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Inverse Analysis of Driven Pile Capacity in Sands

Don C. Warrington
University of Tennessee at Chattanooga

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Don C. Warrington, P.E., PhD.
University of Tennessee at Chattanooga
College of Engineering and Computer Science
Department of Mechanical Engineering

RESEARCH DIALOGUES 2020

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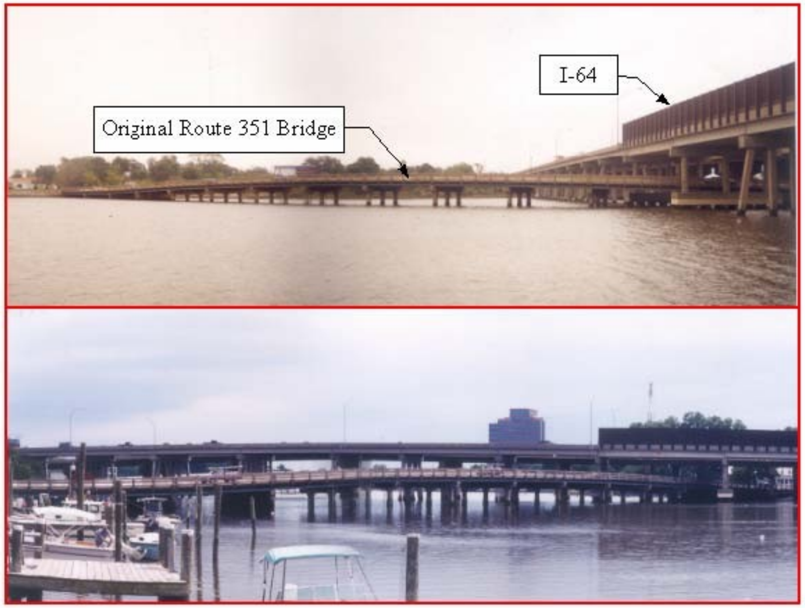
Introduction

- The STADYN computer program was developed to analyze both static and dynamic installation response of impact-driven pile-soil systems
- Recent development have broadened the application of the program to piles driven into predominantly cohesionless stratigraphies
- Previous application of the program to an inverse analysis (given pile top dynamic data, determine static capacity) used a test case with many difficulties
- The need for a well-documented test case to compare STADYN results with has become pressing for the progress of the software

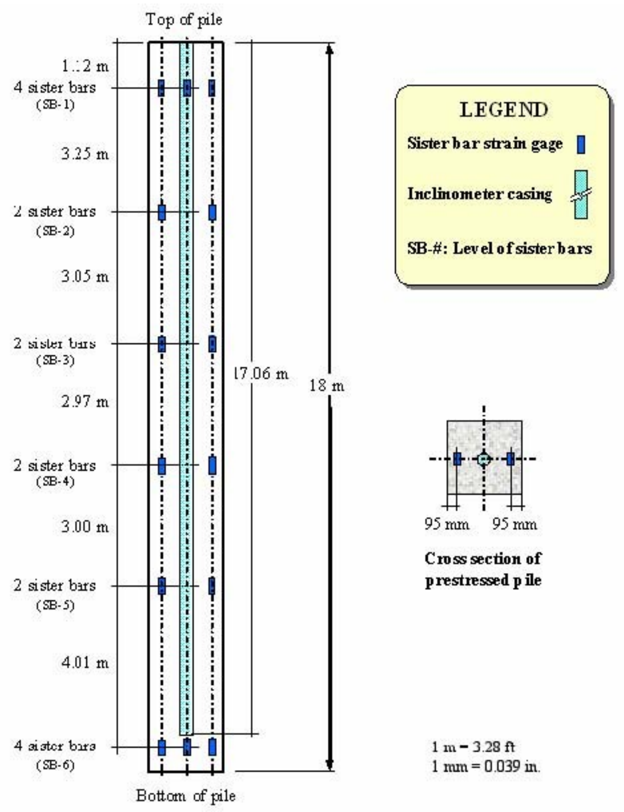
Test Case

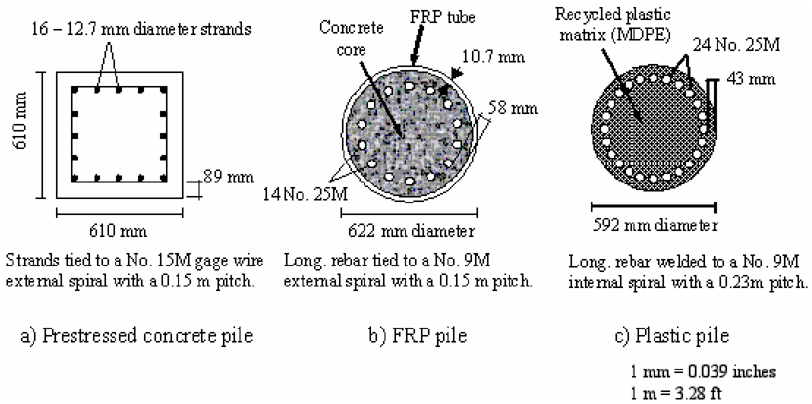
- Replacement of Route 351 Bridge in Hampton, VA
- Test case featured plastic piles, but STADYN comparison will concentrate on the 20” prestressed concrete piles
- Test well documented in Pando et.al. (2006), FHWA-HRT-04-43



(Photos taken from the north side)

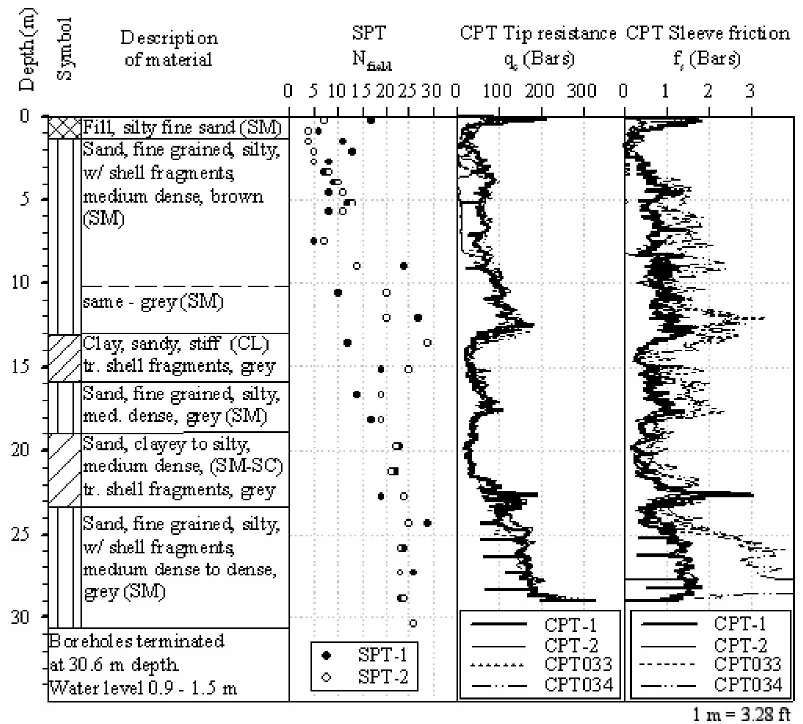
Pile Configuration





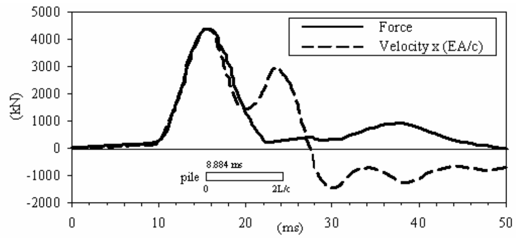
Only concrete pile considered.
Pile driven to a tip elevation of 16.74 m

Typical Soil Stratigraphy and Conversion to ξ–η Soil Scheme

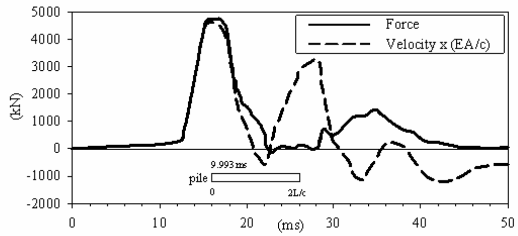


Layer	Depth of Layer Bottom, m	ξ	η
1	1.0	-0.8	-0.6
2	1.3	-0.8	-0.6
3	10	-0.8	-0.2
4	13	0.8	0.2
5	16	-0.8	0.2
6	16.8	-0.4	0.2
Toe	33.5	-0.4	0.2

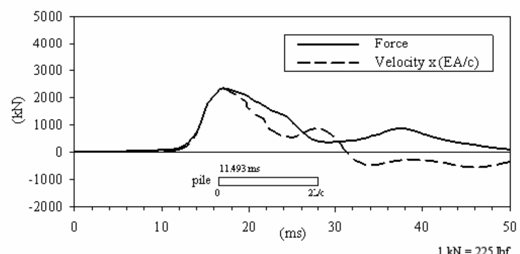
Dynamic and Static Pile Head Responses



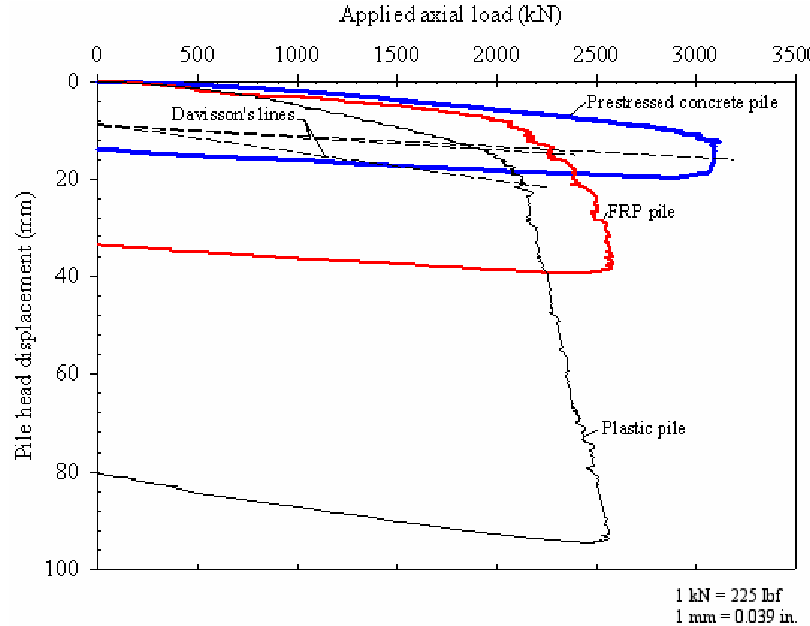
(a) Prestressed concrete pile

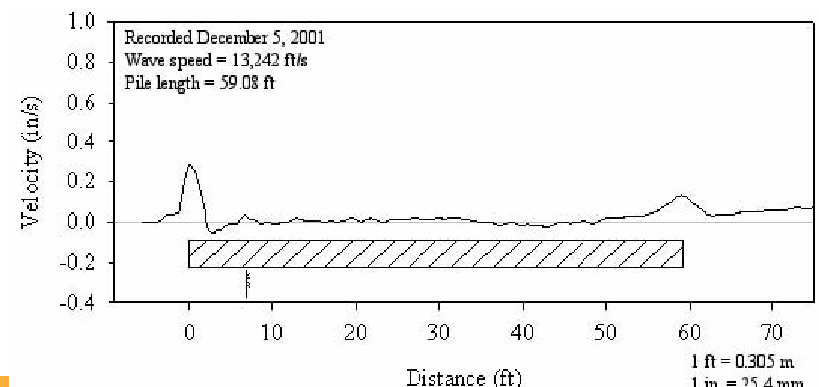


(b) FRP composite pile

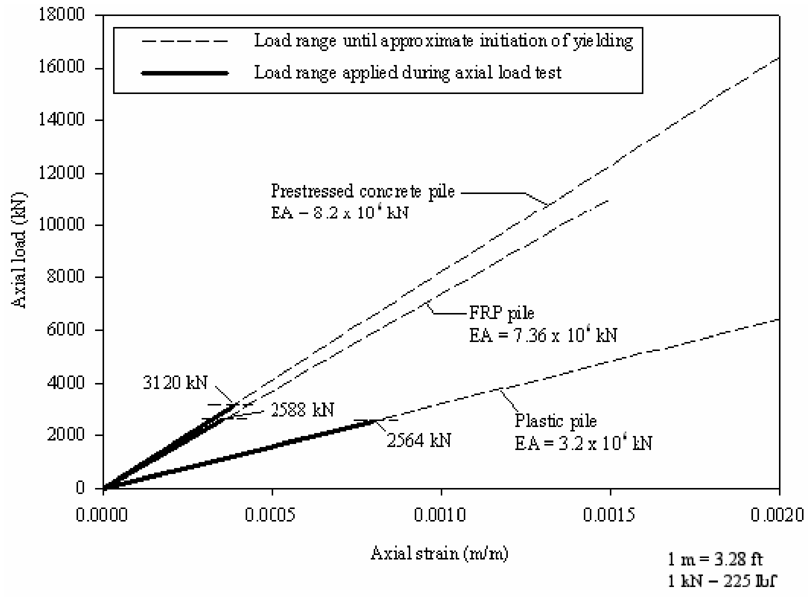


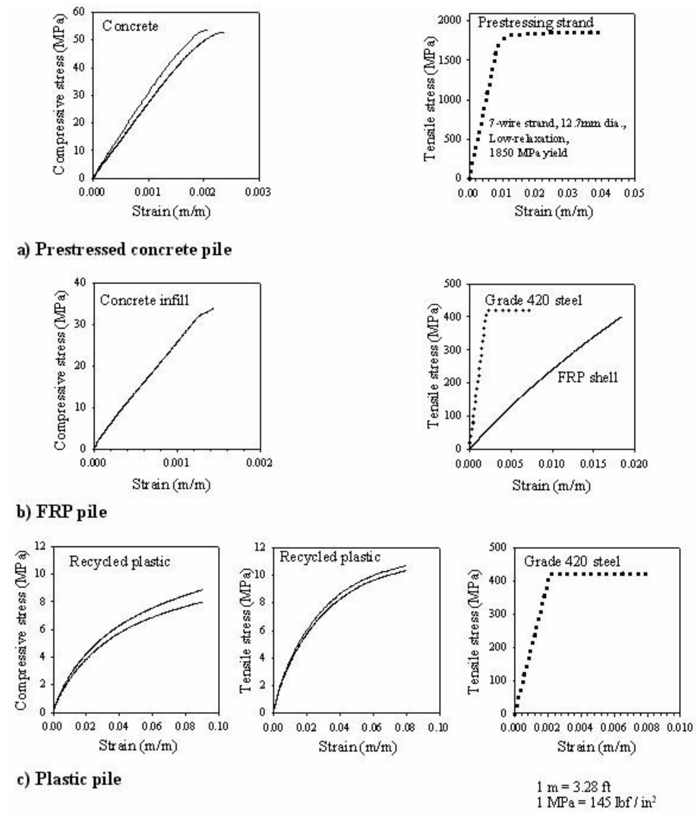
(c) Plastic composite pile





Data on Axial Load-Strain Behavior and Young's Modulus of Concrete





Determination of Actual Young's Modulus of Concrete

- Material properties and axial load-strain behavior indicated that the Young's Modulus of concrete was around 22-25 GPa
- Use of this value in STADYN yielded poor tracking/phase matching between computed and actual velocity-time histories
- Results for dynamic tests (PDA, PIT) suggested that, with standard concrete density, Young's Modulus was around 39.5 GPa is more appropriate
- STADYN's standard value of Young's Modulus is around 32.7 GPa
- Both of these values (with preference for the higher one) are used going forward

Test Cases for STADYN

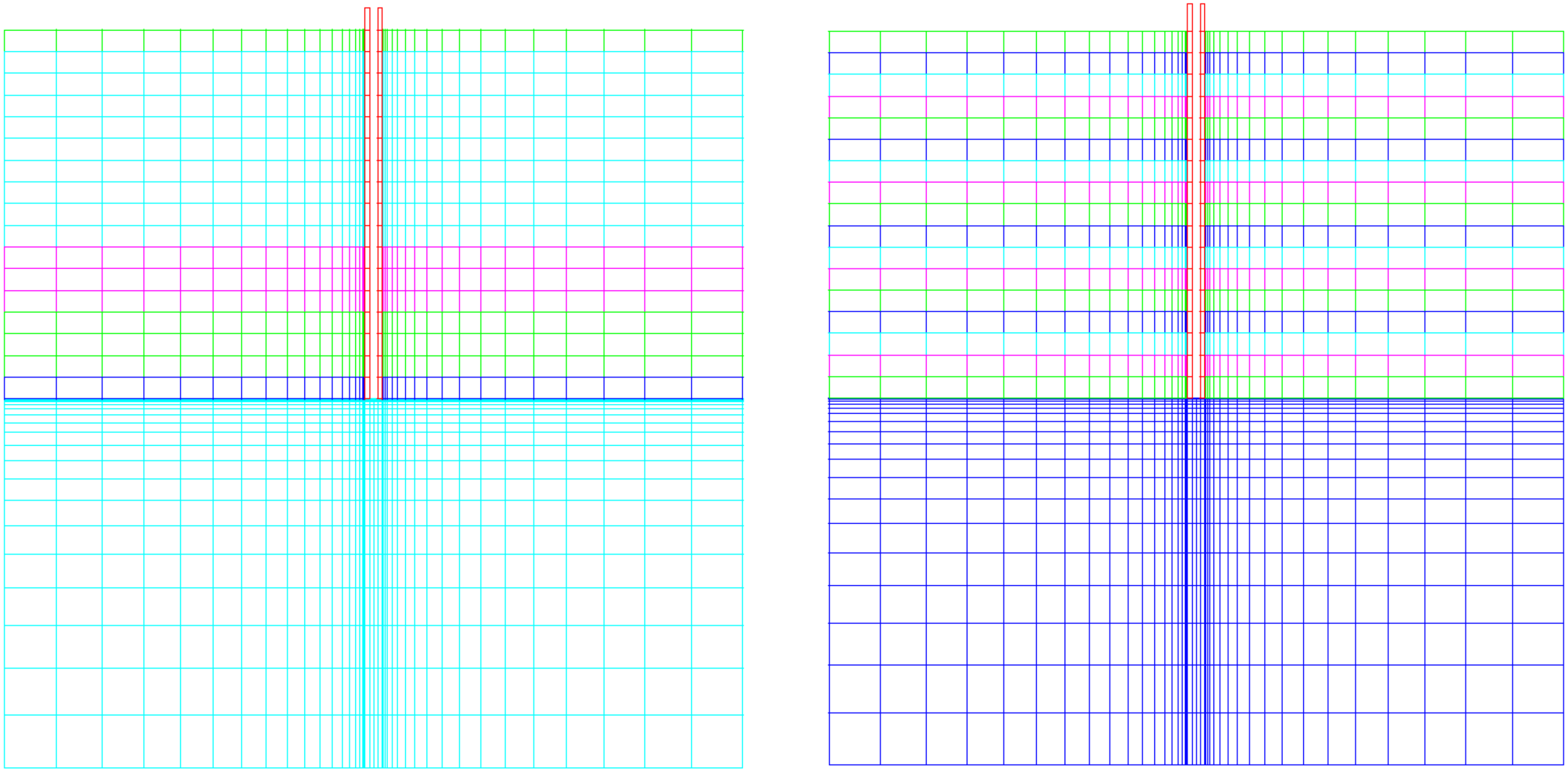
1. Forward method, soil layering based on actual soil layering, typical concrete Young's Modulus E = 32,650 MPa
2. Forward method, soil layering based on actual soil layering,Young's Modulus E = 39,454 MPa based on project data
3. Inverse method, soil layering based on actual soil layering, typical concrete Young's Modulus E = 32,650 MPa
4. Inverse method, soil layering based on actual soil layering, Young's Modulus E = 39,454 MPa based on project data
5. Inverse method, soil layering based on pile discretization, Young's Modulus E = 39,454 MPa based on project data

- Emphasis of analysis is on Cases 2, 4 and 5 (Young's Modulus based on actual dynamic data
- Measurement summary from pile driving is below:

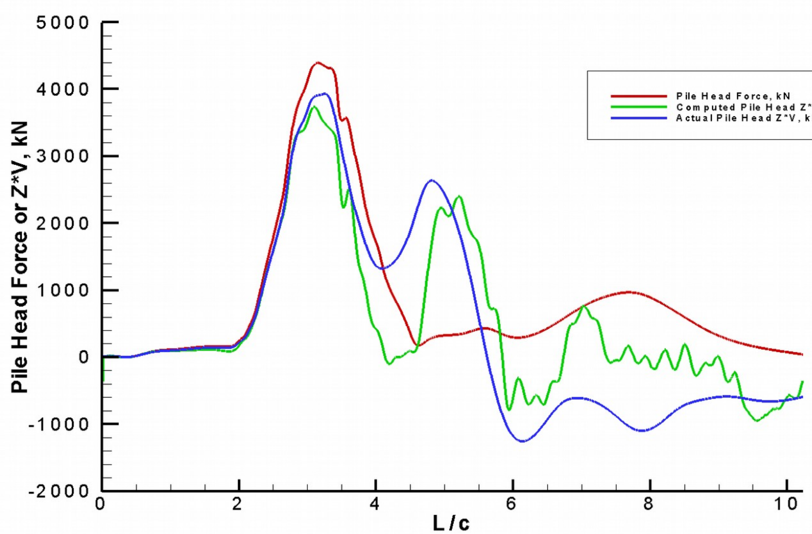
Measurement	Pile Type		
	Prestressed	FRP	Plastic
Wave speed	3,800 m/s	3,782 m/s	3,100 m/s
Maximum compression stress measured during driving	11.0 MPa	16.2 MPa	9.9 MPa
Maximum tensile stress measured during driving	5.6 MPa	8.5 MPa	3.3 MPa
Allowable stresses	Comp. < 24.5 MPa Tension < 6.7 MPa	No standards available	No standards available

1 MPa = 145 lbf/inch^2

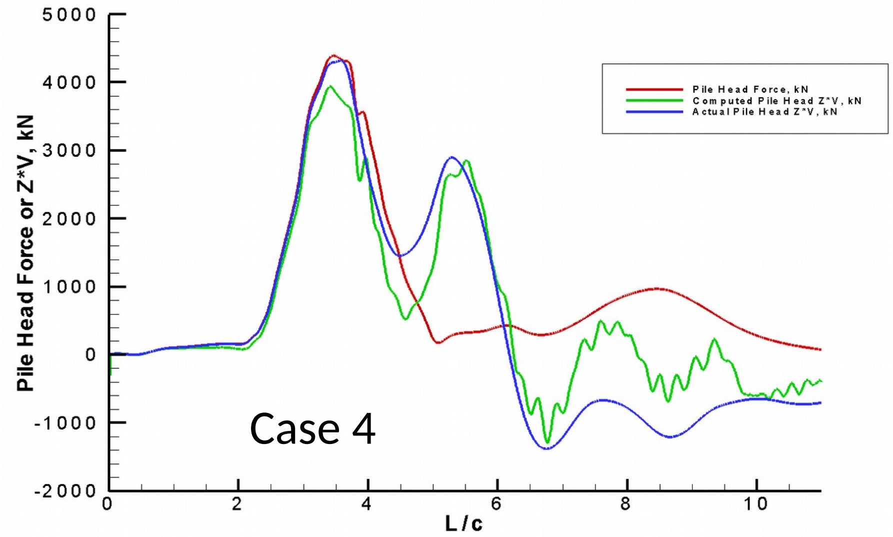
Comparison of Soil Layering Based on Stratigraphy (Left) and Pile Discretization (Right)

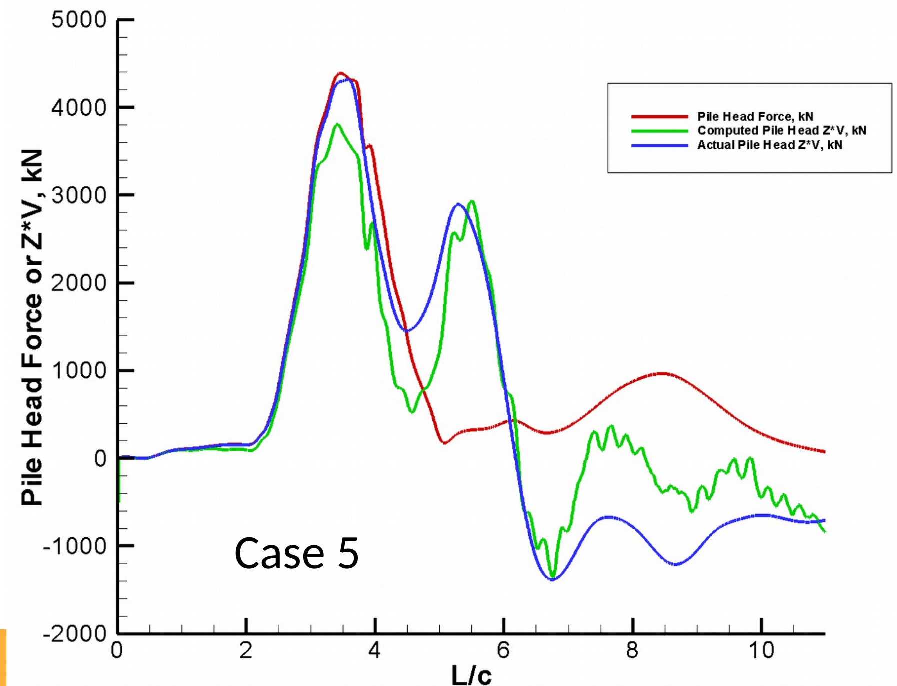


Force-Time Histories

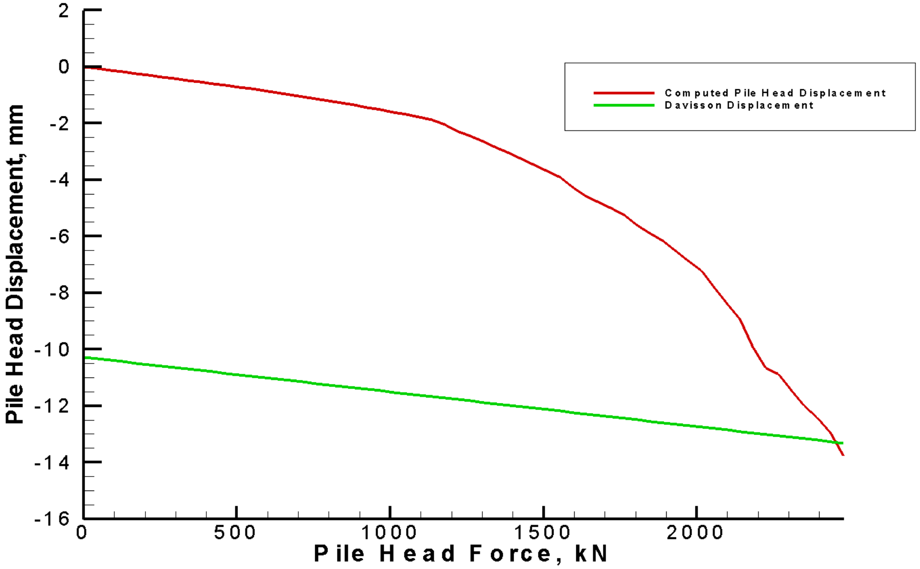


Case 3

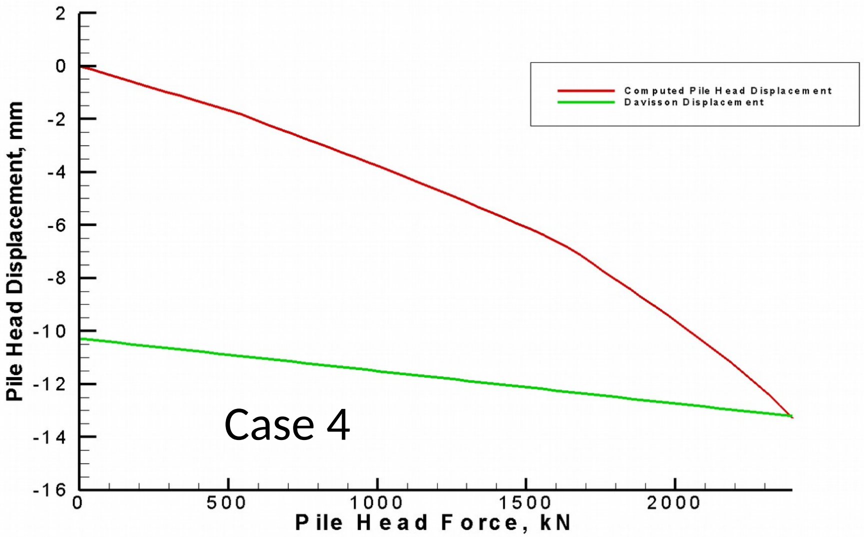


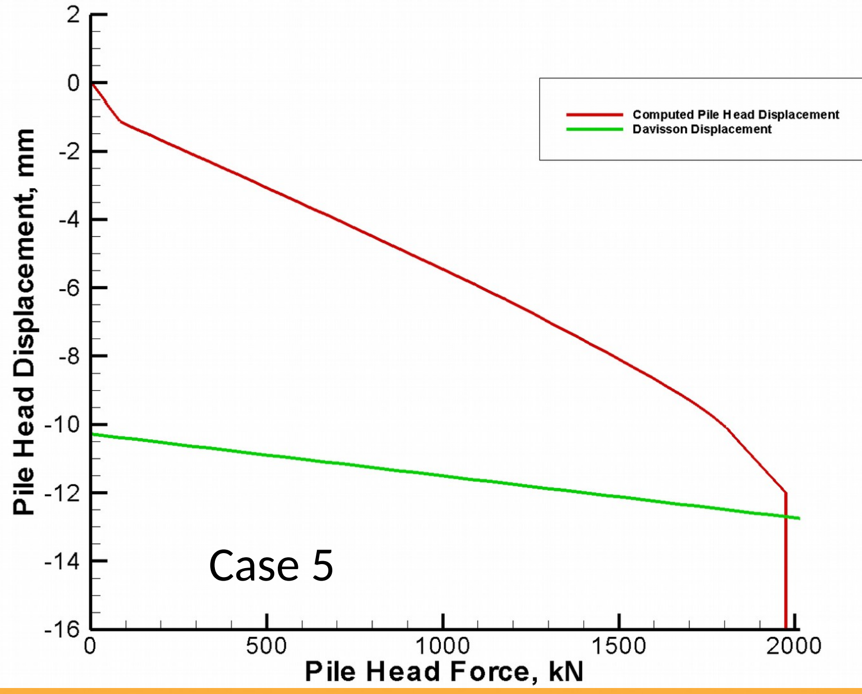


Static Load Test Results



Case 3





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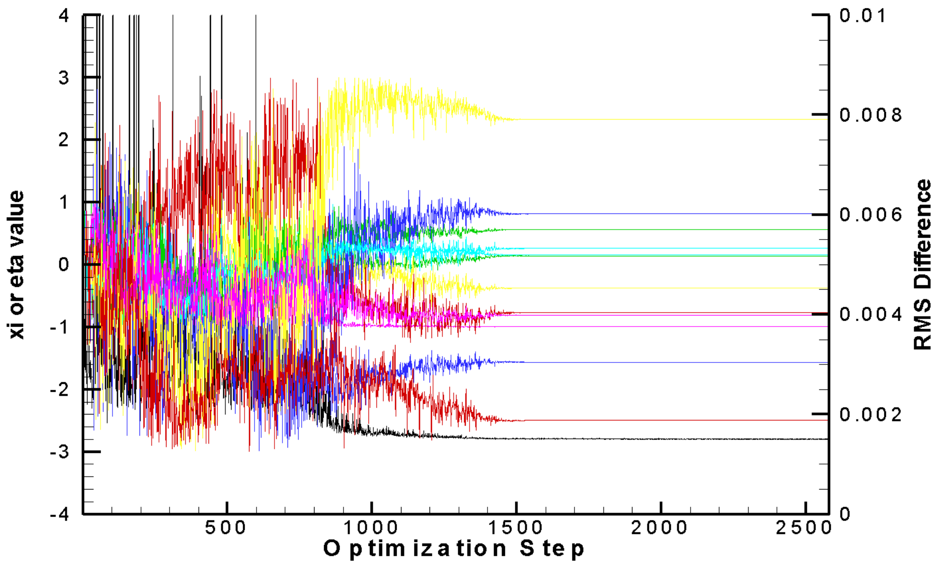
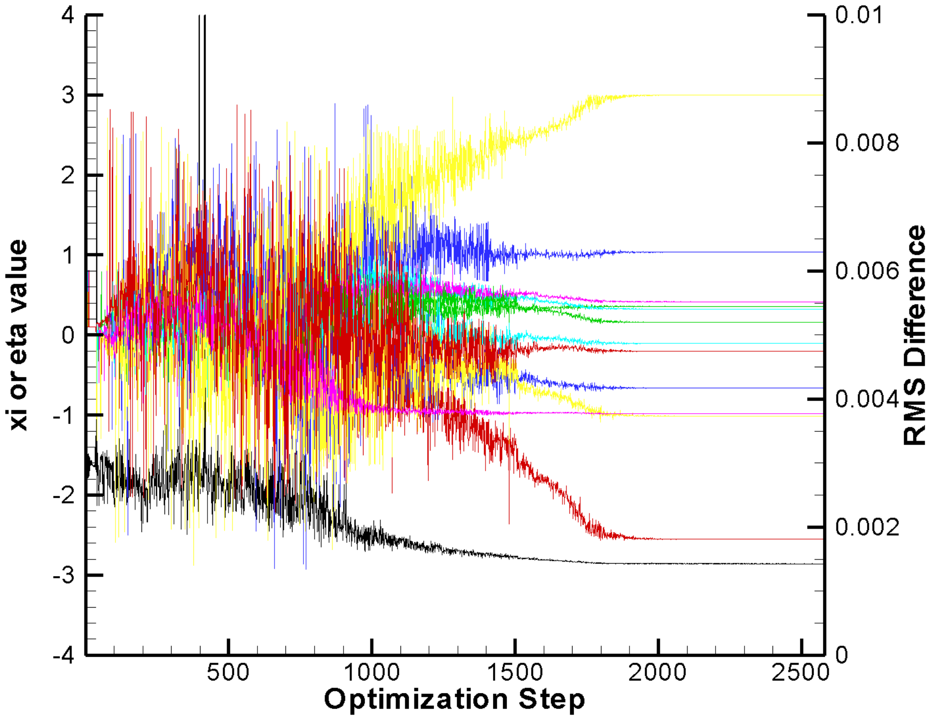
Optimization Tracks, Case 4 (Left) and Case 5 (Right)





Summary of Results

Case	1	2	3	4	5
Davisson Load, kN	2208	2452	1750	2390	1970
Apparent Set-Up Factor	1.40	1.26	1.77	1.29	1.57
Blow Count, $blows/30\ cm$	24.6	26.3	35.5	34.8	37.2
Maximum Tensile Stress, MPa	-5.61	-4.37	-3.6	-2.19	-2.85
Maximum Compressive Stress, MPa	12.1	12	12.1	12.1	12
Signal Matching RMS Norm	N/A	N/A	0.00207	0.0015	0.00142

Case	Weighted ξ	Weighted η
2	-0.67	-0.05
4	0.07	-0.26
5	0.18	-0.23

Conclusions

- The difficulties with the Young's Modulus determination highlight the importance of critically analyzing published data in the course of its use
- The inverse methods indicated a more cohesive stratigraphy than examination of the boring summary would indicate. This may mean that how cohesive a soil is for driven pile analysis may vary from what is typically shown in the Unified System
- The full layering scheme for inverse analysis showed different results than using the layering from the soil borings. Although the full layering results converged properly and agreed more closely with the CAPWAP result, whether they are superior to those with the reduced layering scheme is still an unanswered question