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

Route 17 Bridge Overpass

- Abutment
  - Embankment Fill

- C&O RR
  - Norfolk Fm
  - 15'

- Yadkin Rd
  - Firm silty sand (SM)
  - 40'

- Great Bridge Fm
  - Soft organic clay (OH) w/organics and peat
  - 100' long 12" concrete piles
  - 4/12 Batter

- Yorktown Marl
  - Inter-bedded firm sand and stiff clay w/shells
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

EMBANKMENT FILL

SANDS

SOFT CLAY & PEAT

BEFORE FILL

AFTER FILL

EFFECTIVE VERTICAL STRESS, $\sigma'_v$ (PSF)
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

![Graph showing settlement vs. time with 80% settlement after 3 months and 200 days.](image)

**Graph Details:**
- **Y-axis:** Settlement (ft)
- **X-axis:** Time (days)

**Legend:**
- **N = 1**
- **N = 2**

**Note:**
- 80% settlement is reached after approximately 200 days for both N = 1 and N = 2 scenarios.

**Project Information:**
- **Date:** 7-10-87
- **Project:** Chesapeake Roadways - Route 17
- **Location:** Chesapeake, Virginia
- **Drawing Number:** 5
“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

GROUP F ROADWAYS
SOUTH HORIZONTAL INDICATOR
Project Number NK9-2240

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Distance in Feet

Drawing 10
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
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

Exposed Reinforcing Steel
Tension Failure of Piles due to Negative Drag

Pile head within abutment foundation

Remainder of pile has settled with soil.
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

- Face of backwall
- 2" asphalt overlay
- 1'-0"
- 2'-6"
- Bearing
- Replace deck slab to match existing
- Jacking and blocking point
- Temporary shoring
- Temporary steel H-piles
- Concrete slab slope protection
- Concrete footing
- 16"Ø Steel pipe piles

Note A
Access Holes Cut Through Bridge Deck
Jacking Up End Span
Temporary Shoring

New Abutment Pipe Piles

Temporary Pier
Pipe Piles with Friction Reducer

Spacer Ring
Pile Coatings Applied
Hardened Coatings on Piles
Control Piles being Driven
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).