Analysis of Four Load Tests on Augered Cast-in-Place Piles in the Texas Gulf Coast Soils

Raghu Dass, PE, Woodward Vogt, PE, and Frank Ong, PE

Presented By:

Raghu N. Dass, Ph. D., P.E.

TSI Laboratories, Inc.

Advantages of ACIP Piles

- Speed of Installation
- High Capacity
- Economic
- Adaptable to Limited Access Areas
- Minimal Vibrations from Installation
- Installation Independent from Soil Conditions

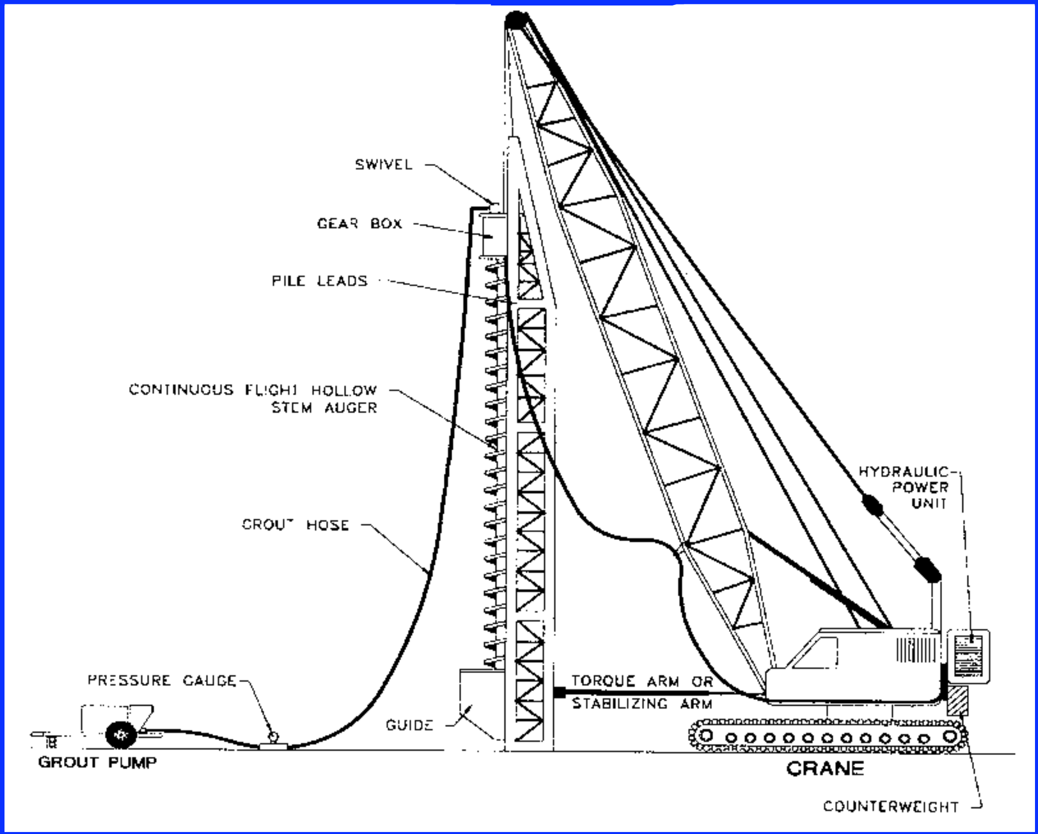
Two Past Areas of Concern

- Soft or loose soil conditions have the potential to result in removal of excessive soils or necking of the pile when using continuous flight auger
- Perceived lack of quality control because you can't see what is being installed.

New Trends

- New installation techniques and equipment: robust equipment with automated grout pumping capability
- New quality control and quality assurance techniques

Typical ACIP Pile Installation Rig



Pile Installation

- Drill to required depth
- Begin pumping grout (blow plug)
- Build up grout head around outside of auger
- Withdraw auger at constant rate
- Continue pumping grout until auger tip reaches ground surface
- Pumped volume should be at least 115% to 150 % of the theoretical volume

Pile Installation - Completion

- Remove spoils from ground surface
- Clean out and screen top of pile
- Install reinforcing steel or access pipes for sonic integrity logging
- Dip or add grout to establish top of pile grade

Reinforcement Cage Installation

Applicable Soil Conditions

Pile Type	Main Soil Condition	Soil Layer/Pile Diameter Limitations
ACIP Pile	Medium dense to very dense sand ; soft to hard clay ; soft rock	If a loose sand layer is present diameters should be limited to 24-inch; if the loose sand is more than 20 ft thick the diameter should be limited to 16-inch.
Partial **Displacement ACIP Pile**	Loose to dense sand with blow counts less than 50	For any diameter stiff, firm and soft clay layers should not exceed 15 ft, 20 ft and 30 ft thick, respectively
Full **Displacement ACIP Pile**	Loose to medium dense sand with blow counts less than 25	For any diameter stiff, firm and soft clay layers should not exceed 5 ft, 10 and 20 ft thick respectively; dense sand layers should not exceed 10 ft

Equipment Specifications

Pile Type	Gearbox Torque	Crowd/Gearbox Weight	Drill Rig Horsepower
Typical ACIP	36,000 ft-lbs	5,000 lbs (wt)	350 hp
Large/Deep ACIP	88,000 ft-lbs	10,000 lbs (wt)	750 hp
LHR ACIP	21,000 ft-lbs	3,000 lbs (wt)	200 hp
Partial Displacement ACIP	150,000 to 180,000 ft-lbs	15 to 20 tons	250 hp
Full Displacement ACIP	150,000 to 180,000 ft-lbs	15 to 20 tons	250 hp

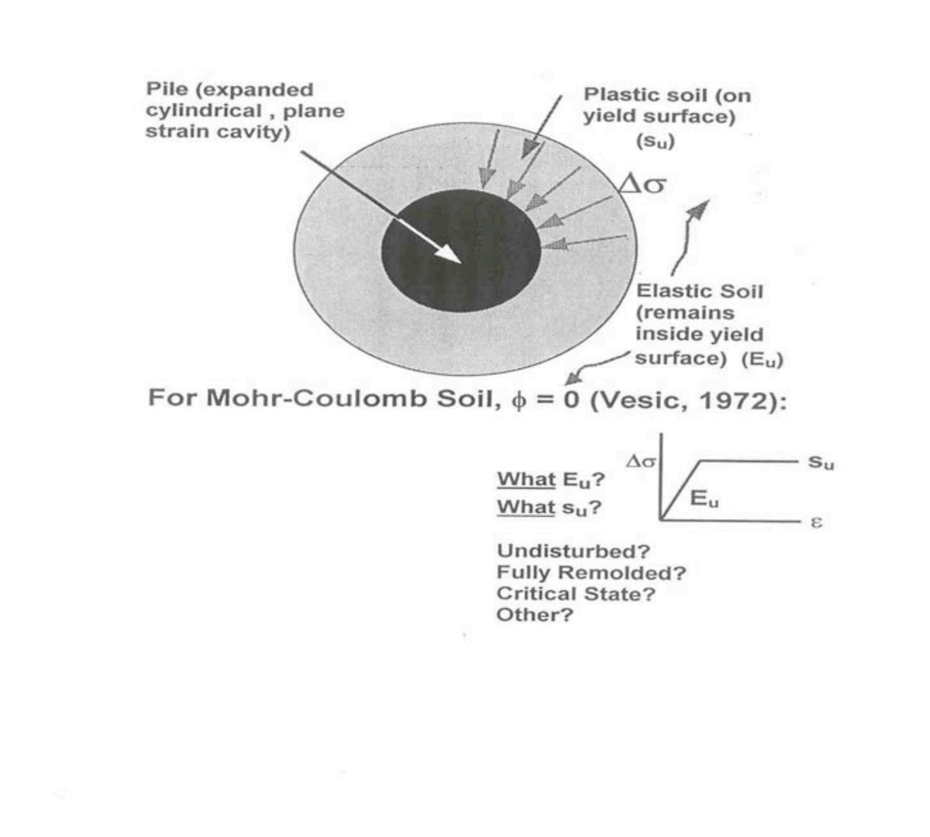
Design Methods – Summary

- Clay: The α Method (FHWA/Reese & O'Neill,1999) TxDOT (2000) and API Method – Total Stress

- Sand: The β Method (FHWA,1999) and Zalada and Stephenson (2000), McVay (1994), Vipulanandan, et al. (2005) – Effective Stress

- Jardine and Saldivar (1999) observed failure surface away from the pile-soil interface into the native clay – Conservative Design

Mohr-Coulomb Failure Criteria



Design of ACIP Piles – The α Method in Clays FHWA α = 0.55, TxDOT α = 0.70

- O'Neill (2001) – The α method is appropriate for clays using total stress principle. The undrained shear strength, s_u can be easily determined in the lab using UU Triaxial testing.
- TXDOT uses a limiting end bearing resistance of 380 kPa
- Pile tip resistance is neglected in clays.
- At Δ= 5% pile dia = 23mm

$$Q_T = R_S + R_B$$

$$R_S = \sum f_{max} A_S$$

$$R_B = cN_c A_B = 9 s_u A_B$$

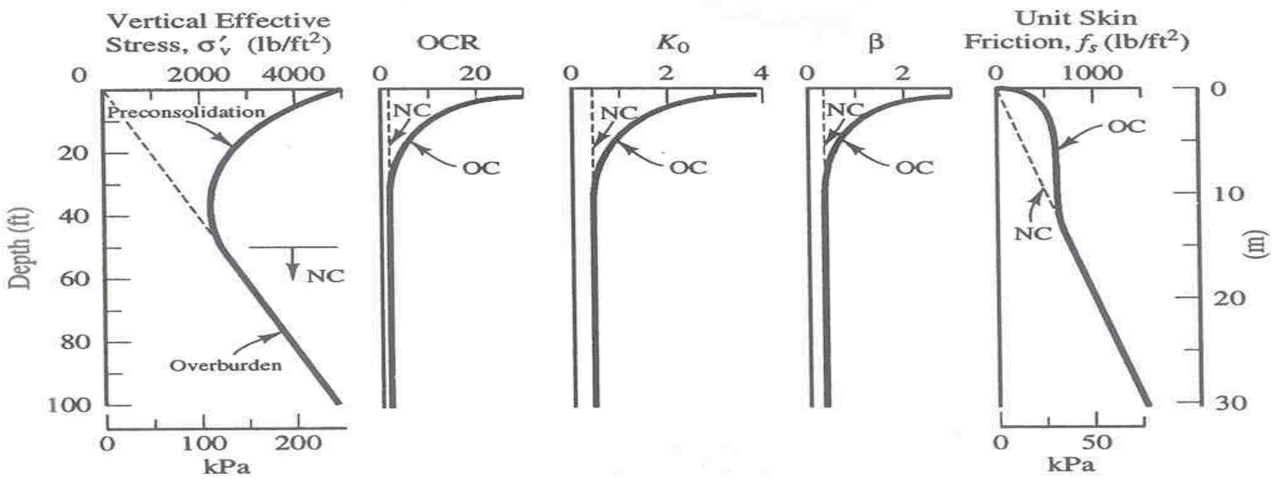
$$\text{The } \alpha \text{ method, } f_{max} = \alpha s_u$$

$$f_{max} = \text{Peak unit side shear}$$

$$\alpha = \text{Adhesion factor}$$

$$s_u = \text{Shear strength}(UU, \phi = 0)$$

The β Method, $f_{max} = \beta\sigma_v'$ ($\beta = K \tan\phi$)



Design of ACIP Piles – The β Method in Sands - FHWA, McVay (1994), Stephenson (2000)

- McVay (1994) – The β method is used for sands using effective stress principle including coefficient of lateral earth pressure, K and friction angle ϕ'.

$$f_s = p_o' K_s \tan\phi = \beta p_o' \leq 150\ kPa$$

p_o' = average effective vertical stress along the pile

K_s = earth pressure coefficient = 1.1

β = friction factor (0.2 to 1.0)

TxDOT, limiting side resistance is 100 kPa.

According to FHWA Method, β varies with depth.

$$\beta = 1.5 - 0.135 z^{0.5} \quad 0.2 \leq \beta \leq 1.2$$

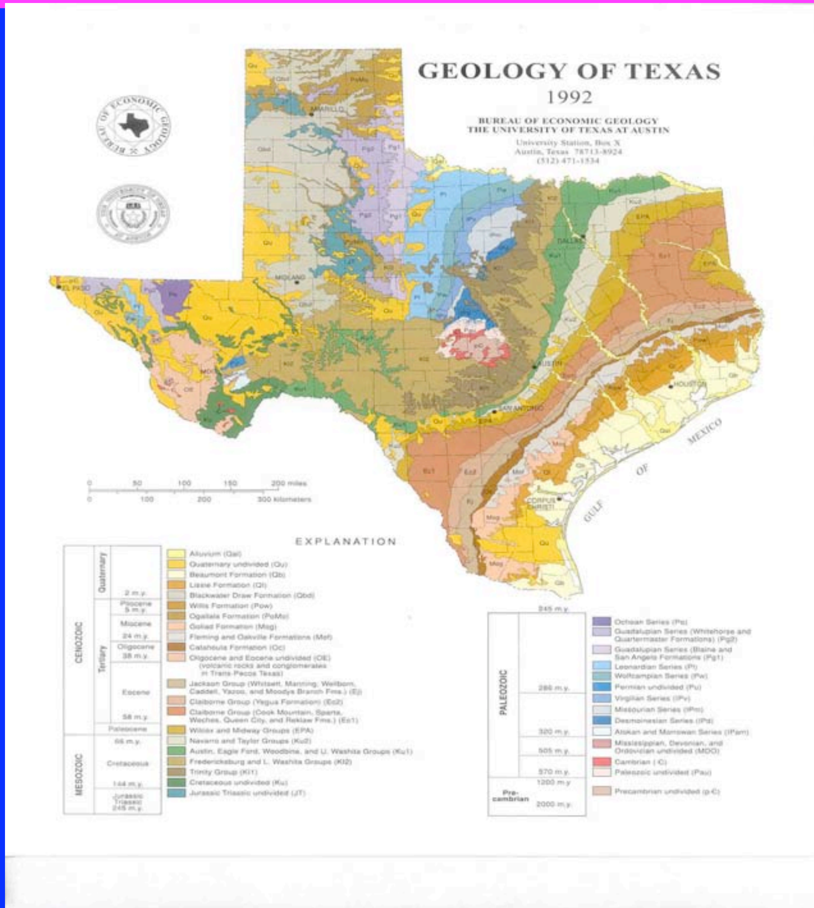
Local Practice - Texas Gulf Coast

- ACIP piles are designed as “Friction Piles”
- Beaumont Formation: Overconsolidated, high plasticity clays and lightly OC sand

Project Soil Properties

- Undrained shear strength- 50 kPa to 280 kPa
- Plasticity Indices = 15 to 44
- SPT N_{60} = 10 to 55 per 305 mm penetration

Geology of Texas Gulf Coast



Four Load Tests on 460-mm Diameter ACIP Piles in Houston, Texas

- 33-Story Residential Tower at 1200 Post Oak Boulevard: Uniform soil profile including fat clays and lean clays – 23m long piles (75 ft)

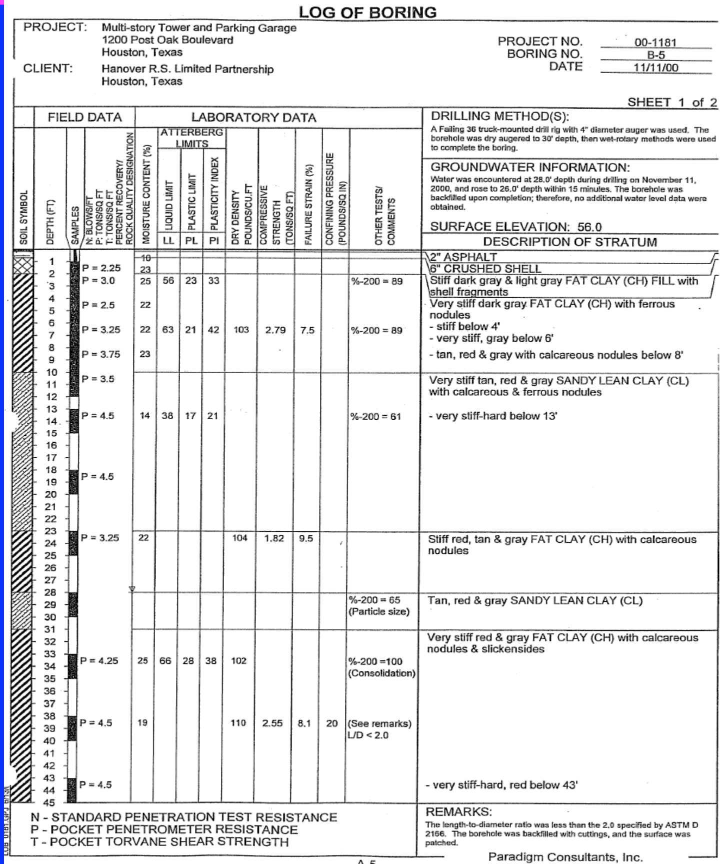
  Load Test # 1 and # 2

- 30-Story Residential Tower – Dominion Post Oak at 2323 McCue Street: Mixed soil profile including clays and sands – 21m and 26m long piles (70 ft & 85 ft)

  Load Test # 3 and # 4

Dominion Post Oak

Boring Logs Showing Site Soils



LOG OF BORING

PROJECT: Multi-story Tower and Parking Garage
1200 Post Oak Boulevard
Houston, Texas

CLIENT: Hanover R.S. Limited Partnership
Houston, Texas

PROJECT NO. 00-1181
BORING NO. B-5
DATE 11/11/00

SHEET 1 of 2

DRILLING METHOD(S): A Failing 36 truck-mounted drill rig with 4" diameter auger was used. The borehole was dry augered to 30' depth, then wet-rotary methods were used to complete the boring.

GROUNDWATER INFORMATION: Water was encountered at 28.0' depth during drilling on November 11, 2000, and rose to 26.0' depth within 15 minutes. The borehole was backfilled upon completion; therefore, no additional water level data were obtained.

SURFACE ELEVATION: 56.0

Depth (FT)	N: Blows/FT; P: Tons/SQ FT; T: Tons/SQ FT; Percent Recovery/Rock Quality Designation	Moisture Content (%)	Liquid Limit LL	Plastic Limit PL	Plasticity Index PI	Dry Density Pounds/CU.FT	Compressive Strength (Tons/SQ FT)	Failure Strain (%)	Confining Pressure (Pounds/SQ IN)	Other Tests/Comments
1–2	P = 2.25	10, 23								
2–3	P = 3.0	25	56	23	33					%-200 = 89
4–5	P = 2.5	22								
6–7	P = 3.25	22	63	21	42	103	2.79	7.5		%-200 = 89
8–9	P = 3.75	23								
10–11	P = 3.5									
13–14	P = 4.5	14	38	17	21					%-200 = 61
18–19	P = 4.5									
23–24	P = 3.25	22				104	1.82	9.5		
28–30										%-200 = 65 (Particle size)
33–34	P = 4.25	25	66	28	38	102				%-200 =100 (Consolidation)
38–39	P = 4.5	19				110	2.55	8.1	20	(See remarks) L/D < 2.0
43–44	P = 4.5									

DESCRIPTION OF STRATUM

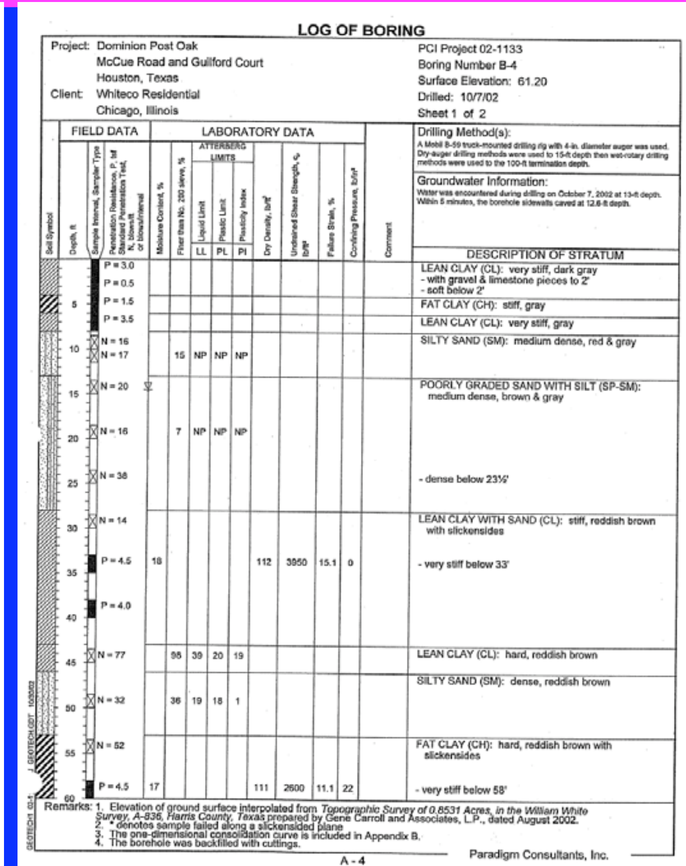
- 2" ASPHALT
- 6" CRUSHED SHELL
- Stiff dark gray & light gray FAT CLAY (CH) FILL with shell fragments
- Very stiff dark gray FAT CLAY (CH) with ferrous nodules
  - stiff below 4'
  - very stiff, gray below 6'
  - tan, red & gray with calcareous nodules below 8'
- Very stiff tan, red & gray SANDY LEAN CLAY (CL) with calcareous & ferrous nodules
  - very stiff-hard below 13'
- Stiff red, tan & gray FAT CLAY (CH) with calcareous nodules
- Tan, red & gray SANDY LEAN CLAY (CL)
- Very stiff red & gray FAT CLAY (CH) with calcareous nodules & slickensides
  - very stiff-hard, red below 43'

N - STANDARD PENETRATION TEST RESISTANCE
P - POCKET PENETROMETER RESISTANCE
T - POCKET TORVANE SHEAR STRENGTH

REMARKS: The length-to-diameter ratio was less than the 2.0 specified by ASTM D 2166. The borehole was backfilled with cuttings, and the surface was patched.

Paradigm Consultants, Inc.

A-5



LOG OF BORING

Project: Dominion Post Oak
McCue Road and Guilford Court
Houston, Texas

Client: Whiteco Residential
Chicago, Illinois

PCI Project 02-1133
Boring Number B-4
Surface Elevation: 61.20
Drilled: 10/7/02
Sheet 1 of 2

Drilling Method(s): A Mobil B-59 truck-mounted drilling rig with 4-in. diameter auger was used. Dry-auger drilling methods were used to 15-ft depth then wet-rotary drilling methods were used to the 100-ft termination depth.

Groundwater Information: Water was encountered during drilling on October 7, 2002 at 13-ft depth. Within 5 minutes, the borehole sidewalls caved at 12.6-ft depth.

Penetration Resistance, P, tsf; Standard Penetration Test, N, blows/ft or blows/interval	Moisture Content, %	Finer than No. 200 sieve, %	Liquid Limit LL	Plastic Limit PL	Plasticity Index PI	Dry Density, lb/ft³	Undrained Shear Strength, c_u, lb/ft²	Failure Strain, %	Confining Pressure, lb/in²	Comment
P = 3.0										
P = 0.5										
P = 1.5										
P = 3.5										
N = 16										
N = 17		15	NP	NP	NP					
N = 20										
N = 16		7	NP	NP	NP					
N = 38										
N = 14										
P = 4.5	18					112	3950	15.1	0	
P = 4.0										
N = 77		58	39	20	19					
N = 32		36	19	18	1					
N = 52										
P = 4.5	17					111	2600	11.1	22	

DESCRIPTION OF STRATUM

- LEAN CLAY (CL): very stiff, dark gray
  - with gravel & limestone pieces to 2'
  - soft below 2'
- FAT CLAY (CH): stiff, gray
- LEAN CLAY (CL): very stiff, gray
- SILTY SAND (SM): medium dense, red & gray
- POORLY GRADED SAND WITH SILT (SP-SM): medium dense, brown & gray
  - dense below 23½'
- LEAN CLAY WITH SAND (CL): stiff, reddish brown with slickensides
  - very stiff below 33'
- LEAN CLAY (CL): hard, reddish brown
- SILTY SAND (SM): dense, reddish brown
- FAT CLAY (CH): hard, reddish brown with slickensides
  - very stiff below 58'

Remarks:
1. Elevation of ground surface interpolated from *Topographic Survey of 0.8531 Acres, in the William White Survey, A-836, Harris County, Texas* prepared by Gene Carroll and Associates, L.P., dated August 2002.
2. * denotes sample failed along a slickensided plane
3. The one-dimensional consolidation curve is included in Appendix B.
4. The borehole was backfilled with cuttings.

Paradigm Consultants, Inc.

A - 4

Full-Scale Pile Load Tests

- Full-scale load tests are routinely conducted to verify the design load as part of foundation design before construction of ACIP production piles.

- Static axial compression load tests on piles are conducted according to ASTM D 1143-94.

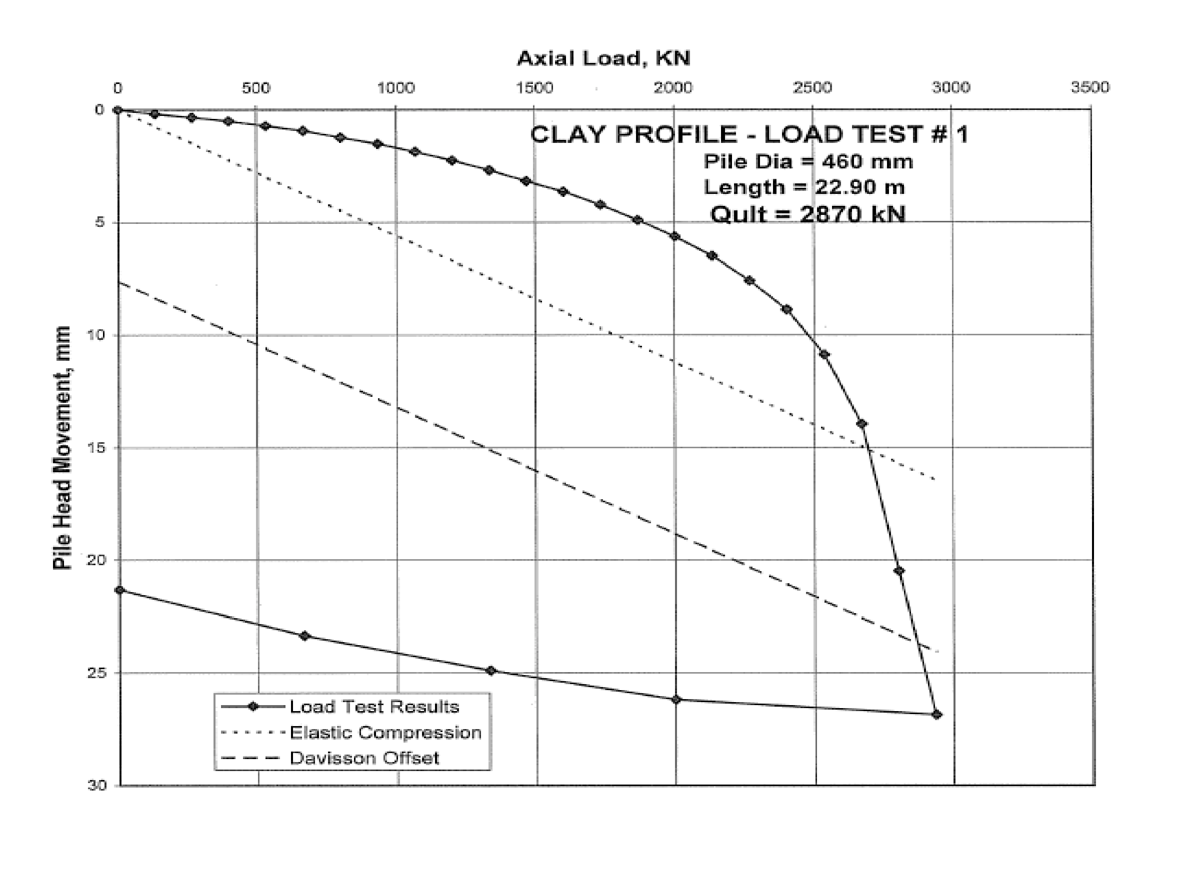
  Quick Test: each load step at 5% of design load maintained for 5-minute, loaded up to design load or capacity of the reaction frame, and unloaded after failure or 25 mm settlement limit

Load Test Setup

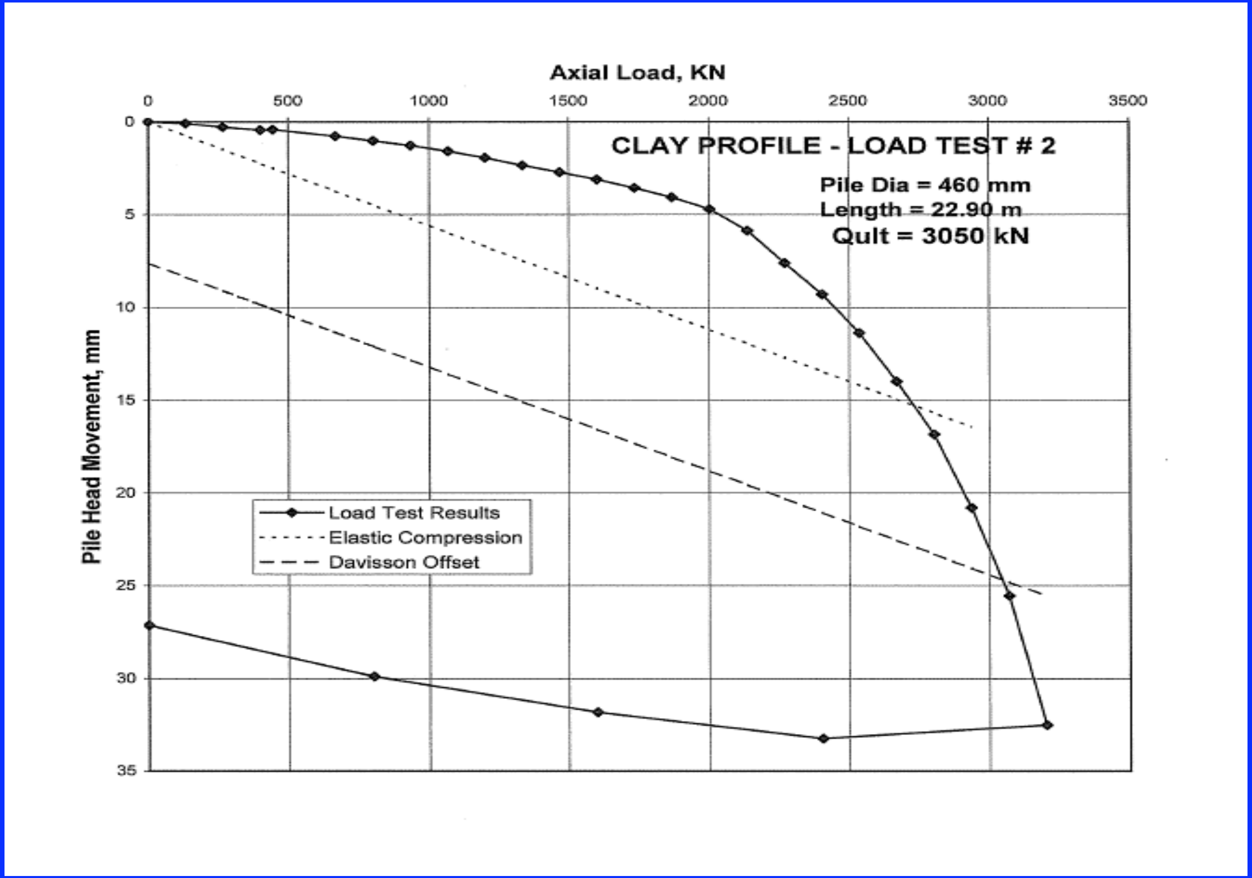
Instrumentation

A Happy Camper

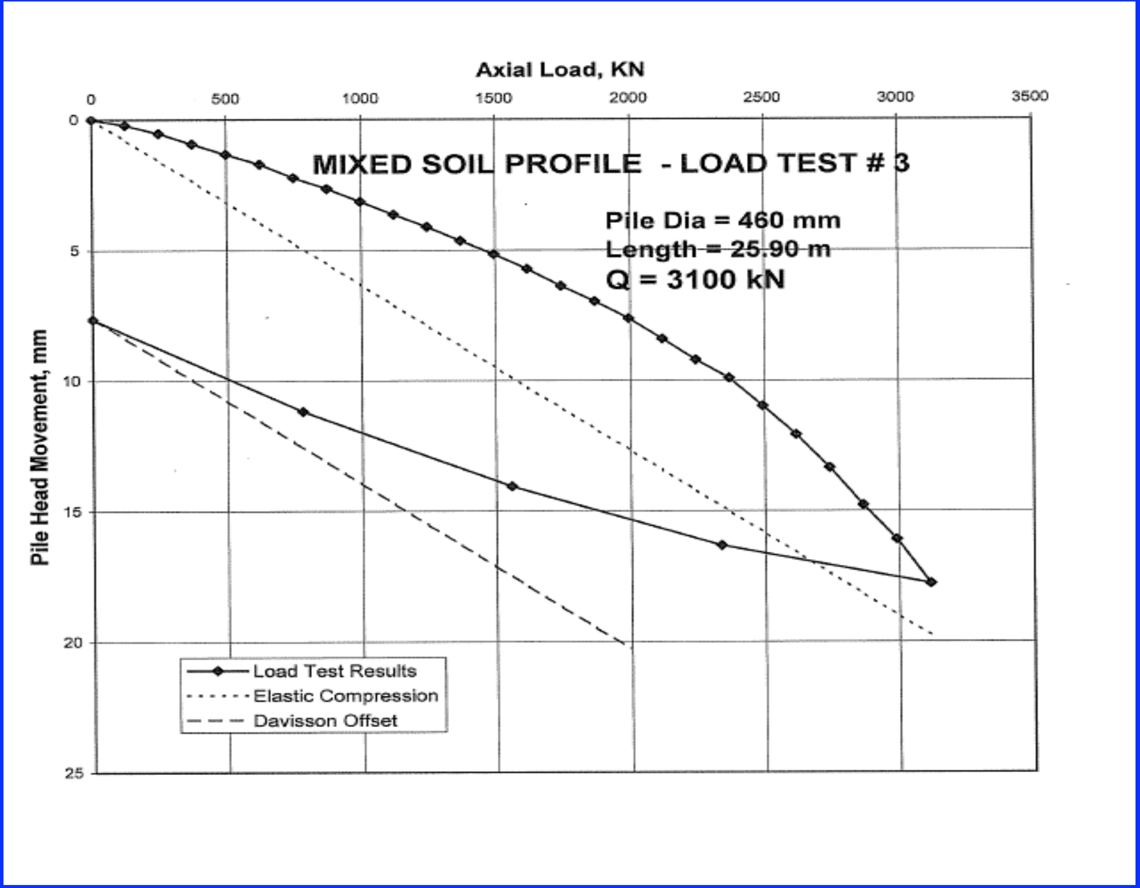
LOAD TEST NO. 1



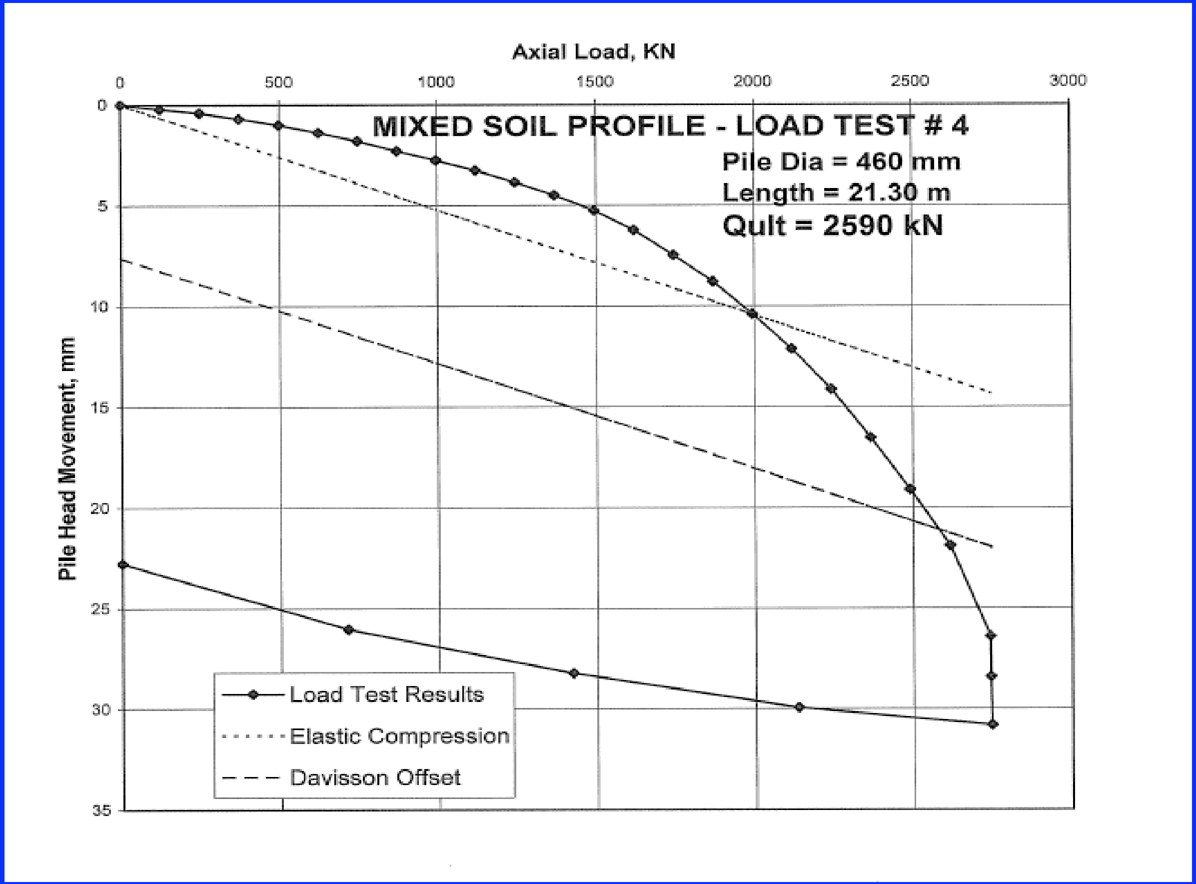
LOAD TEST NO. 2



LOAD TEST NO. 3



LOAD TEST NO. 4



Analysis of Load Test Data

- Ultimate pile capacity was determined for each from load-displacement curve based on Davisson offset limit (QL/AE + 0.15 + D/120).
- An end bearing resistance of 60 kN was deducted from the ultimate capacity to determine the side resistance. Load transfer to the soil occurs through the effective pile length. TxDOT limiting tip bearing = 380 kPa

Comparison with FHWA Method: The β value varied from 0.5 to 1.1

Table 1. Measured and predicted ultimate pile capacities with the calculated α values.

Pile ID	Pile Diameter (mm)	Pile Length (m)	Ultimate Test Capacity Q_t (kN)	Calculated α values	FHWA Q_t (kN)	$[Q_t]_M/[Q_t]_P$	Side Resistance $[Q_s]_M/[Q_s]_P$
1	460	22.90	2940	0.79	2040	1.44	1.45
2	460	22.90	3070	0.84	2040	1.50	1.52
3	460	25.9	3110*	0.75	2225	1.40	1.40
4	460	21.30	2620	0.72	2020	1.30	1.31

*Test stopped at design ultimate pile capacity and 88% of maximum capacity of the reaction frame.

$[Q_t]_M$ = Measured ultimate pile capacity from load-displacement plot.

$[Q_t]_P$ = Predicted ultimate pile capacity using the α method and the β method.

Conclusions

- Side resistance of ACIP Piles in Beaumont Clays is being predicted conservatively.
- Based on the data, the α value ranged from 0.72 to 0.84 with an average of 0.78.
- No appreciable change in the β value in sands was observed.
- An α value of 0.75 may be used for design of ACIP in Beaumont Clays.
- Cost of load tests justifies the saving in foundation costs due to the higher pile capacity measured in the load tests.