Lessons Learned from a Bridge Abutment Failure

GeoVirginia 2015

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The Project - Bridge Overpass, Chesapeake, Virginia

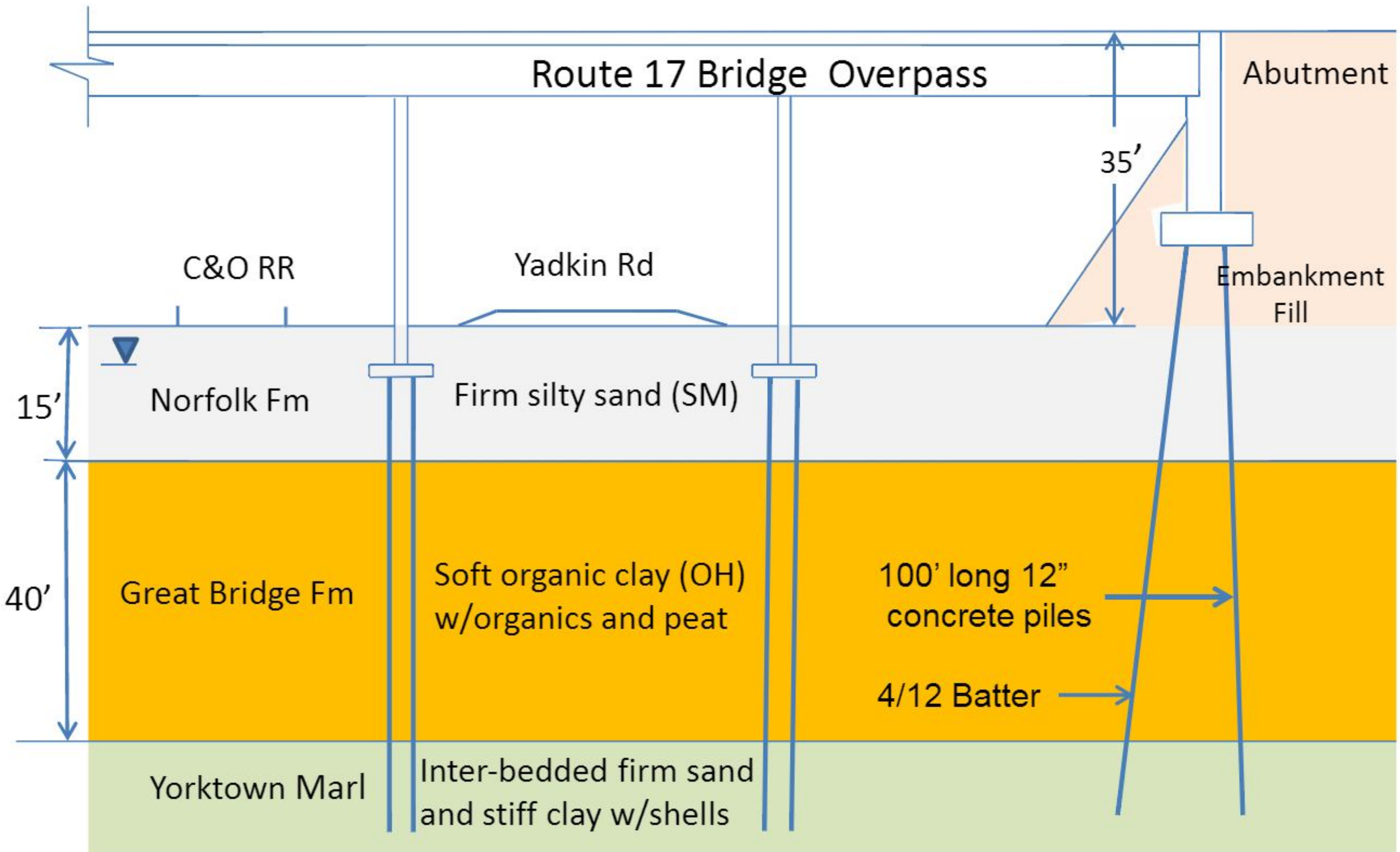
Project Completion

- Bridge designed in 1987
- Construction started Spring 1990
- Construction completed by 1992
- Remedial Evaluations 2000 to 2003
- Reconstruction 2007

Project Details

- Bridge is 100 ft wide and 250 ft long
- Approach embankments: 35 ft high; 90 ft upper width; 2H:1V slopes
- Piers and abutments on 12 inch prestressed, precast concrete piles; 70 and 100 ft long, respectively

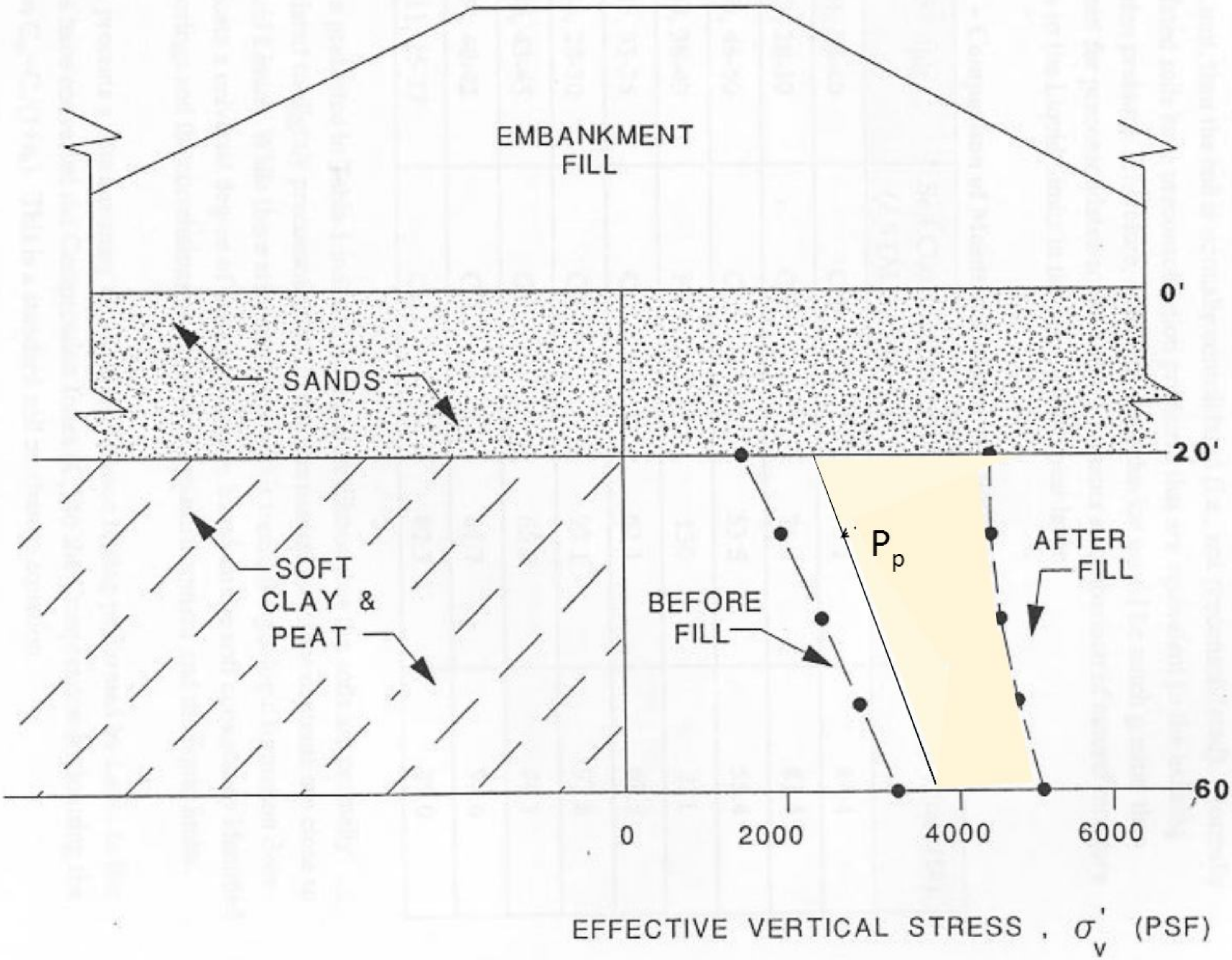
Subsurface Conditions and Design



Properties of Great Bridge Formation

- LL = 52 to 98; PI = 31 to 68; MC = 53 to 92
- Passing No. 200 sieve: 93 to 99%
- Organic content 5.4 to 17.8%
- C_c = 0.6 to 2.2; e_o = 1.4 to 2.6
- OCR = 1.0 to 1.7
- Lab S_u = 500 to 800 psf; N-values = WOR to 2

STRESS CHANGE FROM EMBANKMENT LOADING



Preliminary Report Conclusions

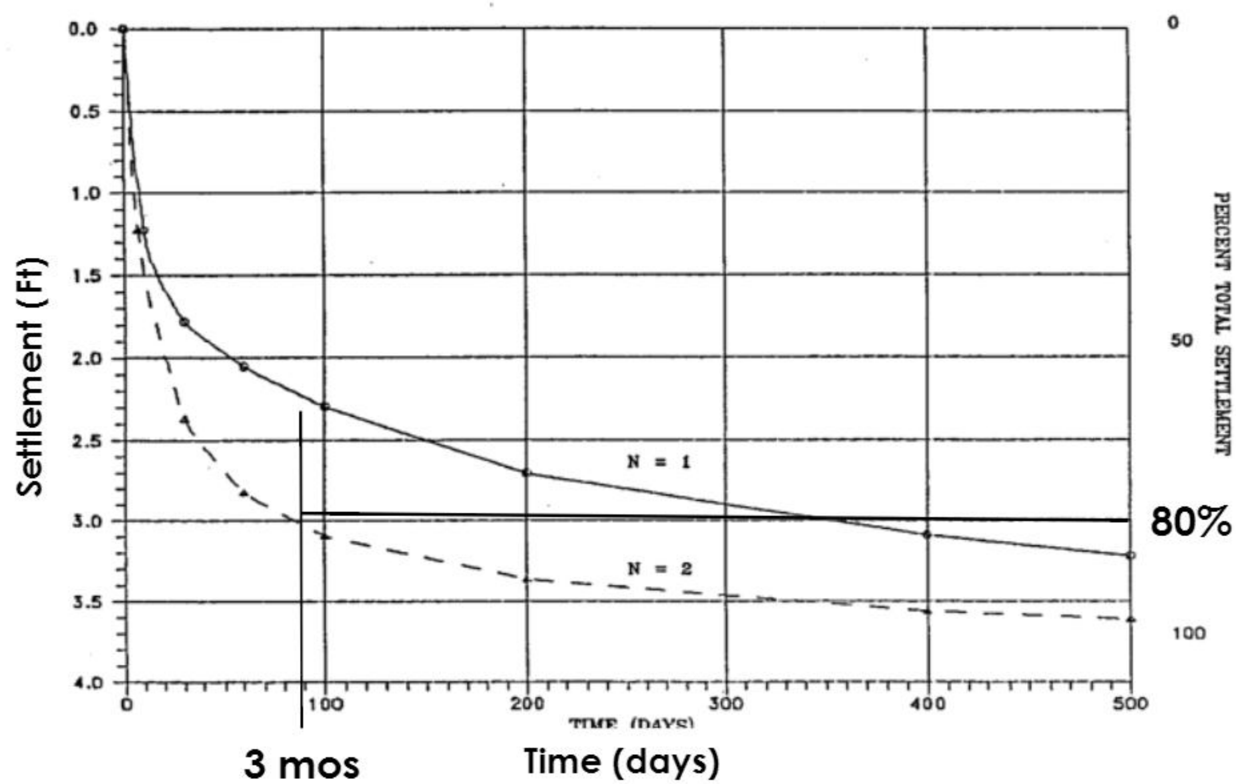
Support bridge on 12-inch concrete piles in Yorktown formation sands and clays for an allowable 100 ton capacity.

Note: No mention of allowance for drag load on piles.

Preliminary Report Conclusions

- "Embankment settlements of 2.5 to 3.5 ft are predicted".
- "While the time required for the total completion of primary settlement is in years, 80% is likely to occur in the first 3 months".
- "Typically in non-homogenous clays with potential sand lenses, settlement rates in the field are usually faster than predicted".
- "It may be possible to accelerate settlement by installing wick drains…"

Estimated Time of Embankment Settlement



SCALE:	APPROVED BY: SAB	DRAWN BY: JEC
DATE: 7-10-87		PROJECT: NK7-1580
Chesapeake Roadways - Route 17 Chesapeake, Virginia		
Settlement v.s. Time		DRAWING NUMBER 5

Preliminary Report Conclusions

- "Consolidation testing indicates sampling procedures are disturbing the soil… recommend in situ testing".

- "Based on prototype test berm…settlements based on dilatometer results were significantly more accurate than those predicted by classical consolidation tests…those settlements were also substantially smaller."

Final Geotechnical Report

- Pile recommendations were unchanged
- No estimate of drag load on piles given
- Settlement estimate reduced to 2.25 ft based on DMT results
- No recommendation for wick drains
- 80% settlement complete in 3 months

Note: This leaves 6 inches of predicted primary consolidation and about 3 inches of secondary compression remaining.

Construction Assumptions

- Construct embankments and wait three months for the predicted 2.25’ of settlement to occur

- Release embankments to the contractor for bridge construction based on performance data

- Drive abutment and pier piles

The Astute Bridge Designer Has a Question

- What about drag load?
- Answer - 15 to 20 tons
- Amendment No. 1 issued by the geotechnical consultant - “drive piles an additional 10 feet to account for any drag load”

Pile Installation

- Pier piles designed for 80 tons and abutment piles for 100 tons
- One static load test conducted at the piers – none at the embankments
- All bridge construction including piles were monitored by the owner

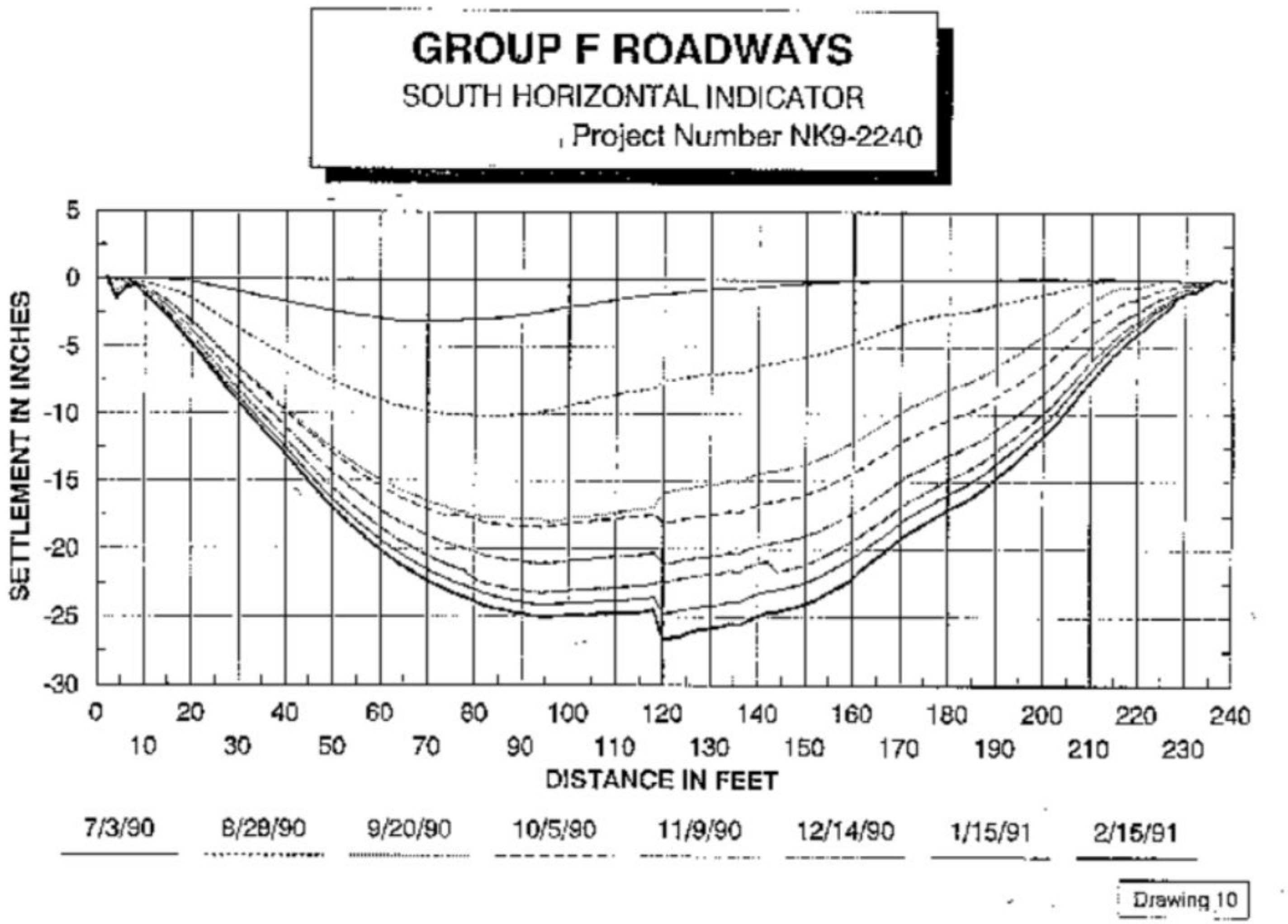
Pile Installation

- Final pile resistances were highly variable
- Some >100 blows/ft and some < 40 blows/ft depending on bearing on clay or sand
- Final tip grades varied by 22 ft

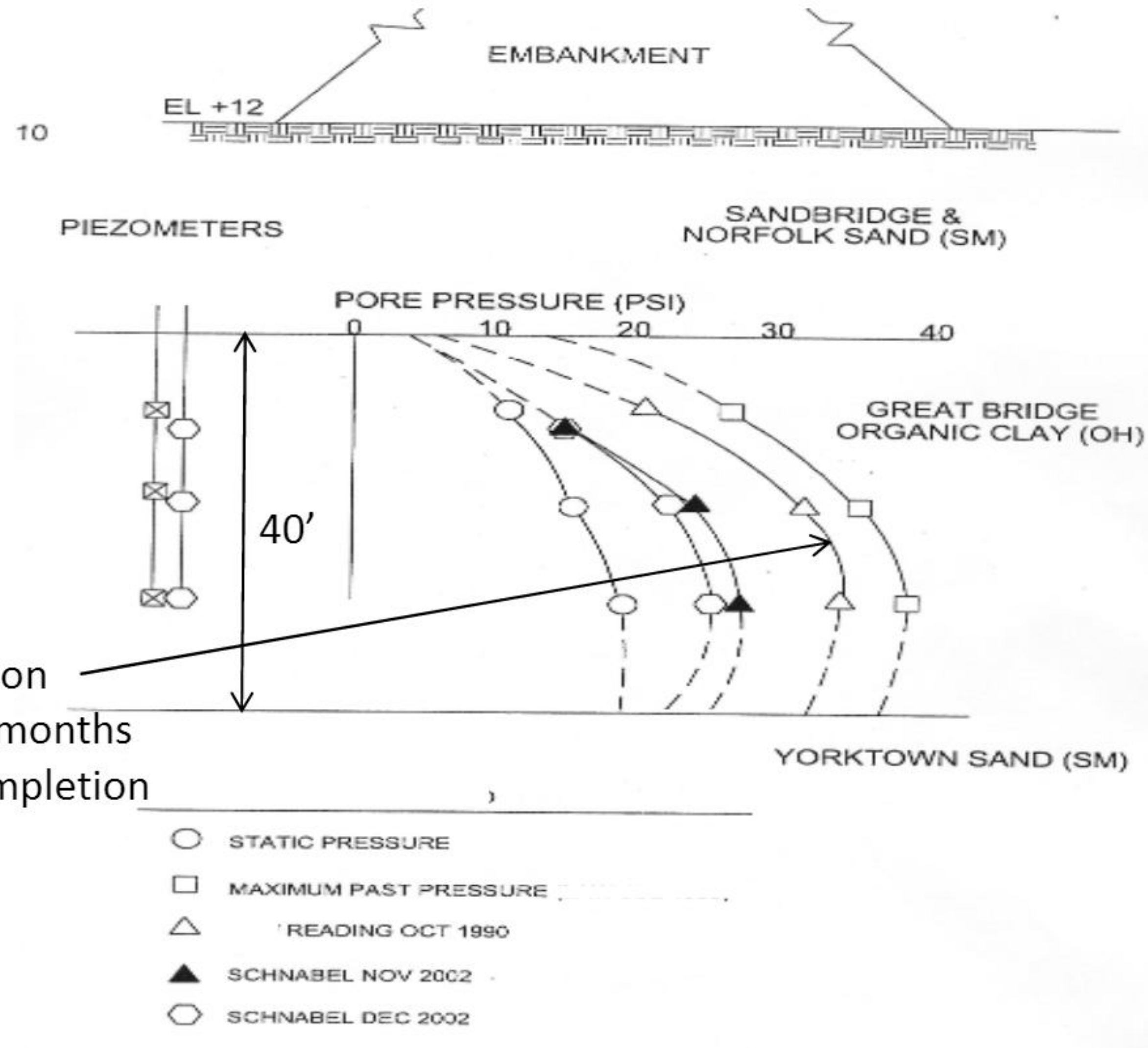
Instrumentation Program Was Impressive

- Ten settlement plates
- Three piezometers
- Four vertical slope indicators
- Two horizontal settlement profile indicators

Field Data – Horizontal Indicator

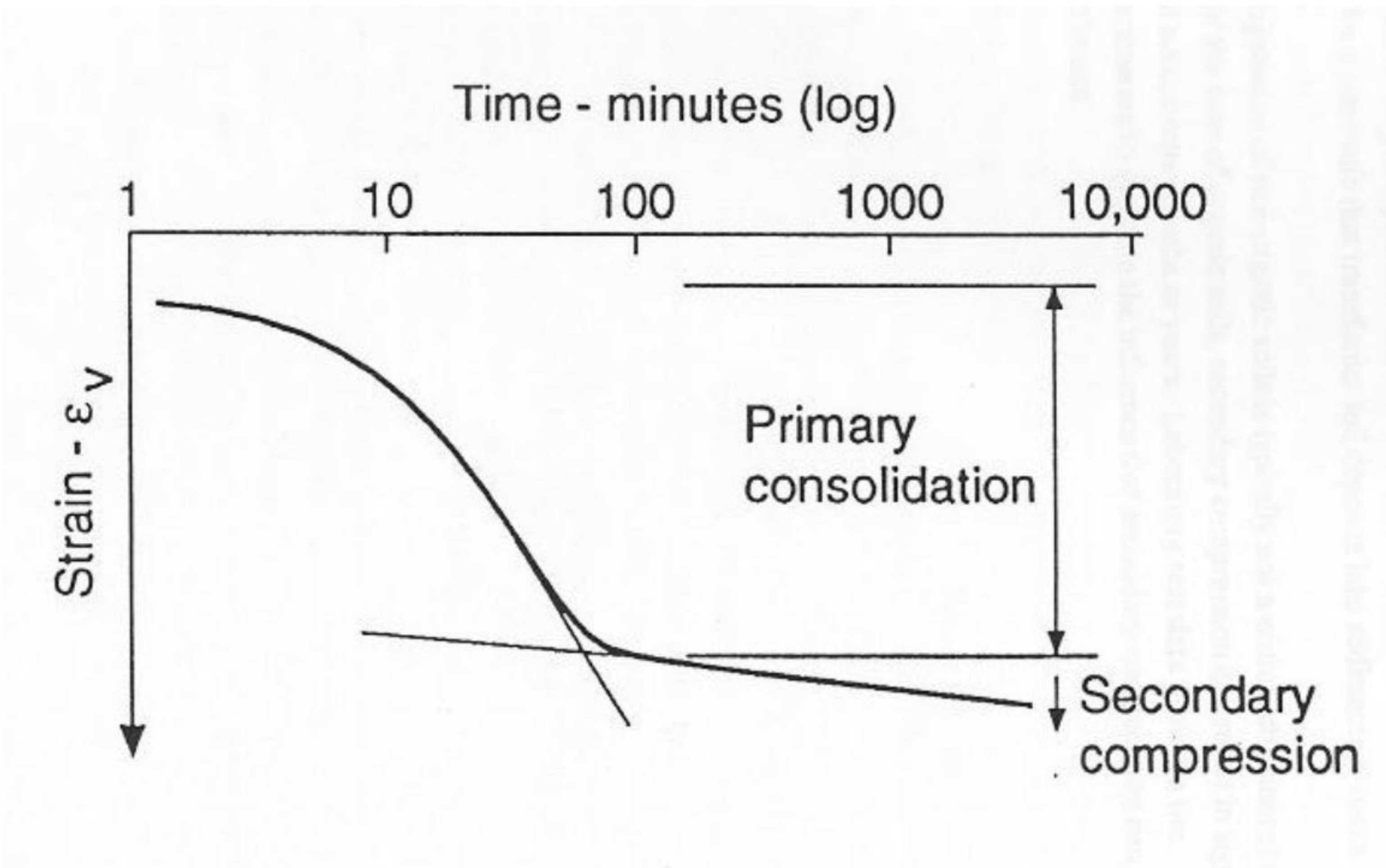


Pore Pressures in Organic Clay Layer

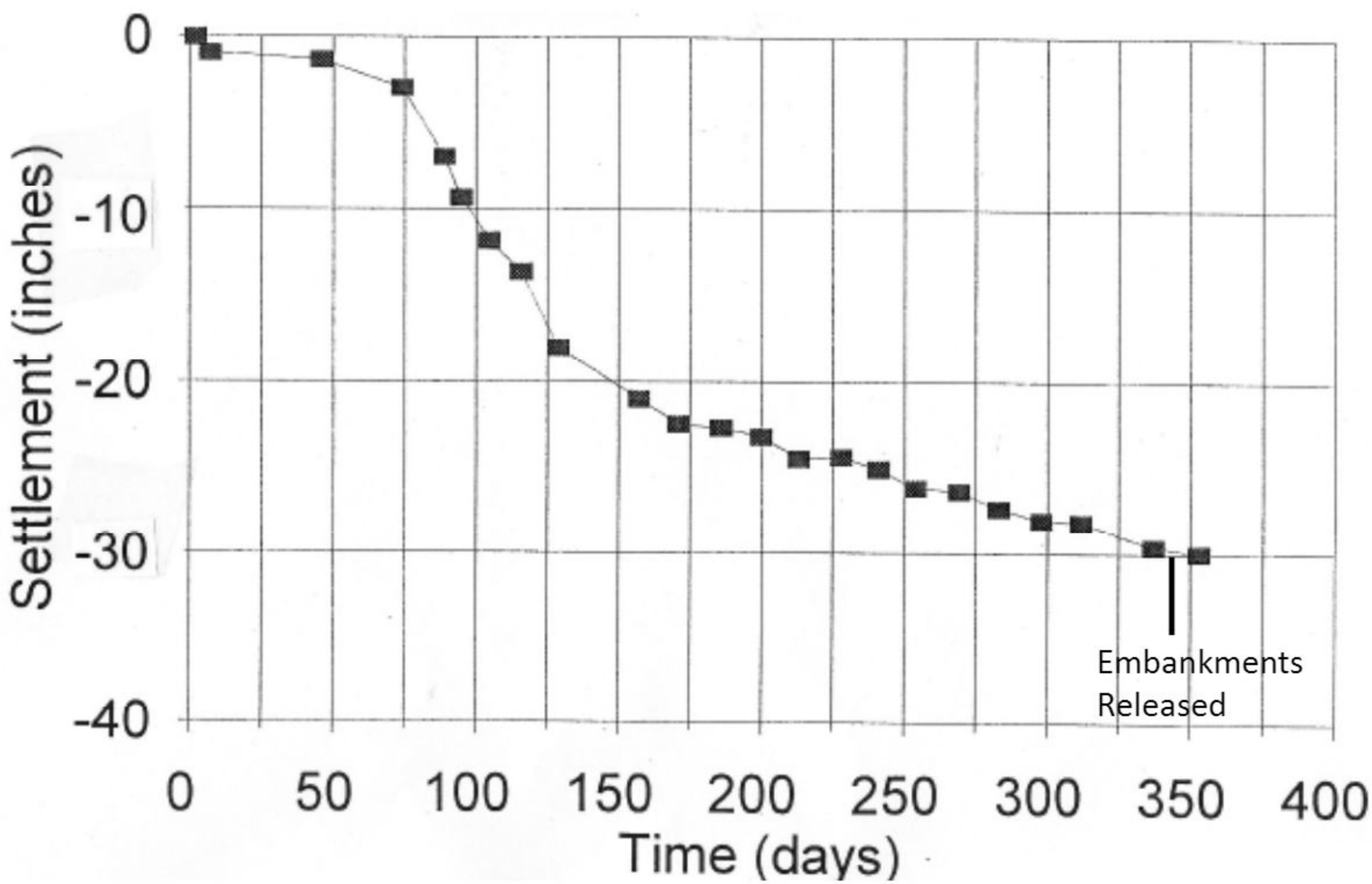


Pore pressure dissipation only about 30% three months after embankment completion (not 80%)

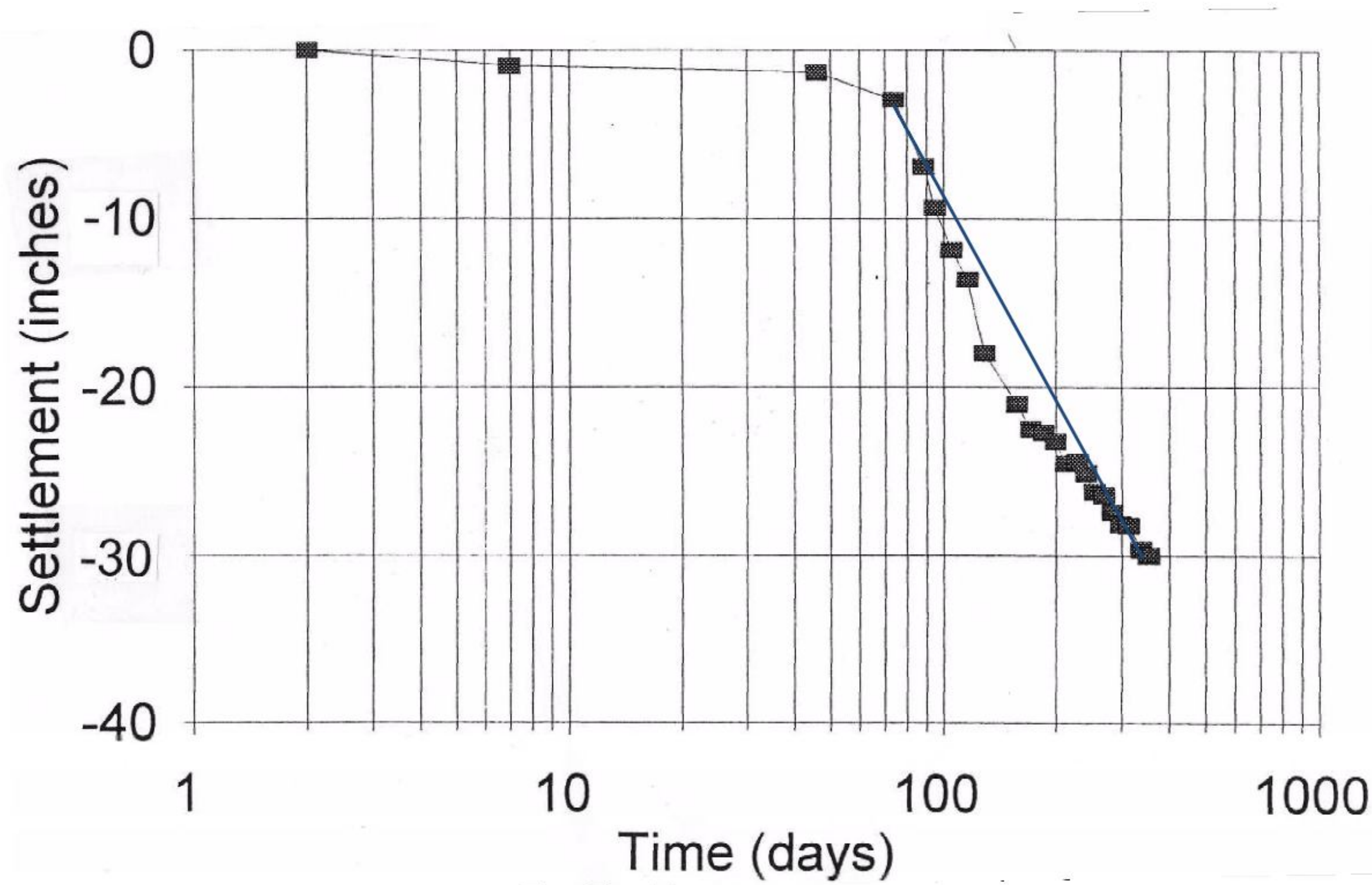
Semi-log Plot of a Typical Laboratory Consolidation Time Curve



Field Data - *Arithmetic* Time-Settlement Plot Of Embankment



Semi-log Plot of Embankment Time-Settlement Data



Conclusions from the "Report of Embankment Instrumentation"

- "Horizontal indicators indicate that the (vertical) settlement is still occurring".
- "Horizontal movement continues…may still be experiencing plastic flow".
- "While pore water pressures have reduced, values indicate consolidation is still occurring".
- "Construction of the overpass bridge and pier foundations can proceed".

Early Problems

- Jan 1992 City noted that “approach grades were lower than bridge grades”
- Final bridge inspection May 1992 – no major deficiencies were noted
- Dec 1996 - additional 11 to 18 inches of settlement noted
- By May 2000 – Additional embankment settlements were 2.5 to 3 ft!

(Note: Total of 5 to 5.8 ft since construction began).

1997 and 2003 Schnabel Studies

- 1997 Study: Described the cause of the observed damage

- 2003 Study:
  - Installed new piezometers
  - Performed laboratory testing
  - Predicted future settlements
  - Made remedial recommendations

2003 Study Results

- Organic clay is consolidated 75 to 95% near the top of the layer and 55 to 75% in the middle.
- Strength gain of about 50% in organic clay has occurred due to consolidation
- Future consolidation settlement up to 22 inches could occur with about 12 inches in the next 17 years.


VISUAL DAMAGE
Depressed sidewalk and guardrail

Vertical crack on beam web above bearing plate

Diagonal Stress Crack in Under Beam

Cracked and Grouted Beam

Rotation of Back Wall

Displacement relative to girder

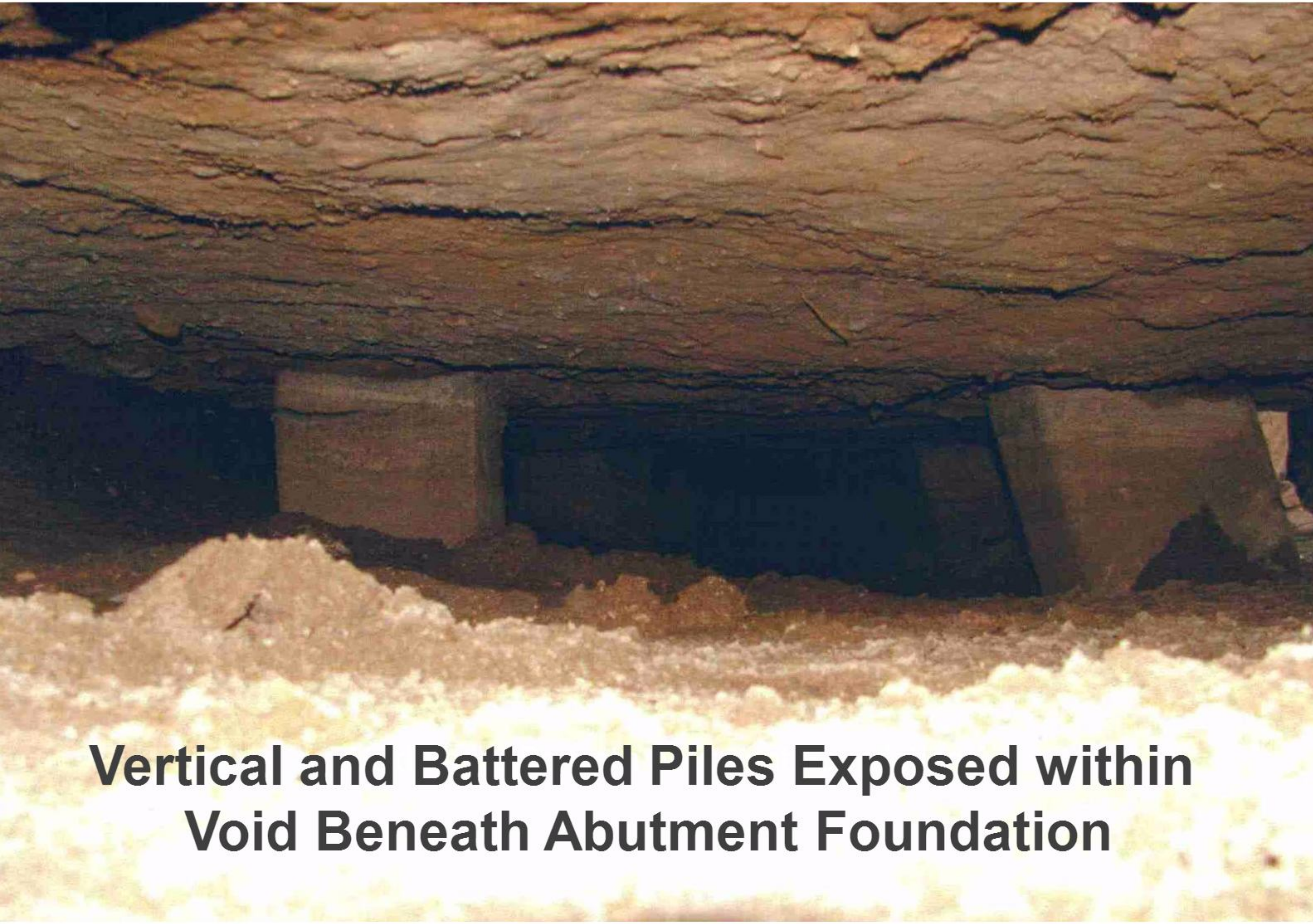
Buckling of Slope Protection

Diagonal Crack in Wing Wall

Owner Seeks Recompense

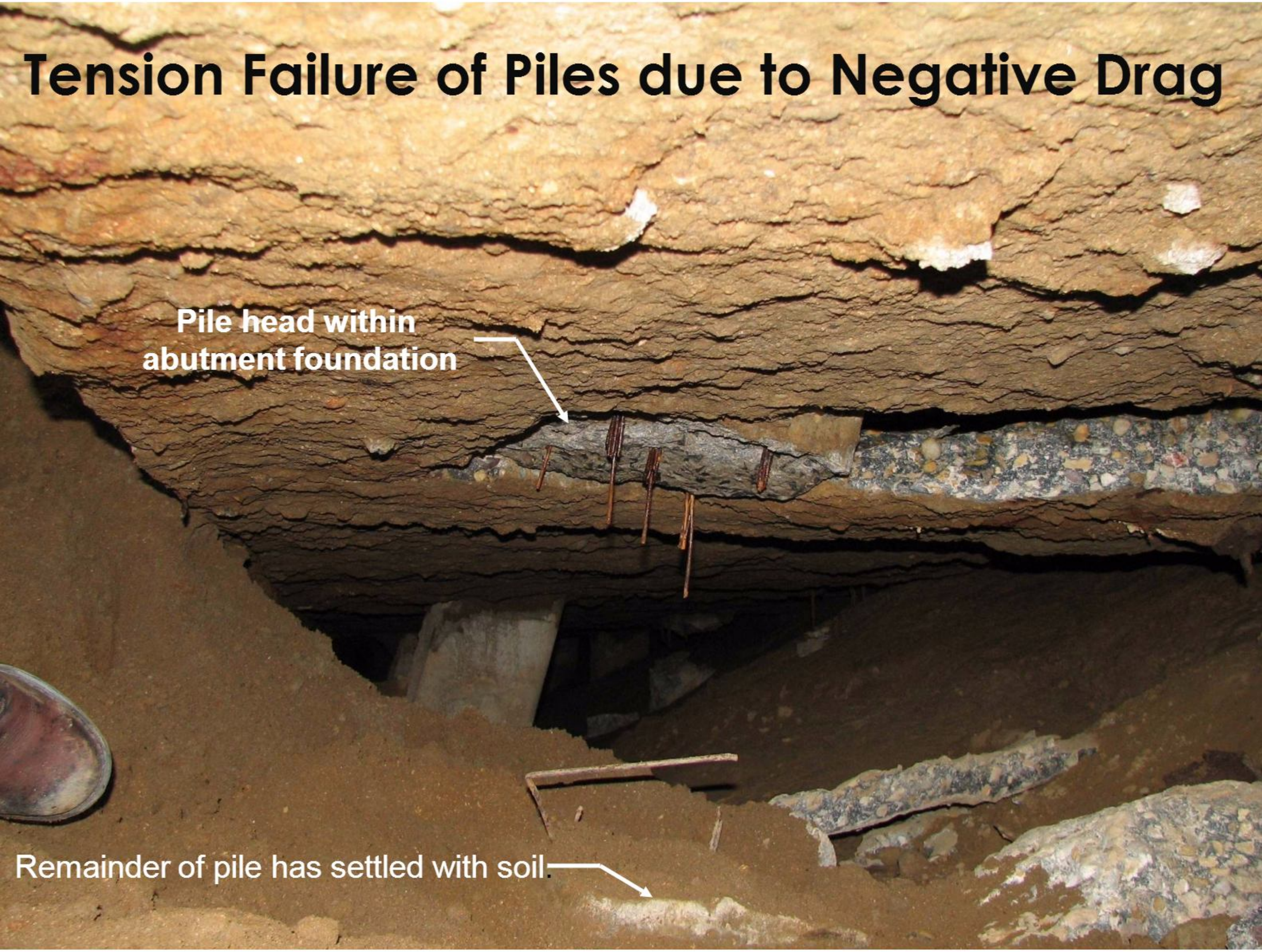
- Maintenance costs for filling approach slab depressions five times over 10 years totaled about $500,000
- Bridge inspections were performed periodically since completion
- No one asked what is going on underground to cause structural damage, or if it would get worse

A Peek Below


Vertical and Battered Piles Exposed within
Void Beneath Abutment Foundation

Concrete Spalled/ Reinforcement Exposed

Tension Failure of Piles due to Negative Drag



You mean they're...............gone?

Contractor Opines on Negative Drag

"I'd always heard you geotechnical guys talk about negative shaft friction, but I never believed in it until now".


Geotechnical Engineer – peeks under failing abutment but does not crawl in


Bridge Engineer –
crawling out from
under failing abutment

Dragload

Calculated as 100 to 120 tons (considering strength gain in clay and drag from overlying sand and embankment fill)

This is 5 to 6 times the original estimate!

Vertical Pile Loads

- Working loads 40 to 60 tons
- Combined working loads and negative drag loads exceeded the design allowable capacity of 100 tons
- For piles bearing in clay the capacities were far exceeded

Post Construction Pile Settlement

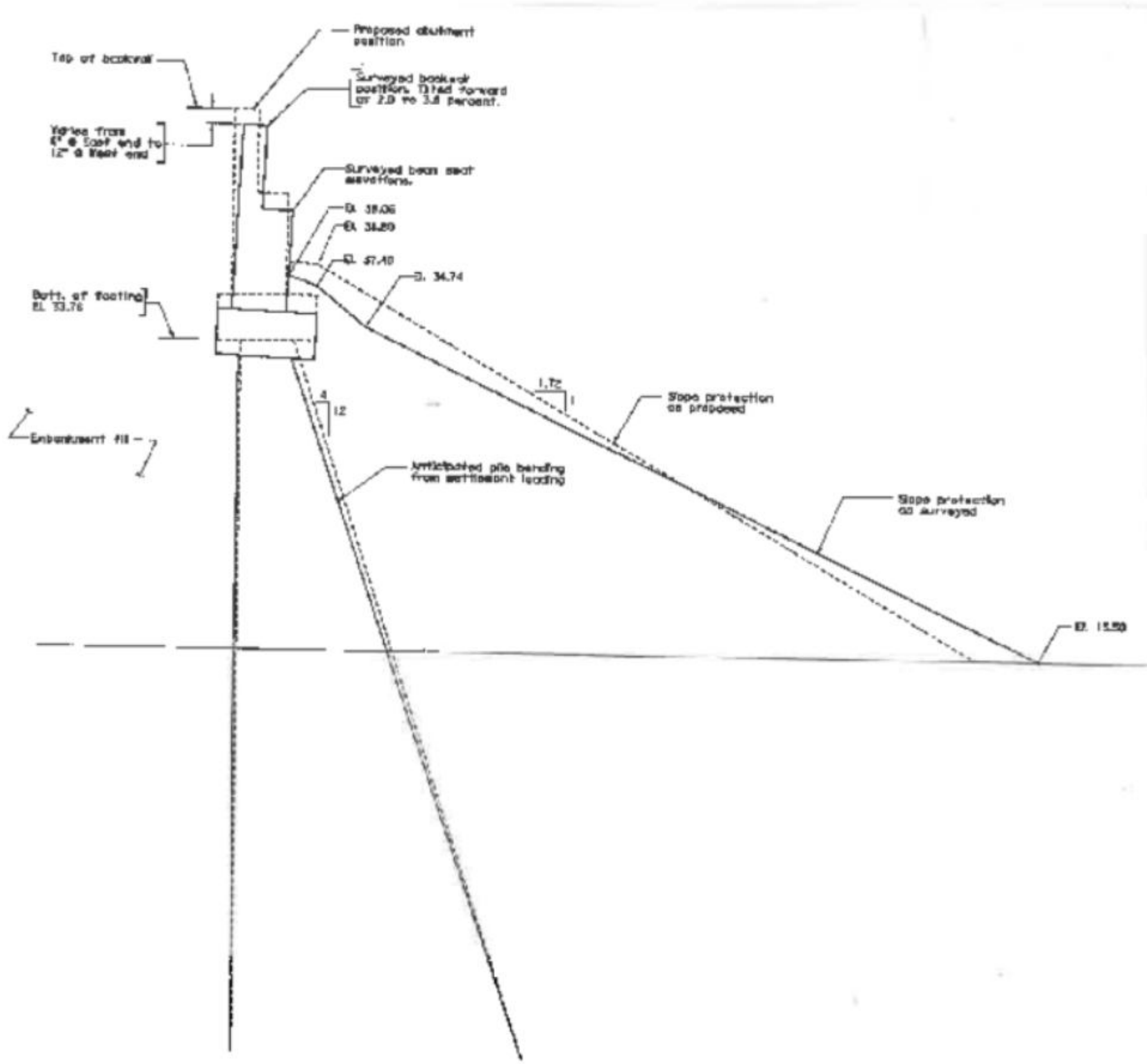
- Center pier piles: up to 1.5 inches
- End pier piles: up to 3.5 inches
- Abutment piles: 4 to 12 inches

As expected, pile settlements varied with distance from the approach embankments.

A Case for Lateral Squeeze

- Slope indicators showed considerable lateral movement
- Joint displacements of 4 to 6 inches between the slope protection and abutment stem plus abutment tilting
- FHWA rule of thumb criteria exceeded for lateral squeeze (embankment pressure greater than 3 x undrained strength)

Rotation of North Abutment



Remedial Alternatives

- Underpin with micropiles
- Underpin with jet grouting
- Partial reconstruction – provide new support for end spans

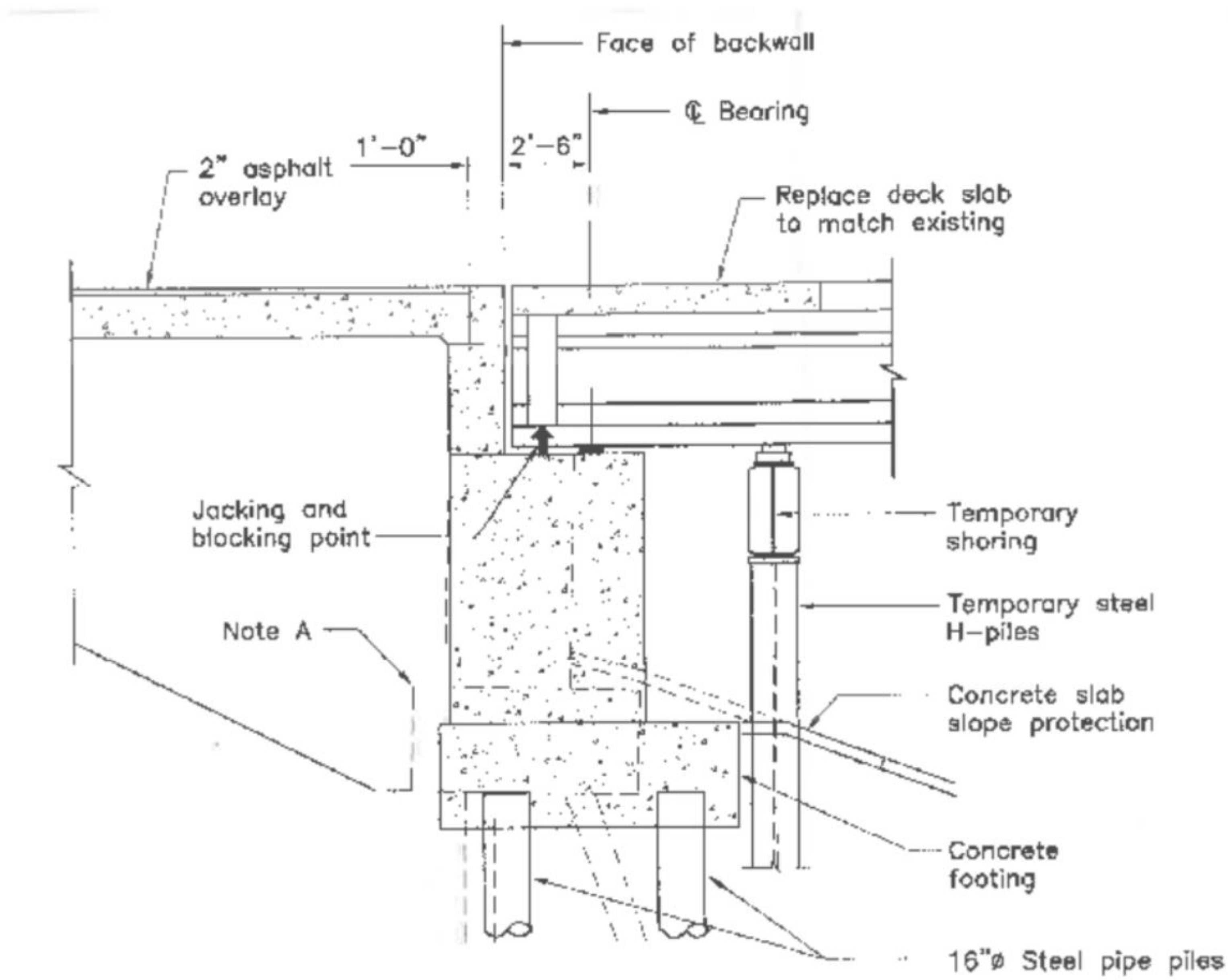
Final Remedial Design

- Reconstruct bridge abutments
- Leave piers and bridge spans in place
- Do not reuse existing back walls and abutment piles
- Use 16" dia. steel pipe piles with 80 ton allowable capacity
- Limit future pile drag load to the extent possible

Remedial Design and Testing

- Use temporary bent to support span while replacing abutment
- Minimize drag load
  - Case upper 50 ft
  - Use pile coatings within clay
- Test piles during construction
  - Dynamic testing: initial drive and restrike
  - Static testing:
    - Compression test on full length pile
    - Tension test on cased & coated portion.

Reconstruct Abutment Using Temporary Pier to Support Bridge Deck

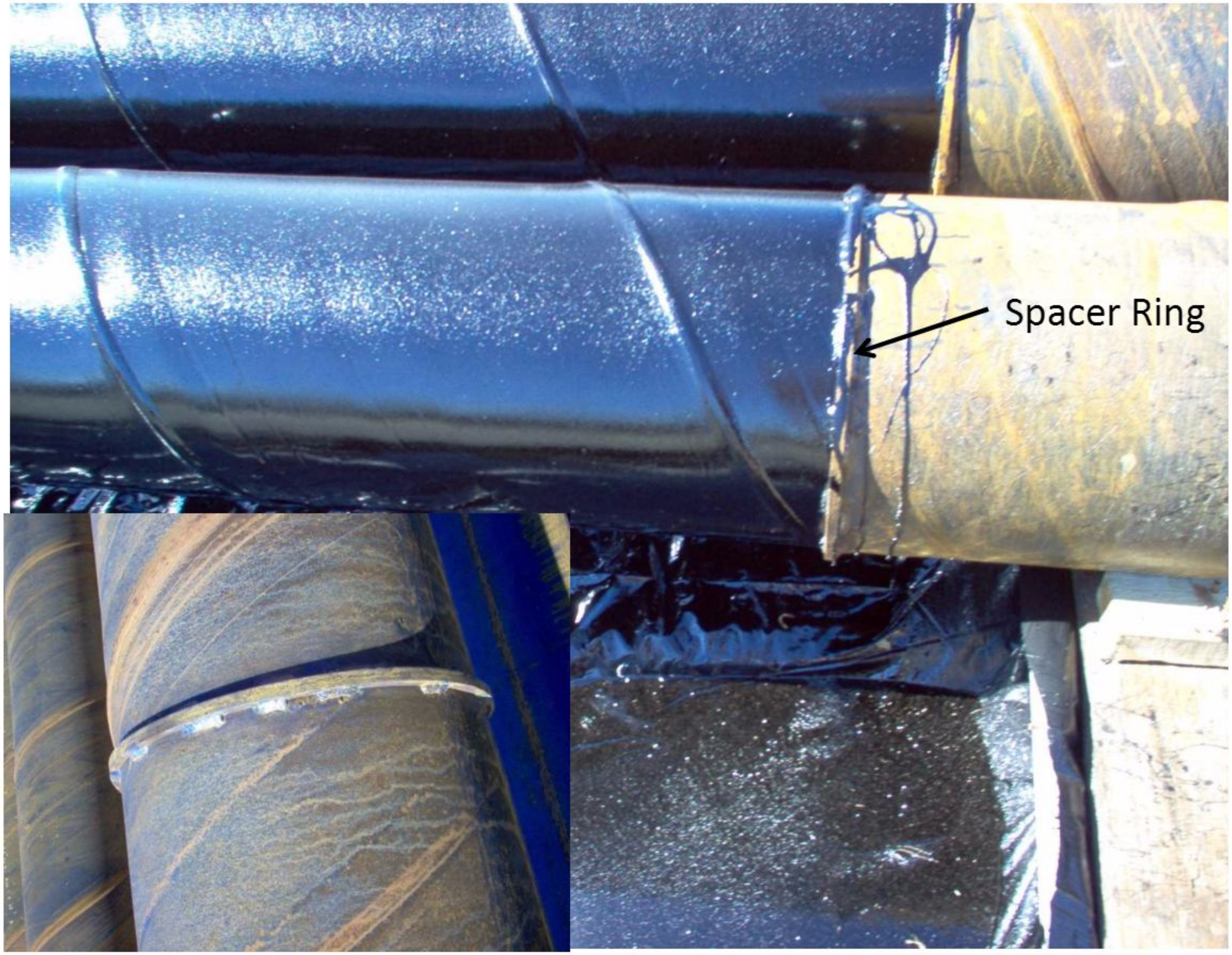


Access Holes Cut Through Bridge Deck

Jacking Up End Span

Temporary Shoring

Pipe Piles with Friction Reducer



Pile Coatings Applied

Hardened Coatings on Piles

Control Piles being Driven

PDA Testing

Pile Load Test

Contractor Insisting He's Right In a Robin Hood–Little John Type Standoff

Pullout Test Setup

Shear Failure Appears to be Mostly in Clay

Lessons Learned

- Using the least conservative method to predict consolidation may not always be the best choice.
- When calculating negative drag, account for strength gain in the compressible material, and don't underestimate strength of more competent overlying layers.
- If you plot field consolidation data **arithmetically** you just might come to the wrong conclusion.
- You cannot ignore redundant field performance data no matter how bad the news is.
- If you inspect a bridge and it seems to be falling apart – you have to ask "why?"

Lessons Learned (continued)

- Observation of construction by people unqualified to do so is a formula for disaster.
- Using pile coatings to reduce pile friction may be dubious, particularly when you're trying to coat a cylinder.
- Don't argue with a contractor while standing above ground on a narrow beam.
- Don't crawl under failing structures (unless you're a bridge engineer).

Questions??

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