  | 0.9 | 0.2 | 1.1                            | 4.3 | 1.1 | 6.5      |
| 275       | 5                    | L2-RWP        | 9.77             | 1.2                  | 0.3                                  | 1.2 | 0.3 | 1.3                            | 5.2 | 1.3 | 7.8      |
| 280       | 5                    | L2-RWP        | 11.75            | 1.6                  | 0.4                                  | 1.6 | 0.4 | 1.7                            | 6.9 | 1.7 | 10.3     |
| 285       | 5                    | L2-RWP        | 11.13            | 1.4                  | 0.4                                  | 1.4 | 0.4 | 1.9                            | 7.5 | 1.9 | 11.3     |
| 290       | 5                    | L2-RWP        | 10.83            | 1.4                  | 0.3                                  | 1.4 | 0.3 | 1.8                            | 7.1 | 1.8 | 10.6     |
| 295       | 5                    | L2-RWP        | 11.48            | 1.5                  | 0.4                                  | 1.5 | 0.4 | 1.8                            | 7.2 | 1.8 | 10.9     |
| 301       | 6                    | L2-RWP        | 10.68            | 1.4                  | 0.3                                  | 1.4 | 0.3 | 2.2                            | 8.6 | 2.2 | 12.9     |
| 305       | 4                    | L2-RWP        | 9.55             | 1.2                  | 0.3                                  | 1.2 | 0.3 | 1.3                            | 5.0 | 1.3 | 7.6      |
| 310       | 5                    | L2-RWP        | 9.87             | 1.2                  | 0.3                                  | 1.2 | 0.3 | 1.5                            | 5.8 | 1.5 | 8.7      |
| 315       | 5                    | L2-RWP        | 9.79             | 1.2                  | 0.3                                  | 1.2 | 0.3 | 1.5                            | 5.9 | 1.5 | 8.9      |
| 320       | 5                    | L2-RWP        | 7.81             | 0.7                  | 0.2                                  | 0.7 | 0.2 | 1.0                            | 3.8 | 1.0 | 5.8      |
| 335       | 5                    | L2-RWP        | 7.81             | 0.7                  | 0.2                                  | 0.7 | 0.2 | 1.0                            | 4.1 | 1.0 | 6.2      |
| 341       | 6                    | L2-RWP        | -                | -                    | -                                    | -   | -   | 1.0                            | 4.1 | 1.0 | 6.2      |
| 346       | 5                    | L2-RWP        | -                | -                    | -                                    | -   | -   | 1.0                            | 4.1 | 1.0 | 6.2      |
| 350       | 4                    | L2-RWP        | -                | -                    | -                                    | -   | -   | 0.5                            | 2.2 | 0.5 | 3.2      |
| 355       | 5                    | L2-RWP        | 6.48             | 0.6                  | 0.1                                  | 0.6 | 0.1 | 0.7                            | 2.9 | 0.7 | 4.3      |
| 360       | 5                    | L2-RWP        | 6.79             | 0.7                  | 0.2                                  | 0.7 | 0.2 | 0.8                            | 3.1 | 0.8 | 4.7      |
| 365       | 5                    | L2-RWP        | 6.56             | 0.6                  | 0.2                                  | 0.6 | 0.2 | 0.8                            | 3.2 | 0.8 | 4.7      |
| 370       | 5                    | L2-RWP        | 5.91             | 0.5                  | 0.1                                  | 0.5 | 0.1 | 0.7                            | 2.8 | 0.7 | 4.1      |
| 375       | 5                    | L2-RWP        | 5.75             | 0.5                  | 0.1                                  | 0.5 | 0.1 | 0.6                            | 2.4 | 0.6 | 3.6      |
| 381       | 6                    | L2-RWP        | 3.78             | 0.1                  | 0.0                                  | 0.1 | 0.0 | 0.4                            | 1.7 | 0.4 | 2.5      |
| 385       | 4                    | L2-RWP        | 5.02             | 0.3                  | 0.1                                  | 0.3 | 0.1 | 0.2                            | 0.9 | 0.2 | 1.3      |
| 395       | 10                   | L2-RWP        | 4.42             | 0.2                  | 0.1                                  | 0.2 | 0.1 | 0.7                            | 2.7 | 0.7 | 4.1      |
| 405       | 10                   | L2-RWP        | 4.72             | 0.3                  | 0.1                                  | 0.3 | 0.1 | 0.6                            | 2.5 | 0.6 | 3.7      |
| 416       | 11                   | L2-RWP        | 4.69             | 0.3                  | 0.1                                  | 0.3 | 0.1 | 0.7                            | 3.0 | 0.7 | 4.5      |
| 425       | 9                    | L2-RWP        | 2.46             | -                    | -                                    | -   | -   | 0.3                            | 1.2 | 0.3 | 1.8      |
| 436       | 11                   | L2-RWP        | 3.94             | 0.1                  | 0.0                                  | 0.1 | 0.0 | 0.2                            | 0.7 | 0.2 | 1.1      |
| 445       | 9                    | L2-RWP        | 5.82             | 0.5                  | 0.1                                  | 0.5 | 0.1 | 0.7                            | 2.7 | 0.7 | 4.1      |
| 455       | 10                   | L2-RWP        | 6.32             | 0.6                  | 0.1                                  | 0.6 | 0.1 | 1.3                            | 5.2 | 1.3 | 7.8      |
| 466       | 11                   | L2-RWP        | 6.32             | 0.6                  | 0.1                                  | 0.6 | 0.1 | 1.6                            | 6.2 | 1.6 | 9.3      |
| 475       | 9                    | L2-RWP        | 5.94             | 0.5                  | 0.1                                  | 0.5 | 0.1 | 1.2                            | 4.8 | 1.2 | 7.3      |
| 486       | 11                   | L2-RWP        | 5.08             | 0.3                  | 0.1                                  | 0.3 | 0.1 | 1.1                            | 4.6 | 1.1 | 6.9      |
| 496       | 10                   | L2-RWP        | 5.05             | 0.3                  | 0.1                                  | 0.3 | 0.1 | 0.8                            | 3.4 | 0.8 | 5.0      |
| 506       | 10                   | L2-RWP        | 5.08             | 0.3                  | 0.1                                  | 0.3 | 0.1 | 0.8                            | 3.4 | 0.8 | 5.1      |
| 514       | 8                    | L2-RWP        | 5.46             | 0.4                  | 0.1                                  | 0.4 | 0.1 | 0.7                            | 3.0 | 0.7 | 4.5      |
| 525       | 11                   | L2-RWP        | 3.98             | 0.1                  | 0.0                                  | 0.1 | 0.0 | 0.8                            | 3.0 | 0.8 | 4.5      |
| 535       | 10                   | L2-RWP        | 2.60             | -                    | -                                    | -   | -   | 0.2                            | 0.7 | 0.2 | 1.0      |
| 546       | 11                   | L2-RWP        | 2.38             | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
| 555       | 10                   | L2-RWP        | 2.52             | 0.1                  | 0.0                                  | 0.1 | 0.0 | 0.1                            | 0.3 | 0.1 | 0.4      |
| 565       | 9                    | L2-RWP        | 4.82             | 0.3                  | 0.1                                  | 0.3 | 0.1 | 0.4                            | 1.6 | 0.4 | 2.3      |
| 575       | 10                   | L2-RWP        | 5.13             | 0.3                  | 0.1                                  | 0.3 | 0.1 | 0.8                            | 3.2 | 0.8 | 4.8      |
| 585       | 10                   | L2-RWP        | 5.81             | 0.5                  | 0.1                                  | 0.5 | 0.1 | 1.0                            | 4.1 | 1.0 | 6.1      |
| 595       | 10                   | L2-RWP        | 7.09             | 0.7                  | 0.2                                  | 0.7 | 0.2 | 1.5                            | 5.9 | 1.5 | 8.8      |
| 606       | 11                   | L2-RWP        | 8.97             | 1.0                  | 0.3                                  | 1.0 | 0.3 | 2.4                            | 9.6 | 2.4 | 14.5     |
| 615       | 9                    | L2-RWP        | 7.11             | 0.7                  | 0.2                                  | 0.7 | 0.2 | 2.0                            | 7.9 | 2.0 | 11.9     |
| 626       | 11                   | L2-RWP        | 3.57             | 0.1                  | 0.0                                  | 0.1 | 0.0 | 1.3                            | 4.3 | 1.3 | 6.9      |
| 635       | 6                    | L2-RWP        | 2.23             | -                    | -                                    | -   | -   | 0.1                            | 0.3 | 0.1 | 0.4      |
| 656       | 21                   | L2-RWP        | 1.24             | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
| 676       | 20                   | L2-RWP        | 1.32             | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
| 695       | 19                   | L2-RWP        | 1.26             | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
| 716       | 21                   | L2-RWP        | 1.17             | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
| 735       | 19                   | L2-RWP        | 1.34             | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
| 756       | 21                   | L2-RWP        | 1.37             | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
| 776       | 20                   | L2-RWP        | 1.32             | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
| 796       | 20                   | L2-RWP        | 1.16             | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
| 815       | 19                   | L2-RWP        | 1.75             | -                    | -                                    | -   | -   | -                              | -   | -   | -        |
|           |                      |               |                  |                      |                                      |     |     | 56                             | 226 | 56  | 339      |

## Inspection Considerations

- Develop a detailed plan to avoid grouting material loss
- Identify drilling depth and condition for each hole
- A minimum of 13-in. depth drilling/no more than 15.0-in. drilling
- MIRA system can be used to identify drilling depth.





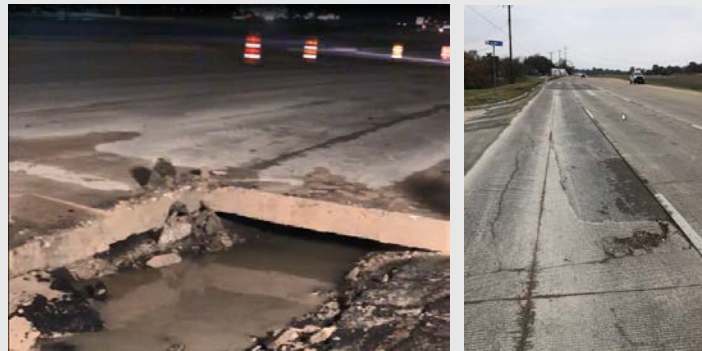
## ❑ Develop Plan to Avoid Material Loss



## 5. Case Study #2 – Ft. Worth District



- The District conducted full-depth repair (FDR) due to pavement settlement.
- The District found **the void under the CRCP during FDR.**
- **Pavement settlement continues** beyond FDR area.
- The request is to investigate **the extent of the void and cause of distress.**



| Attribute       | Information                | Notes |
|-----------------|----------------------------|-------|
| Date Work Begin | 05/10/2003                 |       |
| Date Completed  | 02/10/2006                 |       |
| Pavement Type   | CRCP                       |       |
| Slab thickness  | 8.0-in.                    |       |
| Shoulder Type   | No Shoulder                |       |
| Base Type       | 4.0-in. HMA TY-D           |       |
| Subgrade Type   | 8.0-in. LTS or 8.0-in. CTS |       |
| Drainage Type   | Curb and Gutter            |       |



- A distressed section was previously repaired (full depth)



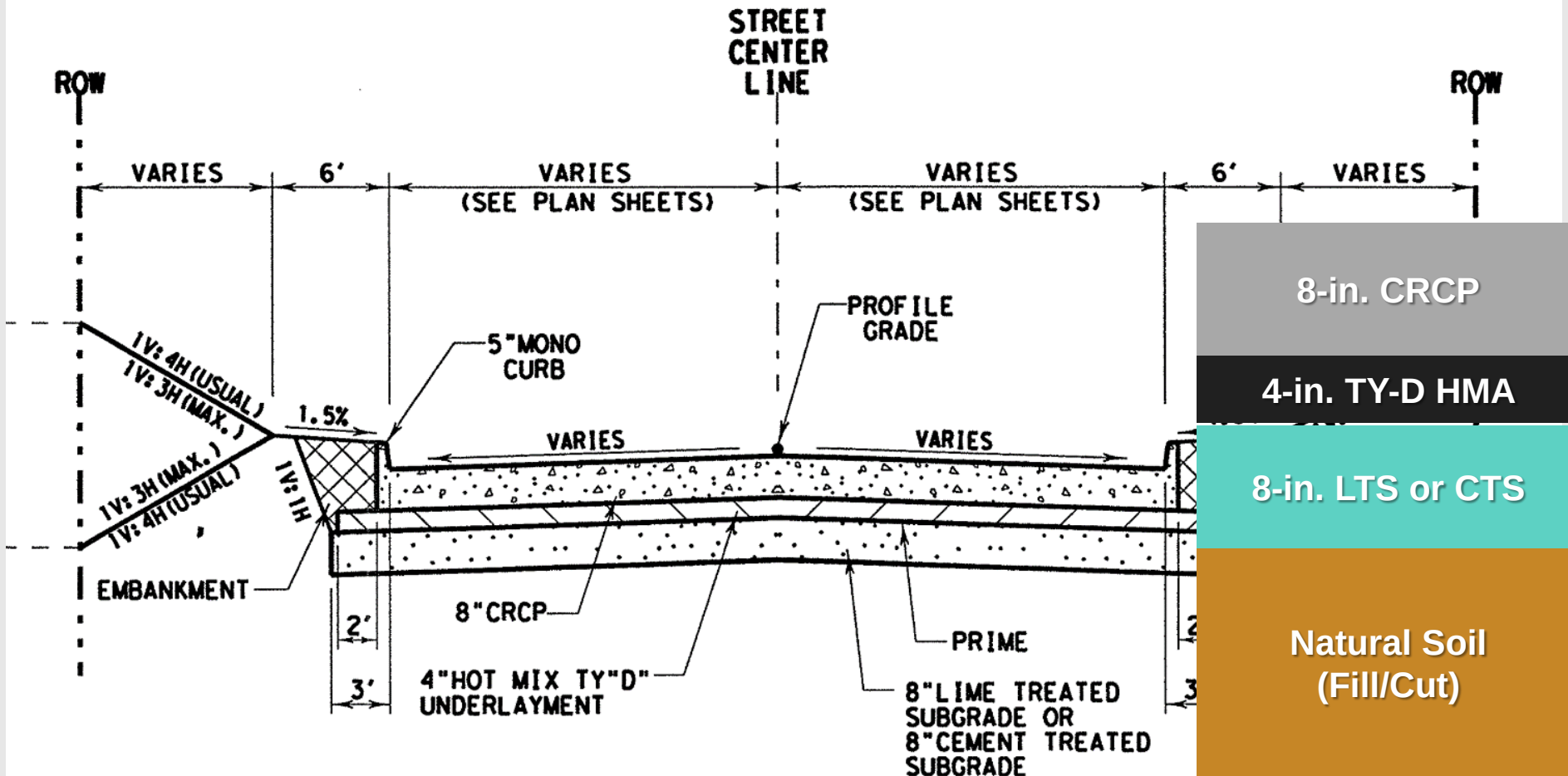
- The problem continues beyond the repaired section



## □ Typical Section – Pavement Structure



- 8.0-in. CRCP + 4-in. HMA TY-D + 8.0-in. LTS or 8.0-in. CTS



TYPICAL CONCRETE SECTION WITH MONO CURB







## □ Location of Test Section



Google Earth



## 5.1 Web Soil Survey and Google Earth Historical Imagery



| Map unit symbol | Map unit name                                                                   | Rating (percent) | PI                                                     |
|-----------------|---------------------------------------------------------------------------------|------------------|--------------------------------------------------------|
| 10              | Bastsil-Urban land complex, 0 to 5 percent slopes                               | 10.0             | <span style="color: red;">■</span> ≤ 14.7              |
| 27              | <span style="border: 2px solid red;">Frio silty clay, frequently flooded</span> | 25.5             | <span style="color: green;">■</span> > 14.7 and ≤ 16.0 |
| 79              | Sunev-Urban land complex, 2 to 8 percent slopes                                 | 19.0             | <span style="color: blue;">■</span> > 16.0 and ≤ 25.5  |
| Map unit symbol | Map unit name                                                                   | Rating (percent) | Organic Matter                                         |
| 10              | Bastsil-Urban land complex, 0 to 5 percent slopes                               | 0.61             | <span style="color: red;">■</span> ≤ 0.47              |
| 27              | <span style="border: 2px solid red;">Frio silty clay, frequently flooded</span> | 2.50             | <span style="color: green;">■</span> > 0.47 and ≤ 0.91 |
| 79              | Sunev-Urban land complex, 2 to 8 percent slopes                                 | 1.45             | <span style="color: blue;">■</span> > 0.91 and ≤ 2.29  |



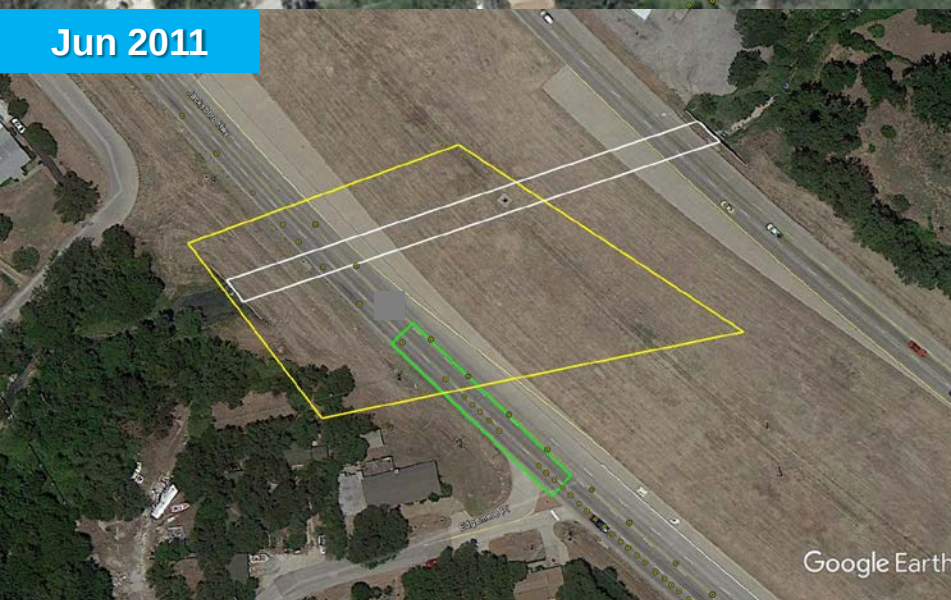
Feb 2001



Mar 2005



Jun 2011

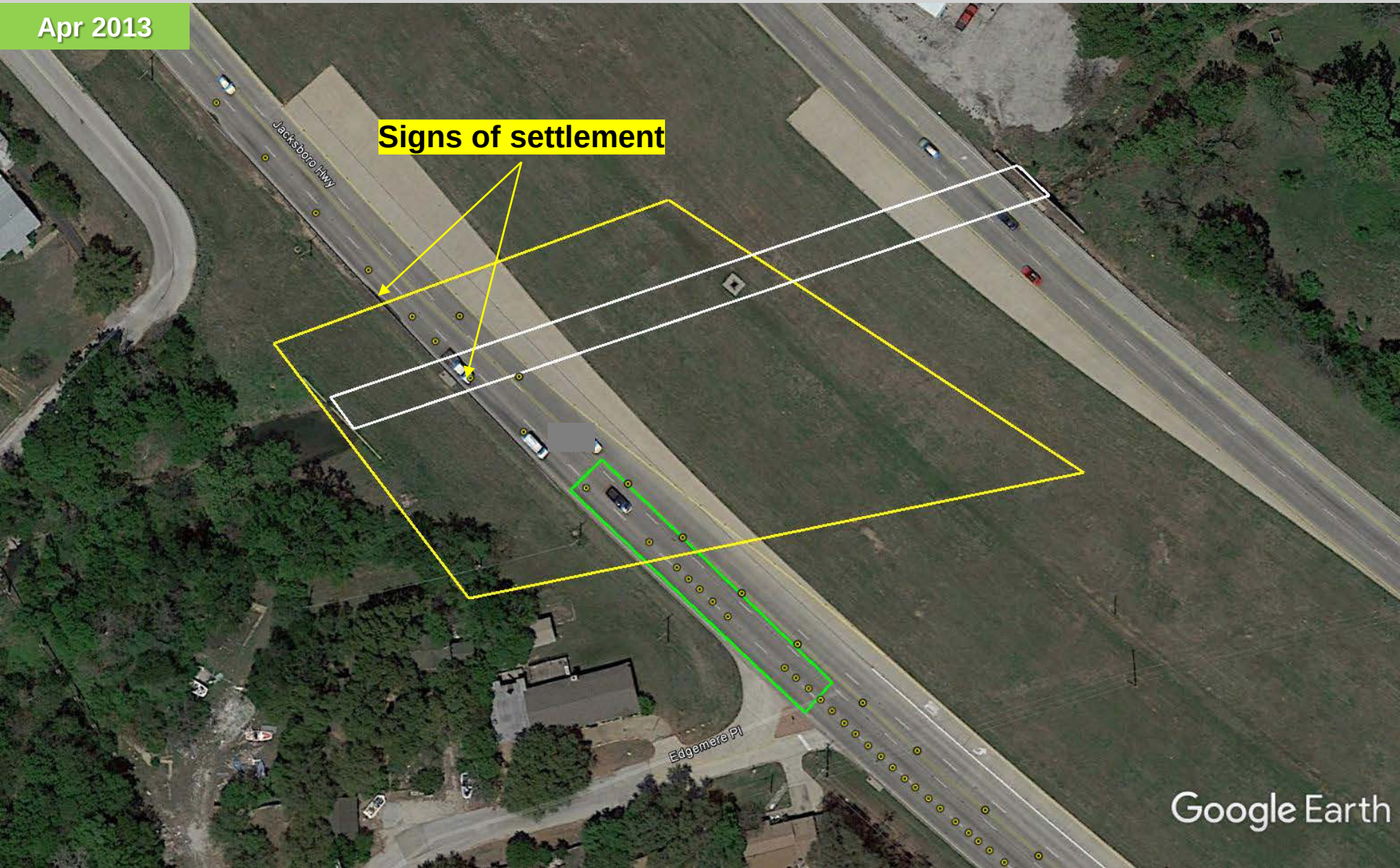


Apr 2013





Apr 2013



Google Earth



### 1) Falling weight deflectometer (FWD) testing

- Evaluate overall pavement structural capacity
- Select in-depth evaluation area

### 2) Dynamic cone penetrometer (DCP) testing

- Subgrade modulus
- Layer consistency

### 3) Void thickness measurement

- Deflection vs. void thickness

### 4) GRP testing

- Ground-Coupled GPR (GC-GPR): layer thickness/void and water detection
- Utility scan

### 5) MIRA testing (spot testing)

- Slab thickness/delamination/steel location/void and water detection

### 6) LiDAR scan

- Field mapping

### 7) Pipe investigation – Video recording

- Purpose of investigation: broken pipe or crack investigation
- Investigation of the 36" RC pipe underneath the GPR test location.
- Video showed no immediate drainage issues or damage to the pipe.



- Longitudinal cracks and pavement settlement
- Secondary distress at FDR joints
  - Free movement at FDR joint (not allowed in CRCP FDR)
    - Cleaning/not enough epoxy injection/not enough epoxy curing time & pull-out strength during epoxy application
    - Continuity should be provided.

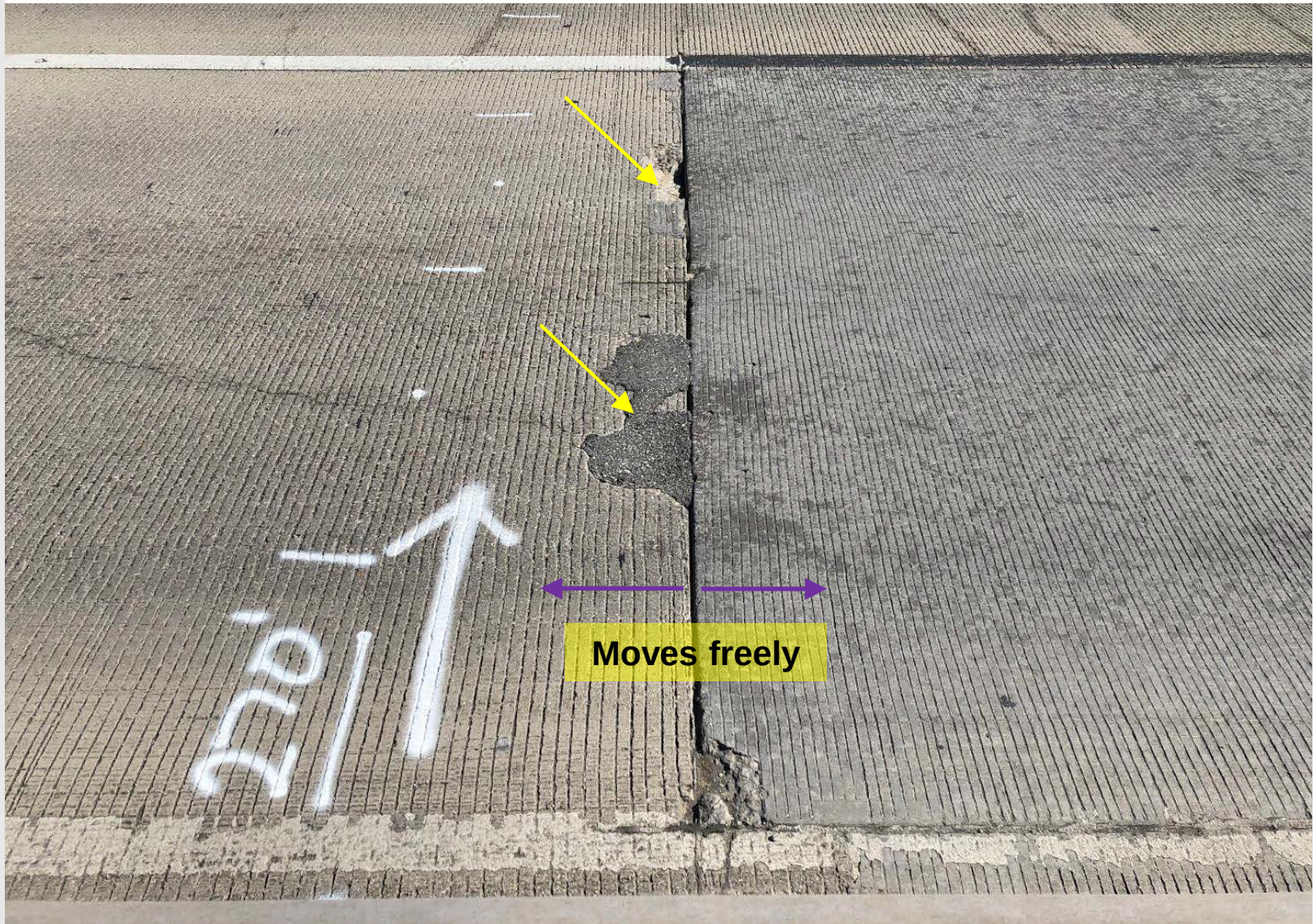




## □ Cause of the Secondary Distress at FDR Joint



Appears to behave as an active joint [Not allowed in CRCP FDR joint]





## 5.3 FWD Testing – Deflection Profile

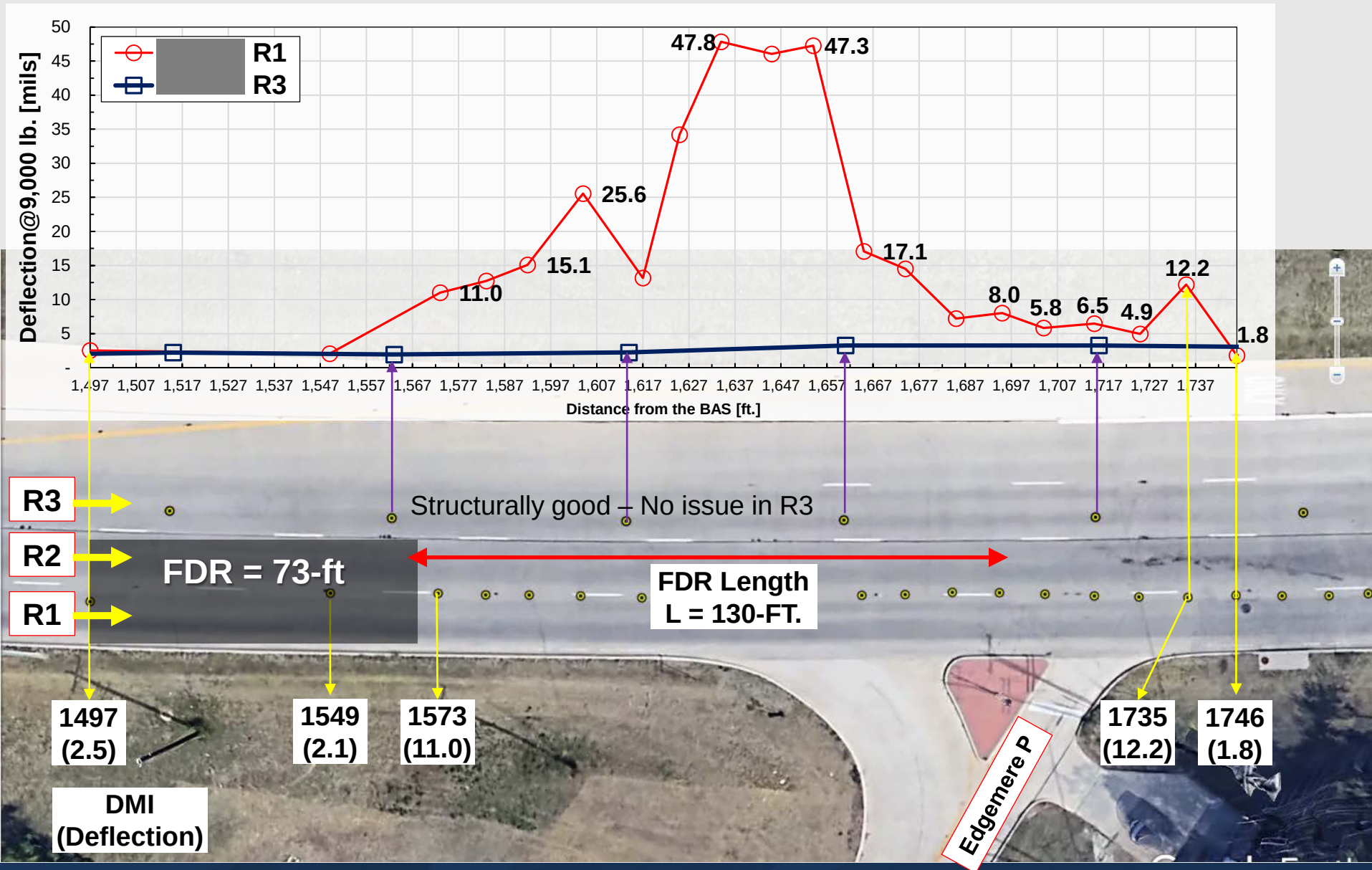


Problem Area at R1 & R2  
(Void beneath CRCP slab due to subgrade settlement → water channel)



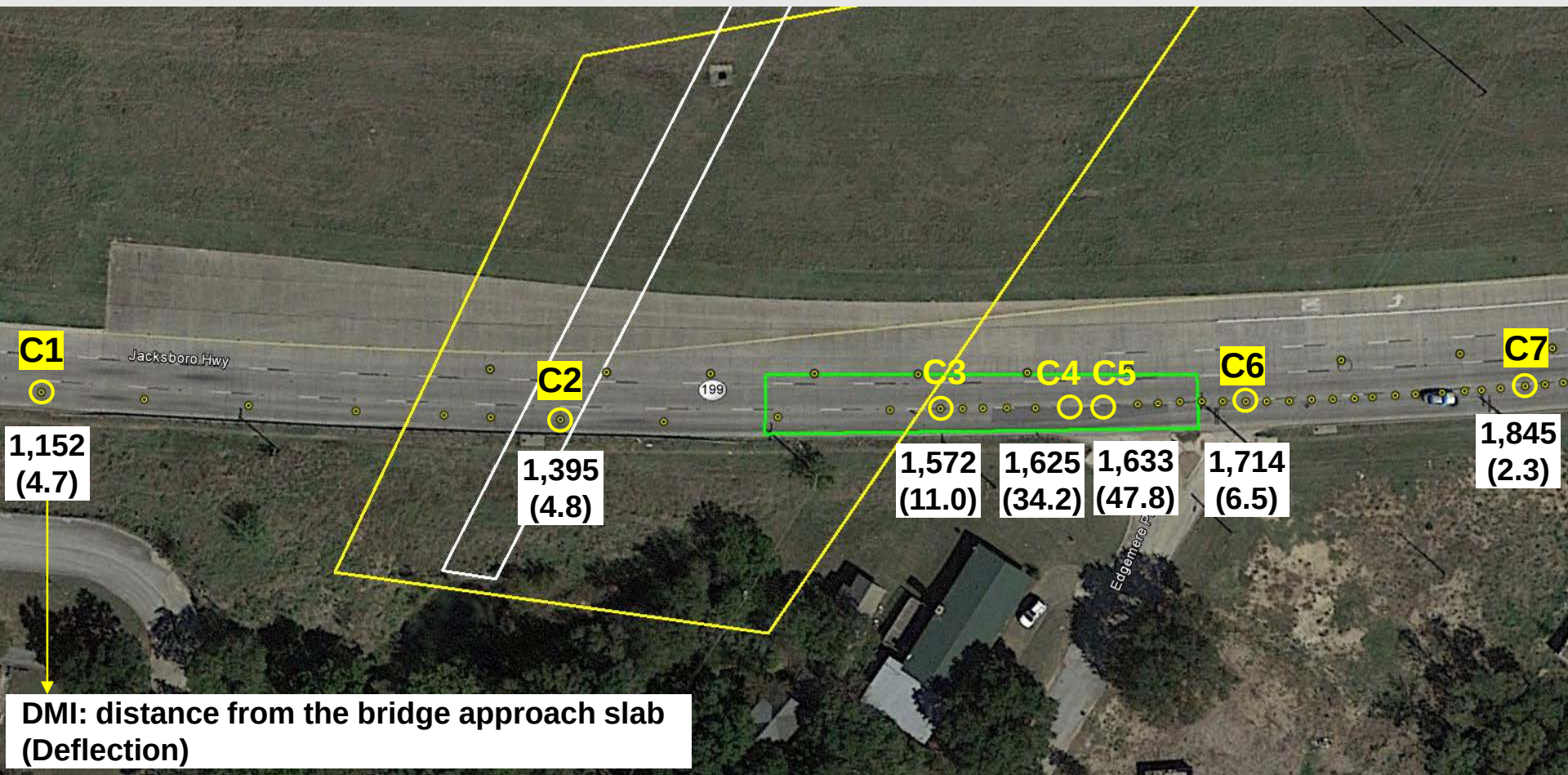


# Localized Large Deflection/Selection of FDR Area



### ■ Coring locations

- DCP testing was conducted at coring location of C1, C2, C6, and C7





| Core # | FWD DMI | CRCP Slab T [in.] | HMA Base T [in.] | Deflection @9,000 lbs [mils] | Void T [in.] | Pavement Layer Information      | Modulus [ksi] |              |
|--------|---------|-------------------|------------------|------------------------------|--------------|---------------------------------|---------------|--------------|
|        |         |                   |                  |                              |              |                                 | Subgrade      | Natural Soil |
| C1     | 1,152   | 8.5               | 10.0             | 4.7                          | 0            | CRCP 8.0 – 9.0-in.              | HMA           | 7.1          |
| C2     | 1,395   | 8.3               | 4.0              | 4.8                          | 0            |                                 | 25.1          | 10.9         |
| C3     | 1,572   | 9.0               | -                | 11.0                         | 2.0          | HMA Base 4.0-in.                |               |              |
| C4     | 1,625   | 8.0               | -                | 34.2                         | 4.5          | Subgrade 8-in. LTS or 8-in. CTS |               |              |
| C5     | 1,633   | 8.0               | -                | 47.8                         | 5.3          |                                 |               |              |
| C6     | 1,714   | 9.0               | 4.0              | 6.5                          | 0            | Natural Soil                    | 15.8          | 10.3         |
| C7     | 1,845   | 8.2               | 3.8              | 2.3                          | 0            |                                 | Strong        | 12.6         |



# Core Description



**C1, 4.7-mil**



**C2, 4.8-mil**



**C3, 11.0-mil**



**8.5-in. CRCP & 10-in. HMA**



**8.3-in. CRCP & 4-in. HMA**



**9.0-in. CRCP**



**No Void (soft soil)**



**No Void (moderate soil)**



**2.0-in. Void**





# Core Description



**C4, 34.2-mil**



**8.0-in. CRCP**



**4.5-in. Void**



**C5, 47.8-mil**



**8.0-in. CRCP**

**Core sample was not collected – no photo.**

**5.3-in. Void**



**C6, 6.5-mil**



**9.0-in. CRCP + 4.0-in. HMA + 8.0-in. CTS**



**No Void (soft CTS & soil)**





### C7, 2.3-mil

- Solid CTS (strong) – DCP testing was not able to be done in CTS layer so **testing was conducted after coring the 12-in. CTS layer**
- Very strong natural soil



8.0-in. CRCP + 3.8-in. HMA + 12.0-in. CTS



No Void (Strong CTS & Soil)



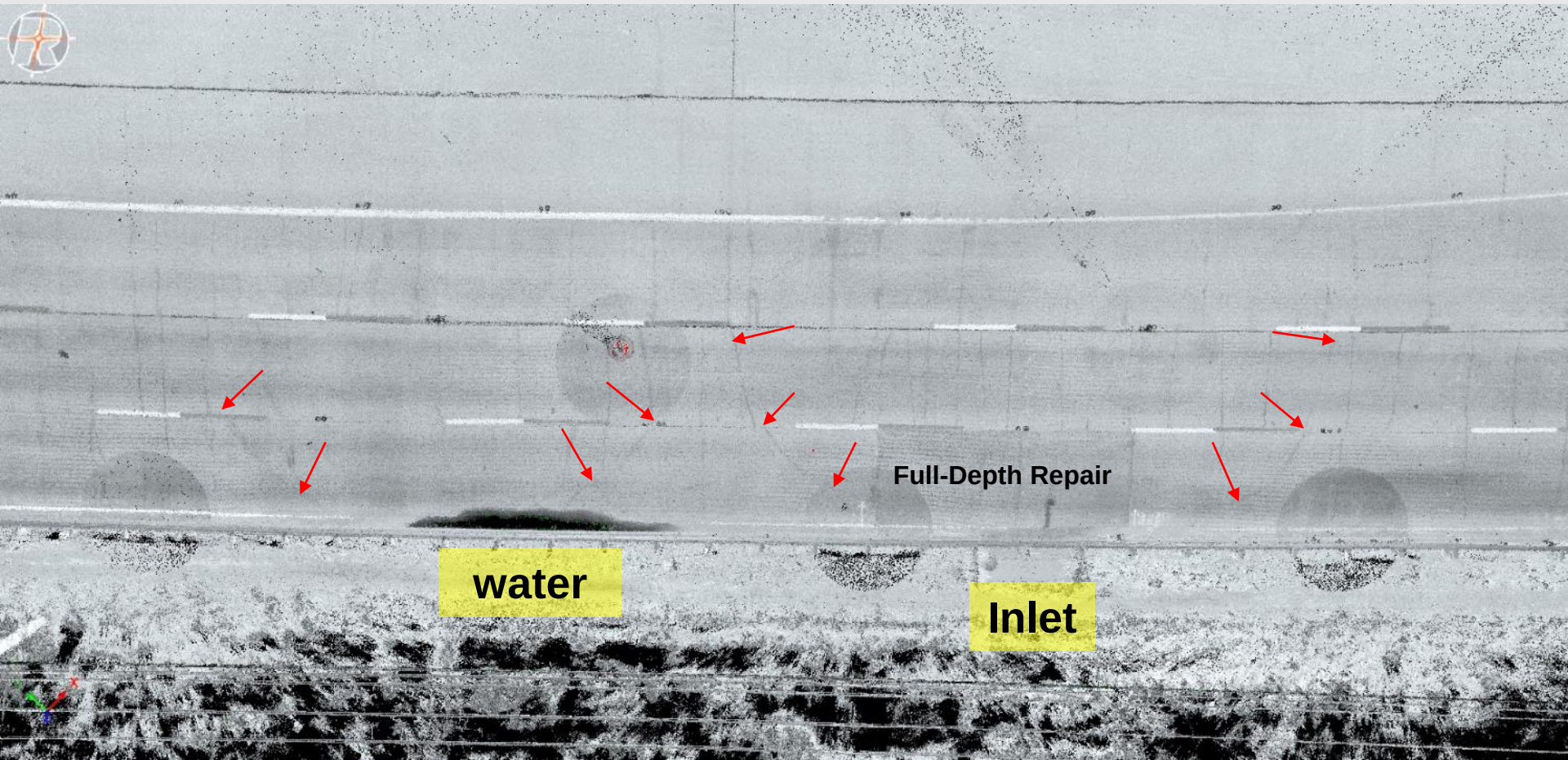


## 5.5 Causes of Pavement Settlement

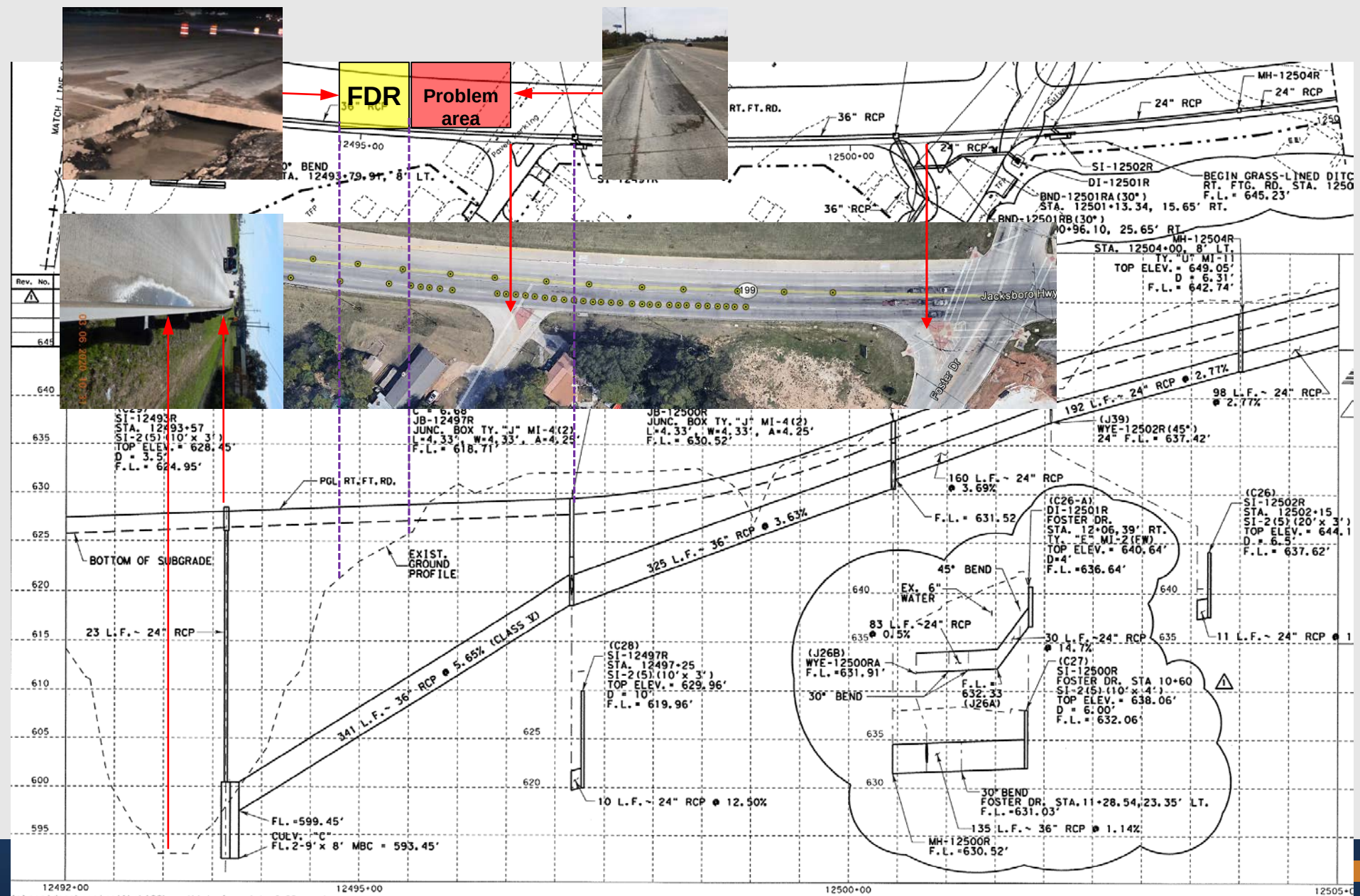




## □ Half-Moon Shape Crack & FDR in Fill Section (LiDAR Image)





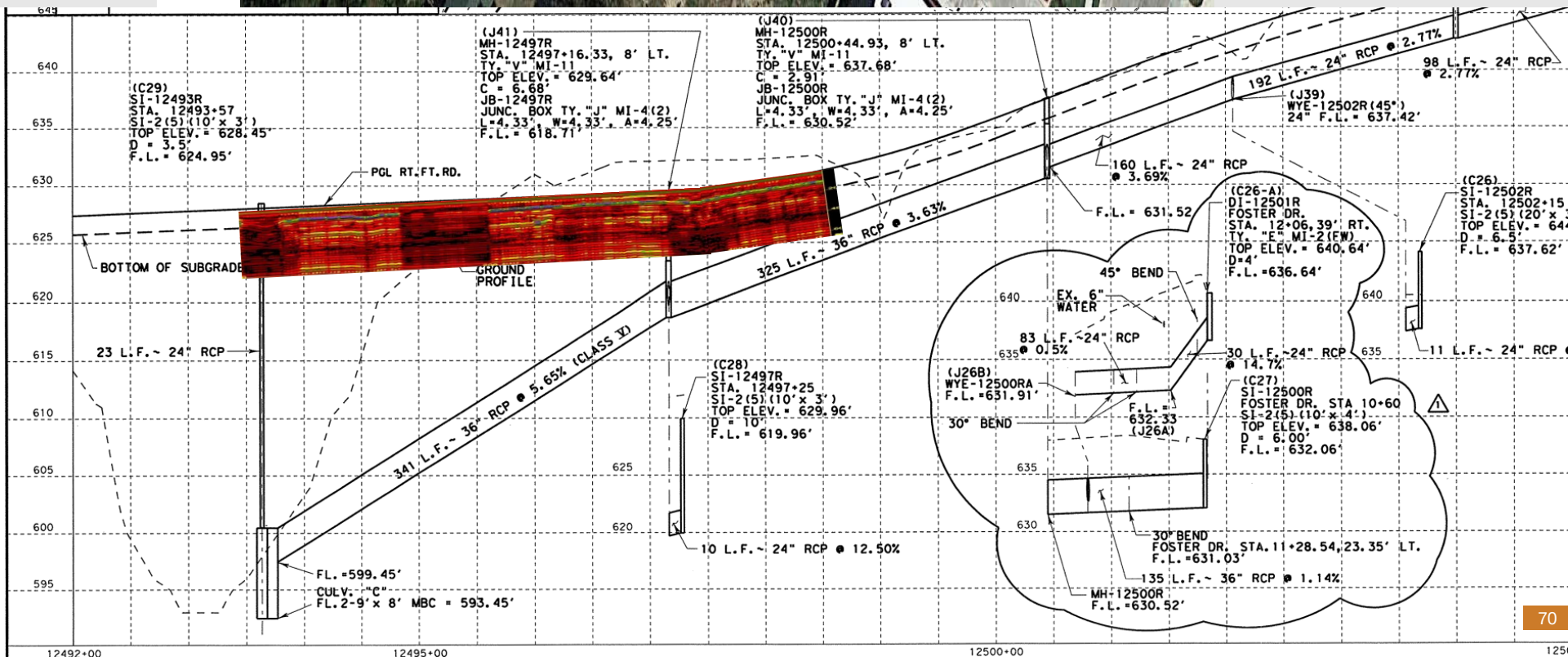




The GC-GPR profile scan is placed on the plans sheet to show the approximate depth.

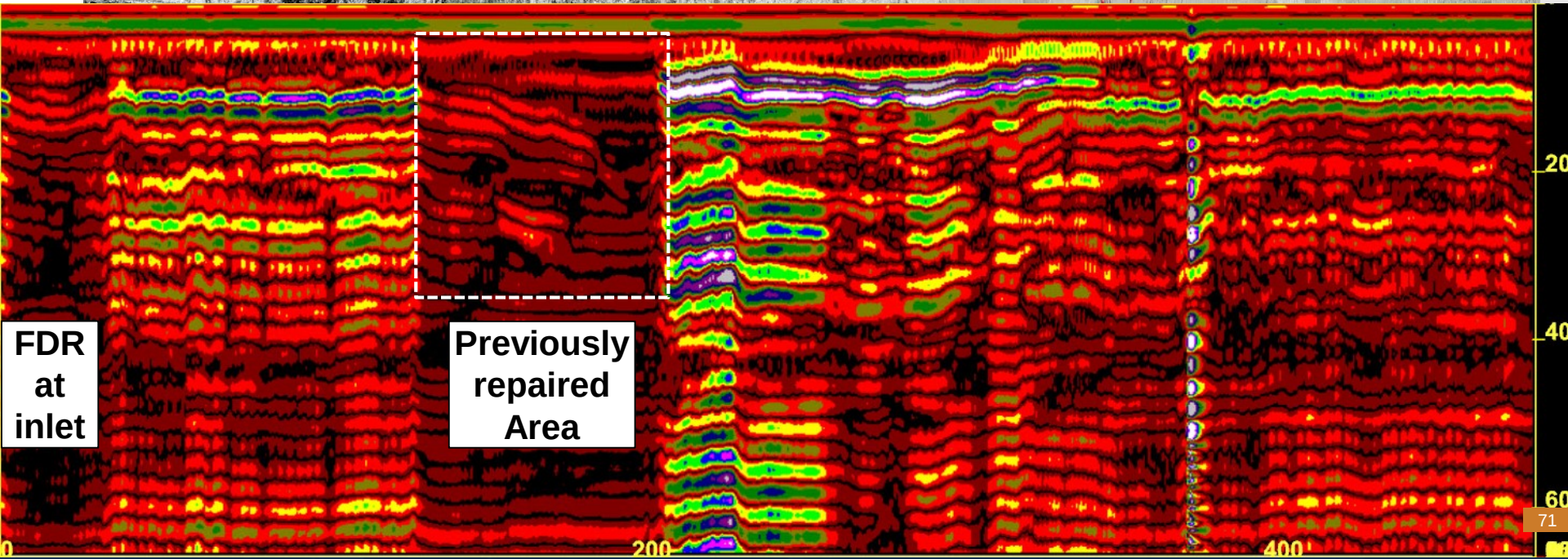
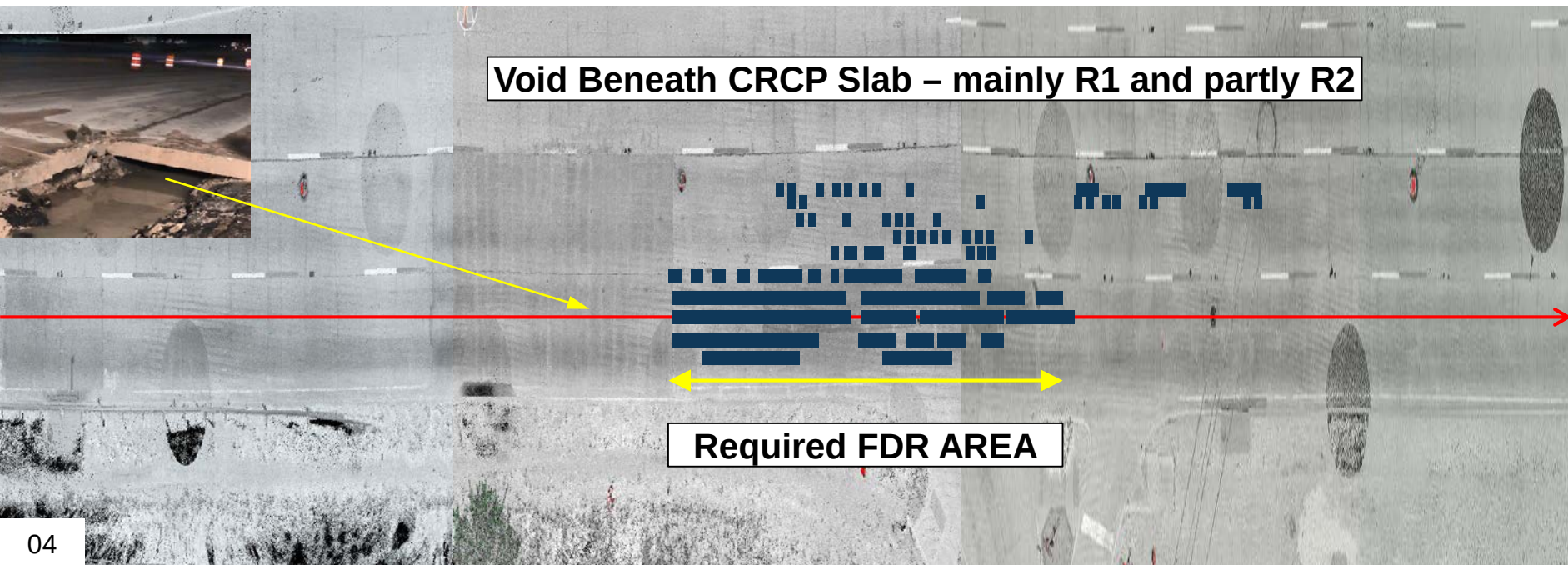


01





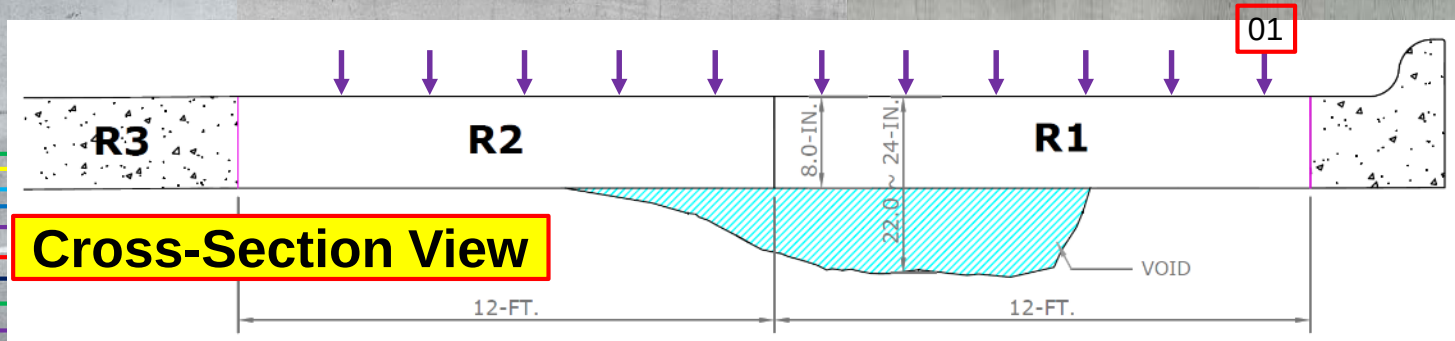
# Location of anomalies w/ negative signal [VOID AREA]



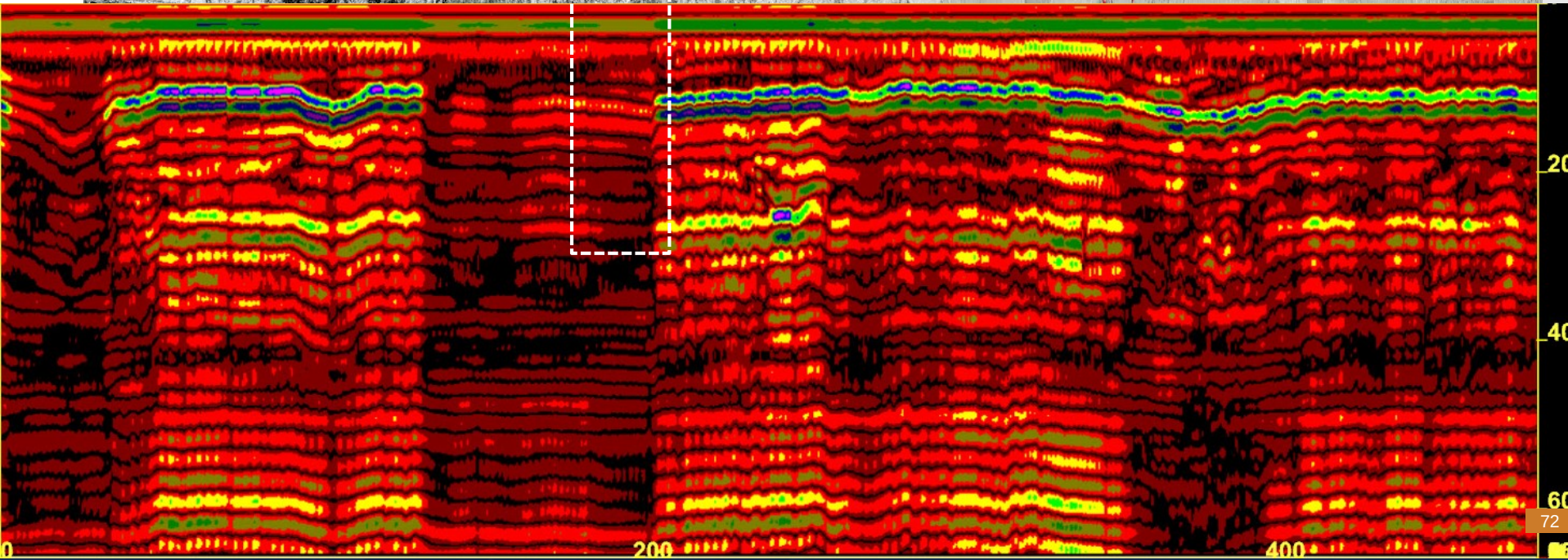
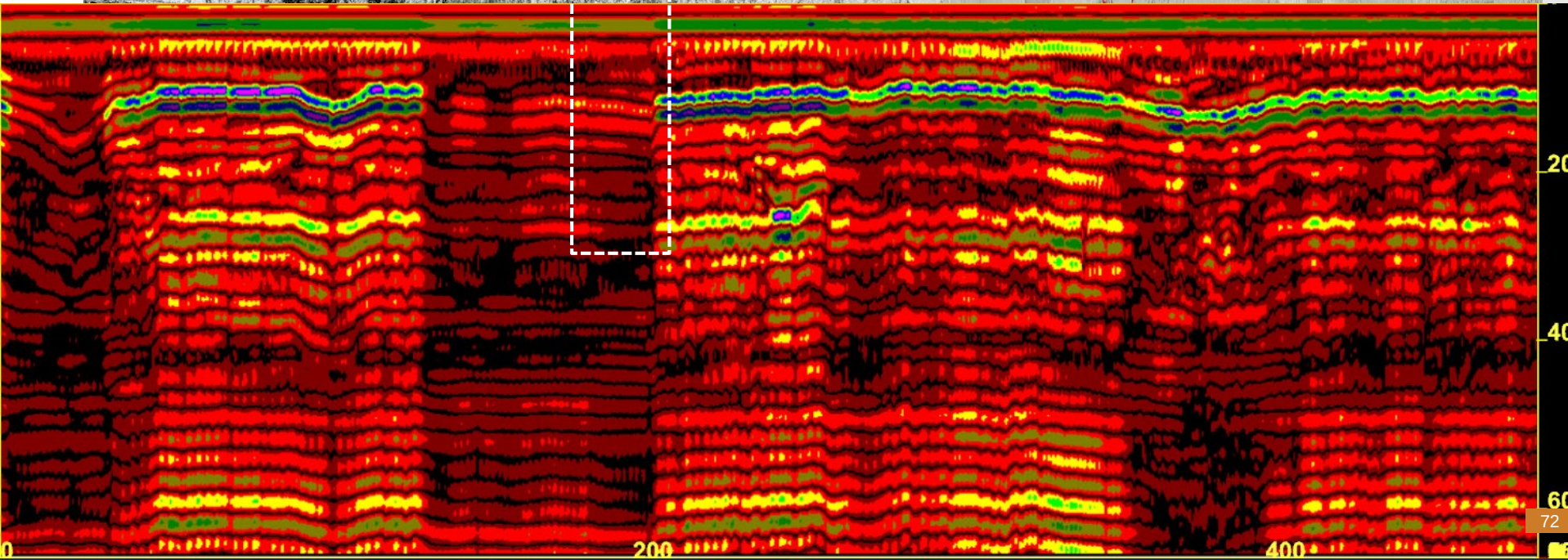


A total of 11 scans were conducted from outside lane to inside lane.

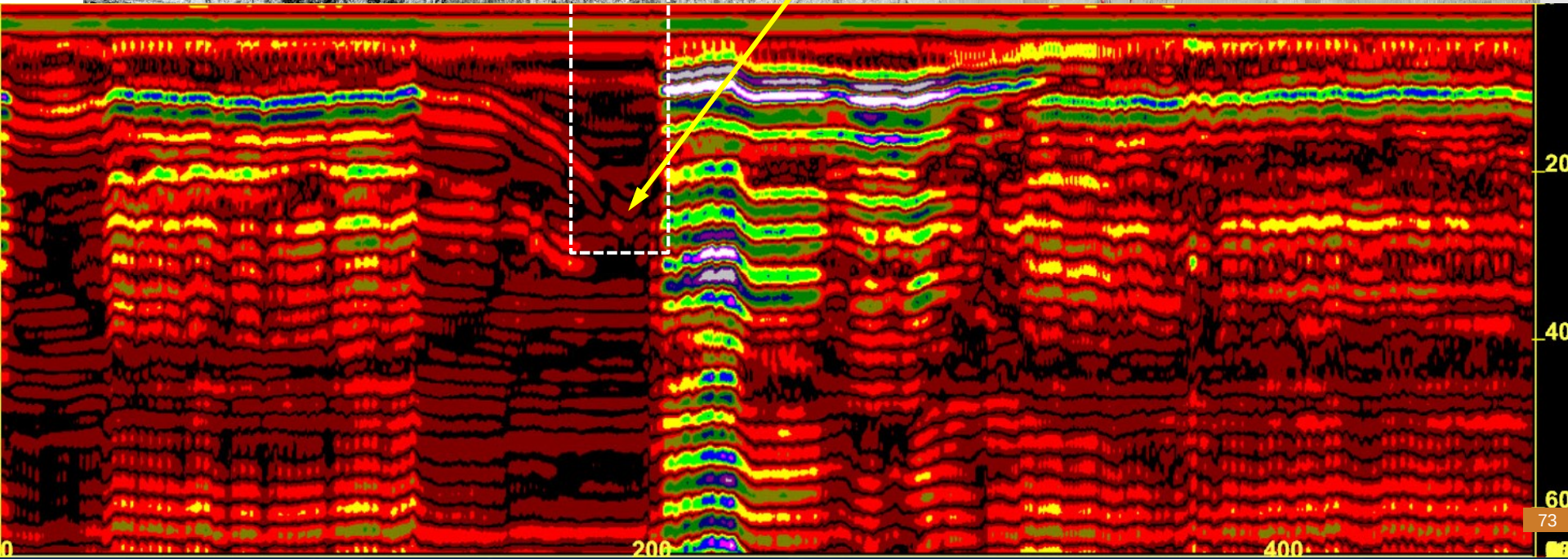
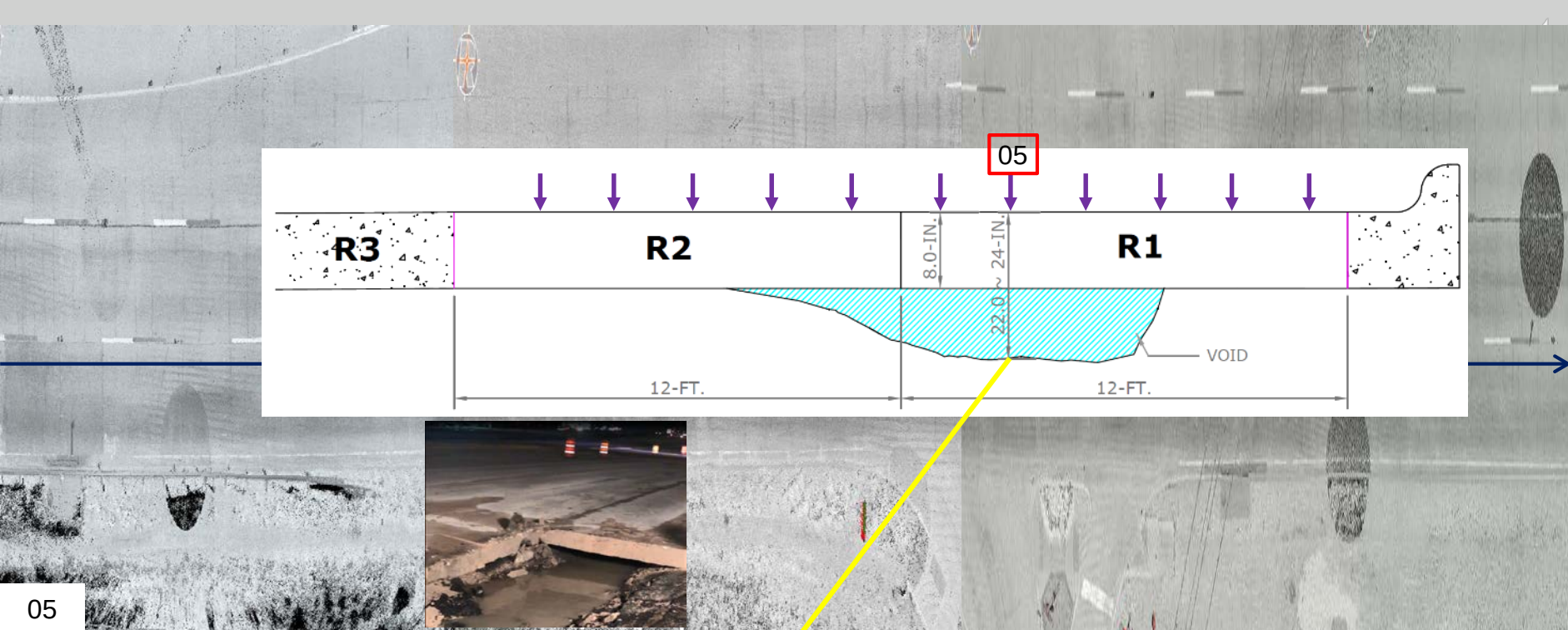
01 through 11



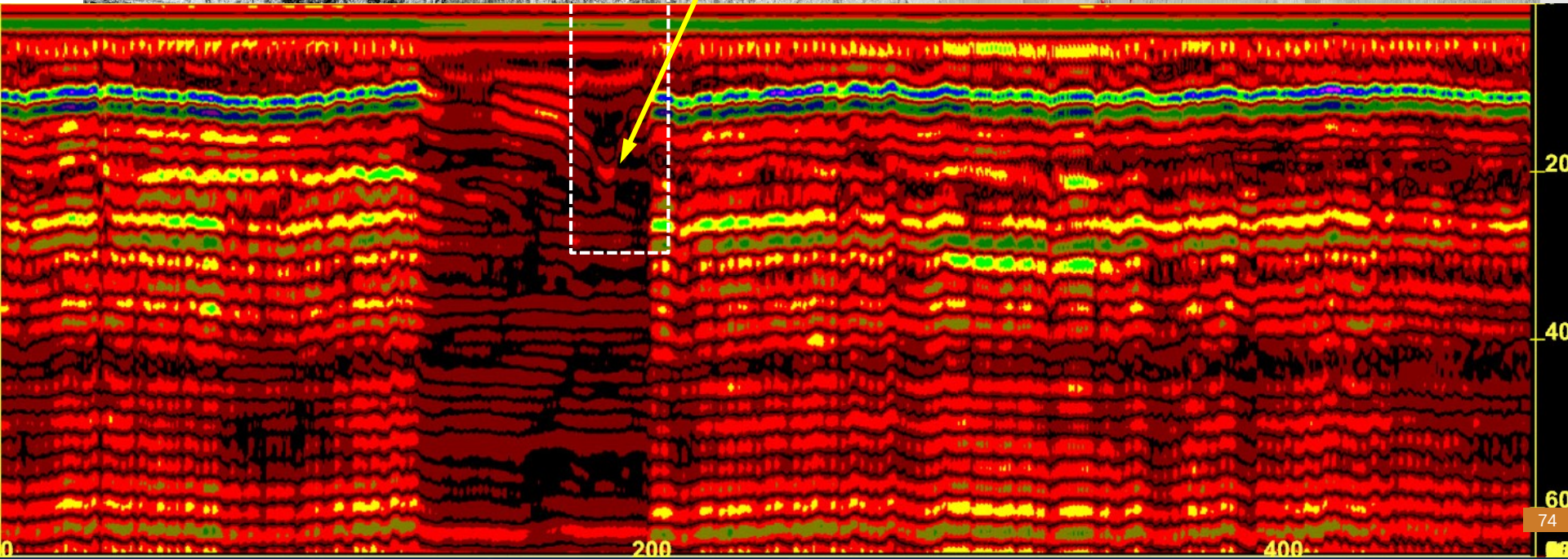
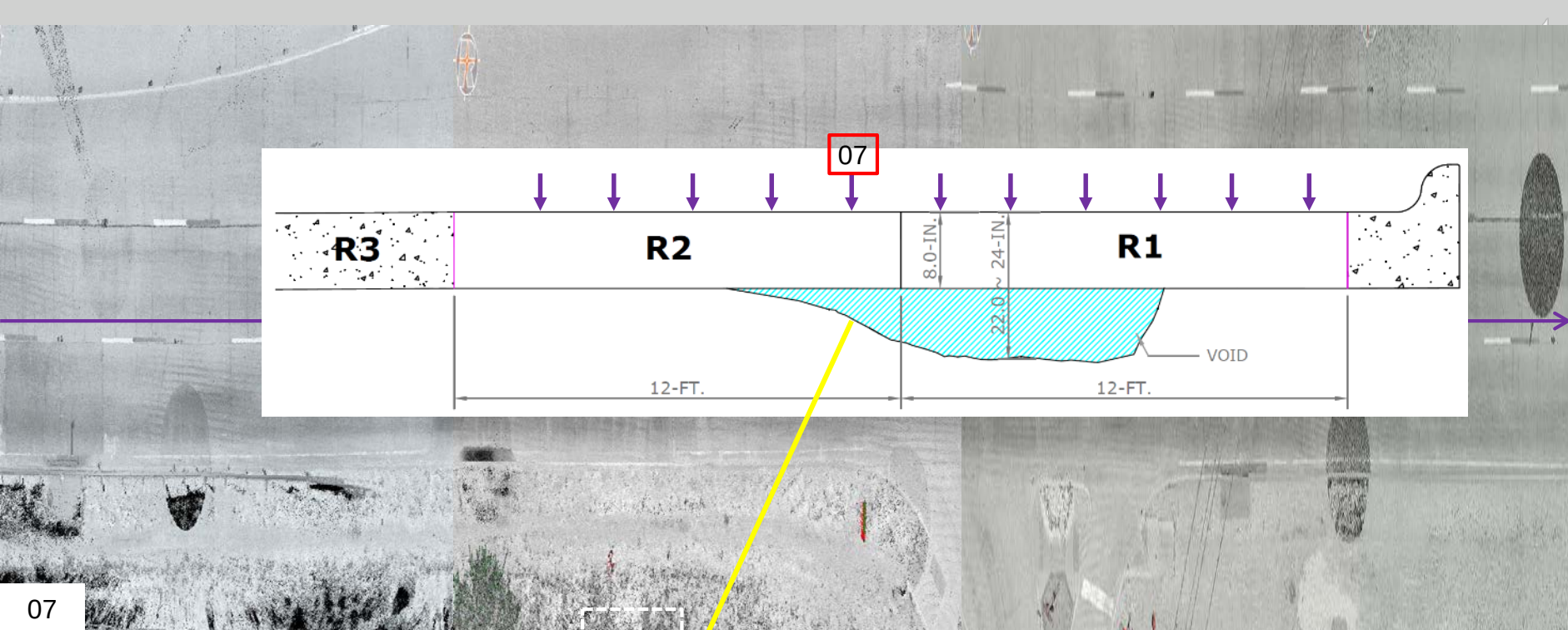
01



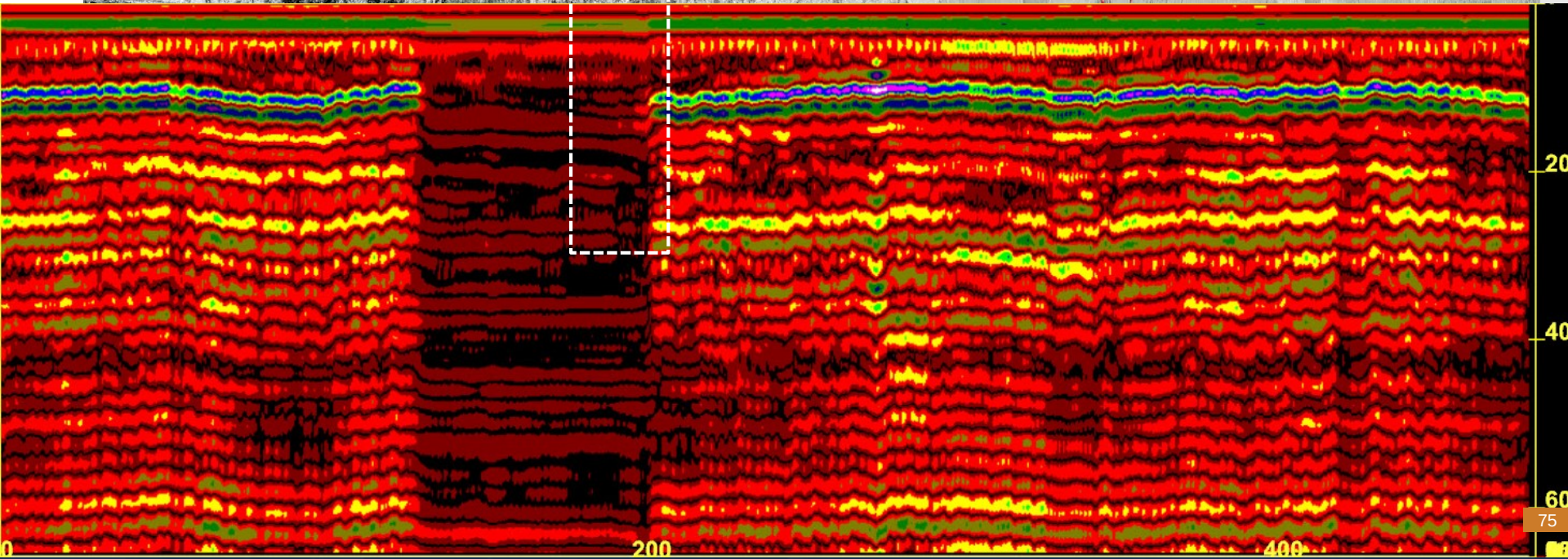
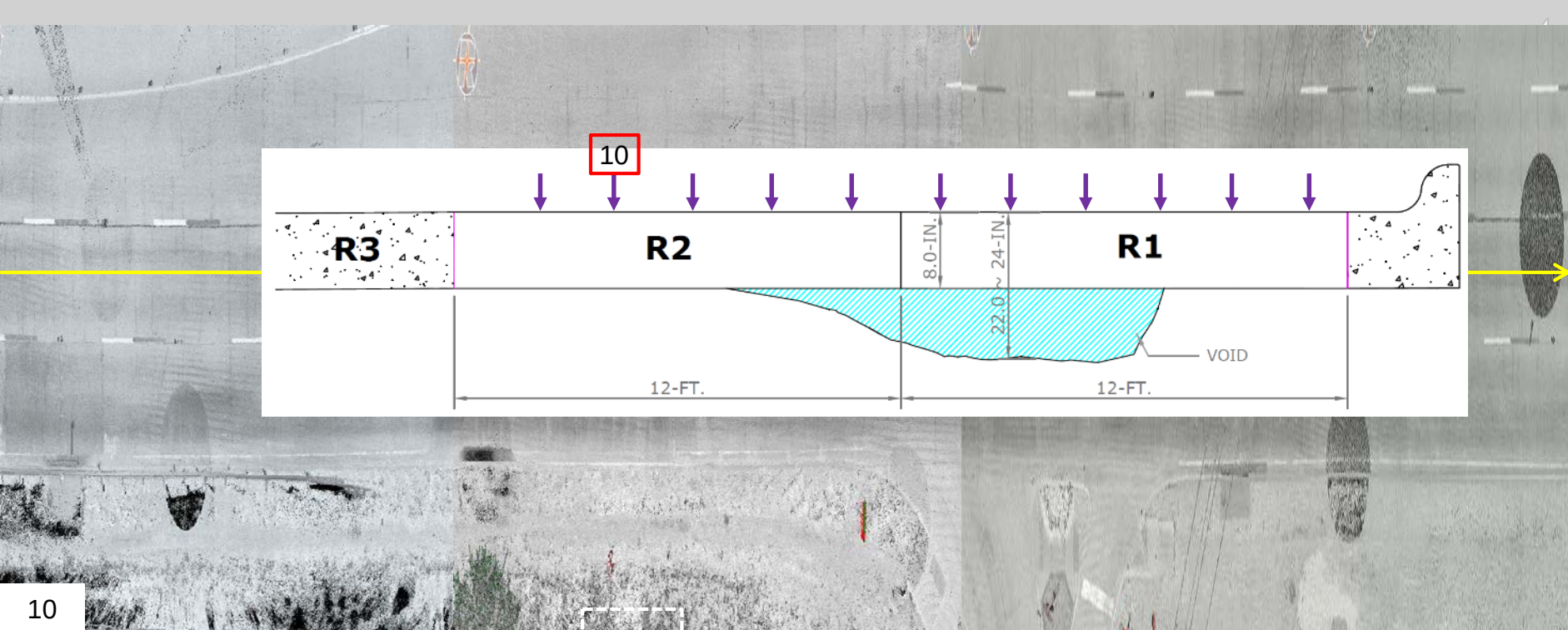














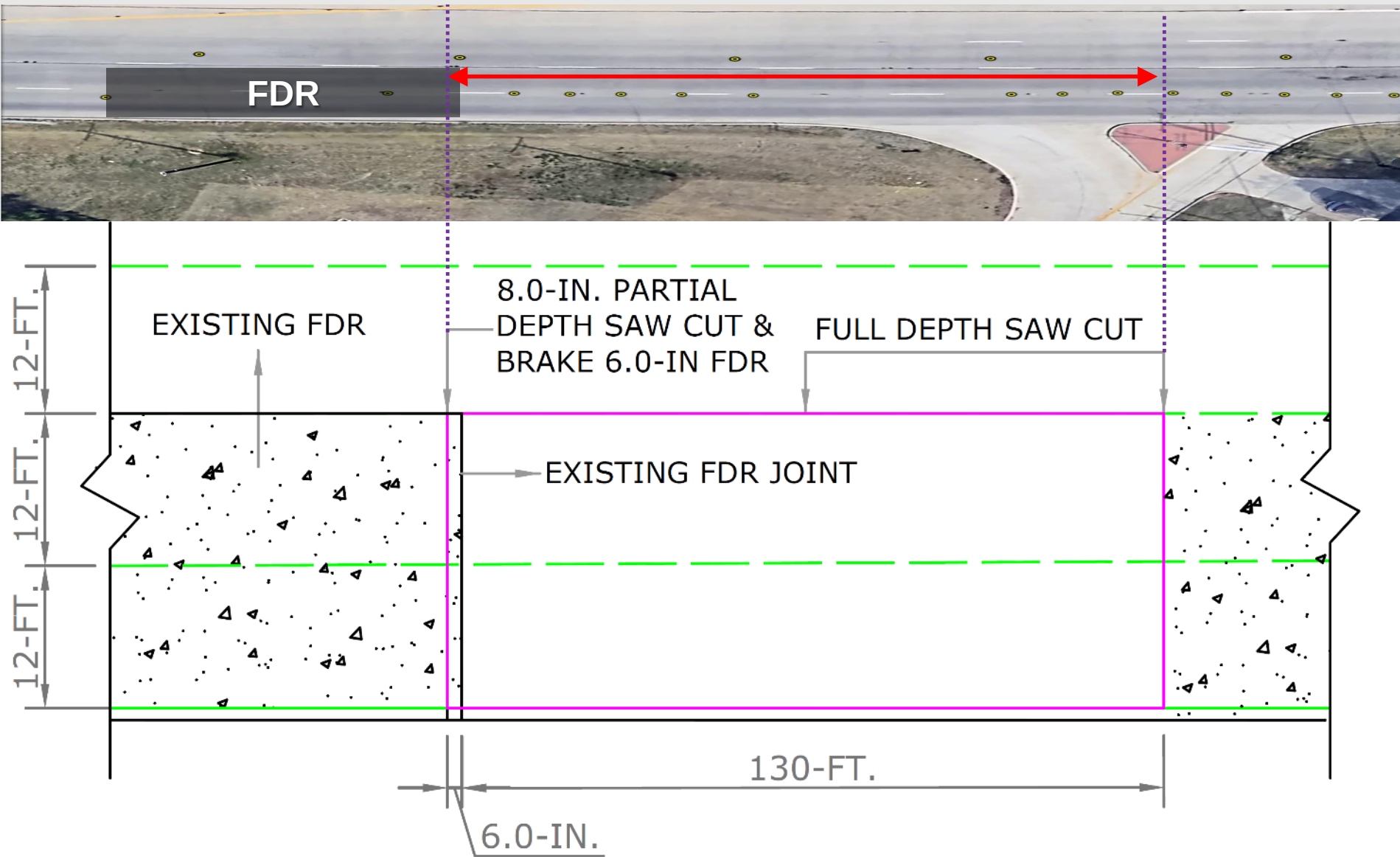
- **Cause of Pavement Settlement and Longitudinal Crack**
  - Subgrade settlement and previous FDR occurred in the area with natural soil with high organic matter/high PI.
  - The fill section was placed over the high organic/high PI zone.
  - **Inadequate compaction around pipe and culvert** resulting in immediate settlement
  
- **Distress at FDR Joints**
  - CRCP **does not allow independent movement at FDR joints**. FDR joints should be fully connected like a single slab.
  - Secondary distresses at FDR joint appear to be related with free movement at FDR joints; possibly due to inadequate epoxy application during construction.





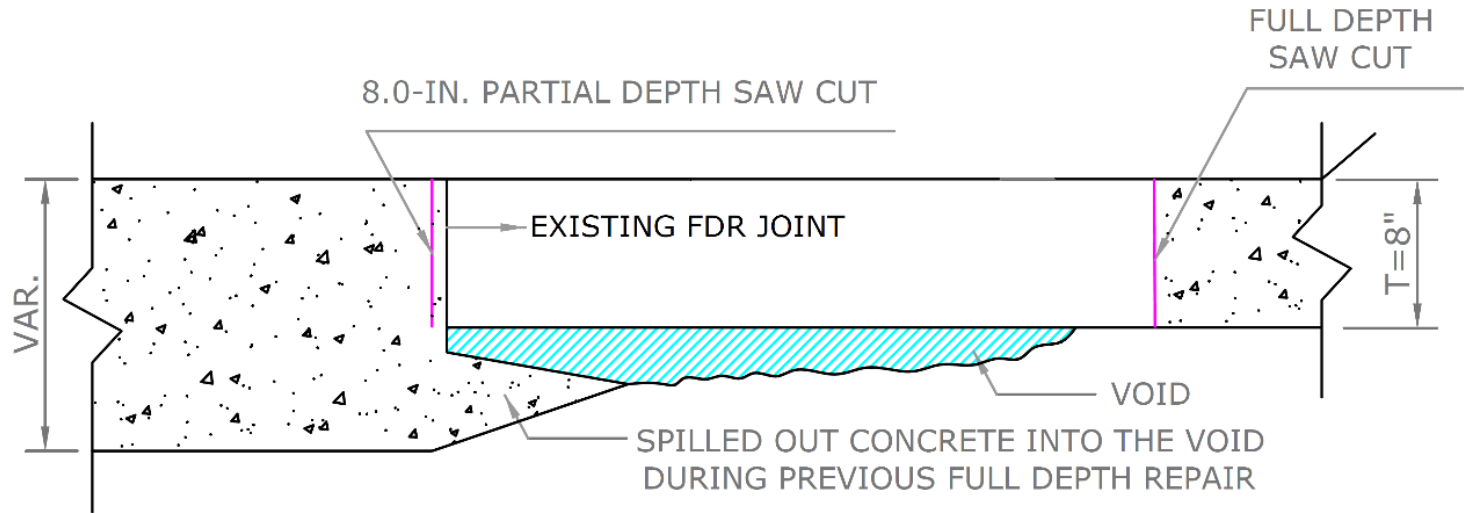
- **Option #1) Full-Depth Repair**
  - Specified design details
  - Inspection checklist
- **Option #2) Replacement**
  - Replacement depth: 24-in.
  - Proposed typical section
    - 8-in. CRCP slab thickness (Item 360 & 361)
    - 4-in. HMA base (Item 341)
    - 12-in. Cement stabilized subgrade (Item 276)

## ❑ Option #1) FDR Design Details [Plan View]

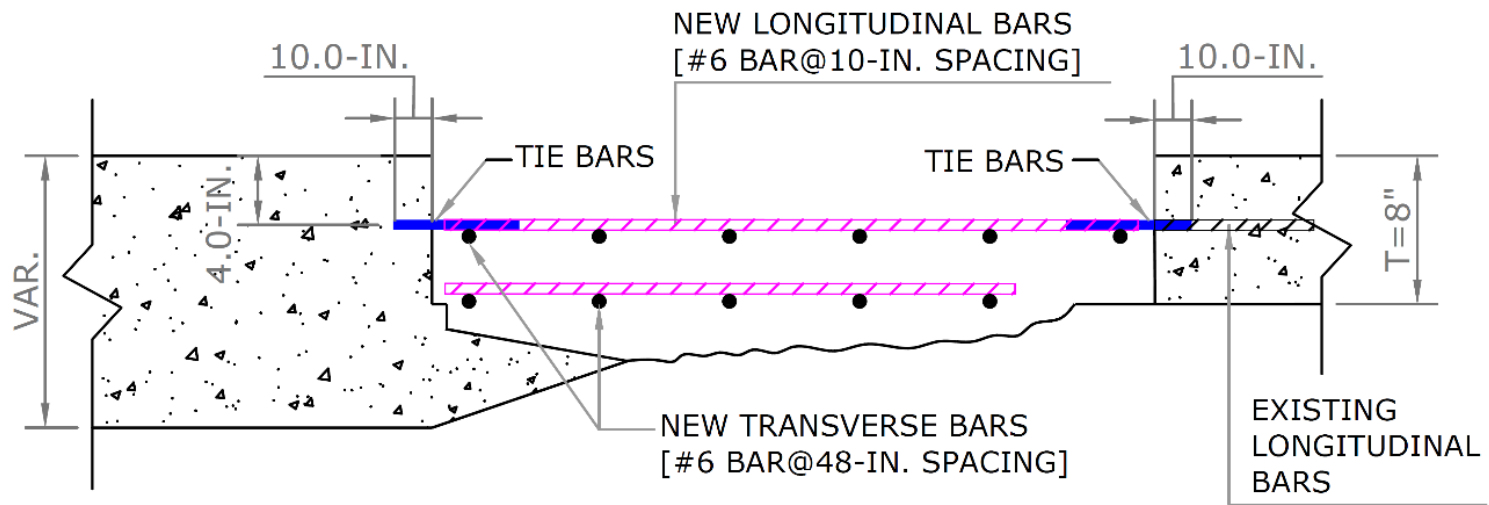




## ❑ Option #1) FDR Design Details [Side View]

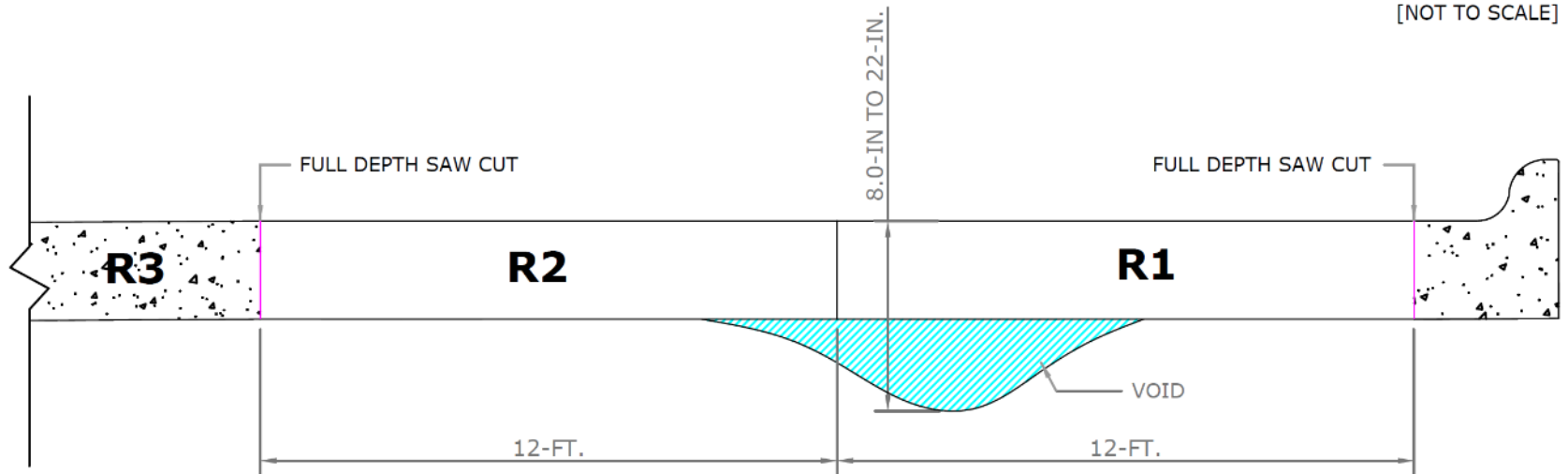


**<SIDE VIEW>**

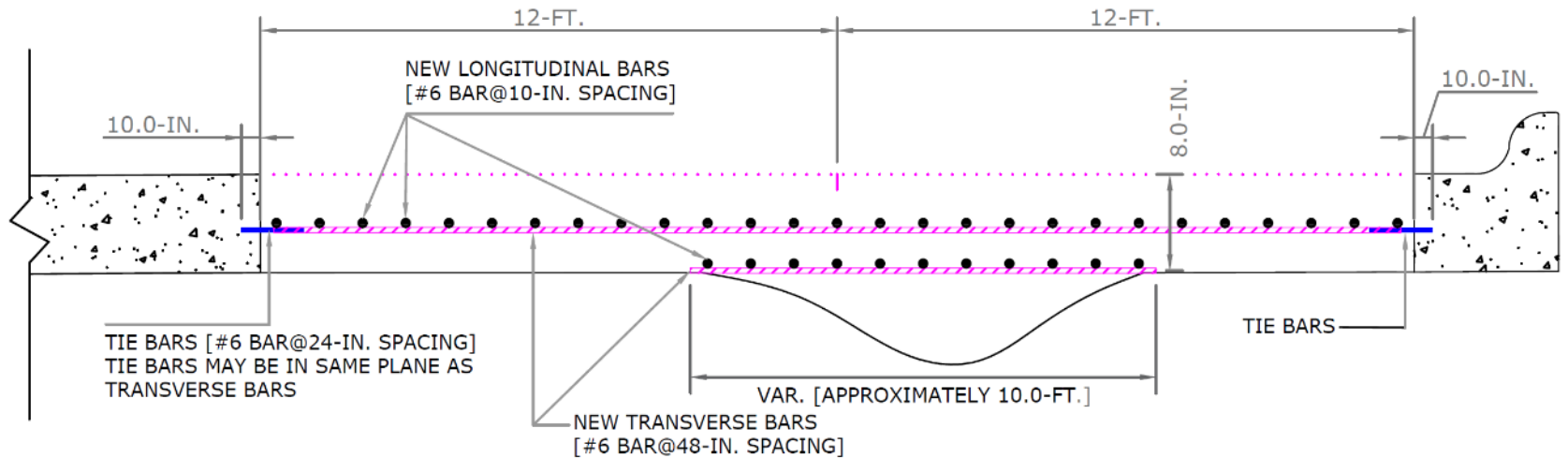


**<BAR PLACEMENT>**

## ❑ Option #1) FDR Design Details [Cross-Section View]



<CROSS-SECTION VIEW>



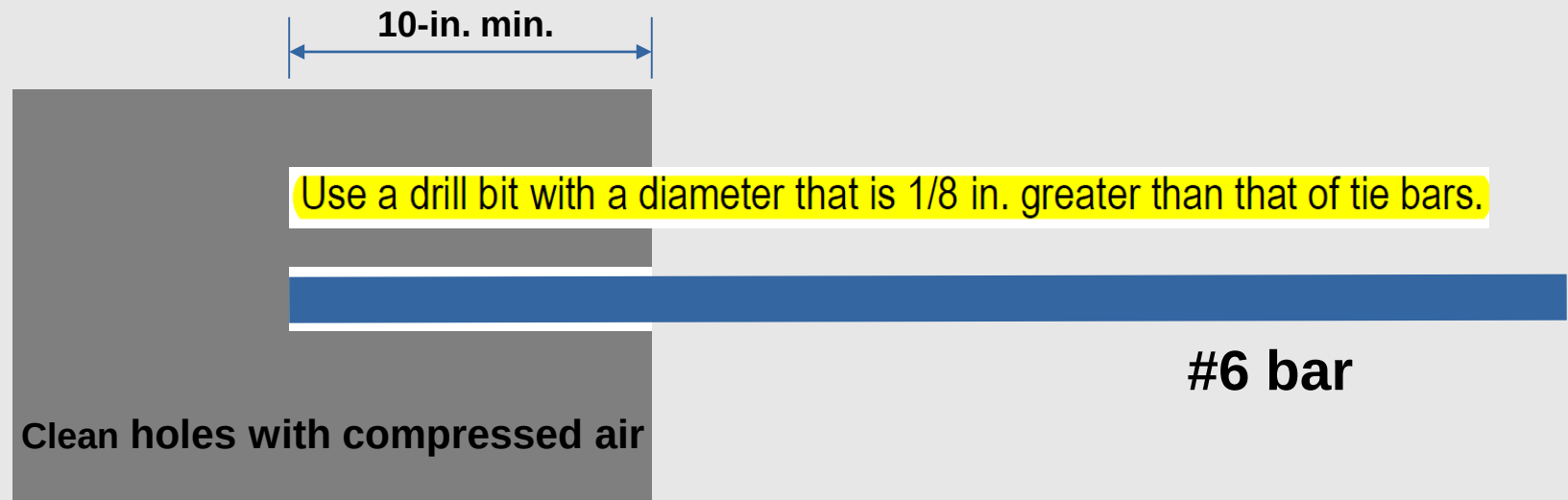
<BAR PLACEMENT>



## ❑ Option #1) FDR Inspection Checklist



- Loose base material should be completely removed.
- Clean drilled holes with compressed air.
- Entire hole has to be filled with epoxy and confirmed by the inspector.
- The number of epoxy cartridges used in FDR should be monitored and verified by the inspector.



## ○ Fill the Entire Hole with Class C Epoxy (Epoxy Injection)



### ■ Field training

Place tie bars as shown on the plans. Drill holes into the existing concrete at least 10 in. deep unless otherwise directed. Use a drill bit with a diameter that is 1/8 in. greater than that of tie bars. Clean the holes with a wire brush and compressed air to remove all the dust and moisture. Follow the epoxy manufacturer's instructions to apply the epoxy. Insert the tip of the epoxy cartridge or the tip of the machine applicator to the end of the tie bar hole, and inject Type III, Class C epoxy to fill the entire hole. Insert tie bars.





## ○ Example of Not Enough Epoxy





## ○ Should Not Be Allowed





# Good practice - Check Number of Epoxy Cartridges



## 19.61 fl oz per cartridge

/ Fasteners / Injectable Adhesive Anchors / HIT-RE 10



### SELECT OPTIONS

Content per can/cartridge  
19.61 fl oz (US)

Package content

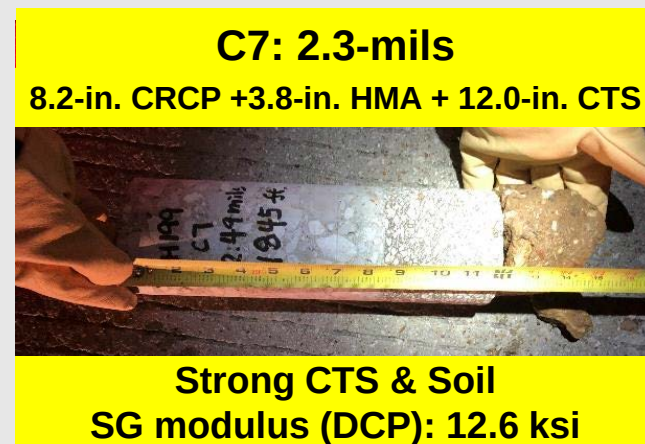
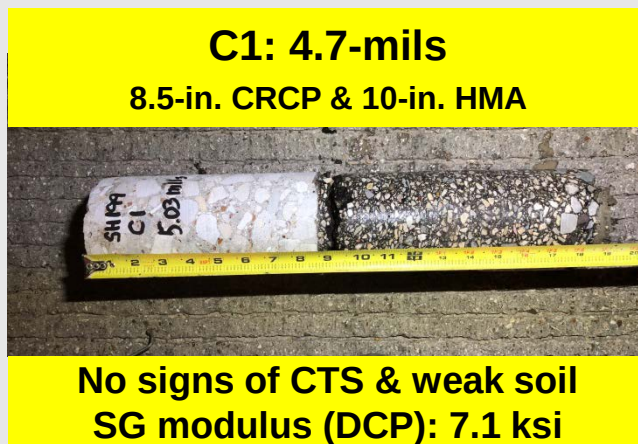
Please select

| INPUT           |                 |         |                           |
|-----------------|-----------------|---------|---------------------------|
| Cartridge       | Content per Can | Unit    |                           |
| Hilti HIT-RE-10 | 19.61           | fl oz   |                           |
|                 | D [in]          | L [in.] | Volume [in <sup>3</sup> ] |
| #6 bar          | 0.75            | 10      | 4.4                       |
| Hole            | 0.875           | 10      | 6.0                       |

### Number of Epoxy Cartridges - Item 361

| Number of Holes | Volume [in <sup>3</sup> ] | Liquids [fl oz] | Number of Cartridges |
|-----------------|---------------------------|-----------------|----------------------|
| 1               | 6.0                       | 3.3             | 0.2                  |
| 2               | 12.0                      | 6.7             | 0.3                  |
| 3               | 18.0                      | 10.0            | 0.5                  |
| 4               | 24.1                      | 13.3            | 0.7                  |
| 5               | 30.1                      | 16.7            | 0.8                  |
| 6               | 36.1                      | 20.0            | 1.0                  |
| 7               | 42.1                      | 23.3            | 1.2                  |
| 8               | 48.1                      | 26.7            | 1.4                  |
| 9               | 54.1                      | 30.0            | 1.5                  |
| 10              | 60.1                      | 33.3            | 1.7                  |
| 11              | 66.1                      | 36.7            | 1.9                  |
| 12              | 72.2                      | 40.0            | 2.0                  |
| 13              | 78.2                      | 43.3            | 2.2                  |
| 14              | 84.2                      | 46.6            | 2.4                  |
| 15              | 90.2                      | 50.0            | 2.5                  |
| 16              | 96.2                      | 53.3            | 2.7                  |
| 17              | 102.2                     | 56.6            | 2.9                  |
| 18              | 108.2                     | 60.0            | 3.1                  |
| 19              | 114.3                     | 63.3            | 3.2                  |
| 20              | 120.3                     | 66.6            | 3.4                  |
| 21              | 126.3                     | 70.0            | 3.6                  |
| 22              | 132.3                     | 73.3            | 3.7                  |
| 23              | 138.3                     | 76.6            | 3.9                  |
| 24              | 144.3                     | 80.0            | 4.1                  |
| 25              | 150.3                     | 83.3            | 4.2                  |
| 26              | 156.3                     | 86.6            | 4.4                  |
| 27              | 162.4                     | 90.0            | 4.6                  |
| 28              | 168.4                     | 93.3            | 4.8                  |

- CRCP shows very good performance in Texas (1.5-in. void – no distress)
- Construction Practices
  - Minimize immediate settlement → adequate compaction around structures such as inlet/pipe/culvert
  - Provide durable base and subgrade → proper subgrade treatment method and base type selection
  - Avoid independent movement at FDR joints – contractor/inspector training
- Design Consideration for CRCP Foundation – Very Important
  - Case study 2: Subgrade quality is critical.







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**Safety: Mission**  
**ZERO**



***Safety Never Stops!***