



Pile Dynamics, Inc.

Considerations for testing

Making the Most of Load Testing Programs

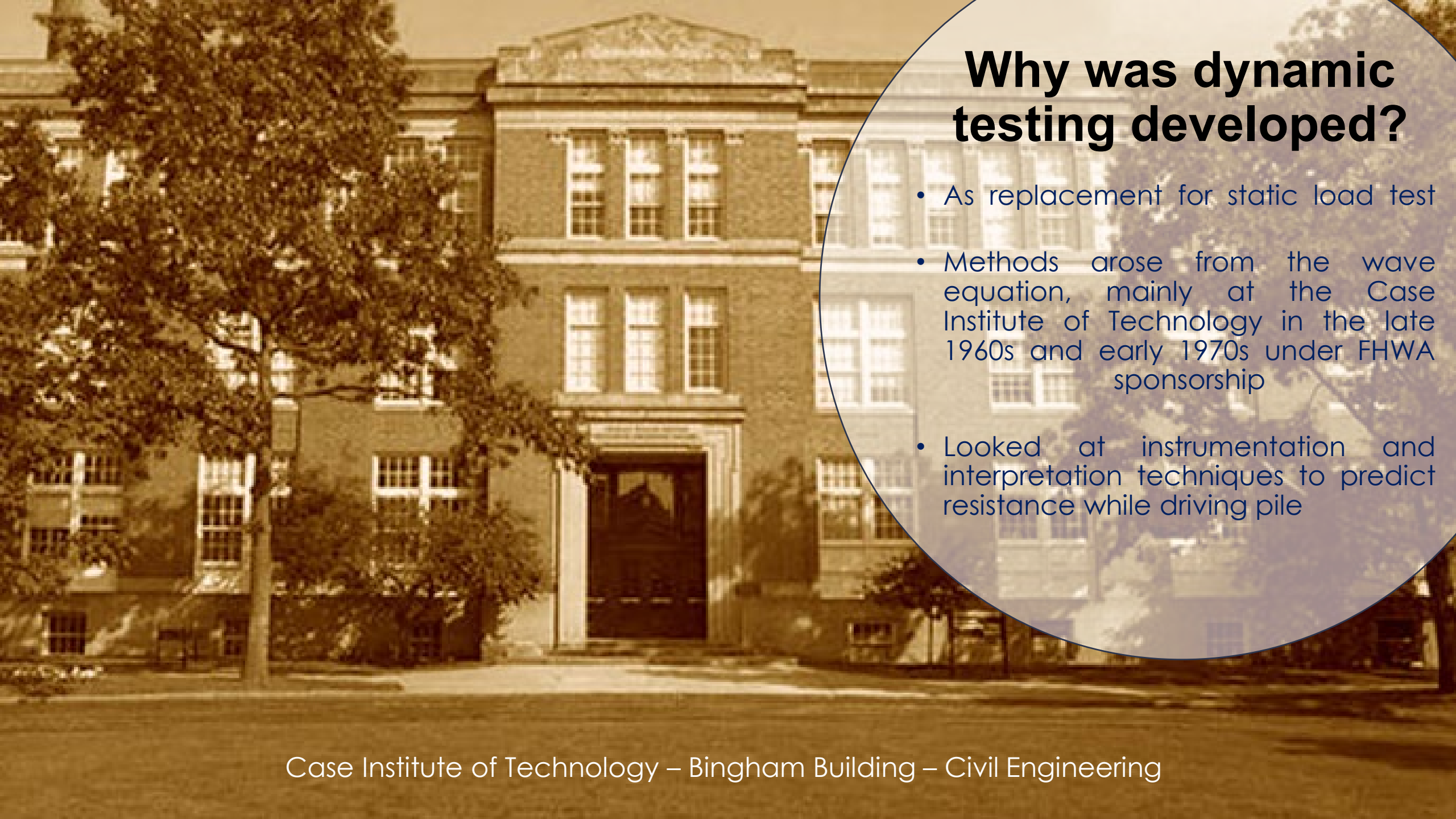
Ryan C. Allin, P.E.



About Pile Dynamics

- Founded in 1972 in Cleveland
- Developed Pile Driving Analyzer for Dynamic Testing of Deep Foundations
- Sensors and data acquisition for load testing, structural integrity and installation verification of deep foundations





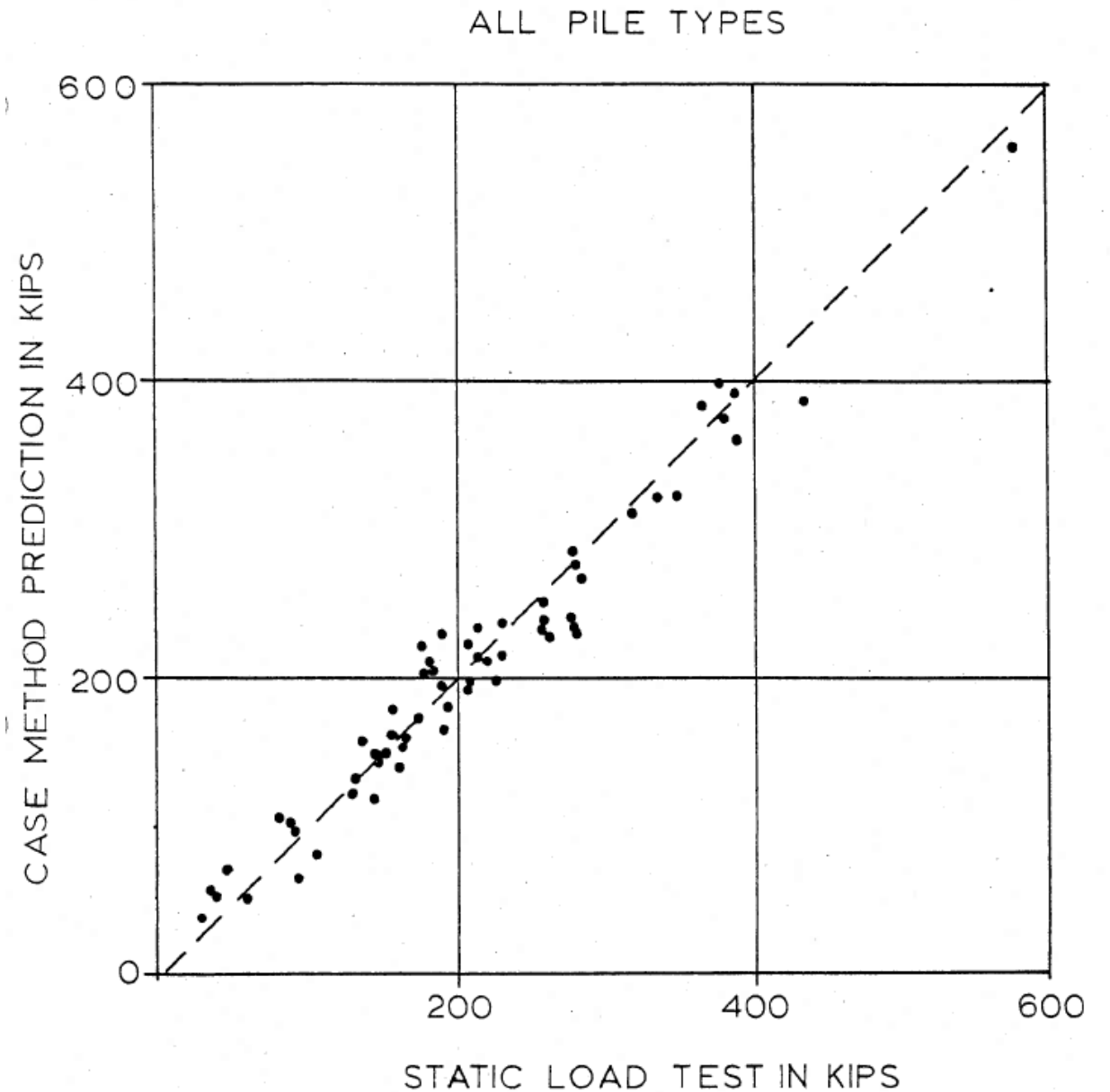
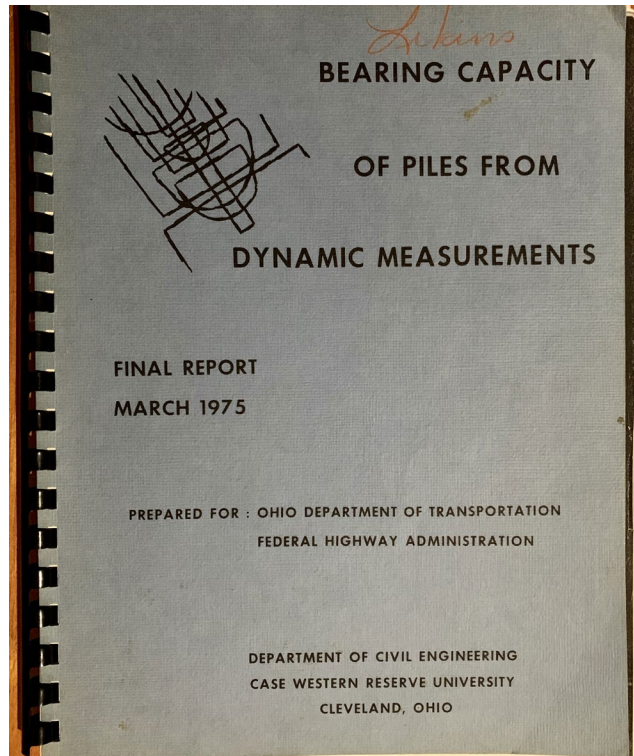
Why was dynamic testing developed?

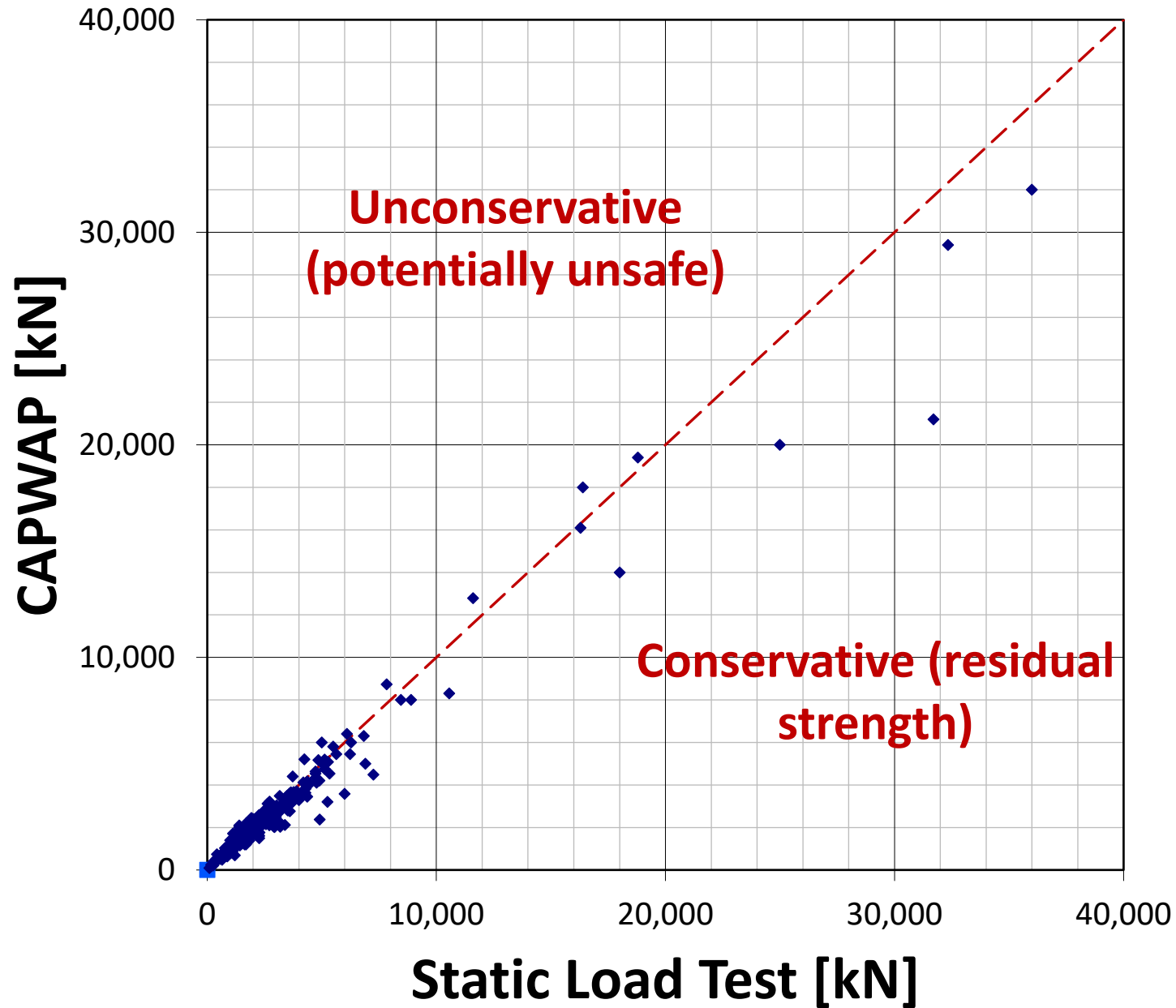
- As replacement for static load test
- Methods arose from the wave equation, mainly at the Case Institute of Technology in the late 1960s and early 1970s under FHWA sponsorship
- Looked at instrumentation and interpretation techniques to predict resistance while driving pile

Case Institute of Technology – Bingham Building – Civil Engineering

Final Report

- Result showed a clear correlation of dynamic results when compared to static load results





2004 Correlation Study

N=303

Correlation of CAPWAP with
Static Load Tests

Likins, G.E., Rausche, F. | August 2004
Proceedings of the Seventh International
Conference on the Application of
Stresswave Theory to Piles 2004:
Petaling Jaya, Selangor, Malaysia; 153-
165. Keynote Lecture



Resistance Activation

Capacity Considerations

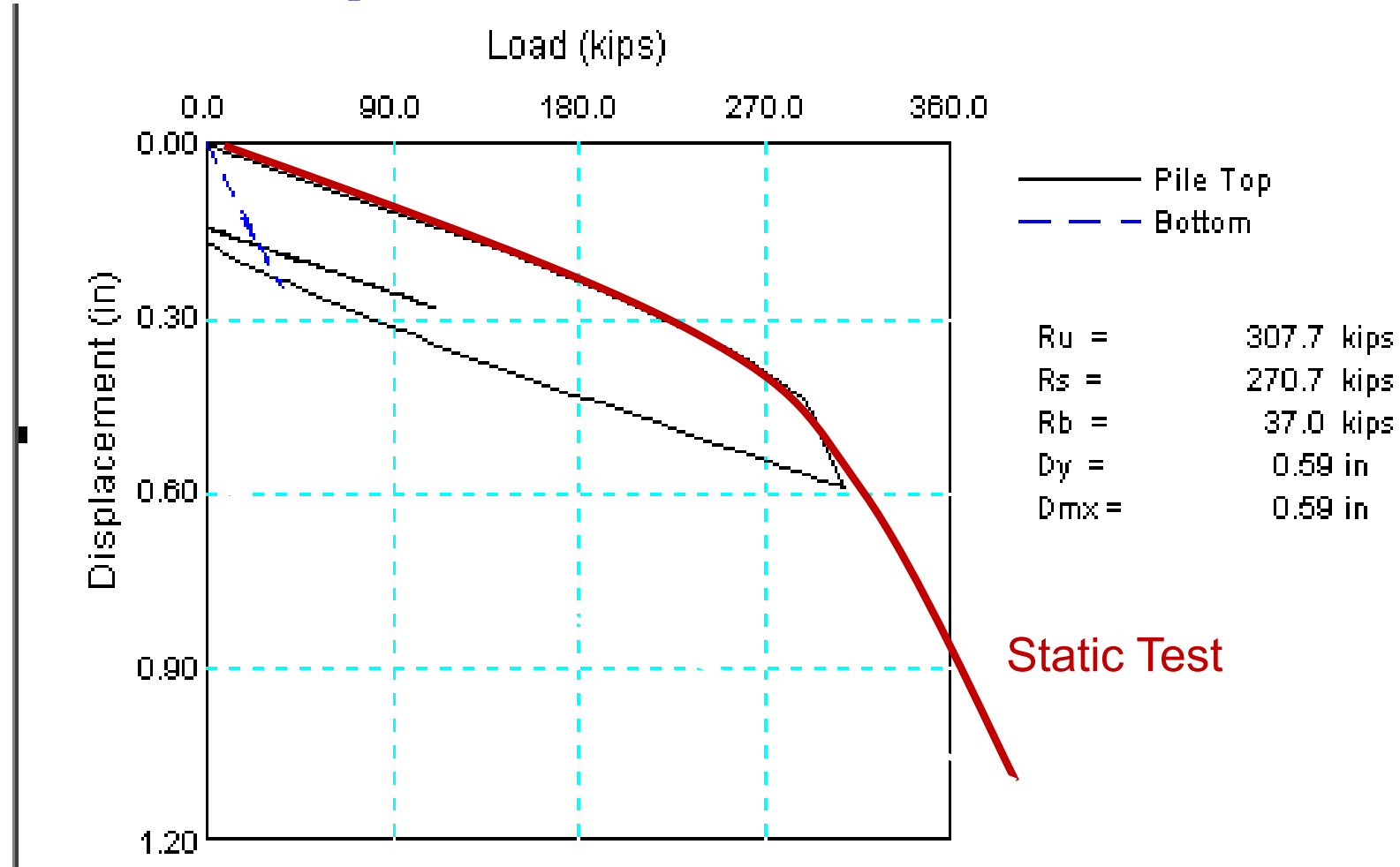
Incomplete Resistance Activation

- small set per blow
< 1/10 inch; 2.5 mm
- What to do?
Bigger hammer;
higher energy hammer
- Caution Watch stresses!
- No point exceeding
6 to 8 mm set per blow
(1/4 to 1/3 inch per blow)





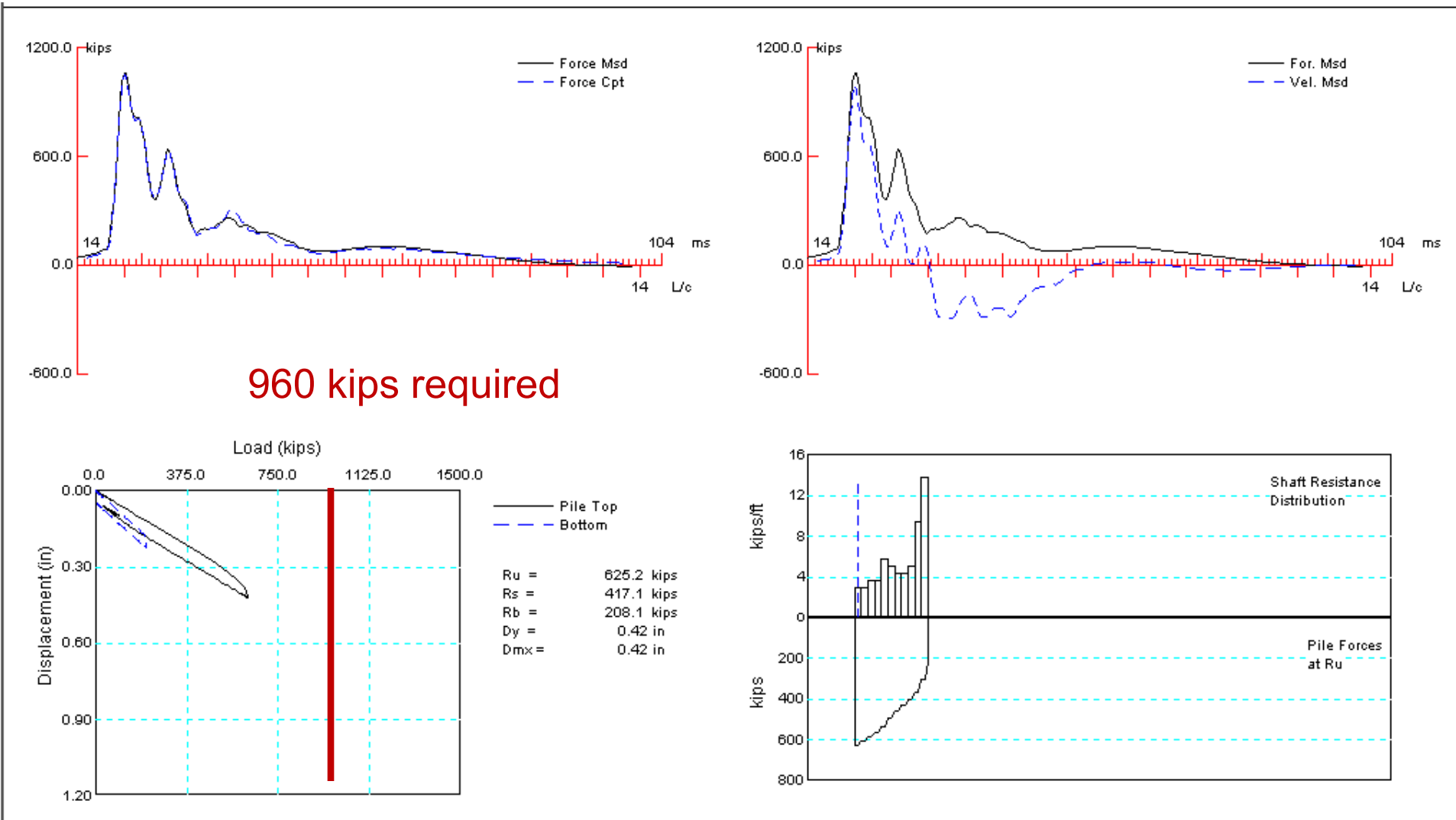
Incomplete Resistance Activation



Greater static energy; greater static set

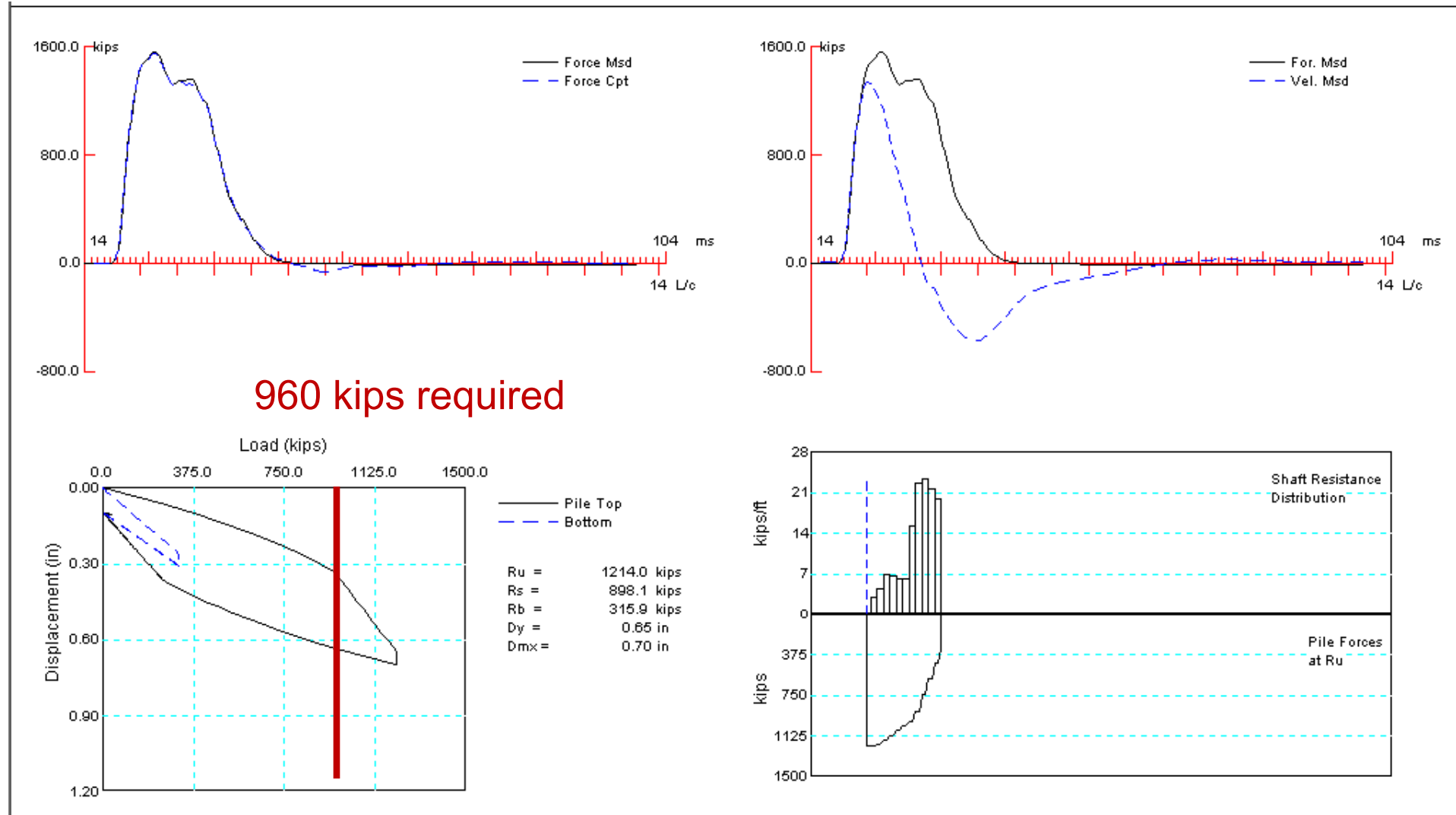


4.5 ton diesel hammer; 9 ft free drop





20 ton ram; 2 ft free drop





Superposition

Capacity Considerations

Summary of PDA/CAPWAP and Static Load Test Results

30 inch concrete pile Length 65 ft	Blow Cont, Blows/foot	Max. Trans Energy Kip-ft	Static Capacity, Kips		
			Skin Friction	End Bearing	Total Capacity
End of Driving	130	47	198	880	1078
Static Load Test					1630
Restrike	120	27	737	228	965
Superposition			737	880	1617

Hussein, M., Sharp, M., Knight, W., ***“The Use of Superposition for Evaluating Pile Capacity”***, Deep Foundations 2002, An International Perspective on Theory, Design, Construction, and Performance, Geotechnical Special Publication No. 116, American Society of Civil Engineers: Orlando, February 2002



Time Dependent Soil Strength Changes

Capacity Considerations

Time dependent soil strength changes

- Temporary Loss/Gain of Capacity during driving
- Increased pore water pressure?
- Arching?
- What to do?
 1. Restrike after sufficiently long wait
 2. Use early, high energy blow!
 3. Use Radiation Damping model (if low set/blow, if drilled shaft)
 4. Use superposition of EOD and BOR (only if BOR set per blow small < 2 mm)



Time Ratio

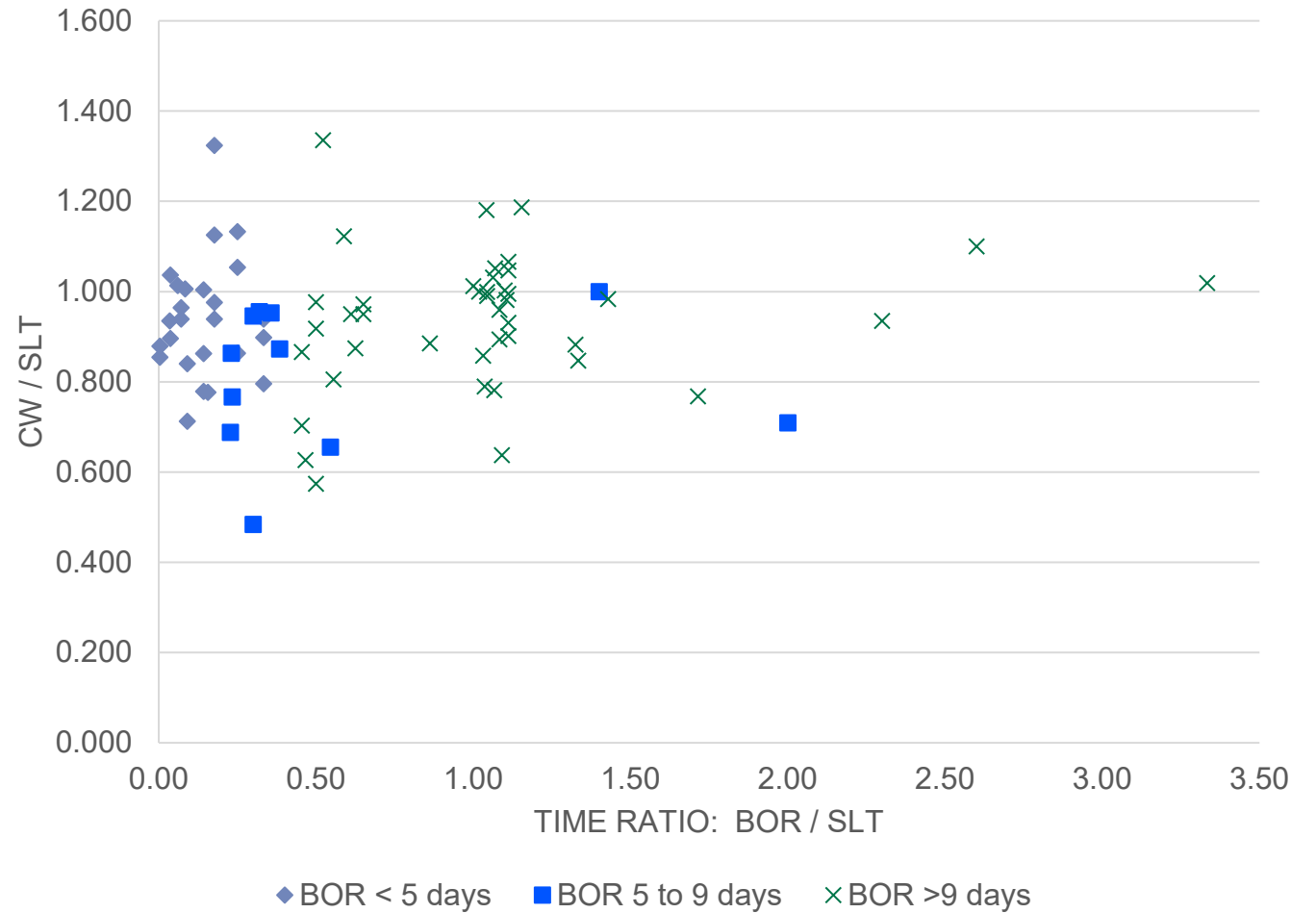
Conclusion:

- Longer wait times suggested for silts and fine sands

WHAT CONSTITUTES A GOOD PDA TEST? Likins, G. , Rausche, F.

Proceedings of the Eighth International Conference on the Application of Stress-Wave Theory to Piles, Lisbon, Portugal, pp 403-407; 2008

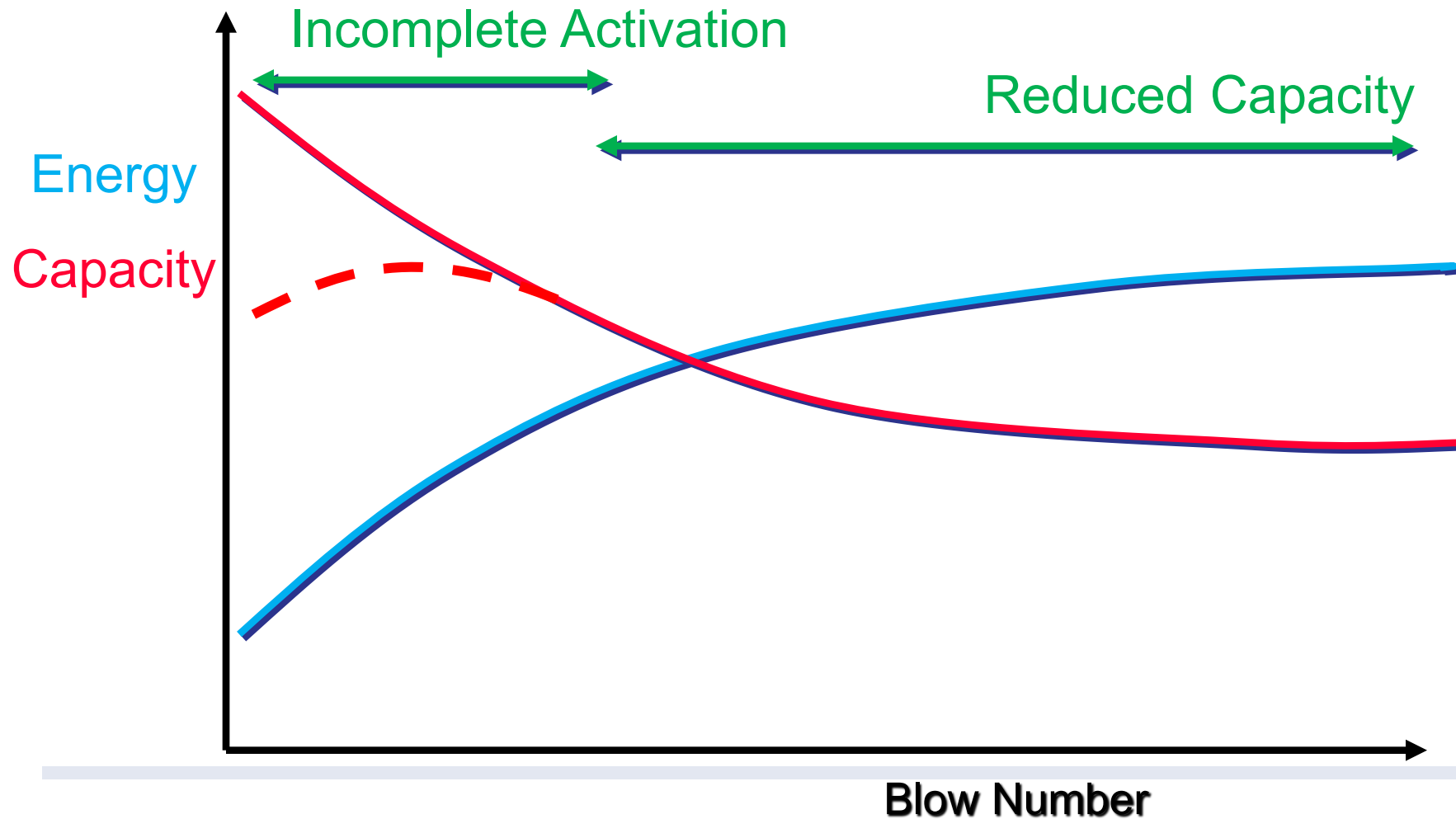
1996 DATA - RESULTS BY TIME RATIO





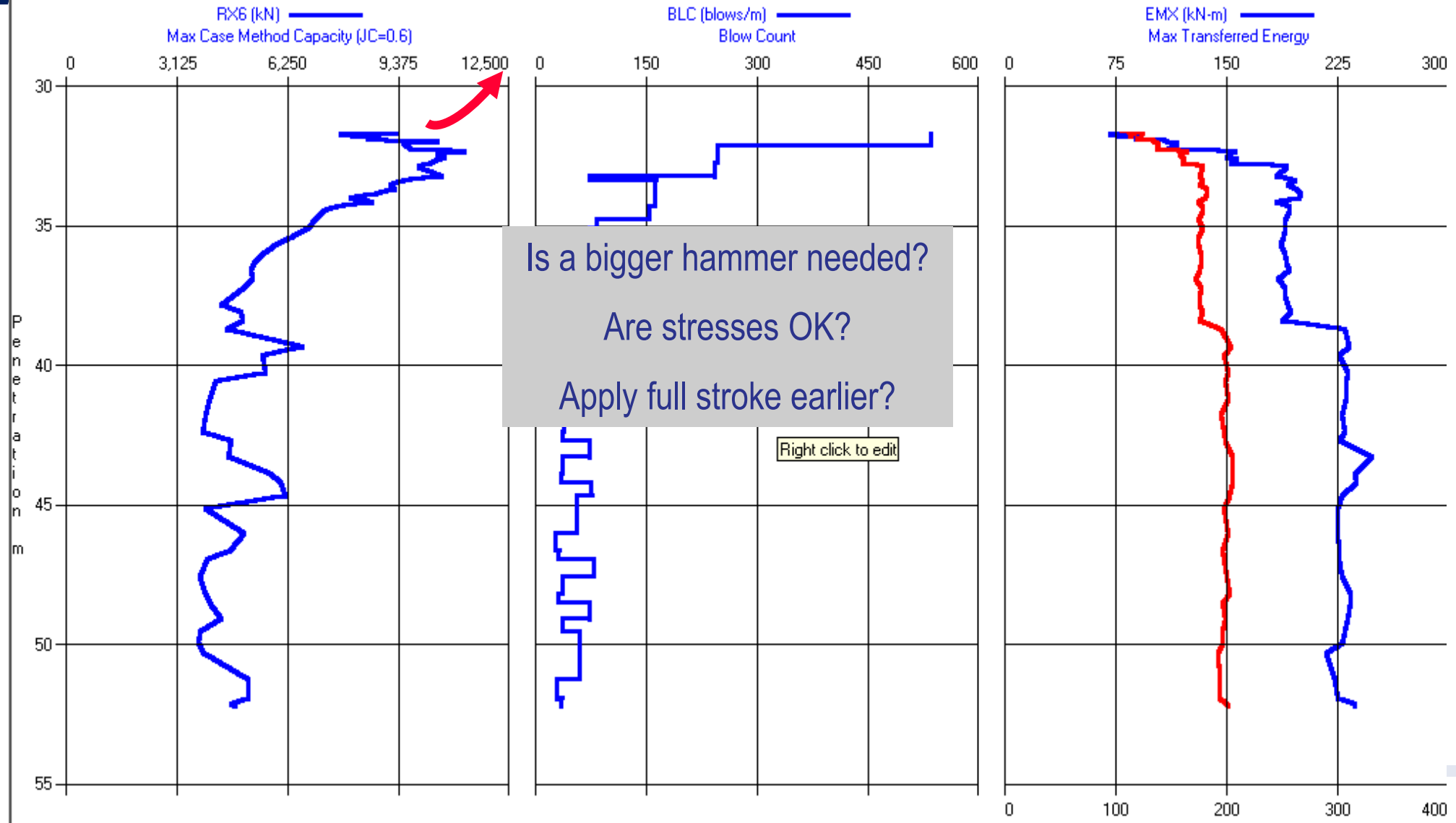
Restrike Blow Selection

Loss of Setup – Increasing Energy





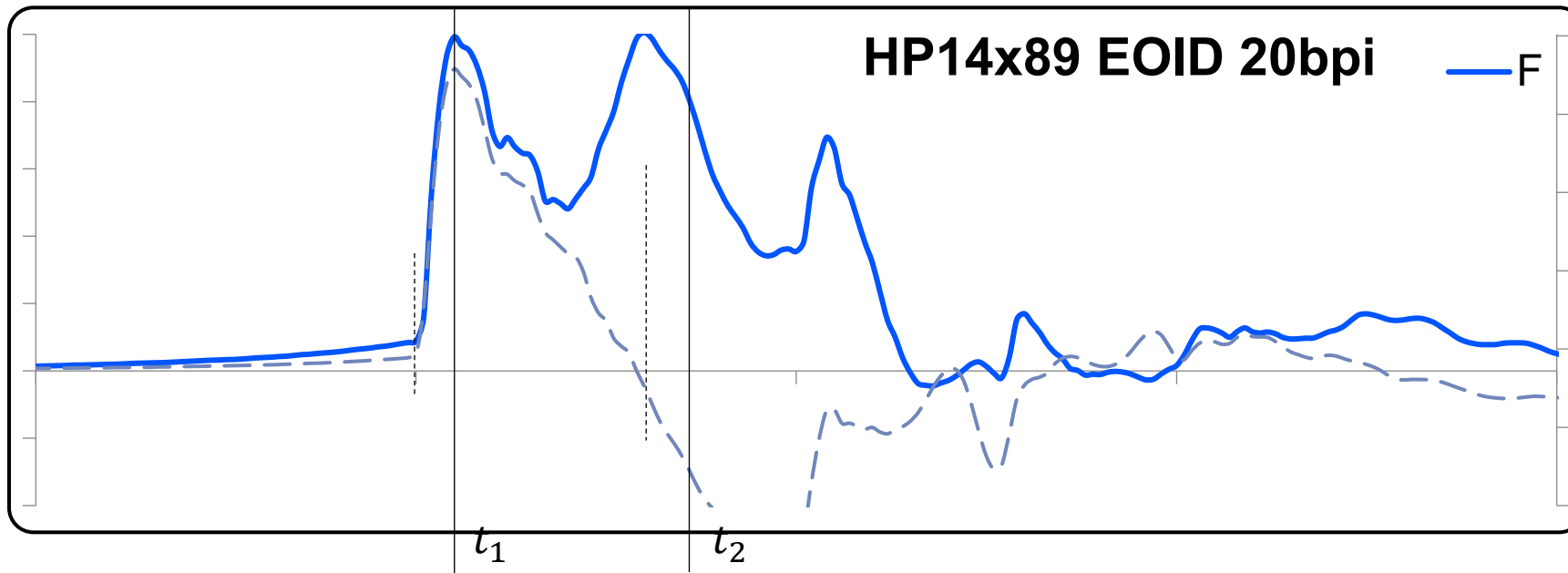
Underprediction



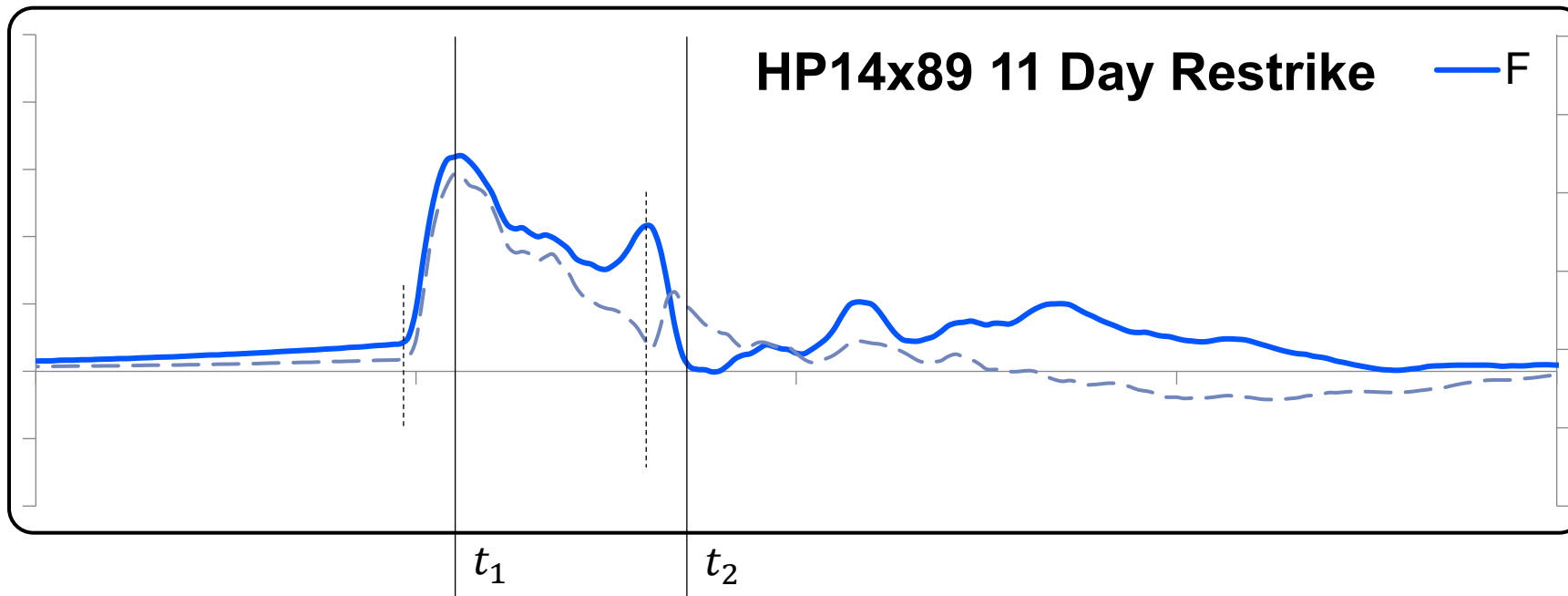


Soil Relaxation

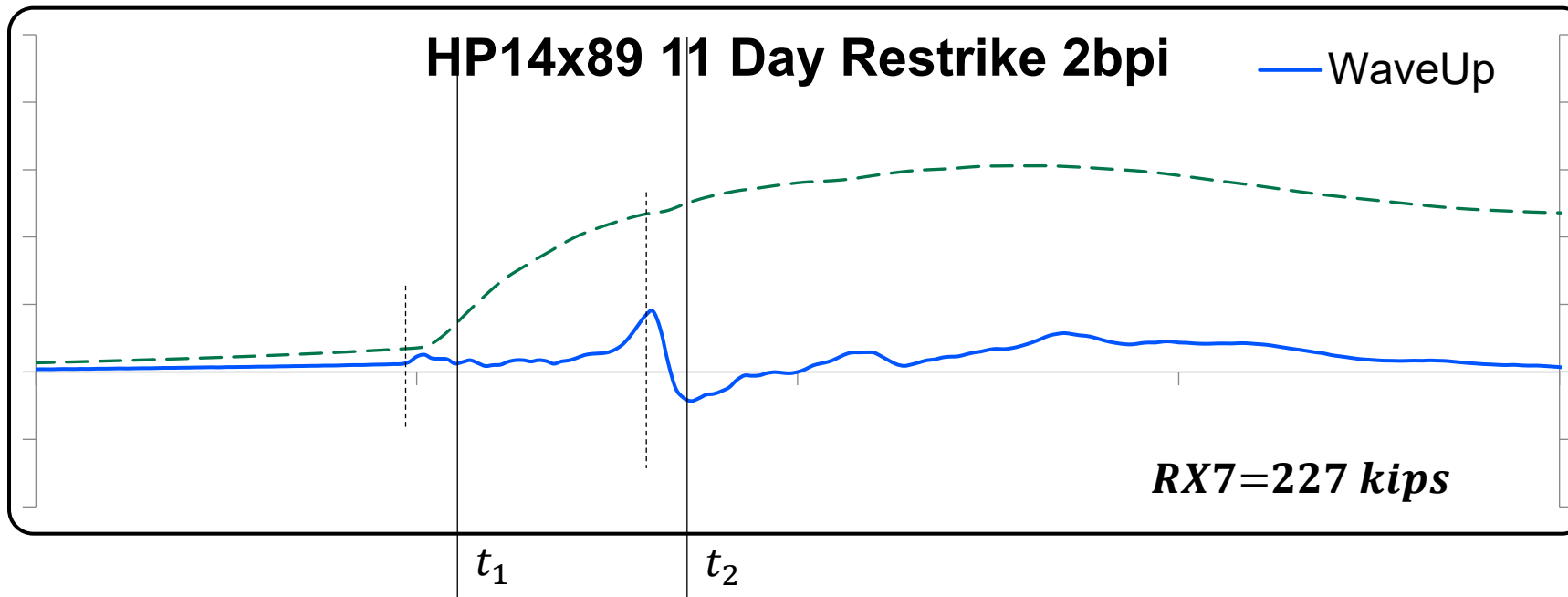
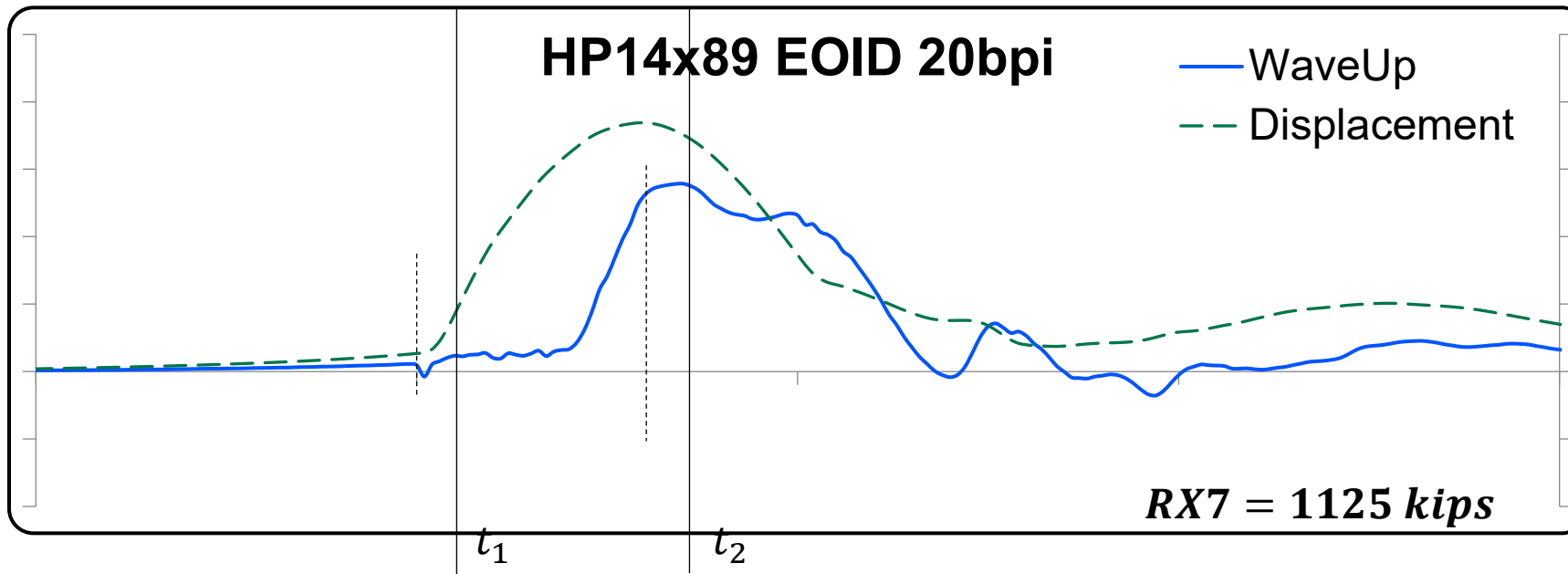
- **Relaxation**
 - Weathered Shales
 - Negative Porewater Pressure (saturated dense silts)
 - Heave
 - **Solution: restrike after wait time (look at high energy early blow)**
-



- Restrike test performed after 11 days



Relaxation Example





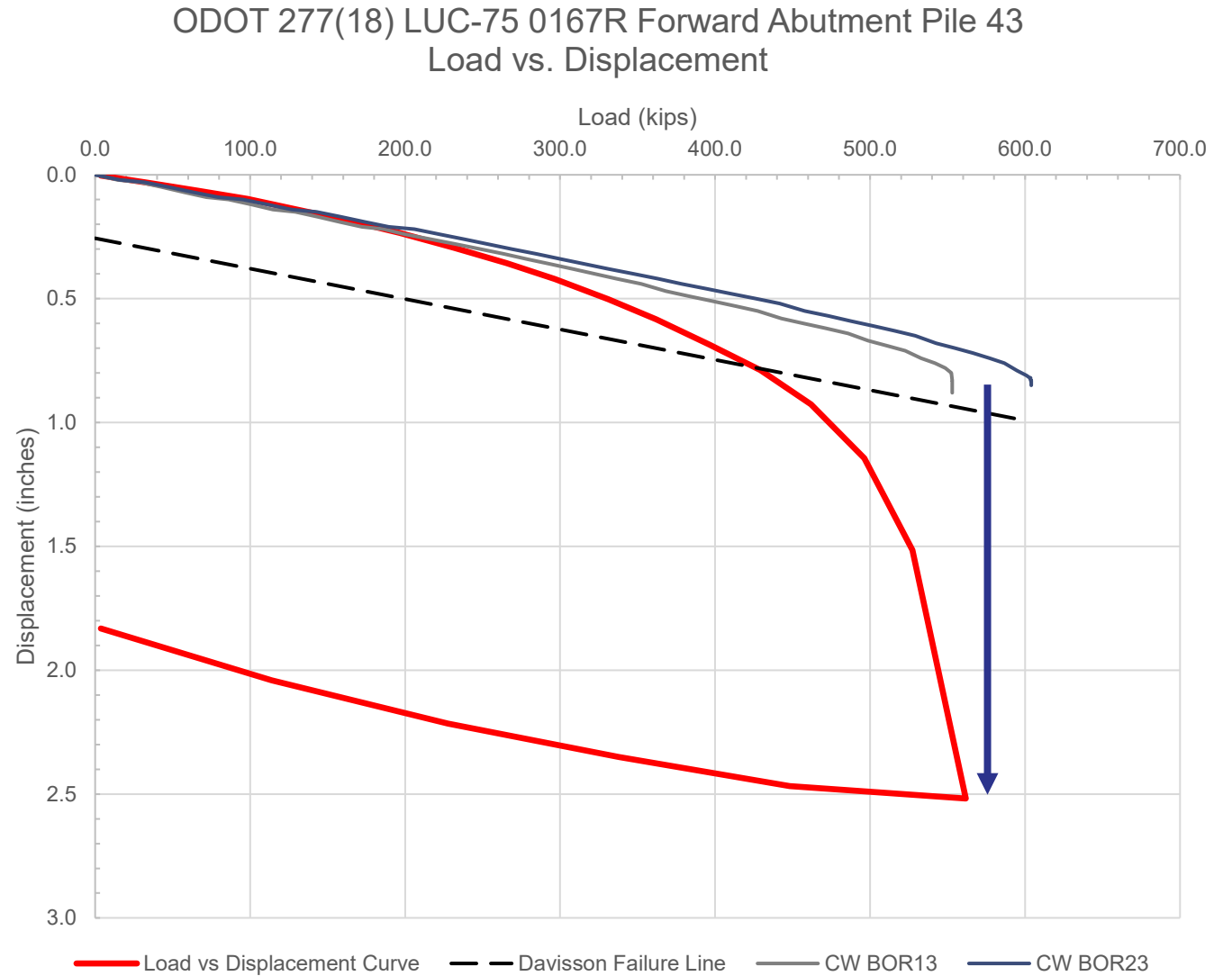
Creep Effects in Soil

Capacity Considerations

Soil Creep

Creep:

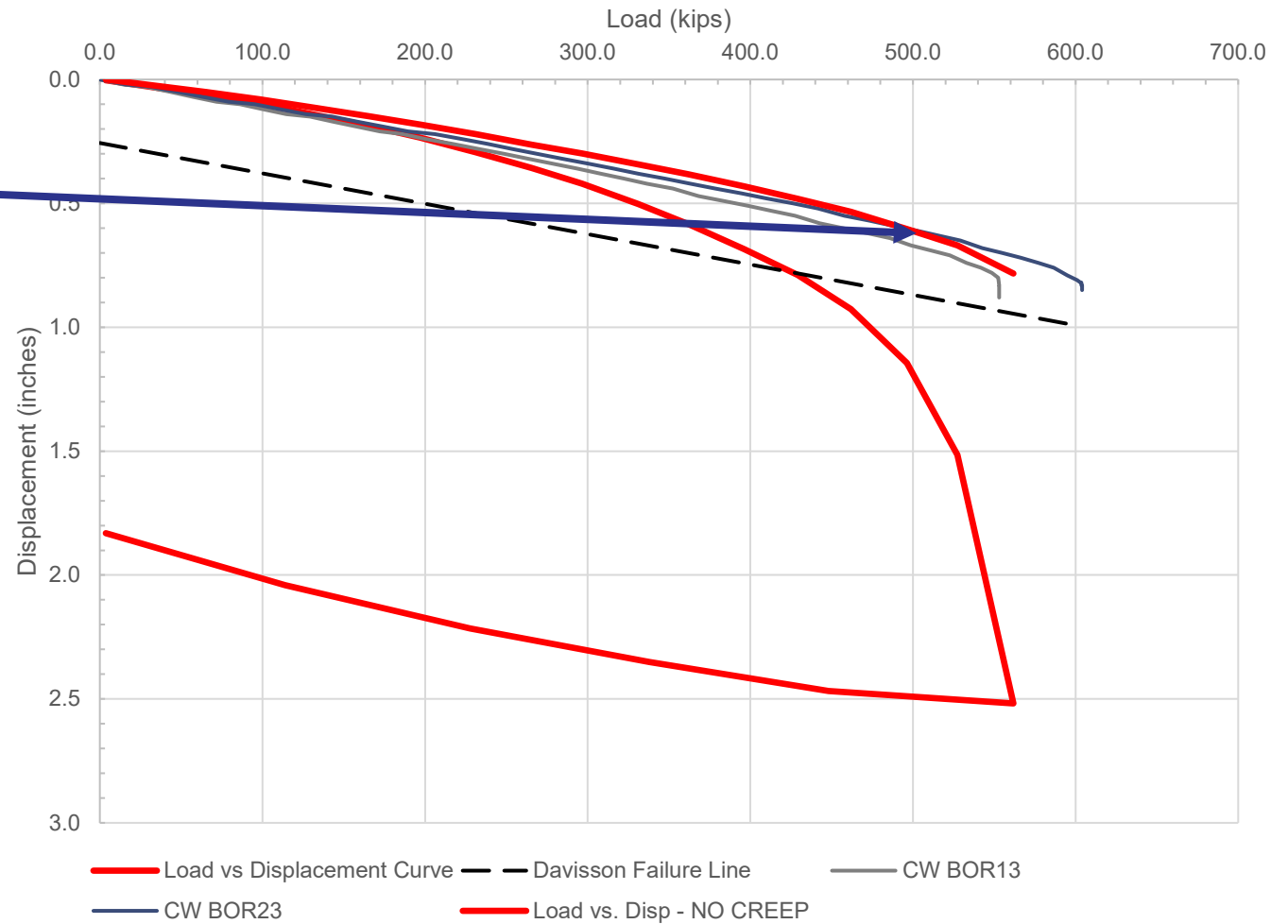
- causes displacement increases over time under sustained loads;
- for load test interpretations where capacity is defined at a fixed displacement value, the apparent bearing capacity is lower for slower load applications.
- Creep effects cause lower static than dynamic strength values.



Soil Creep

ODOT 277(18) LUC-75 0167R Forward Abutment Pile 43
Load vs. Displacement

- Soil Creep Effects removed from SLT curve
- Note that under a dynamic load (where the pile is loaded and unloaded in ~40ms, there is no way to assess soil creep.
- Must be assessed by other means:
 - SLT
 - Static Analysis





Failure Mode

Capacity Considerations

Record Selection

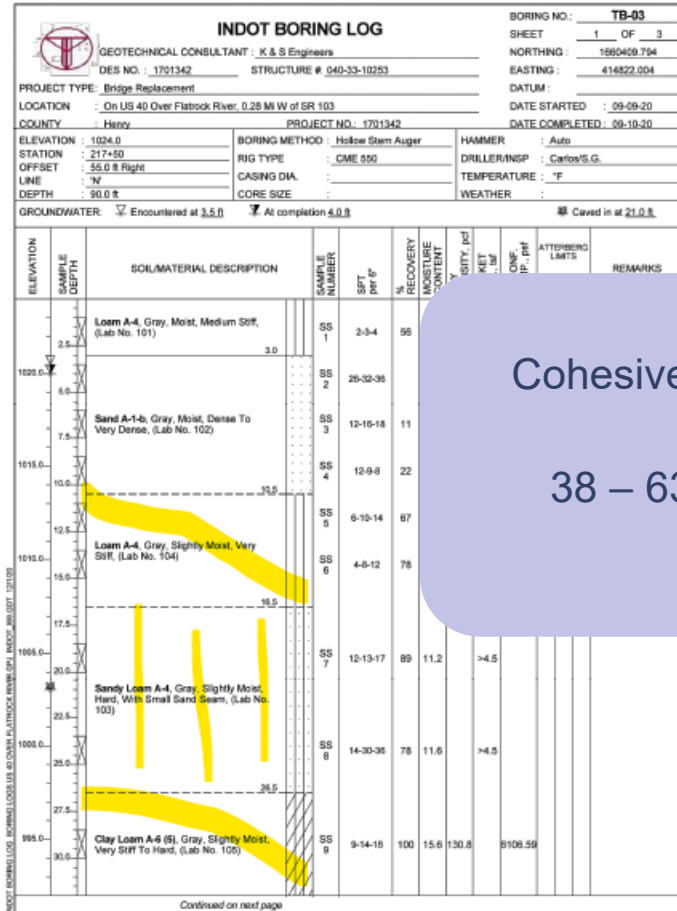
- 24" Open ended pipe pile x 0.5" wall thickness
- 50 ft long, 42 ft pen
- PDA monitored during install (551 kips)
- SLT performed 7 days after install
- Restrike one day after SLT



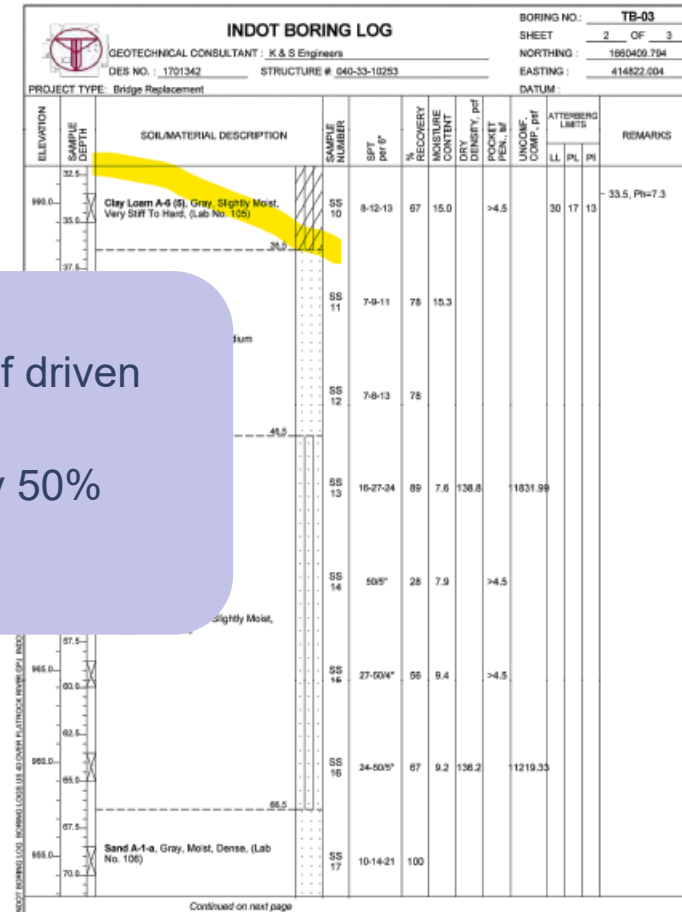


Soil information

Static Load Test Pile Tip EL 978



Cohesive Layers in ~ 15 – 25 feet of driven length
38 – 63% of shaft length, let's say 50%



SLT Test

Intent to achieve maximum load of 1000 kips.

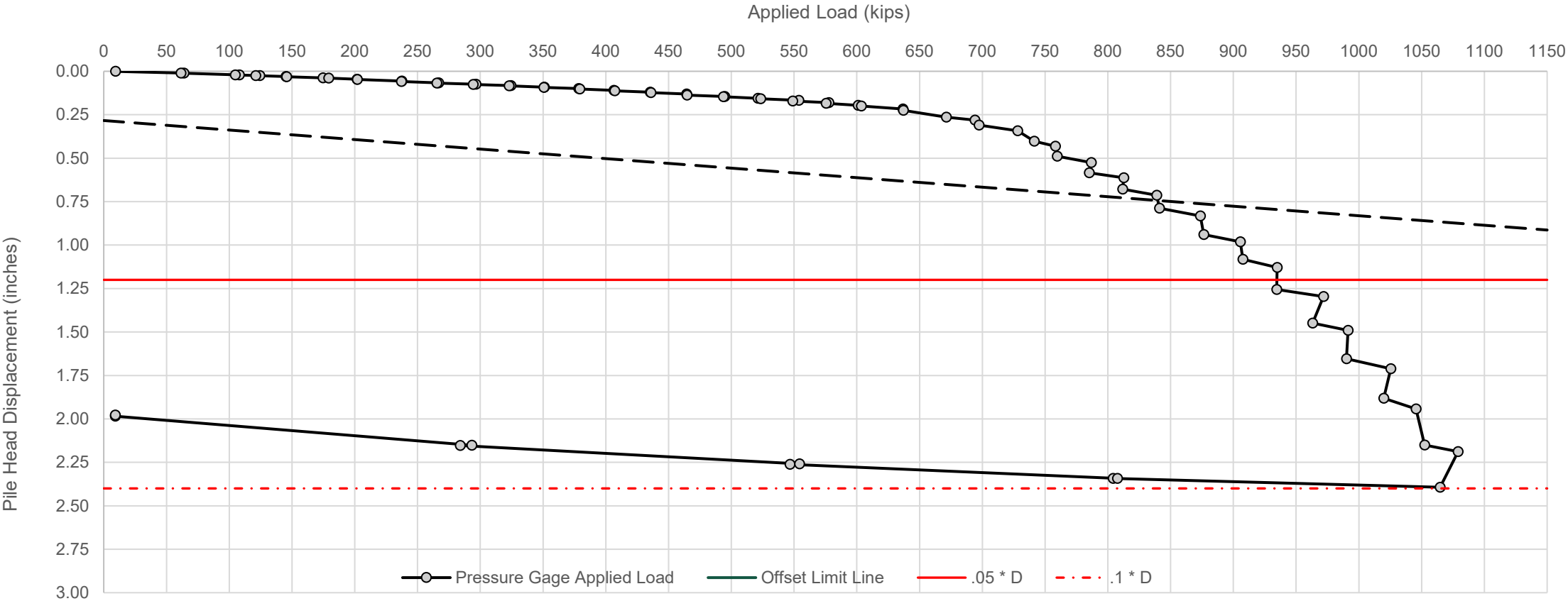
Load applied in 50 kip increments with 5 min hold.





SLT Results

24 Inch OEP Static Compression Test





PDA Results

Blow Number	FMX (kips)	EMX (kip-ft)	STK (ft)
1	887	23.1	-
2*	1402	60.3	10.3
3	1266	49.9	8.9
4	1364	56.7	9.9

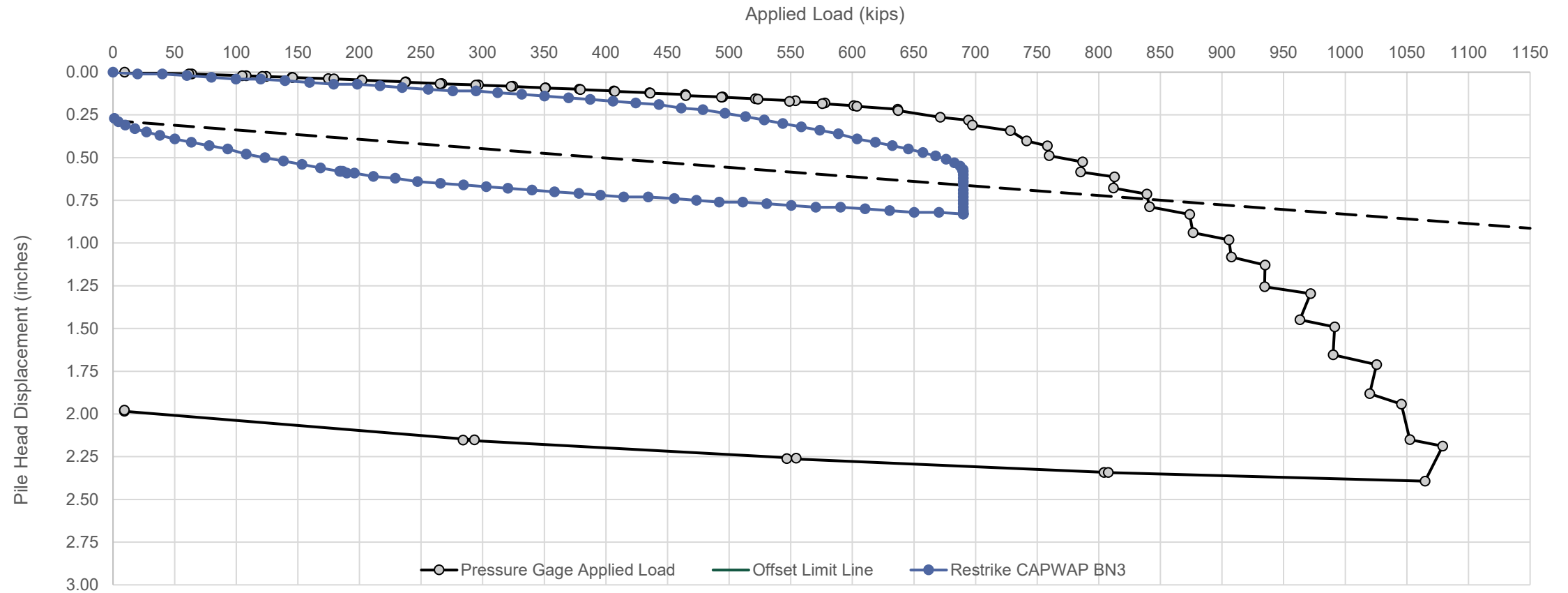
*minor data quality issue observed in BN2

- Restrike Blow counts, 4,3,3,3,4,4



SLT Results & CAPWAP BN3

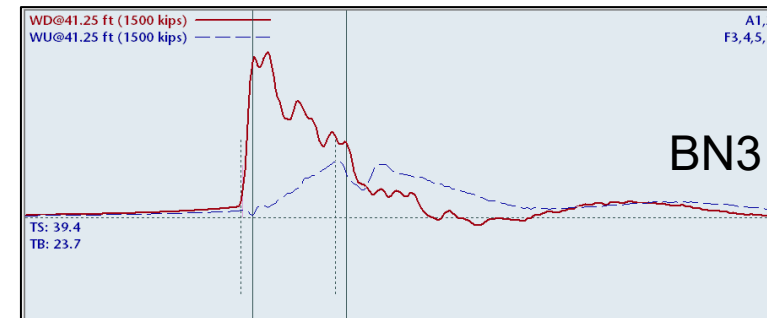
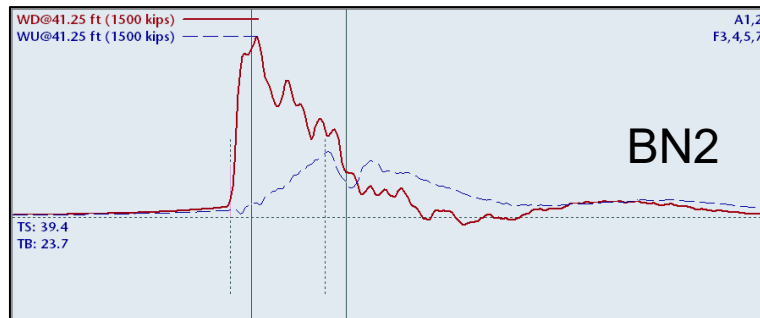
24 Inch OEP Static Compression Test





PDA Results

Blow Number	FMX (kips)	EMX (kip-ft)	STK (ft)
1	887	23.1	-
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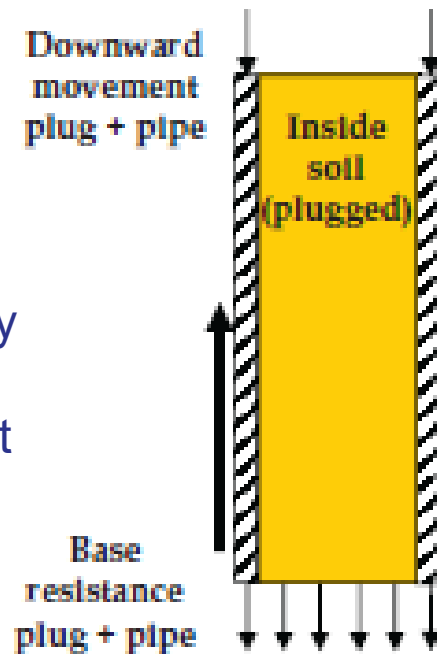




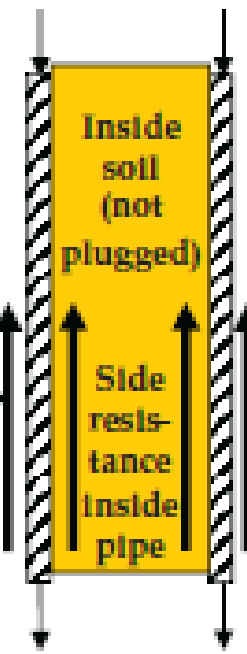
Pile-Soil Response

Static Loading

- Increasing Capacity
(End Bearing) with
Further Displacement



Side
resistance
outside
pipe



Downward
movement
pipe only

Dynamic Loading

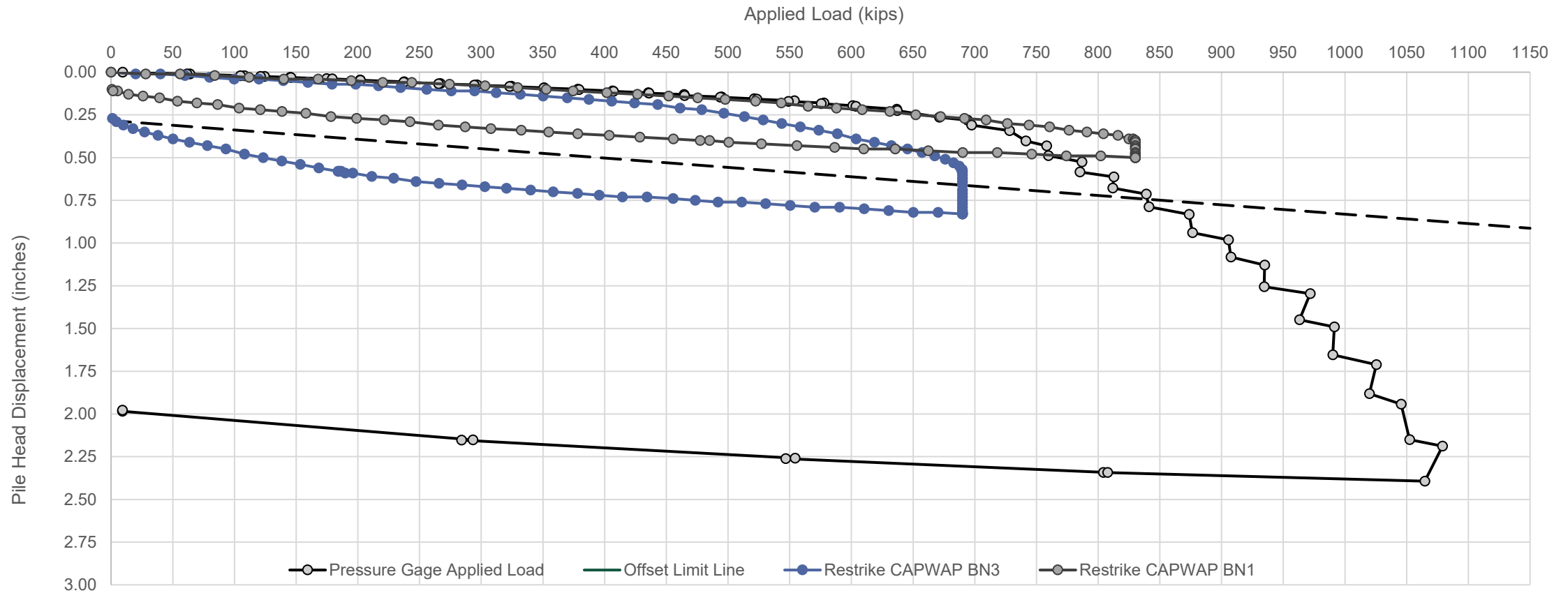
- Low Blow Count and
Decreasing Capacity
during Restrike

NCHRP 478 - Brown, Thompson III



SLT Results & CAPWAP BN1 & BN3

24 Inch OEP Static Compression Test





Summary of CAPWAP Analyses

BN	CAPWAP Resistance			Damping		Quake	
	Shaft	Toe	Total	Shaft	Toe	Shaft	Toe
1	550	280	830	0.26	0.32	0.04	0.08
2	450*	260*	710*	0.23	0.24	0.05	0.17
3	425	265	690	0.23	0.13	0.06	0.13
4	330	260	590	0.28	0.40	0.08	0.18

* Note minor data quality issue



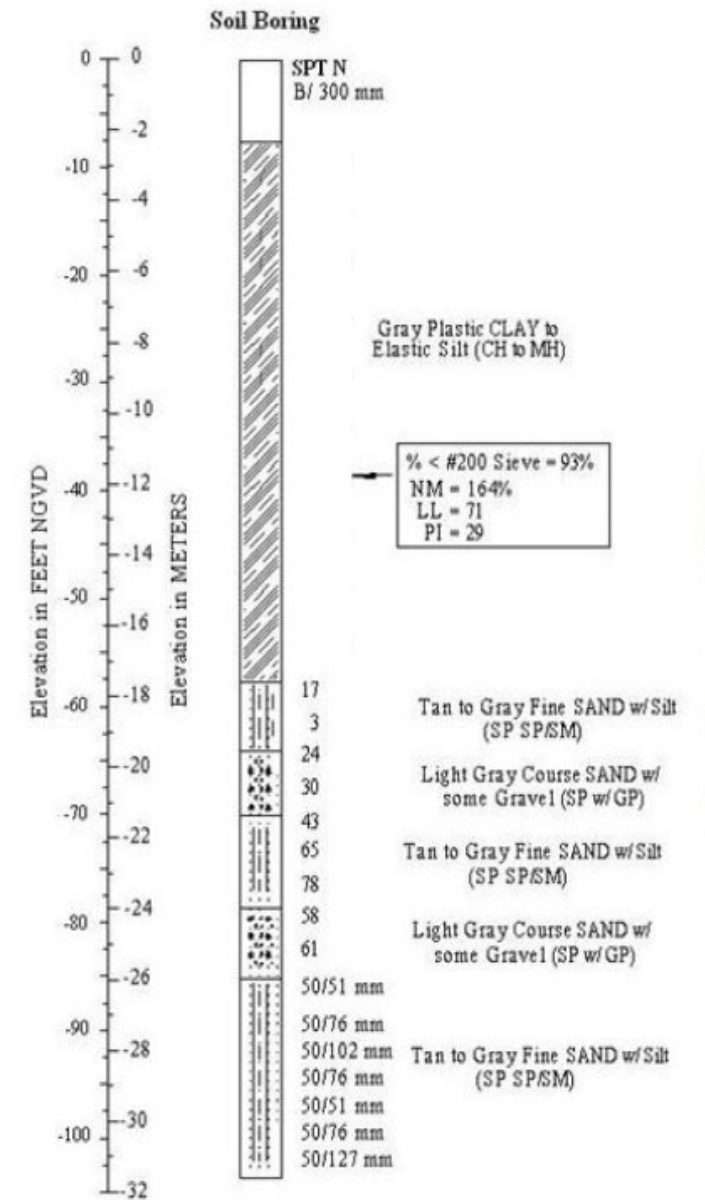
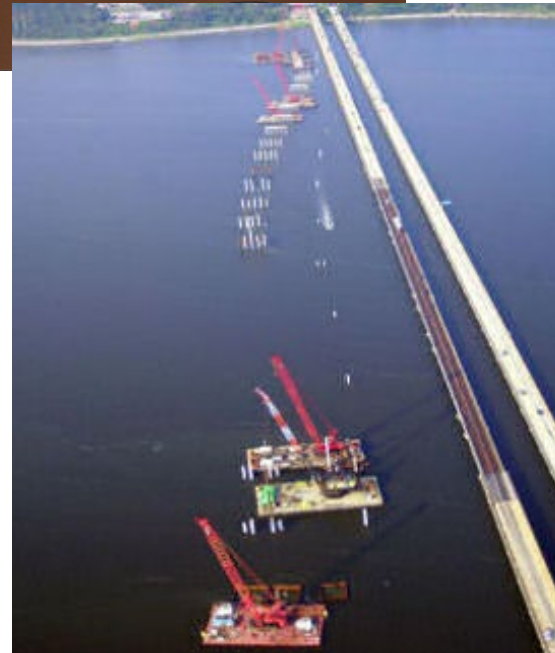
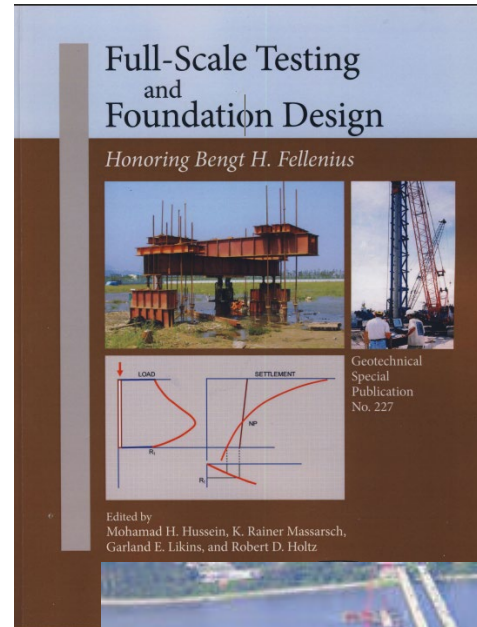
Static Load Test Evaluation

Capacity Considerations

Which answer is Right?

The 2.6-mile long, \$243-million contract, twin bridges were supported on 36-inch square, hollow with 23-inch circular void, prestressed concrete piles with lengths up to 140 feet and the pile under consideration had a required capacity of 5760 kN (1,295 kips)

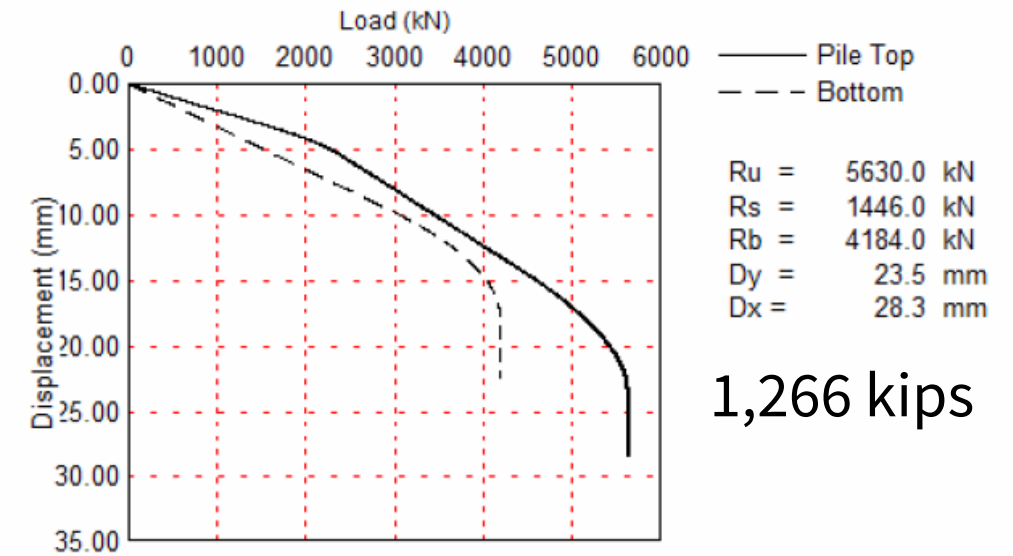
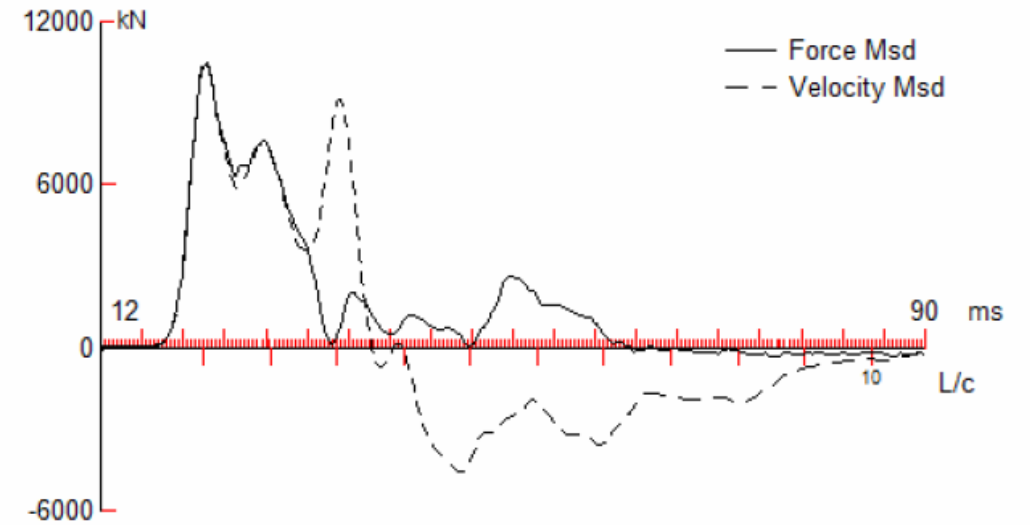
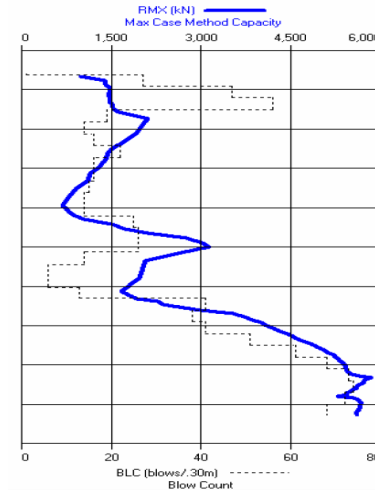
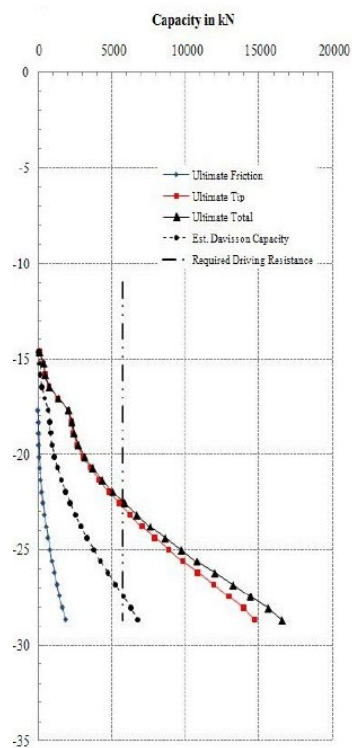
KNOWLEDGE IS BLISS - A CASE FOR SUPPLEMENTAL PILE TESTING TO ASCERTAIN FIDELITY Hussein, M. , McGillivray, R. , Brown, D.
Geo-Institute Geotechnical Special Publication No. 227, pp 322-332; 2012



Dynamic Test Results

Initial Drive

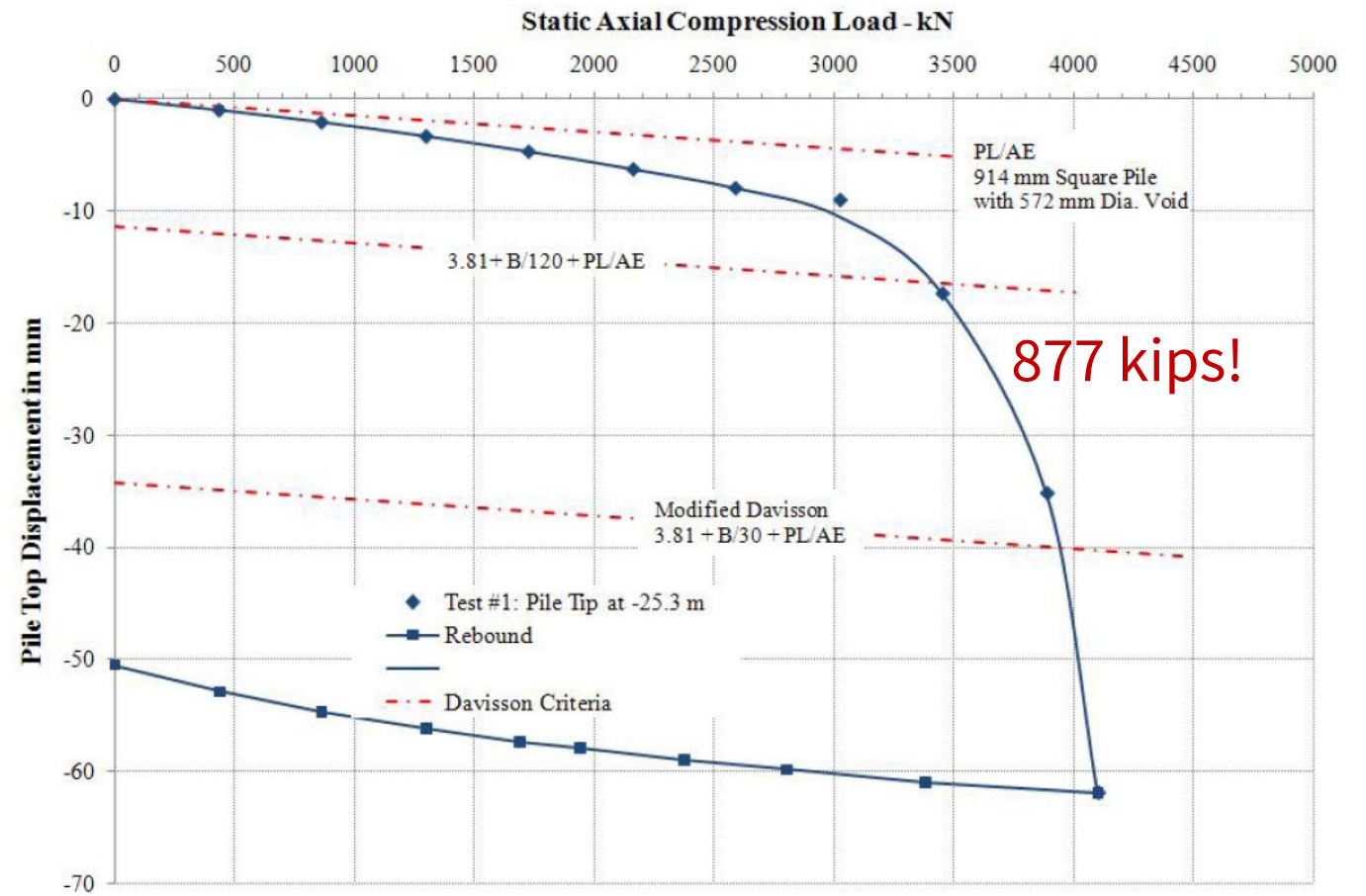
- End of Drive results indicate the pile has capacity



1,266 kips

Static Load Test

- 43 days after the initial installation, a static load test was performed indicating



Restrike after SLT

- A restrike performed after the SLT also indicates a lower capacity?
- So what happened?

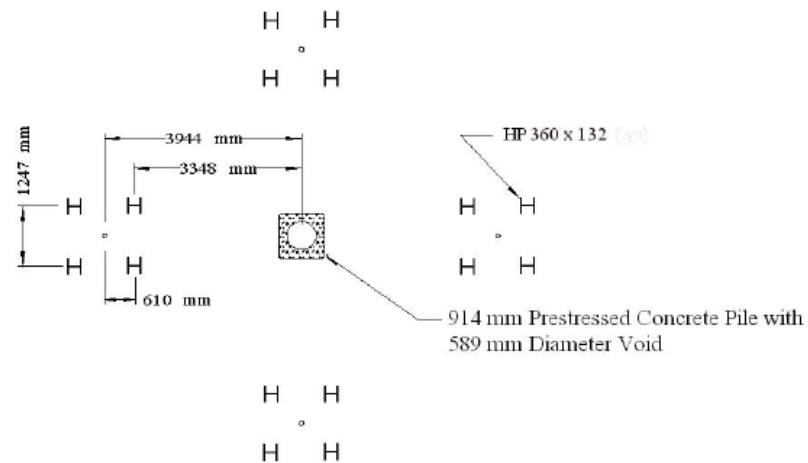
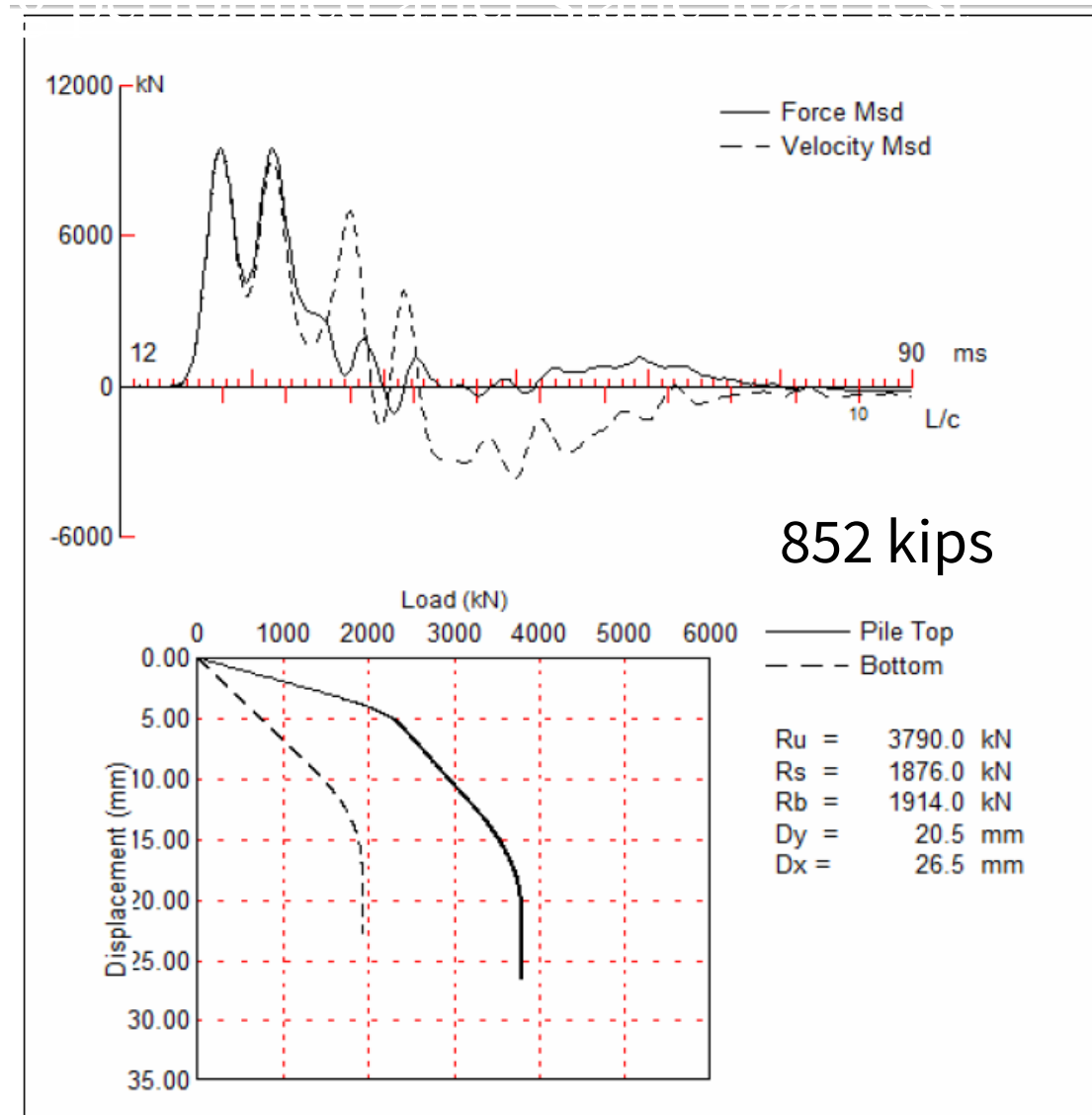
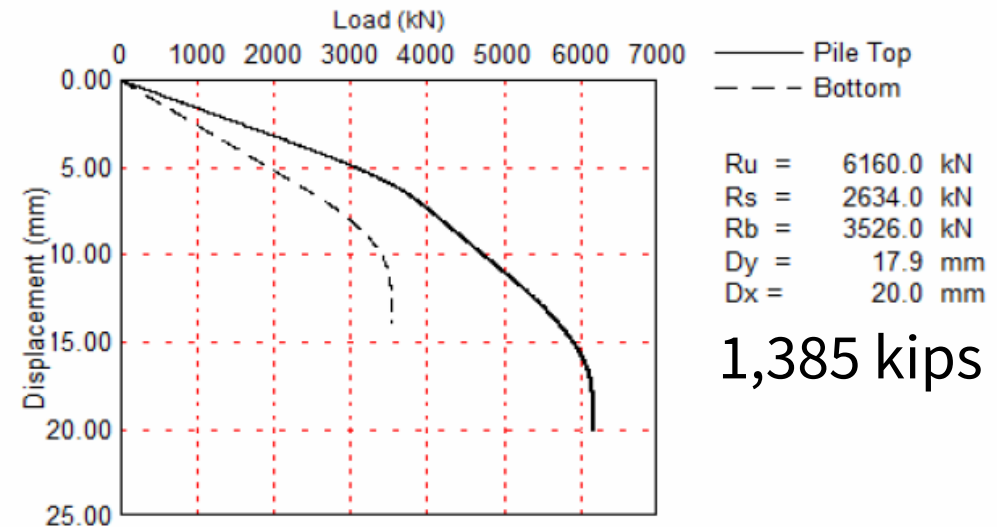
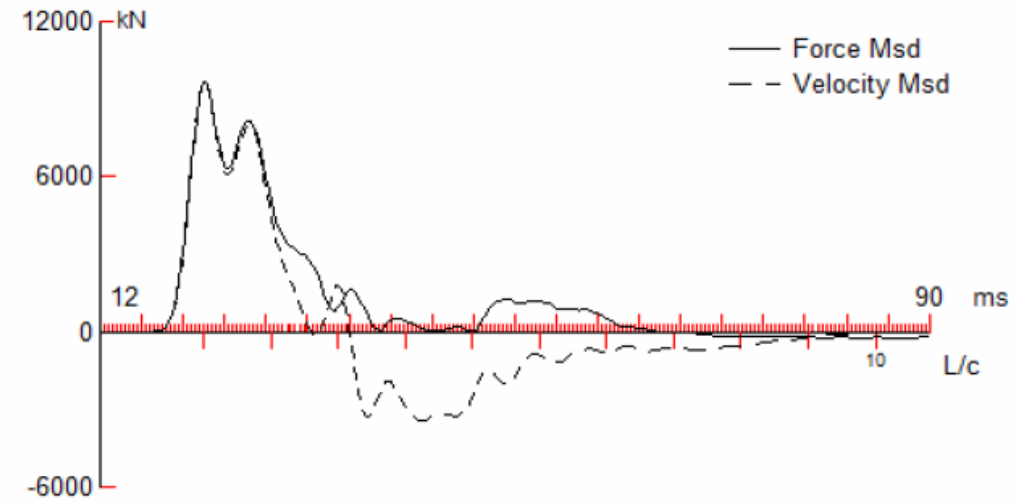


Fig. 4 Layout of test pile and reactions piles.



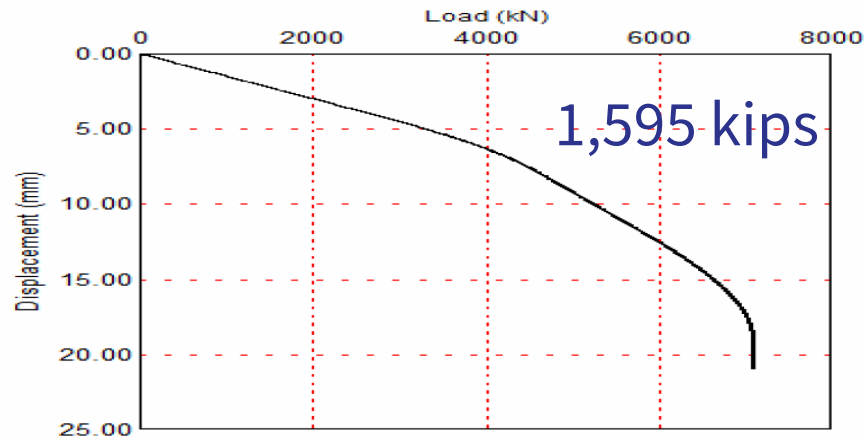
Pile Redrive 6 ft deeper

- With concern raised regarding the vibratory installation of the reaction piles *after* the installation of the test pile, the pile was redriven 6 ft deeper with the SLT performed again.

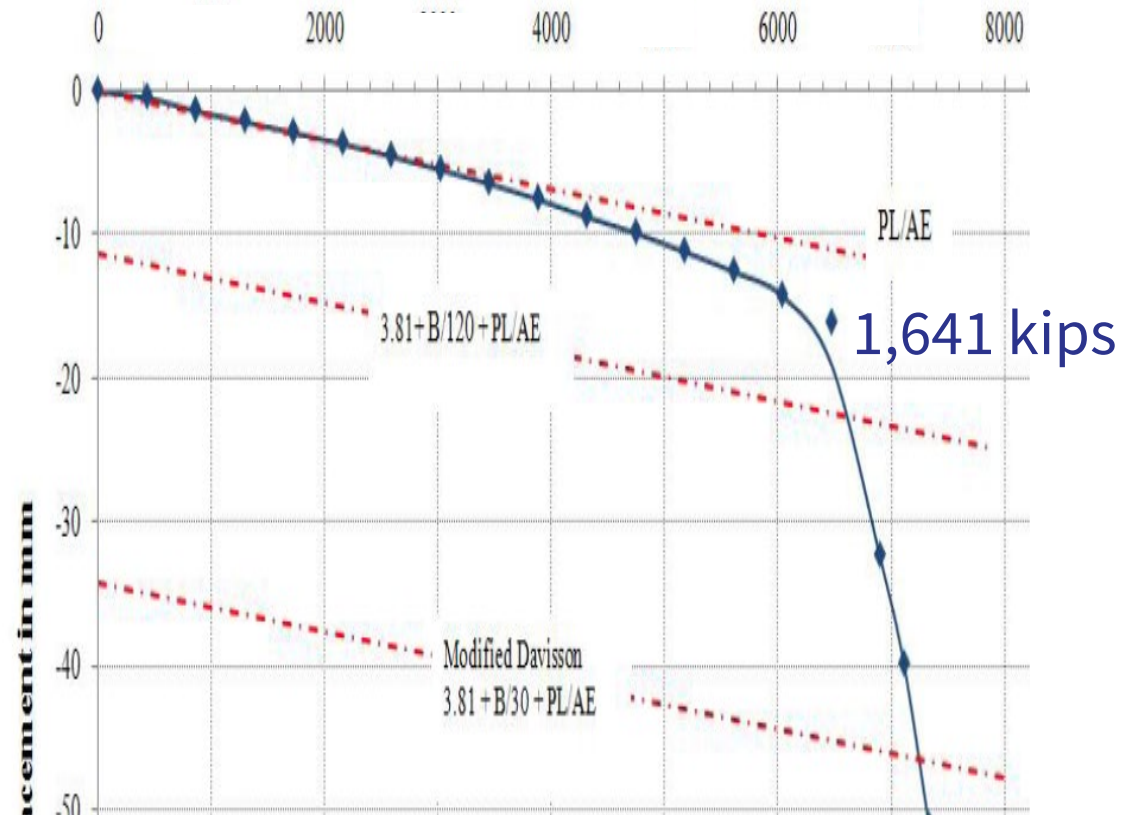




SLT Result vs DLT Restrike after redrive

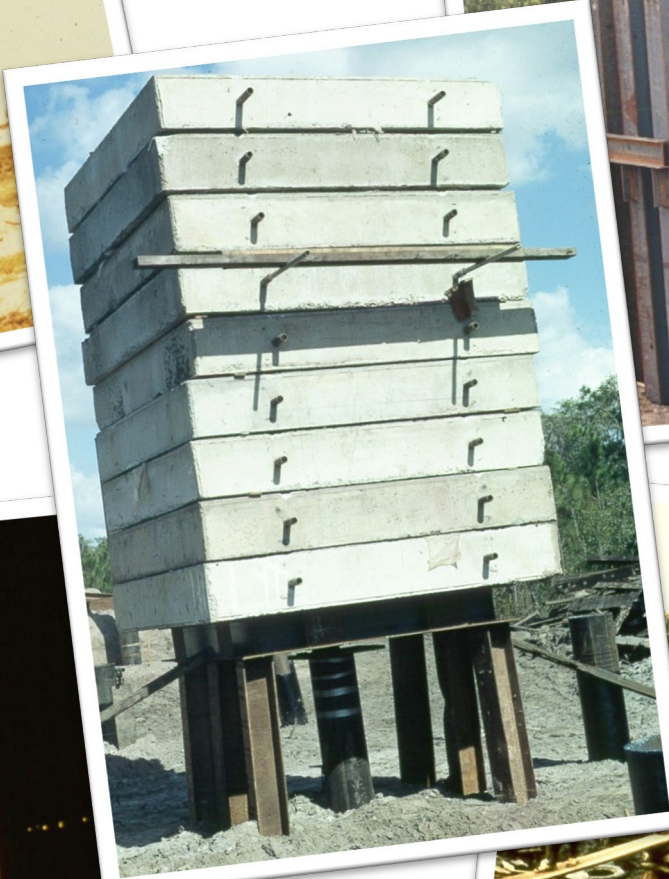


The dynamic testing was able to identify that the vibratory installation of the reaction piles had affected the strength of the soil and thus, SLT results were below the design values.

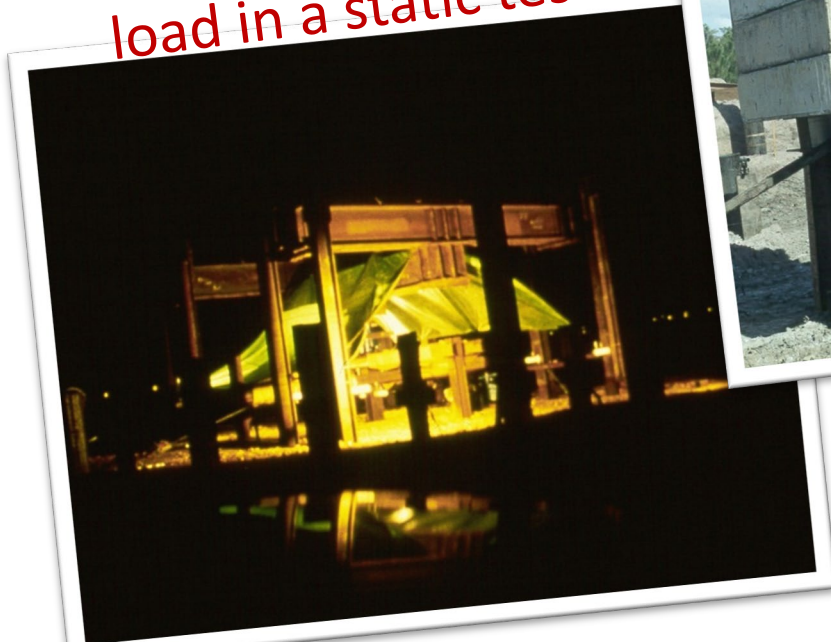




Many ways to apply
load in a static test

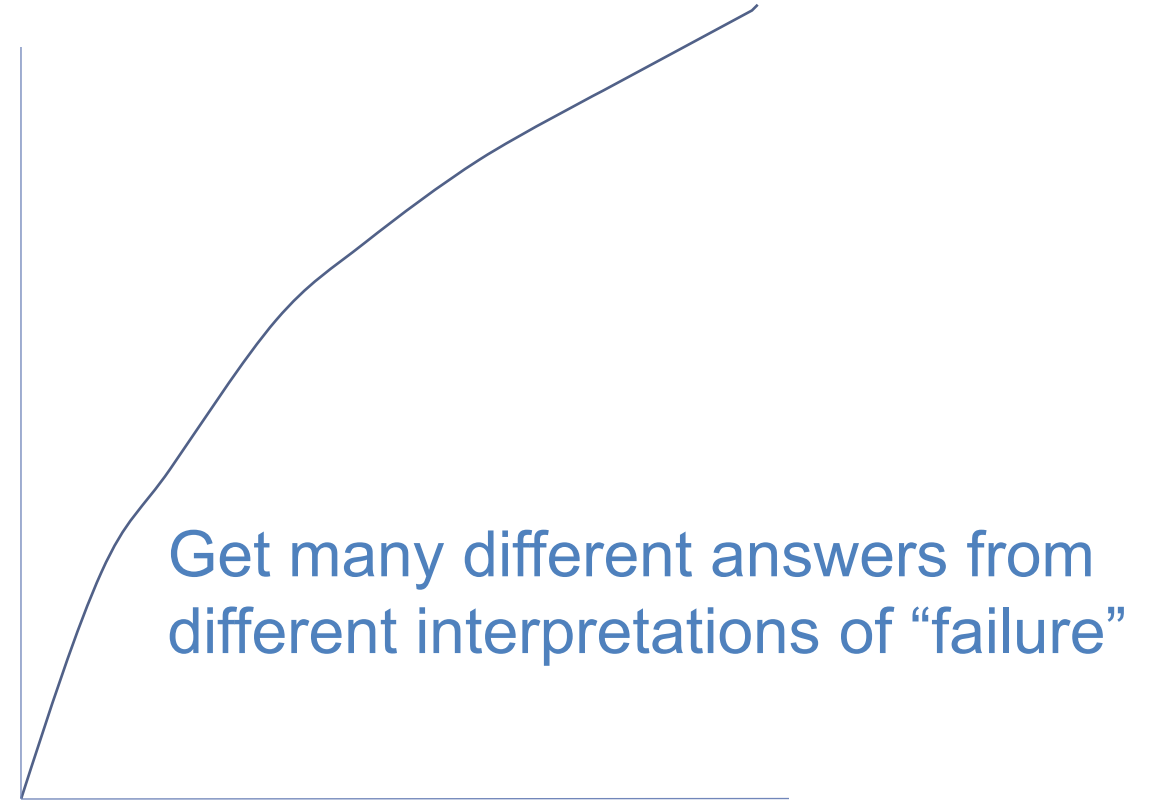
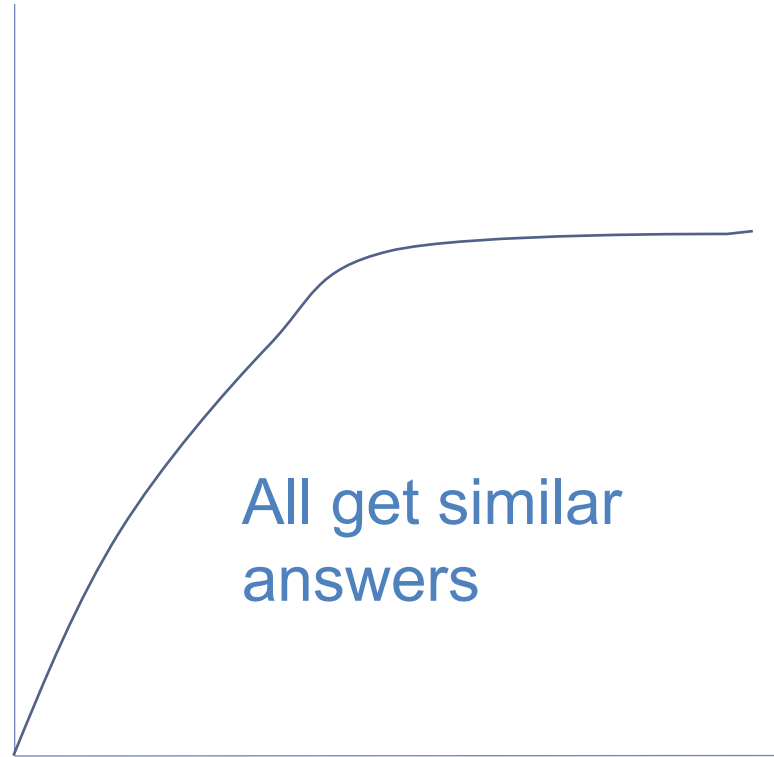


Also, Maintained,
Quick, CRP loading



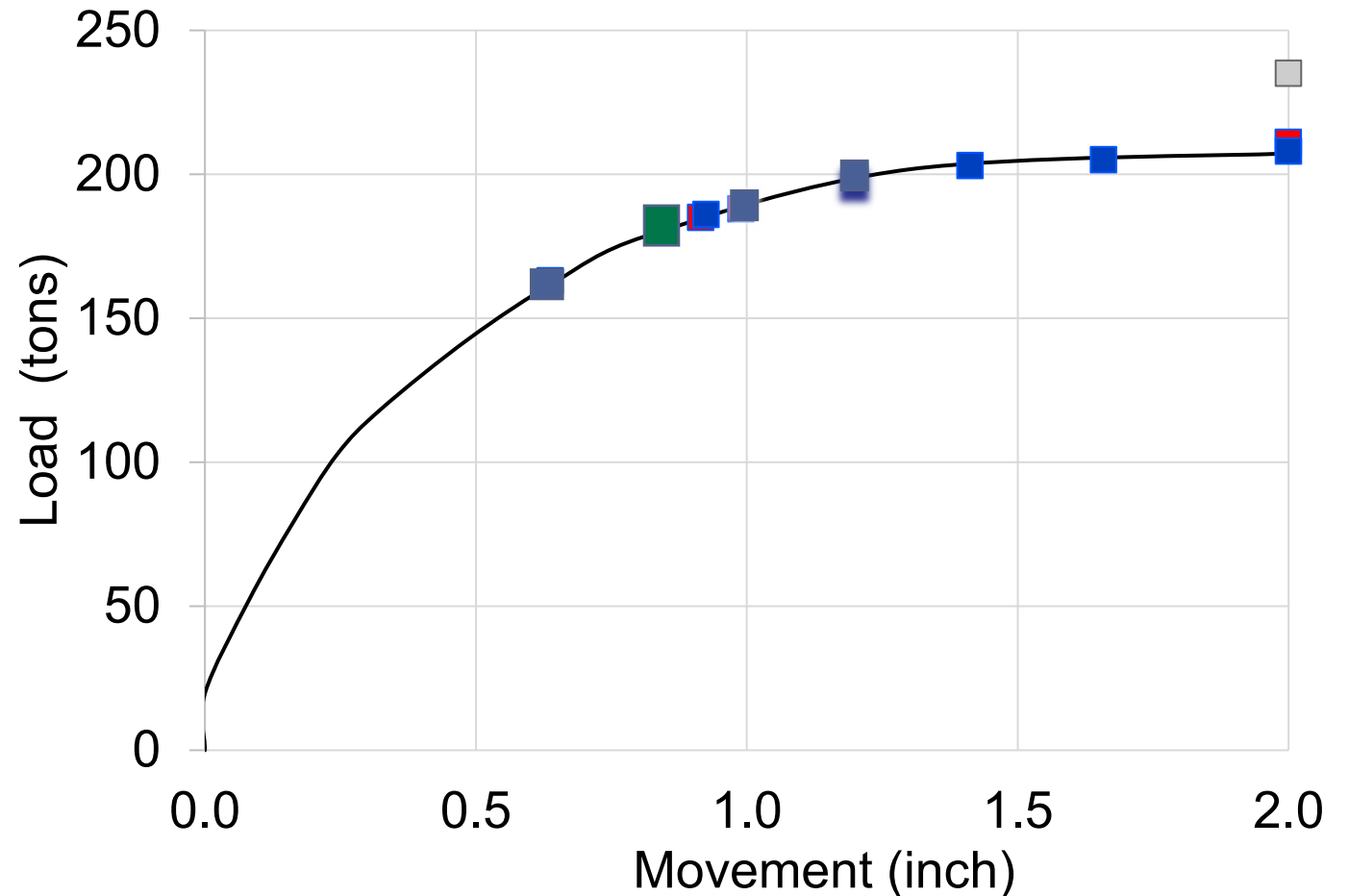


Static Load Test does not give a unique result



Failure criteria – no unique answer

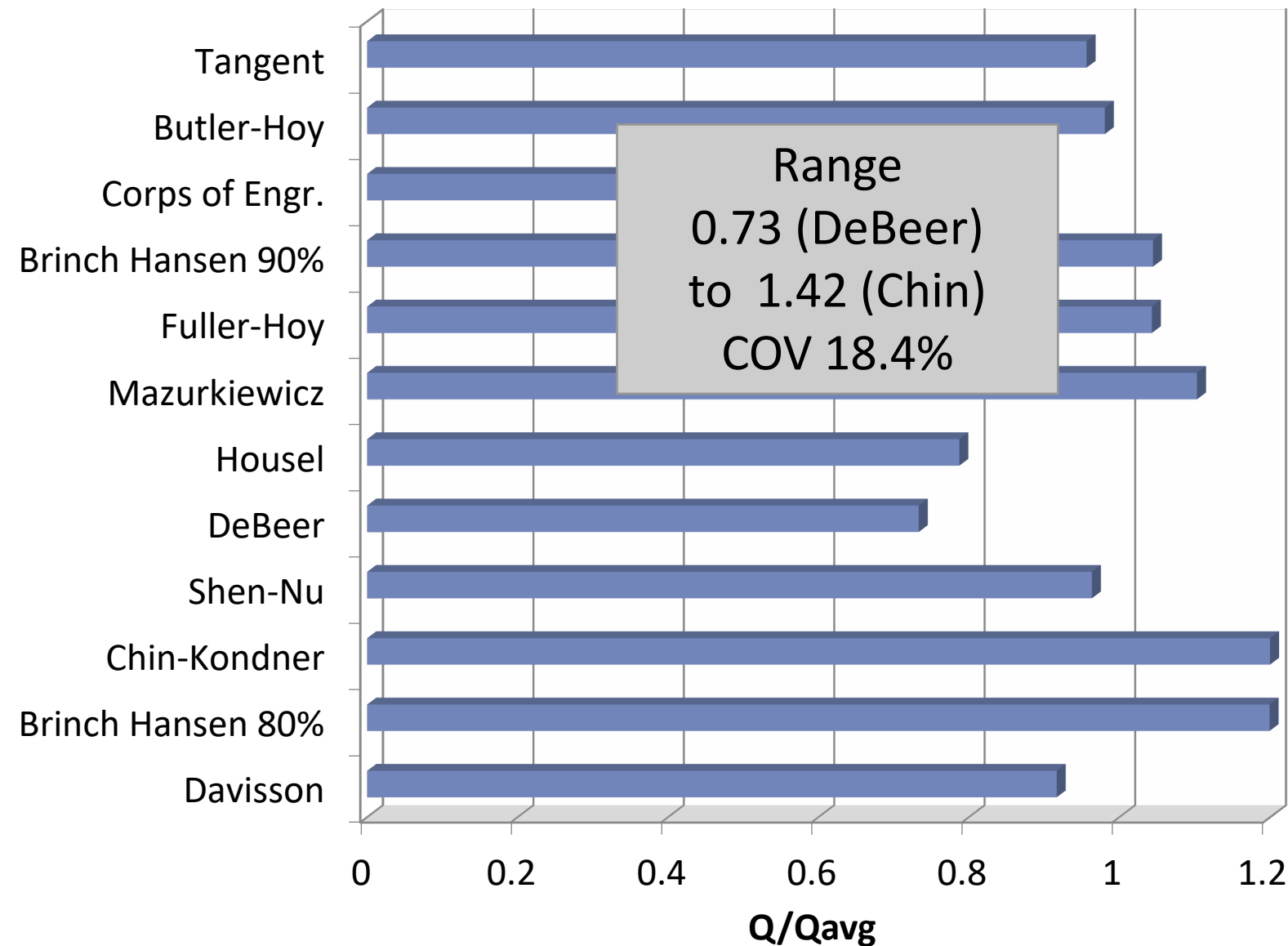
Chin	1.30
Brinch-Hansen 80%	1.17
Mazurkiewicz	1.15
Van Der Veen	1.13
Fuller and Hoy	1.12
De Beer	1.03
Butler and Hoy	1.02
Davisson	1.00
D/20	0.90
D/30 + elastic	1.04
D/10	1.10



After Fellenius, 1990.

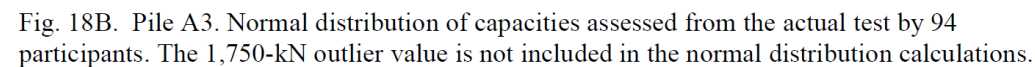
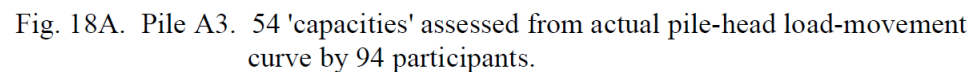
“Guidelines for the Interpretation of static loading tests”

Static Load Test Evaluations



- Duzceer & Saglamar, "Evaluation of Pile Load Test Results"
- DFI Conference - Nice France, 2002

Static Test evaluation- Not Unique !

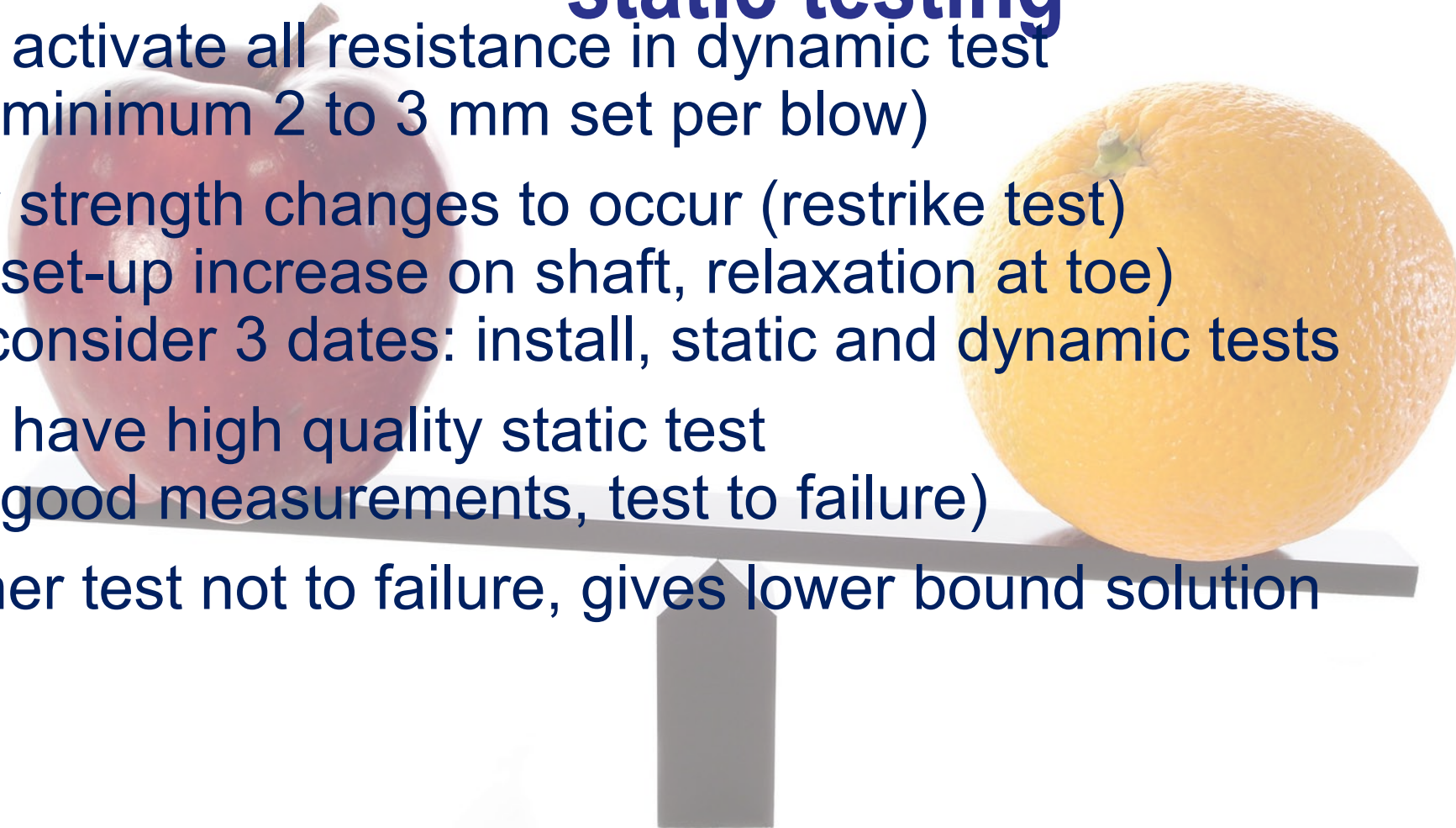


379. Fellenius, B.H., 2017. Report on the B.E.S.T. prediction survey of the 3rd CBFP event. Proceedings of the 3rd Bolivian International Conference on Deep Foundations, Santa Cruz de la Sierra, Bolivia, April 27-29, Vol. 3, pp. 7-25.



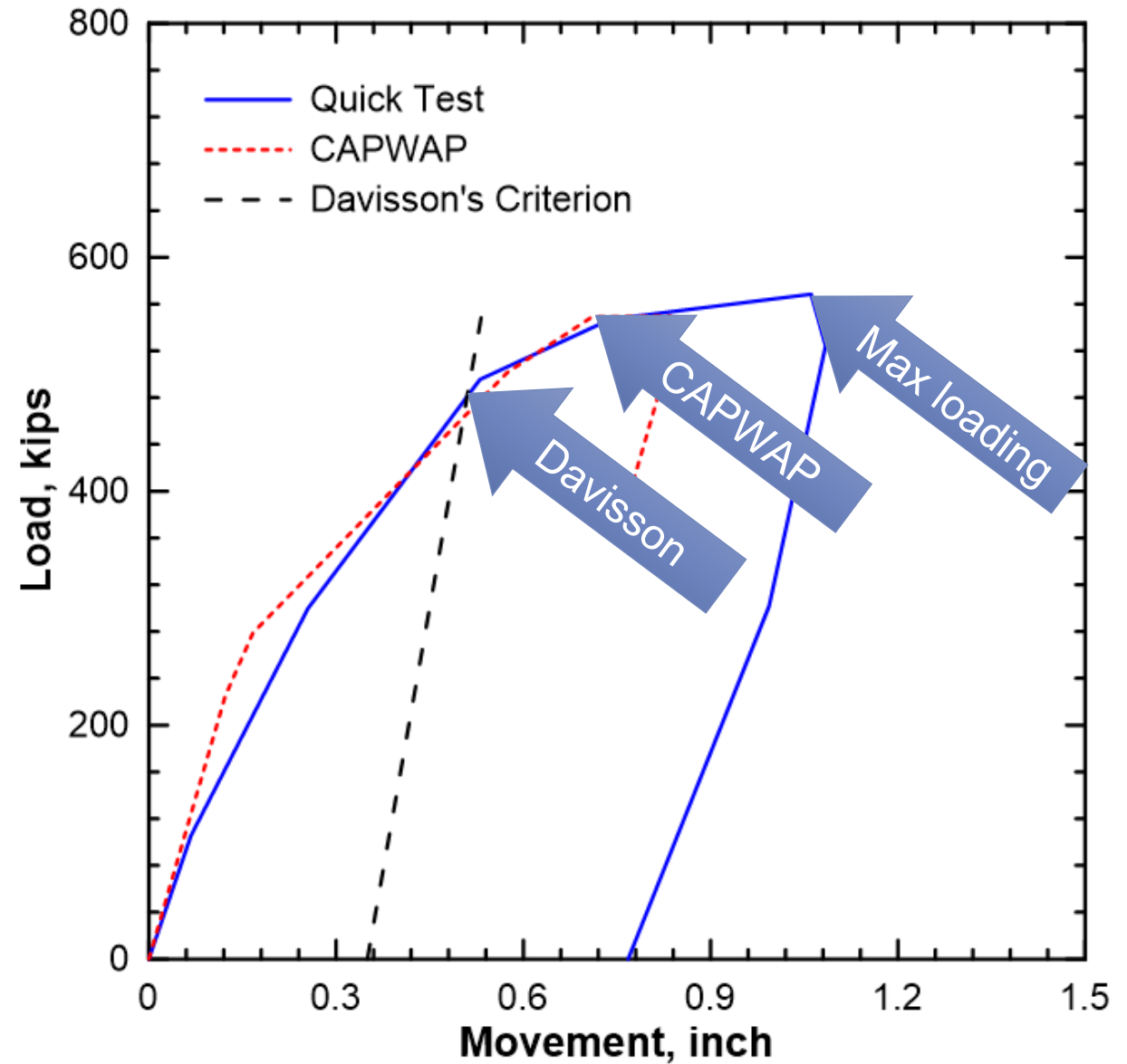
Guidelines for correlation of PDA with static testing

- must activate all resistance in dynamic test (minimum 2 to 3 mm set per blow)
- allow strength changes to occur (restrike test) (set-up increase on shaft, relaxation at toe)
consider 3 dates: install, static and dynamic tests
- must have high quality static test (good measurements, test to failure)
- if either test not to failure, gives lower bound solution



Load-Displacement Behavior

- 24-inch PSC+H Silty and Calcareous Sand
- Looking purely at numbers, the correlation may not appear





Correlations reported should include

- static test to failure
 - static test curve (with load cell)
- dynamic testing data
- F-V data versus time (e.g. measurements)
 - simulated LT curve
 - set per blow (min 0.1 inch; 2.5 mm)
 - 3 dates (install, static and dynamic tests)
 - soil description
-

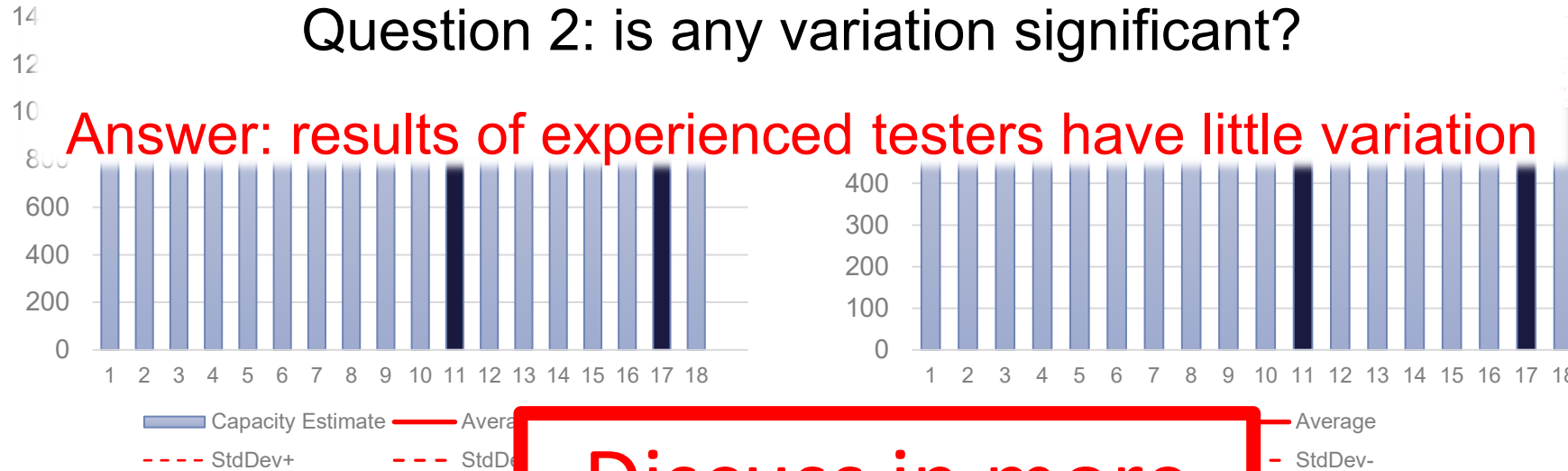


Does CAPWAP have a Unique Solution?

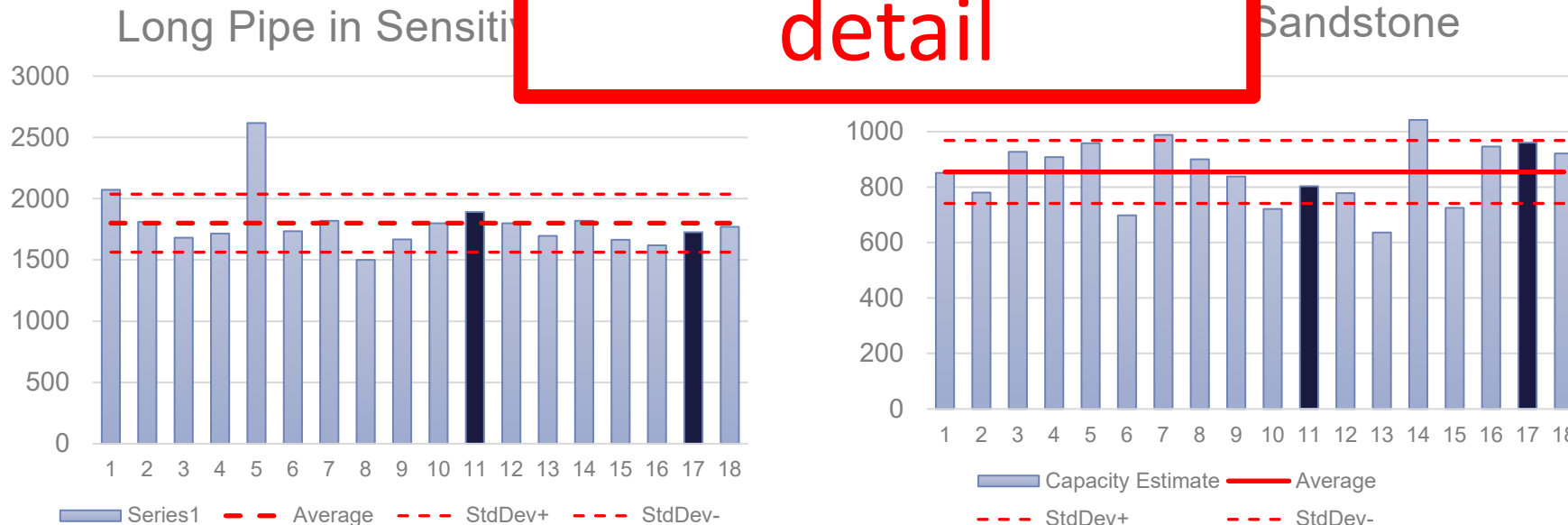
Capacity Considerations

Question 1: is CAPWAP result unique?
 Question 2: is any variation significant?

Answer: results of experienced testers have little variation



Discuss in more detail

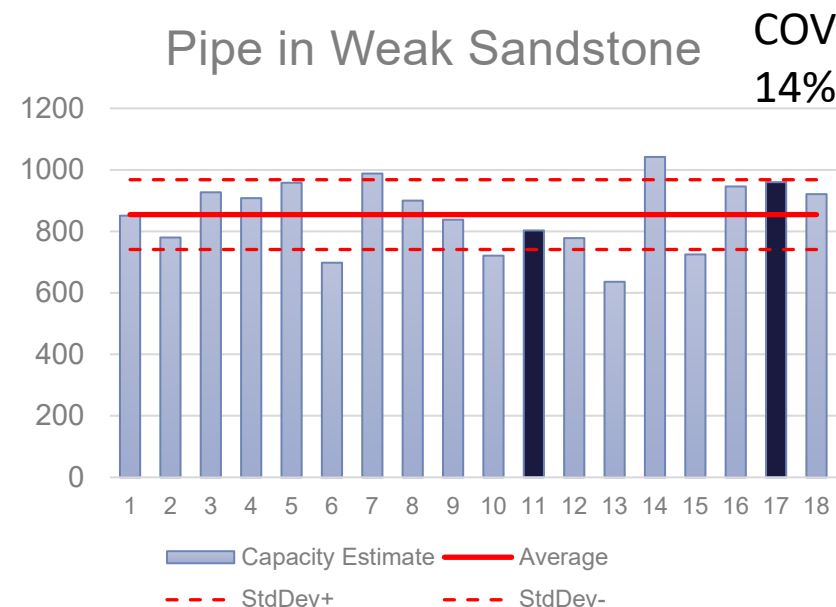
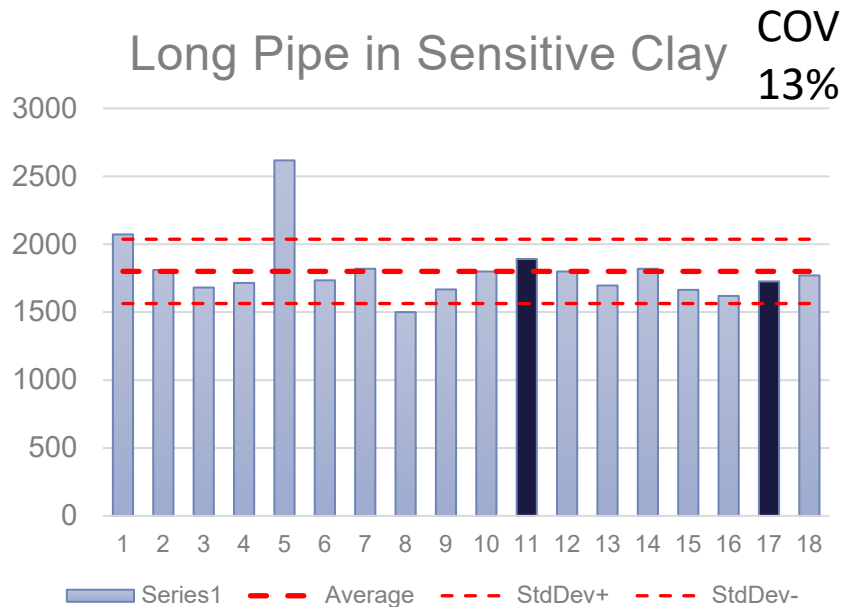
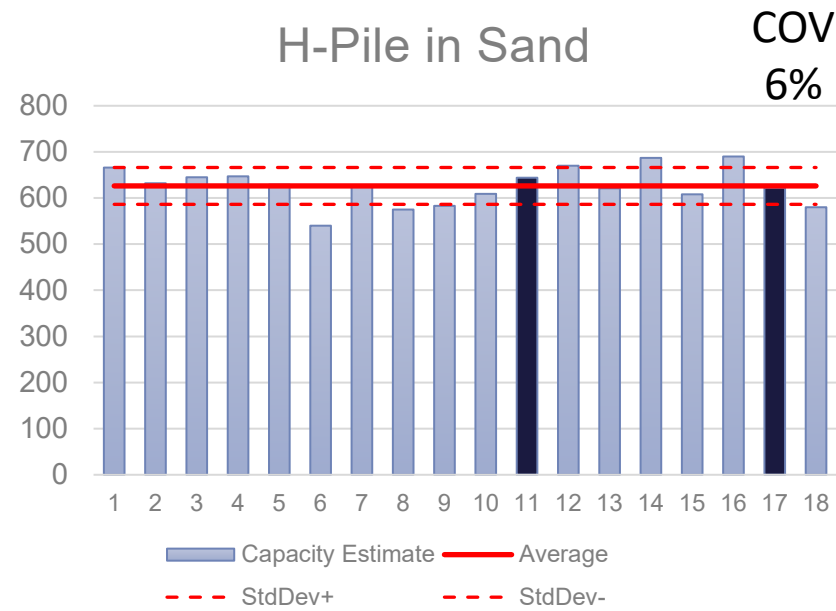
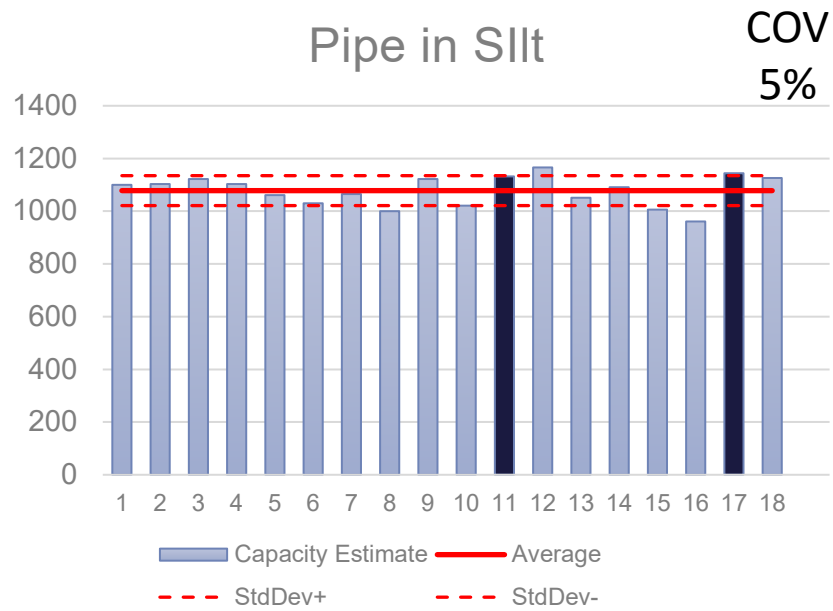


“Variation of CAPWAP Results as a Function of the Operator”

- by Fellenius, Third Int'l Conf. on Application of Stress-wave Theory to Piles, 1988

“Variation of CAPWAP Results as a Function of the Operator”

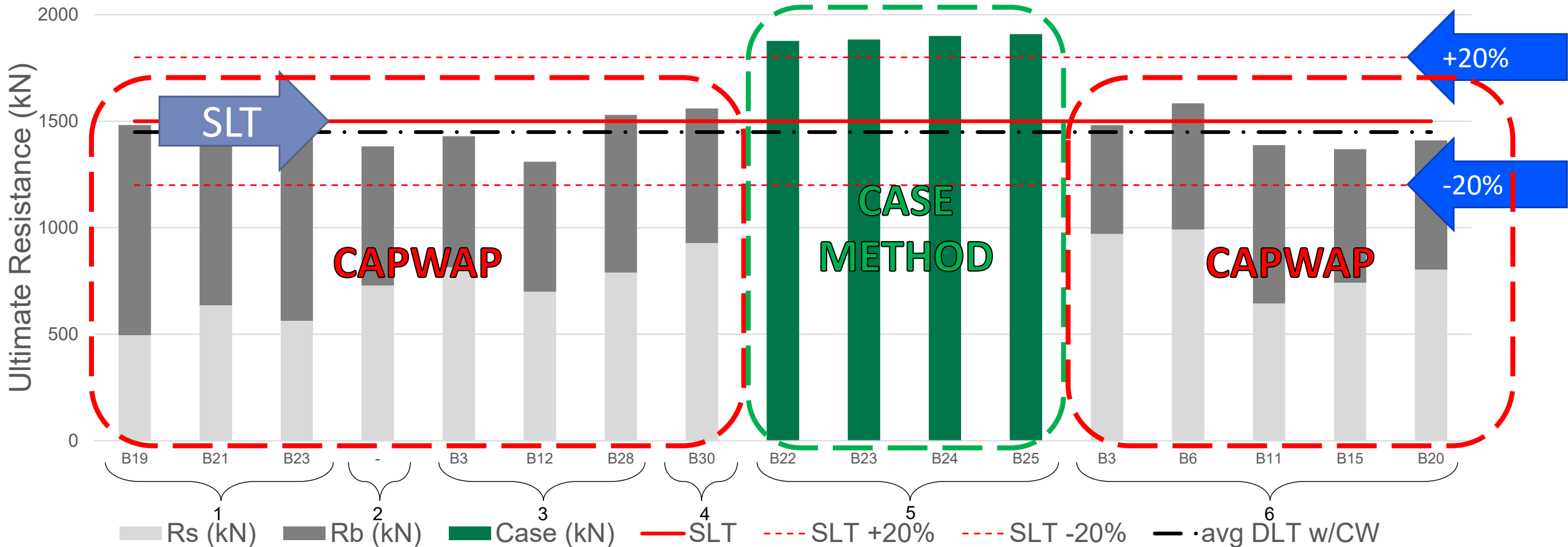
- by Fellenius, Third Int’l Conf. on Application of Stress-wave Theory to Piles, 1988





International Prediction Event on the Behavior of Bored, CFA and Driven Piles in CEFEUP/ISC'2 experimental site – 2003

High Strain Dynamic Test Results (referenced from Table 20)





Is CAPWAP Unique?

Unique solution?

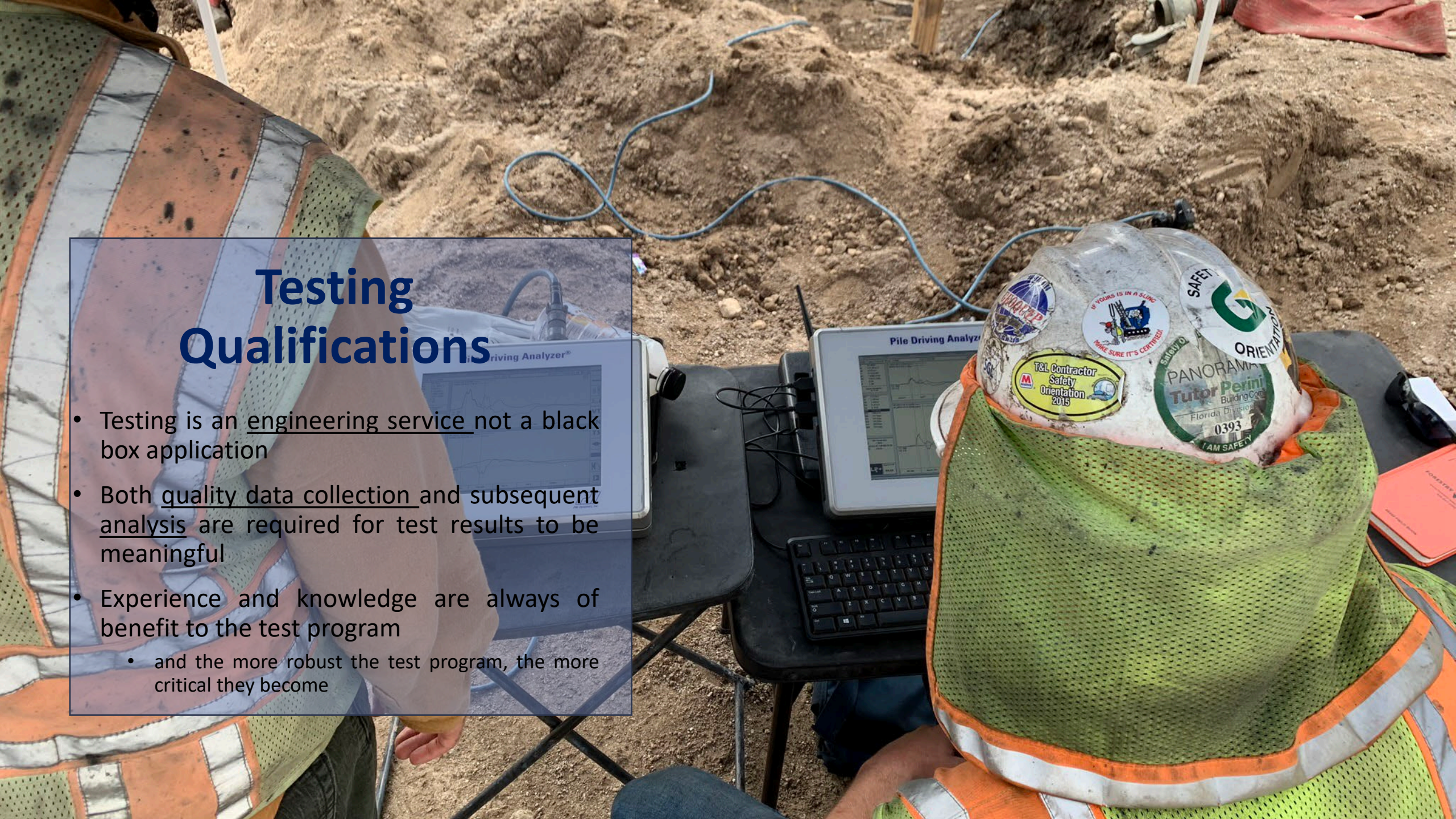
- Yes - if you pursue to get the absolute minimum error in Match Quality.

But does it really matter?

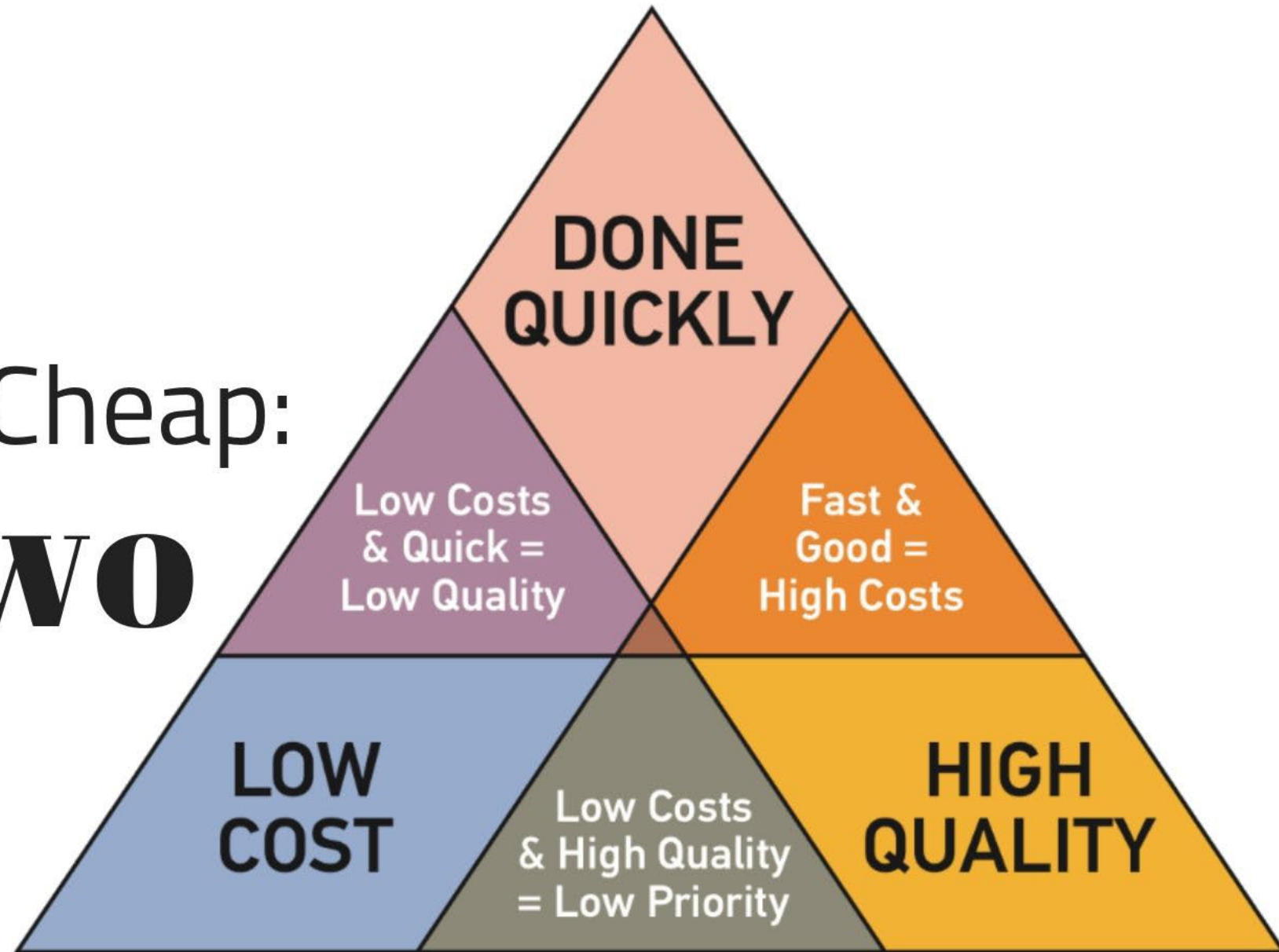
- No – since solutions are generally all similar (within reasonable tolerance) and different blows may give slightly different answers
 - **Static test interpretation also is not unique!**
-

Testing Qualifications

- Testing is an engineering service not a black box application
- Both quality data collection and subsequent analysis are required for test results to be meaningful
- Experience and knowledge are always of benefit to the test program
 - and the more robust the test program, the more critical they become



Good, Fast, or Cheap:
Pick Two





Dynamic Test Results

- Data should be in accordance with ASTM but merely stating that in specifications may be inadequate.
 - ASTM covers the 'how to' but analysis of the data should then be used to help establish driving criteria
 - Results should be considered and as testing progresses, procedures can be refined
-

Specifying a Test Program?

Consider:

- What are you trying to characterize?
- Where is the resistance expected based on soil investigations?
- Should soil set-up be considered?
 - Restrikes would give a better indication of long-term resistance
 - End of drive capacity is still useful to establish a baseline for quantification of setup factors for the site.
 - Layers subject to scour or down-drag may also be quantified during testing
- Piles driven to rock may have sufficient capacity at EOID





Site Characterization

- What is the variability of the site?
 - Inadequate soil investigations may lead to 'surprise' results in a test program.
 - Soil investigations can help define the scope of the test program:
 - Fairly uniform sites may point to a more limited test program
 - Highly variable sites may require a more robust test program



Where NOT to Start?



- Unfortunately, many specs are just a copy of a previous specifications
 - May not be applicable to your project
 - May be outdated in terms of current state of practice
 - Identification of potential cost savings is best identified early



Capacity Considerations – Summary

- Dynamic Testing has a long-published correlation with SLT
 - In the typical range of the applied load CAPWAP using the standard model adequately accounts for the dynamic resistance during the impact event.
 - Dynamic Test Results should consider:
 - Was the resistance fully mobilized?
 - Does the test reflect the long-term soil conditions (restrike)?
-



Navy Pier

- Chicago's busiest attraction - 9 million visitors per year
- Built in 1916
- Many uses since built
- Opened as a tourist attraction in 1995

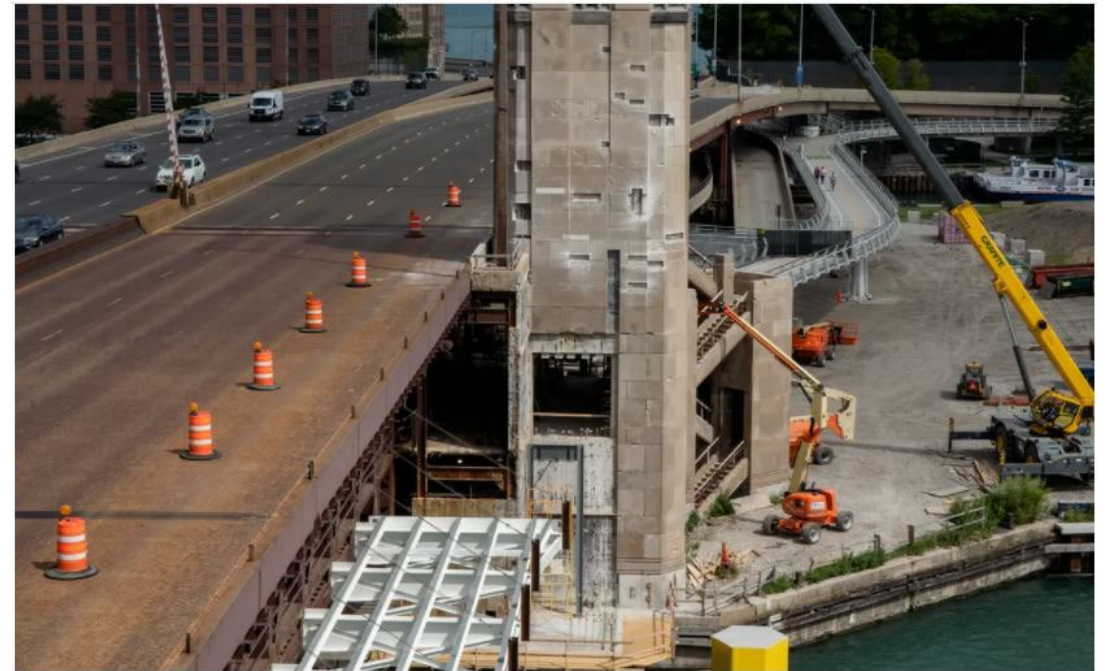
The Problem – Congestion!



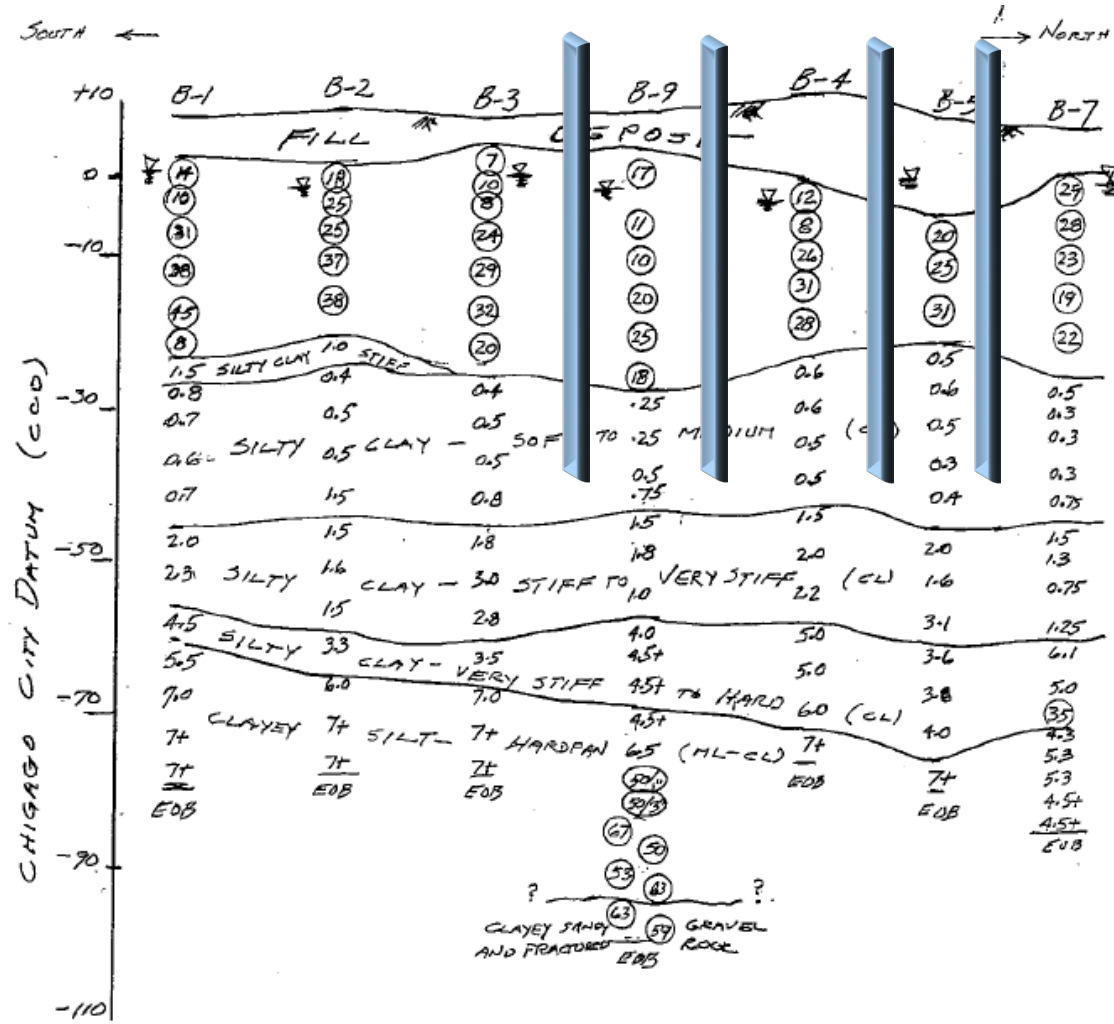
Flyover Solution



Flyover Phase II



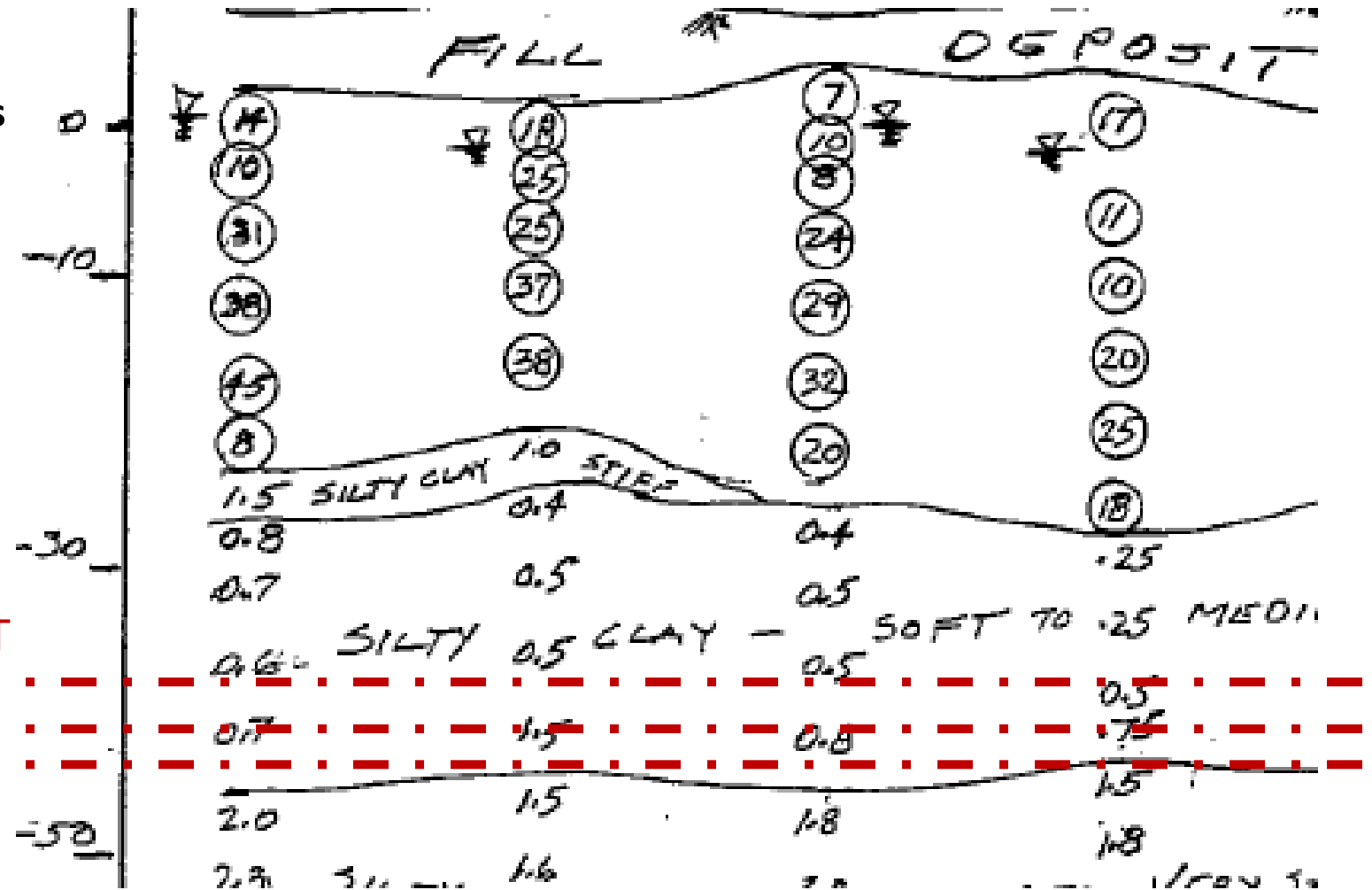
Flyover Phase II – Soil Profile



Flyover Phase II – Test Pile Program

- HP 10 x 42 Piles - Targeting Tip Elevations
- 5 Test Piles – All dynamically tested
- Short and Long Term Restrikes (1 and 30 days)
- One Static Load Test
- PILECO D8-22

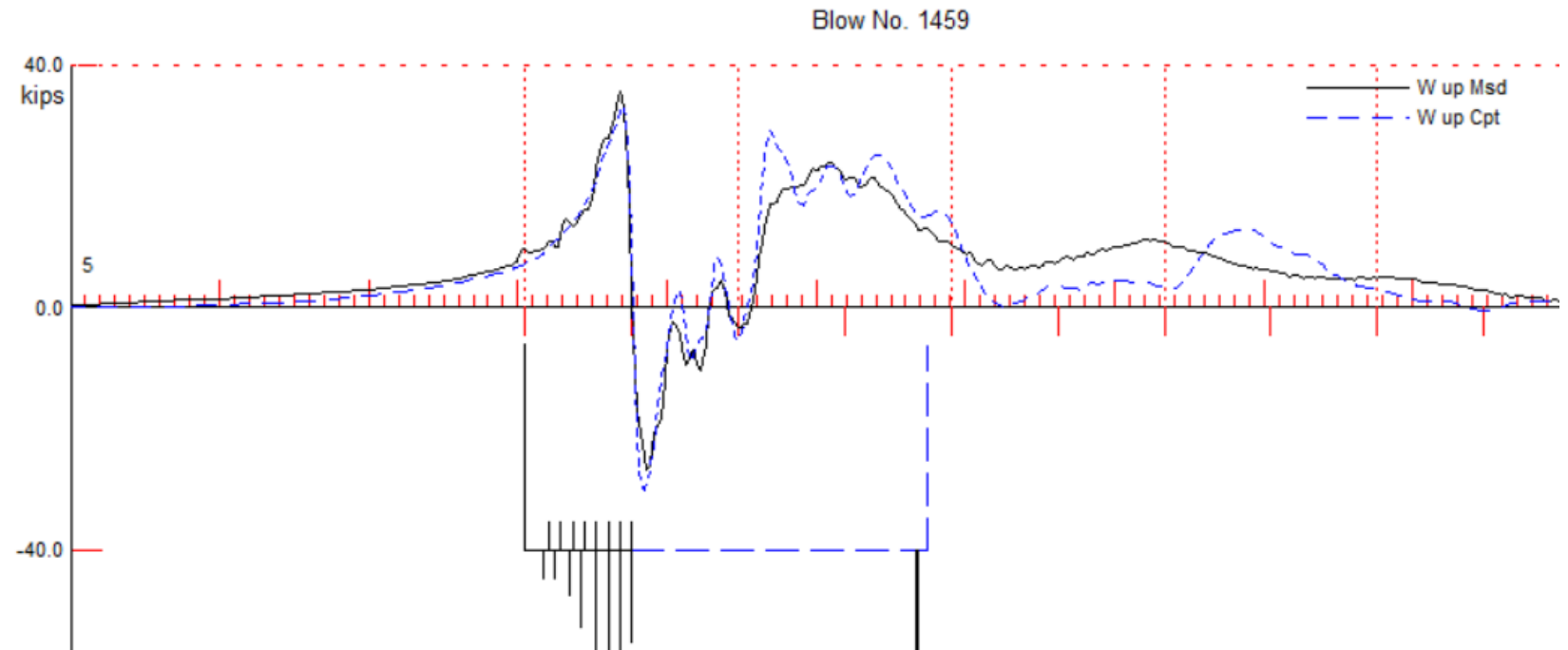
Two Piles
Including SLT



End of Drive Results

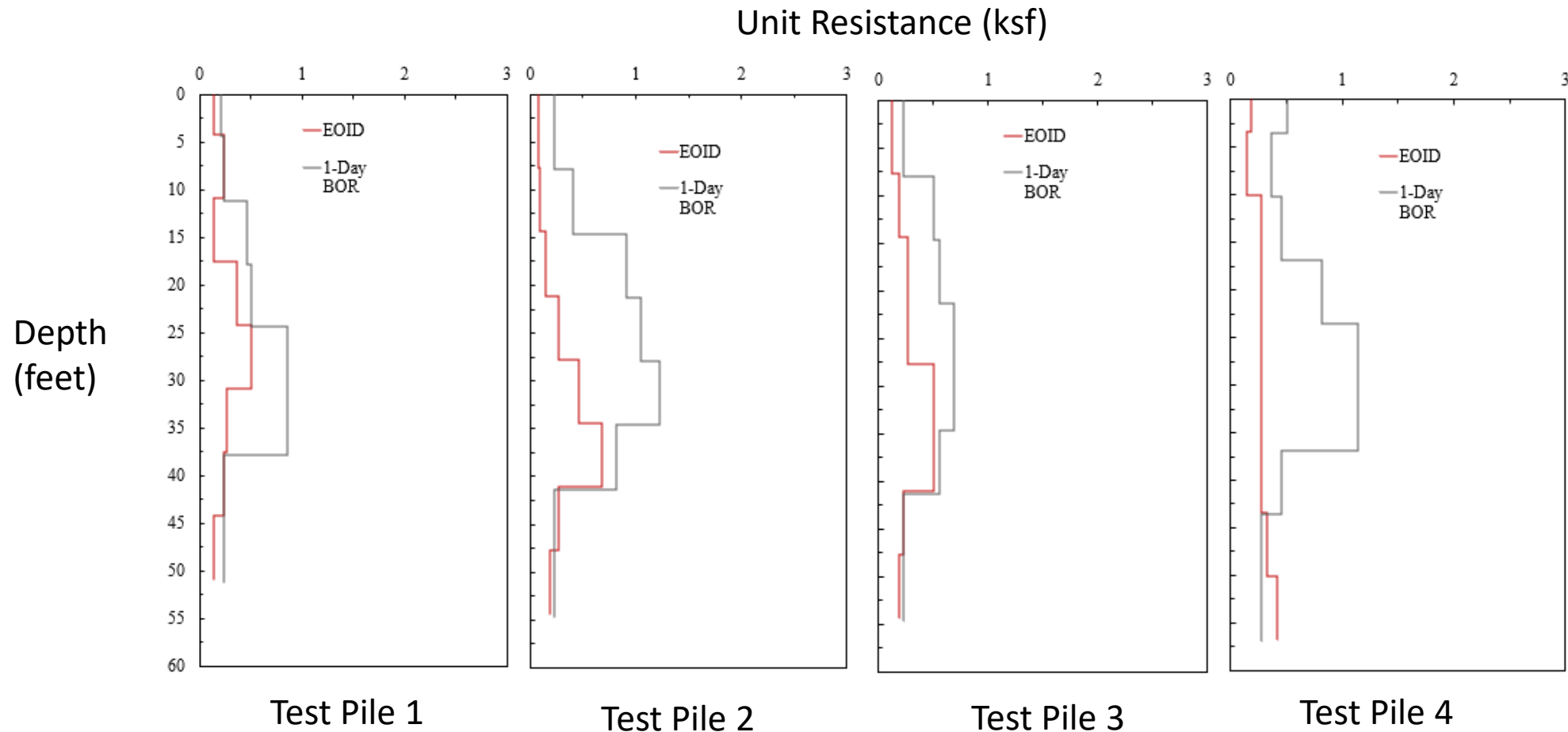
Res	R	Unit R	Delta	Depth
	kips	kips/ft^2	kips	ft
1	2.0	0.08	0.6	7.7
2	2.0	0.09	-1.5	14.4
3	3.0	0.14	-0.6	21.1
4	5.0	0.23	-1.0	27.7
5	9.0	0.41	2.3	34.4
6	13.0	0.59	0.8	41.1
7	8.0	0.36	1.8	47.7
8	6.0	0.27	-1.1	54.4
Toe	4.0	5.89	-2.1	54.4

All Piles - 47 – 58 kips



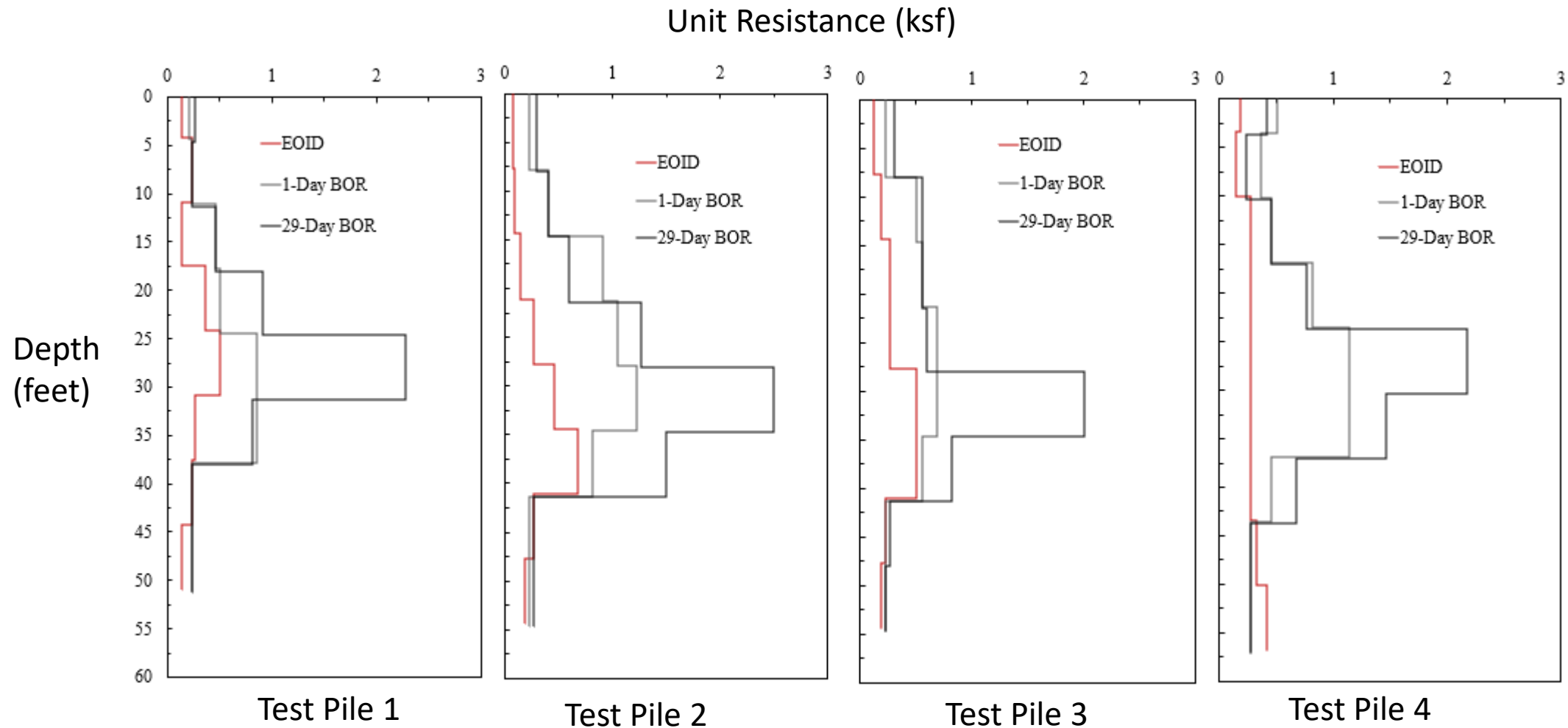
Short Term Restrikes

- Setup Factor - $\text{Friction}_{\text{restrike}} / \text{Friction}_{\text{end of driving}}$
ranged from 1.6 – 2.3



Long Term Restrikes

- Setup Factor ranged from 2.4 – 3.3



Static Load Test

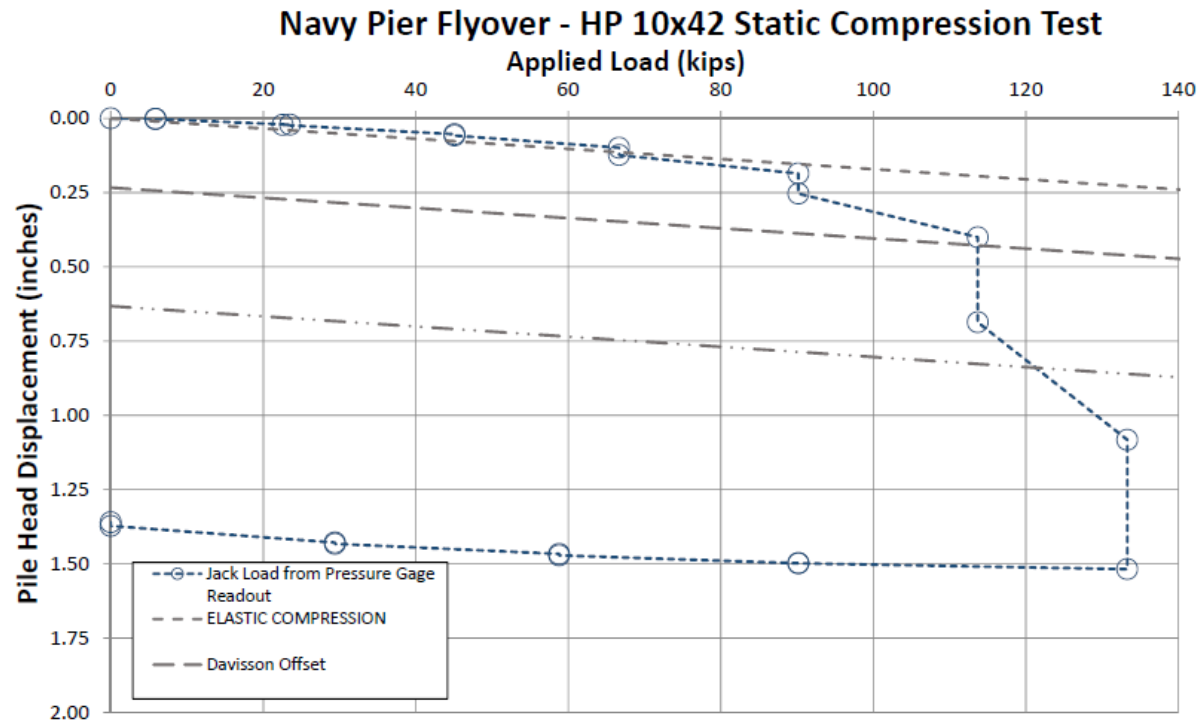
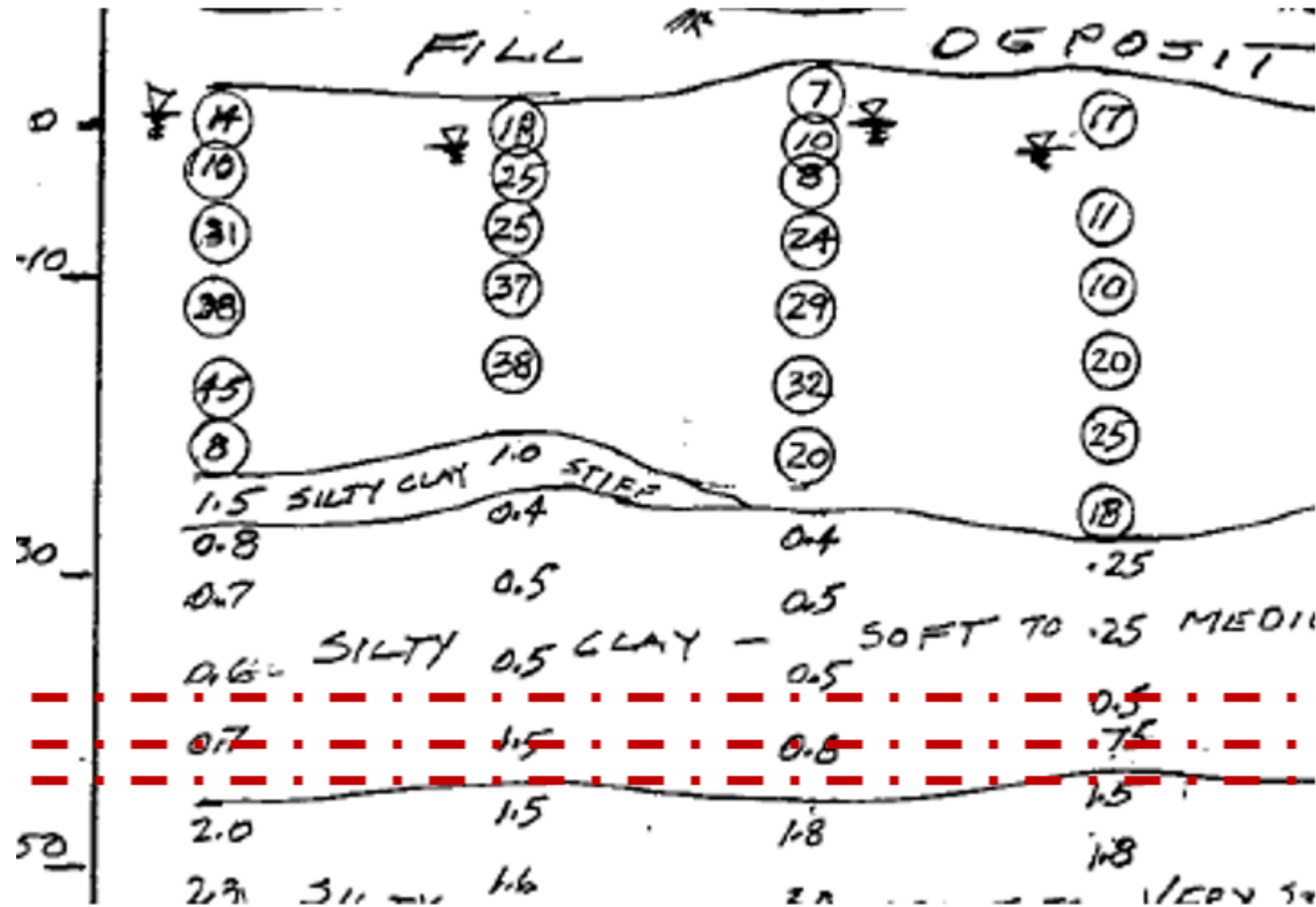


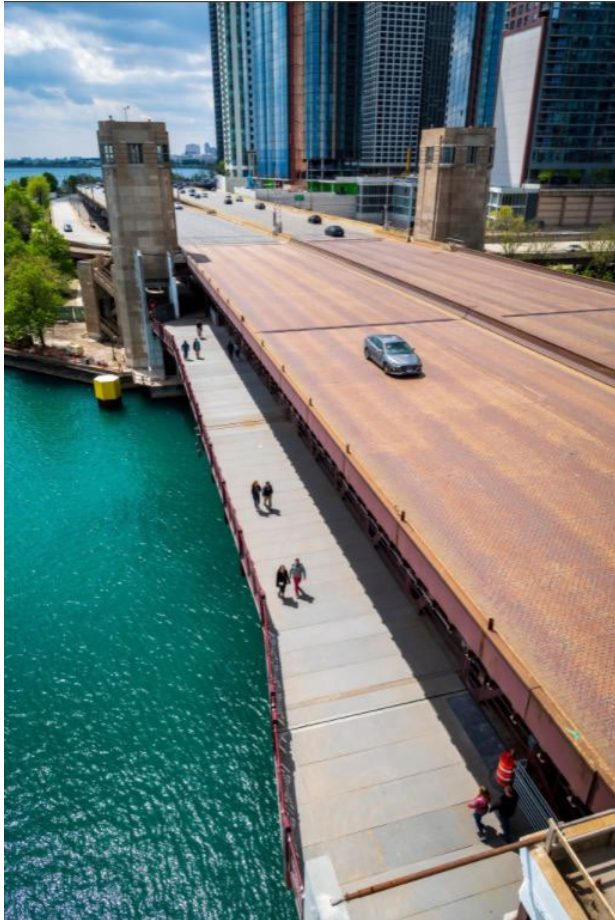
Figure 2: Static Compression Test Results

- Davisson Offset – 115 kips
- City of Chicago Settlement Criteria
- based on pile diameter
- $\frac{1}{5} \sqrt{d / \log(d)}$ - ~120 kips

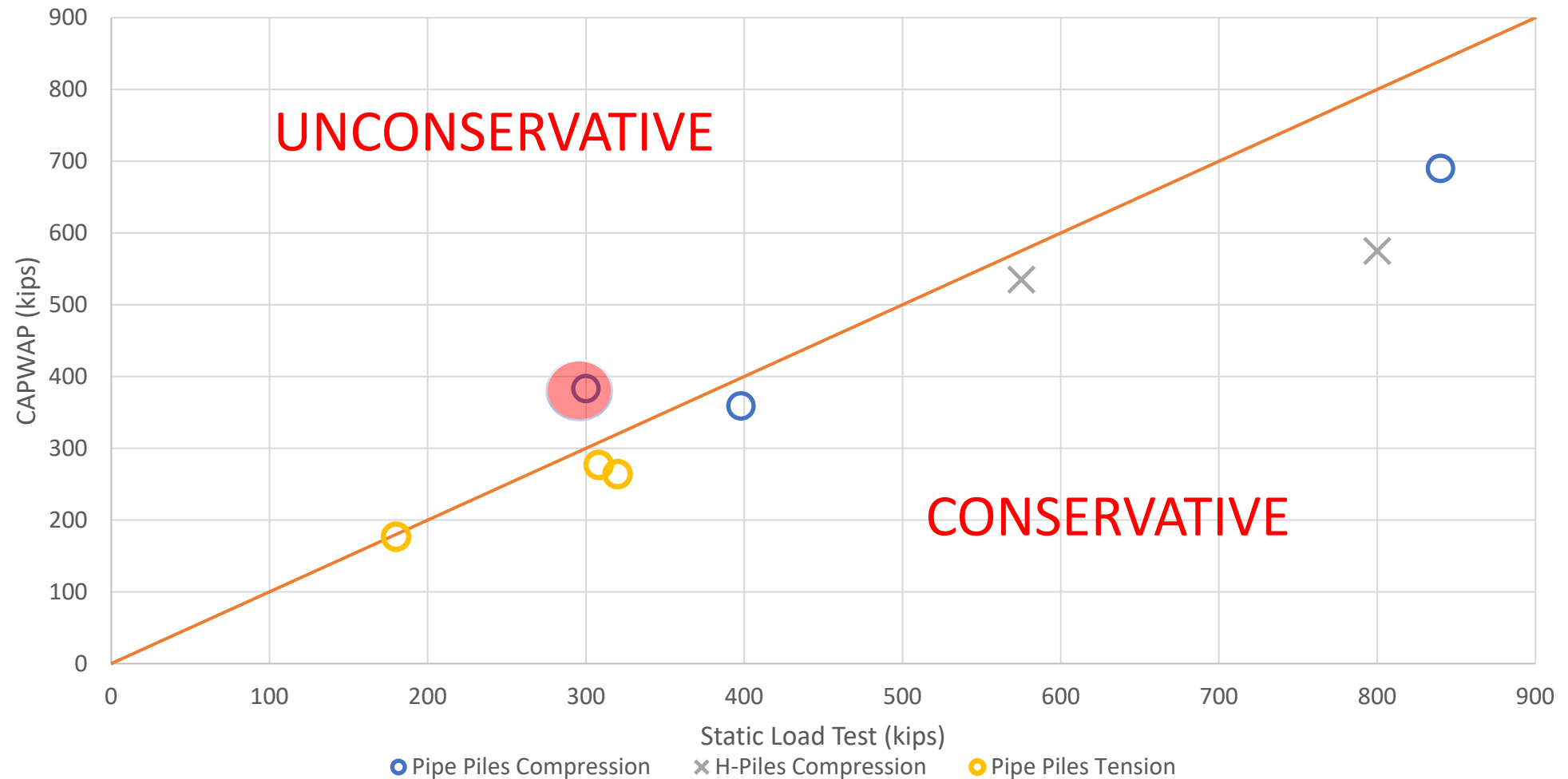
Final Capacity Results



Completed Navy Pier Flyover

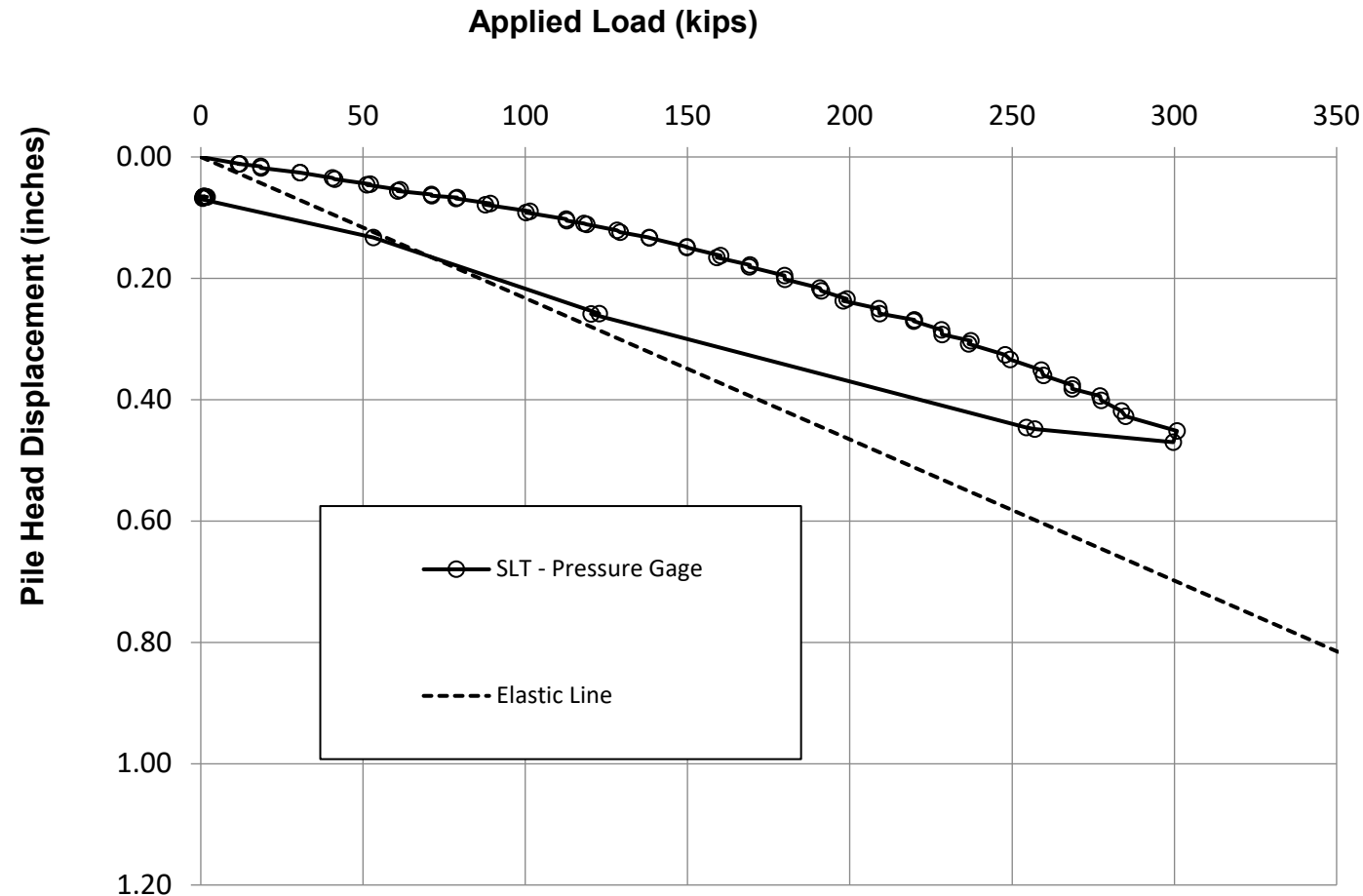


Test Pile Programs – Midwest Projects

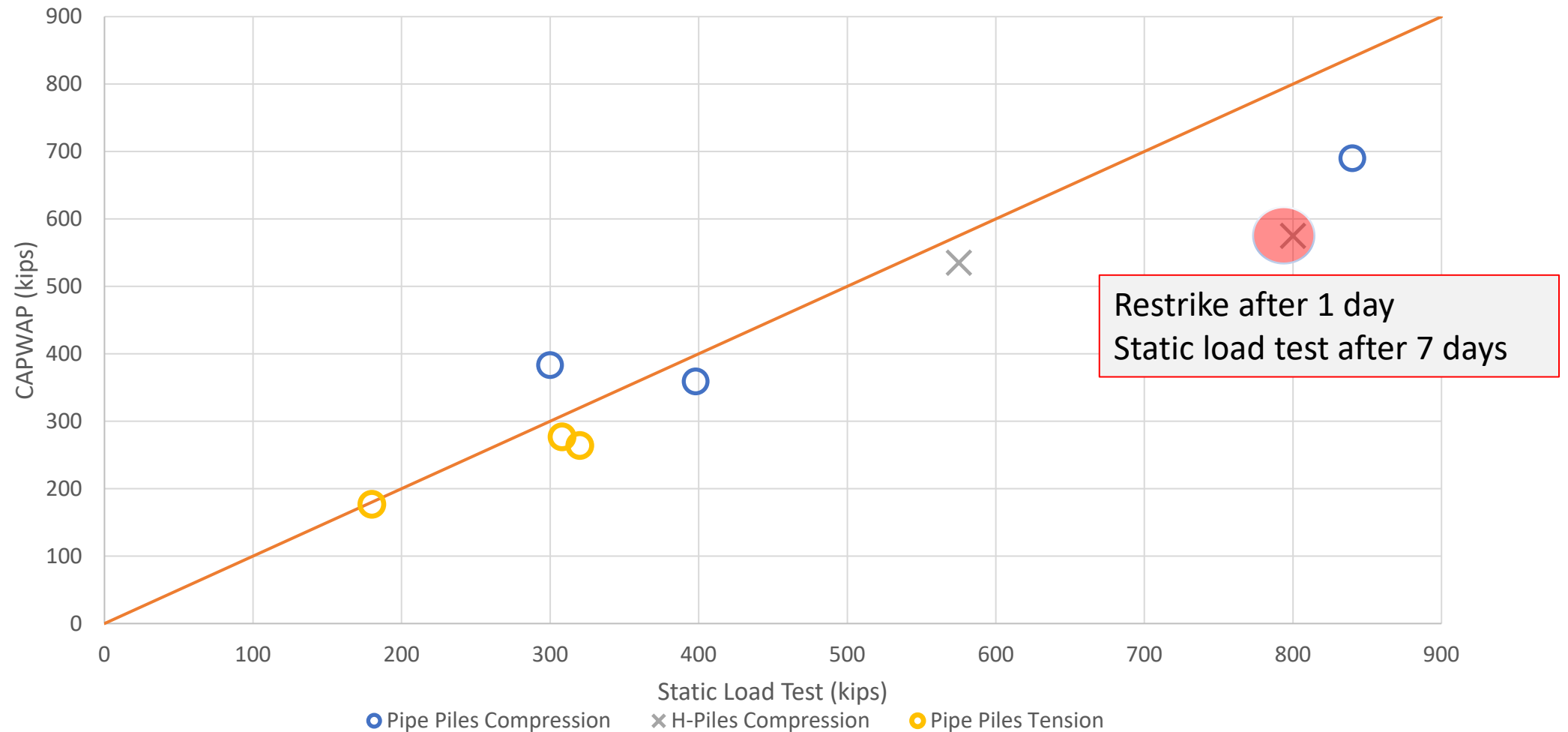


Test Pile Programs – Midwest Projects

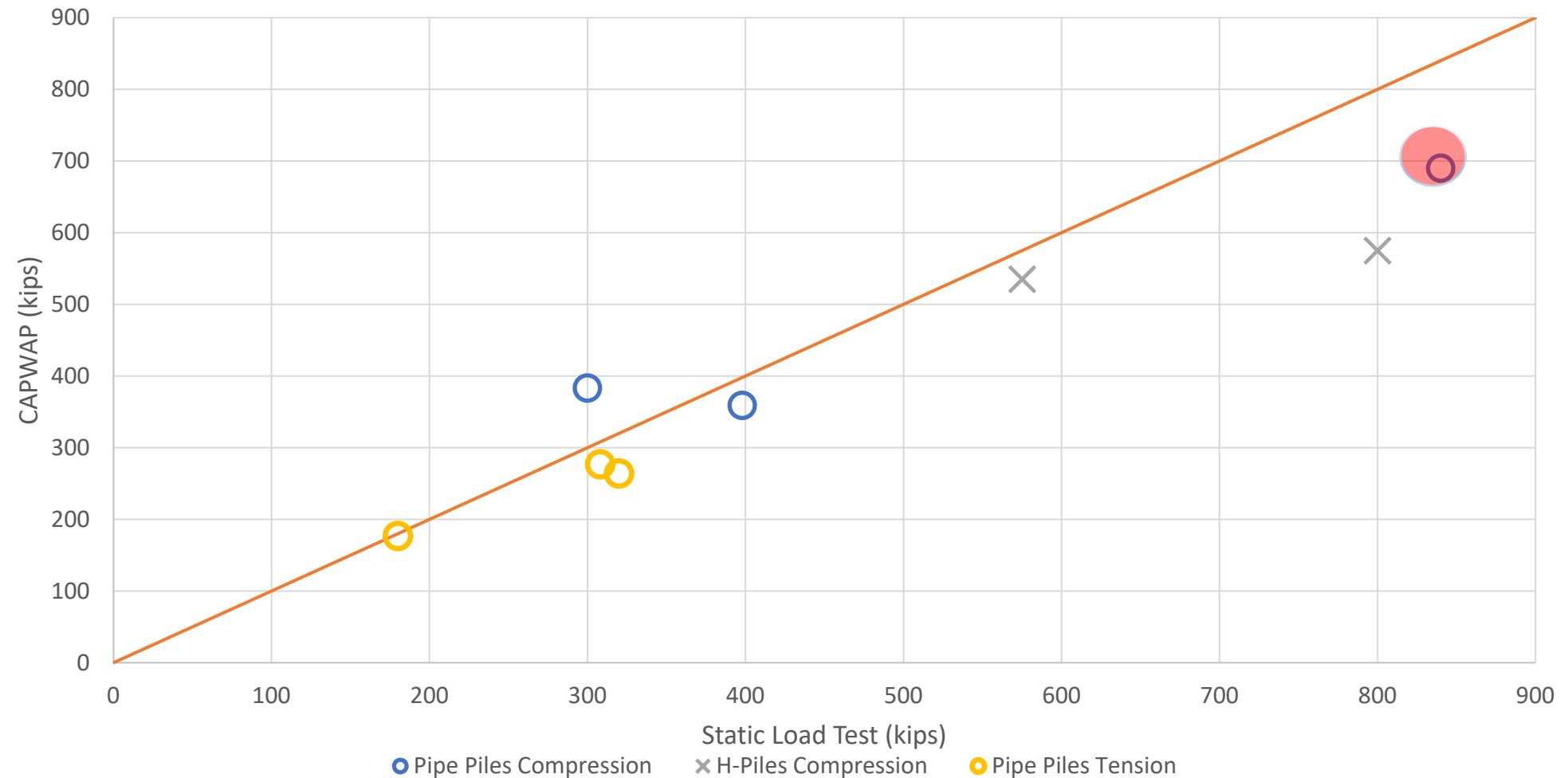
16 Inch CEP Static Compression Test



Test Pile Programs – Midwest Projects



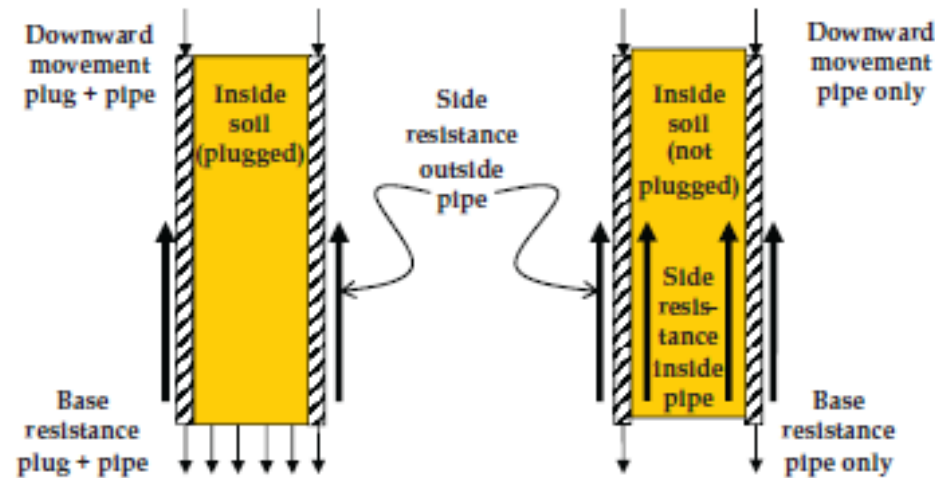
Test Pile Programs – Midwest Projects



Test Pile Programs – Midwest Projects

Static Loading

Increasing Capacity
(End Bearing) with
Further Displacement



Dynamic Loading

Low Blow Count and
Decreasing Capacity during
Restrike

NCHRP 478 - Brown, Thompson III

Conclusions

These Test Pile Programs had some combination of

- Test events at inconsistent intervals
- Multiple tests on a single pile

The most accurate method to compare dynamic and static load test results should have

- A separate pile for each test method
- Similar depths and driving resistances
- Tests performed on the same time interval after installation