



Anatomy Of A Bridge Failure

GEO3T2 Conference



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April 10, 2015

The Project - Bridge Overpass, Chesapeake, Virginia



Project Completion

- Bridge designed in 1987
- Construction started Spring 1990
- Construction completed by 1992

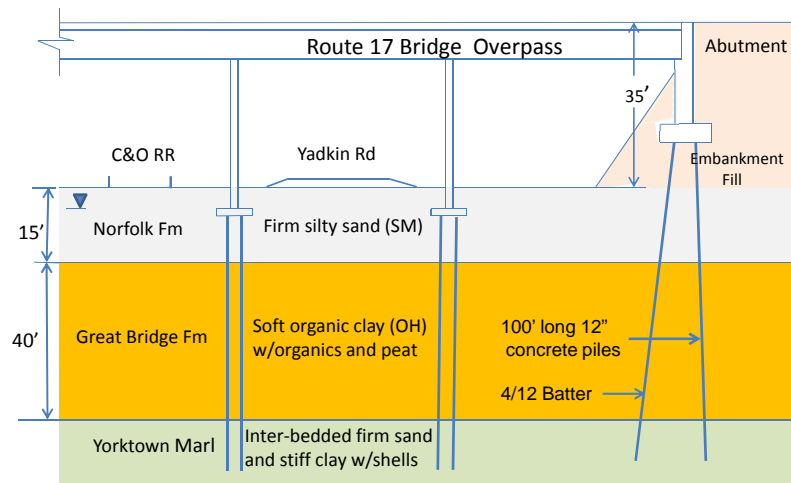


Project Details

- Bridge is 100 ft wide and 250 ft long
- Horizontally curved alignment; vertically curved grade with 5% gradients.
- Bridge deck super-elevated at 4%
- 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

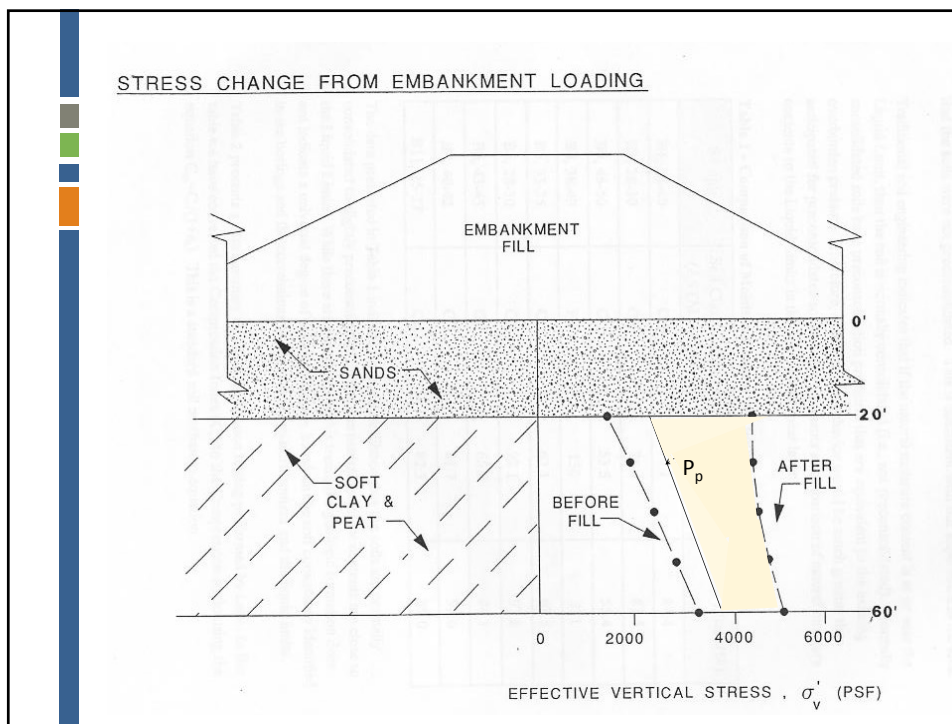


Subsurface Conditions and Design



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 ; $e_0 = 1.4$ to 2.6
- OCR = 1.0 to 1.7
- Lab $S_u = 500$ to 800 psf;
N-values = WOR to 2
- $k = 6.7 \times 10^{-4}$ to 1.9×10^{-5} ft/day



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.

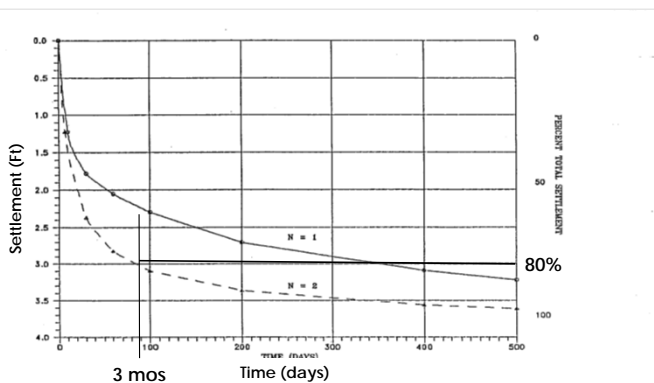


Preliminary Report Conclusions

- “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	DRAWN BY
DATE	SAB	JEC
7-10-87		PROJECT
Chesapeake Roadways - Route 17		NK7-1580
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.”



Preliminary Report Conclusions

“Since the time required to complete the predicted settlements is critical to the construction schedule, we recommend that the approach embankments be instrumented to evaluate actual settlements, pore water pressure distribution and stability.”



Final Geotechnical Report

- Pile recommendations were unchanged
- No estimate of drag load on piles given
- **Settlement** estimate from DMT results was 2.25 ft
- 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 embankment and wait three months for the predicted 2.25' of settlement to occur
- Release embankment to the contractor for bridge construction based on performance data
- Drive abutment and pier piles



The 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

- 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
- All pile inspection was done by the Owner

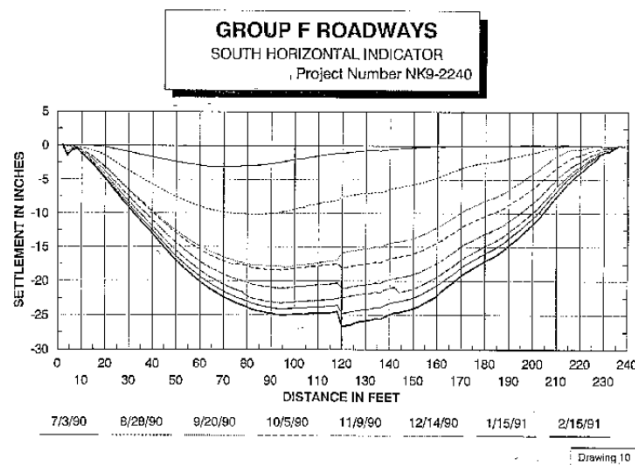


Instrumentation Program Was Impressive

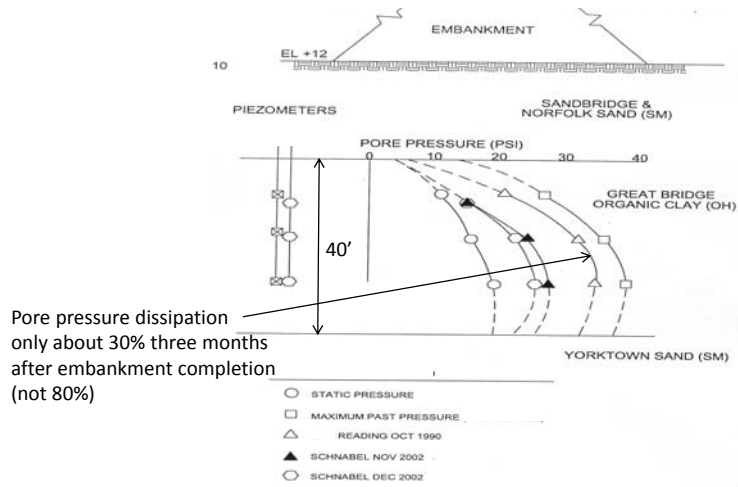
- Ten settlement plates
- Three piezometers
- Four vertical slope indicators
- Two horizontal settlement profile indicators



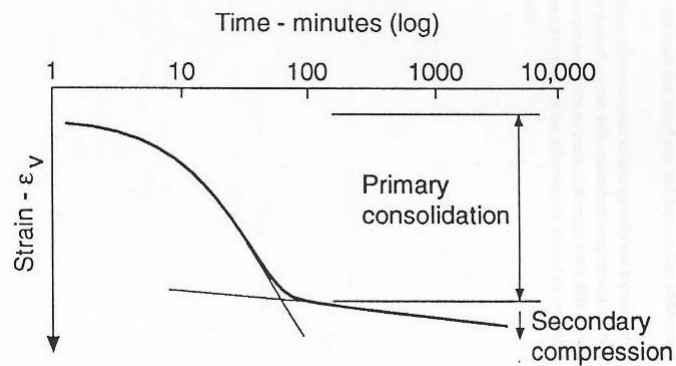
Field Data – Horizontal Indicator



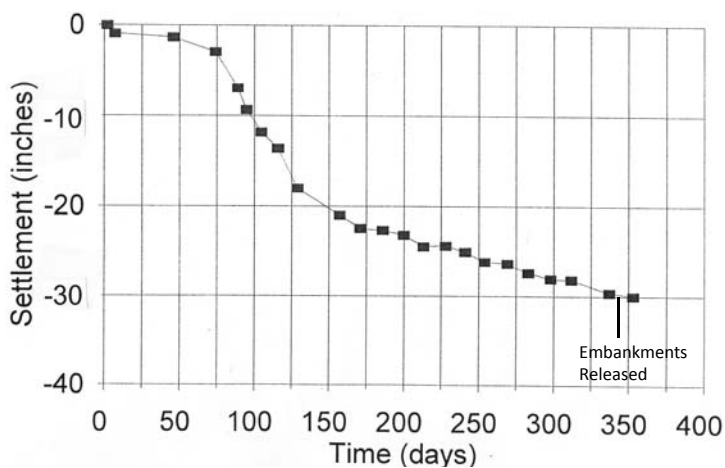
Pore Pressures in Organic Clay Layer



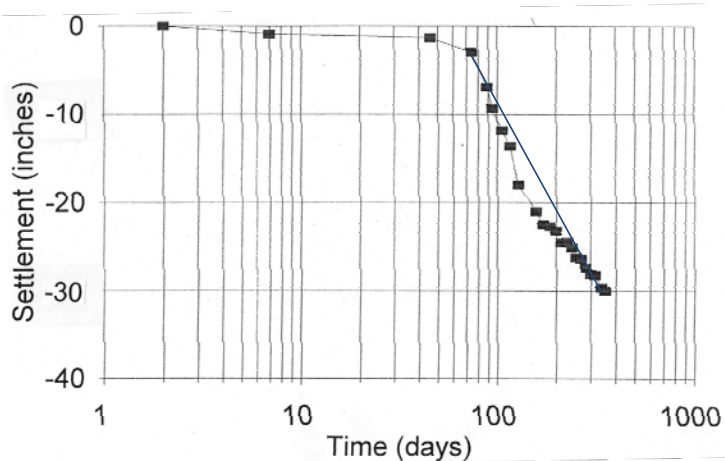
Semi-log Plot of a Typical Laboratory Consolidation Time Curve



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 inspection May 1992 – no major deficiencies were noted
 - Dec 1996 - additional 11 inches of settlement noted
 - By May 2000 – Additional embankment settlements were 2.5 to 3 ft!
- (Note: Total of 5 to 5.5 ft since construction began).



2003 Schnabel Study Results

- Post construction approach settlements are up to 3 ft
- 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% has occurred due to consolidation



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

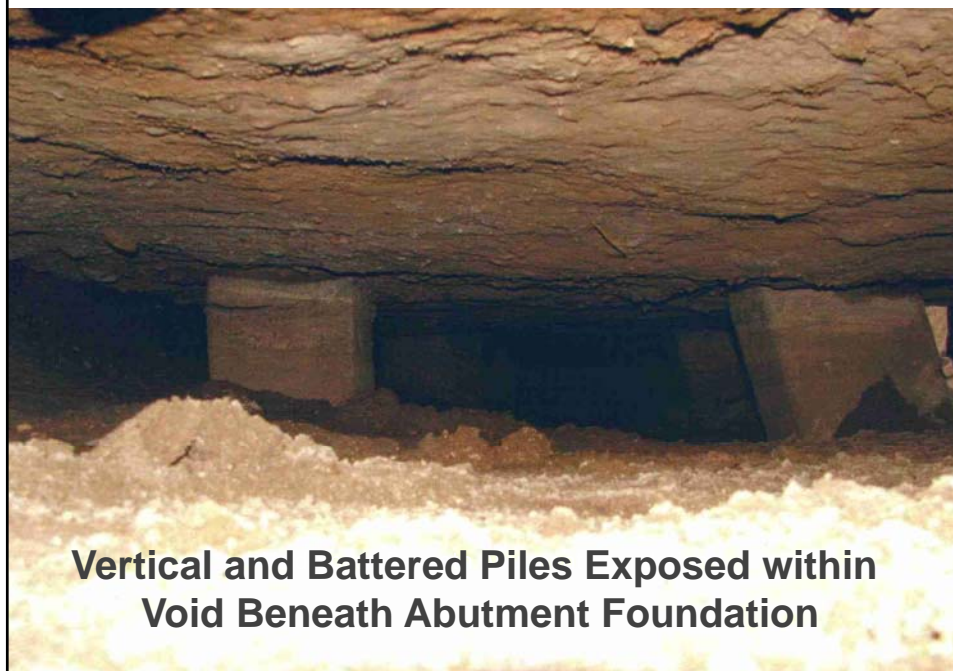


Owner Seeks Recompense

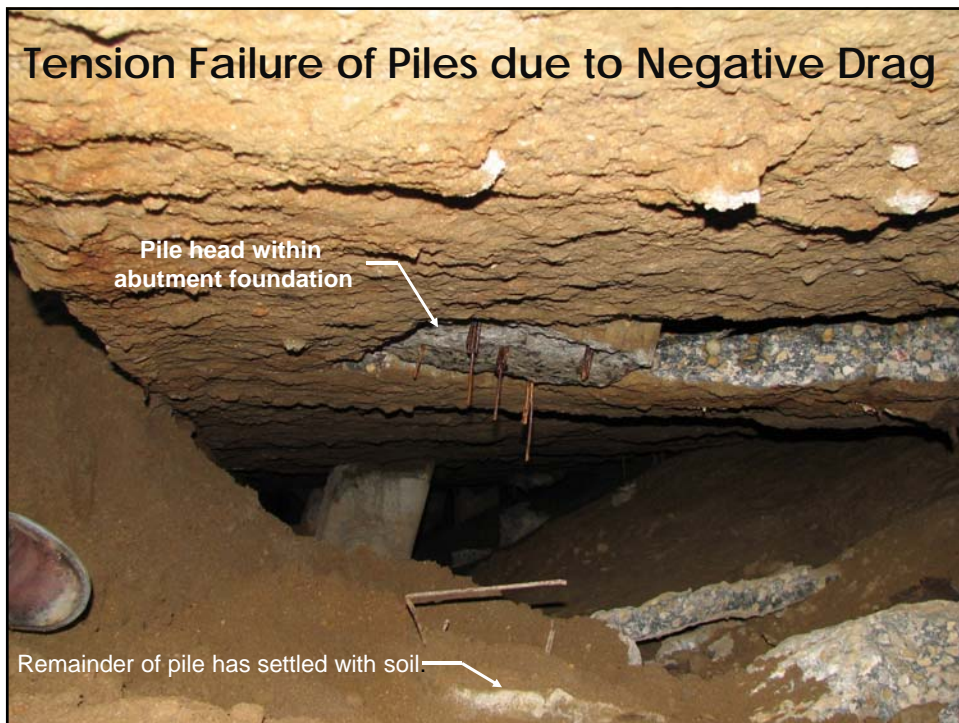
- Maintenance costs for filling approach slab depressions five times over 10 years totaled about \$500,000
- Bridge inspections performed since completion
- Did no one ask why damage occurred or if it will get worse?



A Peek Below



**Vertical and Battered Piles Exposed within
Void Beneath Abutment Foundation**



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



Geotechnical Engineer –
peeks under abutment
but does not crawl in



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”.



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.



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

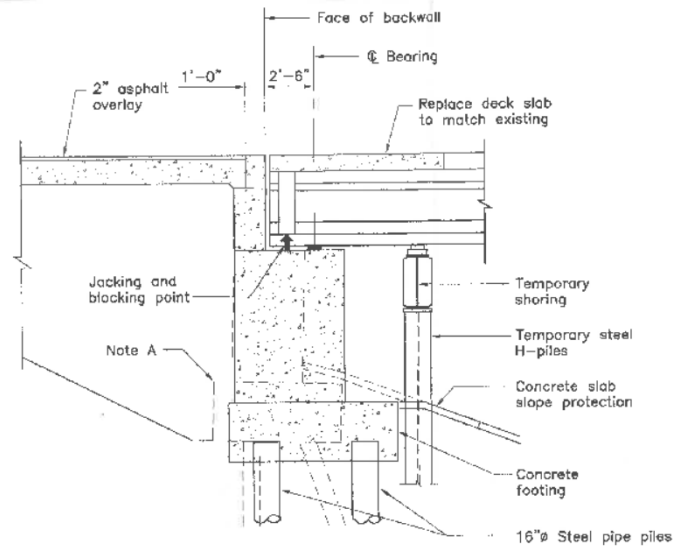


Remedial Design and Testing

- Use temporary bent to support span while replacing abutment
- Minimize drag load
 - Case upper 50 ft
 - Using pile coatings within clay
- Testing 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



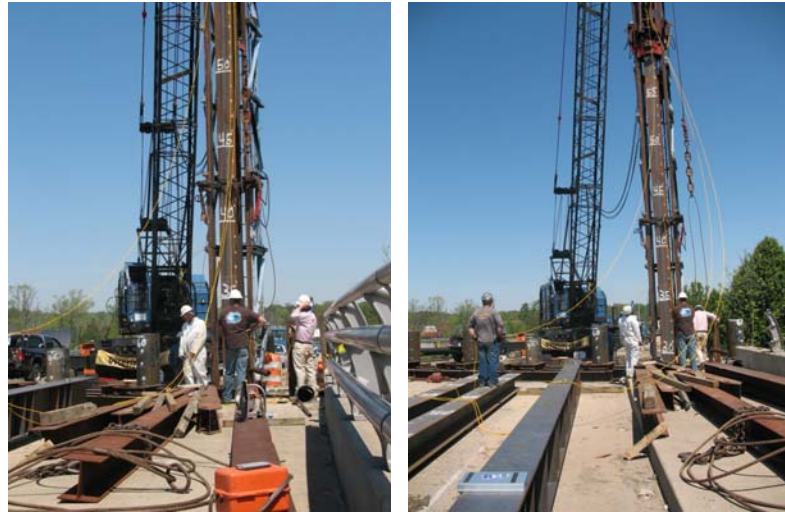
Pile Coatings Applied



Hardened Coatings on Piles



Control Piles being Driven



PDA Testing



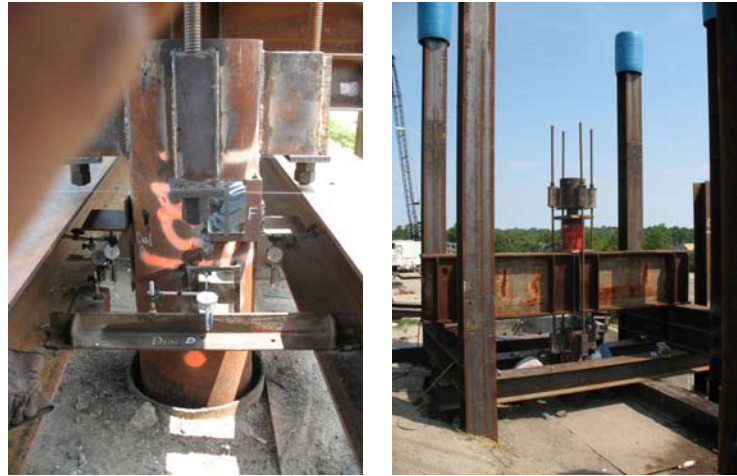
Pile Load Test



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



Pullout Test Setup



Shear Failure Appears to be Mostly in Clay



Pile Driving Template



JS1

Template With Outer Pipe Sleeves



Slide 60

JS1 This may be a good place to talk about the exploding casing event.
Jim Seli, 11/24/2014

Driving Replacement Pipe Piles



Lessons Learned

- Using the least conservative method to predict consolidation may not always be the best choice.
- 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)

- 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??

