LADOTD Pile Setup Research and Practice

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Bridge Foundations in Louisiana

- Concrete
  - Prestressed precast piles
    - Majority of the bridges
  - Spun cast cylinder piles
  - Large Cassions
    - Very few
- Timber piles– legacy or off-system bridges
- Steel
  - H piles
  - Pipe piles
  - Insignificant numbers
- Drilled Shafts

Design Considerations for Driven Piles

- Capacity
- Settlement/Deformation
- Vibration/Noise
- Constructability

Pile Capacity

- Static pile capacity calculation methods
  - 20+ widely used methods
  - downdrag
- Factors affecting capacity measurement
  - Loading method
  - Load duration
  - Monotonic or cyclic loading
  - Failure criteria
  - **Time of loading**
- Pile Capacity?


20 MN
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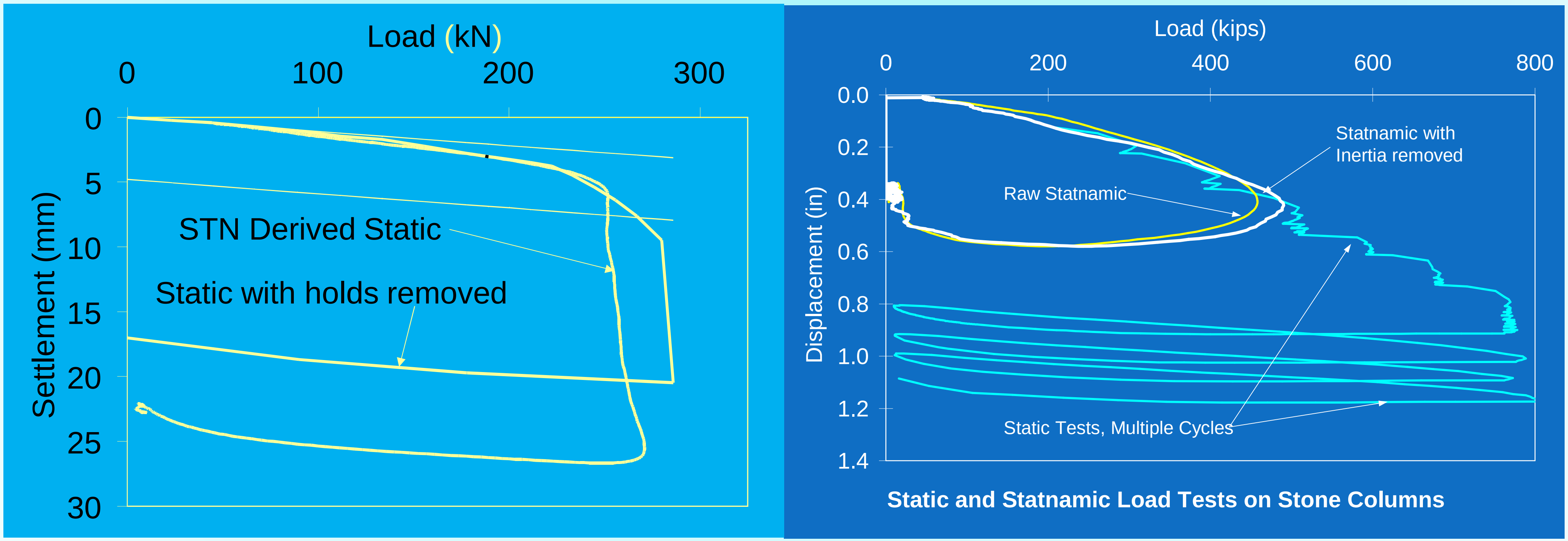
20MN Static Load Test


PDI
Pile Driving Analyzer

Effect of Test Method



Failure Criteria

- Published criteria
  - Davisson
  - Butler & Hoy
  - De Beer
  - Fuller & Hoy
  - Vander Veen
  - Brinch Hansen
  - Chin
  - A few more
- Bengt Fellenius (1980) - 30% difference between Davisson and Chin
- LADOTD - Davisson

Two Takeaways

- Ultimate pile capacity is a value that is difficult to define

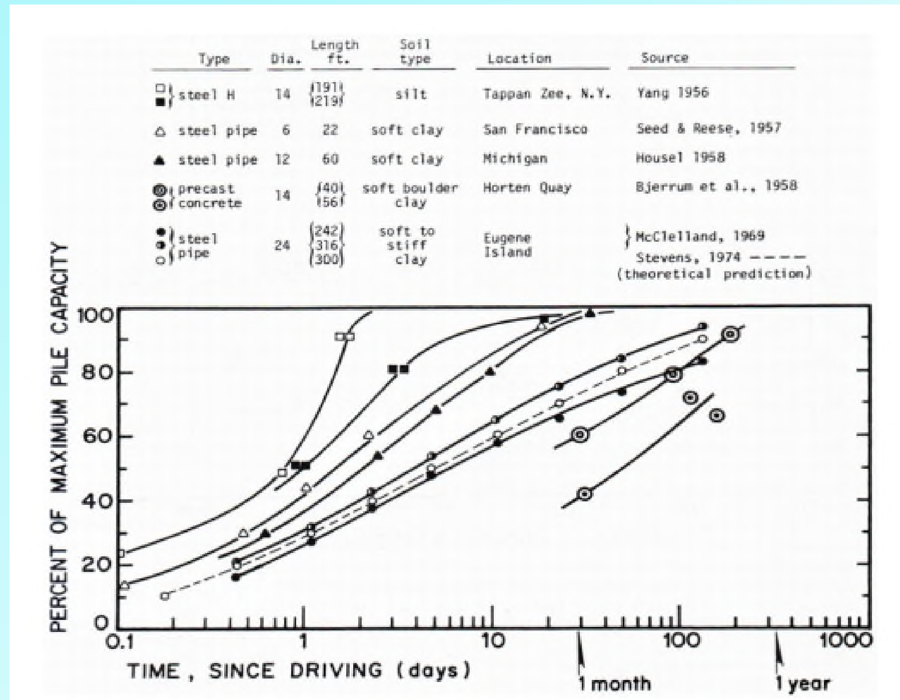
- Geotechnical engineers can provide an estimate of usable resistances for a specific design limit state and condition.

LET'S CONCENTRATE ON TIME COMPONENT

Time Effect on Pile Resistance

- Behavior is known since 1950s
  - Some suggested 10X EOD resistance
- How to evaluate time effect?

  >10 published models
- How to incorporate time in LRFD foundation design?
- How comfortable are we in designing a pile without verification?



Pile Design without Setup

Before PDA

- Static analyses
  - Time is not explicitly considered
  - assume to be resistance at 14 days
- Verification
  - Test Pile –
    - Test pile only
    - static load test at 14 days
  - Acceptance test - Modified Gates formula
    - Restrike if needed?

Post PDA

- Static analyses
  - Same as Before PDA
- Wave equation analyses
- Verification
  - Test Pile
    - Dynamic test – initial drive, restrikes
    - Static load tests at 14 days
  - Acceptance test
    - Initial driving
    - 1-day or longer restrike until pass

Pile Design with Setup

- Design
  - What is the criteria for time selection?
  - What resistance factor/safety factor?
- Testing
  - Testing time?
  - Establish site specific set-up model
  - Extrapolation!
- Acceptance
  - When to test?
  - What ifs?
- Others
  - Foundation reuse

LADOTD Research

Early Research Effort

- Tavera and Wathugala (1999) – Bayou Boeuf Bridge Extension
  - Multiple O-cell load tests on same pile for 2 years
  - No formal report issued
- Titi and Wathugala (1999) – Numerical modeling

Recent Research

- LA Tech – Dr. Jay Wang (2009-2011)
  - Phase I – paper study
  - Proposed "growth" model

- LSU/LTRC – Dr. Murad Abu-Farsakh (after 2011)
  - Phase II – includes test piles
  - Adopted "Skov-Denver" model

Growth Model

Dr. Jay Wang (2011) Louisiana Tech U

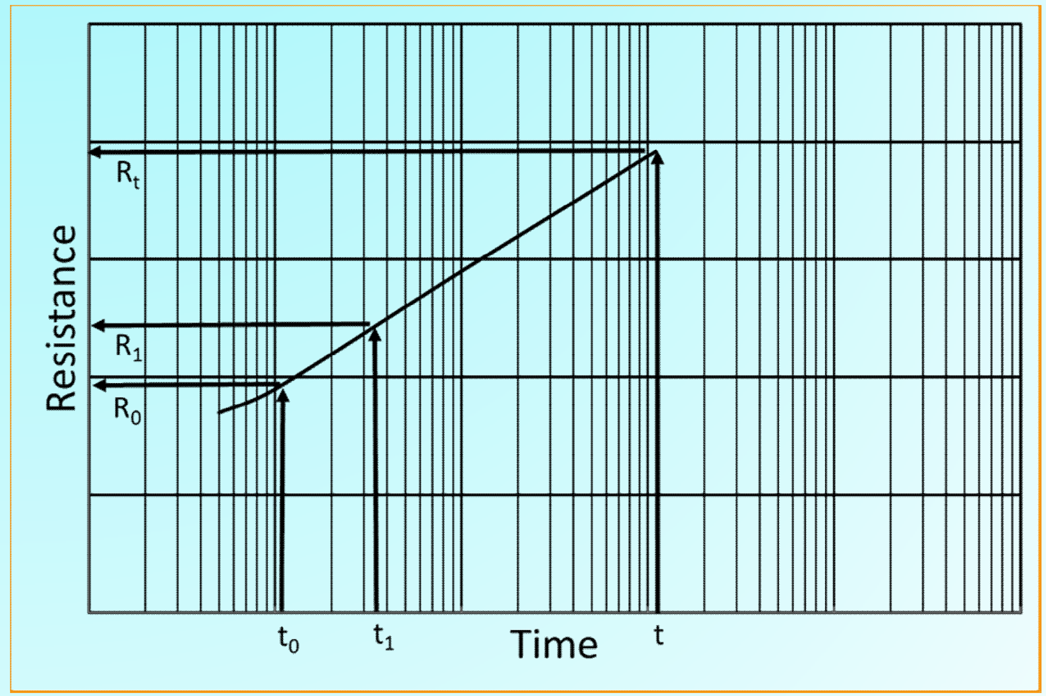
$$s(t) = \frac{s(\infty)s(0)}{S(0) + \left(S(\infty) - S(0)\right)e^{r\left(t\ -\ t0\right)}}$$

– Based on whole pile resistance
– Assumes long-term ultimate resistance exists
– Requires multiple tests to establish site specific model
– Not user friendly

Adopted Model – Skov-Denver

$$R_t = R_0\left(A\,log\left(\frac{t}{t_0}\right) + 1\right)$$

- A (whole pile) – rate constant for clay or sand
- t_0 - reference time
  - Clay -1 day
  - Sand - 0.5 day
- R_0 - pile resistance at t_0



Introduction to LRFD

- Generalized form

$$\gamma_d DL + \gamma_l LL <= \sum \emptyset Rn$$

- AASHTO resistance factors (2007) for driven piles
  - Static Analyses: 0.35 to 0.4
  - Static load test: 0.75 to 0.8
- Implications
  - Encourage verification testing
- LADOTD calibrated resistance factors (14-day resistance)
  - 0.45 (sand), 0.5 (clay), and 0.55 to 0.6 (CPT)

Static Analysis Methods

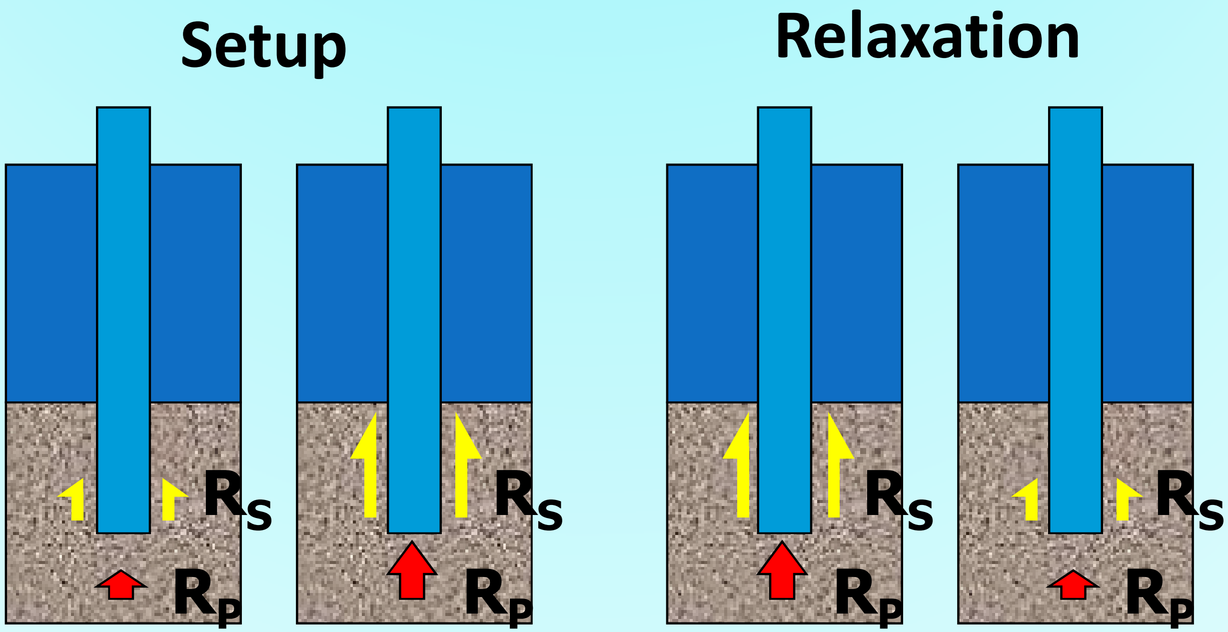
- Primary use is for pile length estimation for contract drawings and feasibility.
- Secondary use for estimation of downdrag, uplift resistance and scour effects
- Should rarely be used as sole means of determining pile resistance. ONLY IN SPECIAL SITUATIONS.

Pile Testing Methods

Analysis Method	Resistance Factor (ϕ) (AASHTO 2010)	Factor of Safety (FS)	Estimated			Measured		
			Capacity	Stress	Energy	Capacity	Stress	Energy
Dynamic formula	0.10 or 0.40	3.50	X					
Wave equation	0.50	2.75	X	X	X			
Dynamic testing	0.65 or 0.75	2.25	X				X	X
Static load test	0.75 to 0.80	2.00				X		

Jerry DiMaggio – Professor's
Deep Foundation Training

AASHTO (Article 10.7.3.4)



LRFD Pile Design Recap

- Requires "calibrated" resistance factors
- AASHTO's resistance factors are not for any specific setup time
- LADOTD's resistance factors are based on 14-day resistances
- AASHTO LRFD BDM has discussions on time effect but leaves out how to incorporate into design
- Need resistance factors for $t \neq 14$ days

Current DOTD Pile Testing Practice

- Test pile
  - Driven in advance of the permanent piles
  - Load tested
  - Dynamic testing is typically done as well
- Indicator pile
  - Same as test pile
  - Dynamic testing only
- Monitoring pile
  - Permanent pile with dynamic monitoring

- Dynamic test
  - Initial driving
  - Restrike at 24 hours
  - After static load test, if needed
- Static load test
  - 14 days after installation

Criteria in Selecting a Setup Model

- Match actual behavior
- Easy to use
- Conforms to or requires little change to current practices

Improvement to Original Model

Completed

- Mixed soil conditions
  - Breakup model into layers
  - Parametric study to simplify analyses
- Set-up rate factor A=f(PI, Su)

Dr. Murad Abu-Farsakh

$$R_t = R_0\left(A\,log\left(\frac{t}{t_0}\right)+1\right)$$

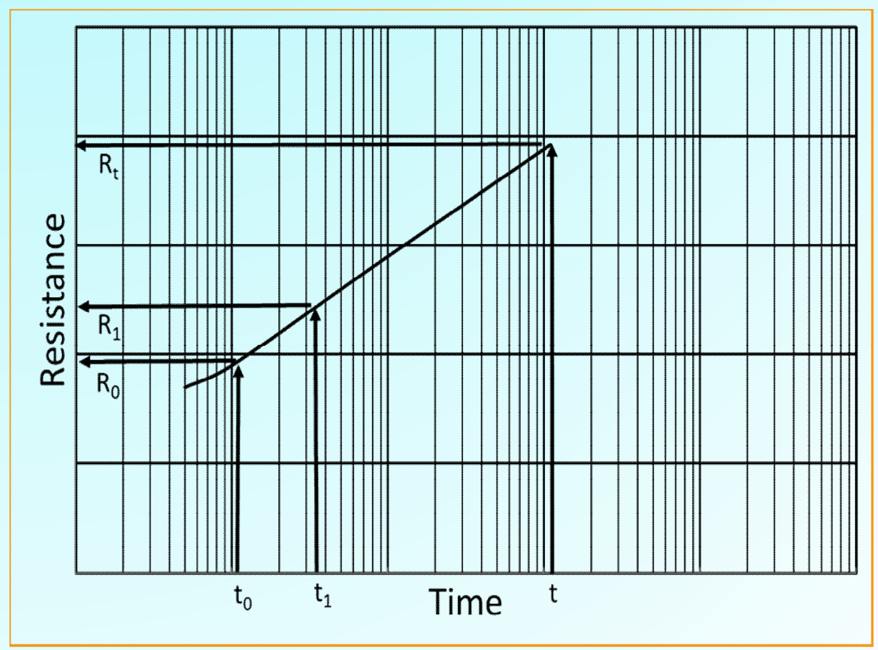
Whole pile only

A is t_0 dependent

Arbitrary t_0

Ongoing and Future

- Time effect of set-up rate factor (A)
- Verifications
- Resistance factors for pile resistance at various setup times



Case Histories

- LA-1 (Phase 1)
  - Design in 2003
  - Construction 2006-2011

- McArthur Drive (Phase 1)
  - Construction 2015-2016

LA-1 Project Summary

- 18-mile corridor in Lafourche Parish, LA
- Connects Golden Meadow, LA to Port Fourchon and LOOP oil facilities

LA-1 Project Vicinity Map

Why Do We Need It?

- Existing LA-1 is at grade & submerges during storms, is not adequate as a hurricane evacuation route
- By 2030, large portions of existing highway are expected to be inundated on a monthly basis
- Only means of evacuation for 35,000 coastal residents and offshore workers
- Phase 1 was constructed first to bring LA-1 within Golden Meadow protection levee

After Hurricane Isaac (2012)
Courtesy of LA-1 Coalition

Why Do We Need It?

LA-1 Project Alignment: Phases 1 & 2

- A new high-level bridge was needed to replace drawbridge over Bayou Lafourche
- LA-1 supports 18% of the nation's total oil and gas supply
- Per D.H.S., a 90-day closure of access to Port Fourchon could yield a $7.8-billion loss in annual GDP

Phase 1 Construction

Elevated Highway on Phase 1

- Construction began 2006, completed 2011
- 8 miles of elevated highway, connectors, and a high-level bridge
- Almost 300 borings & CPT soundings made
- 17 test piles
- 2 instrumented embankments
- About 500 production piles tested with PDA
- 100 lineal miles of piles driven

Existing Data: Soil Borings

Soil Boring & CPT Locations

Environmentally Sensitive Area

- Disturbance to the marsh had to be minimized
- Tire & tracked vehicles not allowed
- Water depth generally too shallow for boats/barges
- Only means of access was an airboat

Laying Out Borings from Airboat

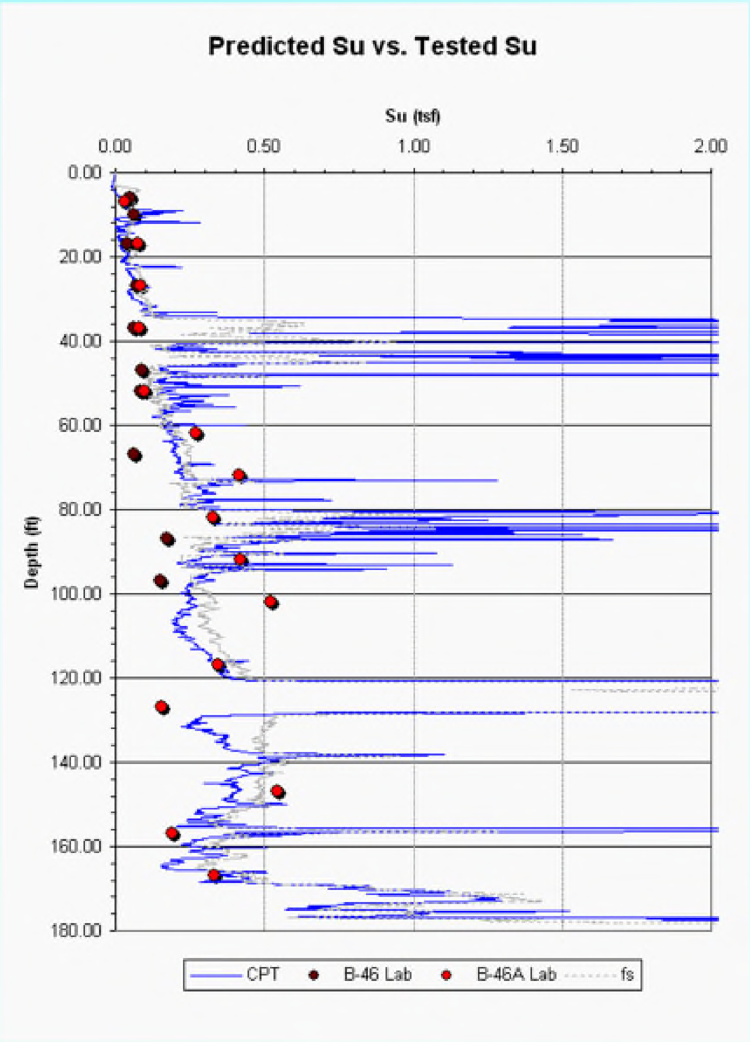
Water Depths

Drilling from Barge in Deeper Water

Drilling from Airboat in Shallow Water

Subsurface Conditions

- Delta plain deposits of the Holocene Age
- Consists mainly of normally (and under-) consolidated clays
- Surficial soils are very soft and include some peat
- Intermittent sand layers



S_u, Lab Testing vs. CPT (N_k = 15)

End-On Construction Summary

- Phase 1B/1C was constructed from barges
- No barge access for the 8-mile Phase 1A alignment
- Modified end-on construction used the new bridge as a construction platform

Looking off the Front of the Trestle

Lead Crane

Lead Crane Driving Temporary Piles

- Lead crane drove temporary pipe piles and constructed trestle
- Trestle consisted of a rail that supported the crane platforms and gantry cranes
- Pipe piles were later vibrated out and “leapfrogged” back to the front

Pile Driving Crane

- Second crane followed with permanent piles and caps
- Pile driving crane sat on a platform that could advance along the rail system

Pile Driving Crane and Hammer

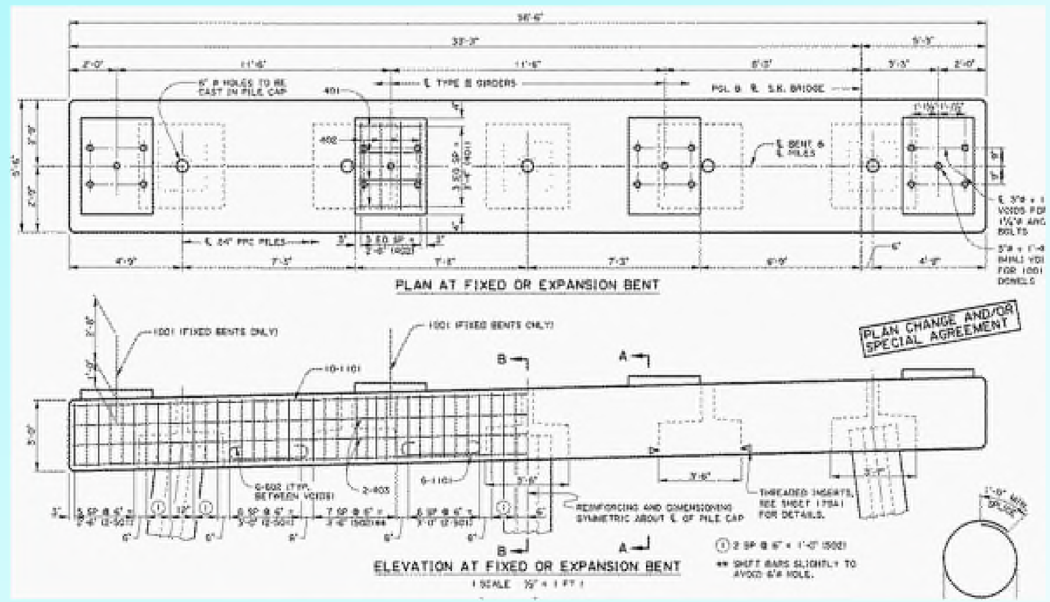
Gantry Cranes

Gantry Cranes and Rail System

- Gantry cranes moved piles and supplies to the front of the rail
- Inner and outer rail allowed the cranes to pass each other
- As deck was built, it was used to transport and stockpile supplies

Pile Driving

- Pile driving affected all of the trailing operations
- Schedule was accelerated and problems had to be solved immediately
- Precast contingency caps accepted 2 additional piles in case of damage or low capacity



Contingency Cap Design

Pile Capacity Verification

Permanent Piles Beneath Trestle

- Permanent piles supported construction loads
- Blow count could not be used for acceptance
- Pile acceptance could not delay construction
- Worked with contractor to determine the most efficient time for a PDA restrike

Test Piles

- **17 test piles tested between 2004 & 2010**
  - 24” Sq. PPC: 12 piles
  - 16” Sq. PPC: 1 pile
  - 30” Sq. PPC: 1 pile
  - 54” Cyl. : 2 piles
  - 30” Steel Pipe: 1 pile
- **About half the piles were instrumented**
- **Setup curves developed on all piles**
- **One lateral load test on instrumented pile**

Static Load Test in Progress

Test Piles

Test Pile Locations – Phase 1

Production Piles

Preparing for PDA Monitoring

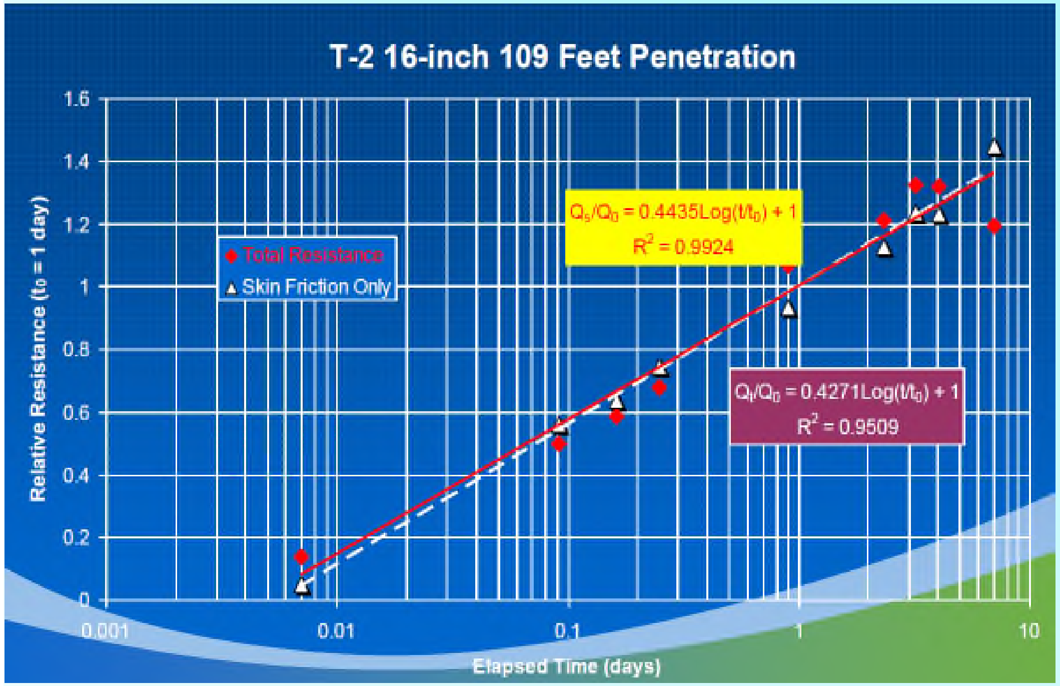
- About 500 production piles were established as “monitor piles”
- Monitor piles were monitored with PDA for initial drive and restrike (at a minimum)
- Full driving logs taken for all piles on the project

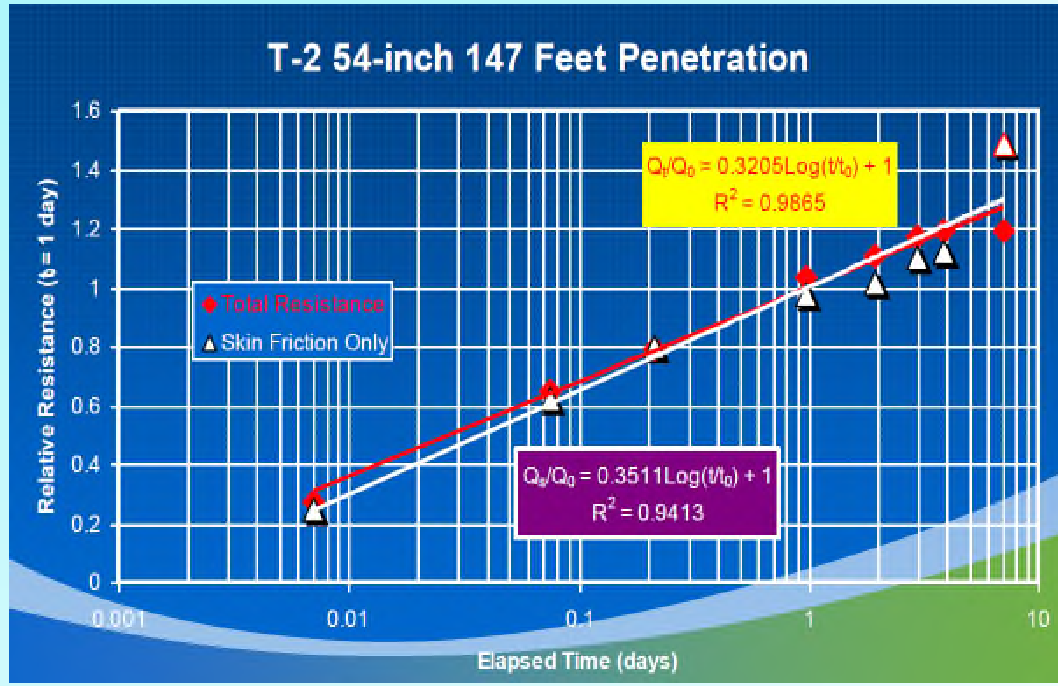
Phase 1 Verification Process

AFT's Statnamic Load Apparatus

- **Drive test pile**
  - Perform several restrikes from 15-min out to 7-day
  - Perform static or Statnamic load testing at 7 days
  - Construct a pile setup curve
- **Drive production pile**
  - Restrike at ≈24 hours
  - Perform CAPWAP
  - Compare to setup curve
  - Issue acceptance

Set-up Test Results

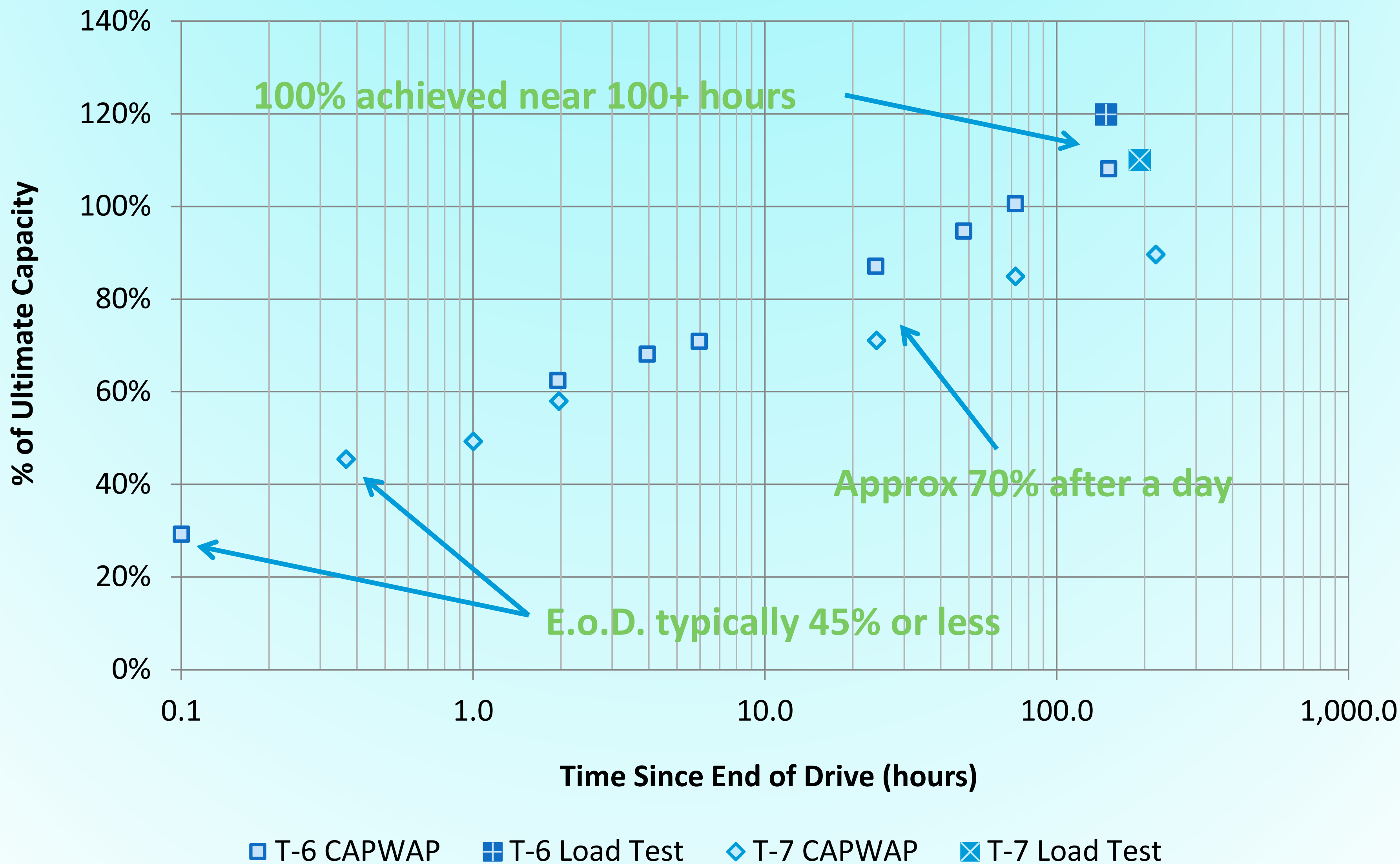




Set-up Results and Acceptance Criterion

- Setup rate 30% to 68%
- Average 45%
- 24-hr resistance > 65% of 14-day resistance or 85% of 5-day resistance
- Acceptance - 24 hrs at 65% nominal resistance

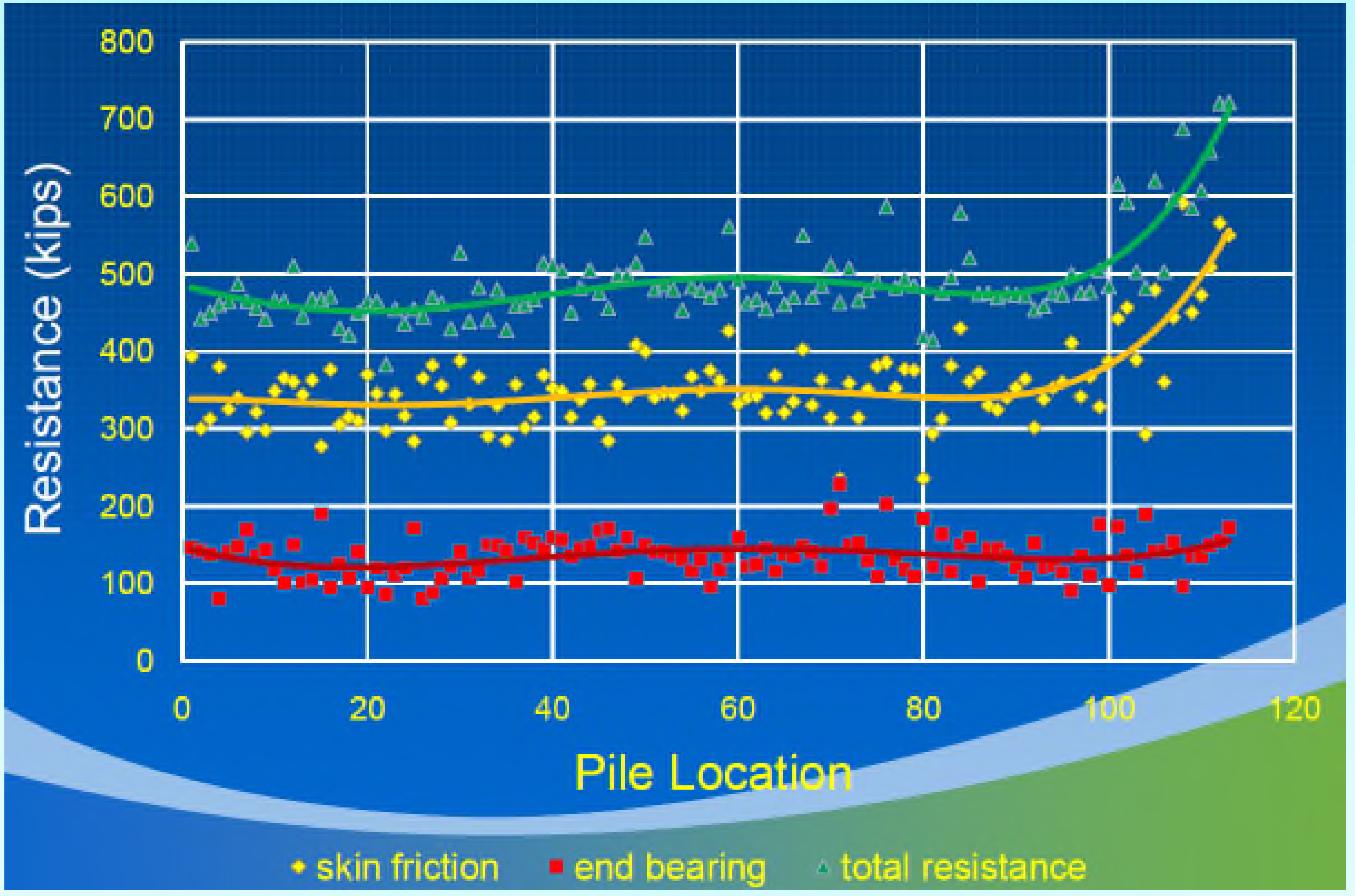
Pile Capacity Verification



Construction Testing and Actual Performance

- Test one pile per bent
  - Initial driving to check driving system
  - 1-day restrike for acceptance check
- Over 99% accepted with 1-day restrike
- Two piles were subjected to multiple restrikes
- 1-day resistance
  - Range 57% to 141% of design resistance
  - Average 74%
  - COV 13%
- Average construction rate: 1 bent/6 days

Lagniappe

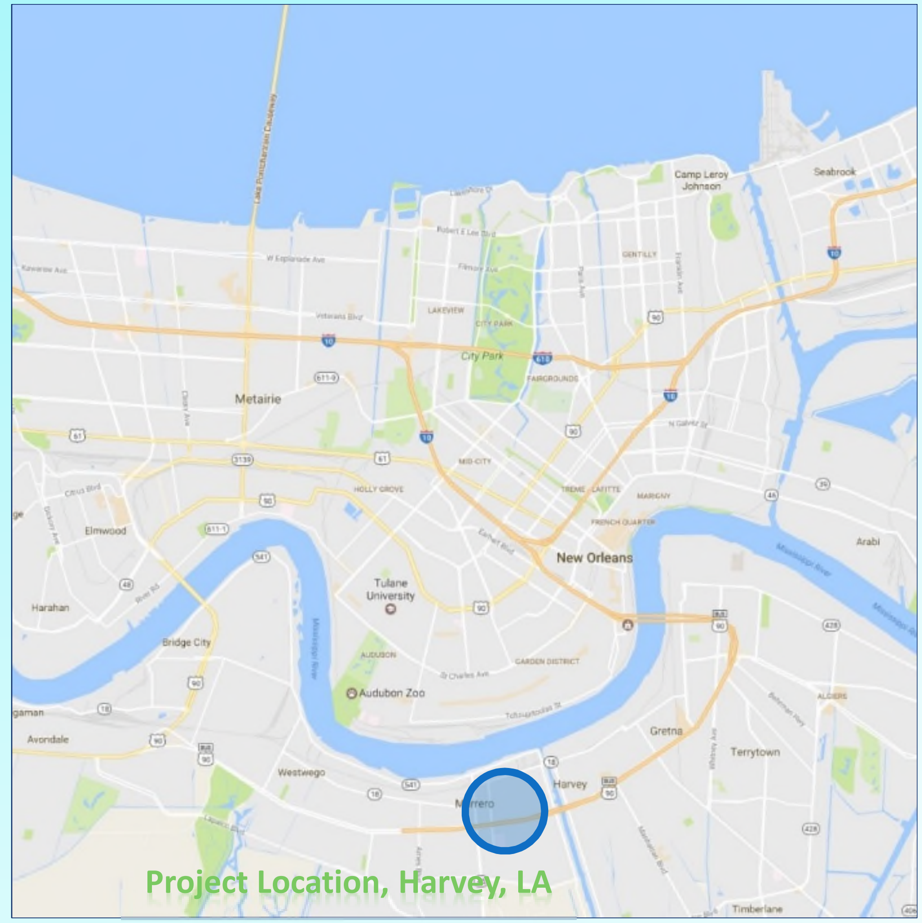


Resistance (kips)
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
Pile Location
skin friction
end bearing
total resistance

McArthur Drive Phase I

Project Overview

- Construct 2 ramps to access Westbank Express Way
- Foundations consisted of 14” PPC pile bents, 24” PPC pile bents, and HP 14x73 piers
- New piers were constructed adjacent to existing piers

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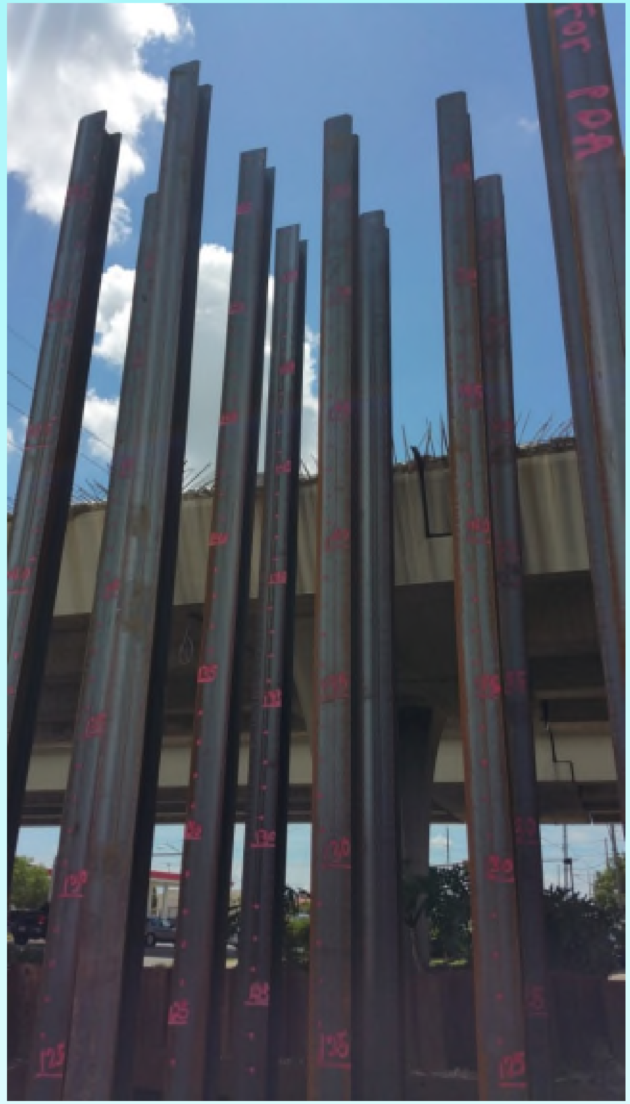
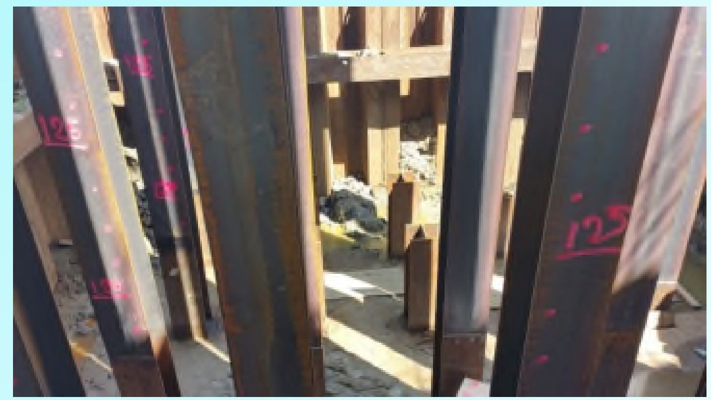
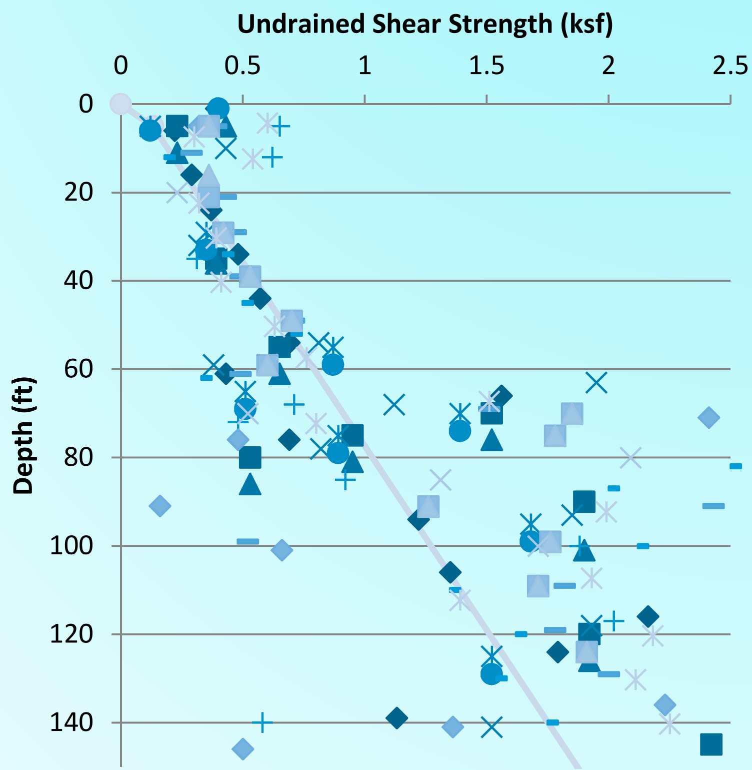




Geotechnical Overview

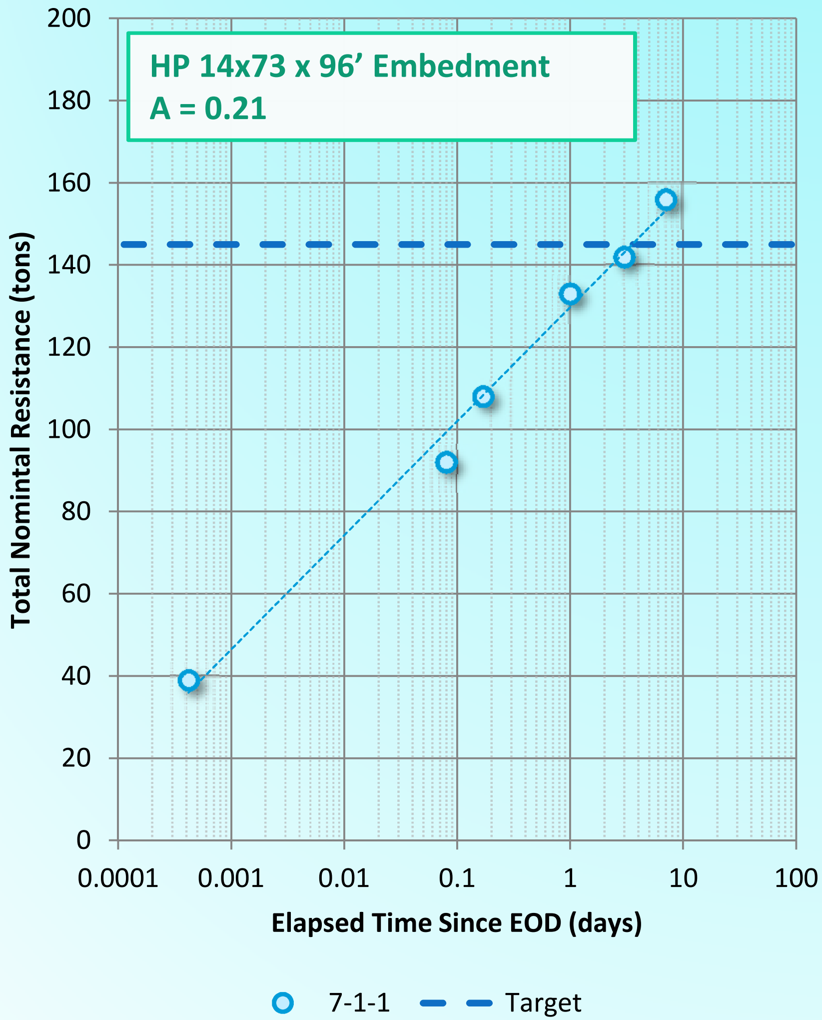


- 0 to 60’: Normally consolidated clay (Holocene)
- 60 to 80’: Clay and sand layers
- > 80’: Over-consolidated clay (Pleistocene)

Project Challenges

- Project had to be finished jointly by 3 different consultants
- High-profile/politically sensitive
- Not enough room for static load testing
- Vibration concerns
- Steel piles to minimize potential construction delays
- Pile acceptance based on dynamic testing only
- Restrikes were performed as early as possible

Pile 7-1-1



- Due to vibration levels, District requested earlier restrikes
  - 4 days > 100% required resistance
  - 1 day ≈ 90% required resistance
- We decided to attempt 1-hr restrikes

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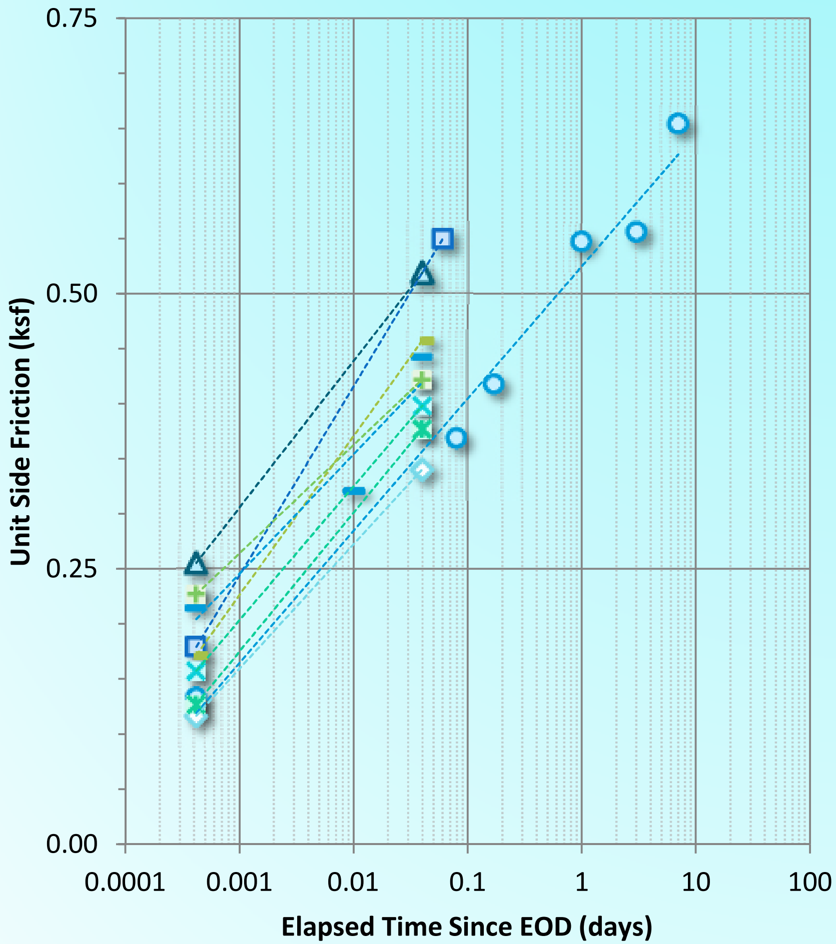
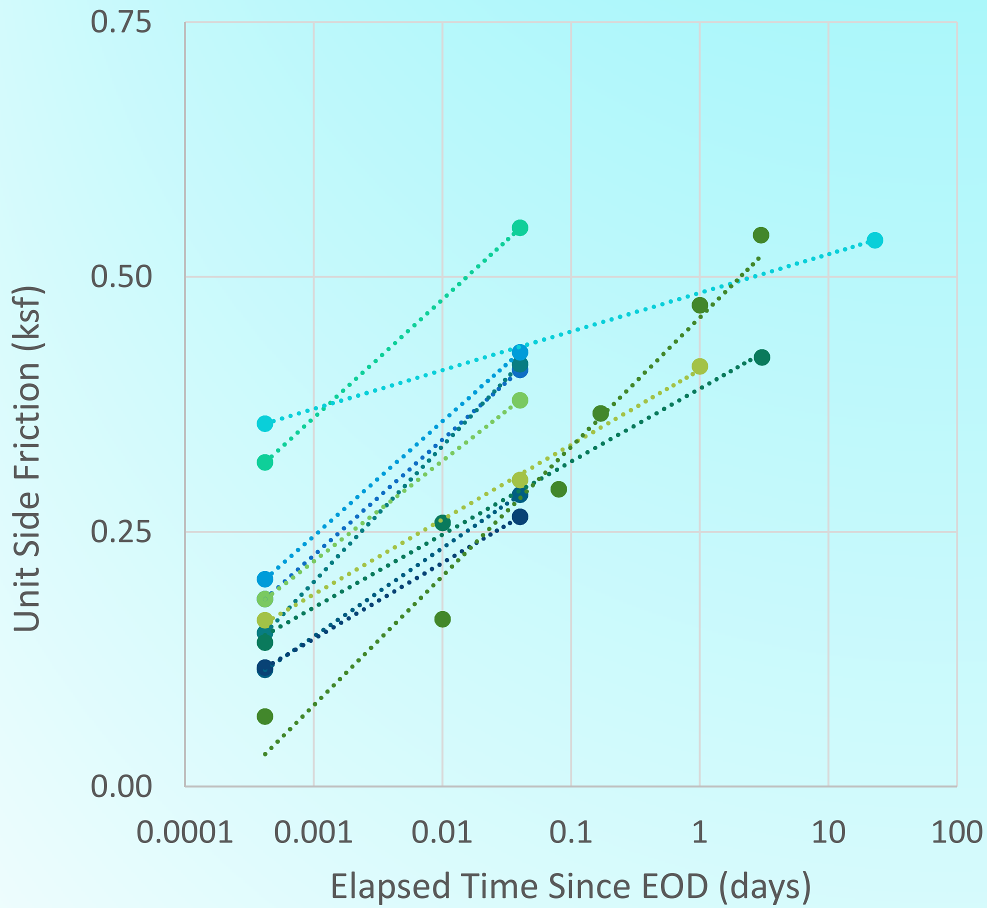
Ramp 7 – Pile Setup



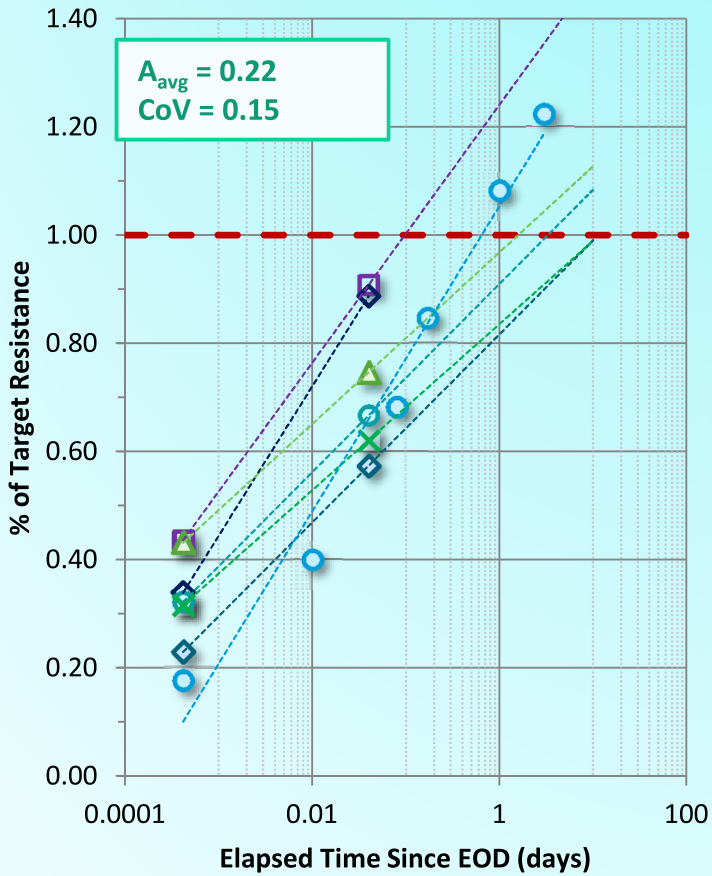
- 8 of 9 piles projected 100% of their required resistance within a day
- Rate of setup was consistent
  - Average A = 0.21
  - CoV = 0.09

Ramp 8 – Pile Setup

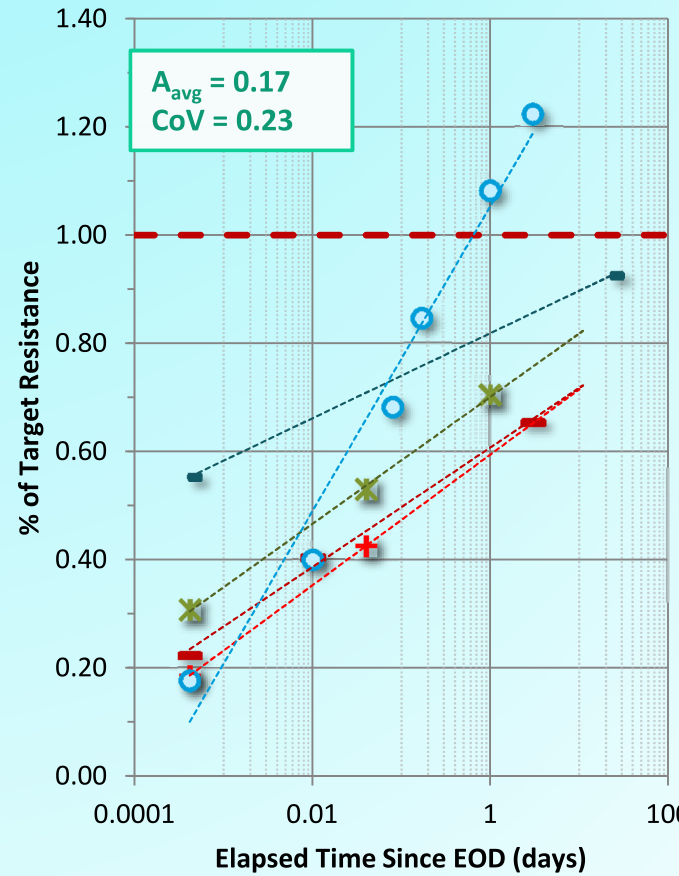


- Pile 8-17-1 driven first
  - 1 day ≈ 100% required resistance
  - A = 0.28
- Rate of setup less consistent than Ramp 7
  - Average A = 0.19
  - CoV = 0.21

Ramp 8 – Pile Setup



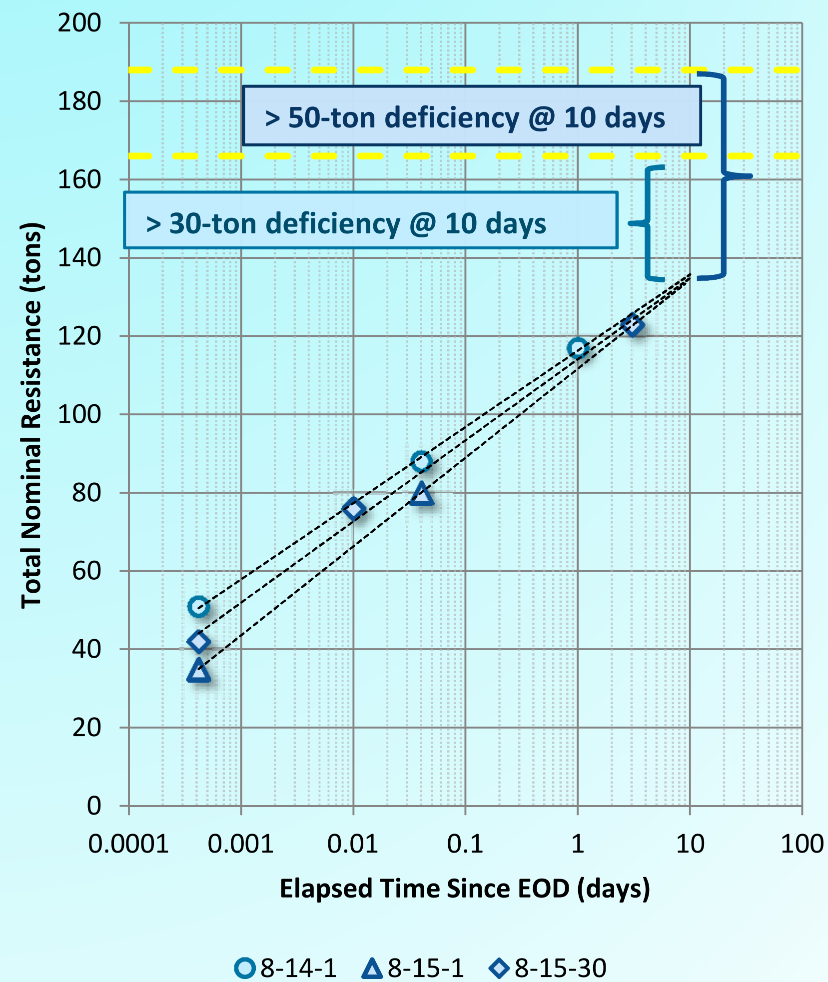
Piers
8-6
8-8
8-10
8-11
8-12
8-13



Piers
8-14
8-15

Piers 8-14 and 8-15

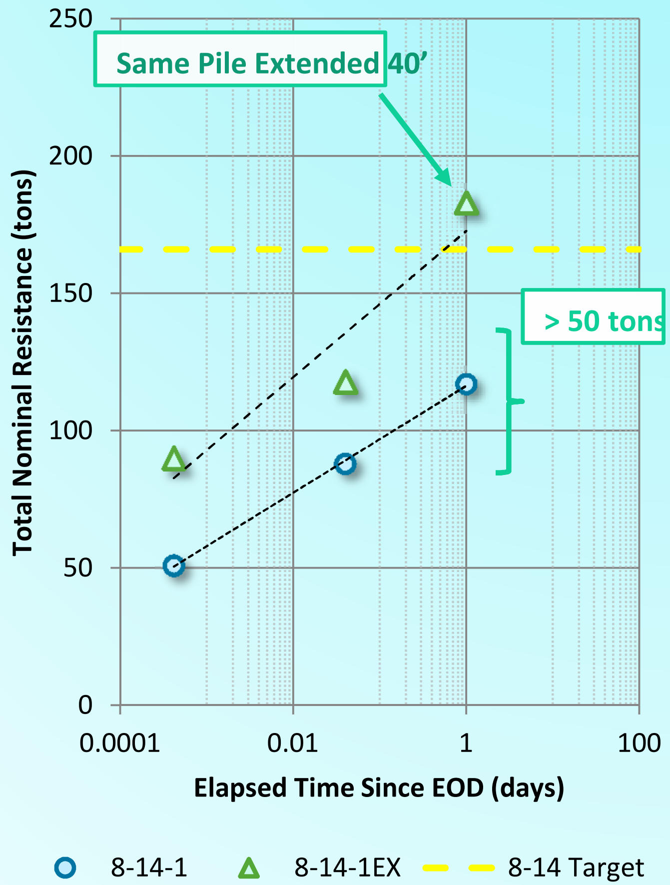
- Pier 8-14
  - 20 x HP14x73 piles
  - 118’ long
  - 166-ton req. resistance
- Pier 8-15
  - 30 x HP14x73 piles
  - 124’ long
  - 188-ton req. resistance

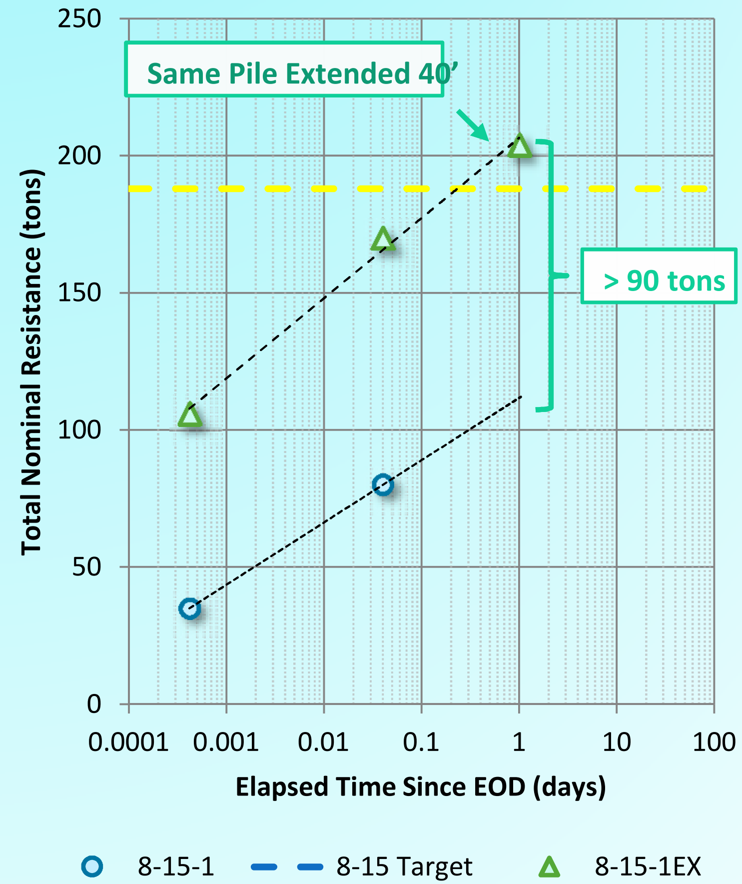


Deficient Piles

- Pile resistance only projected out to 10 days
  - Another log cycle could put us into column construction
- Considered pile driving logs, soil borings, & NDT
- Structural consultant was provided with estimated resistance deficiency and resistance distribution from CAPWAP
  - 40’ extensions were added to the piles in 8-14 and 8-15

Extend Piles 40 feet





More Work Needed

- Design
  - Resistance factors for projected resistance
  - Max set up time?
  - Impact of changing reference time from 1 day to 14 days
- Construction
  - Can we use initial drive to project resistance? How about 10, 15, 30 min restrikes?
  - Can we shorten the wait time to perform load test?
  - What is the shortest acceptable wait time for restrike(s)?

Comments?

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