Civil & Coastal Engineering

Embedded data collector (EDC) Evaluation phase II – Comparison with instrumented Static Load Tests

FDOT Contract No.: BDK-75-977-24

Project Managers:
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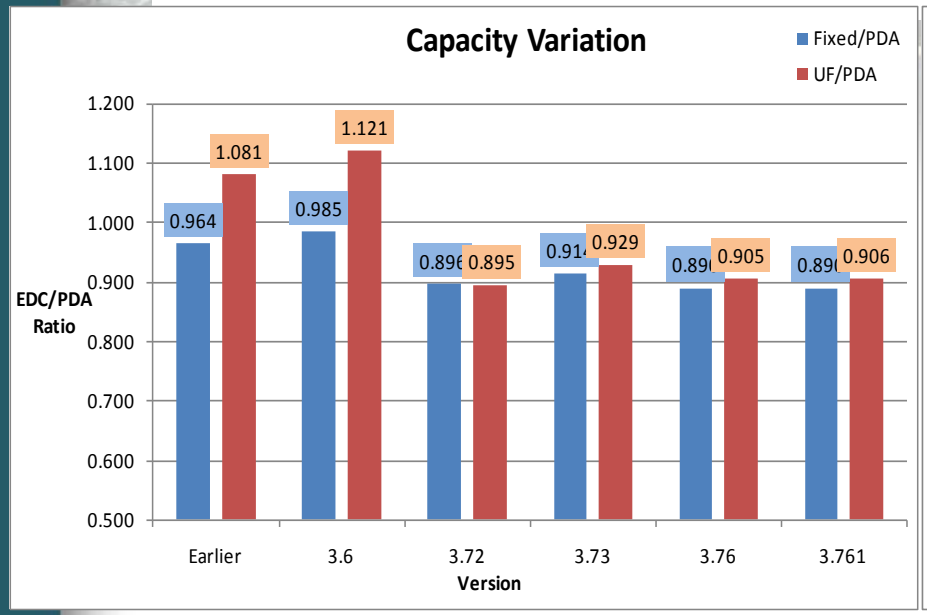
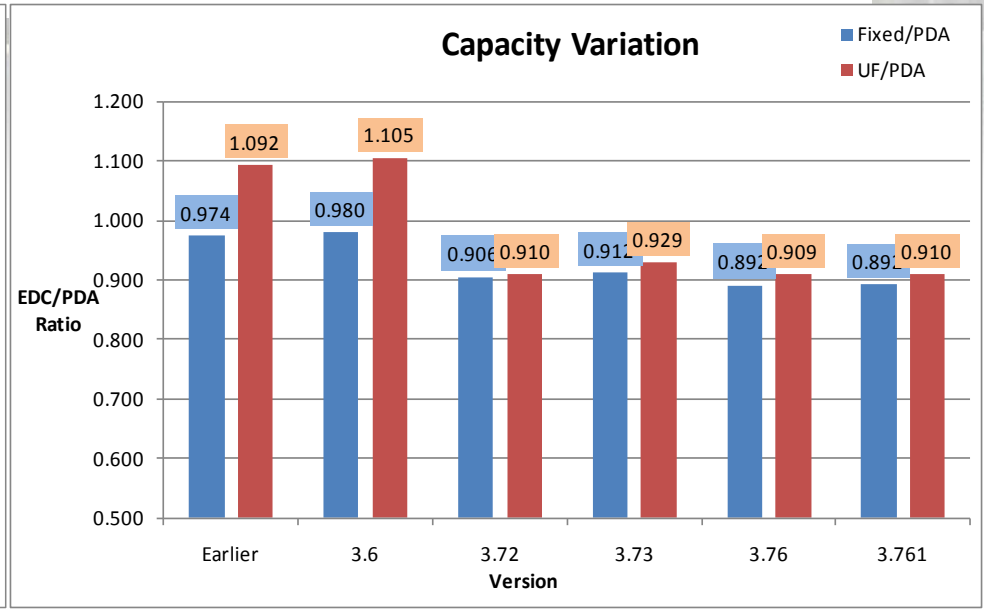
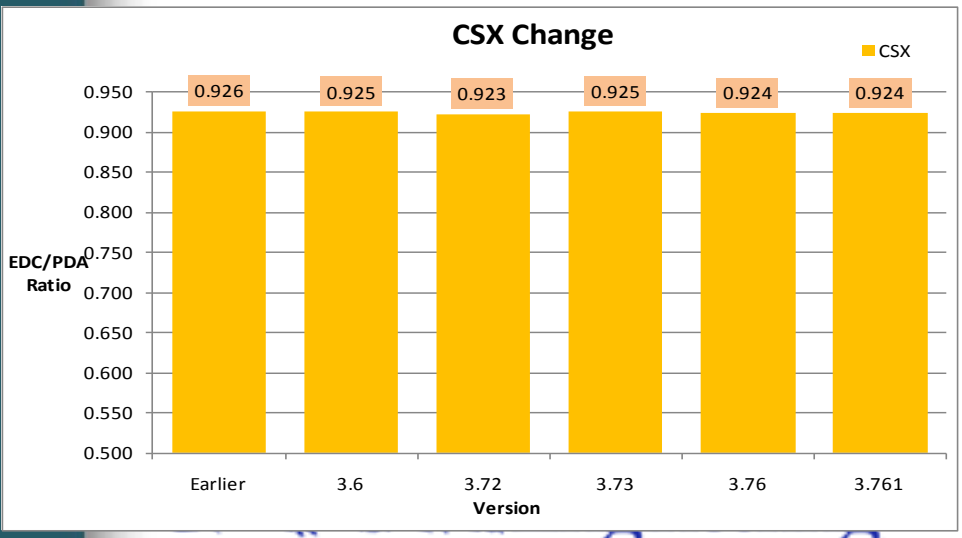
Overview

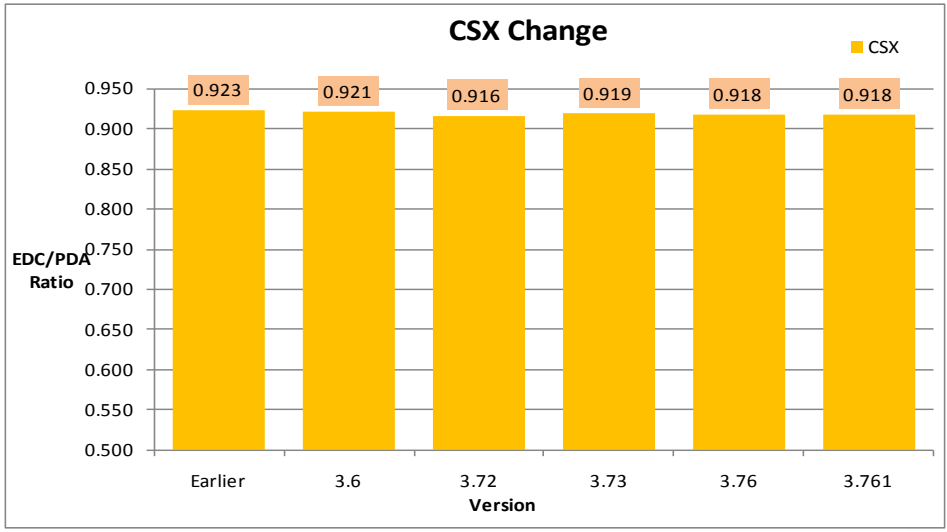
- TASK 1 : EDC – PDA – CAPWAP Comparison
  - Capacities, Stresses, Energies, and Beta
- Task 3: Improvements in Estimating Skin Friction and End Bearing
- Task 3: Pile Freeze – Prediction of Pile Skin Friction and End Bearing separately and changes in each with time

TASK 1 : EDC – PDA Comparison
139 Monitored Piles and 213,000 Blows

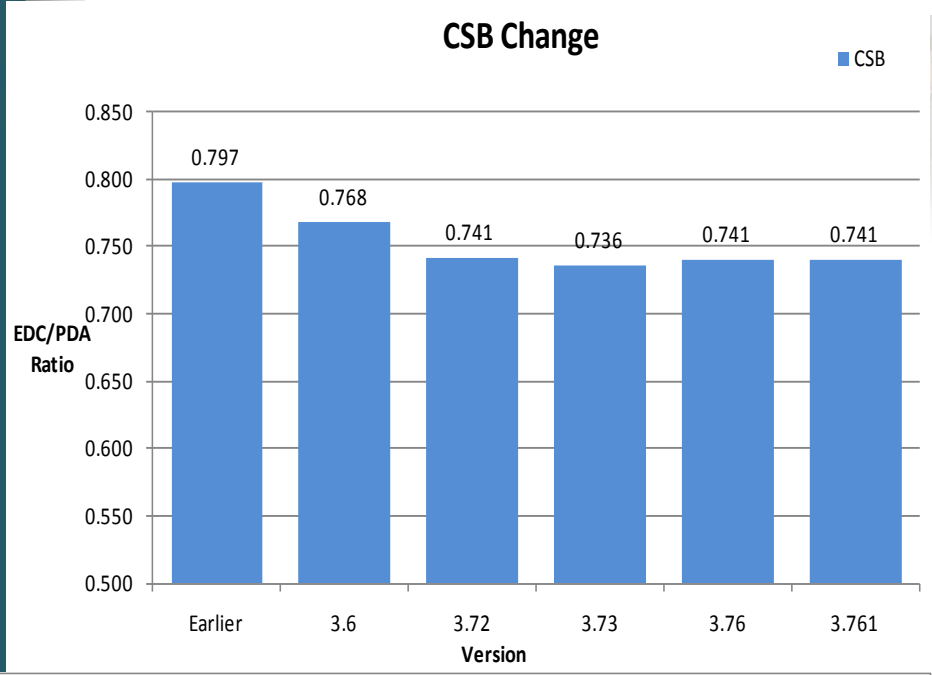


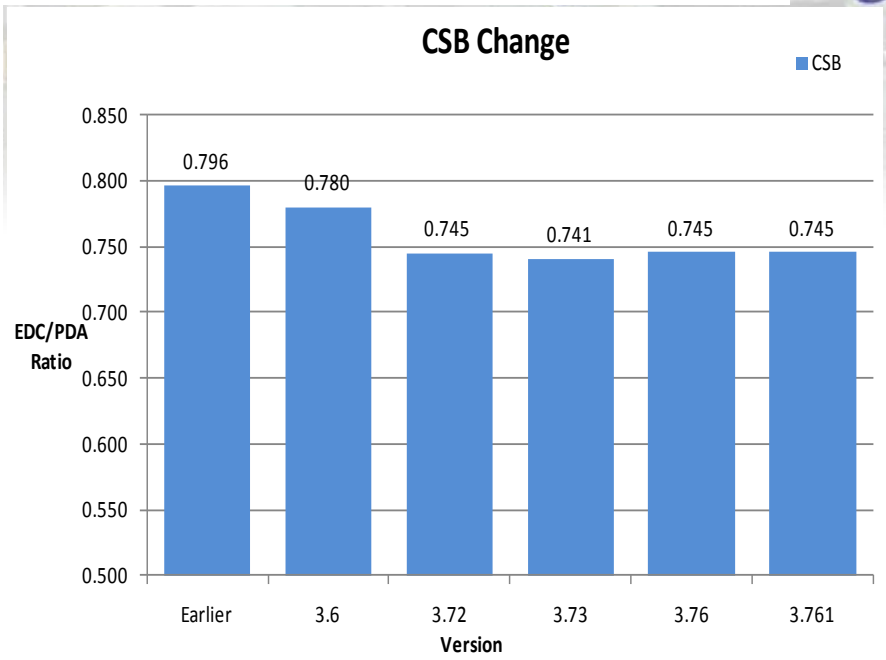


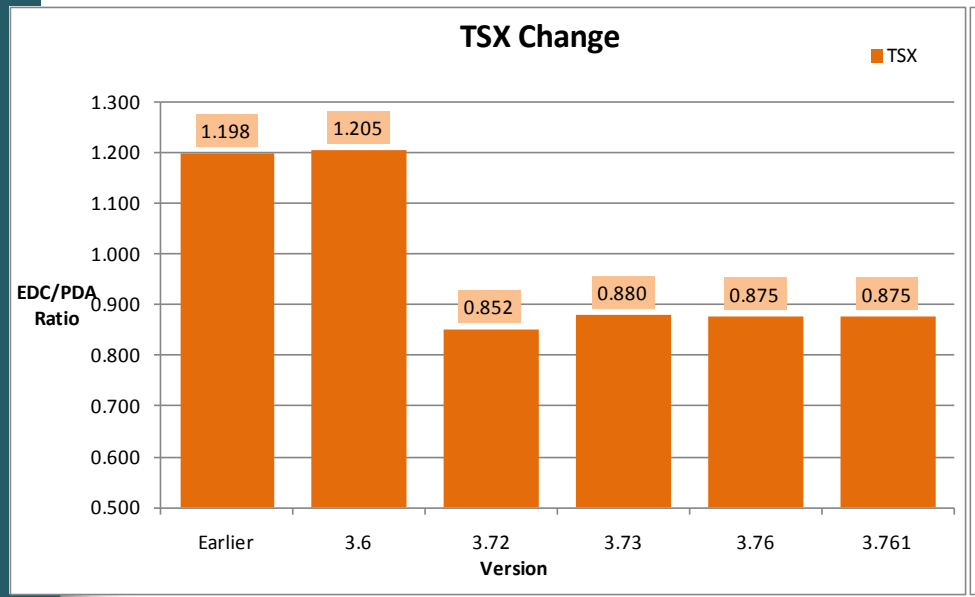


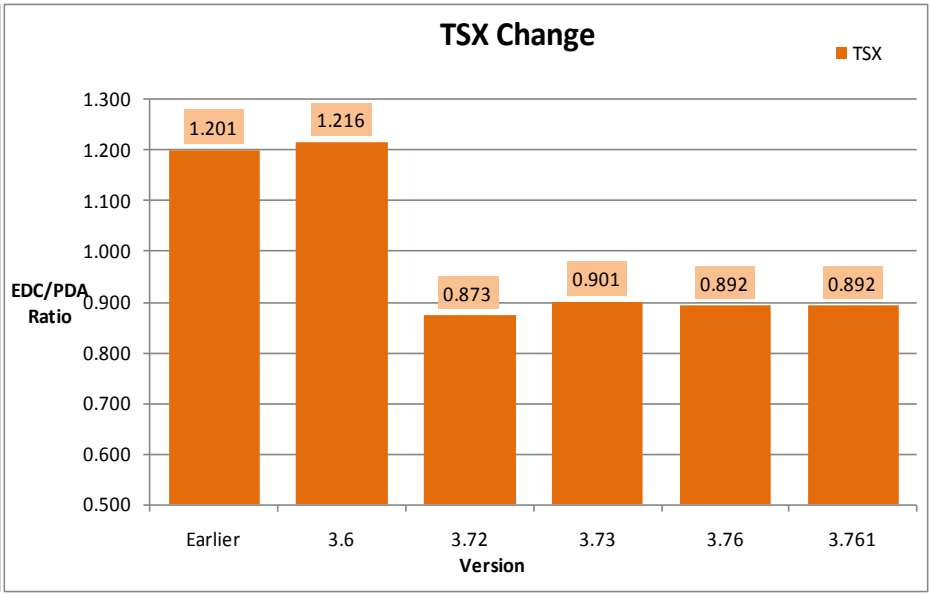


TASK 1 : EDC – PDA Comparison
139 Monitored Piles and 213,000 Blows









Statistical Results for various versions : Based on Per Pile

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SMART PILE VERSION - 3.761 (all piles, old + new) - 7/27/2011							
Based on per pile, Smart Pile version 3.761							
	Fixed/PDA	UF/PDA	CSX	CSB	TSX	EMX	Beta
Count	148	148	149	143	140	148	147
Average	0.89277	0.90959	0.93195	0.74471	0.87614	0.98772	0.96620
Stddev	0.14992	0.15786	0.09558	0.17598	0.25159	0.25370	0.10824
COV	0.16792	0.17354	0.10256	0.23630	0.28716	0.25685	0.11202
%n	0.98667	0.98667	0.99333	0.95973	0.98592	0.98667	0.98000
Median	0.92610	0.91317	0.93820	0.74987	0.89874	0.96670	0.99576

Based on Councurrent blows, Smart Pile version version 3.761							
	Fixed/PDA	UF/PDA	CSX	CSB	TSX	EMX	Beta
Count	148	148	149	143	140	148	147
#Blows	233824	233673	233844	225455	226138	233579	230933
Sum	208926.7	213868.5	217434.3	168829.3	201612.2	227872.2	222098.5
Average	0.89352	0.91525	0.92983	0.74884	0.89155	0.97557	0.96174
Stddev	0.14992	0.15786	0.09558	0.17598	0.25159	0.25370	0.10824
COV	0.16778	0.17247	0.10279	0.23500	0.28220	0.26005	0.11254
%n	0.87710	0.89784	0.91281	0.70877	0.84639	0.95663	0.93240
Median	0.92610	0.91317	0.93820	0.74987	0.89874	0.96670	0.99576

- EDC is conservative when compared to PDA with Fixed Jc for Capacity estimates for both pile and concurrent blow comparisons. 0.173 < COV

- **UF EDC (Variable Jc) is conservative, UF/PDA <0.915 and 0.173 <COV;**

- **Top Compressive Stress, CSX varies from 0.92 to 0.93 with COV < 0.1**

- **Compression Tip Stress, CSB – 0.74 to 0.75 with 0.24 < COV**

- **TSX varies from 0.87 to 0.89& 3.6 of 1.2 to 0.89 with 0.28 < COV**

EDC Version 3.761 – CAPWAP Comparison

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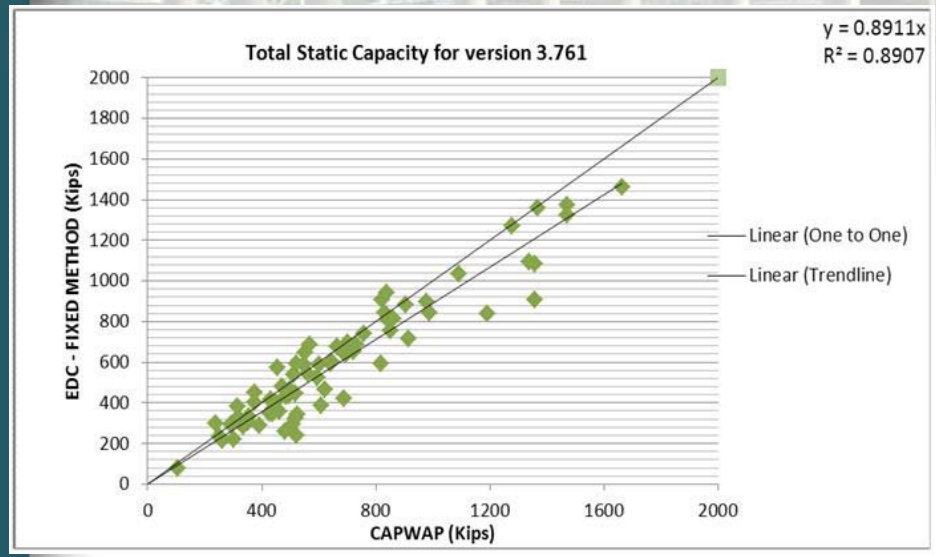

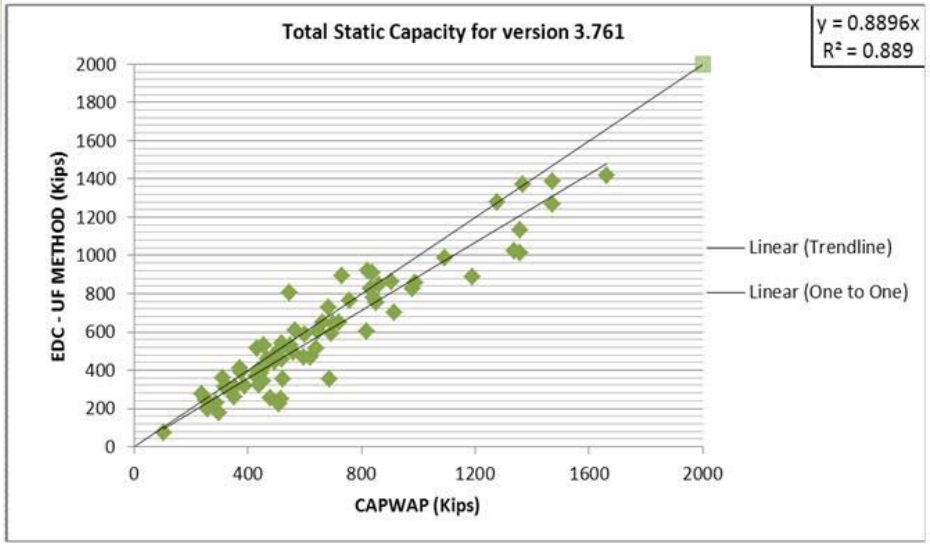

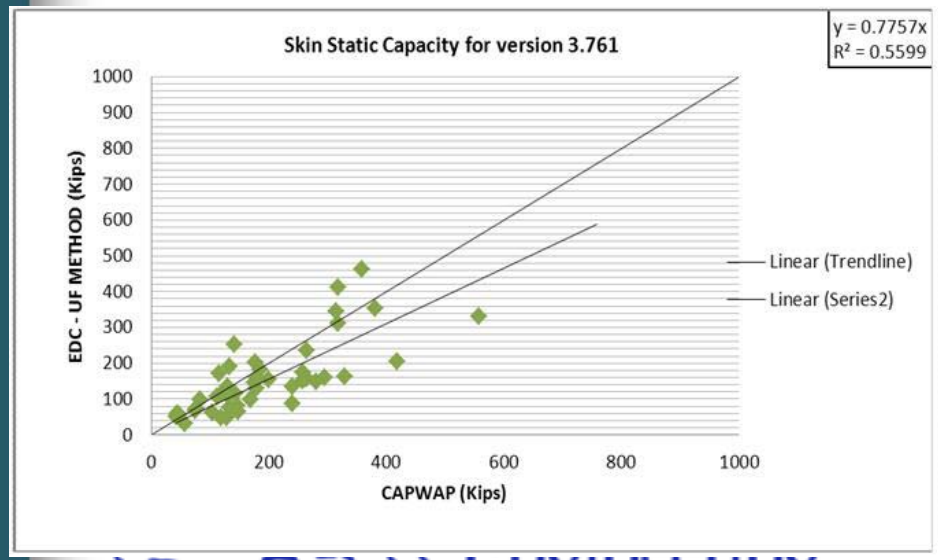

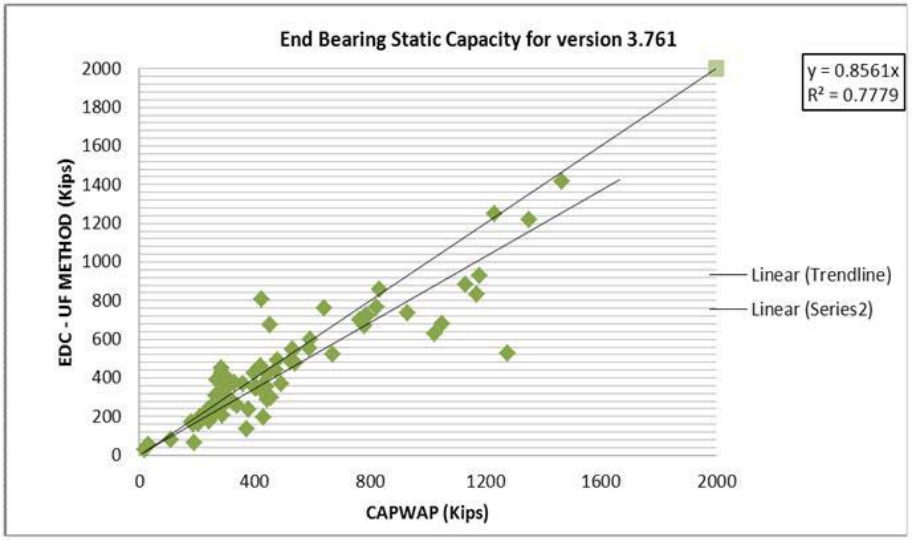

TASK 3 Improved Side Friction Predictions

Prior: 2010 to 2011

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

journal homepage: www.elsevier.com/locate/soildyn

A new method for estimating driven pile static skin friction with instrumentation at the top and bottom of the pile

Khiem T. Tran [a,*], Michael McVay [a], Rodrigo Herrera [b], Peter Lai [b]

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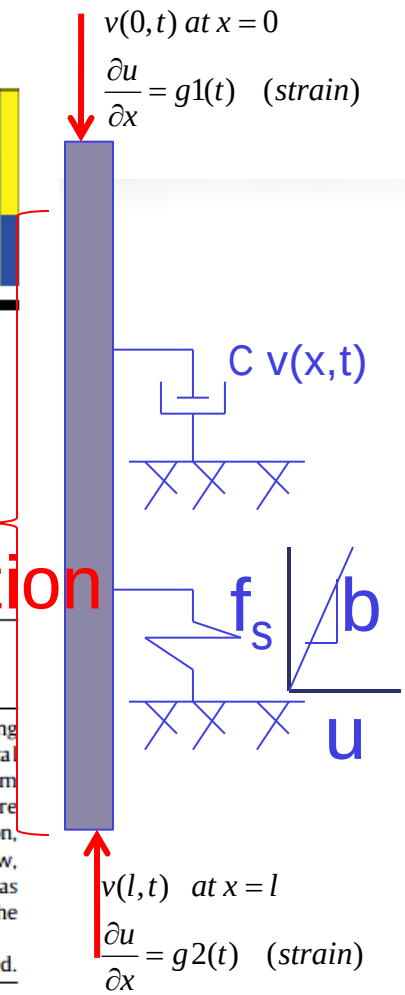
[b] Florida Department of Transportation, 605 Suwannee St., Tallahassee, FL, USA

Homogeneous

Linear Skin Friction



ARTICLE INFO

Article history:
Received 29 September 2010
Received in revised form
16 April 2011
Accepted 4 May 2011

Keywords:
Green's function
Ultimate skin friction
Genetic algorithm

ABSTRACT

A numerical technique is presented to estimate ultimate skin friction of a driven pile using instrumentation installed at the top and bottom of a pile. The scheme is based on an analytical solution of the 1D wave equation with static skin friction and damping along with a genetic algorithm for solution. Specifically, acceleration and strains measured at both the top and bottom of the pile are used to develop an observed Green's function, which is matched to an analytical Green's function, which is a function of secant stiffness and viscous damping. Requiring 1–3 s of analysis time per blow, the algorithm provides a real time assessment of average skin friction along the pile. The technique was applied to four driven piles having ultimate skin frictions varying from 700 to 2000 kN, with the predicted skin frictions generally consistent with measured static load test results.

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$$a^2 \frac{\partial^2 u}{\partial x^2} = \frac{\partial^2 u}{\partial t^2} + c\frac{\partial u}{\partial t} + bu(x,t)$$

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TASK 3 Improved Side Friction Predictions

New: 2011 to 2012

Computers and Geotechnics 41 (2012) 79–89

Contents lists available at SciVerse ScienceDirect

Computers and Geotechnics

journal homepage: www.elsevier.com/locate/compgeo

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Estimation of nonlinear static skin friction on multiple pile segments using the measured hammer impact response at the top and bottom of the pile

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[b] Florida Department of Transportation, 605 Suwannee St., Tallahassee, FL, United States

ARTICLE INFO

Article history:
Received 1 July 2011
Received in revised form 7 October 2011
Accepted 17 November 2011

Keywords:
Dynamic pile
Ultimate skin friction
Genetic algorithm

ABSTRACT

A technique is presented to estimate the nonli
and accelerations at the top and bottom of a
numerical solution of the 1-D wave equation w
portional damping. The soil–pile system is div
quency content of the measured signal. Each
(bilinear loading with independent unloading)
tom of the pile are used to solve for the unkno
unloading stiffness of each pile segment from a
particle velocities at the top and bottom of the
ven into layered sand and clay deposits with m
2700 kN. The analysis was carried out on five s
static load tests. The approach was shown to gi
placements of the measured static load test re

Fig. 1. Forces acting on pile.

Pile Divided Into Segments With Nonlinear Skin Friction

Comparison of Numerical And Analytical Solution for Homogenous Linear Soil Skin Friction

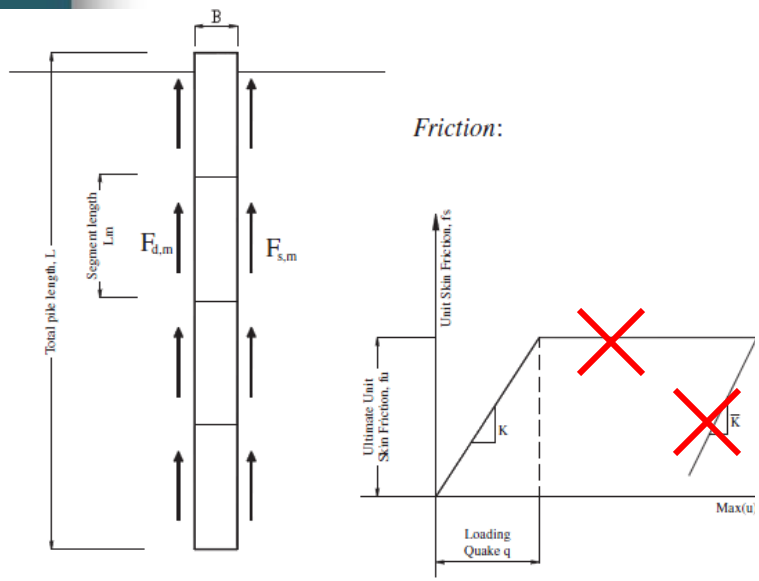
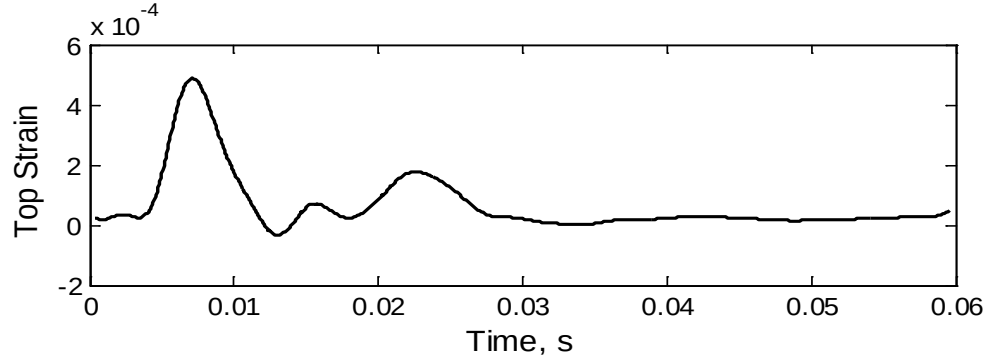
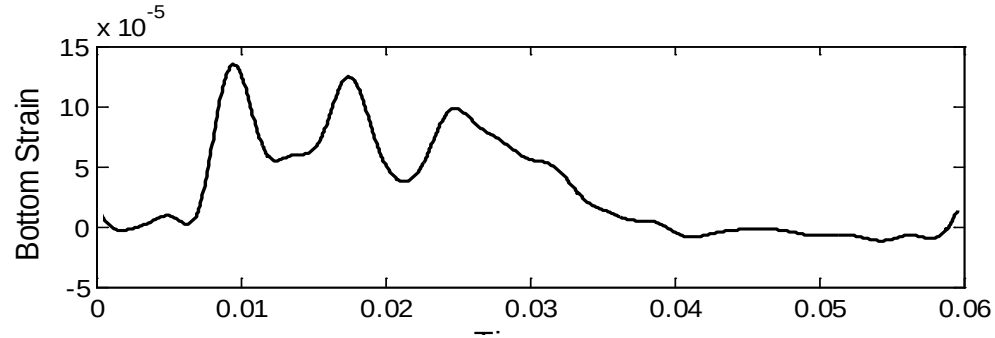
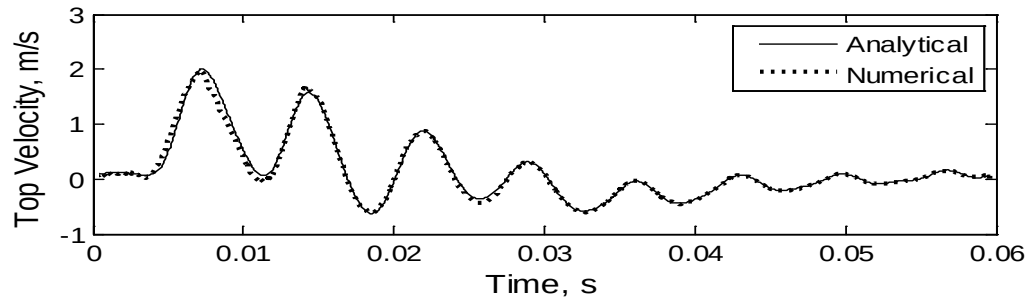
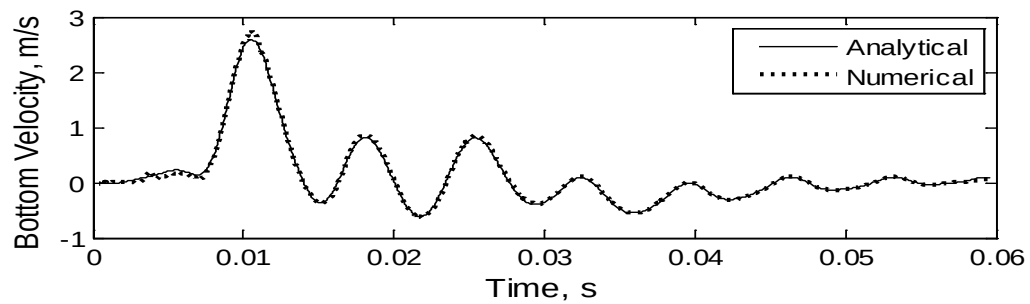


Fig. 1. Forces acting on pile.









Example Dixie Highway:

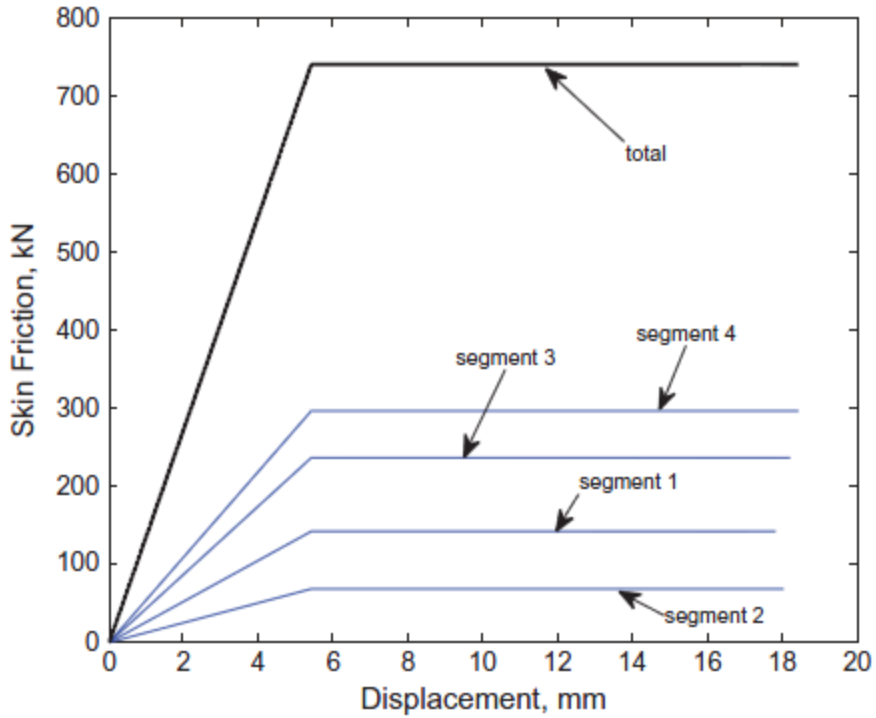


Fig. 8. Estimated skin friction of Dixie Highway Pile 1 for one blow.

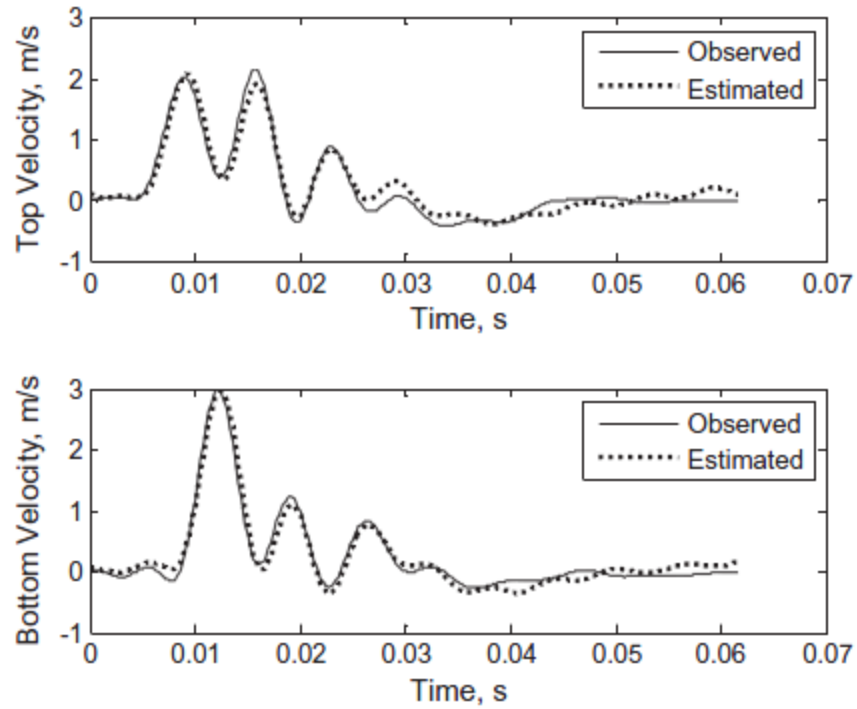


Fig. 7. Dixie Highway Pile 1: comparison of the observed and estimated velocities at the top and bottom of the pile.

Table 1
Estimated parameters of Dixie Highway Pile 1.

Blow #	Loading stiffness parameter, k (1/s^2)				Loading quake, q (mm)	Damping coefficient, β (s/m)	Unloading Coefficient, α (dimensionless)
	Seg #1	Seg #2	Seg #3	Seg #4			
1	7922	6431	9647	14,549	6.64	0.62	1.88
2	8000	3843	13,333	16,706	5.42	0.51	2.99
3	6739	5668	11,435	16,414	5.35	0.41	2.27
4	7814	4133	7381	10,909	7.13	0.40	2.01
5	7352	4384	9325	13,890	6.30	0.38	2.00

Example Dixie Highway:

Restrike Blows 1 week after EOID

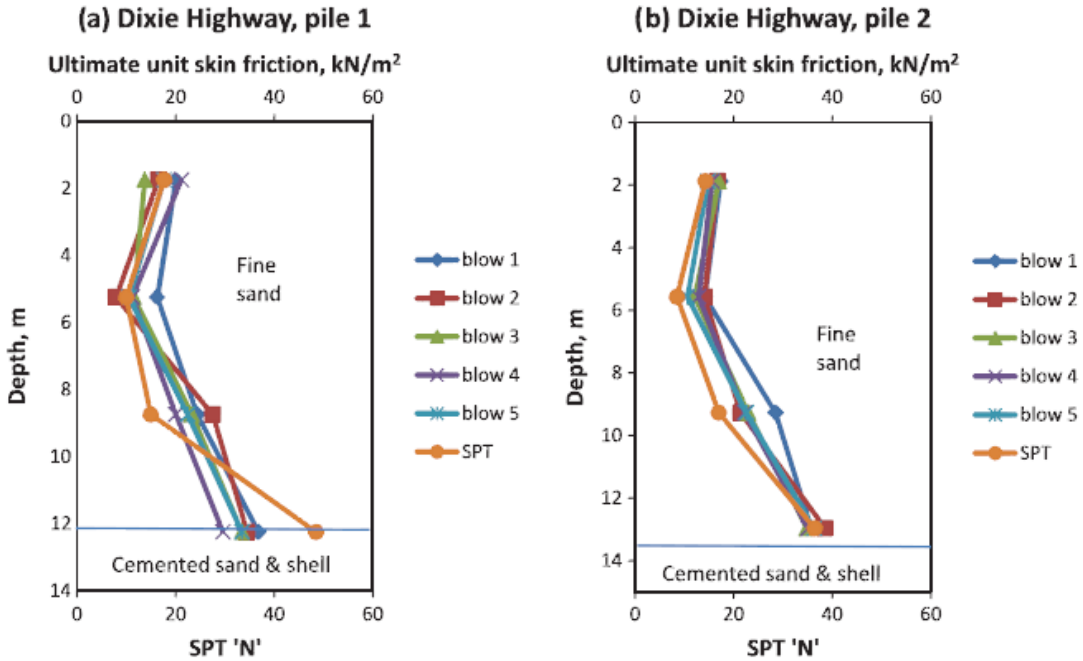


Fig. 9. Ultimate unit skin friction on pile segments and SPT '*N*' values at Dixie Highway.

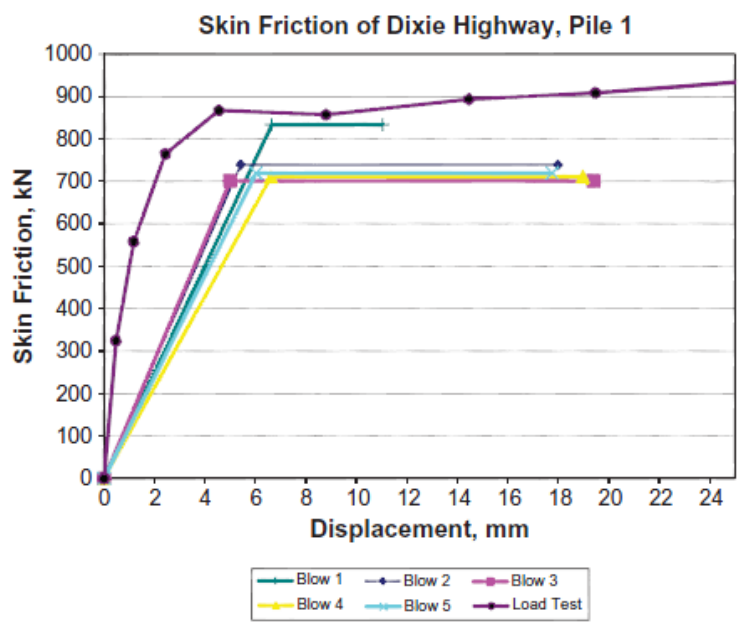


Fig. 10. Skin friction of Dixie Highway Pile 1.

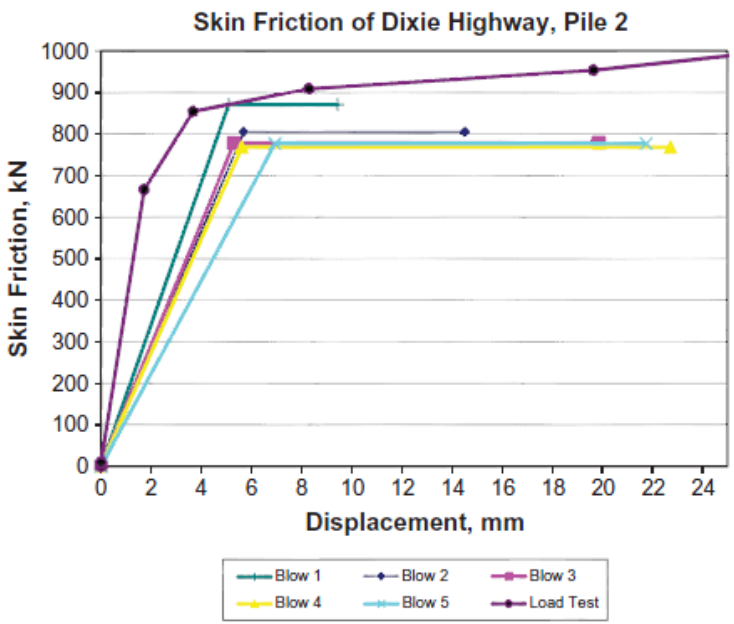


Fig. 11. Skin friction of Dixie Highway Pile 2.

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Example Caminada Bay, Louisiana

30”x30”x70 ft Prestressed Concrete in Sand, Silt & Clay

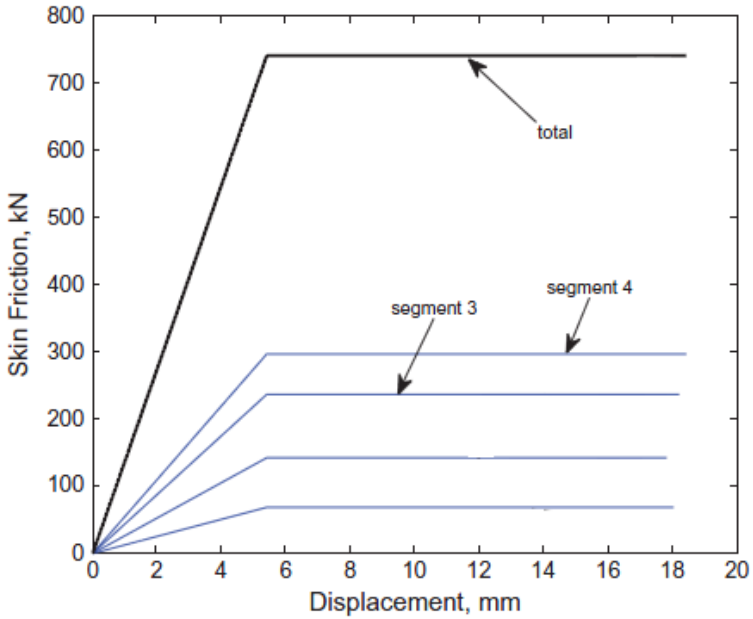

Fig. 8. Estimated skin friction of Dixie Highway Pile 1 for one blow.

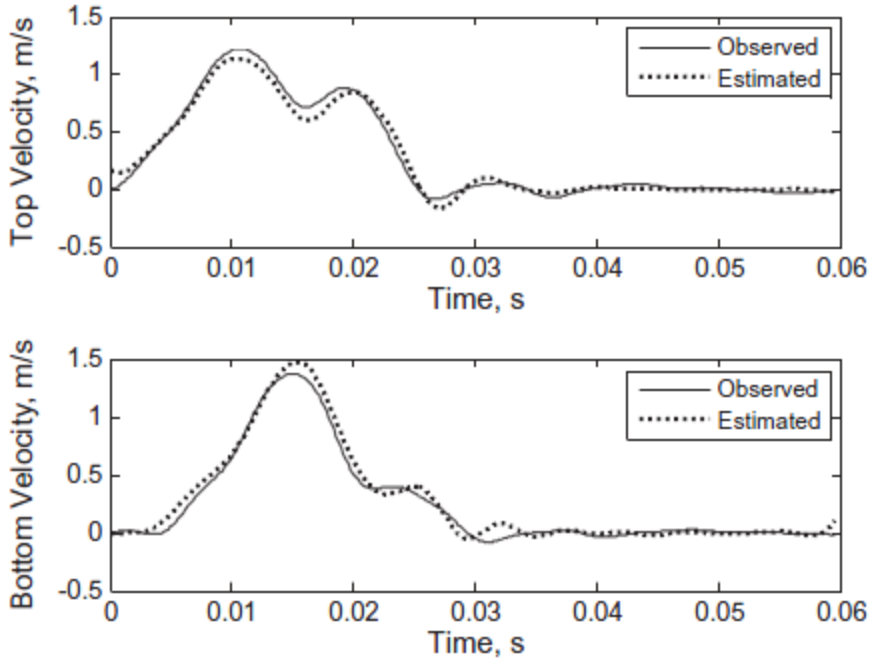

Fig. 12. Caminada Bay Pile 1: comparison of the observed and estimated velocities at the top and bottom of the pile.

Table 3
Estimated parameters of Caminada Bay Pile 1.

Blow #	Loading stiffness parameter, k ($1/s^2$)					Loading quake, q (mm)	Damping coefficient β (s/m)	Unloading coefficient α (dimensionless)
	Seg #1	Seg #2	Seg #3	Seg #4	Seg #5			
1	9608	12,941	24,510	30,980	35,686	3.84	0.37	10.12
2	6961	10,882	16,863	23,431	30,686	5.03	0.41	15.23
3	6667	8039	15,980	21,569	35,784	5.43	0.37	16.87
4	8392	12,941	15,490	19,020	38,471	4.85	0.34	19.25
5	11,212	16,001	25,627	27,373	36,690	4.29	0.34	18.43

Example Caminada Bay, Louisiana

Restrike Blows 1 week after EOID

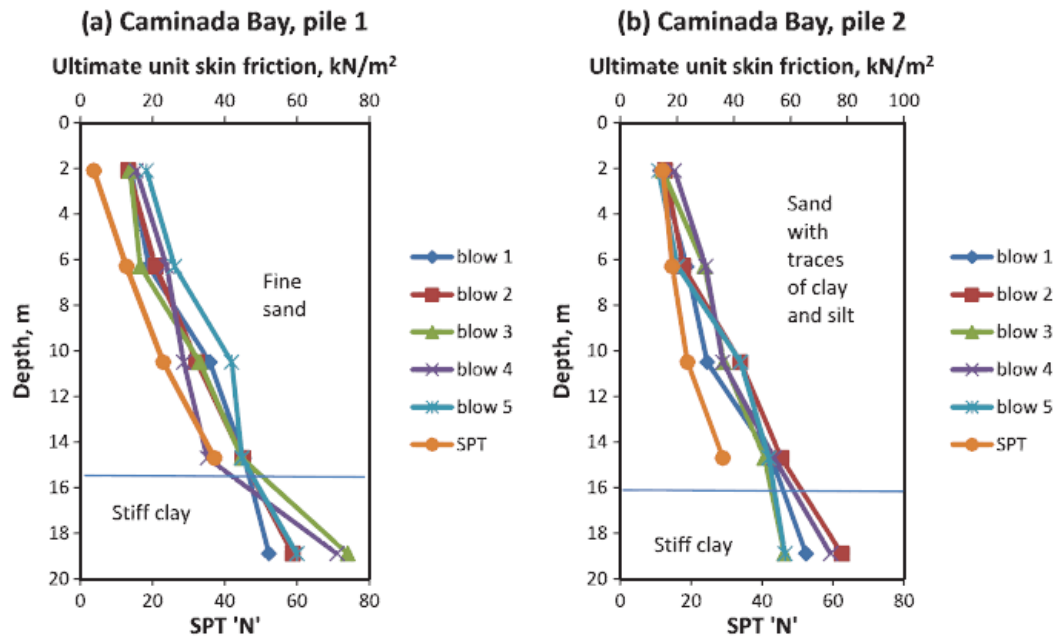

Fig. 13. Ultimate unit skin friction on pile segments and SPT '*N*' values at Caminada Bay.

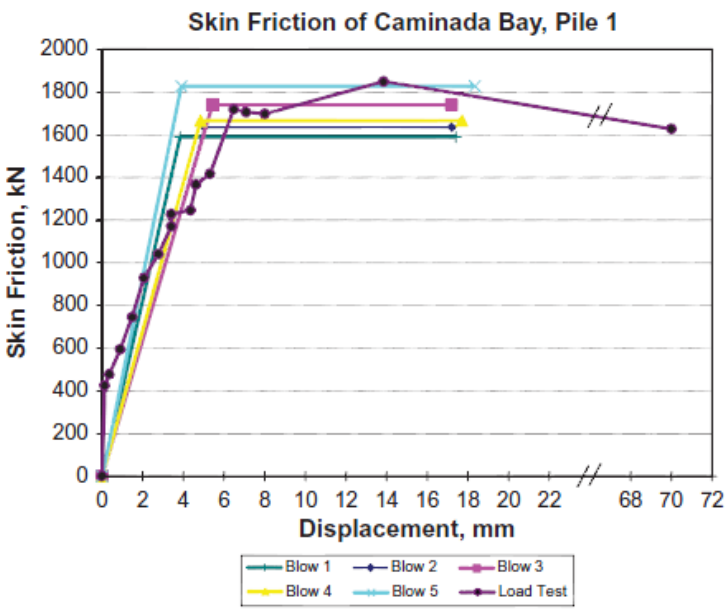

Fig. 14. Skin friction of Caminada Bay Pile 1.

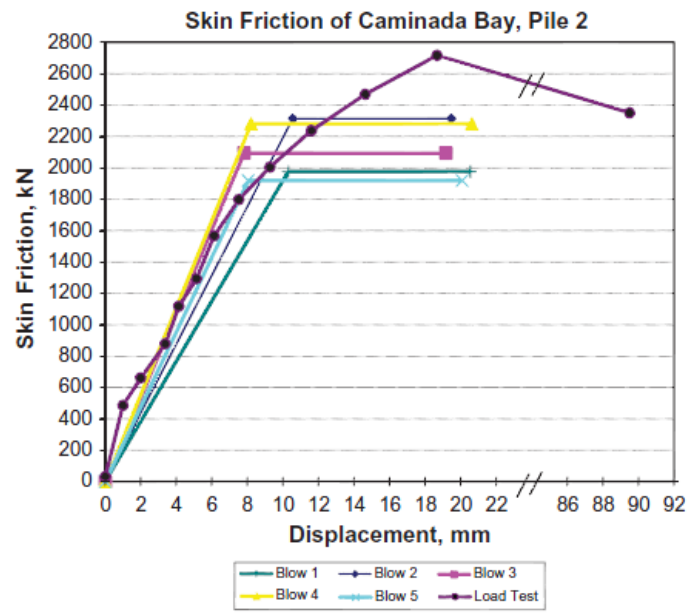

Fig. 15. Skin friction of Caminada Bay Pile 2.

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Dixie Highway, Pier 4, Pullout Test

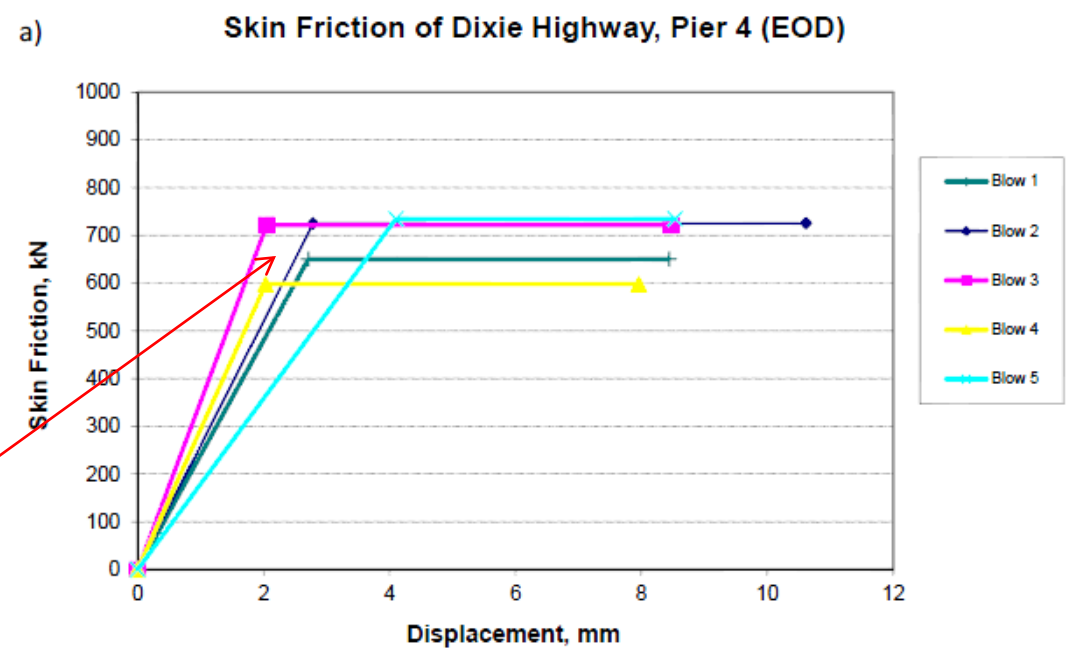
Average Skin Friction

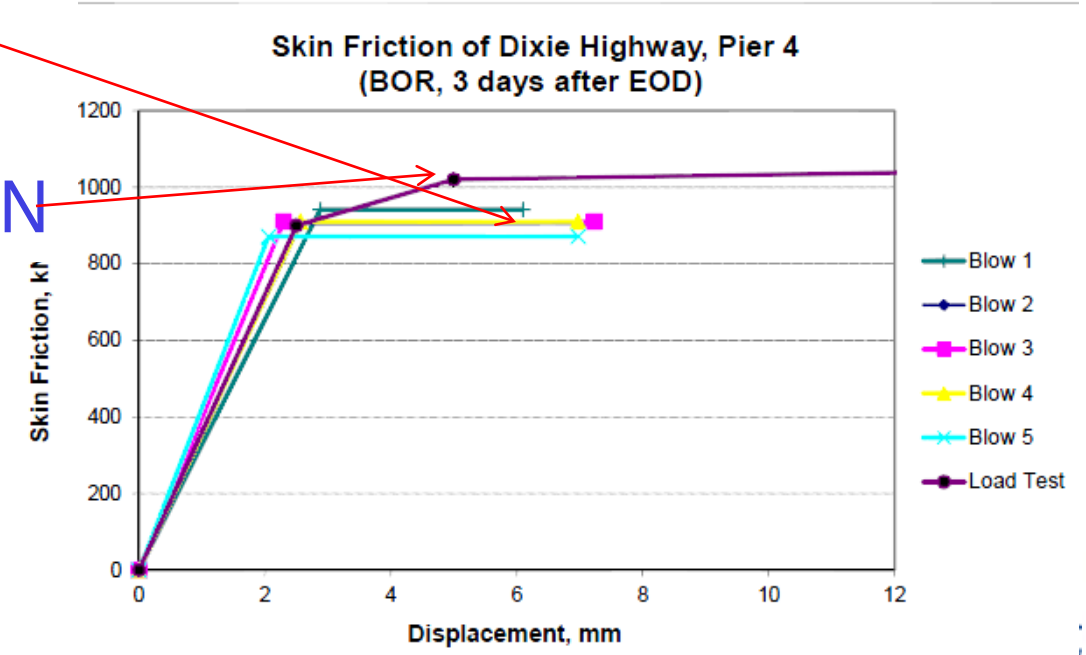
EOD ~ 620 kN

BOR – 3Days ~950 kN

50% Increase in 3Days

Load Test, 7days 1000kN





Skin Friction Freeze At Other Load Test Piles 1 & 2

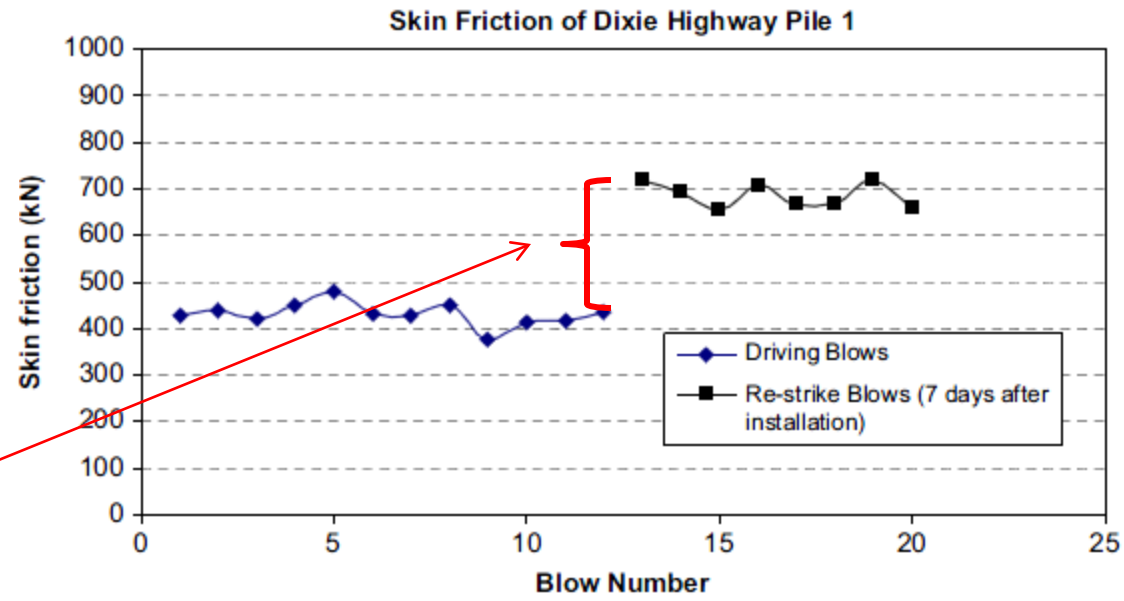


Fig. 7. Estimated skin friction of Dixie Highway Pile 1.

Average Skin Friction Increased:

45% - Pile 1 and

55% - Pile 2

After 7 days vs.

38% after 3 days in Pier 4

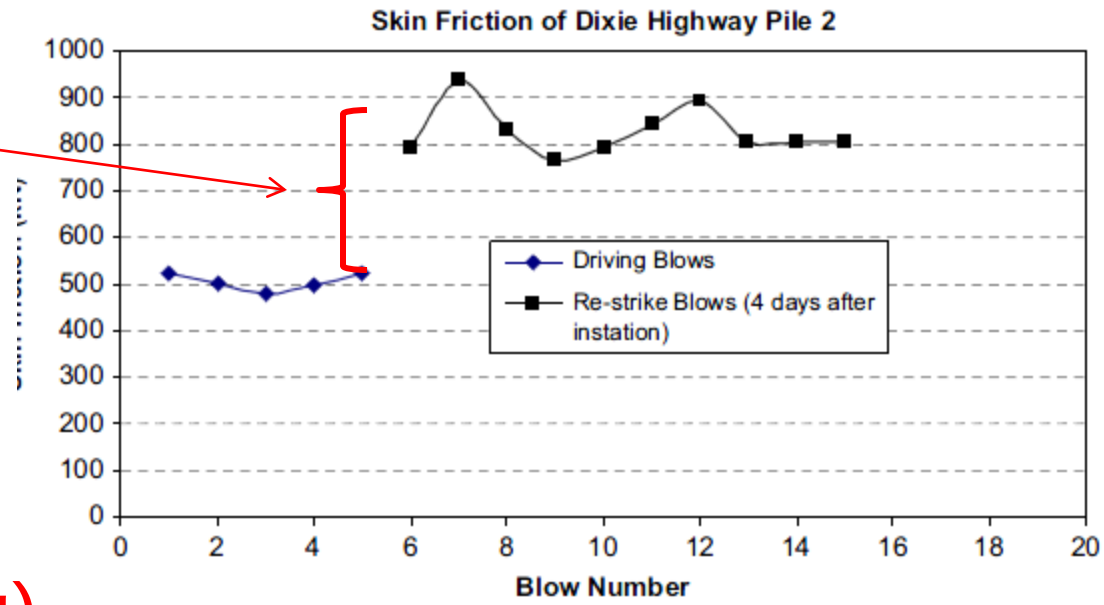


Fig. 9. Estimated skin friction of Dixie Highway Pile 2.

Suggesting Increase function of Time (log)

Estimation of Skin Friction Changes with Time

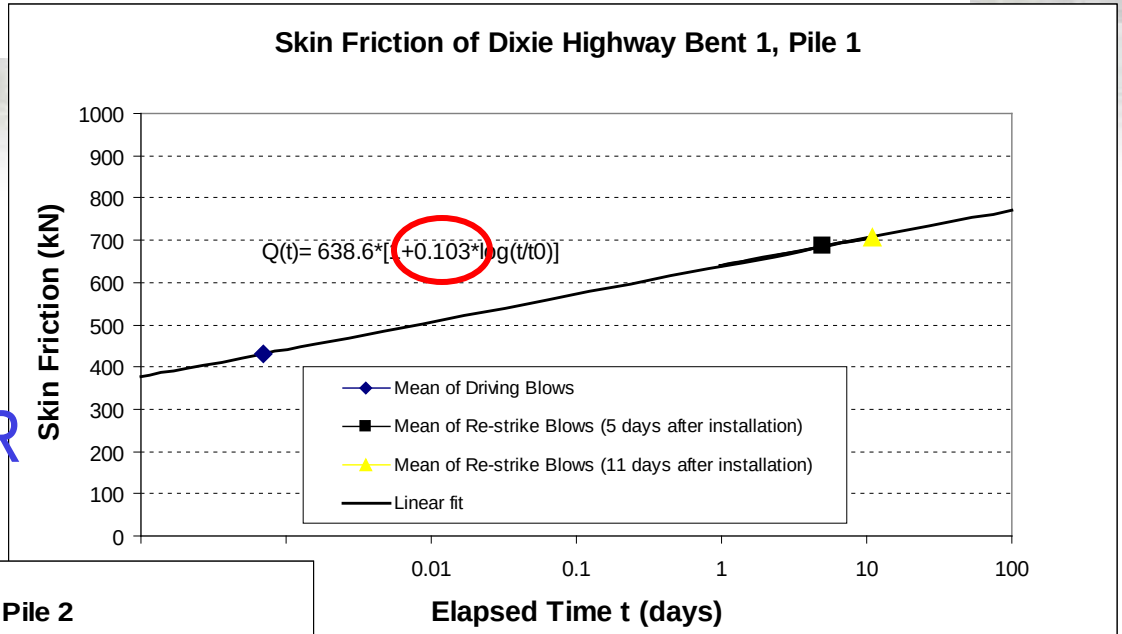
$$Q(t) = Q_0(t_0)\left[1 + A\log_{10}\left(\frac{t}{t_0}\right)\right]$$

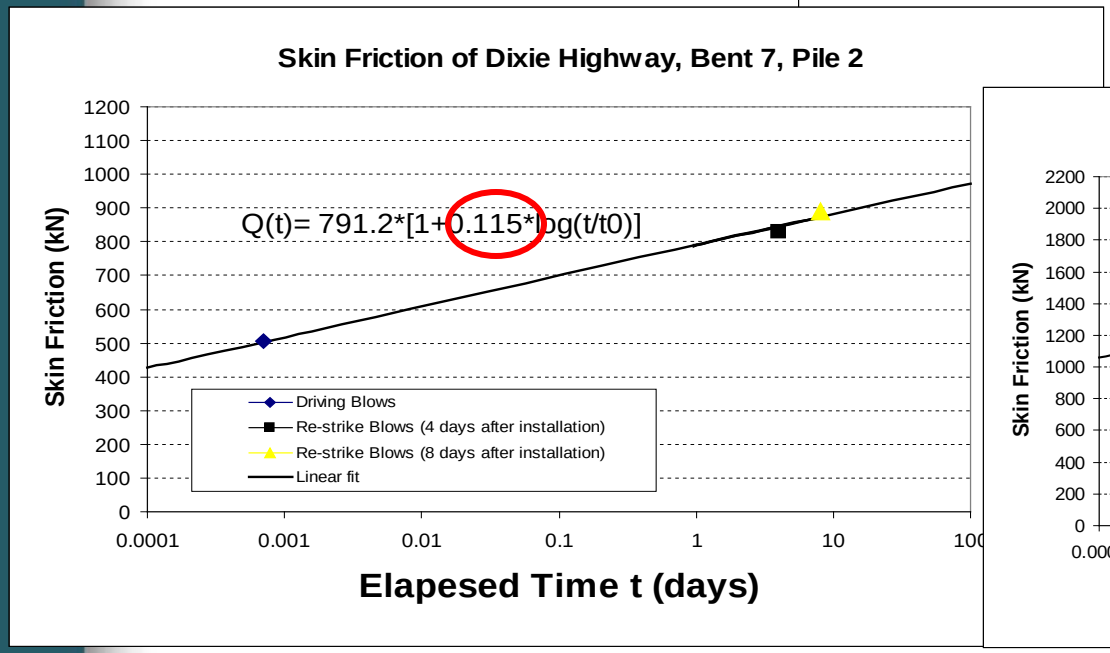
Bullock 2005

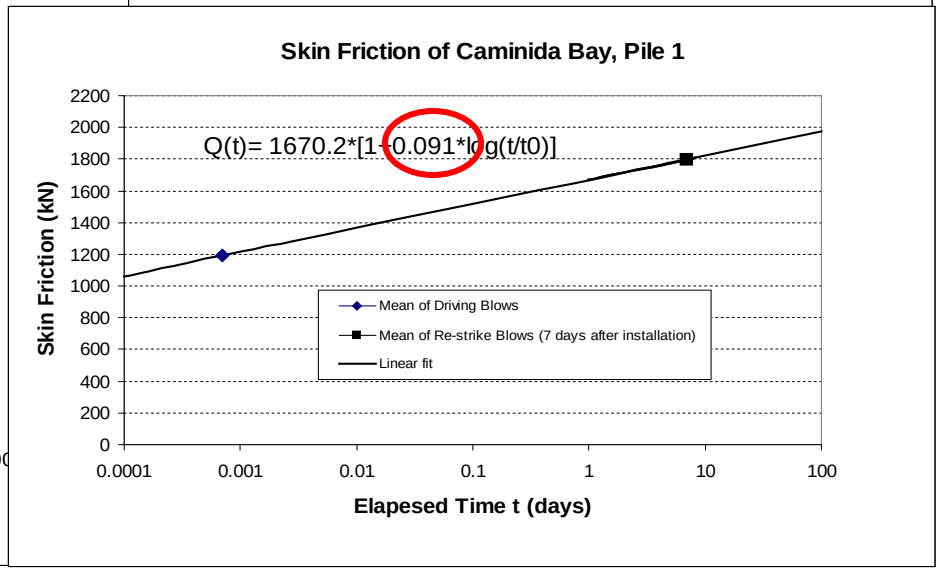
0.1< A < 0.5

EOD for Tip and BOR

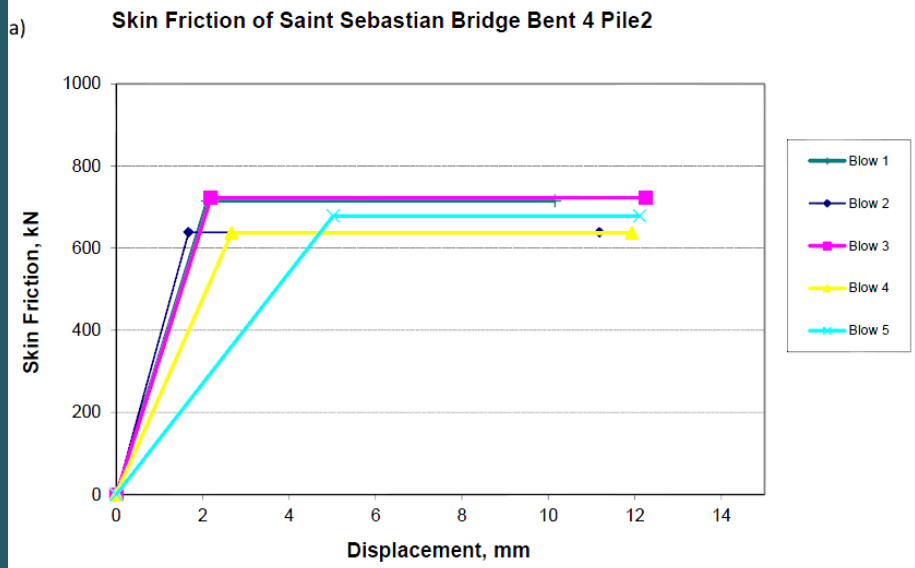
For Side Friction

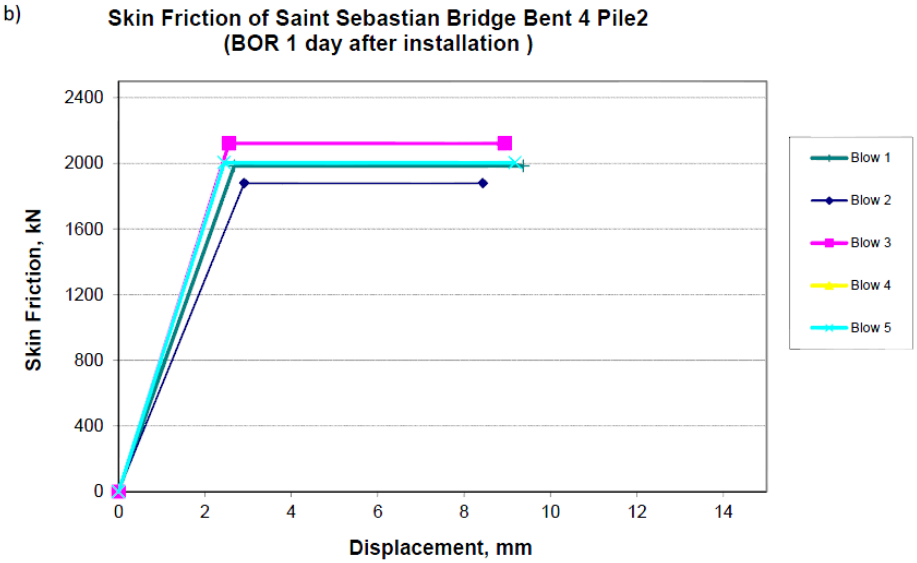


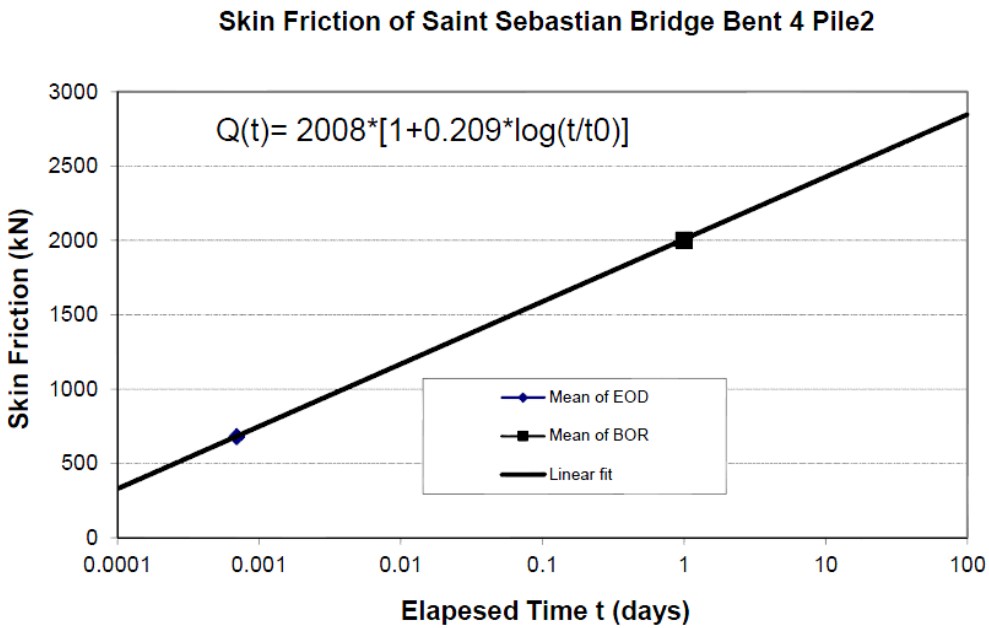




Skin Friction Freeze At Other Sites

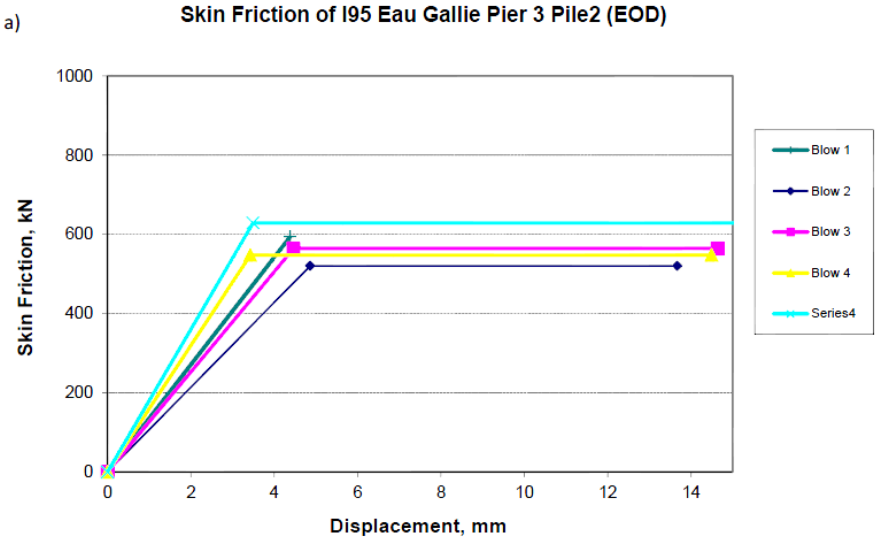




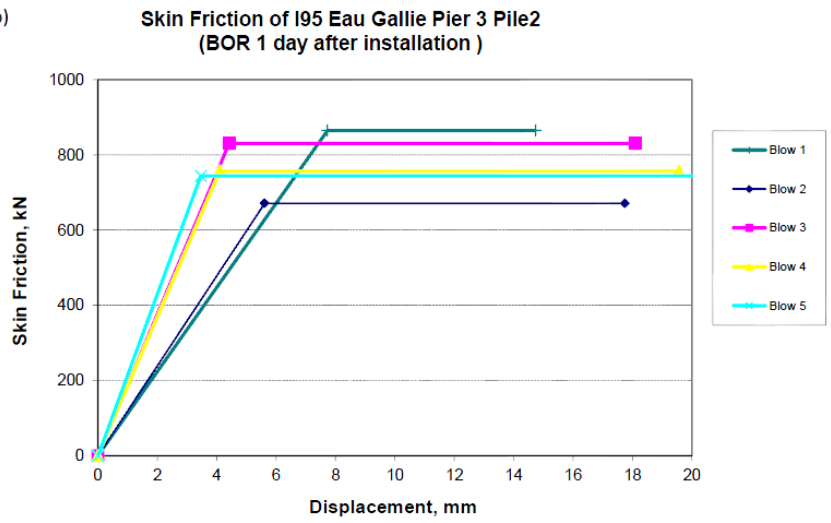


Skin Friction Freeze At Other Sites

a)



b)



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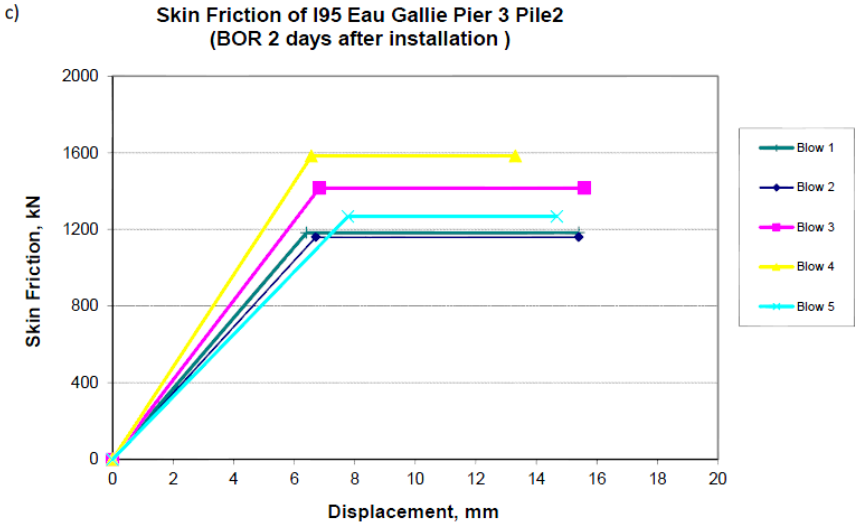
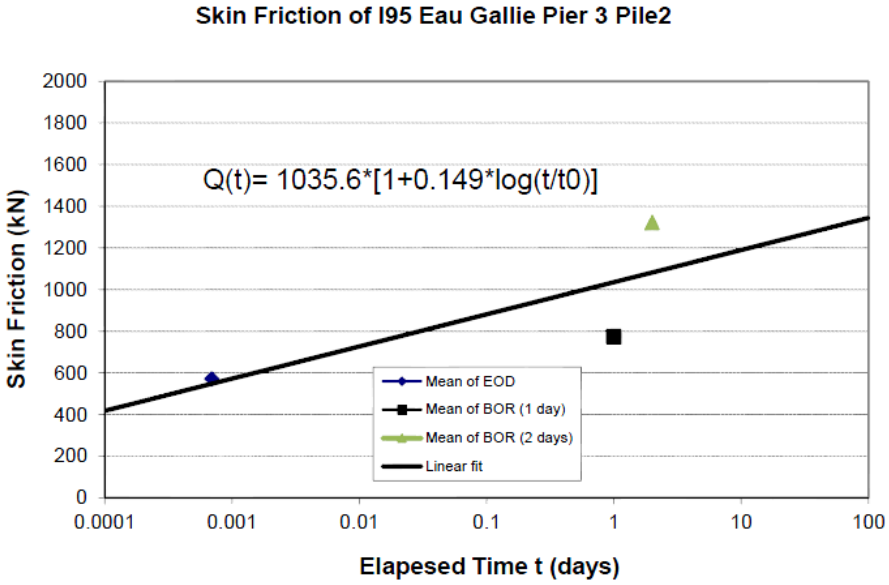
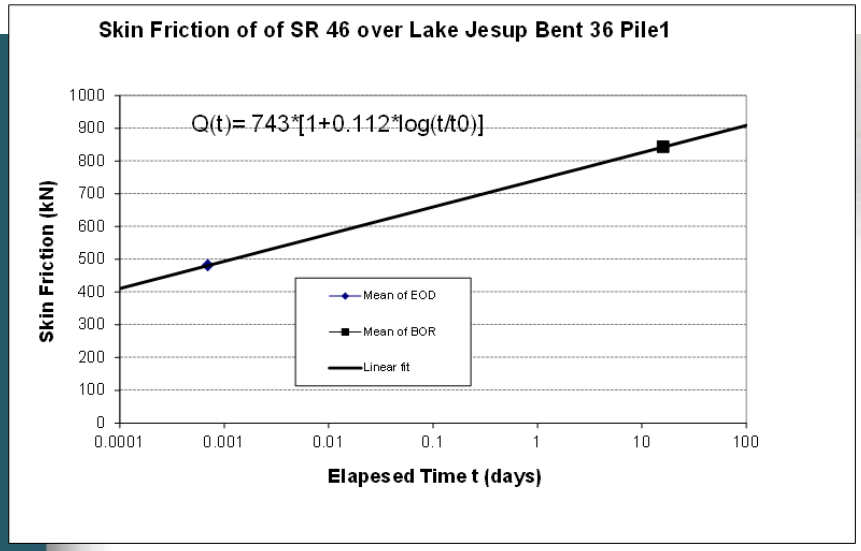
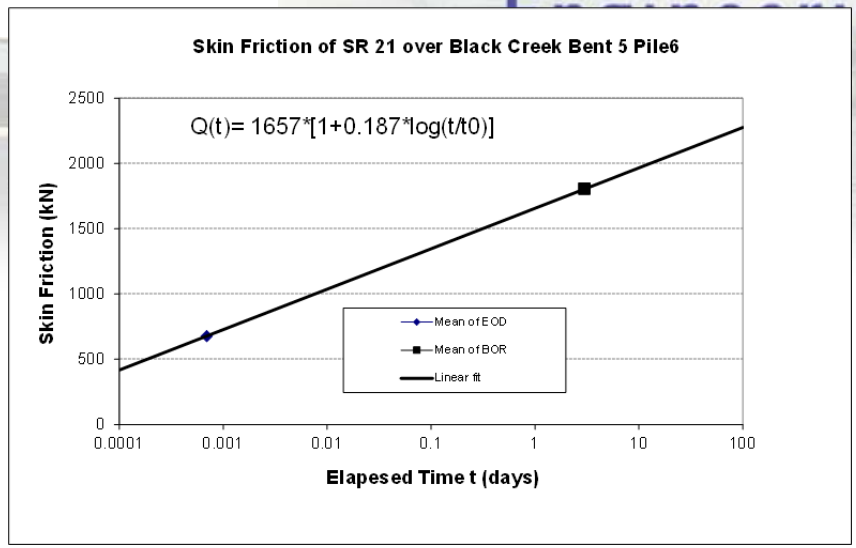
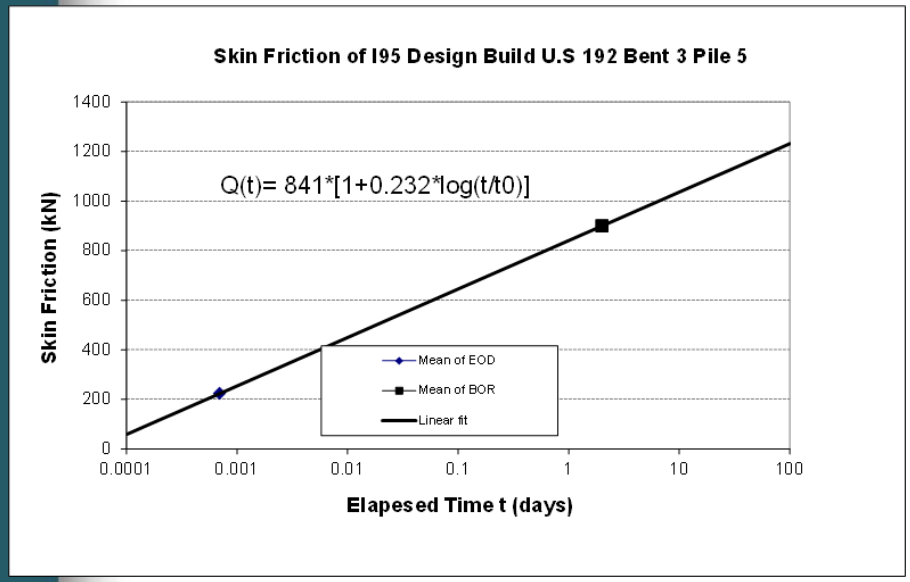


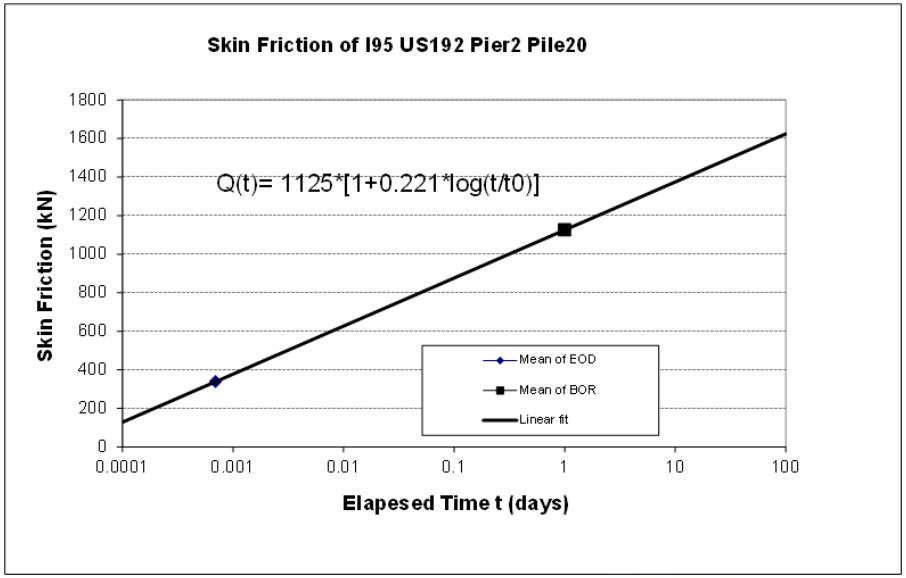


Skin Friction Freeze At Other Sites









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Skin Friction Freeze At Other Sites

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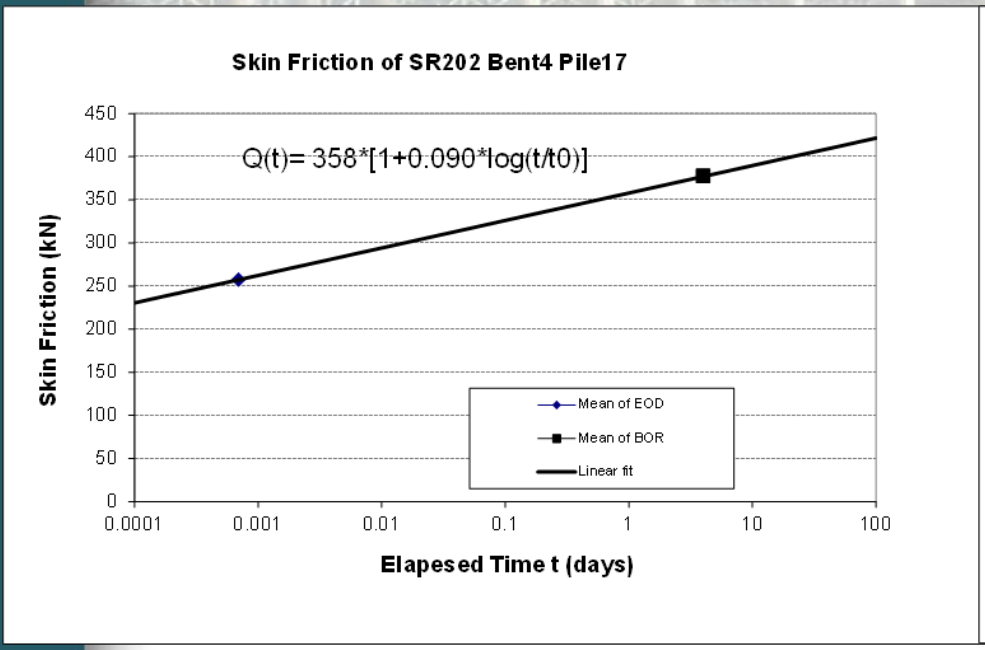

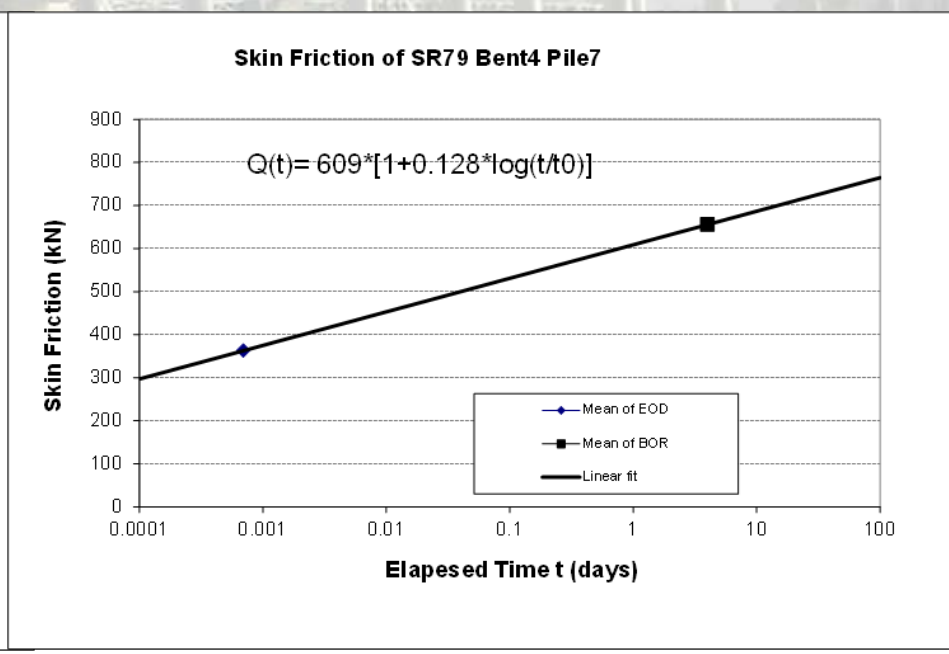

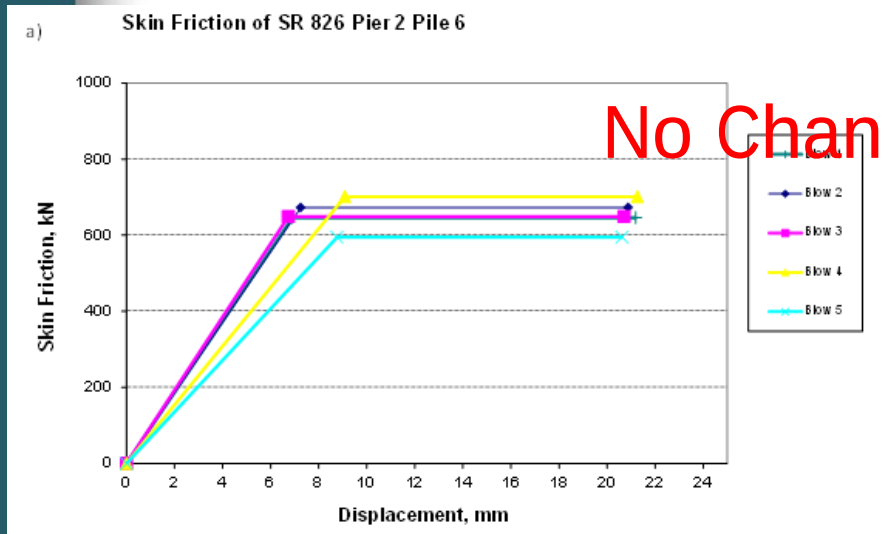

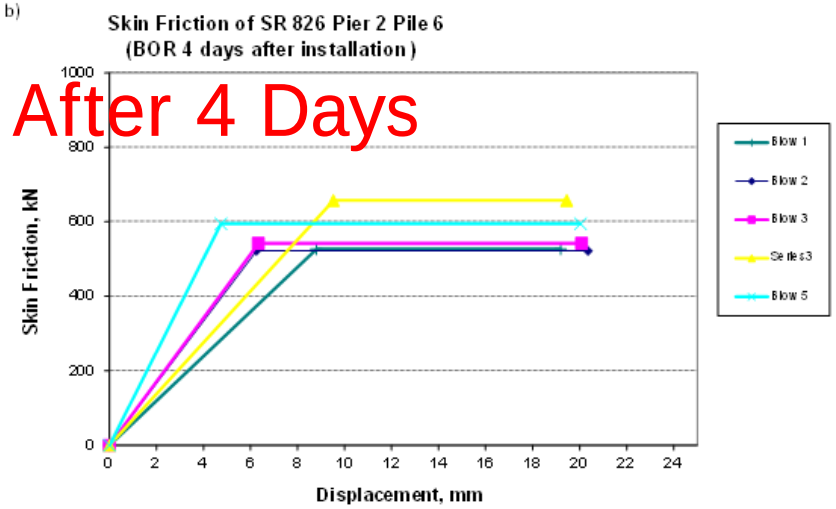

No Change After 4 Days

Estimation of Tip Resistance Changes with Time

Estimating static tip resistance of driven piles with bottom pile instrumentation

Khiem T. Tran, Michael McVay, Rodrigo Herrera, and Peter Lai

Abstract: A technique is presented to estimate static tip resistance of a pile during driving from embedded strain and accelerometer data located one diameter (*D*) from the bottom of the pile. The approach uses a nonlinear single degree of freedom system to satisfy force and energy equilibrium with a global genetic inversion approach. By balancing force and energy from inertia, damping, and stiffness against the measured tip data, the unknown parameters (mass, damping, and nonlinear stiffness) are estimated. Requiring a few seconds for analysis for each blow, the algorithm ensures a real-time assessment of static tip resistance as a function of displacement, which is important when setting pile lengths. The proposed approach was applied to four test piles at two bridge sites (Florida and Louisiana). Mobilized static tip resistances ranging from 400 to 1500 kN as a function of displacement were predicted. The predicted static resistance versus displacements compared favorably with measured values from static load tests. Interestingly, the maximum recorded increase in tip resistance in silty to clayey sands was less than 20% when piles were re-struck at times ranging from 2 to 30 days after initial drive.

Key words: tip resistance, driven pile, genetic algorithm, real-time assessment.

Received 7 December 2010. Accepted 22 December 2011.
Published at www.nrcresearchpress.com/cgj on 16 March 2012.

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Can. Geotech. J. **49**: 381–393 (2012)

Task 3: Improve Pile Freeze and Pile Capacity

Improved Pile Tip Capacity:

Tip Accelerometer

Tip Strain Gage

- **Use of Force Equilibrium and Energy to Assess Static Tip Resistance**

$$F_{inertia}\left(m\ddot{x}\right)+F_{damping}\left(c\dot{x}\right)+F_{static}\left(kx\right)=P\left(t\right)$$

Force Equilibrium

Inertia force

Damping force

Static force

Applied force

$$\int_{t}^{t+T}\left(\underbrace{m}_{\text{mass}}\overbrace{\ddot{x}}^{\text{accel}}+\underbrace{c}_{\text{viscous damp}}\overbrace{\dot{x}}^{\text{Vel.}}+\underbrace{k}_{\text{stiffness}}\overbrace{x}^{\text{Dis.}}\right)\dot{x}\,dt=\int_{t}^{t+T}P\left(t\right)\overbrace{\dot{x}}^{\text{strain}}\,dt$$

Energy Equilibrium

In Time Domain

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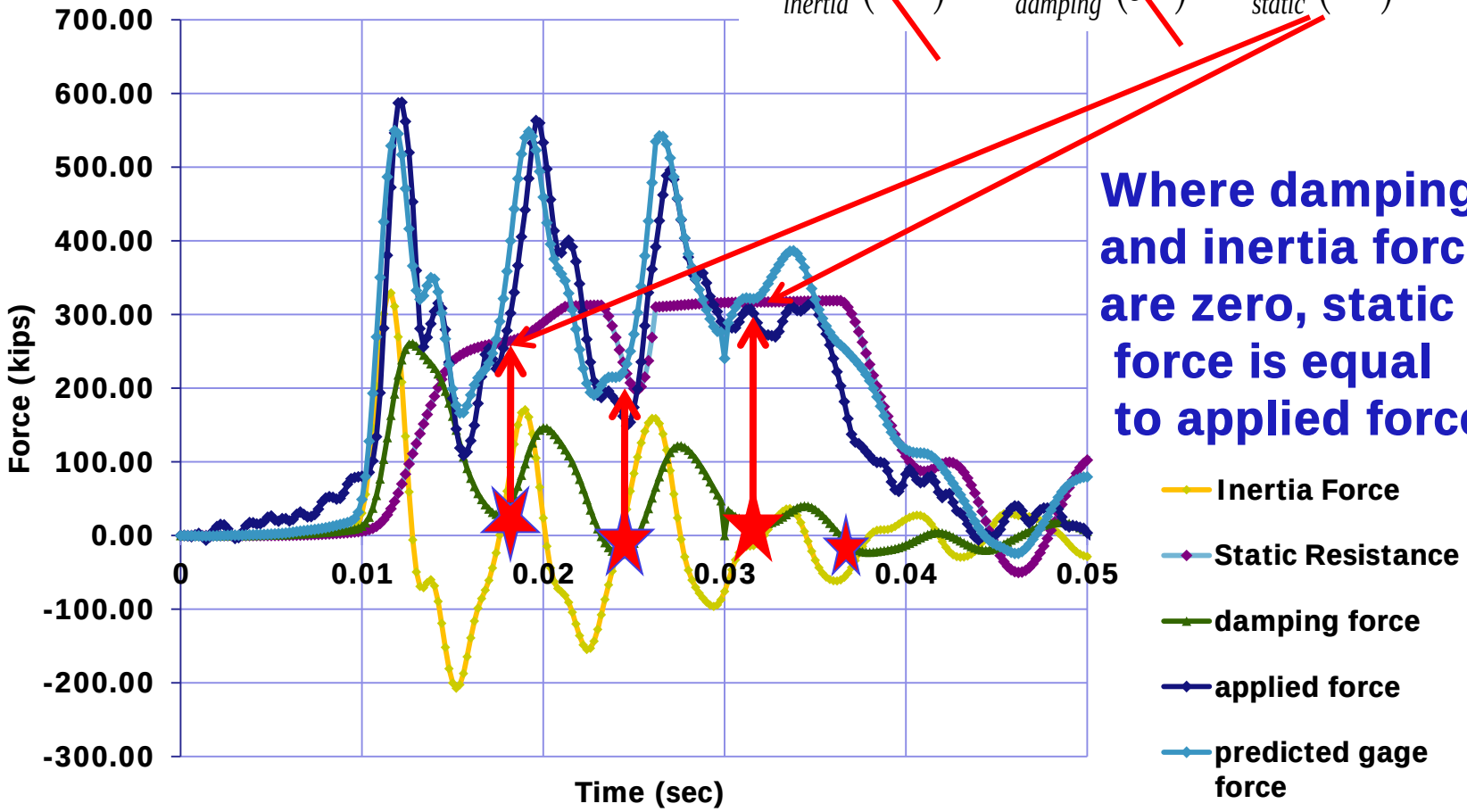
Energy Method For Accessing Damping and Static forces

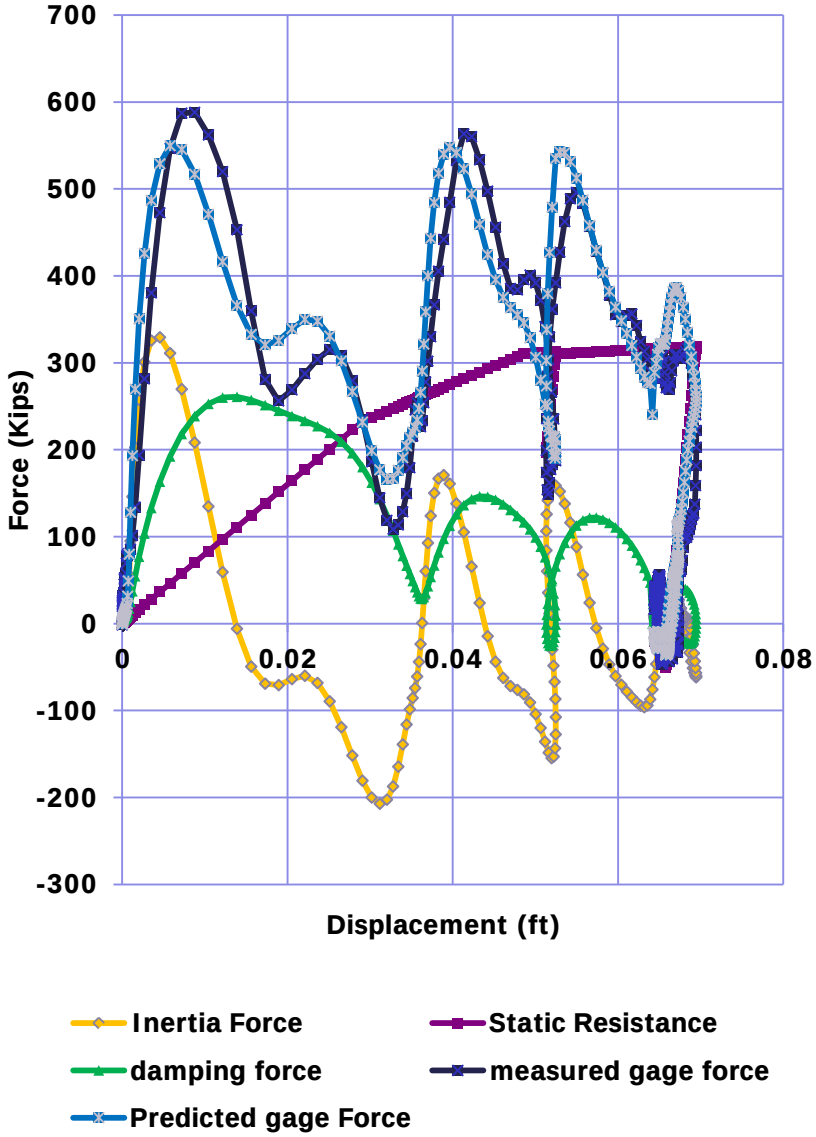
$$F_{inertia}(m\ddot{x}) + F_{damping}(c\dot{x}) + F_{static}(k\,x) = P(t)$$

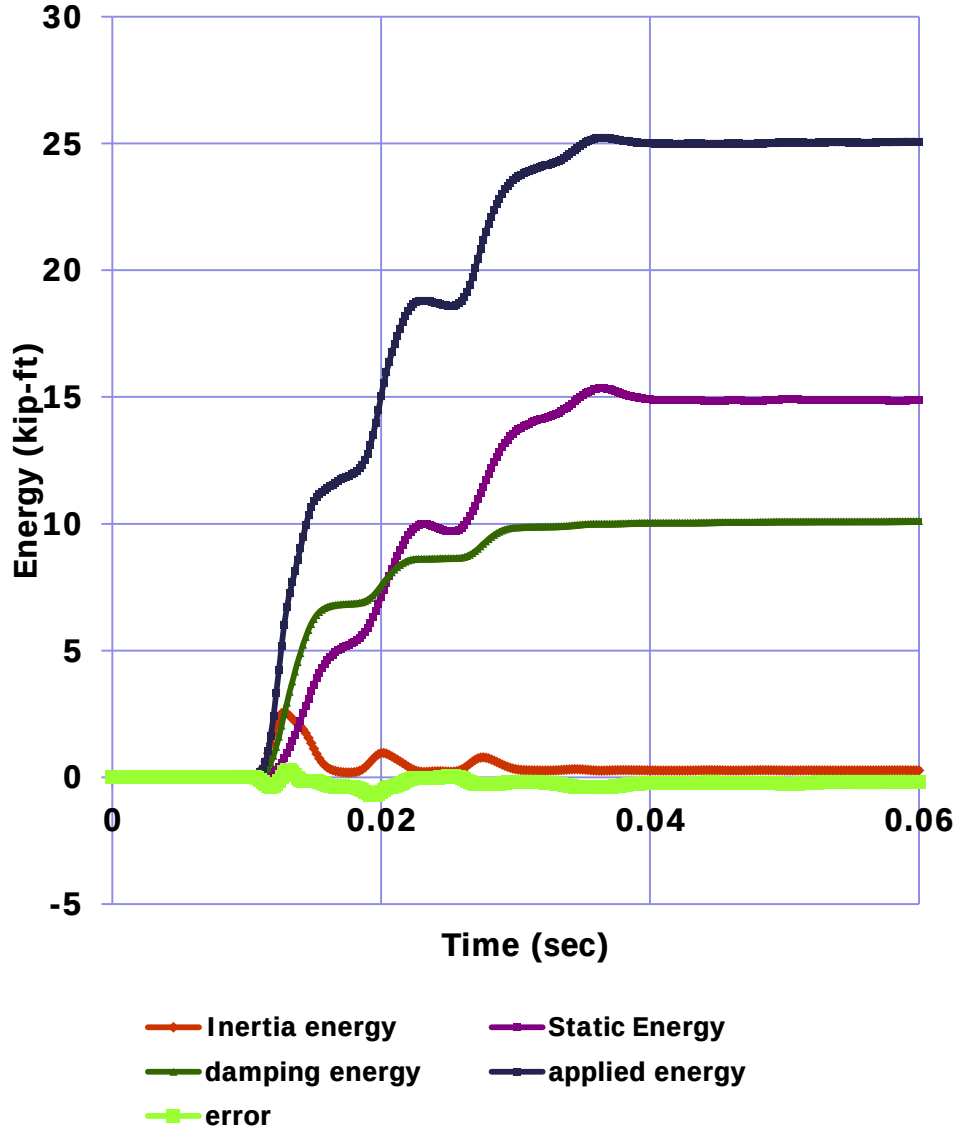
0 0



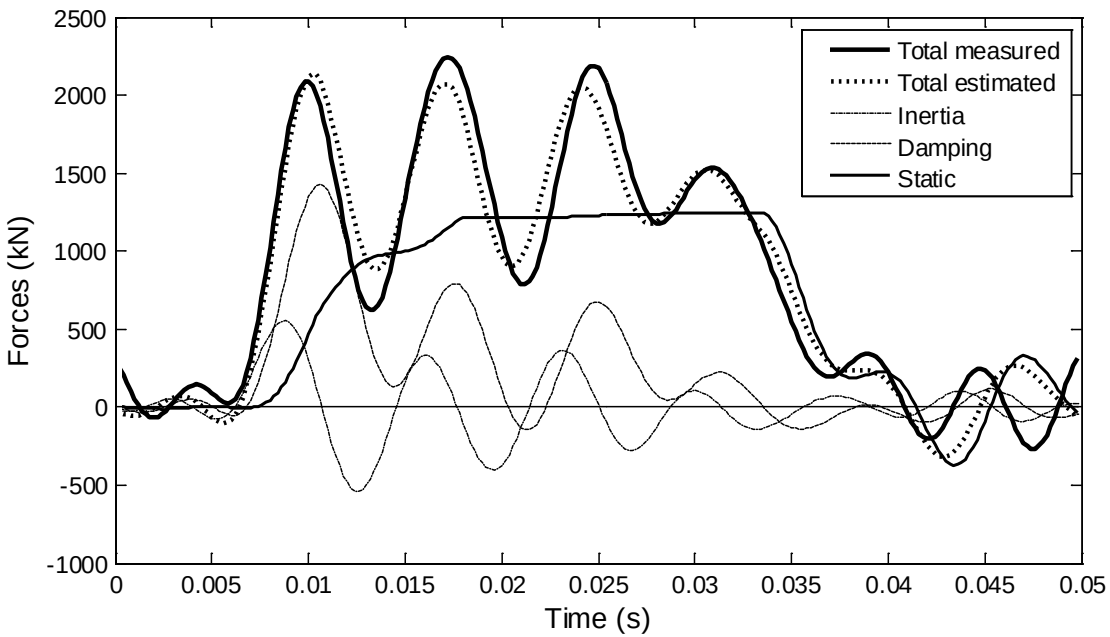
Where damping and inertia forces are zero, static force is equal to applied force.

Energy Method For Accessing Damping and Static forces



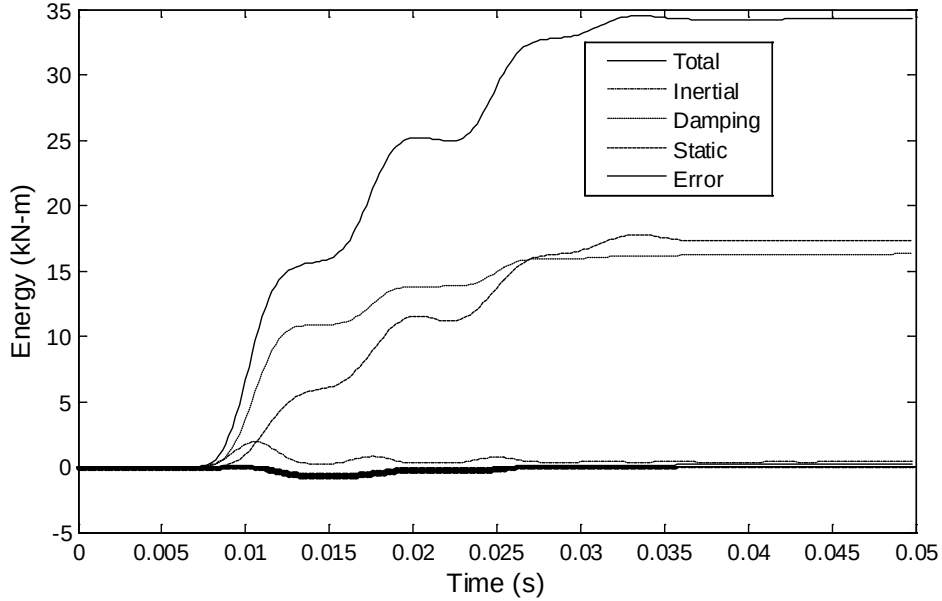


Dixie Highway 24”x50’, Pile 1



Matching Forces: Inertia, Damping & Static

Conserving Energy: Inertia, Damping & Static



Dixie Highway 24”x50’

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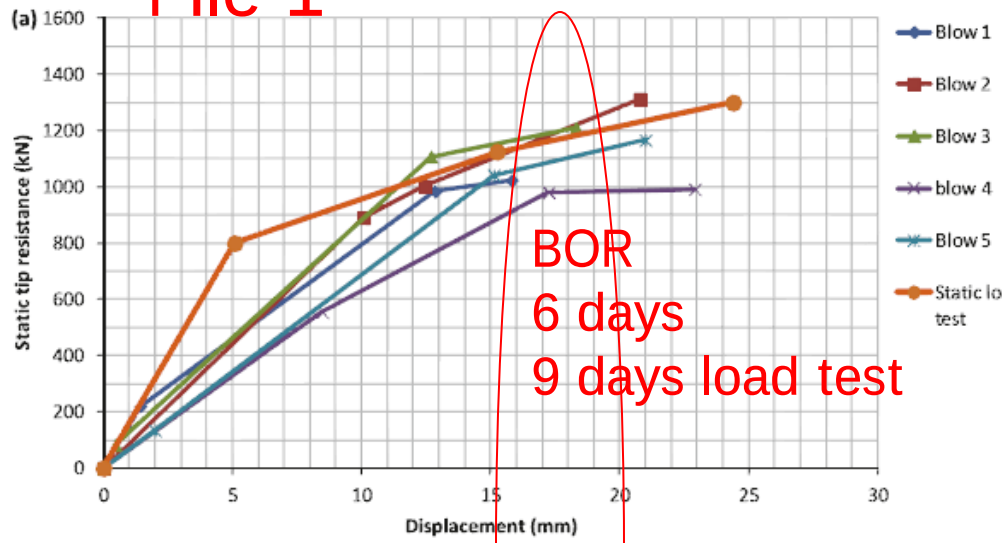
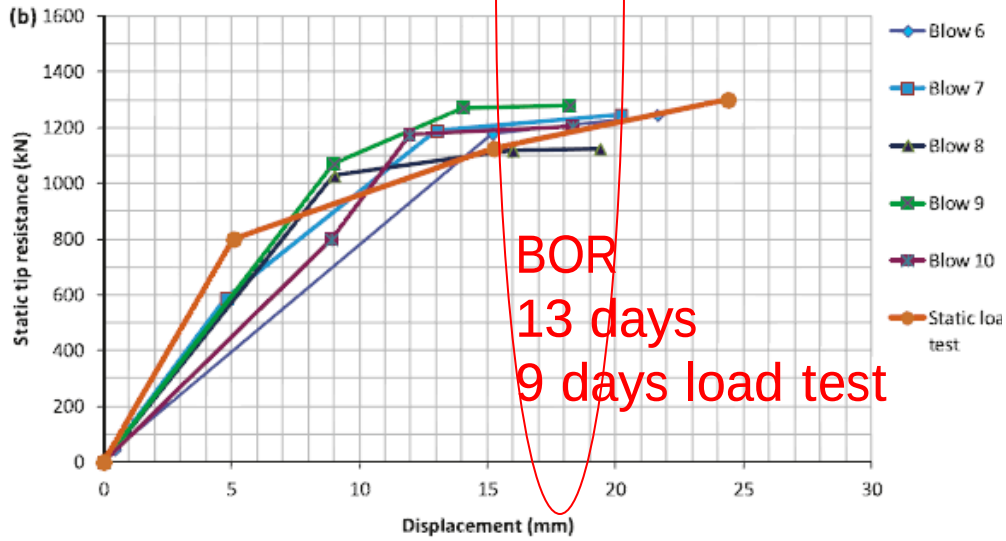
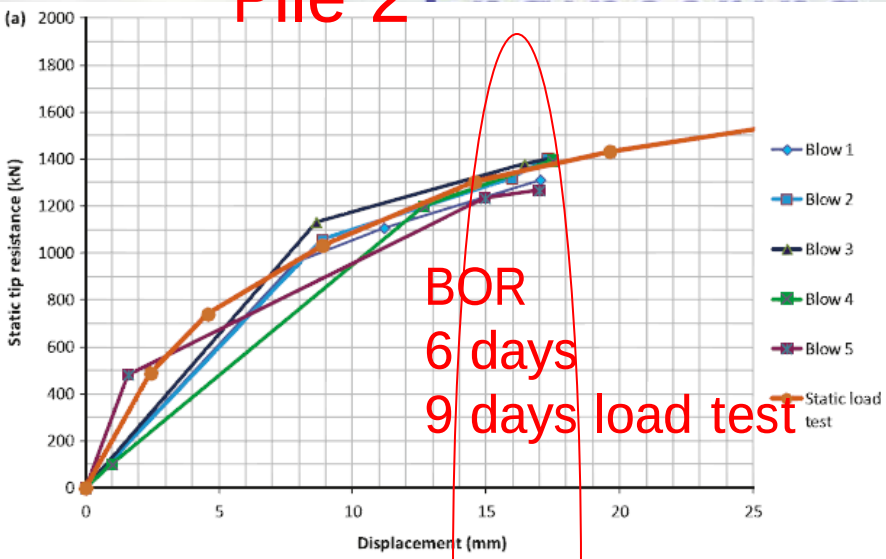
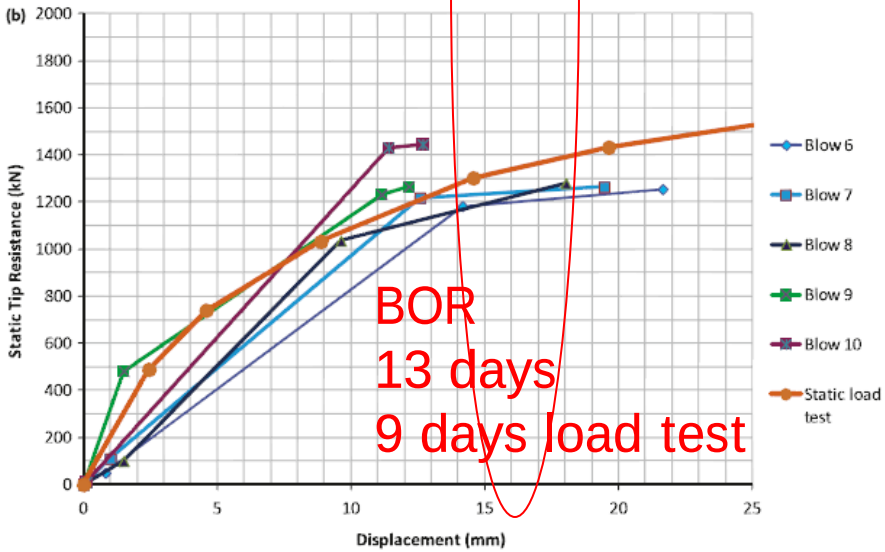
Pile 1





Pile 2





Approx ~ 20% Increase in Tip Resistance Due to Freeze

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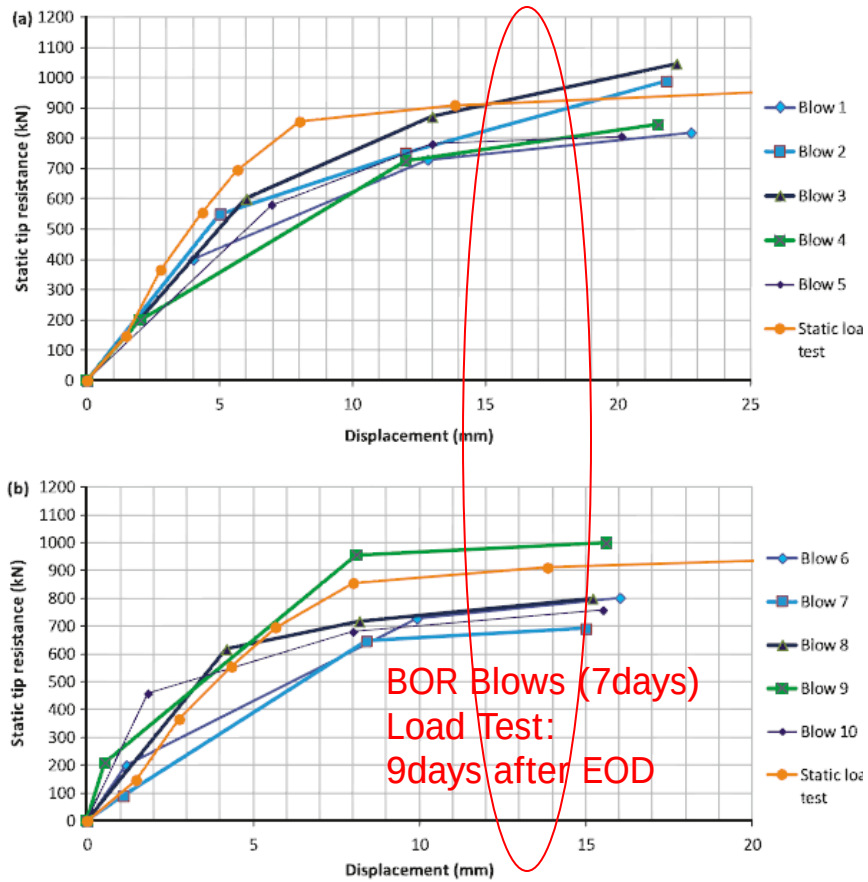
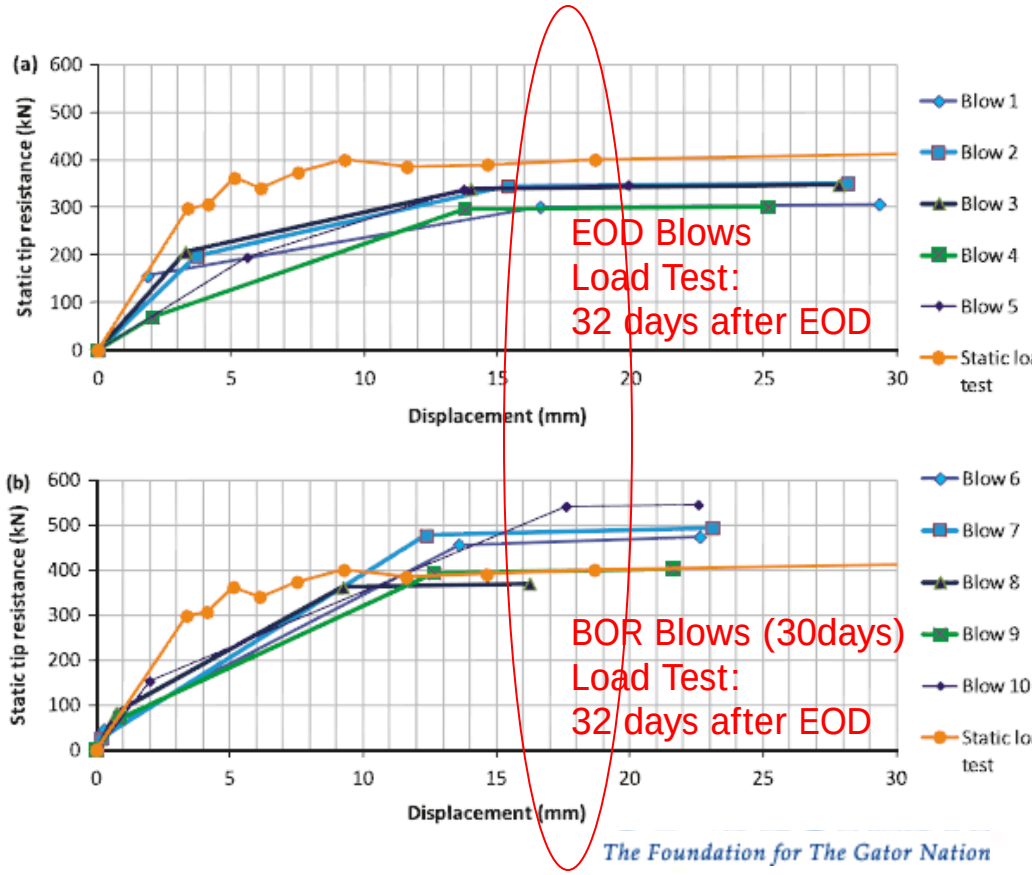
Example Caminada Bay, Louisiana

30”x30”x70 ft Prestressed Concrete in Sand, Silt & Clay

15% Increase in Tip Resistance Due to Freeze

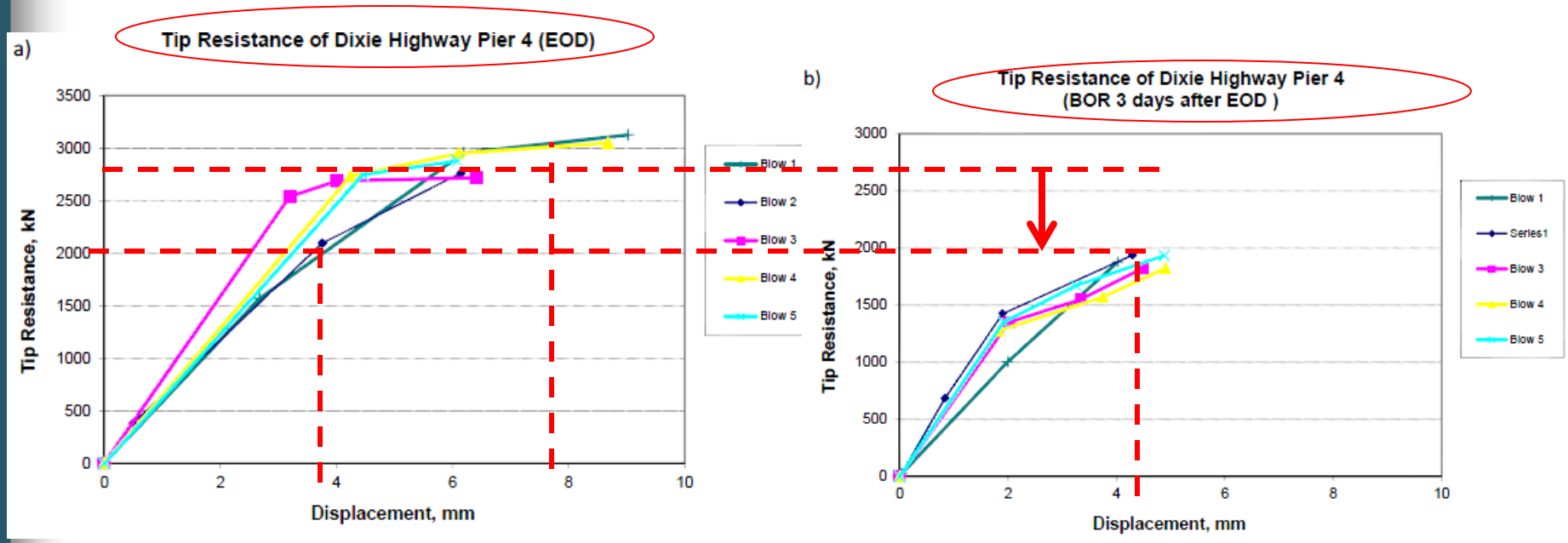
23% Increase in Tip Resistance Due to Freeze





Insufficient Hammer Energy to Pile Tip

Dixie Highway, Pier 4



Skin Friction 620 kN

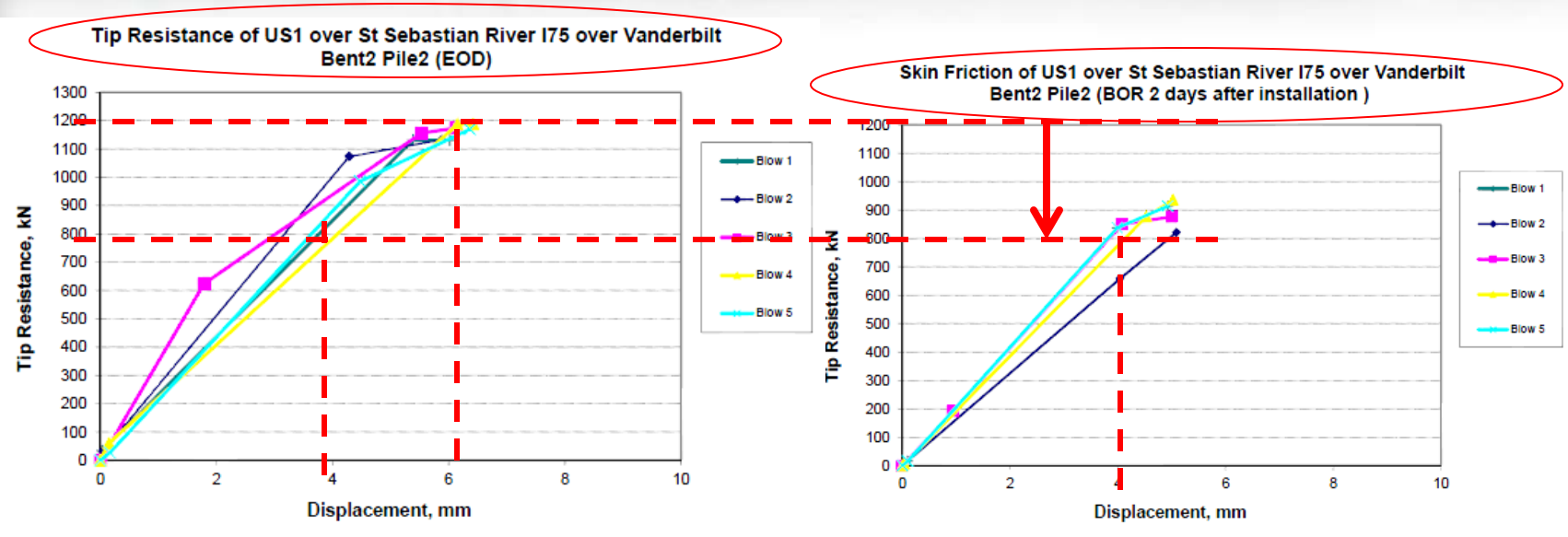
End Bearing 2800 kN

Skin Friction 950 kN

End Bearing 2000 kN

Insufficient Hammer Energy to Pile Tip

St Sebastian River I75



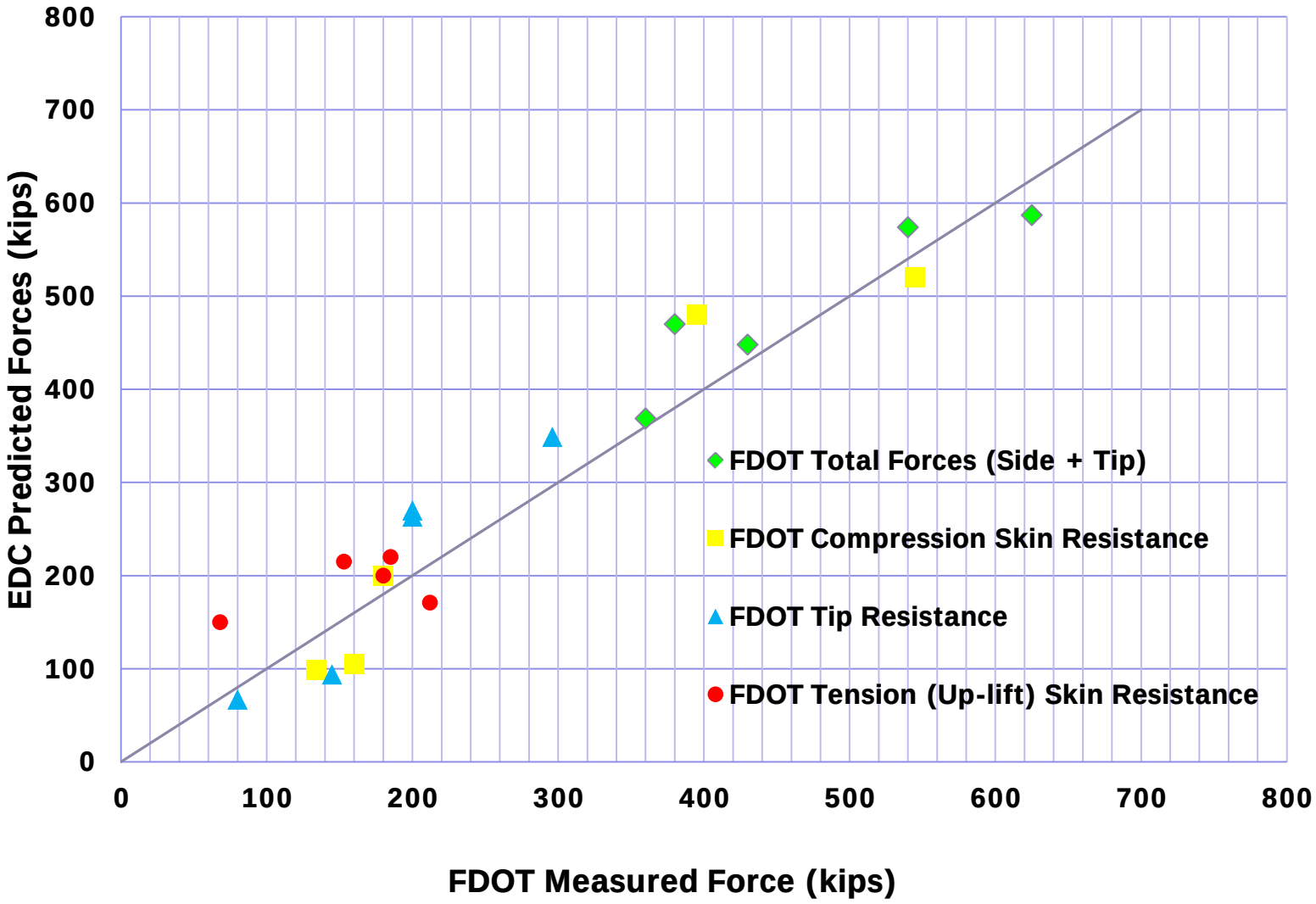
End Bearing 1200 kN

End Bearing 800 kN

Loss of 1/3 EB (400kN) Due to 1/3 Loss Mobilized Displacement

NCHRP Synthesis 20-5, Topic 41-10 (2010) “Developing Production Pile Driving Criteria From Test Pile Data ---Use of Superposition to combine base resistance from initial drive with side Resistance from early blows of restrike”

Comparison of (FDOT) Measured and EDC Predicted Forces (20 Values)



References:

Khiem T. Tran, Michael McVay, Rodrigo Herrera, and Peter Lai (2011), “A New Method for Estimating Driven Pile Static Skin Friction with Instrumentation at the Top and Bottom of the Pile”, ***Soil Dynamics and Earthquake Engineering***, Vol. 31 (9), pp 1285-1295.

Khiem T. Tran, Michael McVay, Rodrigo Herrera, and Peter Lai, (2012) “Estimation of Nonlinear Static Skin Friction on Multiple Pile Segments Using Measured Hammer Impact Response at the Top and Bottom of the Pile” ***Computers and Geotechnics***, Vol 41, pp 79-89.

Khiem T. Tran, Michael McVay, Rodrigo Herrera, and Peter Lai, (2012) “Estimating Static Tip Resistance of Driven Piles with Bottom Pile Instrumentation”, ***Canadian Geotechnical Journal***, Vol. 49, pp 381-393