A Comparison of Static Axial Capacity Between Drilled and Driven Piles

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Outline

- Factors Affecting Driven Pile Performance
- Factors Affecting Drilled Pile Performance (emphasis on CFA piles)
- Comparison of Unit Capacities
- Case History / Comparative Tests
- Advantages/Disadvantages

Factors Affecting Driven Pile Performance

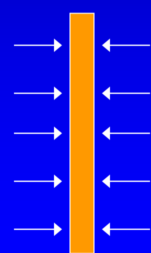
- Effect of Pile Installation on Soil
- Effect of Time
- Residual Stresses
- Construction Control

Effect of Pile Driving on Soil

- Pile displaces and remolds soil
- Pile installation alters state of stress in the ground

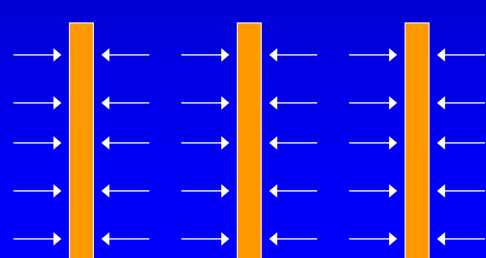
Effect of Pile Driving on Soil

- Pile installation alters state of stress in the ground
  - Increase in horizontal stress related to displacement



Effect of Pile Driving on Soil

- Group effects tend to amplify the effects of displacement on stresses and soil densification!



Effect of Pile Driving on Soil

Vesic, A.S., "Design of Pile Foundations NCHRP Synthesis of Highway Practice No. 42, TRB, 1977

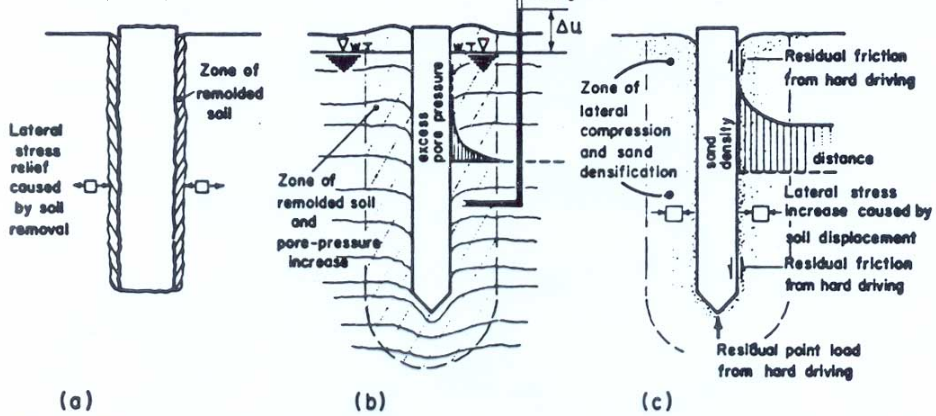
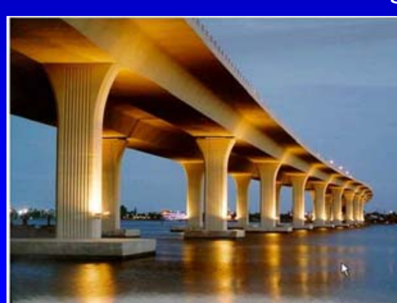


Figure 6. Effects of placement of pile into a soil mass.

Effect of Pile Driving on Sandy Soil

- Pile displaces and remolds soil
  - Sands often densified
    - Ex: Roosevelt Bridge 5X increase in dmt



Effect of Pile Driving on Clay Soil

- Pile displaces and remolds soil
  - Remolding/reconsolidation of clay soils

McClelland, B. "Design of Deep Penetration Piles for Ocean Structures," Journal of the Geotechnical Eng'g Div., ASCE, Vol. 100, No. GT7, July, 1974, 709-747

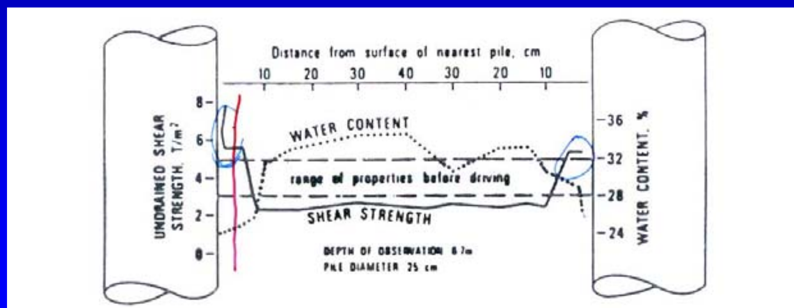


FIG. 15.—**Shear Strength and Water Content Variations Between Two Driven Piles** (6)

Effect of Time on Driven Piles

- Time dependent setup due to:
  - Dissipation of transient pore pressures
  - Relaxation/creep in soil around pile

Effect of Time on Pore Pressures (Clay Soils)

O'Neill, M.W. 1983 "Group Action in Offshore Piles" Proc., Geotechnical Practice in Offshore Engineering, ASCE, Austin, TX, 25-64.

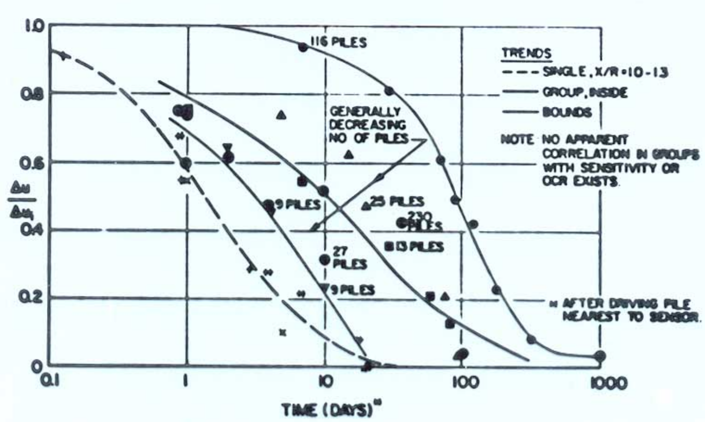


Fig. 7. Pore Water Pressure Dissipation Rates: Full-Scale Single Piles and Groups in Clay.

Effect of Time on Axial Capacity (Clay Soils)

Vesic, 1977

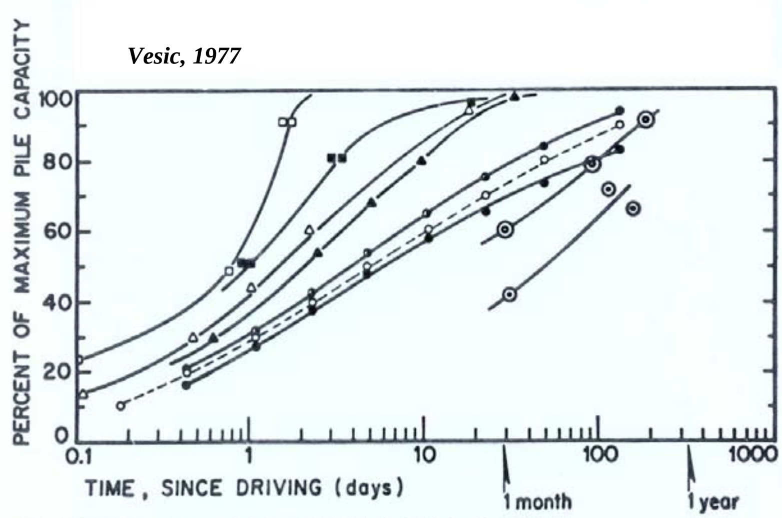


Figure 13. Field data on increase of bearing capacity with time for friction piles in clay.

Effect of Time in Sands

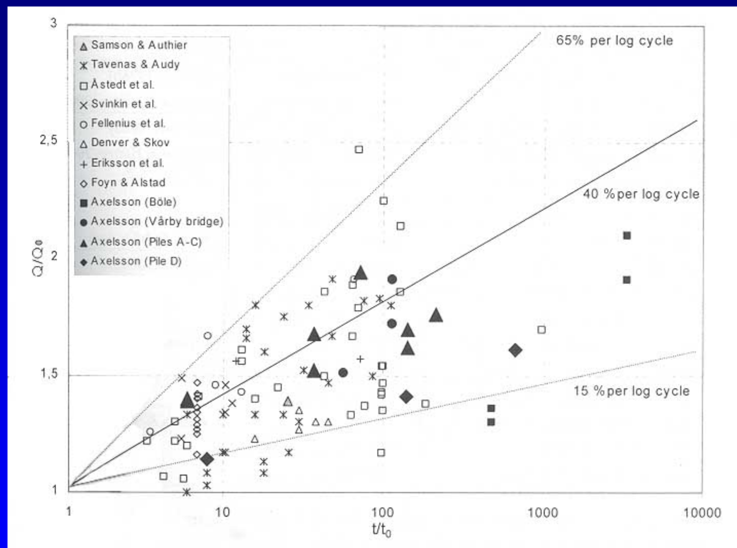


Figure 1. Case histories of long-term pile set-up (t_0 is 0.5-4 days after EOD).

Axelsson, G., 2002. "A Conceptual Model of Pile Set-Up for Driven Piles in Non-Cohesive Soil", GSP 116, ASCE, 64-79.

Effect of Time in Sands

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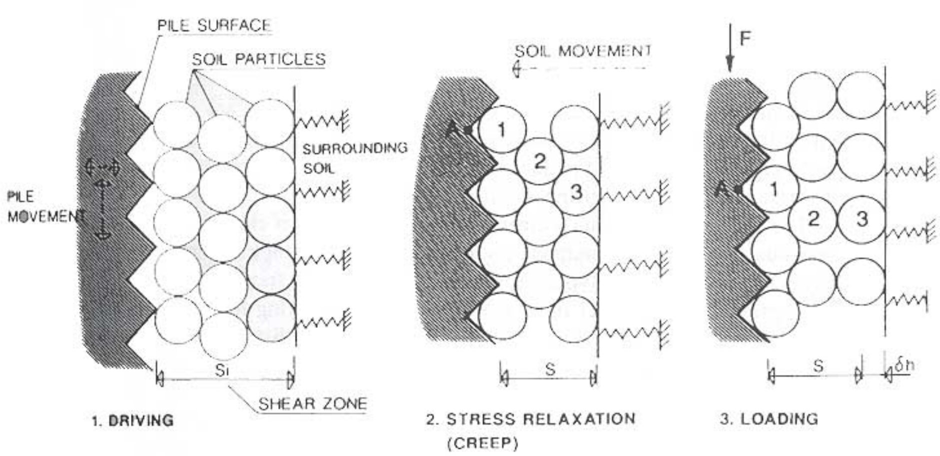


Figure10. Schematic illustration of stress relaxation and increasing constrained dilatancy over time with regard to piling.

Residual Stresses in Driven Piles

- Acts to "preload" the tip resistance
- Difficult to measure correctly, but the effect is always there!

O'Neill, M.W., Hawkins, R.A., and Audibert, J.M.E., 1982. "Installation of Pile Group in Overconsolidated Clay", Journal of the Geotechnical Eng'g Div., ASCE, Vol. 108 No. GT11, 1369-1386.

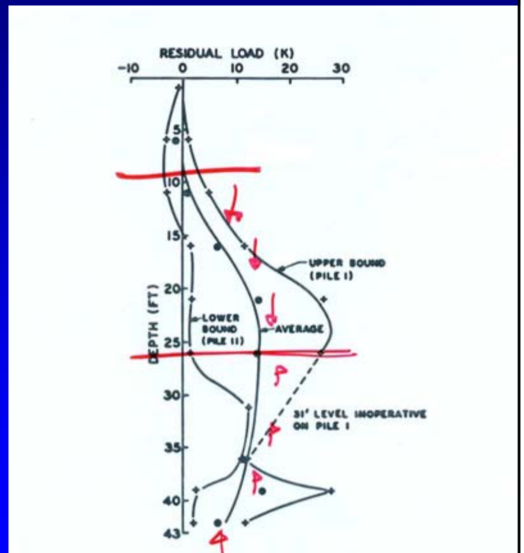


FIG. 13.—Residual Load versus Depth; Reference Piles (1 ft = 0.305 m; 1 kip = 4.45

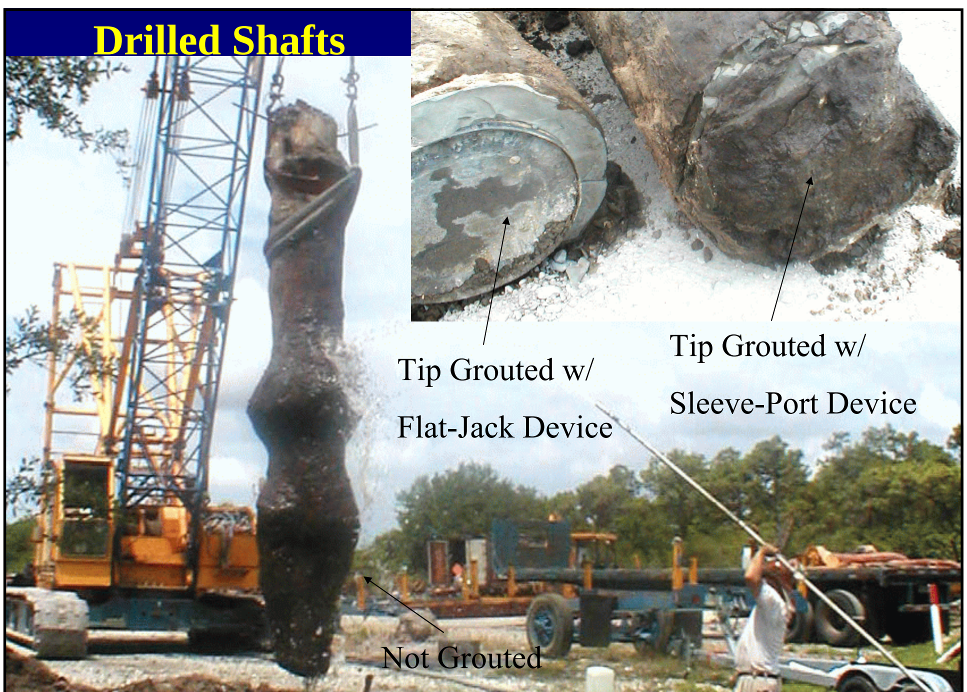
Construction Control - Driven Piles

- Measurement of driving resistance provides some indication of axial capacity
  - Wave Equation Analysis
  - Dynamic Measurements
- End of Drive measurements usually conservative due to setup
- Reliability related to hammer performance

Factors Affecting Drilled Pile Performance

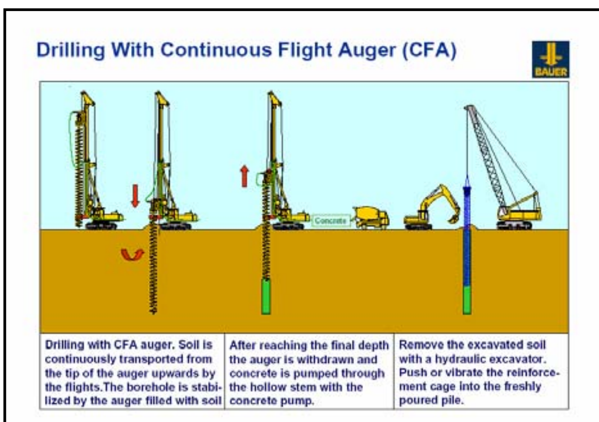
- Sidewall roughness and adhesion
- Effect of installation on *in-situ* stresses
- Mobilization of tip resistance
- Construction control

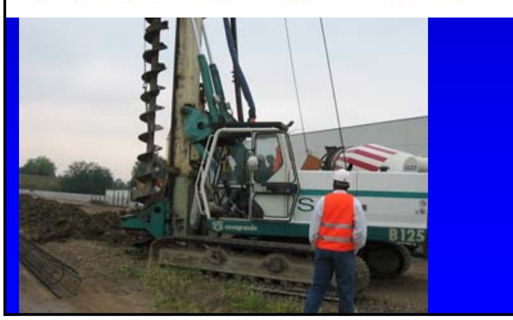
Drilled Shafts



Drilled Shafts

Conventional CFA Piles





Drilled Displacement Piles

Sidewall Roughness Drilled Piles

– Bonding of grout/concrete can be terrific in cemented material, e.g. limerock (Miami), cemented sands

– Remolding in the near field in cohesive materials, ex. = Houston clays where CFA essentially = drilled shaft

Effect of Drilled Pile Installation on in-situ stresses

– Lateral stress is reduced by Drilled Shaft installation

– Lateral stress is typically reduced by conventional CFA Pile installation

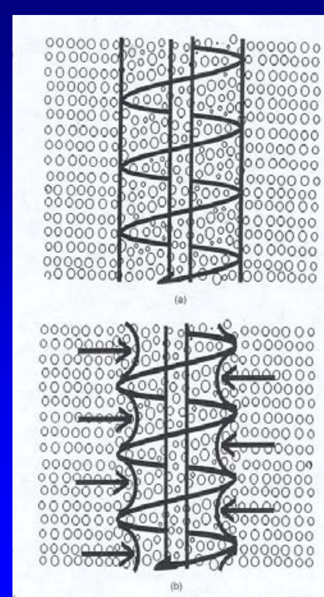
* Rate of auger penetration is critical in uncemented materials; this needs to be controlled!

Effect of Over Excavation in Cohesionless Soil

a) auger w/ rapid penetration

b) auger w/ slow penetration, insufficient base feed to keep flights full, auger feeds from side

Fleming, W.G.K. 1995. "The understanding of continuous flight auger piling, its monitoring and control" *Proc. Instn Civ. Engrs Geotech. Engng*, **113**, July,157-165

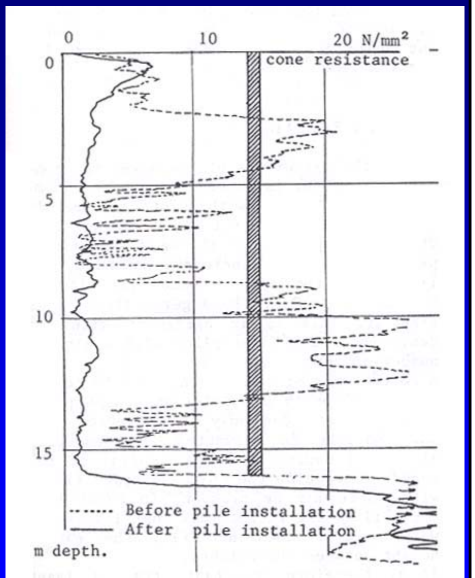


Suggested Guidelines for Penetration Rates

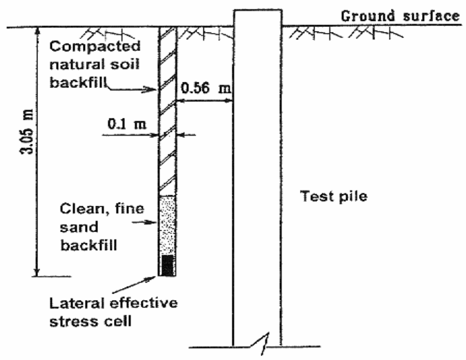
- Clay: 2 to 3 Rev's per auger pitch
- Sand: 1.5 to 2 Rev's per auger pitch

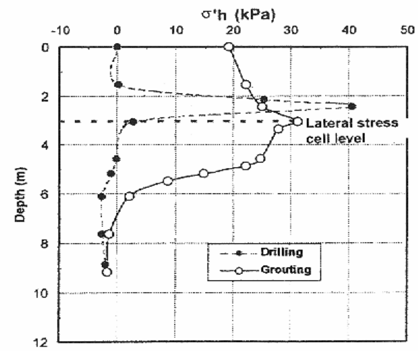
CPT from nearby CFA pile in sandy soil

Van Weel, A.F. 1988. "Cast-in-situ piles – Installation methods, soil disturbance and resulting pile behaviour" *Proc., 1st Int'l Geotech Seminar on Deep Foundations on Bored and Auger Piles*, (Ghent, Belgium) Van Impe, ed, Balkema, Rotterdam, 219-226.



Measurements of *in-situ* Stress During CFA Pile Installation In Clay Soils





O'Neill, M. W., Ata, A., Vipulanandan, C., and Yin, S., (2002). "Axial Performance of ACIP Piles in Texas Coastal Soils", Geotechnical Special Publication No. 116, Ed. by M. W. O'Neill and F. C. Townsend, American Society of Civil Engineers, February, Vol. 1

Measurements of *in-situ* Stress During a CFA Pile Installation

Van Impe, W.F. and Peiffer, H., 1997. "Influence of screw pile Installation on the stress state in the soil" Design of Axially Loaded Piles – European Practice, De Cock & Legrand (eds) Balkema, Rotterdam, 3-20.

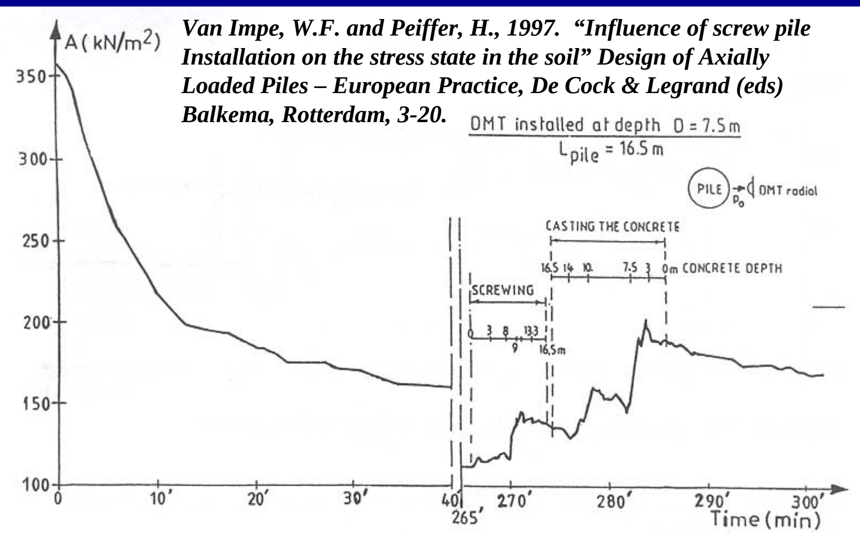


Figure 11. DMT test during pile installation of PCS-pile at Dendermonde test site

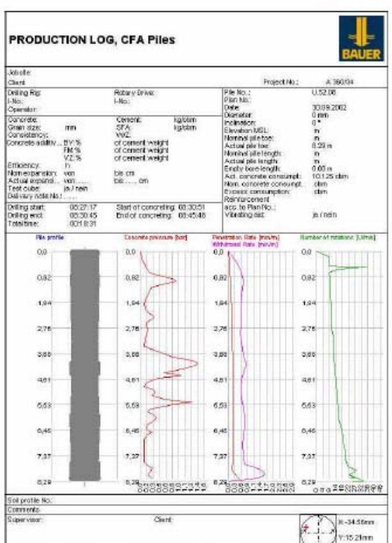
Mobilization of Tip Resistance

- Tip resistance MAY require significant displacement to mobilize; very dependent upon soil/rock type and construction technique
- For ACIP and Drilled Displacement Pile: Grout Pressure may help to mitigate some disturbance.
- For Drilled Shafts: Tip Grouting may allow for tip mobilization within reasonable displacements, as well as proof test some resistance.

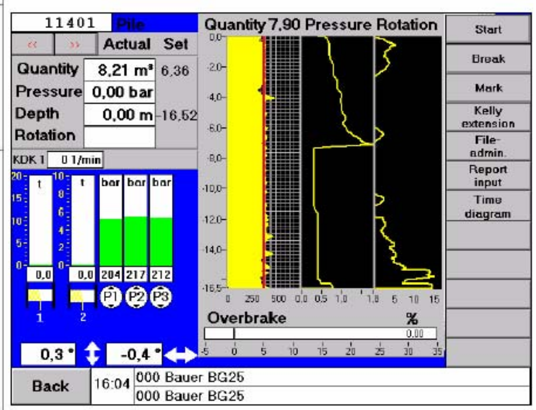
Construction Control (Historically a "Lack Of")

- There is a compelling need for monitoring during installation & withdrawal of augers:
  - Rate of penetration relative to torque & crowd
  - Grouting pressures
  - Grouting volume

B- Tronic Control System



CFA pile production



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Automated Monitoring Systems

PIR System

Grouting Data (1999-07-26_07:49)

Vol/inc x1.25: 4.421 ft3

depth	volume	strks	grout
44	7.88	22	0
42	4.63	7	0
40	4.63	8	0
38	4.59	8	0
36	4.45	8	0
34	4.84	8	0
32	4.63	8	0
30	4.49	7	0
28	4.27*	8	0
26	4.73	9	0
24	4.34*	8	0
22	5.01	9	0
20	4.70	7	0
18	4.70	9	0
16	4.45	8	0
14	4.66	8	0
12	4.56	7	0
10	4.49	8	0
8	4.66		

Photograph and figures courtesy of Pile Dynamics Inc

Construction Control

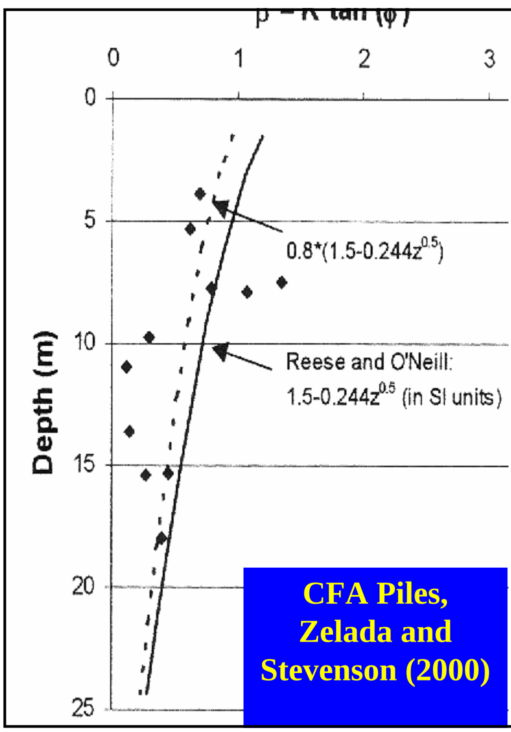
- Establish Construction Parameters of Test Piles
- Load Test Initial Test Piles
- Hold Contractor to Established Construction Parameters
- Load Test Some Production Piles Selected by ENGINEER

- While this greatly helps to ensure a well constructed pile, always remember there is No DIRECT feedback on capacity during installation as with a Driven Pile

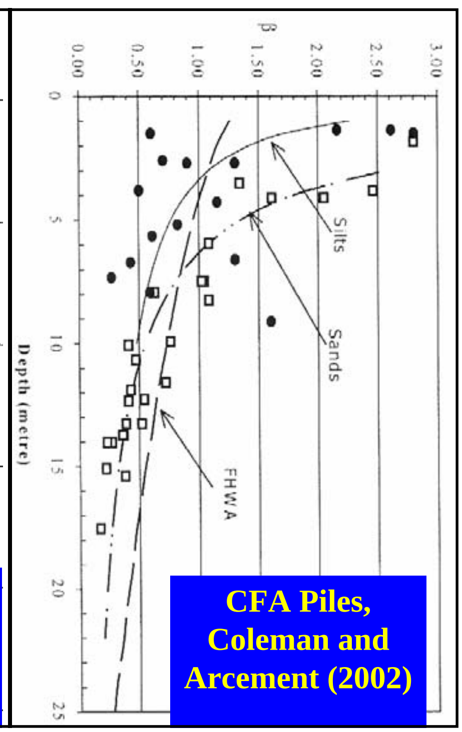
US - FHWA Practice

Granular soils: $f_s = \beta\sigma'_v$	Side Shear Method	β	Unit Tip resistance
Closed end pipe (14”)	Nordlund, $\phi = 37^o$ Nordlund, $\phi = 34^o$	0.72 0.50	$4N_{spt}$, tsf
Precast concrete (12”)	Nordlund, $\phi = 37^o$ Nordlund, $\phi = 34^o$	0.92 0.62	$4N_{spt}$, tsf
Drilled shafts, Reese & O’Neill (FHWA)	β= 1.5-.135(z,ft)$^{0.5}$ $0.25 \le \beta \le 1.2$	0.82 @ 25’ 0.65 @ 40’	$0.6N_{spt}$ $\le$ 45 tsf
CFA piles, Zelada and Stevenson, 2000 (GSP 100)	β= 1.2 – 0.108z$^{0.5}$ $0.2 \le \beta \le 0.96$	0.66 @ 25’ 0.52 @ 40’	q_b = 1.7 N_{spt} $\le$ 75 tsf
CFA piles, Colman and Arcemont 2002 (GSP 116)	β= 2.2683·$z_M^{-0.6744}$ (Silty) β= 10.716·$z_M^{-1.2982}$ (Sandy) $0.2 \le \beta \le 2.5$	0.57 – 0.77 @ 25’ 0.42 @ 40’	No Recommend-ation
Drilled Displacement Piles, NeSmith 2002 (GSP 116)	0.05·N+Ws $f_s \le$ 2.2 tsf	Not Used, See Chart	1.9·N+Wt $q_p \le$ 89 tsf

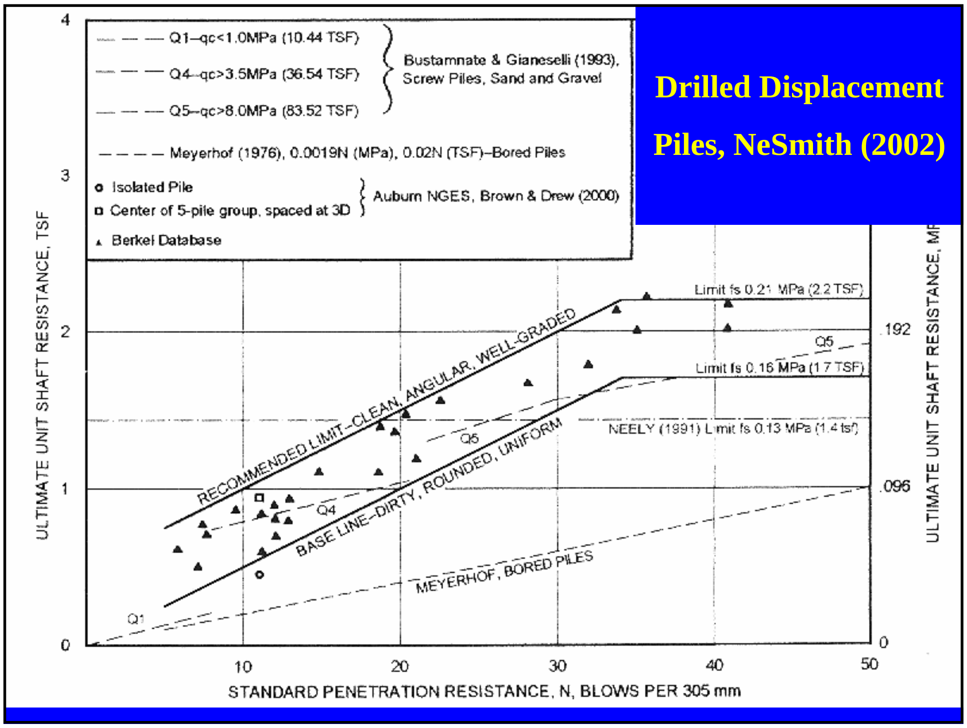
Notes: tip for drilled shafts mobilized at 5% x diameter, cfa mobilized at 10% .

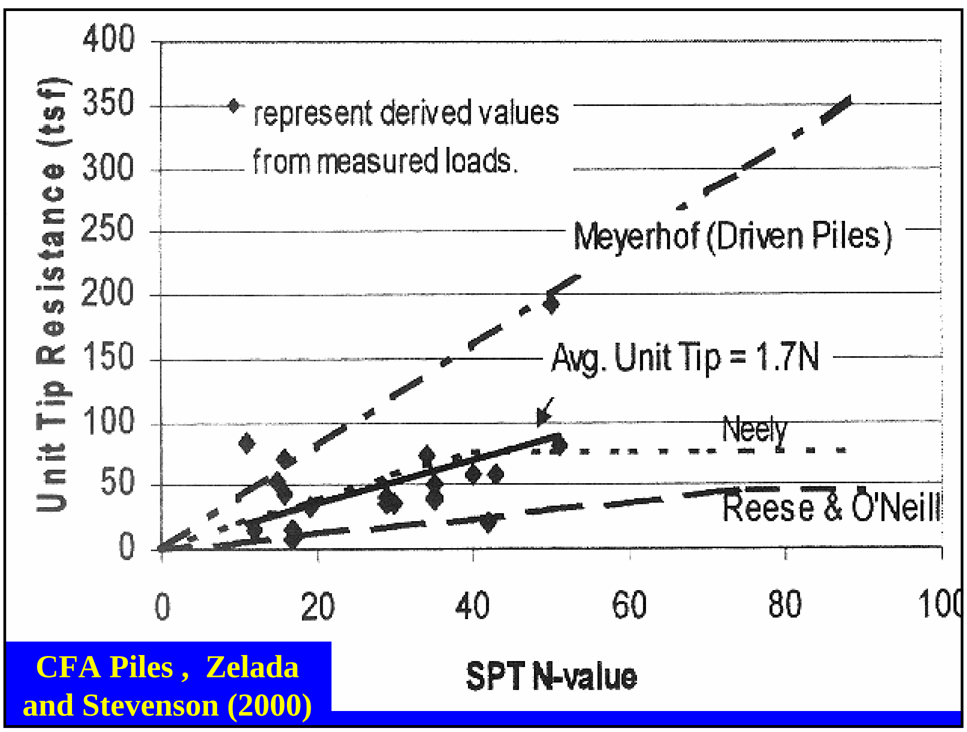


CFA Piles, Zelada and Stevenson (2000)

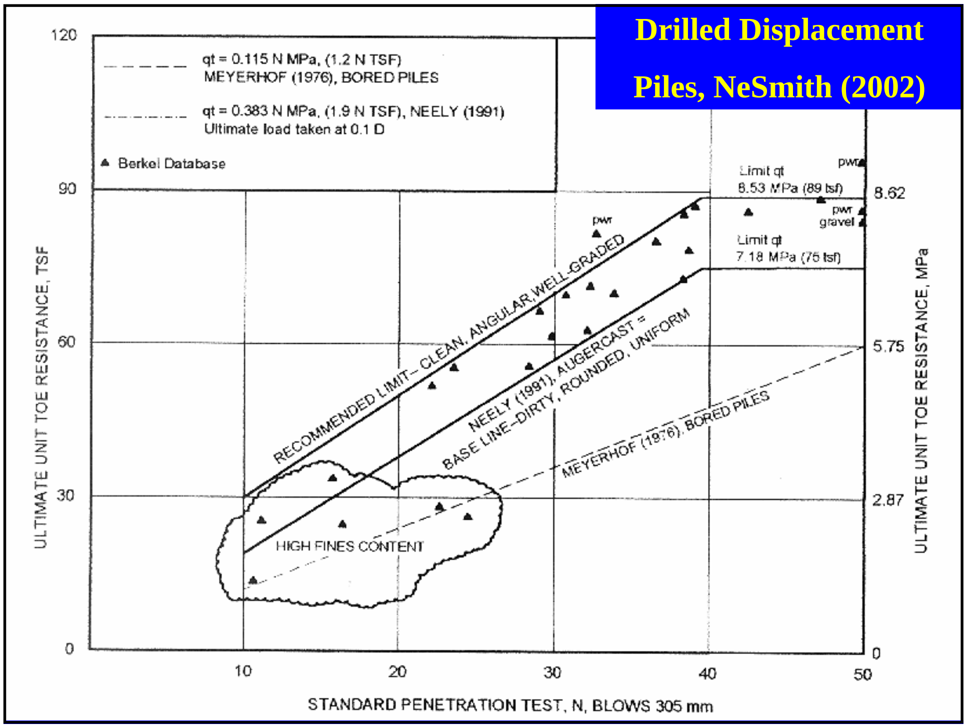


CFA Piles, Coleman and Arcement (2002)


Drilled Displacement Piles, NeSmith (2002)
Q1--qc<1.0MPa (10.44 TSF)
Q4--qc>3.5MPa (36.54 TSF)
Q5--qc>8.0MPa (83.52 TSF)
Bustamnate & Gianeselli (1993), Screw Piles, Sand and Gravel
Meyerhof (1976), 0.0019N (MPa), 0.02N (TSF)--Bored Piles
Isolated Pile
Center of 5-pile group, spaced at 3D
Auburn NGES, Brown & Drew (2000)
Berkel Database
RECOMMENDED LIMIT--CLEAN, ANGULAR, WELL-GRADED
BASE LINE--DIRTY, ROUNDED, UNIFORM
MEYERHOF, BORED PILES
NEELY (1991) Limit fs 0.13 MPa (1.4 tsf)
Limit fs 0.21 MPa (2.2 TSF)
Limit fs 0.16 MPa (1.7 TSF)
ULTIMATE UNIT SHAFT RESISTANCE, TSF
STANDARD PENETRATION RESISTANCE, N, BLOWS PER 305 mm


CFA Piles , Zelada and Stevenson (2000)
represent derived values from measured loads.
Meyerhof (Driven Piles)
Avg. Unit Tip = 1.7N
Neely
Reese & O'Neill
Unit Tip Resistance (tsf)
SPT N-value

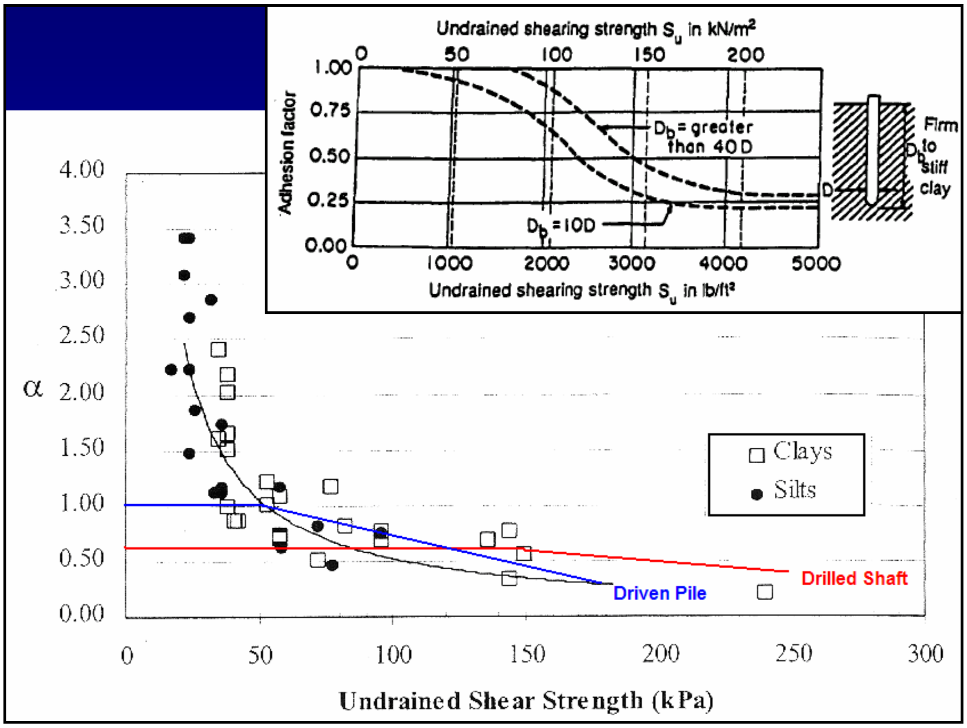
Drilled Displacement Piles, NeSmith (2002)



US - FHWA Practice

Clay soils:	Method	Side Shear: α ($f_s = \alpha c_u$)		
driven piles	Tomlinson (1987)	C_u < 50 kPa α ≈ 1	Interp.	C_u > 180 kPa α ≈ 0.28
Drilled Shafts	Reese & O'Neill (1999)	C_u < 150 kPa α = 0.55	Interp.	C_u > 250 kPa α = 0.45
CFA Piles	Colman and Arcement (2002)	$\alpha = 56.192 \cdot Cu^{-1.0162}$ $0.35 \leq \alpha \leq 2.5$		

End Bearing: $q_{tip} \approx 9 \cdot C_u$ (for all Piles in Clay)



Case History
IFCO Building, Holland

- Building on 55 piles of 6 different types
- 7m of soft clay & peat underlain by firm sand
- Load cell atop each pile, 35 piles subjected to static tests

Ref: Van Impe, W.F., Van Impe, P.O., and Verstaeten, K., 1998. "Experiences with CFA pile type under an existing building" Proc., BAPIII, 273-279.

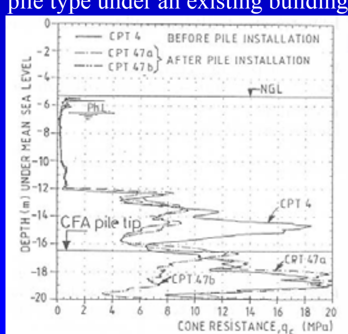


Fig. 3. CFA-installation - CPT-results

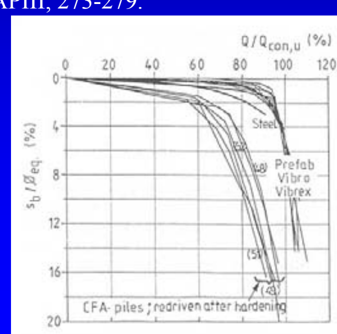


Fig. 12. Dimensionless load-settlement curves

Comparative Tests, Belgium

Kallo, Belgium (sand)

B = 600mm	**Ratio of capacity, bored concrete / driven steel**	
S/B	f_s	q_b
2	0.5	0.28
10	0.83	0.38
30	1.0	0.53

Ghent, Belgium (sand/clay)

B = 320 to 450mm	**Ratio of capacity, cfa pile / driven conc.**
S/B	Q_{total}
2	0.61 to 0.63
10	0.72 to 0.74

DeBeer., 1988. "Different behaviour of bored and driven piles, BAPI, Ghent, 1988

CFA Piles

Advantages

- Good side shear bond in cemented materials
- Low cost
- Low noise/vibration
- Easy construction in cohesive soils

Drilled Shafts:

Rock Sockets

Limitations/Problems

- Inadequate QC/QA (U.S. current practice)
- Potential for lost ground/subsidence in cohesionless soils
- No direct field control of axial capacity
- Concerns for structural integrity, rebar placement
- ***GROUP EFFECTS?***

Driven Piles

Advantages

- Displacement pile "improves" soil
- Installation process provides feedback on capacity
- Good control over structural integrity
- Potential high end bearing on rock or strong layer
- Group efficiency almost always >100%

Limitations/Problems

- Potential for noise/vibration concerns
- Handling of long piles
- Inability to penetrate hard shallow layer w/o driving aids
- Measured capacity at or shortly after end of driving underestimates capacity