Malcolm Drilling Company Inc.

Seismic Retrofit of an Underground Reservoir

San Francisco, CA

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Malcolm Drilling Company

OBJECTIVES

- Case history of micropile installation for seismic retrofit
  - 542 DCP Threadbar piles – 1335 kN design loads Tension & Comp
  - Owner designed Plans & Specifications – LOW BID AWARD
- Highlight solutions used to create drilling and testing access
- Detail the unusual load testing requirements and criteria
  - Anchor Type Testing – 100% on micropiles
  - Creep and apparent free length, not total deflection criteria
  - Present data from various soil profiles across site

MICROPILES FOR SEISMIC RETROFIT – NORTHERN CALIFORNIA

- Severe Seismic Risk in San Francisco Area
  - Hayward 21 km, M_w 7.3, 30 yr probability 27%
  - San Andreas 8 km, M_w 7.9, 30 yr probability 21%
- High Load Capacity – 1000 to 2500 kN (225 - 560 kip)
- Require equivalent tension AND compression capacity
- Life Safety & Serviceability considerations in seismic event
- Nominal Dead + Live Loading = self weight of upgrades
- Active geology – soft ground and extremely variable
- Upgrade existing structures - limited access work

BACKGROUND

University Mound North Basin Reservoir

- Located in San Francisco, CA
- Original construction in 1885, 1924 embankment raised, 1962 roof and concrete lining added
- Capacity = 200,000 M^3
- Dimensions 230 M north-south & 170 M east-west
- Reservoir sides 6.6 M high at 3:1 slope
- Provides offline water storage for emergency situations
- Part of the Hetch Hetchy Water Supply System
  - Water from Sierra Nevada Mountains to San Francisco (over 320 KM)
  - Crosses 3 major active faults (Calaveras, Hayward, and San Andreas Faults)

BACKGROUND

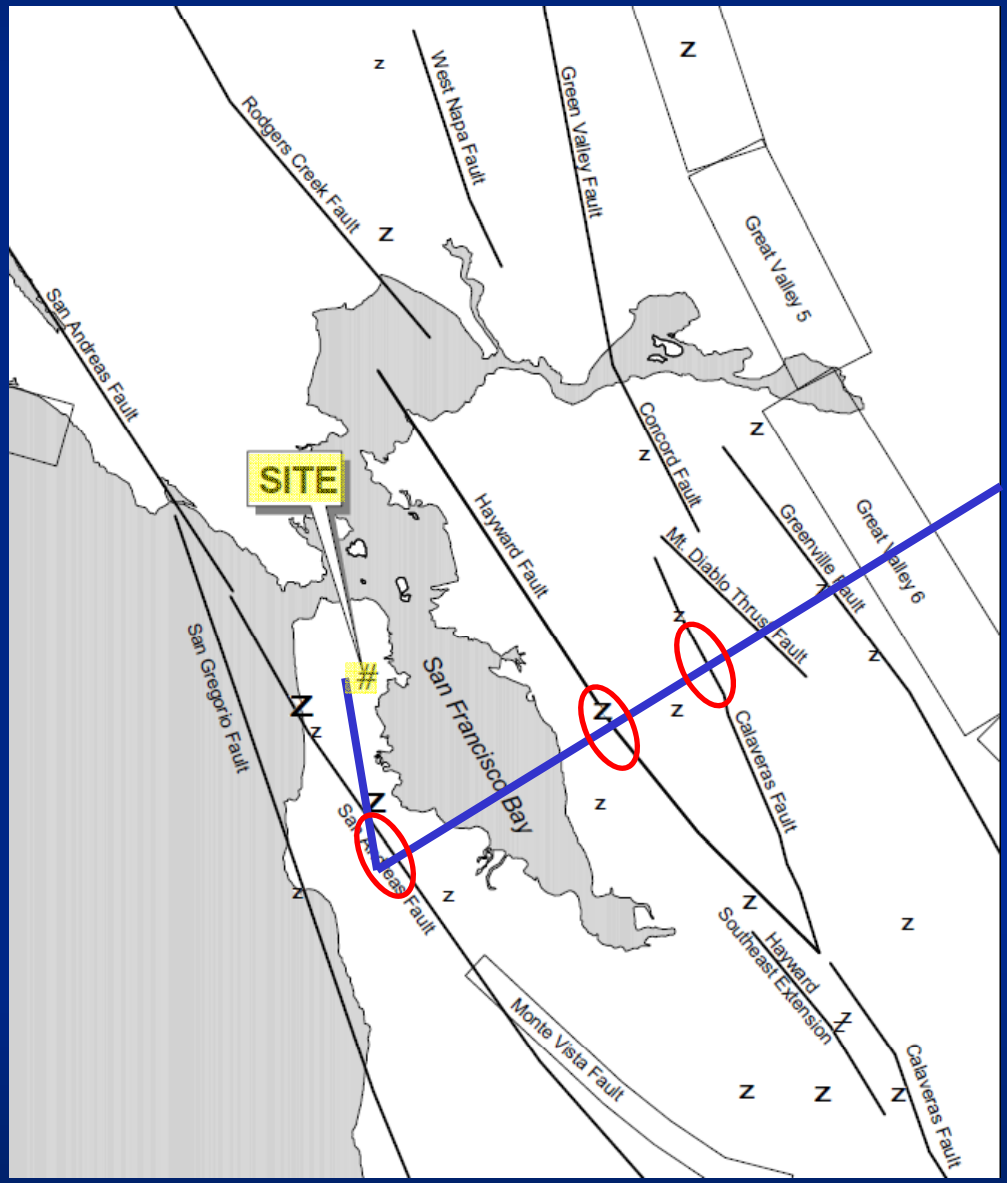
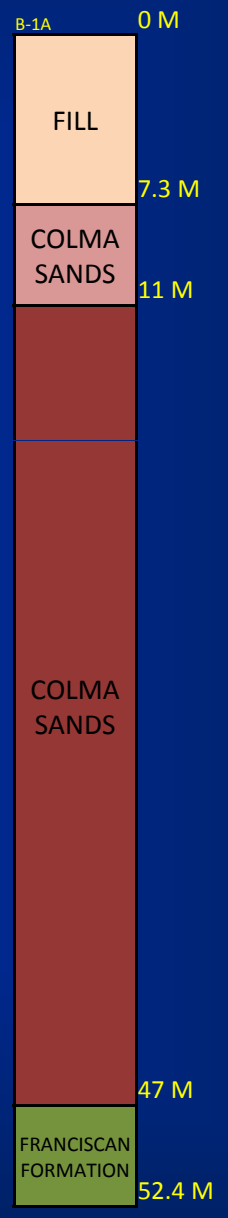


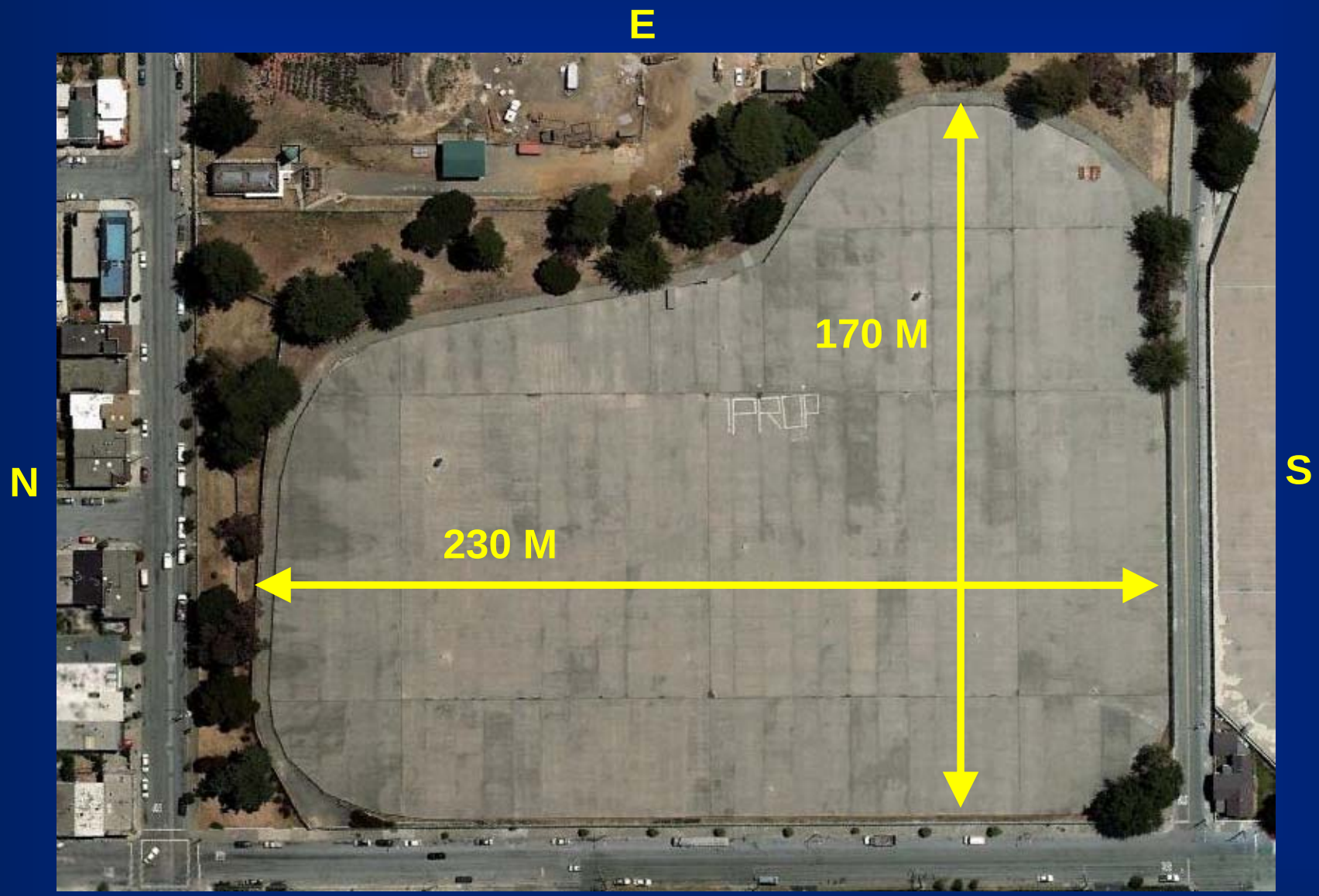
Figure sited from Treadwell & Rollo Geotechnical Investigation, 2007

SUBSURFACE CONDITIONS

- Fill, overlying native clayey and silty sand, overlying bedrock
- Varies across large jobsite – sample boring NE Corner
- Embankment fills up to 7.3 M
- Colma Formation – clayey to silty sand
  - Medium dense upper zone – SPT 'N' value = 15 to 25 [up to 3.7 M thick]
  - Dense to very dense lower zone – SPT 'N' value > 50 [up to 36 M thick]
- Franciscan Formation – bedrock
  - Tectonic melange : sandstone and shale with mafic volcanic rocks and occurrences of serpentinite
  - Basalt: Intensely to closely fractured, moderate to deeply weathered, and weak to moderately hard.
  - SPT 'N' values = 64 to 148



SITE LAYOUT



RETROFIT SCHEME

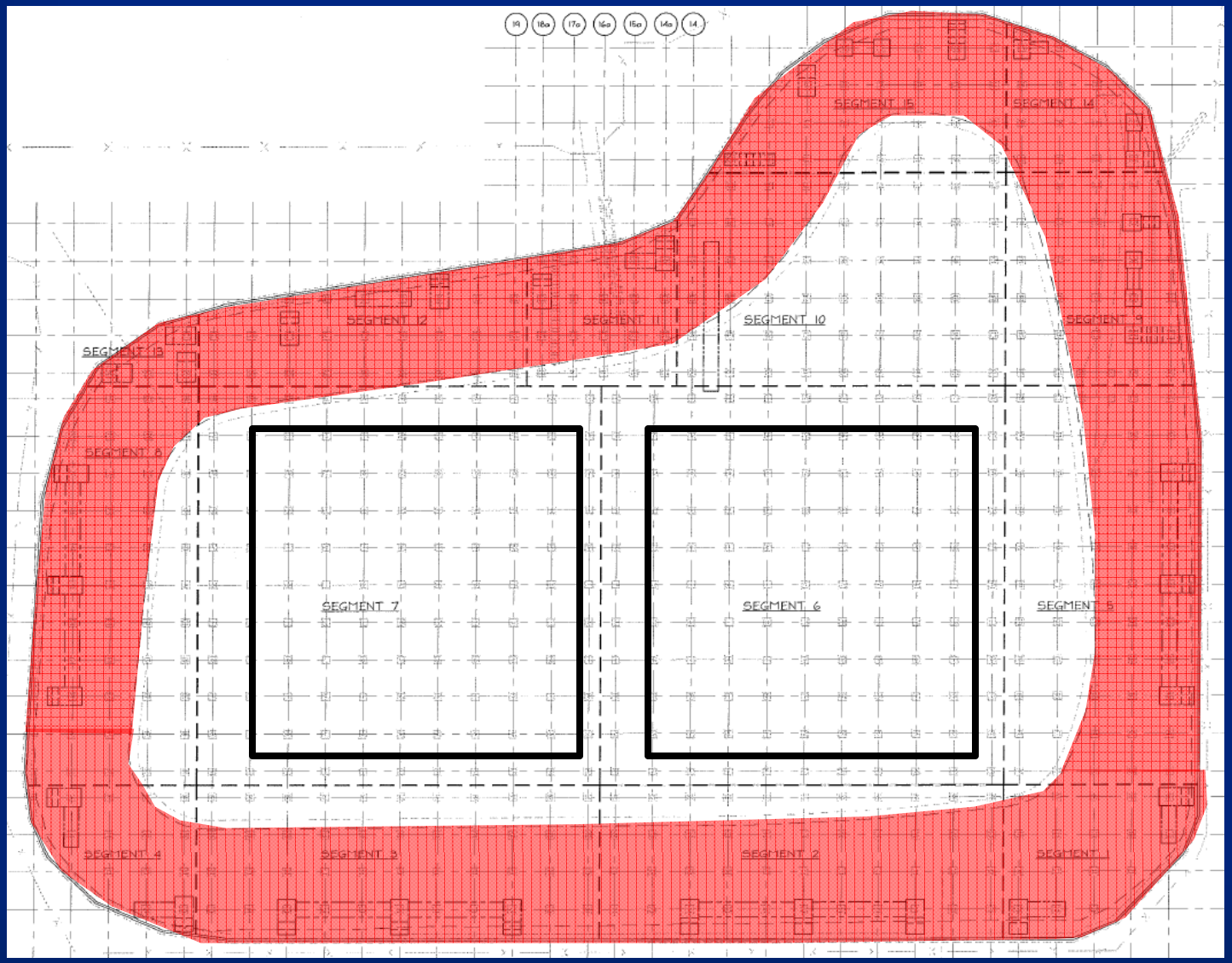
- Primary concern during seismic event was structural:
  - Reservoir Roof and Supporting columns
- Embankment fills evaluated but ground improvement not required.

RETROFIT SCHEME

Structural Upgrade

- 2 EA central 60 M square stainless steel braced frames
  - Founded on grade beams
- Floor to ceiling concrete shear walls connecting existing columns on the reservoir side slopes
  - Founded on 47 pile caps – total 542 micropiles
  - Design seismic load = 1335 KN (tension & compression)
  - Reinforced by 57 mm diameter, Gr150 threadbar only
  - Minimum 3 M unbonded length
  - No load transfer allowed in fill material (NE corner)
  - Bond length designed by contractor [9 M minimum]

RETROFIT SCHEME



RETROFIT SCHEME

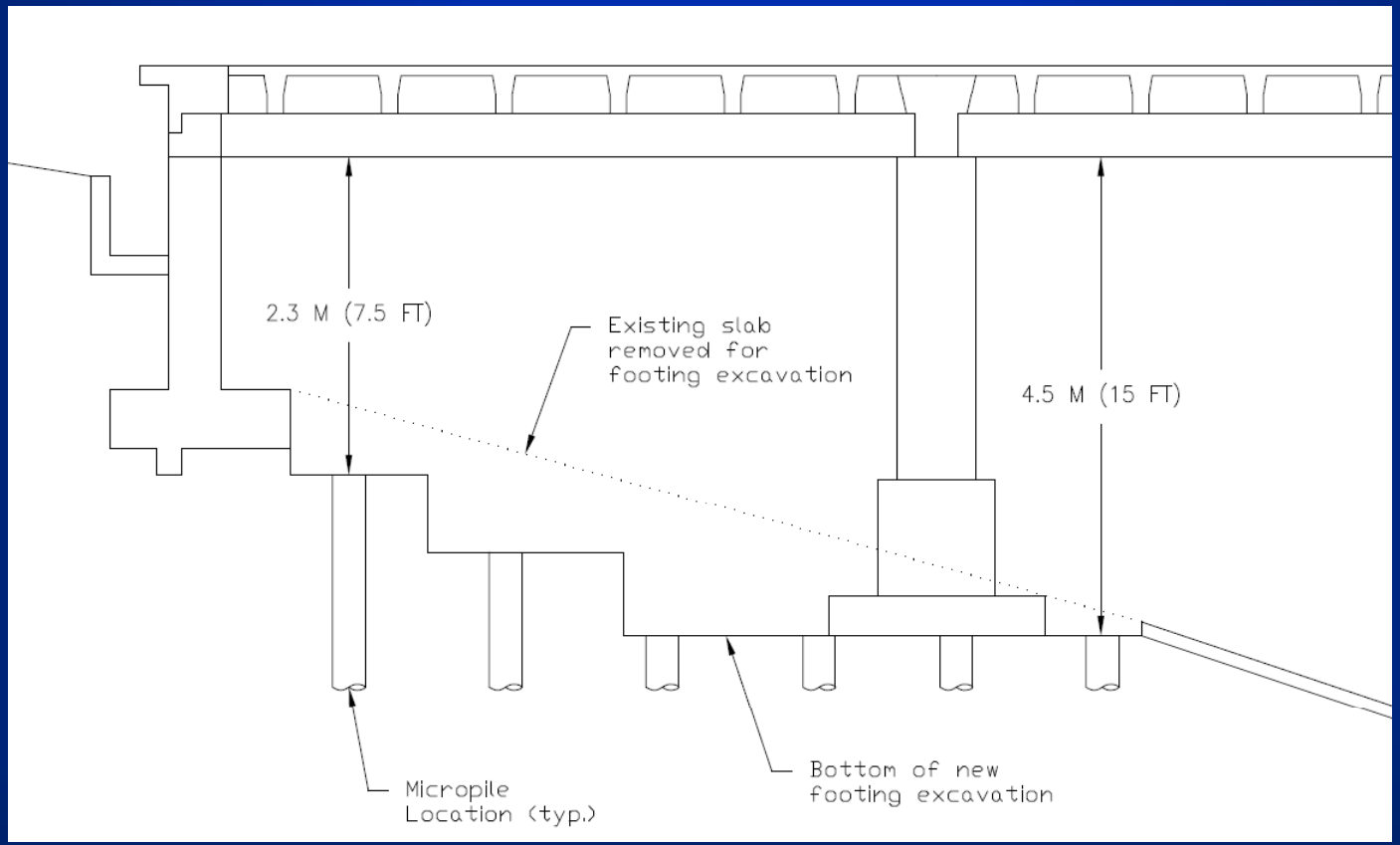
Pile Cluster at Columns, Stepped Pile Cap matches slope

RETROFIT SCHEME

Typical stepped pile cap layout.

Each Pile independently evaluated for:

Headroom, Overburden Thickness, Bearing Strata Type



RETROFIT SCHEME

Contractor design

- Bond lengths
  - 9 M – Franciscan formation
  - 12 M – Colma sands
- Unbonded lengths
  - 3 M – dense native soils
  - 5 M – embankment fills
- Developed detailed schedules to minimize pile lengths

MICROPILE CONSTRUCTION

Key Challenges

- Low overhead clearances (range from 2.3 M to 8.5 M)

MICROPILE CONSTRUCTION

Key Challenges

- Pile caps located on a 3:1 slope (18°)

MICROPILE CONSTRUCTION

Key Challenges

- Fabricated adjustable drilling platforms

SAFE WORKING CONDITIONS

LOAD TESTING

Specifications required:

- **100% testing of all installed micropiles**
- **Tension test to 1780 KN**
- **No load into existing columns and footings**
- **5% performance tested**
- **1 extended creep test**

LOAD TESTING

Specifications required:

- **Procedures specified under Federal Highway Administration (FHWA-IF-99-015 GEC No. 4 Ground Anchors, 1999)**

- **Apparent Free Length (L_a) = length of micropile reinforcing that is, based on elastic movements at the test load, not bonding to surrounding grout or ground.**

- **Acceptance Criteria**
  - **L_a exceeds Jacking Length + 80% Design Unbonded Length**
  - **L_a is less than Jacking Length + Unbonded Length + 50% Bond Length**
  - **Creep at 1780 KN (400 kips) < 2 mm (0.08”) per log cycle**

LOAD TESTING

Multiple setup configurations – 100% of piles tested

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LOAD TESTING

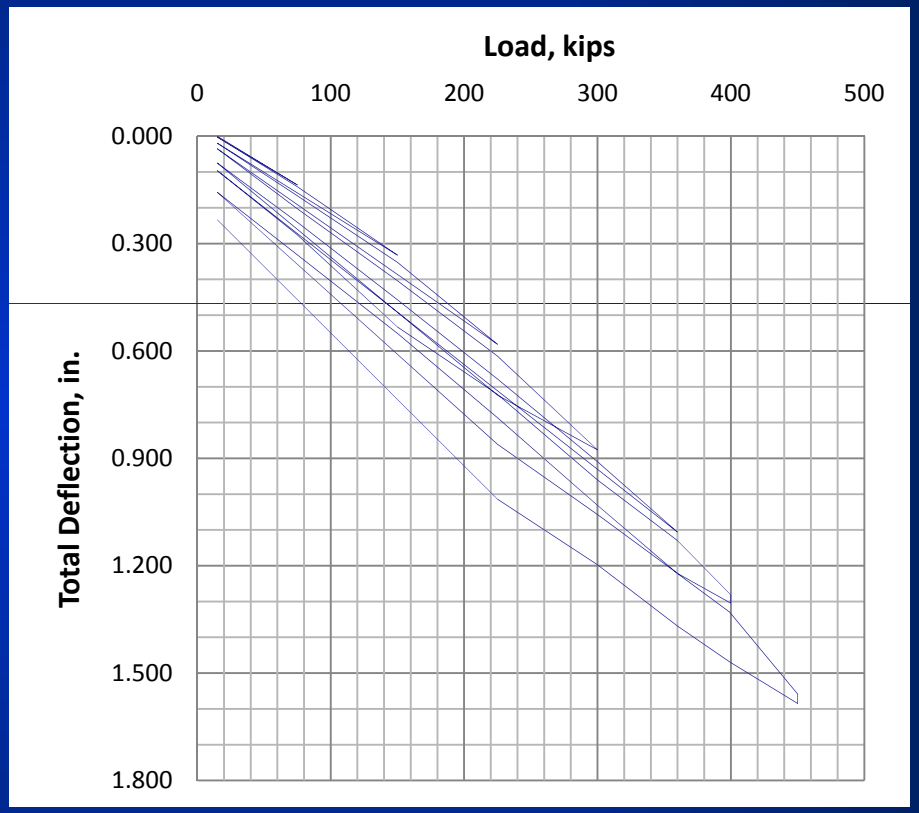
Pre-Production Performance Test

- Installed at contractor's option
- Only 1 location available
- Confirm selected drilling methods
- Verified assumed geotechnical load transfer

LOAD TESTING

Pre-Production Performance Test

- Bond Length = 12 M
- Unbonded Length = 4.5 M
- Jacking Length = 2.3 M
- 5.9M < L_a (spec) < 12.9 M

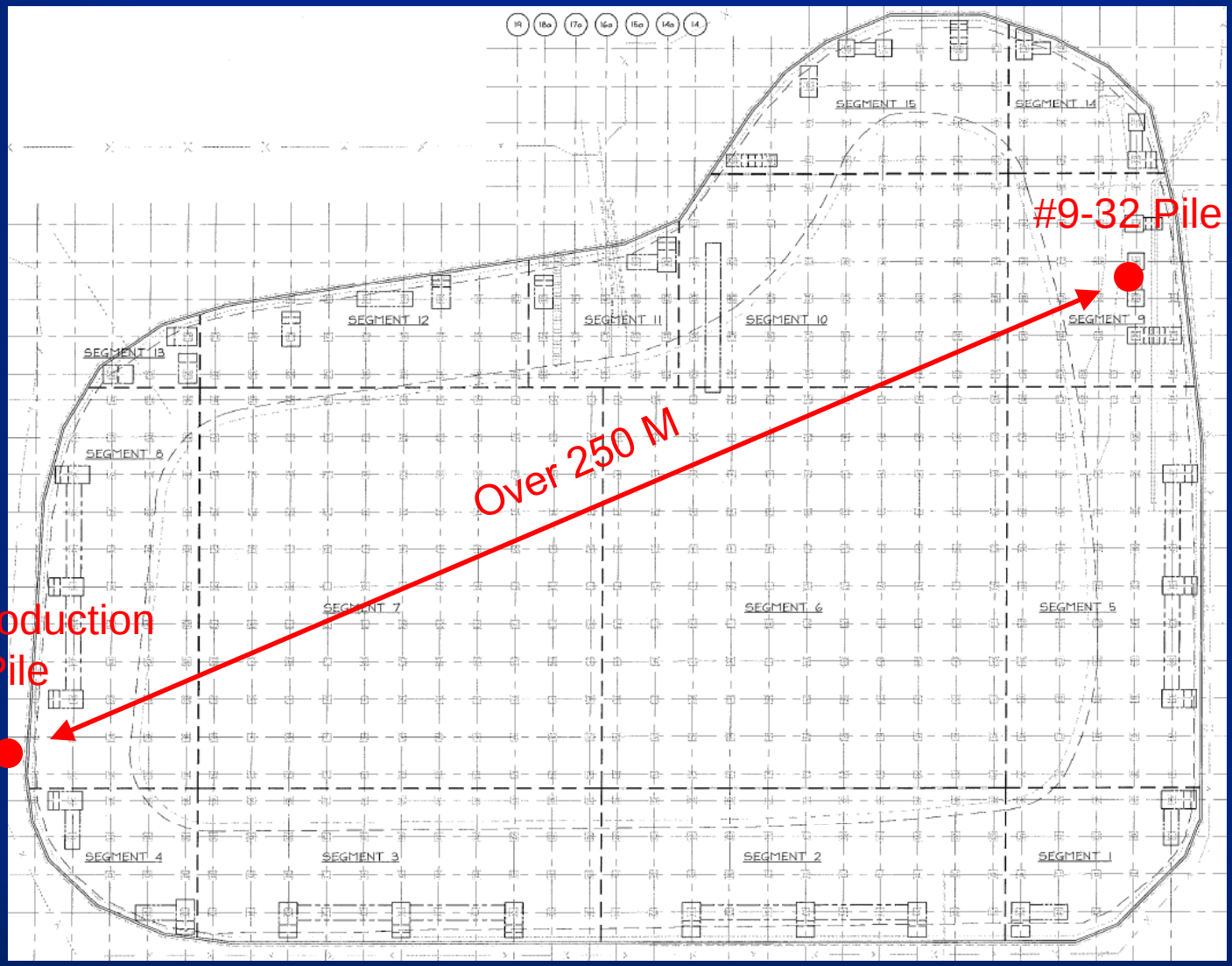


Results

- L_a = 8.4 M at 1780 kN
- L_a = 8.8 M at 2000 kN
- Max creep = 0.6 mm at 10 min hold

LOAD TESTING

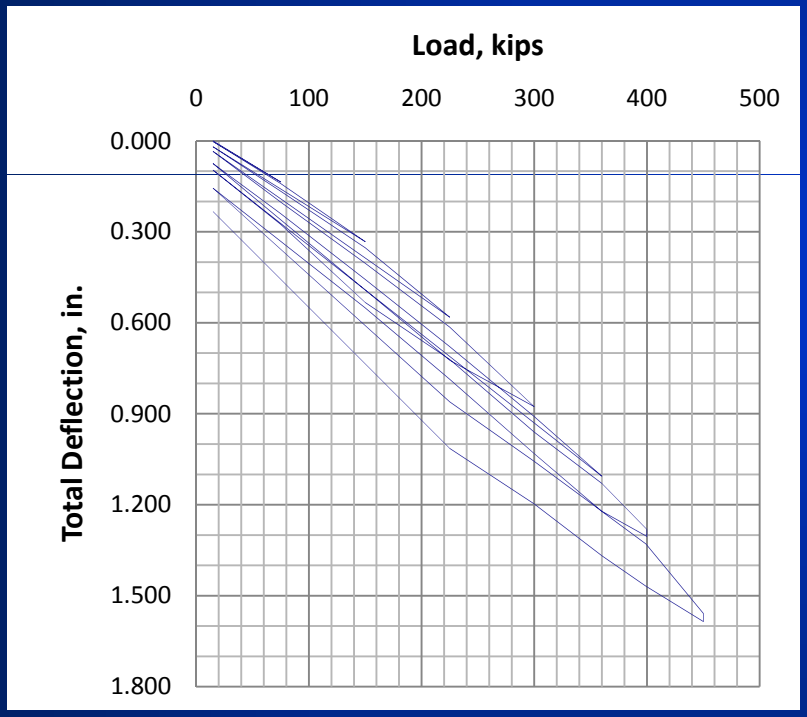
Correlation of Pre-Production to Production Performance Tests



LOAD TESTING

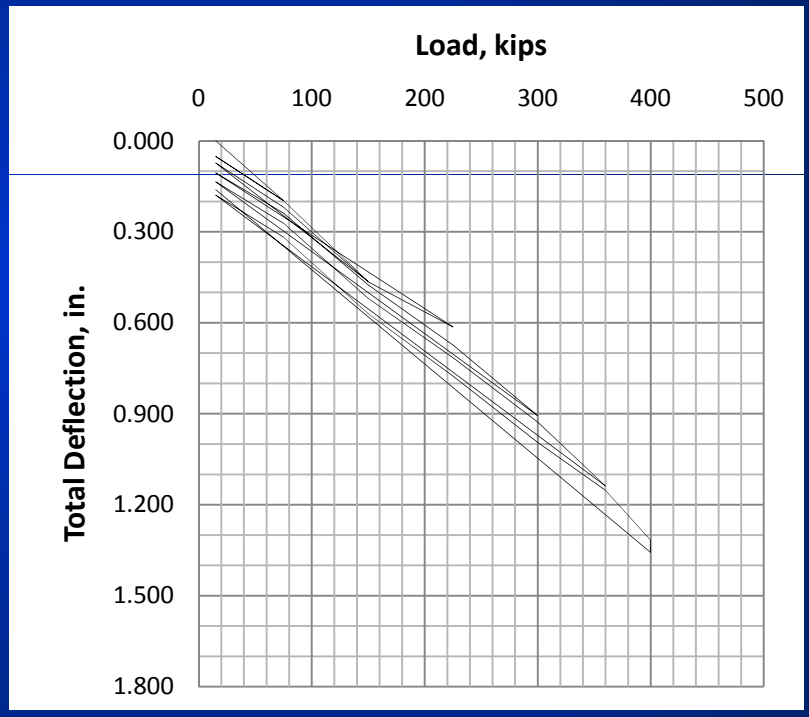
Pre-Production Pile

- Colma sands



#9-32 Pile

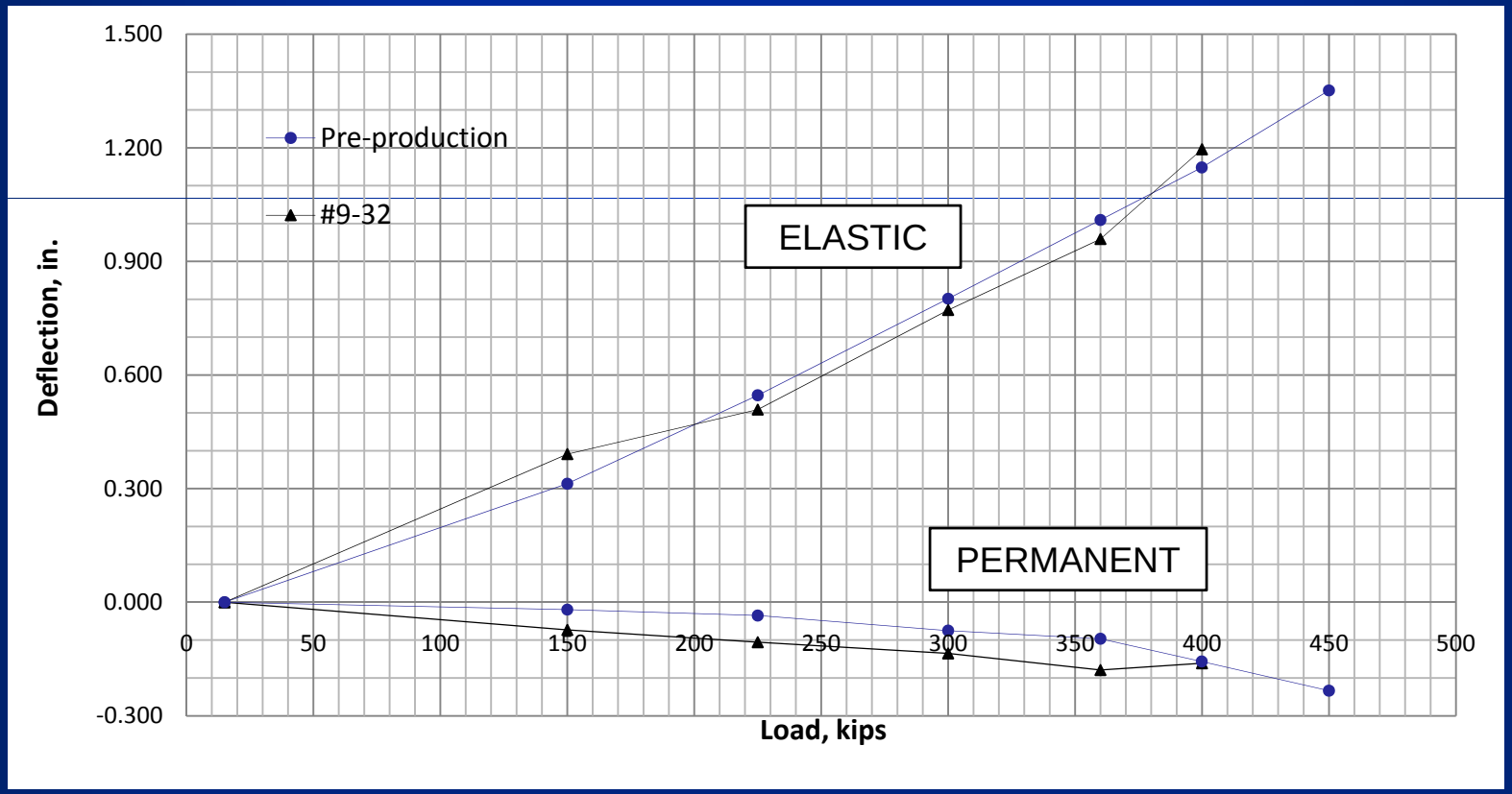
- Franciscan rock



- Similar pile performance behavior
- Elastic behavior

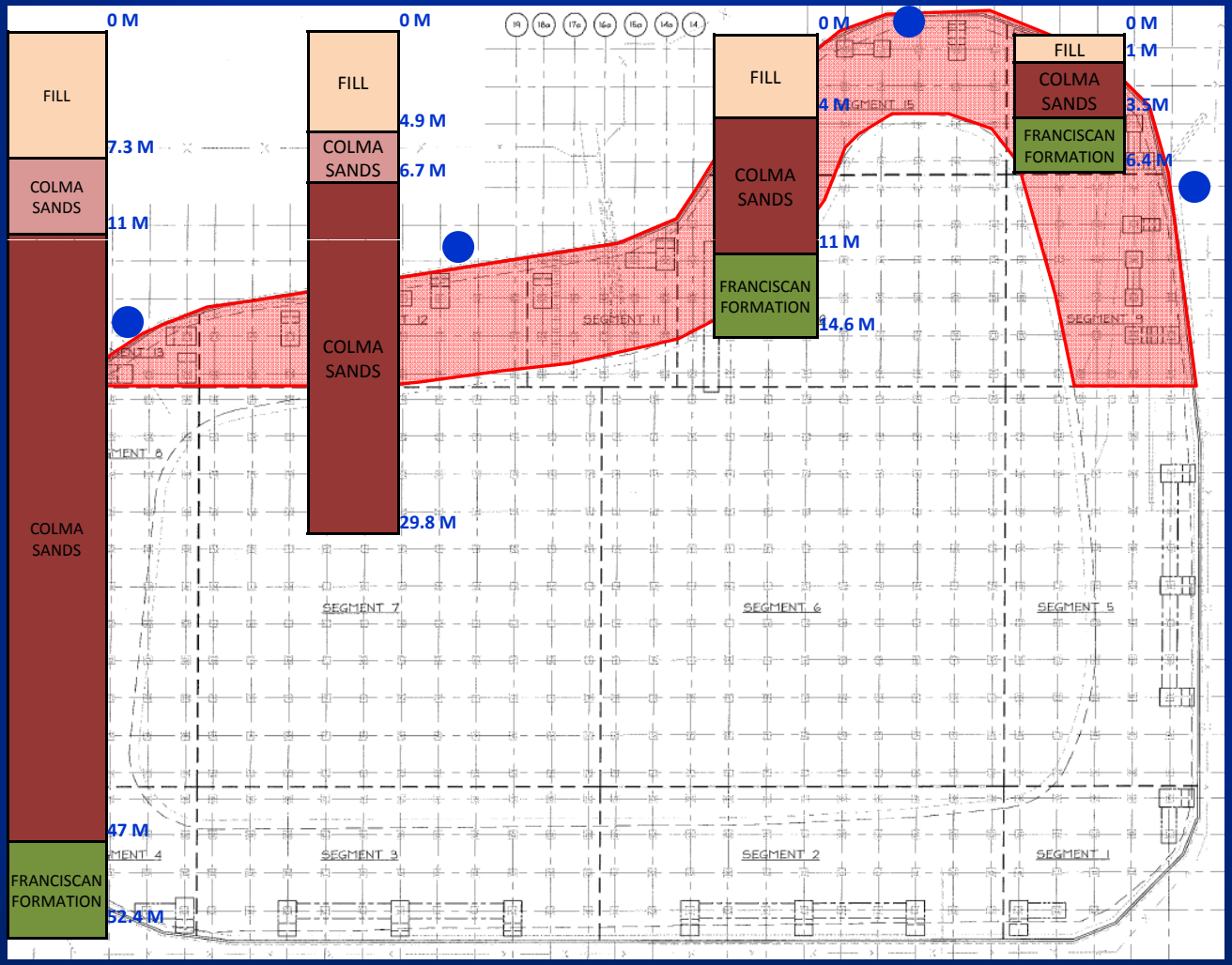
LOAD TESTING

Correlation of Pre-Production to Production Performance Tests



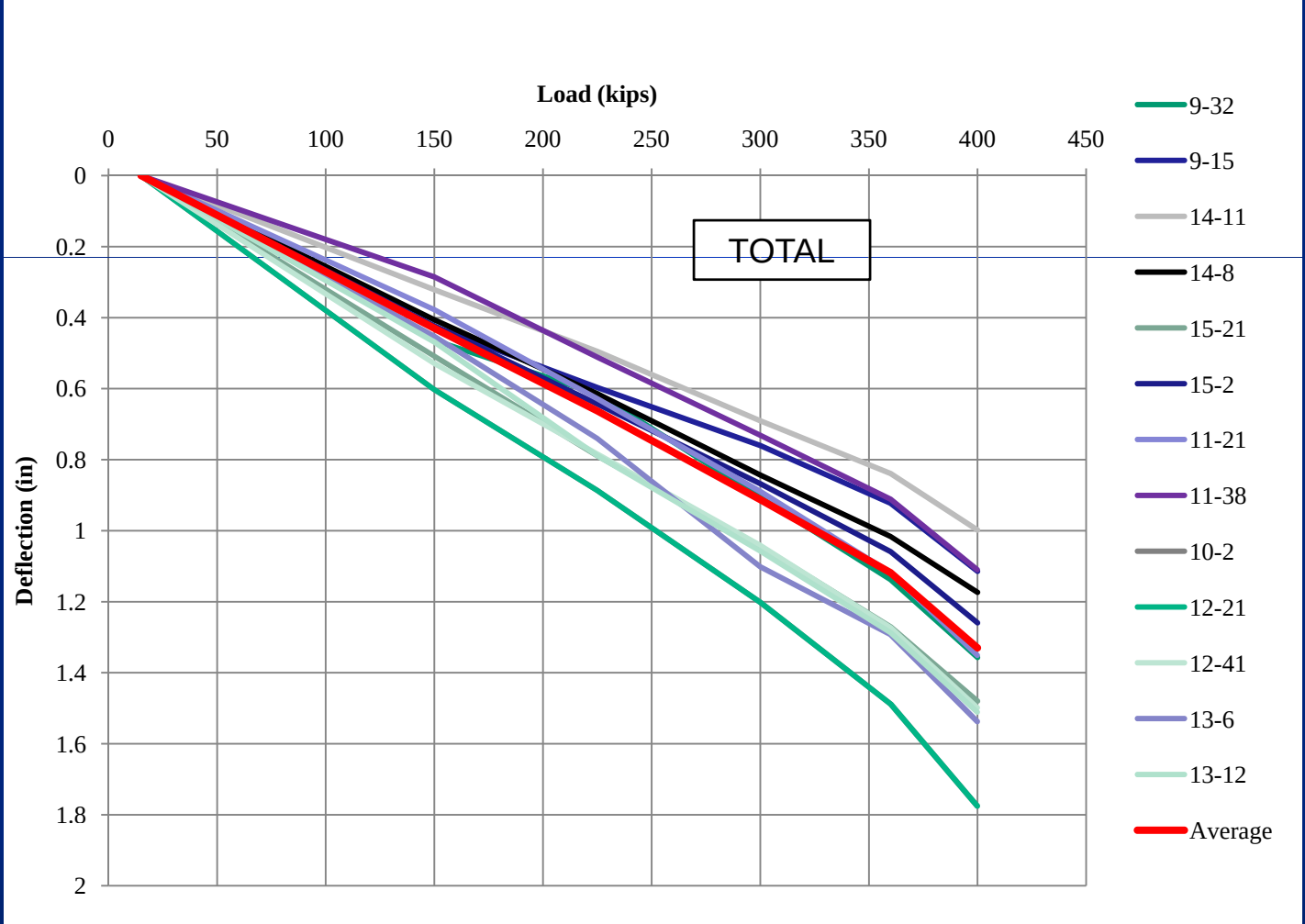
PERFORMANCE TESTING

Analyzed East Wall - Segments 9 - 15



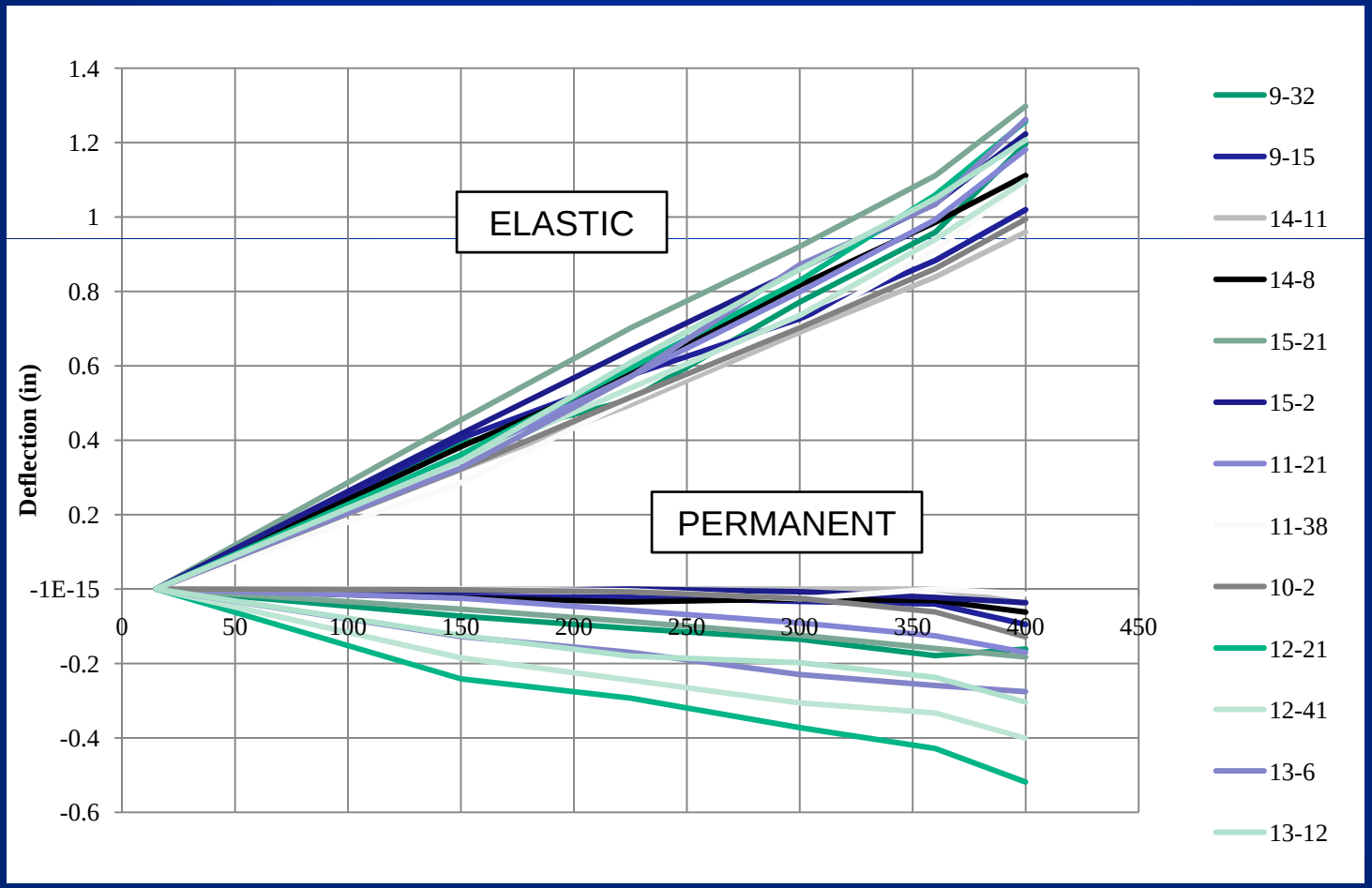
PERFORMANCE TESTING

Total Deflection



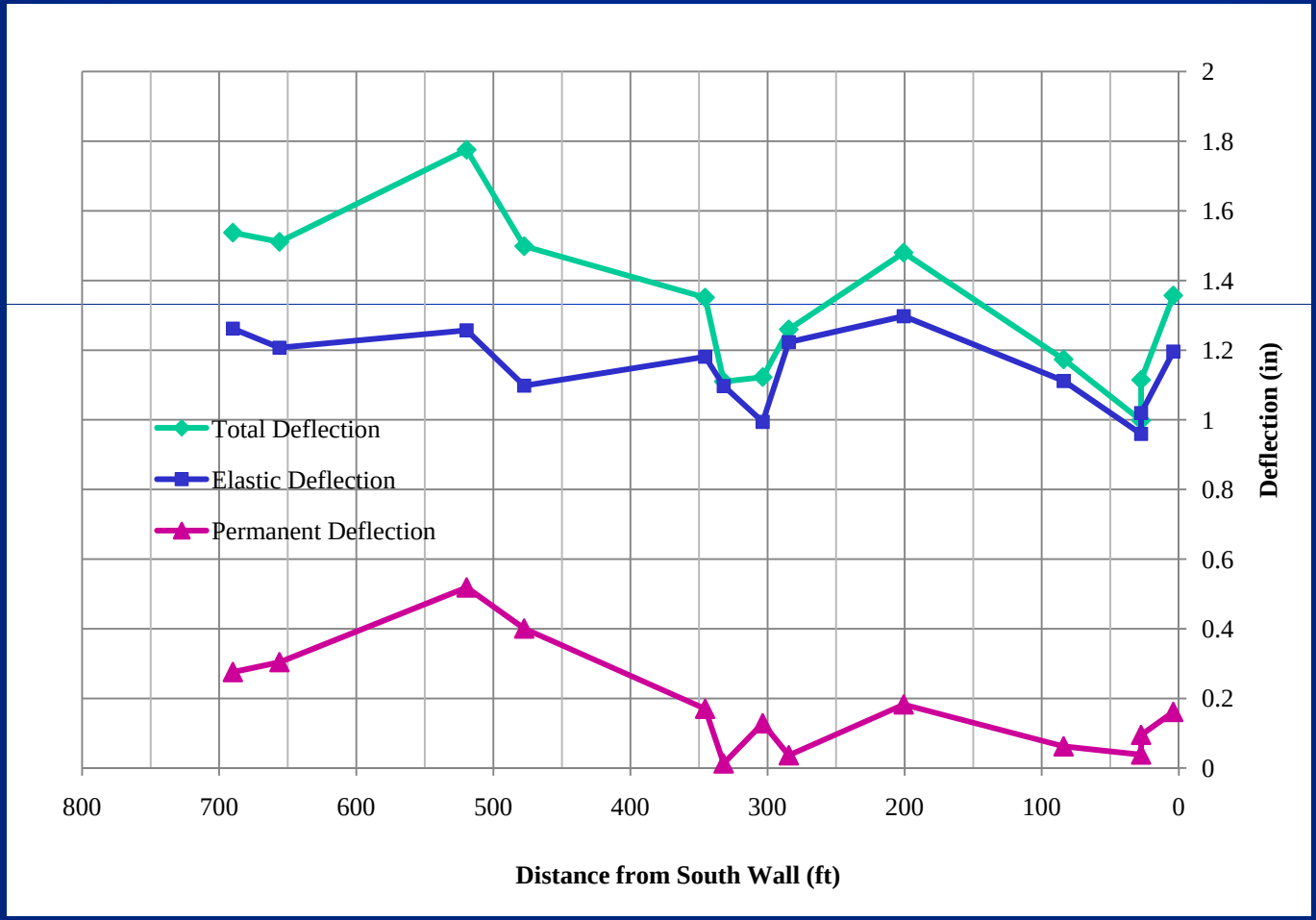
PERFORMANCE TESTING

Elastic vs. Permanent



PERFORMANCE TESTING

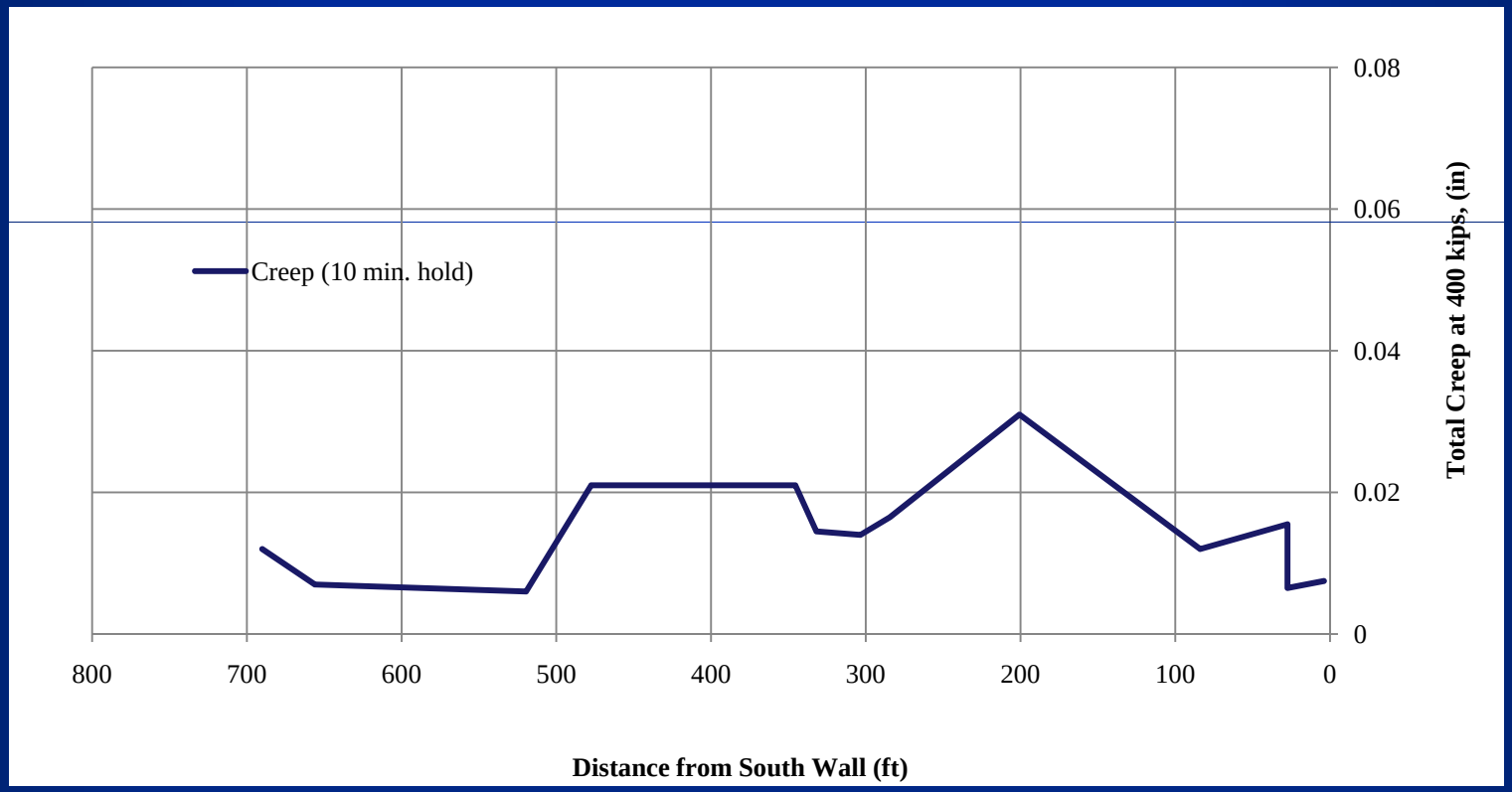
Distance from South Wall



Colma Sands ⟷ Franciscan Formation

PERFORMANCE TESTING

Creep at 400 kips



Colma Sands ⟷ Franciscan Formation

PERFORMANCE TESTING

Results of Analysis

- Total deflection increases south to north
- Relatively uniform elastic elongation of piles
- Greater permanent set in piles at north end (zone +/- 500ft)
- More deflection to mobilize bond in Colma vs. Franciscan

- Excellent load transfer in both Colma and Franciscan
- Low creep even at maximum test load – 1780 kN
- Piles did not appear to approach geotechnical failure

SUMMARY

Conclusions:

- 542 piles installed for seismic retrofit of Reservoir
- All piles tested and verified load capacity
- Access challenges for drilling and testing work
- Project completed on budget and ahead of schedule
- Excellent geotechnical load transfer throughout site
- “Conservative” bond design influenced by creep criteria
- Test move up to 50 mm, but total deflection was not critical
- Authors highlight that load-deflection behavior of micropiles is frequently critical to seismic performance

Acknowledgements, Questions and Comments

Owner:	San Francisco Public Utilities Commission
Structural:	MWH-Structus JV
Geotechnical:	Treadwell & Rollo / SF Bureau of Engineering
Contractor:	S J Amoroso
Malcolm:	Superintendents: Troy Meyer, Mike Graves
	Drillers: Dave Engan, Brandon Ritter
	Support & Testing: Randy Sparks, Matt Wagner

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QUESTIONS AND COMMENTS?