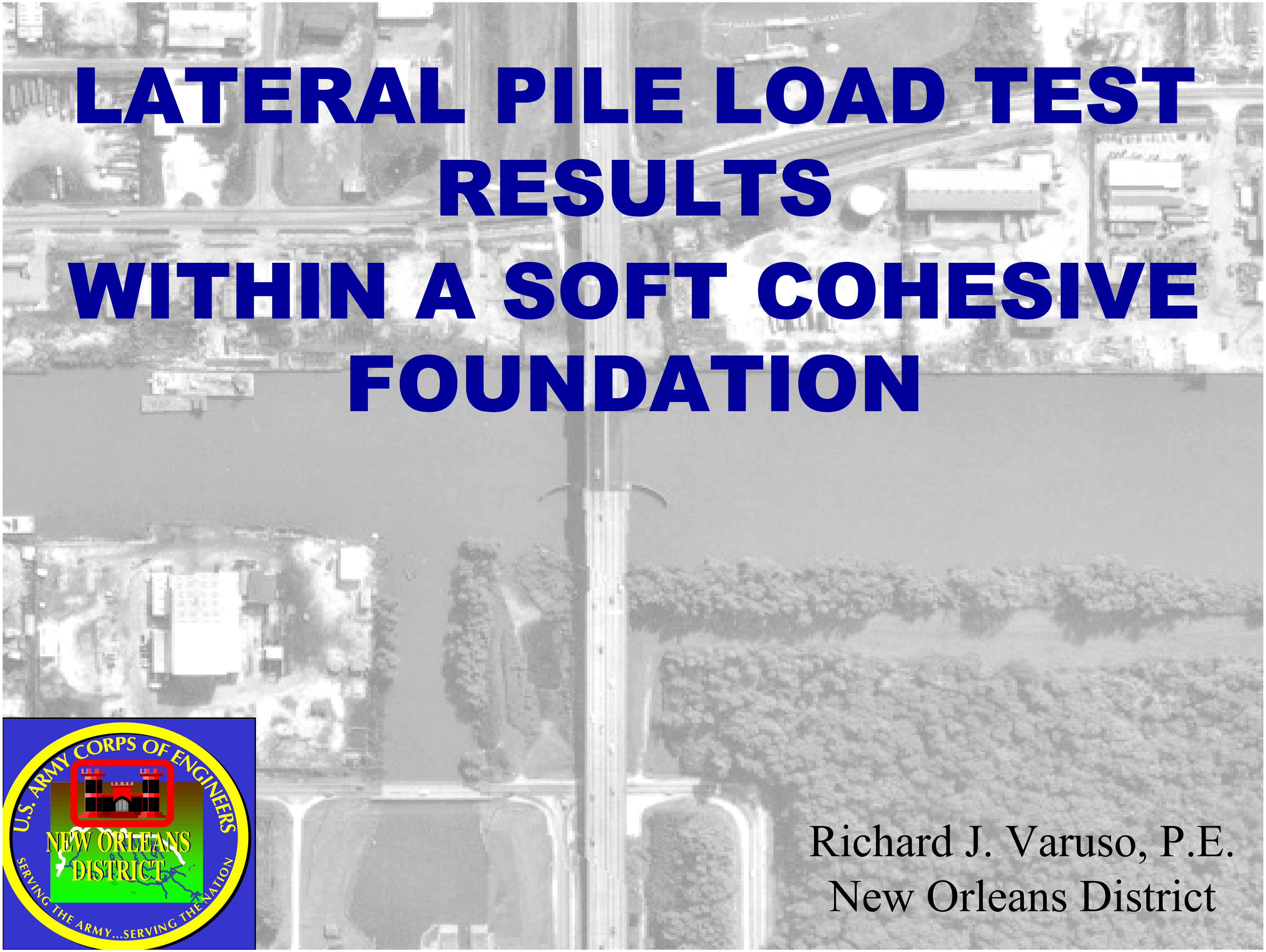
U.S. ARMY CORPS OF ENGINEERS

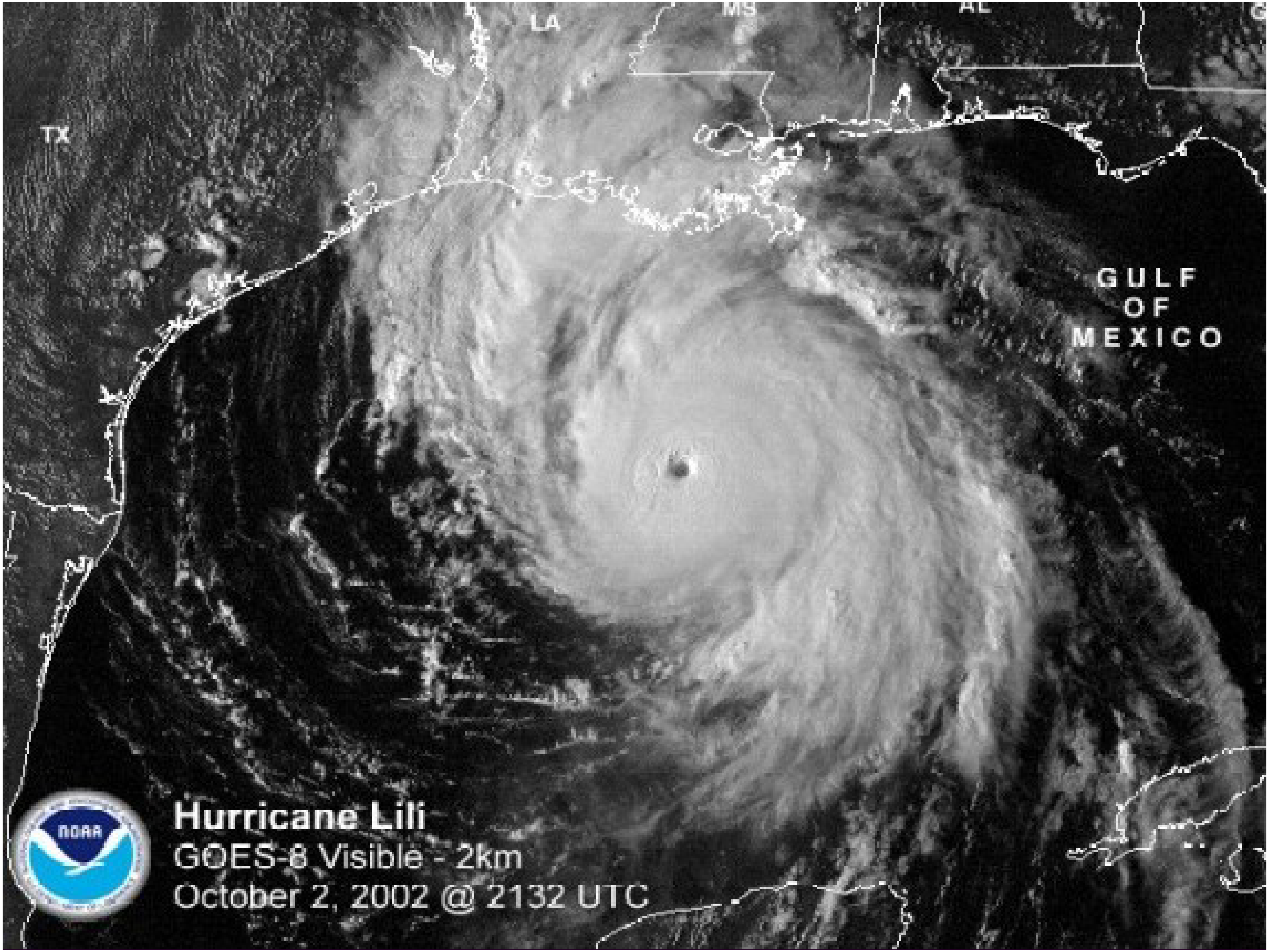
NEW ORLEANS DISTRICT

SERVING THE ARMY...SERVING THE NATION



LATERAL PILE LOAD TEST RESULTS WITHIN A SOFT COHESIVE FOUNDATION

Richard J. Varuso, P.E.
New Orleans District


LA
MS
AL
TX
GULF
OF
MEXICO
Hurricane Lili
GOES-8 Visible - 2km
October 2, 2002 @ 2132 UTC

TROPICAL STORM FRANCES 1998
BOLLINGER SHIPYARD
HARVEY CANAL

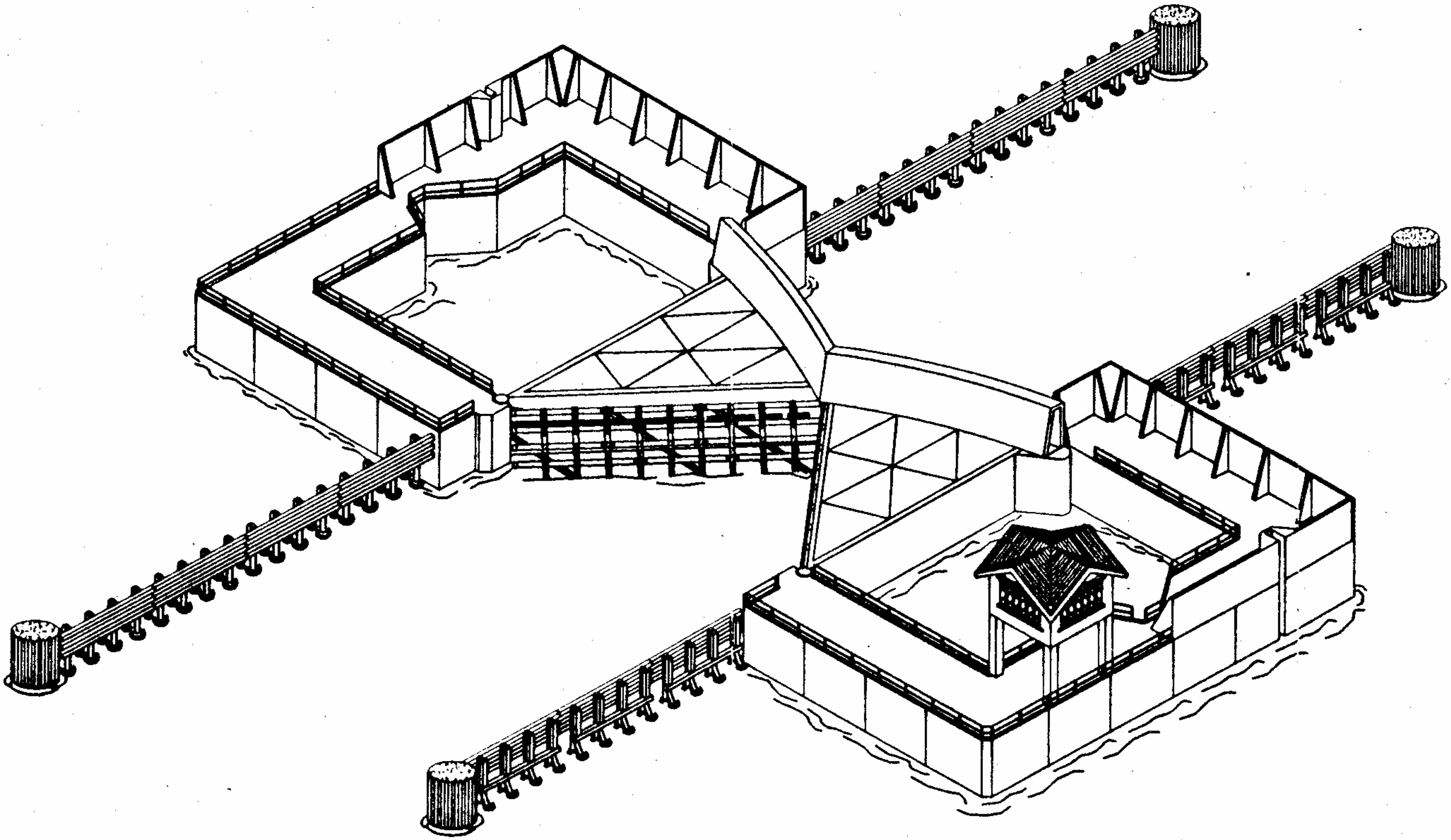
West Bank & Vicinity, New Orleans, LA, Hurricane Protection Project Facts

- WRDA 1986
  - Authorized Westwego to Harvey Canal
- WRDA 1996
  - Modified project to add Lake Cataouatche
  - Also authorized East of Harvey Canal
- WRDA 1999
  - Combined the 3 projects into one
- Cost shared
  - 65% Federal / 35% Non-federal
- Sponsor
  - LADOTD for construction & WJLD for O&M
- Current estimated total project cost: $308M

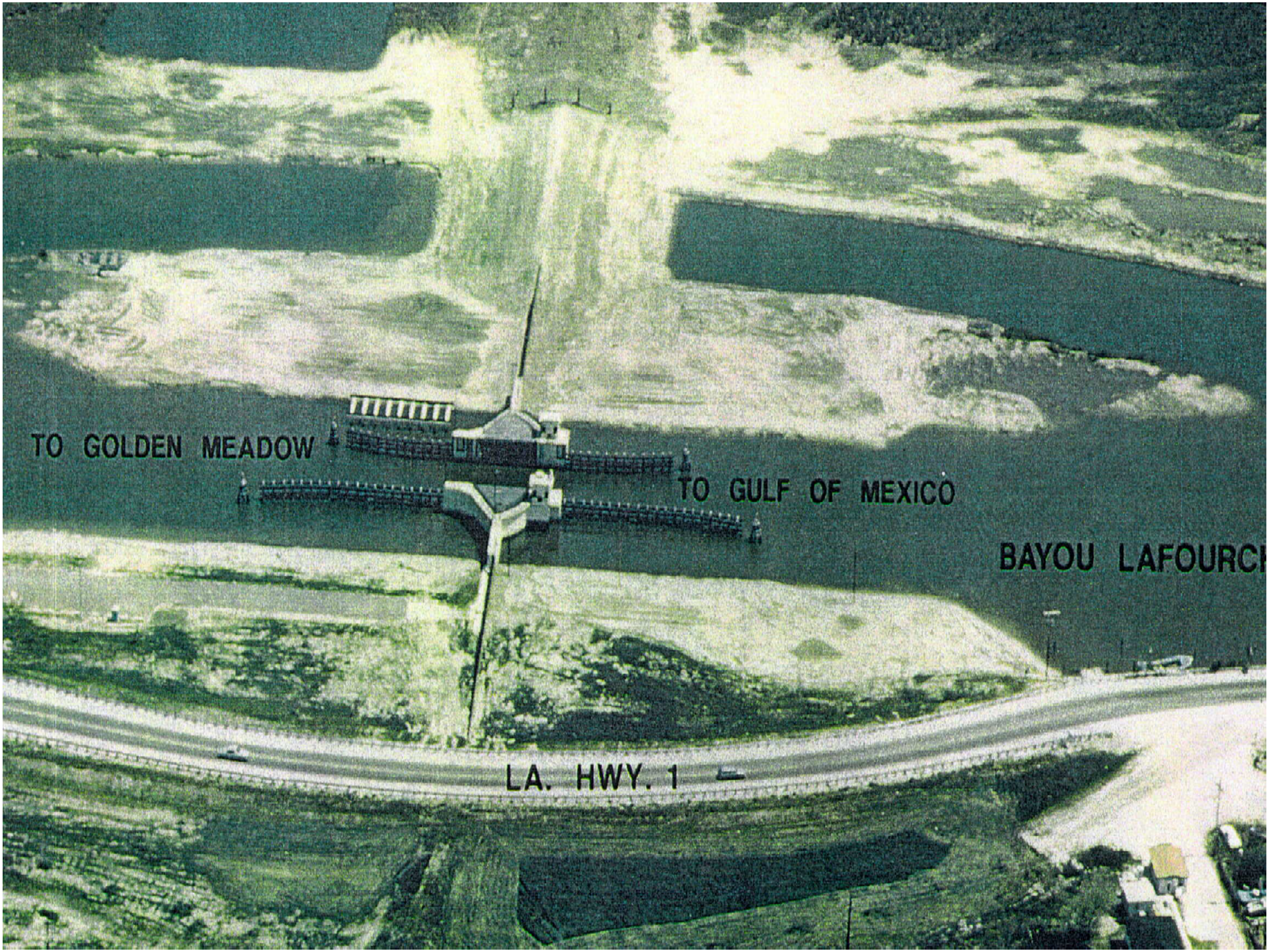
West Bank & Vicinity, New Orleans, LA, HPP Summary

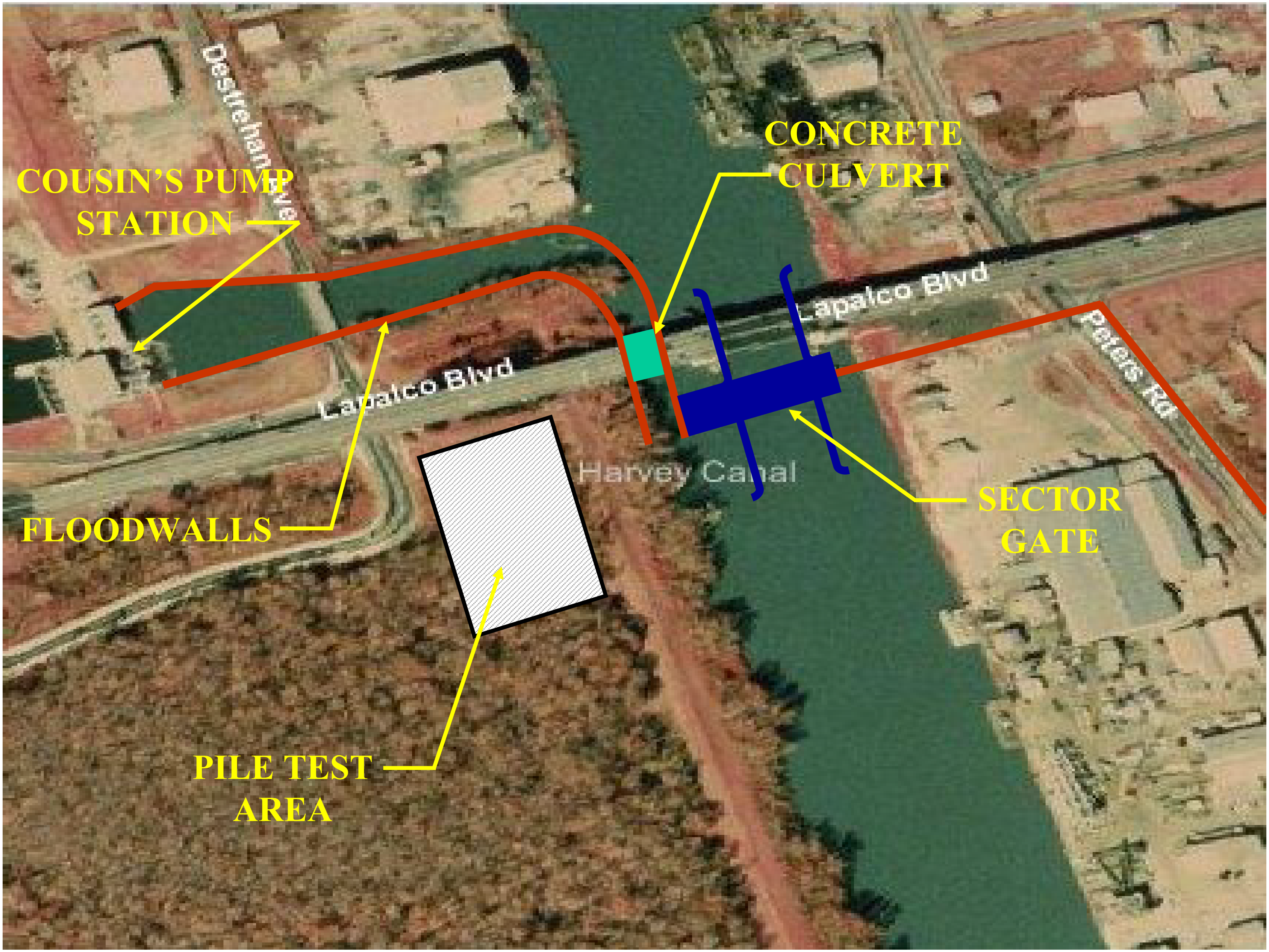
- Project construction began in 1991
- Will protect approximately 250,000 citizens
- When complete, will cover over 65 miles of levees, floodwalls and floodgates in Orleans, Plaquemines and Jefferson
- Will protect over 65,000 homes and businesses in tri-parish area
- By the end of 2005, federal & local sources will have spent over $100 million
- B/C = 5.1

West Bank & Vicinity, New Orleans, LA, Hurricane Protection Project



CONCRETE GRAVITY FLOODGATE
WITH
BUOYANT STEEL SECTOR GATES

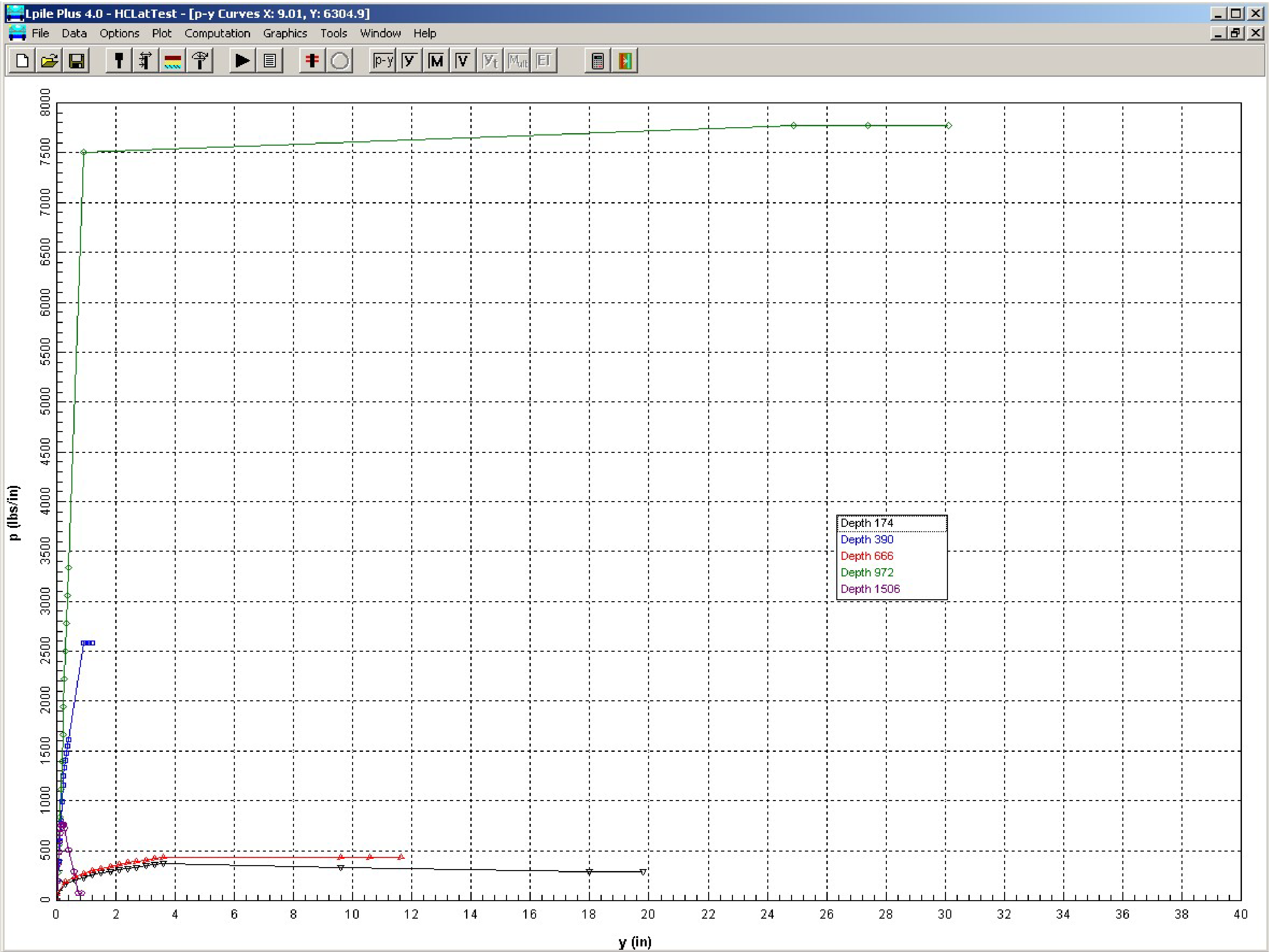

TO GOLDEN MEADOW
TO GULF OF MEXICO
BAYOU LAFOURCH
LA. HWY. 1



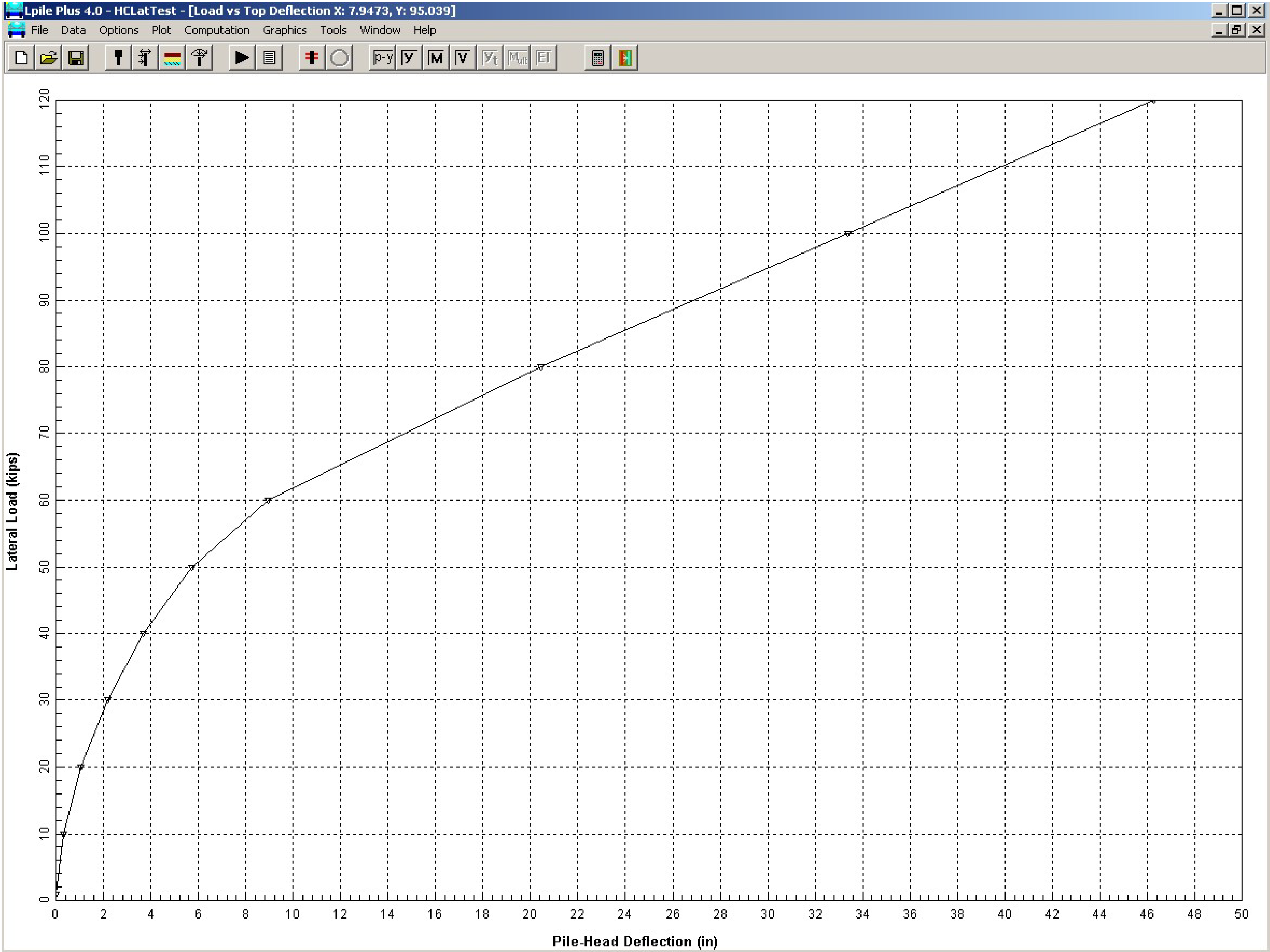
CONCRETE CULVERT
COUSIN'S PUMP STATION
Destrehan Ave
Lapalco Blvd
Lapalco Blvd
Peters Rd
Harvey Canal
FLOODWALLS
SECTOR GATE
PILE TEST AREA

DESIGN ALTERNATIVES

- CASE Pile Group Analysis (CPGA)
  - Rigid Base Analysis
  - Single "Average" value of E_s
- G-Pile
  - Utilization of multiple p-y curves
  - Development of Pile Head Deflection curves
  - Develop Moment vs Deflection curves



Lpile Plus 4.0 - HCLatTest - [p-y Curves X: 9.01, Y: 6304.9]
File Data Options Plot Computation Graphics Tools Window Help
p (lbs/in)
y (in)
Depth 174
Depth 390
Depth 666
Depth 972
Depth 1506


Lpile Plus 4.0 - HCLatTest - [Load vs Top Deflection X: 7.9473, Y: 95.039]
File Data Options Plot Computation Graphics Tools Window Help
p-y y M V
Lateral Load (kips)
0 10 20 30 40 50 60 70 80 90 100 110 120
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50
Pile-Head Deflection (in)

G-PILE / CPGA COMPARISION (Normal Operating Case)

G-PILE RESULTS

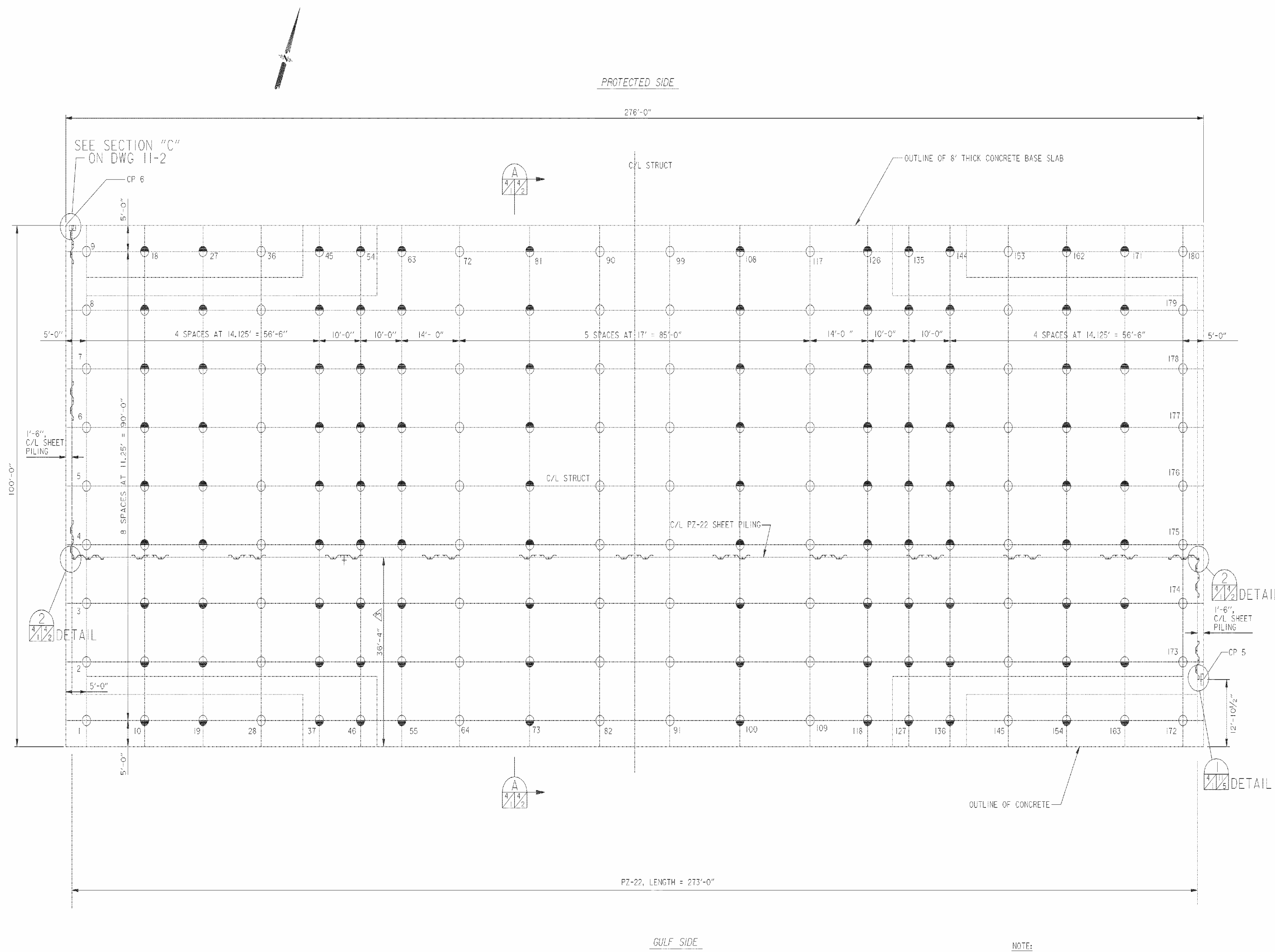
- Average E_s = 0.44 k/in^2
- CBF = 0.31
- δ_{max} = 0.125 in

CPGA RESULTS

- Average E_s = 0.17 k/in^2
- CBF = 0.59
- δ_{max} = 0.258 in

PILE FOUNDATION DESIGN HISTORY AND DETAILS

- Structure was designed as a Float-In Structure
  - 91 Piles (56 vertical – 35 battered)
  - 48” Dia. Pipe piles
- Solicited as a Best Value Contract - Contractor elected to construct in place
- Resulted in new pile foundation
  - 180 Piles (72 vertical – 108 battered)
  - 24” Dia. Pipe piles



PILE AND SHEETPILE LAYOUT

SCALE: 1/8" = 1'- 0"

NOTE:

PILE C/L DIMENSIONS TAKEN AT EL.-24.0

SCALE: 1/8" = 1'- 0"

0 5' 10' 15' 20' 25'

PILE LEGEND

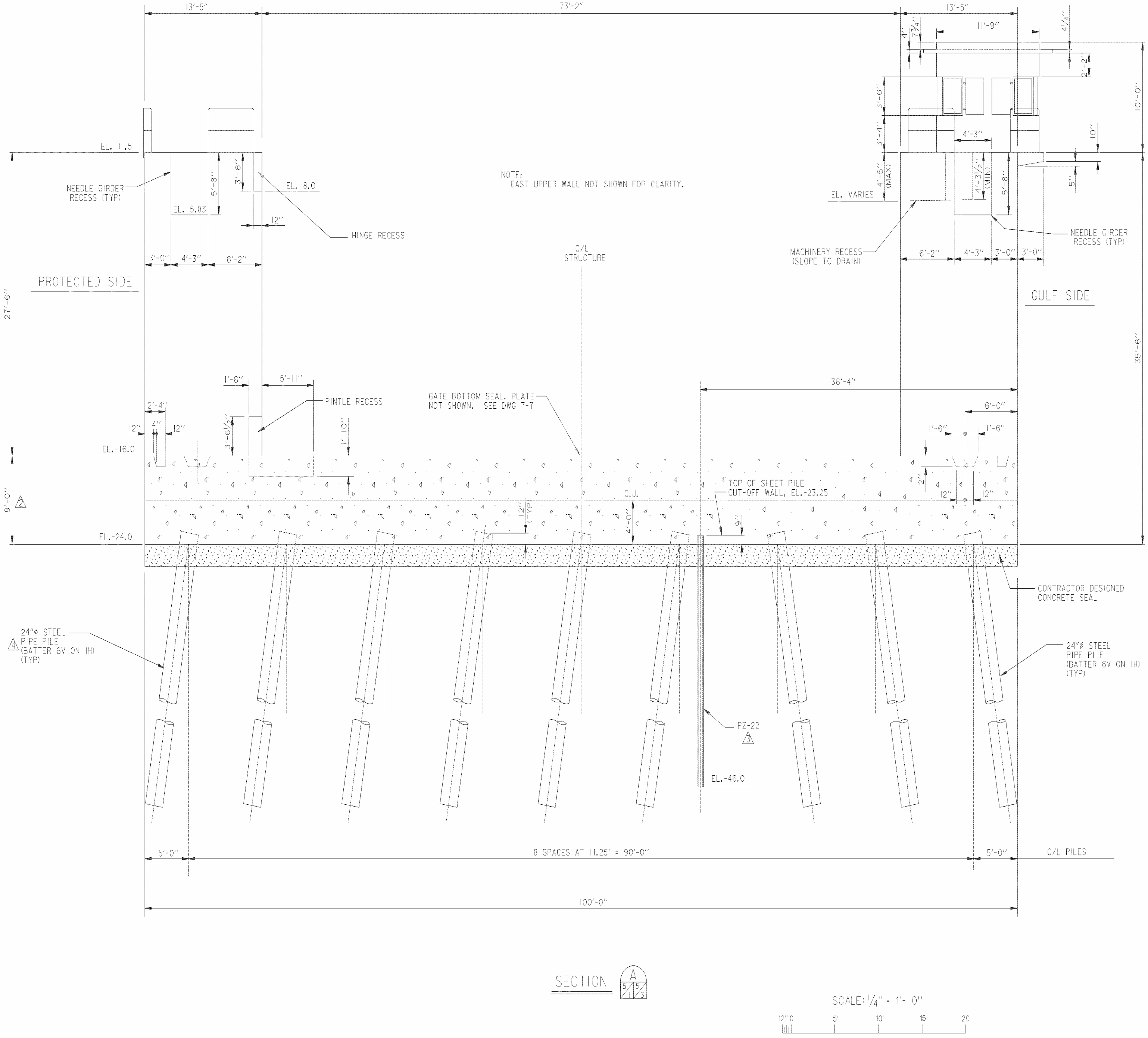
- DIRECTION OF BATTER
- 6V ON 1H BATTER PILES
- VERTICAL PILES
- 21 - PILE NUMBER

SECTOR GATE STRUCTURE
PILE SCHEDULE

TOTAL NUMBER OF PILES	PILE BATTER	PILE TIP ELEVATION	PAYMENT LENGTH WITH 12" EMBED.	SERVICE LOAD	
				COMP (k)	TENSION (k)
108 PILES	6V ON 1H	-163	142 FT	300	50
72 PILES	VERTICAL	-163	140 FT	300	50

PILE NOTES:

1. ALL PILES ARE 24"ø X 1/2" THK WALL STEEL PIPE PILES CONFORMING TO ASTM A252, GRADE 3.
2. EXACT LENGTHS OF STEEL PIPE PILES SHALL BE DETERMINED AFTER PILE TESTS ARE CONDUCTED. LENGTHS SHOWN ARE FOR ESTIMATING PURPOSES ONLY.
3. FLOODWALL PILES SHOWN ON DWGS. 11-4 AND 15-6



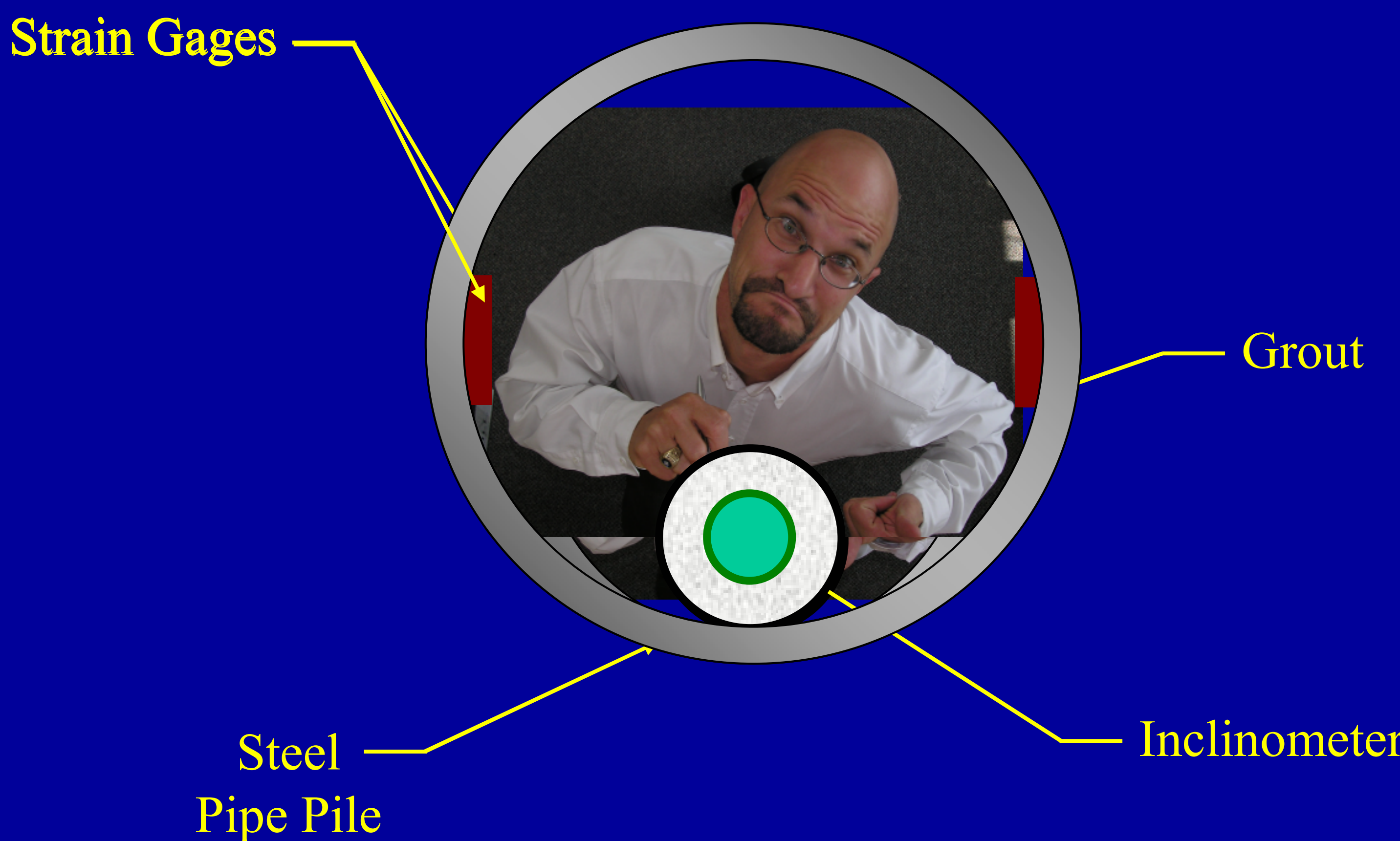
SECTION A

SCALE: 1/4" = 1'- 0"

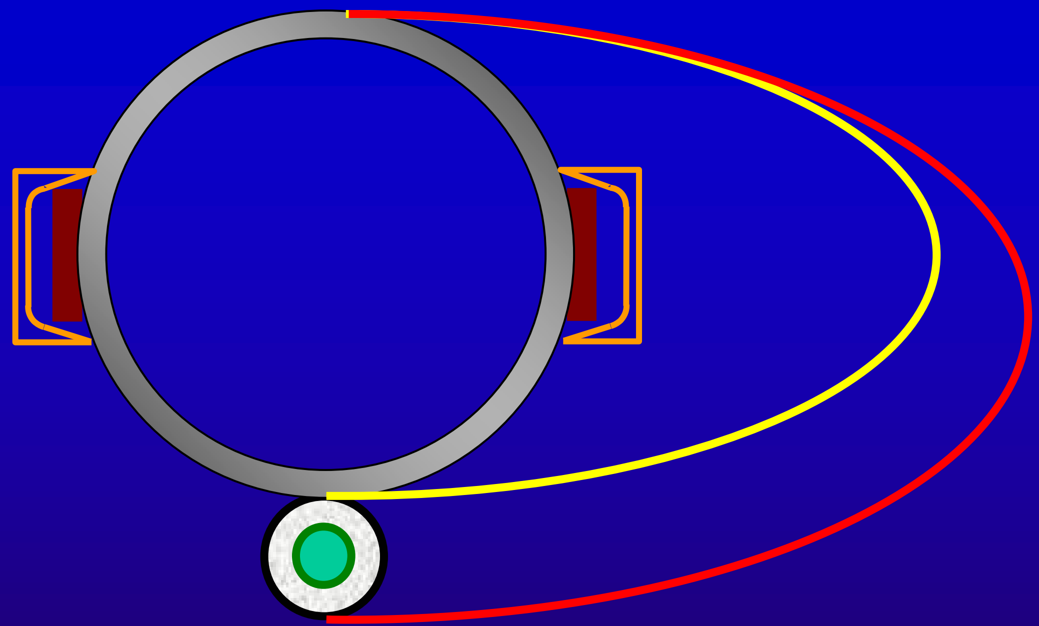
LATERAL PILE LOAD TEST REQUIREMENTS

- Apply/Record Lateral Load
  - Horizontal Jack
  - Load Cell
- Record Pile Head Deflections vs Load
  - Scales
  - Wire Lines
- Acquire p-y Data
  - Inclinometers
  - Strain Gages

PILE INSTRUMENTATION
48” DIA PIPE PILE

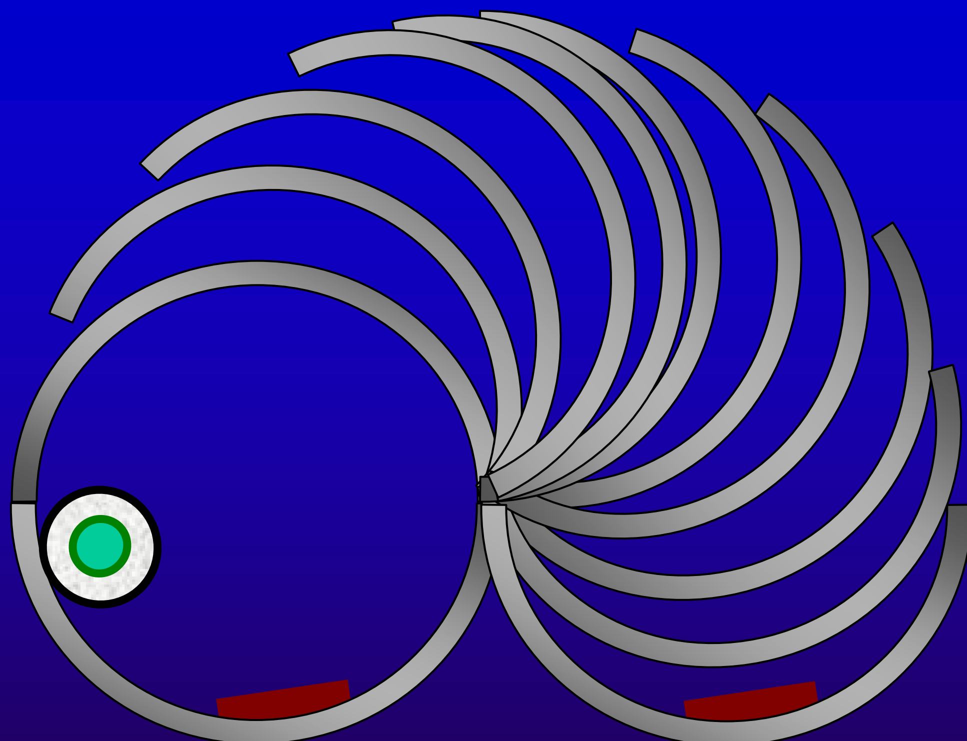


PILE INSTRUMENTATION
24" DIA PIPE PILE

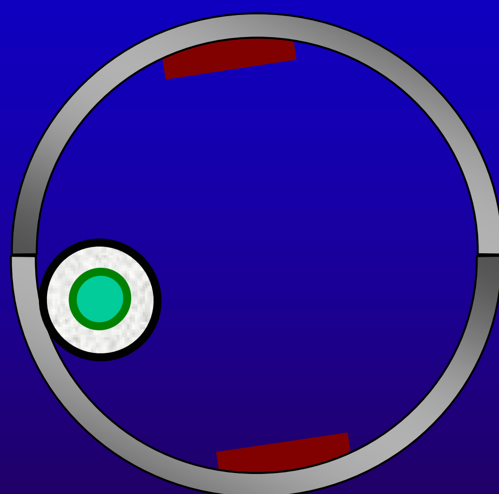


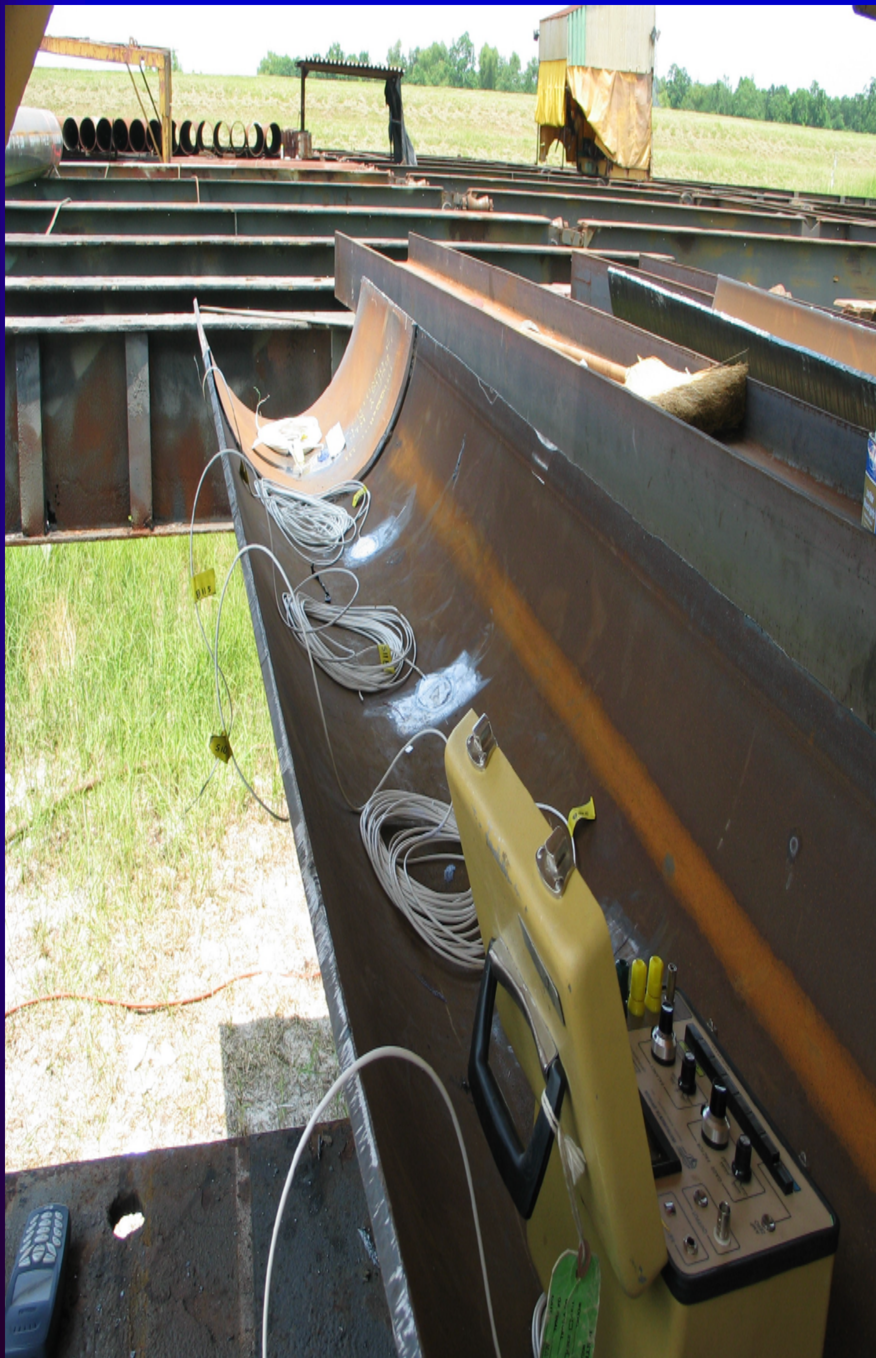
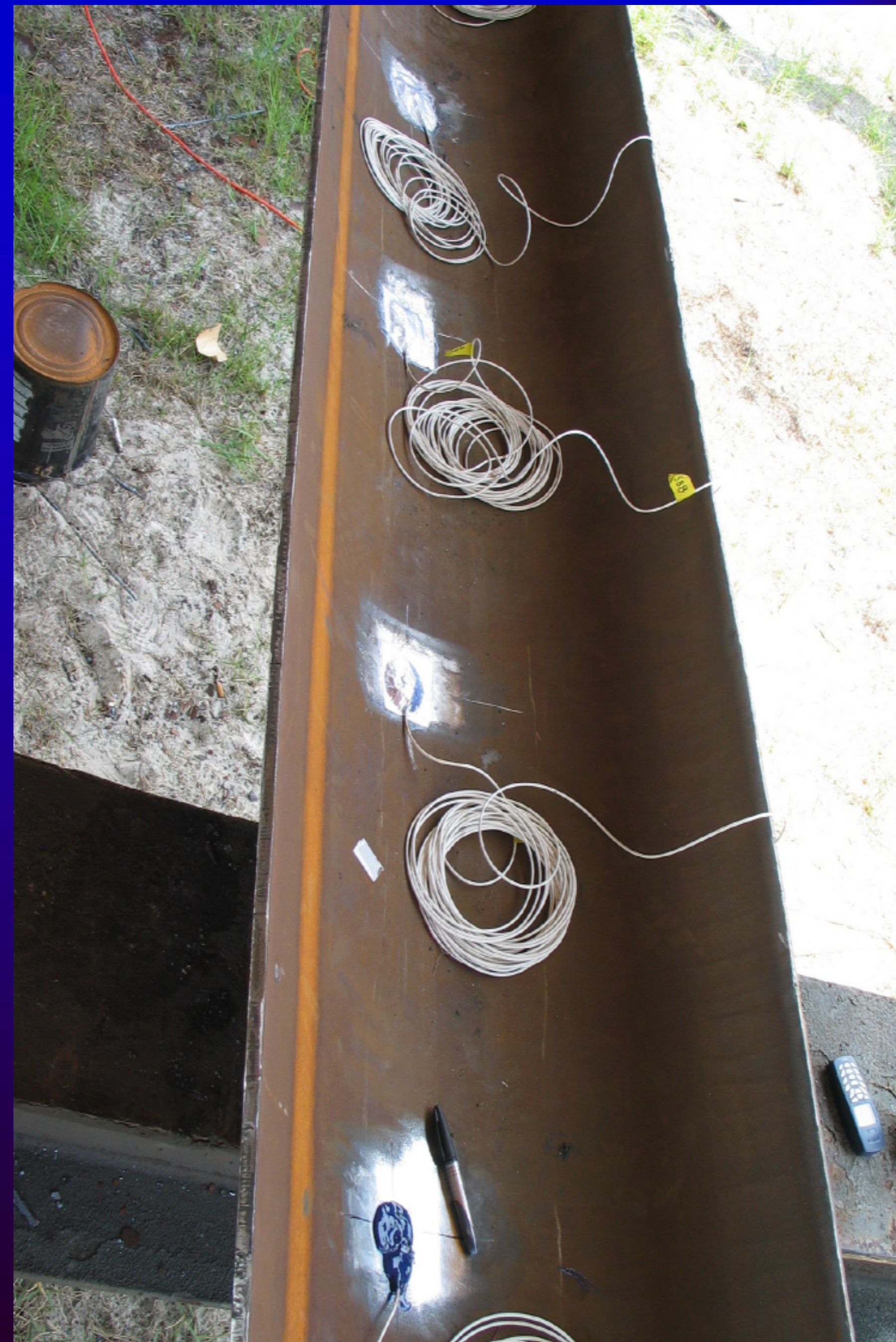
- Concerns with Additional Steel:
  - Increase pile stiffness
  - Alter/Widen pressure bulb

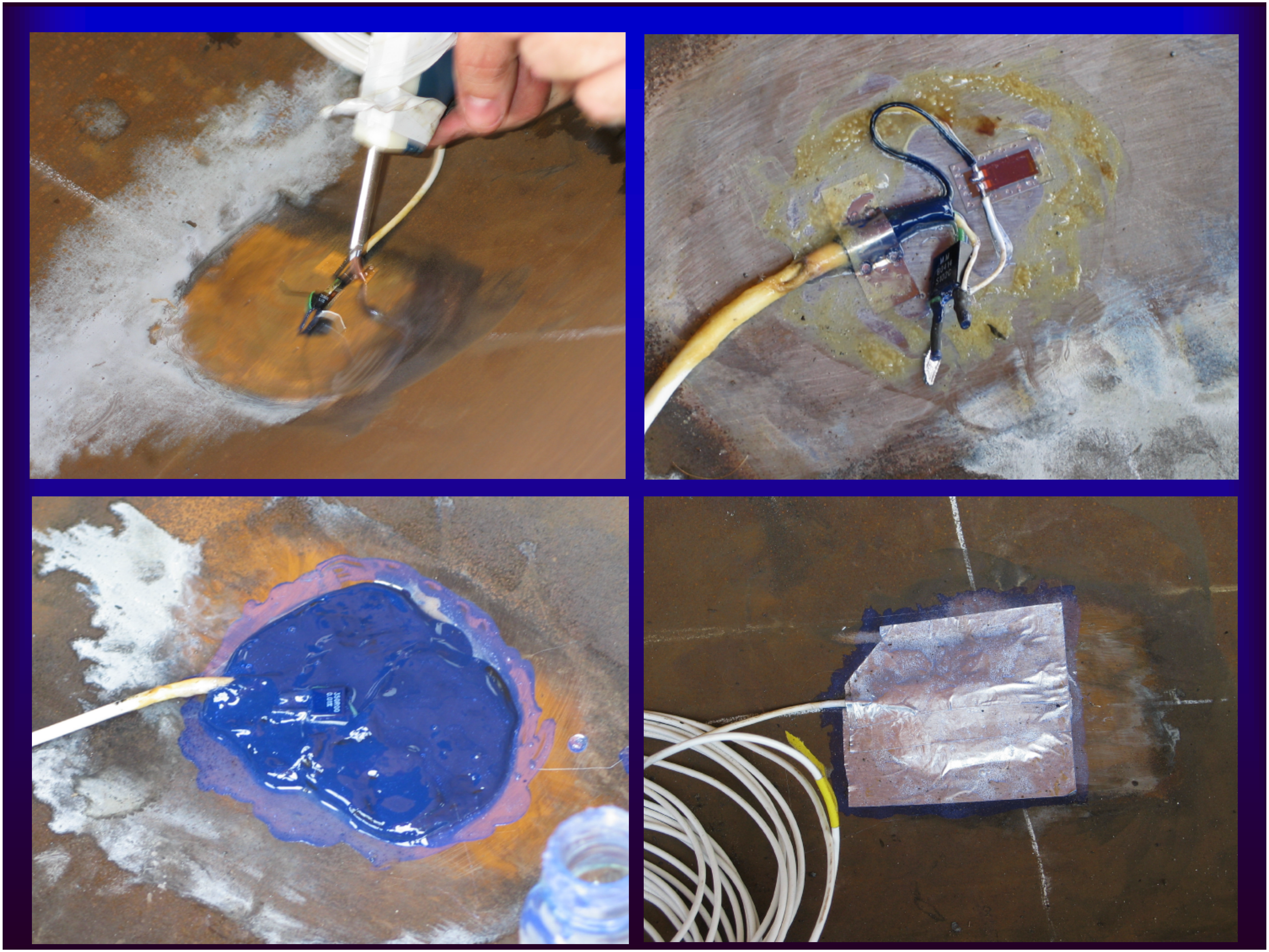
PILE INSTRUMENTATION
24” DIA PIPE PILE



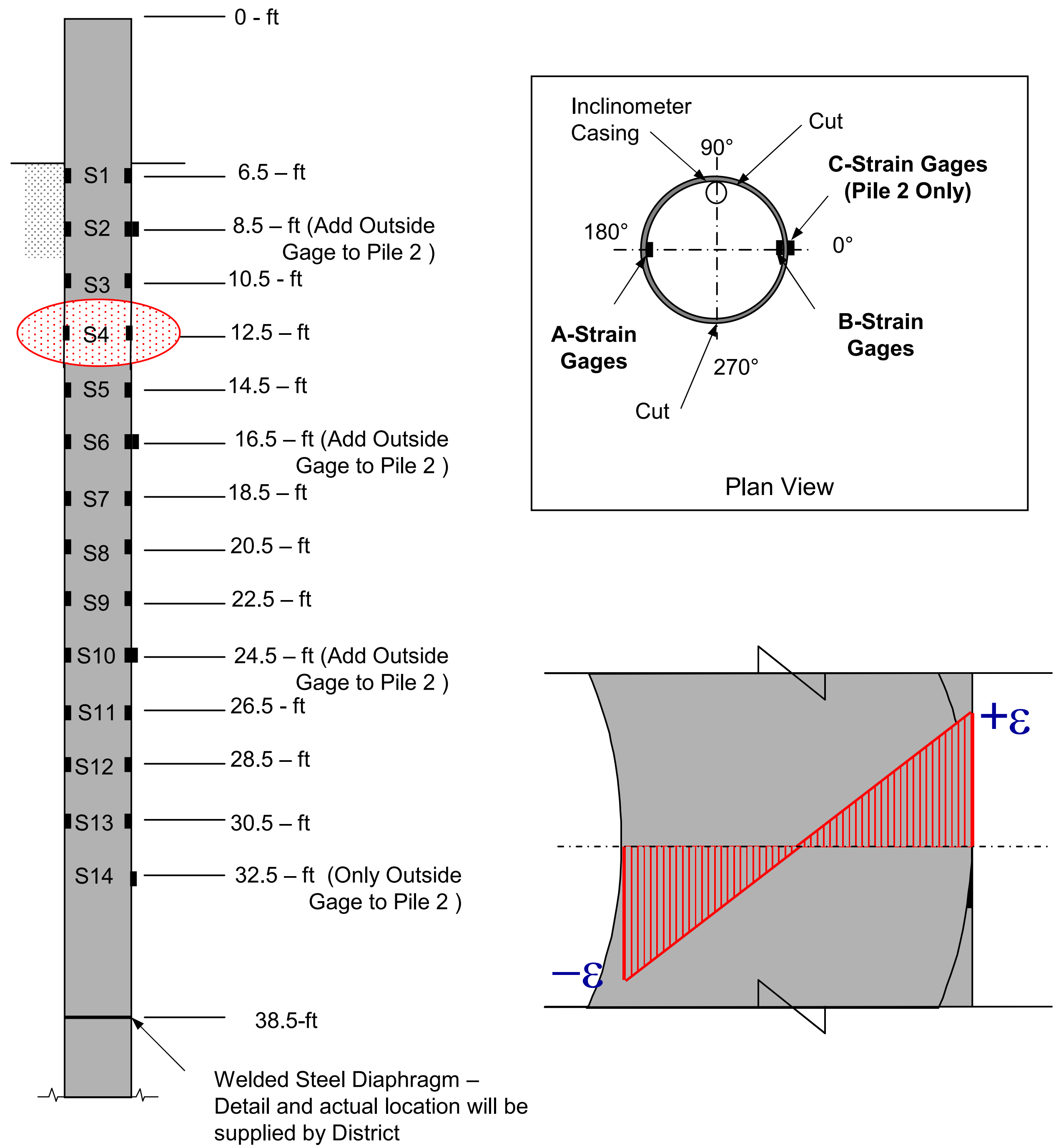
PILE INSTRUMENTATION
24” DIA PIPE PILE



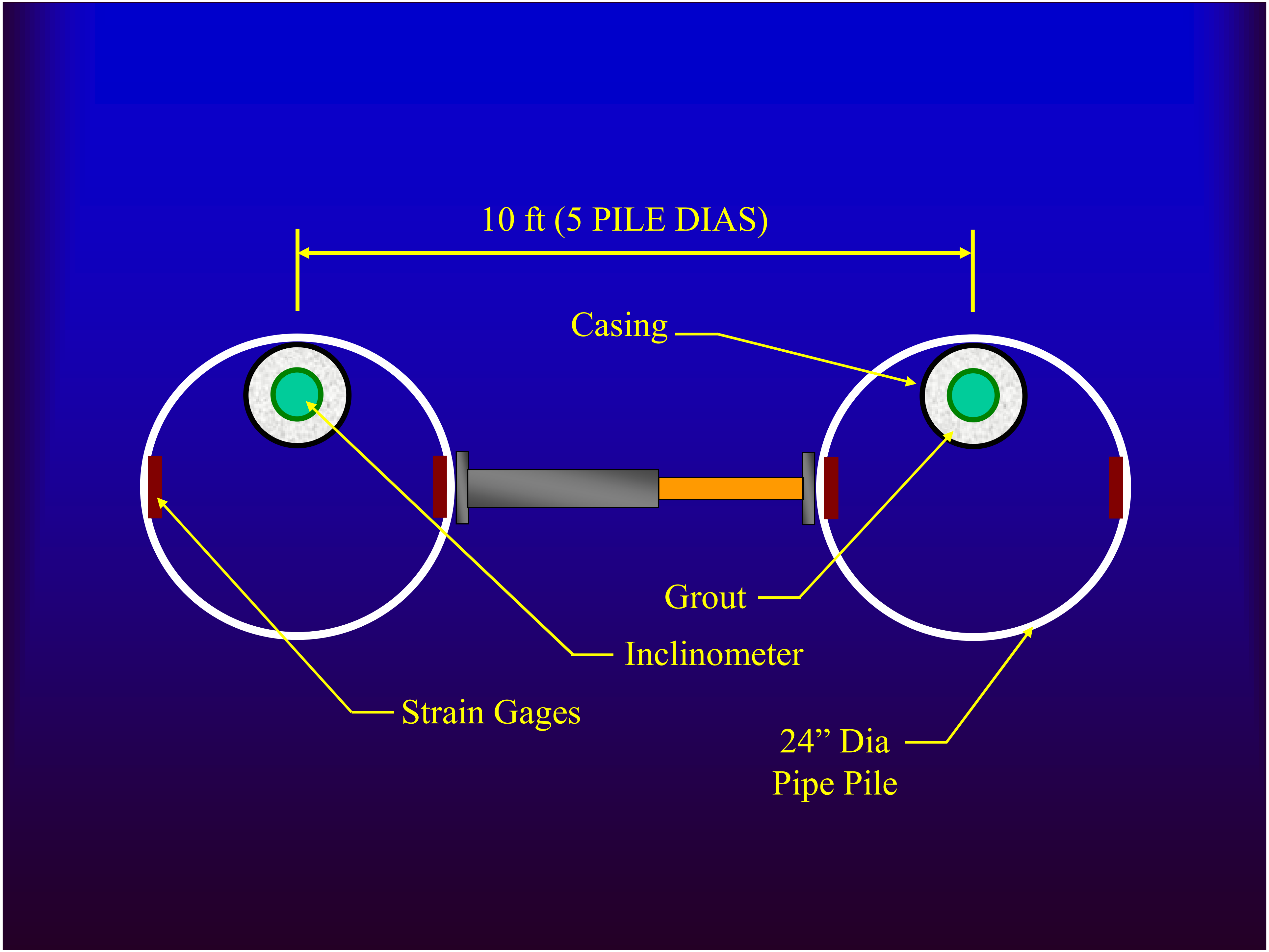








0 - ft
S1
6.5 – ft
S2
8.5 – ft (Add Outside Gage to Pile 2)
S3
10.5 - ft
S4
12.5 – ft
S5
14.5 – ft
S6
16.5 – ft (Add Outside Gage to Pile 2)
S7
18.5 – ft
S8
20.5 – ft
S9
22.5 – ft
S10
24.5 – ft (Add Outside Gage to Pile 2)
S11
26.5 - ft
S12
28.5 – ft
S13
30.5 – ft
S14
32.5 – ft (Only Outside Gage to Pile 2)
38.5-ft
Welded Steel Diaphragm – Detail and actual location will be supplied by District
Inclinometer Casing
Cut
90°
C-Strain Gages (Pile 2 Only)
180°
0°
A-Strain Gages
B-Strain Gages
270°
Cut
Plan View
+ε
−ε


POWER TEAM


10 ft (5 PILE DIAS)
Casing
Grout
Inclinometer
Strain Gages
24” Dia
Pipe Pile

LOAD APPLICATION

- Service Load = 30 Tons

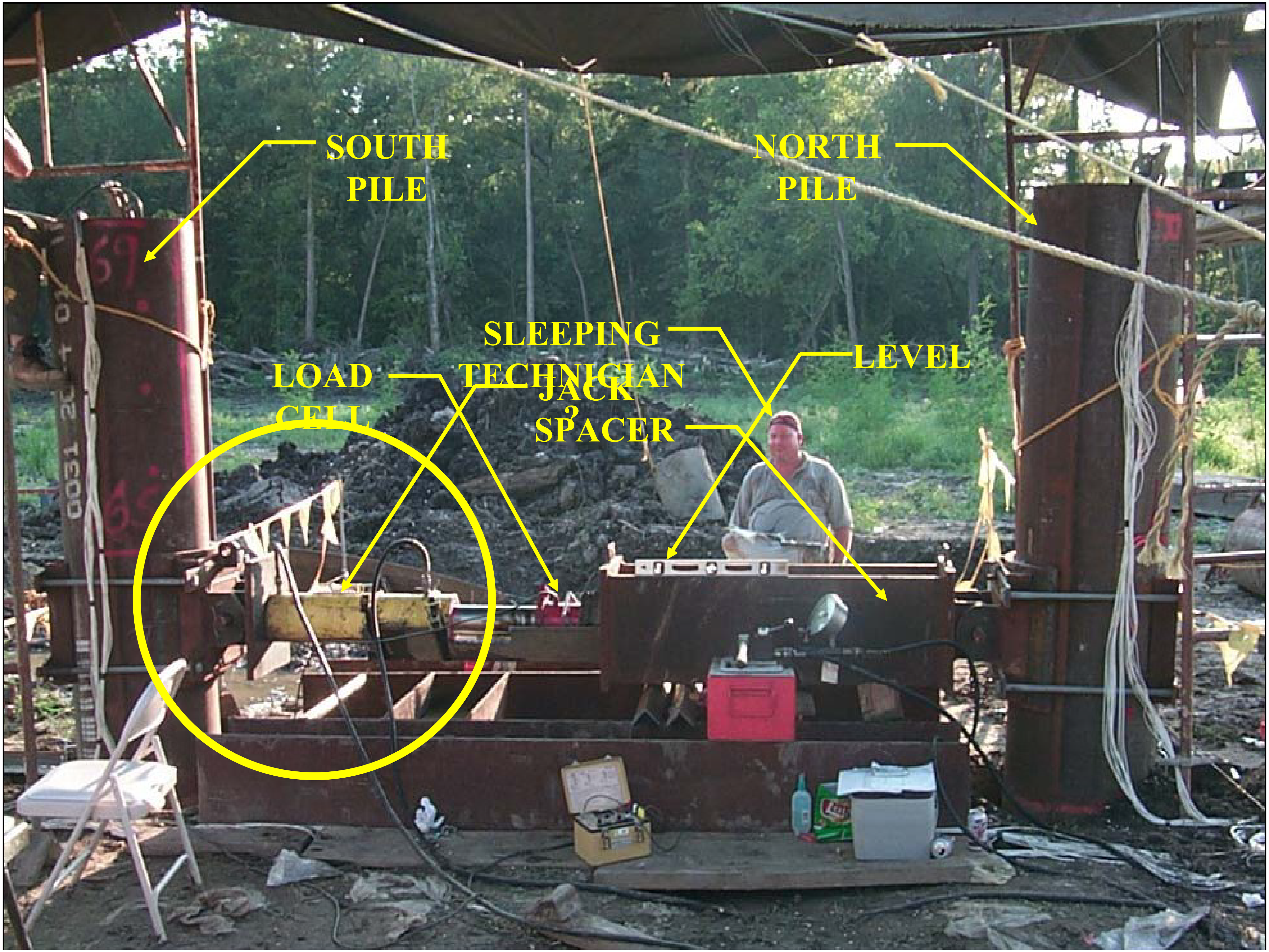
- Load Increments:

  12.5%, 25%, 37.5%, 50%, 62.5%, 75%, 87.5%, 100%, 125%, 150%, 160%, 170%, 180%, 190%, 200%

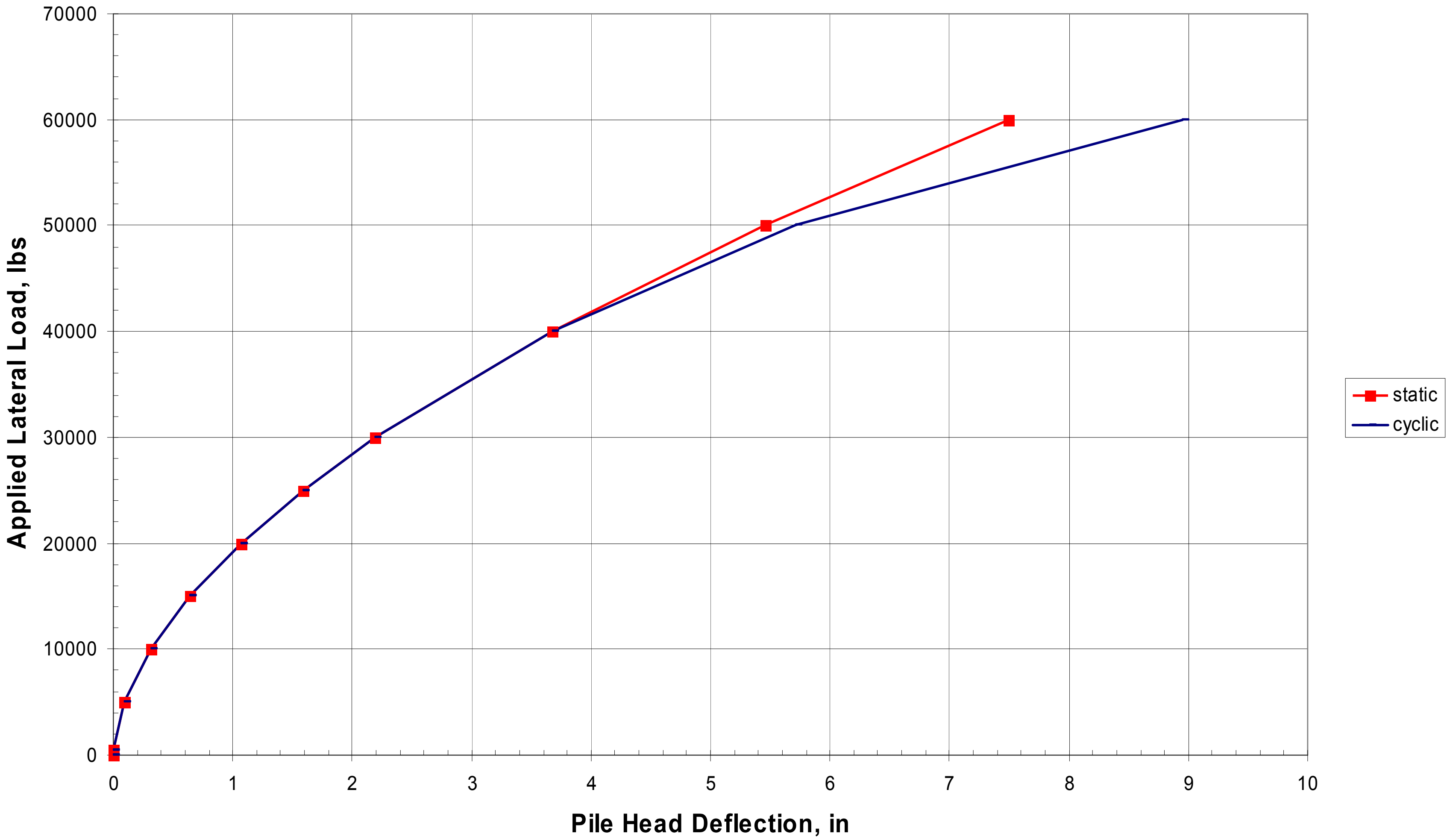
- Load Decrements:

  150%, 100%, 50%

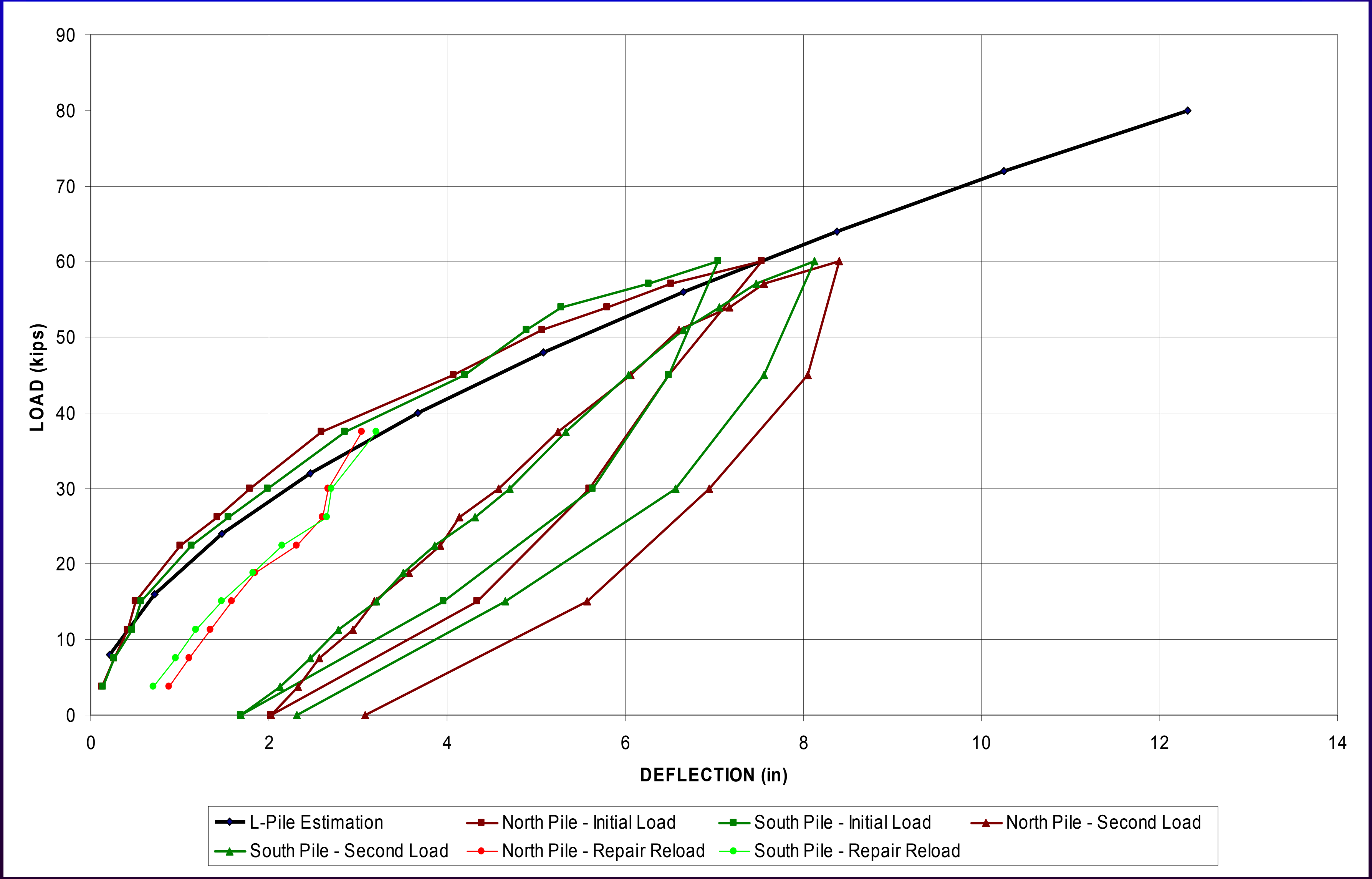
- Repeat Loading Procedure

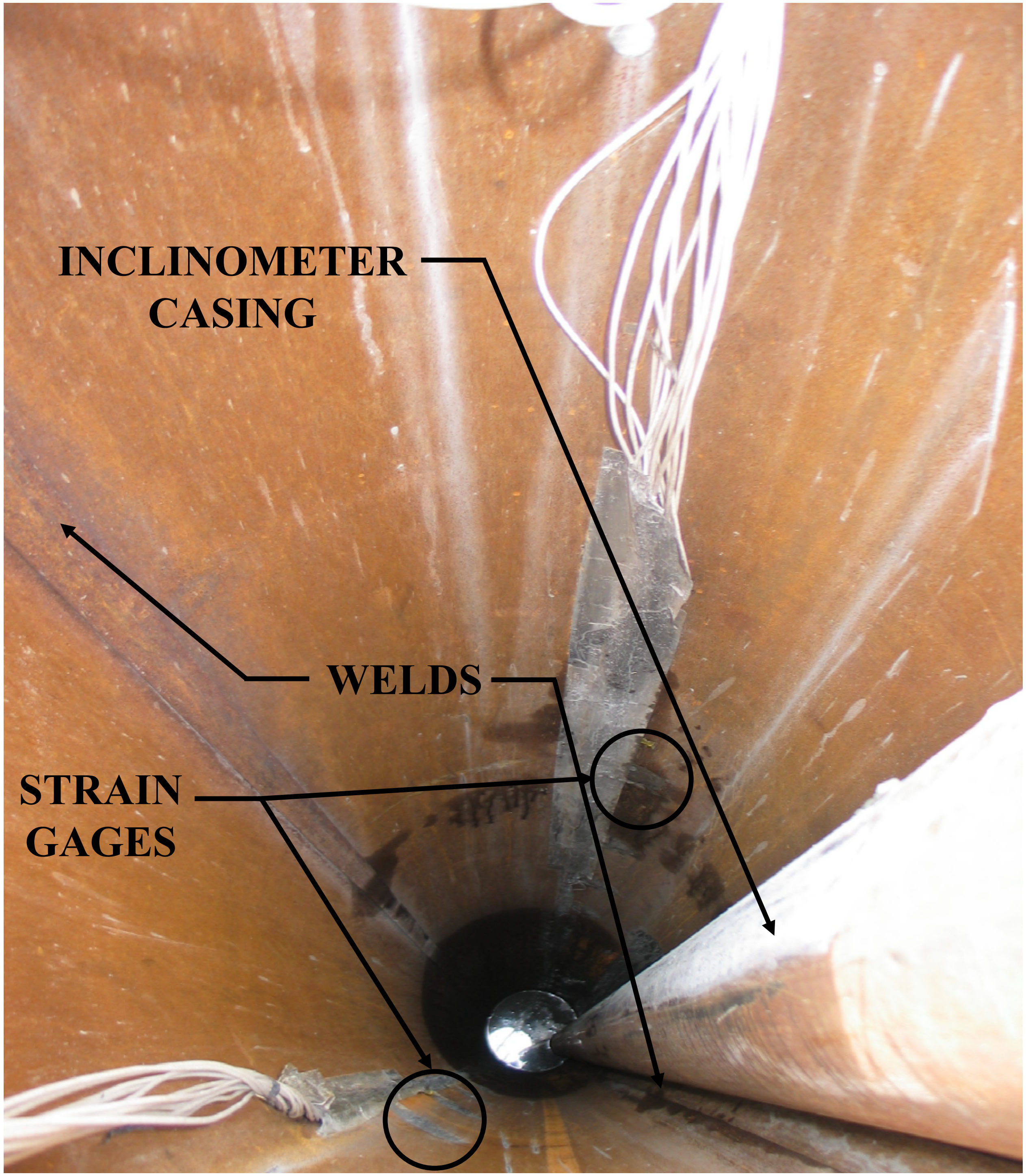

SOUTH PILE
NORTH PILE
SLEEPING TECHNICIAN
LEVEL
LOAD CELL
JACK SPACER

STATIC VS CYCLIC LOADING

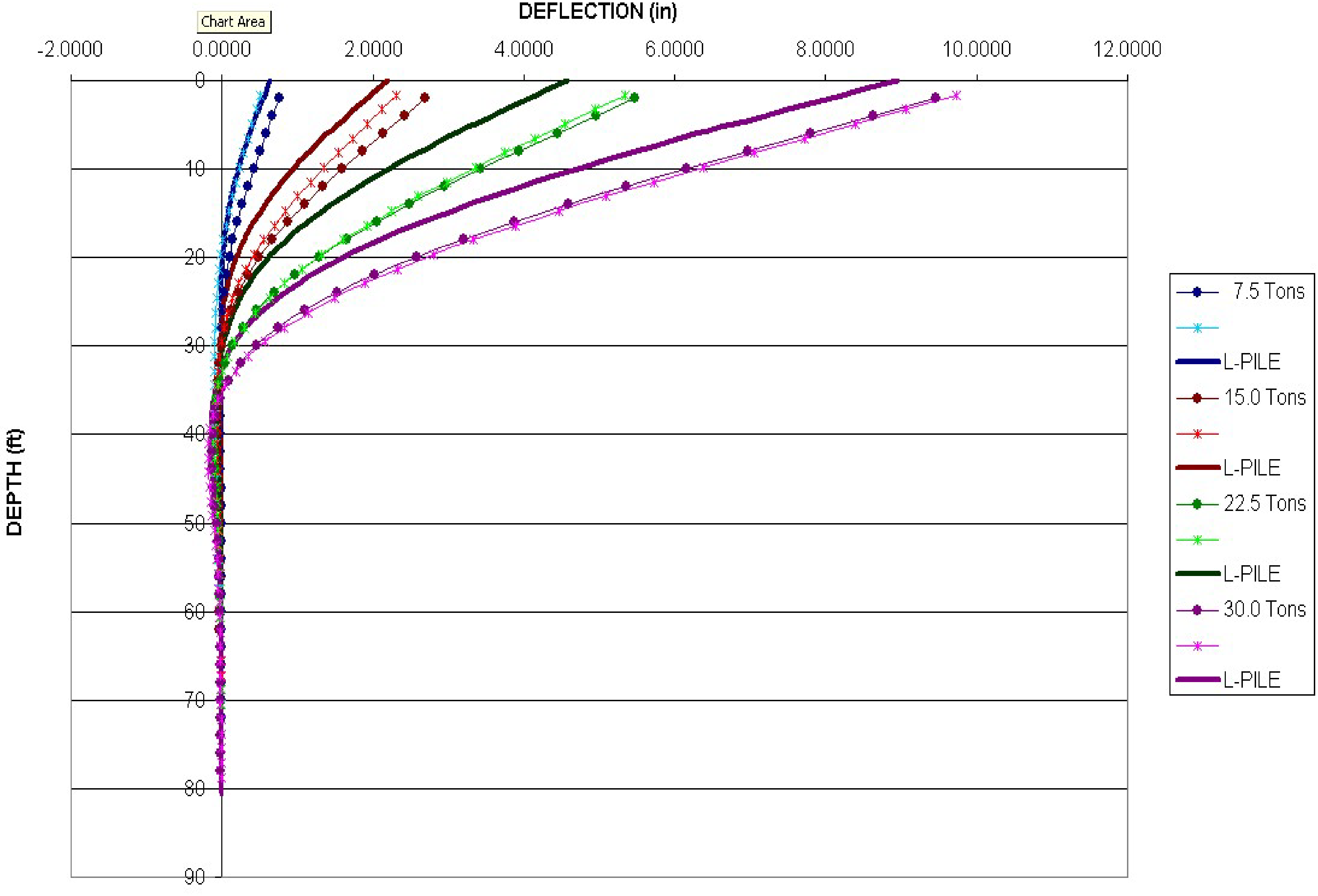


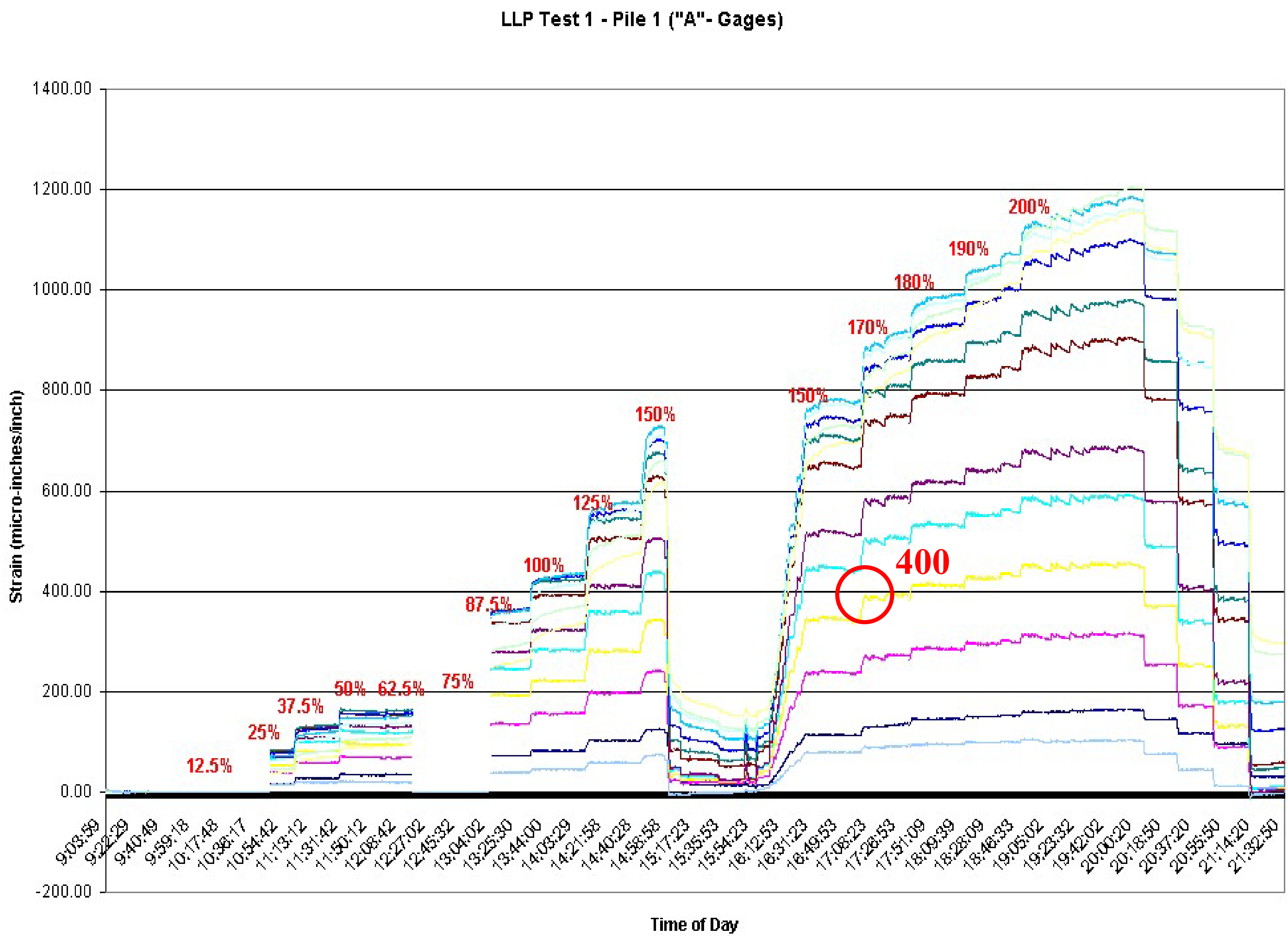
PILE HEAD DEFLECTIONS

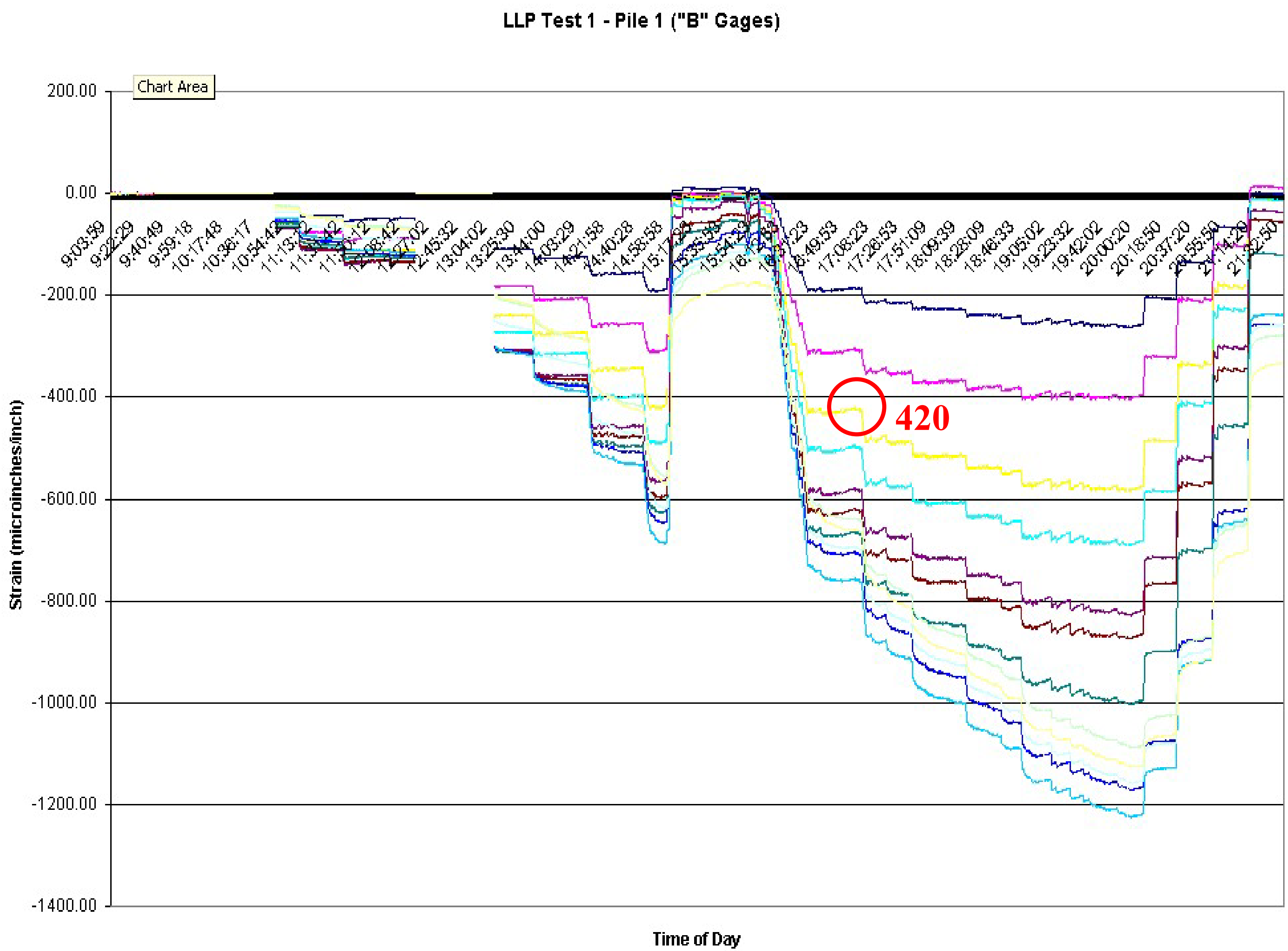


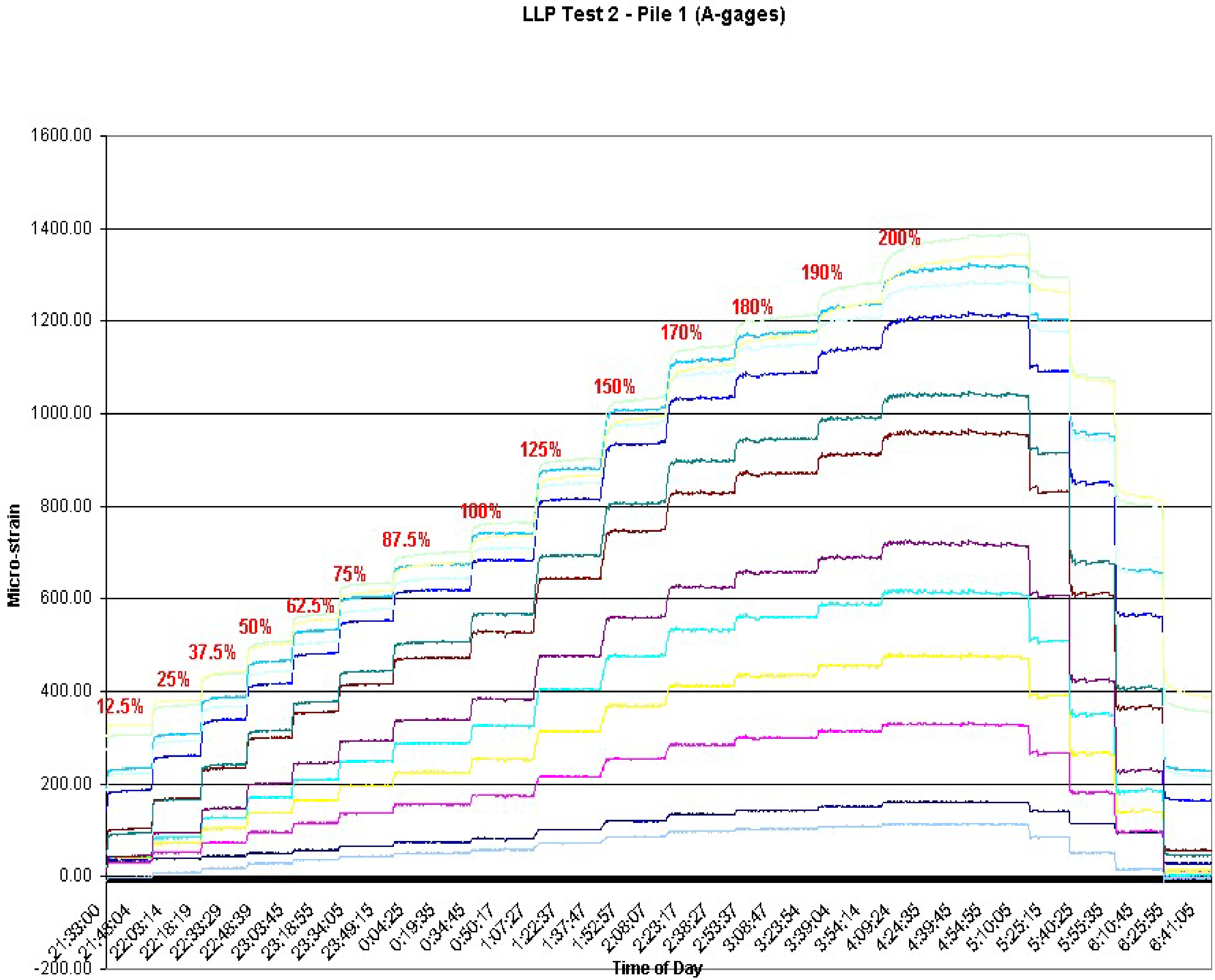

INCLINOMETER
CASING
WELDS
STRAIN
GAGES

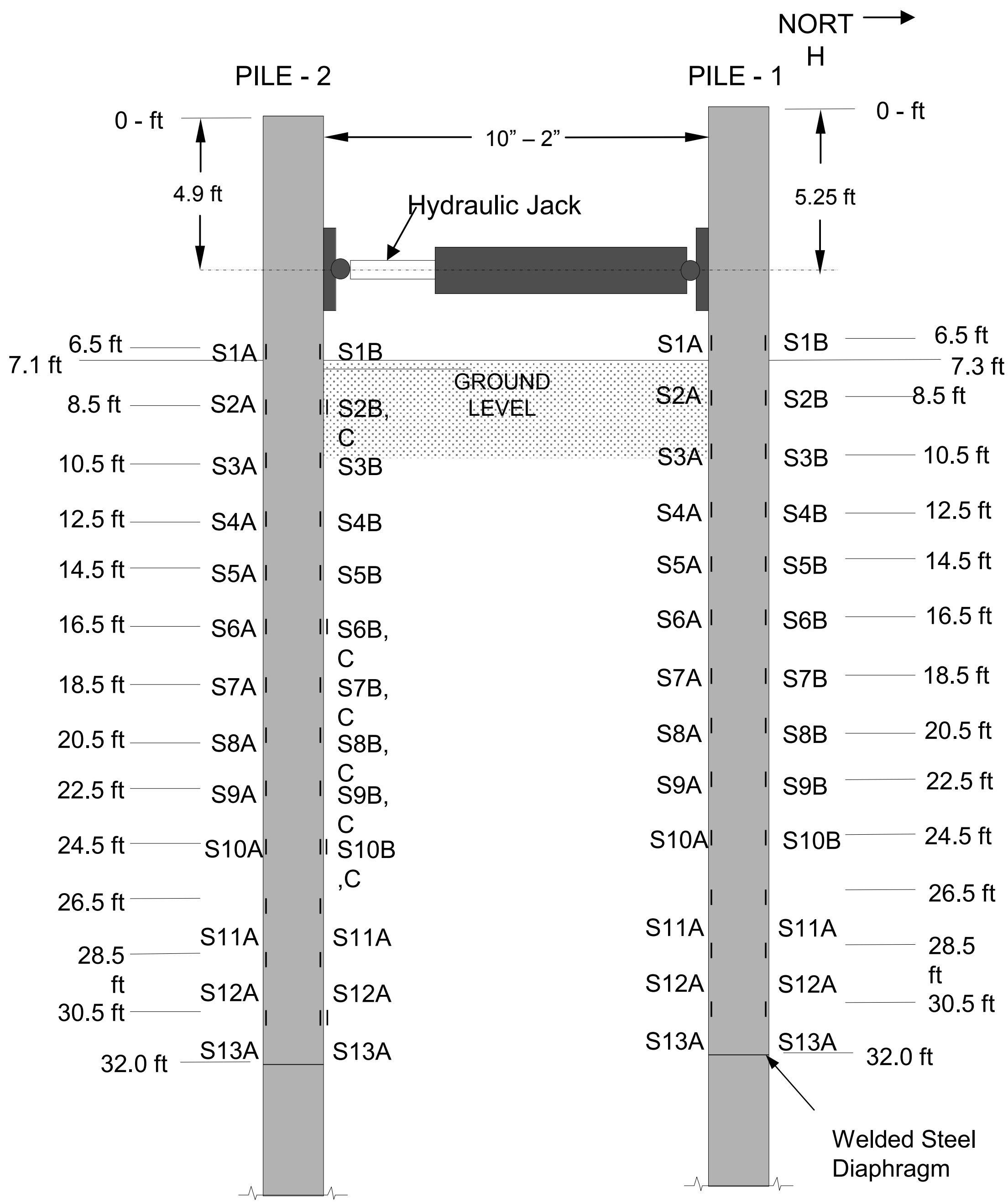
INCLINOMETER DATA




LLP Test 1 - Pile 1 ("A"- Gages)
Strain (micro-inches/inch)
Time of Day
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
-200.00
12.5%
25%
37.5%
50%
62.5%
75%
87.5%
100%
125%
150%
150%
170%
180%
190%
200%
400
9:03:59
9:22:29
9:40:49
9:59:18
10:17:48
10:36:17
10:54:42
11:13:12
11:31:42
11:50:12
12:08:42
12:27:02
12:45:32
13:04:02
13:25:30
13:44:00
14:03:29
14:21:58
14:40:28
14:58:58
15:17:23
15:35:53
15:54:23
16:12:53
16:31:23
16:49:53
17:08:23
17:26:53
17:51:09
18:09:39
18:28:09
18:46:33
19:05:02
19:23:32
19:42:02
20:00:20
20:18:50
20:37:20
20:55:50
21:14:20
21:32:50


LLP Test 1 - Pile 1 ("B" Gages)
Chart Area
200.00
0.00
-200.00
-400.00
-600.00
-800.00
-1000.00
-1200.00
-1400.00
Strain (microinches/inch)
Time of Day
420


LLP Test 2 - Pile 1 (A-gages)
Micro-strain
Time of Day
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
-200.00
12.5%
25%
37.5%
50%
62.5%
75%
87.5%
100%
125%
150%
170%
180%
190%
200%
21:33:00
21:48:04
22:03:14
22:18:19
22:33:29
22:48:39
23:03:45
23:18:55
23:34:05
23:49:15
0:04:25
0:19:35
0:34:45
0:50:17
1:07:27
1:22:37
1:37:47
1:52:57
2:08:07
2:23:17
2:38:27
2:53:37
3:08:47
3:23:54
3:39:04
3:54:14
4:09:24
4:24:35
4:39:45
4:54:55
5:10:05
5:25:15
5:40:25
5:55:35
6:10:45
6:25:55
6:41:05

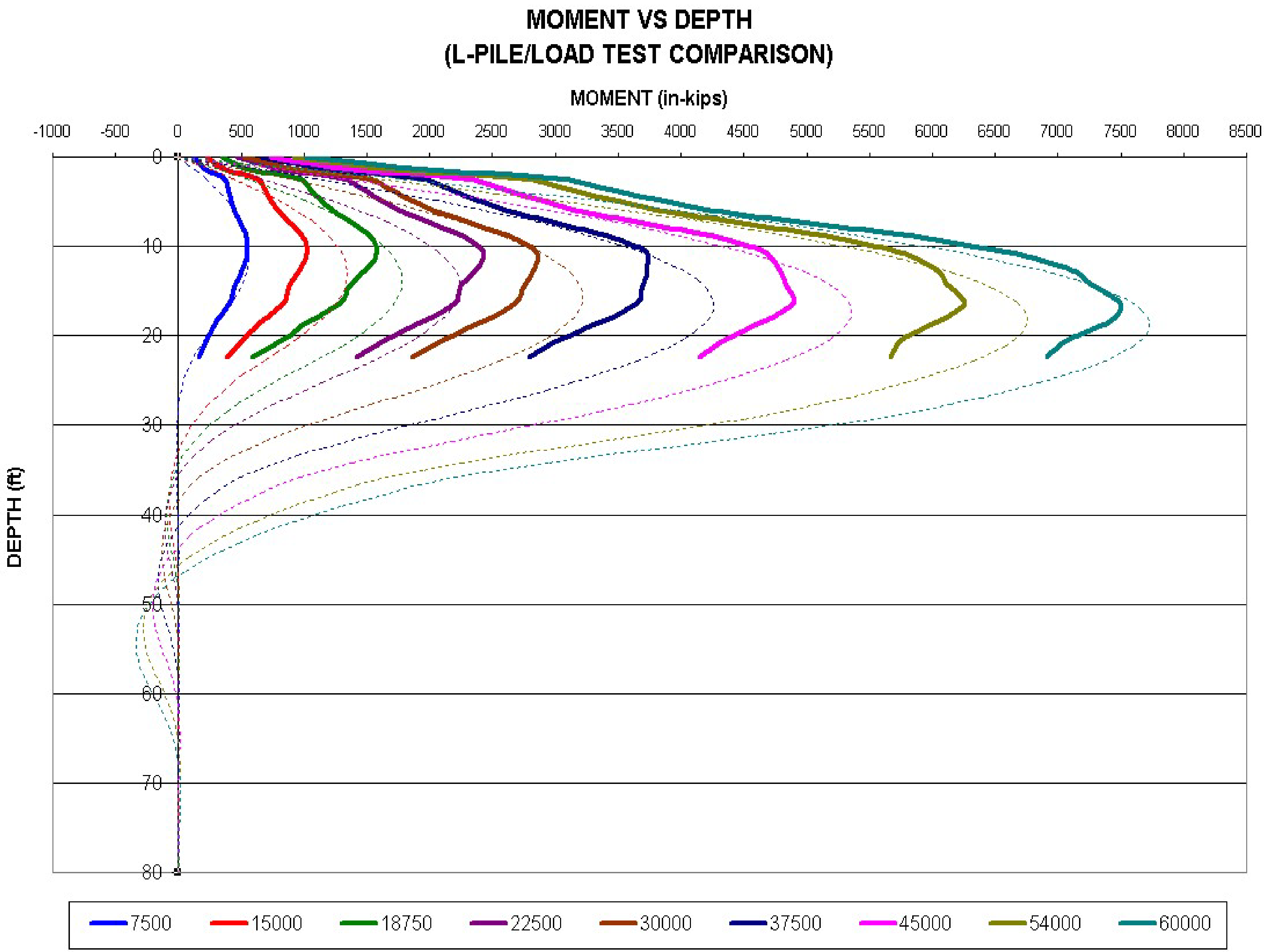


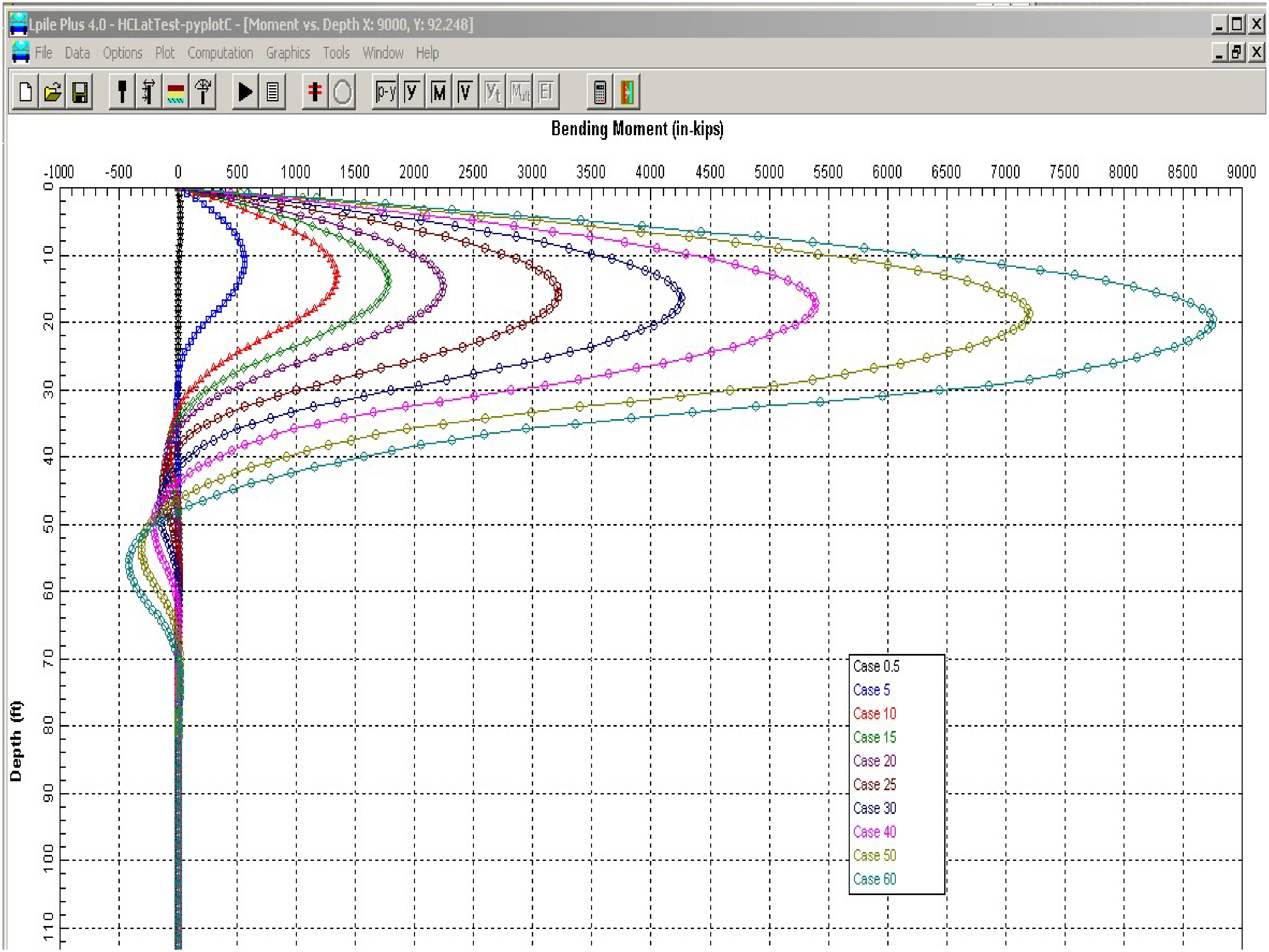
$$\sigma = E\varepsilon = \frac{P}{A} + \frac{M}{S}$$

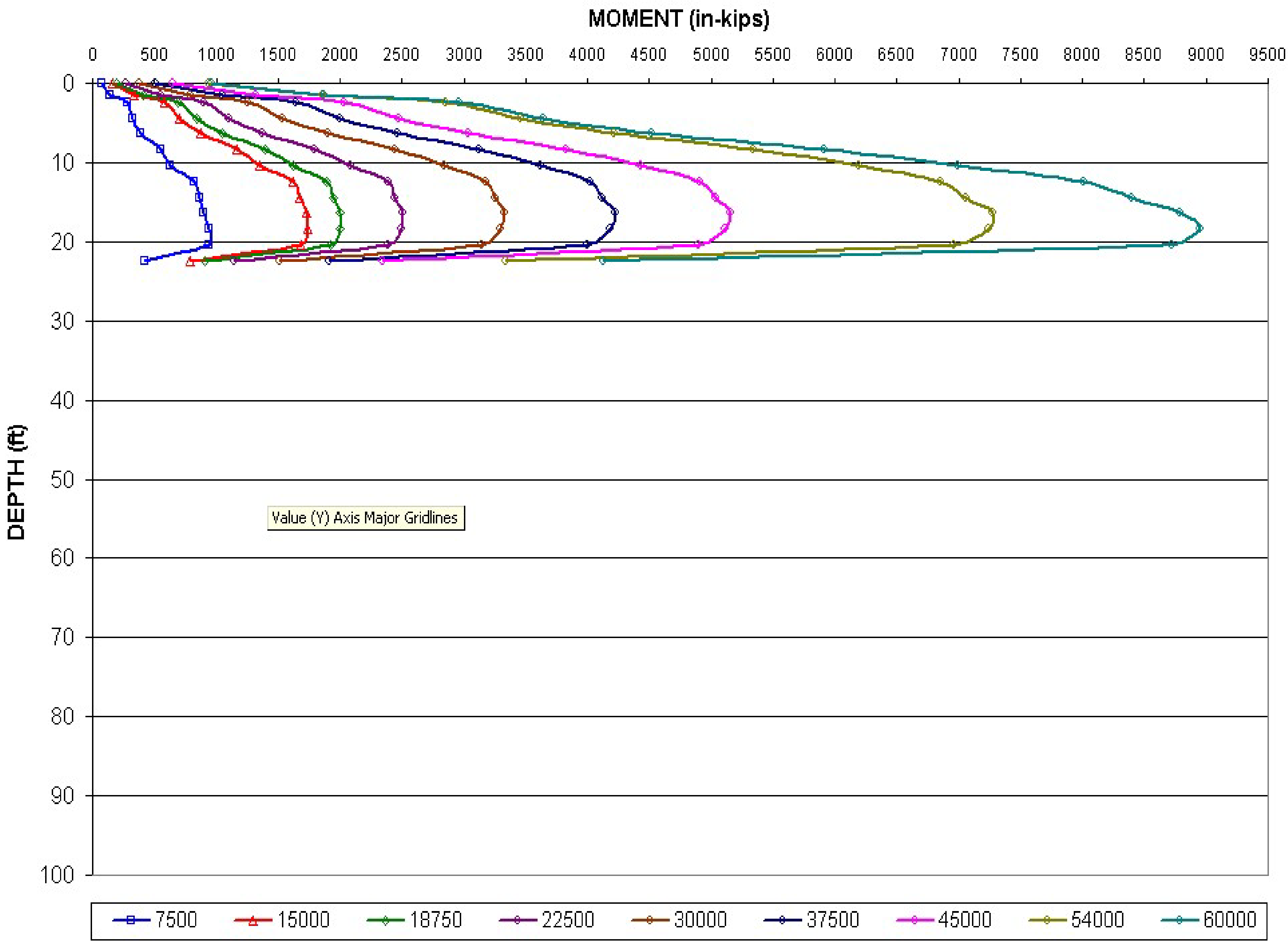
$$\sigma_A - \sigma_B = \frac{P_A}{A} + \frac{M_A}{S} - \frac{P_B}{A} - \frac{M_B}{S}$$

$$\Delta\sigma = \frac{2M}{S}$$

$$M = \frac{\Delta\sigma \cdot S}{2}$$


MOMENT VS DEPTH
(L-PILE/LOAD TEST COMPARISON)
MOMENT (in-kips)
-1000 -500 0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000 6500 7000 7500 8000 8500
DEPTH (ft)
0 10 20 30 40 50 60 70 80
7500
15000
18750
22500
30000
37500
45000
54000
60000


Lpile Plus 4.0 - HCLatTest-pyplotC - [Moment vs. Depth X: 9000, Y: 92.248]
File Data Options Plot Computation Graphics Tools Window Help
Bending Moment (in-kips)
-1000 -500 0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000 6500 7000 7500 8000 8500 9000
Depth (ft)
0 10 20 30 40 50 60 70 80 90 100 110
Case 0.5
Case 5
Case 10
Case 15
Case 20
Case 25
Case 30
Case 40
Case 50
Case 60



MOMENT (in-kips)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
9500
DEPTH (ft)
0
10
20
30
40
50
60
70
80
90
100
Value (Y) Axis Major Gridlines
7500
15000
18750
22500
30000
37500
45000
54000
60000

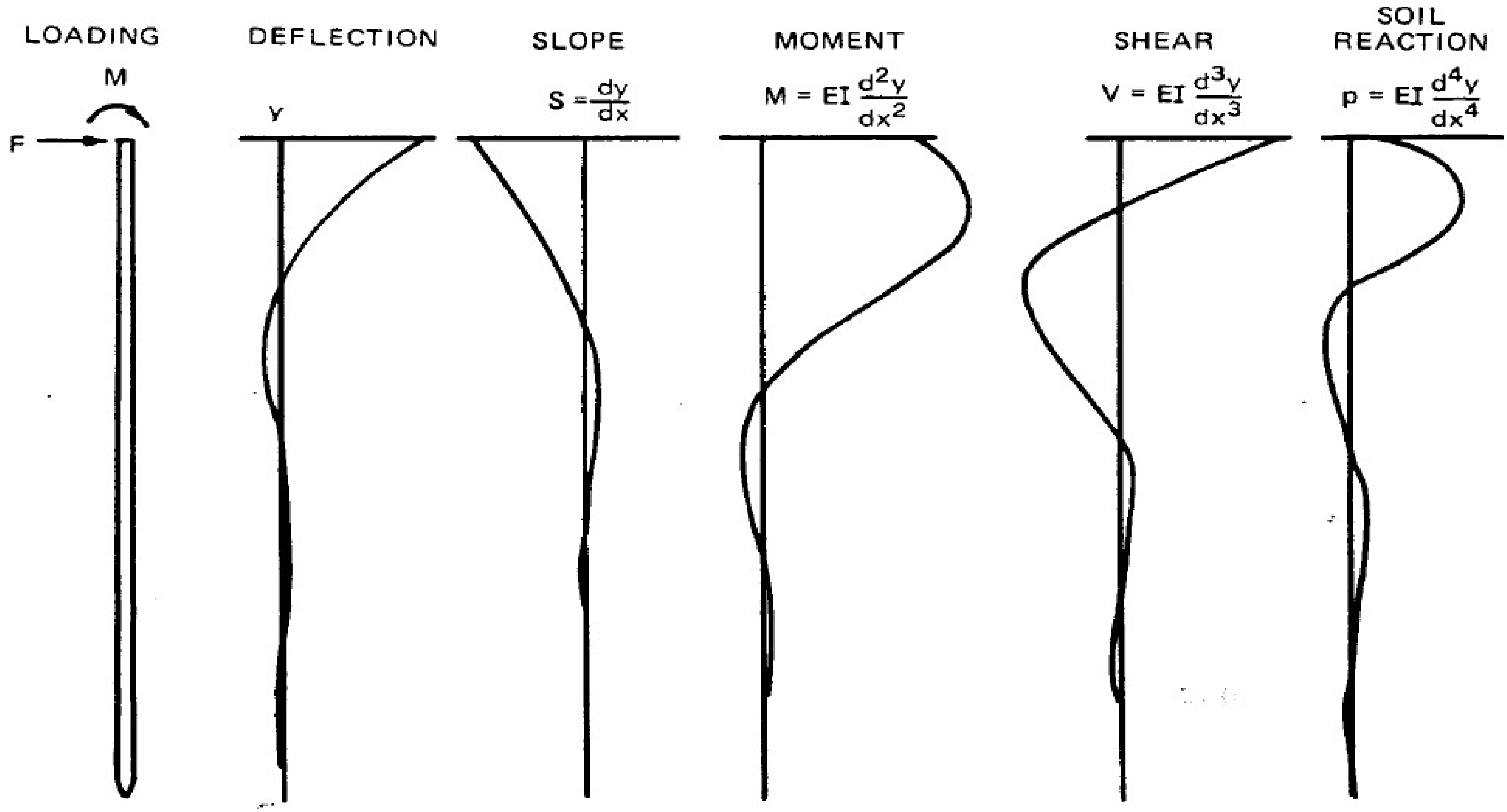


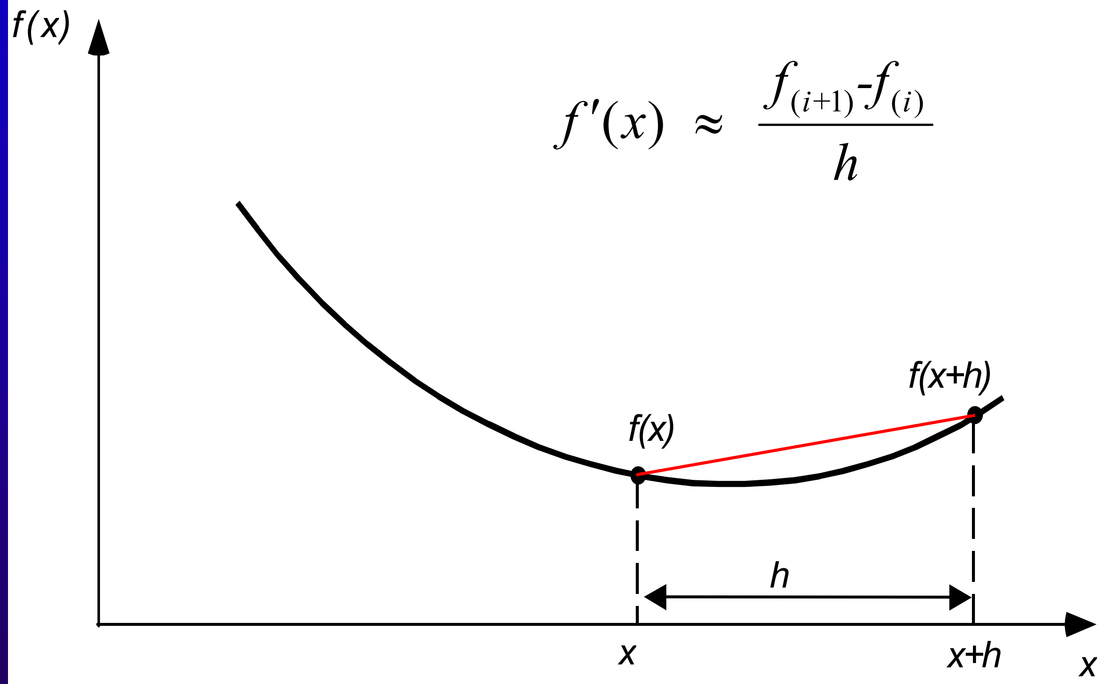
Figure 4. Form of the results obtained from a laterally loaded pile (Reese and Cox 1968)

$$p = \frac{d^2M}{dx^2}$$

- Consider the Taylor series expansion of *f(x)* near a point *x*

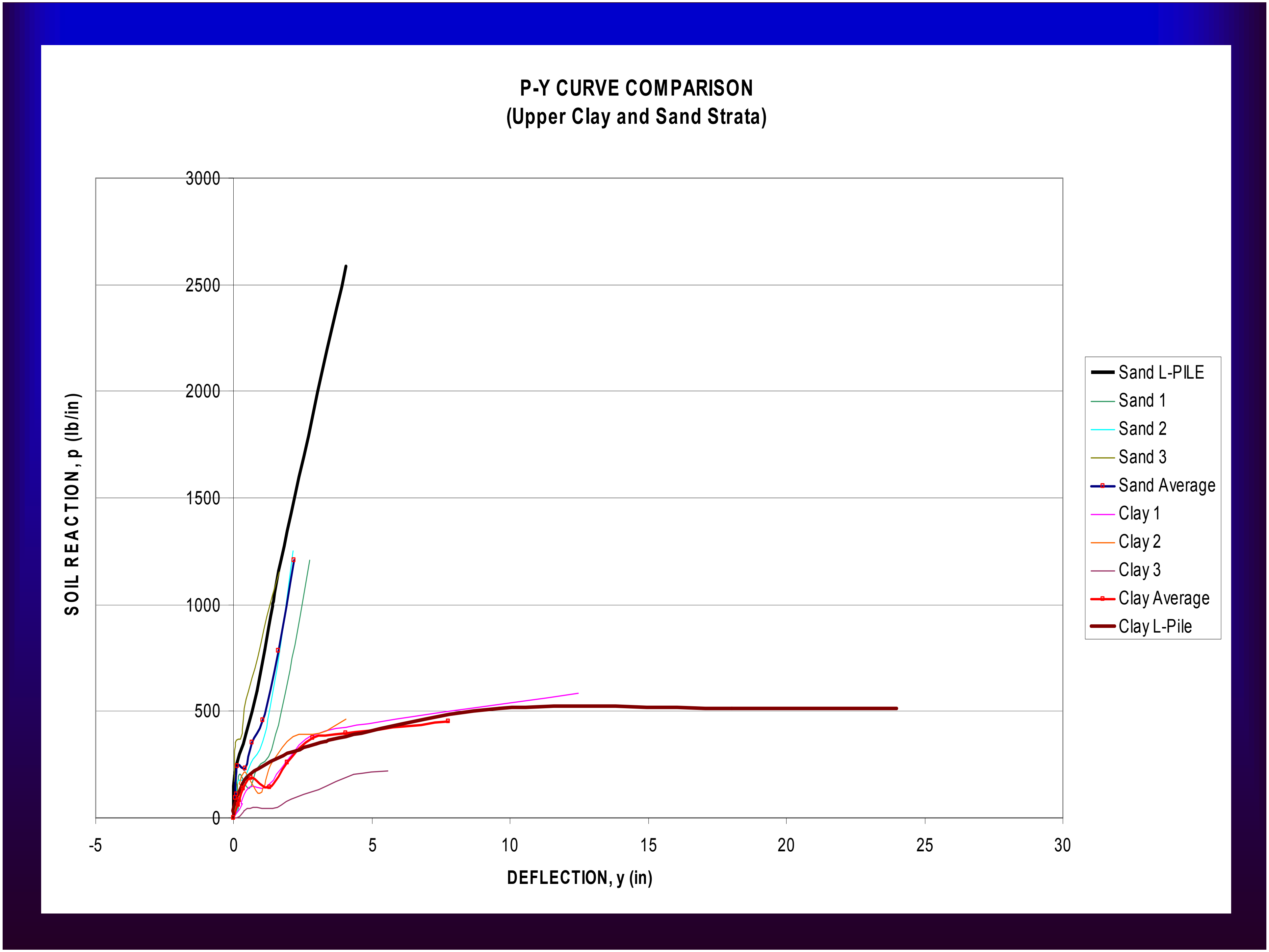
$$f(x+h) = f(x) + hf'(x) + \frac{h^2}{2!} f''(x) + \frac{h^3}{3!} f'''(x) + \cdots$$

$$f'(x) \approx \frac{f_{(i+1)} - f_{(i)}}{h}$$



$$f''(x) \approx \frac{f'_{(i+1)} - f'_{(i)}}{h}$$

$$f''(x) \approx \frac{f_{(i+1)} - 2f_{(i)} + f_{(i-1)}}{h^2}$$

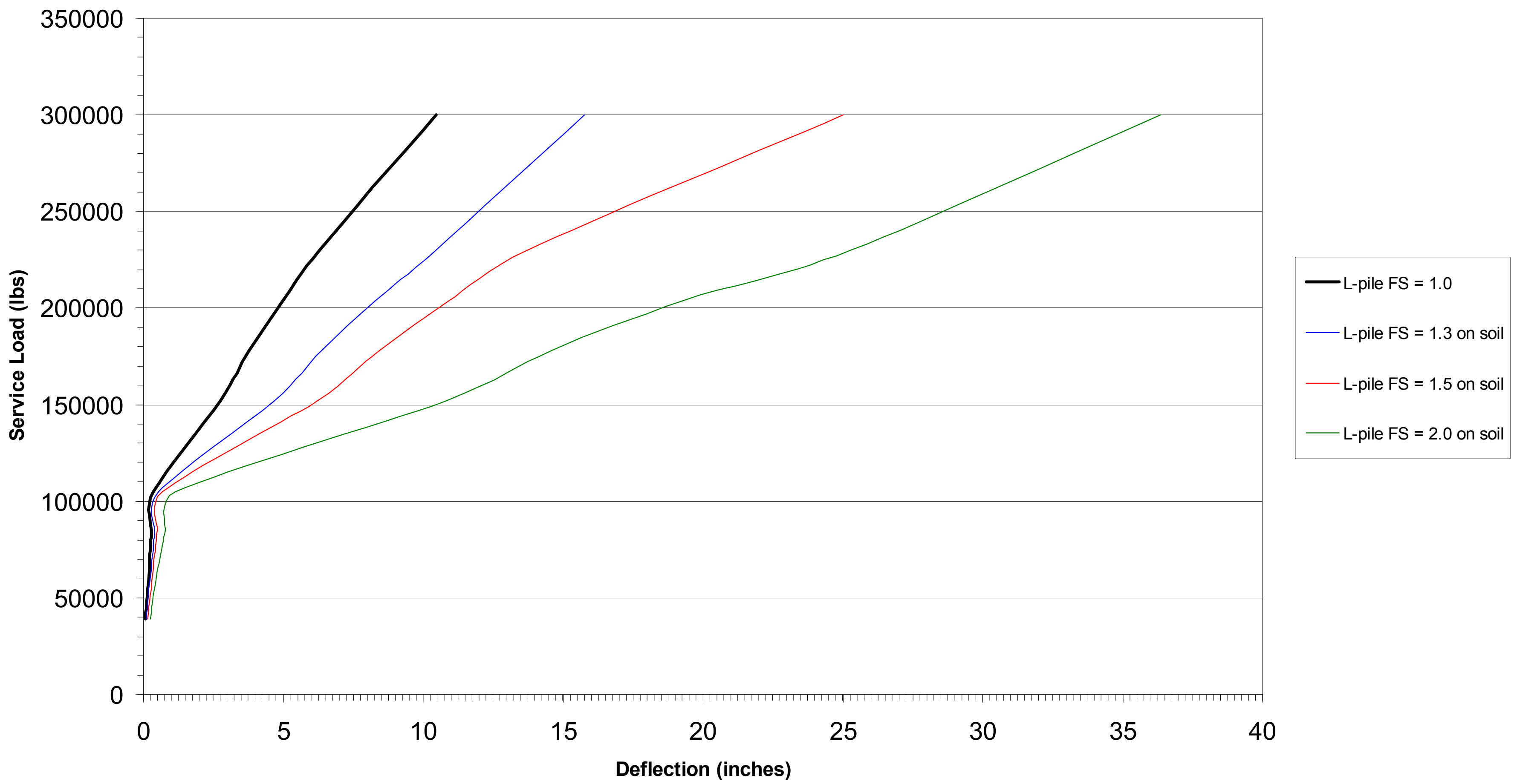


P-Y CURVE COMPARISON
(Upper Clay and Sand Strata)
SOIL REACTION, p (lb/in)
DEFLECTION, y (in)
3000
2500
2000
1500
1000
500
0
-5
0
5
10
15
20
25
30
Sand L-PILE
Sand 1
Sand 2
Sand 3
Sand Average
Clay 1
Clay 2
Clay 3
Clay Average
Clay L-Pile

BENEFITS OF LATERAL PILE LOAD TEST

- Establish Pile Head Deflections
  - Identify Plastic Limit of Soil
  - Verify Group Effects
- Develop Moment vs Depth Curves
  - Structural Analyses
  - Determine Pile Tip
- Develop p-y Curves
  - Pile Stresses & Deflections
  - G-Pile or CPGA

RESULTING PILE HEAD DEFLECTIONS
ALTERING SOILS FACTORS OF SAFETY



LESSONS LEARNED

- Strain gage/inclinometer system well suited for p-y data development
- Allow adequate time for inclinometer readings
- Mark piles and ground fully for alignment
- Cycle load during test before 200%
- Secure jacking device
- Two pile system effective/redundant

LESSONS LEARNED

- p-y development/utilization less conservative
- Apply adequate load to pile to develop full p-y data
- Outside gage coating successful
- Relatively inexpensive
- Utilize F.S. = 1.0 on soils when developing soil reaction data
- Update EM with design and F.S. criteria

ACKNOWLEDGEMENTS

- Bruce Barker – ERDC
- Leo Koestler – ERDC
- Robert Ebeling – ERDC
- Kevin Abraham – ERDC
- Alpha Testing & Inspecting, Inc.
- Applied Foundation Testing, Inc.

THANK YOU!