Full Day Seminar - Expanded Base Micropiles
Micropile Behavior Predictions using Advanced In-Situ Soil Characterization - SDMT & CPTu
Full Scale In-Situ Load Tests: Compression, Uplift, Lateral, PDA

30/10/2025

# *Laterally Loaded Piles (LLP) using P-Y curves from DMT test results*


Diego Marchetti diego@marchetti-dmt.it

Kaustav Das k.das@marchetti-dmt.it

Studo Prof. Marchetti – Rome Italy


www.marchetti-dmt.it

# Presentation Outline

- Introduction
- P-Y curves for LLP applications
- Three methods for P-Y curves from DMT:
  - Gabr and Borden 1988
  - Robertson 1989
  - Marchetti 1991
- Case history Livorno LLP test (1991) analysis and validation of deflections
- Gatineau test site: Sample LLP analysis

# Introduction

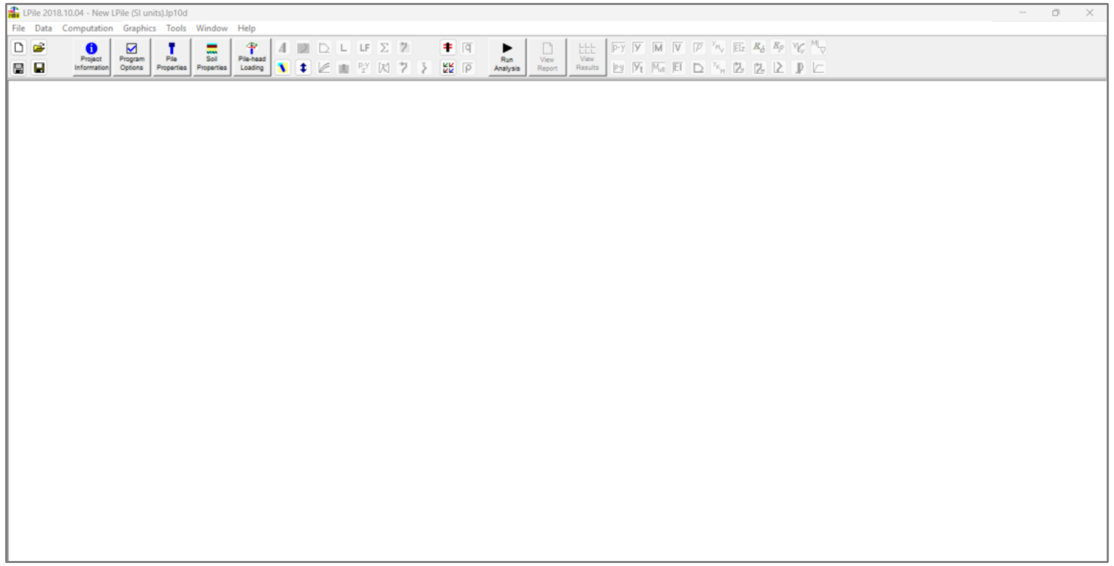
- Pile foundations are structural elements to transfer loads from superstructures to deeper, competent soil or rock strata
- Piles are commonly designed to resist axial loads (compression or tension), but sometimes also laterally loaded
- When a pile is laterally loaded, it deflects primarily in the loading direction, mobilizing soil resistance along its length
- The soil–pile interaction is nonlinear and depends on factors such as soil stiffness, strength, pile geometry and load magnitude
- The response is characterized by bending moments, shear forces and lateral deflections along the pile shaft, with maximum deformation typically occurring at shallow depths

# Introduction to LLP and P-Y Curves

- LLP analysis is generally more complex than for axially loaded piles, because of the nonlinear and heterogeneous nature of soil response
- Numerical or semi-empirical methods based on P–Y curve approach are widely adopted
- P-Y curves approach (Hetenyi 1946): soil is modeled with a series of independent and nonlinear springs (Winkler model), where the lateral soil reaction (P) at each depth is expressed as a function of the local lateral deflection (Y)
- Three main methods were developed to estimate P-Y curves from DMT results :
  Gabr and Borden (1988), Robertson (1989), Marchetti (1991)
- Prediction of the two latter methods are compared with measured deflections in the case history LLP test site of Livorno (Italy 1991)

# Software for LLP analysis using P-Y curves

- LLP analysis using Ensoft LPi 2018
- The freeware version of the software may be downloaded from https://getintopc.com/softwares/ensoft-lpi-2018-free-download/



# Gabr and Borden (1988) method

$$\frac{\mathbf{P}}{\mathbf{P_{ult}}} = \mathbf{tanh}\left(\frac{\boldsymbol{E_{s1}\,y}}{\mathbf{P_{ult}}}\right)$$

## Ultimate soil resistance $P_{ult}$

$$P_{ult} = N_p S_u d \qquad N_p = 3 + \frac{\sigma'_{v0}}{S_u} + J\left(\frac{Z}{d}\right) \leq 9$$

$N_p$= non dimensional ultimate clay resistance coefficient

$S_u$= undrained shear strength from DMT

$\sigma'_{v0}$= effective vertical stress at depth Z

J = empirical coefficient; 0.5 for soft clay, 0.25 for stiff clay

Z = depth

d = pile diameter

## Initial Tangent Modulus $E_{s1}$

$$E_{s1} = 6.5\left(\frac{P_o - \sigma_{h0}}{b}\right) d$$

$P_o$ first DMT reading

$\sigma_{h0}$ in-situ horizontal at-rest pressure

b half blade thickness (7 mm)

d pile diameter

# Gabr and Borden (1988) method

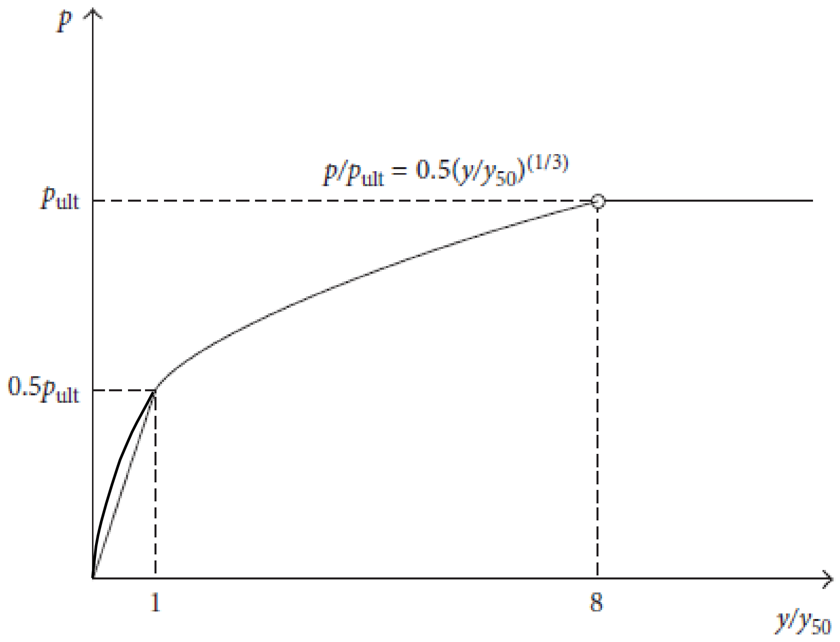
Comments:

- First method for P-Y curves from DMT data
- Developed specifically for stiff OC clay and tends to overpredict deflections in non OC clays
- $E_{S1}$ based on $P_0$, related to total horizontal stress and not to soil compressibility

# Robertson 1989 method for P-Y curves from DMT data

(for clay and sand)

# Robertson 1989 method




**Parameters:**

p : soil reaction

y : pile deflection

$p_{ult}$ : ultimate soil resistance

$p/p_{ult}$ : ratio of soil resistance

$y_{50}$ : pile deflection for p = 50% $p_{ult}$

$y/y_{50}$ : ratio of pile deflection

- Adaptation of early Matlock 1970 method: $y/y_{50} \geq 8 \rightarrow p/p_{ult} = 1$ (asymptot $p = p_{ult}$)
- Applicable in OC and NC clay and based on Su
- Applicable in sand (based on φ)

# Robertson 1989 method

$$\frac{\mathbf{P}}{\mathbf{P_{ult}}} = \mathbf{0.5}\,\left(\frac{\mathbf{y}}{\mathbf{y_{50}}}\right)^{\mathbf{0.33}}$$

## Ultimate soil resistance ($P_{ult}$)

$$P_{ult} = N_p S_u d \qquad N_p = 3 + \frac{\sigma'_{v0}}{S_u} + J\left(\frac{Z}{d}\right) \leq 9$$

$N_p$ = non dimensional ultimate clay resistance coefficient

$S_u$ = undrained shear strength from DMT

$\sigma'_{v0}$ = effective vertical stress at depth Z

J = empirical coefficient; 0.5 for soft clay, 0.25 for stiff clay

Z = depth

d = pile diameter

## Reference pile deflection ( $y_{50}$)

$$y_{50} = \frac{23.67 k S_u (D^{0.5})}{F_c E_D}$$

$F_c$ = 10 (empirical stiffness factor)

$E_D$ = dilatometer modulus

$S_u$ = undrained shear strength from DMT

$k$ reduction factor to capture the effects of pile installation

$$k = \begin{cases} 1, \ OCR \leq 1 \\ \frac{4}{3} - \frac{OCR}{3}, 1 \leq OCR \leq 2 \\ \frac{2}{3}, OCR > 2 \end{cases}$$

# LLP Livorno case history with Robertson 1989 method

- DMT data exported from SDMT Pro (Z, $\sigma'_{v0}$, $E_D$, Su, OCR)
- Evaluate all other parameters (k, Np, Pult, Y50)

| | |
|---|---|
| Pile Length [m] | 18 |
| d [m] | 0.5 |
| Fc | 10 |

| Z | σ'v0 | $E_D$ | Su | OCR | k | Np | $P_{ult}$ | Y50 |
|---|---|---|---|---|---|---|---|---|
| [m] | [kPa] | [MPa] | [kPa] | [] | [] | [] | [kN/m] | [m] |
| 0.8 | 14 | 6.2 | 38 | 2.40 | 0.67 | 4.17 | 52.80 | 0.00684 |
| 1 | 17 | 5.6 | 37 | 2.10 | 0.67 | 4.46 | 55.28 | 0.00741 |
| 1.2 | 20 | 5.3 | 37 | 1.90 | 0.70 | 4.74 | 61.39 | 0.00818 |
| 1.4 | 24 | 5.5 | 33 | 1.70 | 0.77 | 5.13 | 64.86 | 0.00770 |
| 1.6 | 27 | 4.0 | 29 | 1.50 | 0.83 | 5.53 | 66.83 | 0.01011 |
| 1.8 | 30 | 2.4 | 28 | 1.50 | 0.83 | 5.87 | 68.50 | 0.01627 |
| 2 | 33 | 3.4 | 34 | 1.50 | 0.83 | 5.97 | 84.58 | 0.01395 |
| 2.2 | 37 | 3.7 | 44 | 1.60 | 0.80 | 6.04 | 106.32 | 0.01592 |
| 2.4 | 40 | 6.0 | 49 | 1.60 | 0.80 | 6.22 | 121.84 | 0.01093 |
| 2.6 | 43 | 5.1 | 35 | 1.30 | 0.90 | 6.83 | 107.55 | 0.01034 |
| 2.8 | 47 | 3.1 | 32 | 1.20 | 0.93 | 7.27 | 108.55 | 0.01613 |
| 3 | 50 | 3.0 | 29 | 1.00 | 1.00 | 7.72 | 112.00 | 0.01618 |
| 3.2 | 53 | 2.8 | 25 | 0.93 | 1.00 | 8.32 | 104.00 | 0.01494 |
| 3.4 | 56 | 1.7 | 22 | 0.82 | 1.00 | 8.95 | 98.40 | 0.02166 |
| 3.6 | 59 | 1.5 | 21 | 0.77 | 1.00 | 9.00 | 94.50 | 0.02343 |
| 3.8 | 62 | 0.9 | 22 | 0.76 | 1.00 | 9.00 | 99.00 | 0.04091 |
| 4 | 65 | 0.6 | 21 | 0.73 | 1.00 | 9.00 | 94.50 | 0.05858 |
| 4.2 | 66 | 1.1 | 20 | 0.69 | 1.00 | 9.00 | 90.00 | 0.03043 |
| 4.4 | 67 | 0.8 | 21 | 0.70 | 1.00 | 9.00 | 94.50 | 0.04394 |
| 4.6 | 68 | 0.8 | 21 | 0.70 | 1.00 | 9.00 | 94.50 | 0.04394 |
| 4.8 | 69 | 1.3 | 20 | 0.68 | 1.00 | 9.00 | 90.00 | 0.02575 |
| 5 | 70 | 1.1 | 21 | 0.68 | 1.00 | 9.00 | 94.50 | 0.03195 |

# LLP Livorno case history with Robertson 1989 method

## Evaluate P-Y values: calculation every 1 m depth and selection of Y/Y50 as in the table below

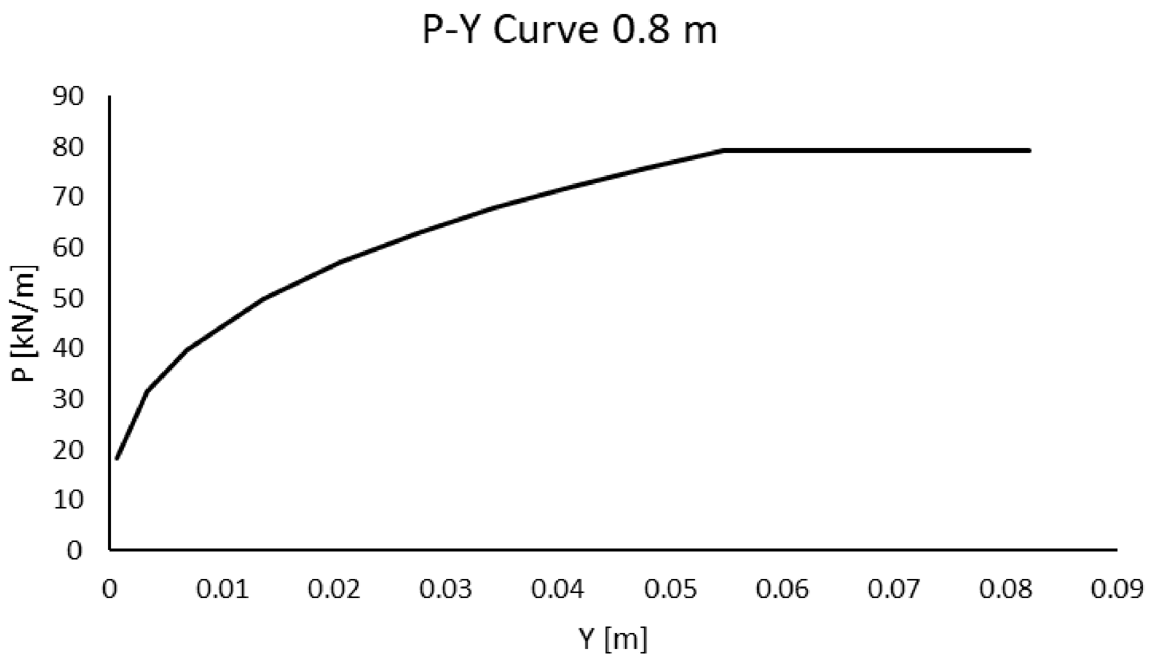
**P-Y Graph**

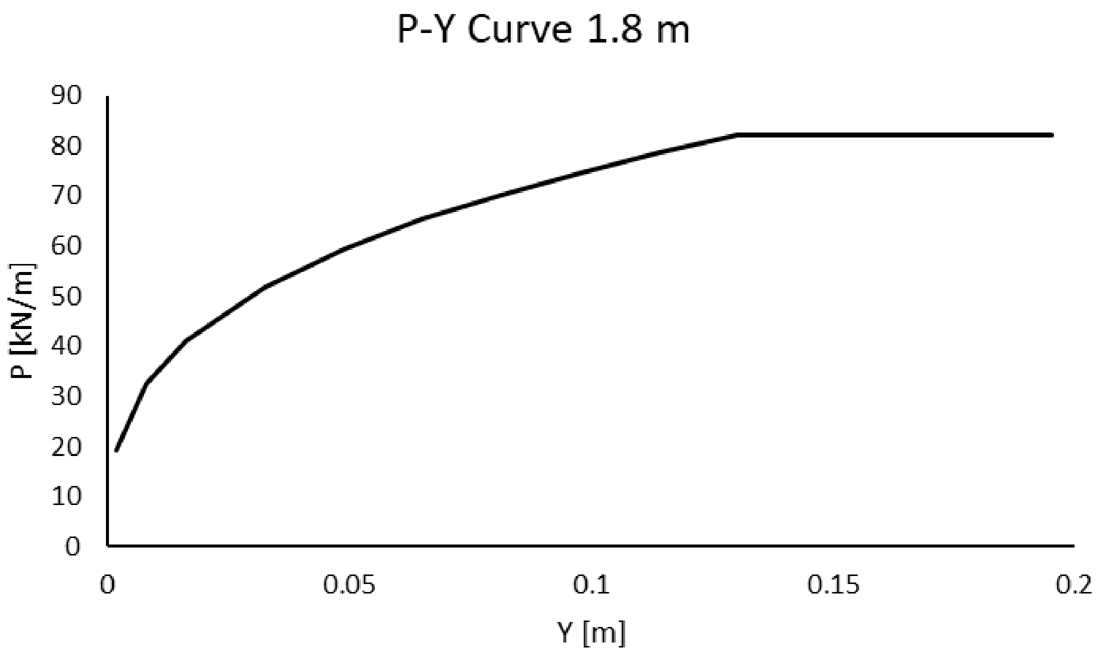
| Depth [m] | Y/Y50 | y [m] | P/Pu | P [kN/m] |
|---|---|---|---|---|
| 0.8 | 0.1 | 0.00068 | 0.23 | 18.38 |
| | 0.5 | 0.00342 | 0.40 | 31.43 |
| | 1 | 0.00684 | 0.50 | 39.60 |
| | 2 | 0.01368 | 0.63 | 49.89 |
| | 3 | 0.02052 | 0.72 | 57.11 |
| | 4 | 0.02736 | 0.79 | 62.86 |
| | 5 | 0.03419 | 0.85 | 67.72 |
| | 6 | 0.04103 | 0.91 | 71.96 |
| | 7 | 0.04787 | 0.96 | 75.75 |
| | 8 | 0.05471 | 1 | 79.20 |
| | 9 | 0.06155 | 1 | 79.20 |
| | 10 | 0.06839 | 1 | 79.20 |
| | 11 | 0.07523 | 1 | 79.20 |
| | 12 | 0.08207 | 1 | 79.20 |

| Depth [m] | Y/Y50 | y [m] | P/Pu | P [kN/m] |
|---|---|---|---|---|
| 1.8 | 0.1 | 0.00163 | 0.23 | 19.08 |
| | 0.5 | 0.00814 | 0.40 | 32.62 |
| | 1 | 0.01627 | 0.50 | 41.10 |
| | 2 | 0.03254 | 0.63 | 51.78 |
| | 3 | 0.04882 | 0.72 | 59.28 |
| | 4 | 0.06509 | 0.79 | 65.24 |
| | 5 | 0.08136 | 0.85 | 70.28 |
| | 6 | 0.09763 | 0.91 | 74.68 |
| | 7 | 0.11391 | 0.96 | 78.62 |
| | 8 | 0.13018 | 1 | 82.20 |
| | 9 | 0.14645 | 1 | 82.20 |
| | 10 | 0.16272 | 1 | 82.20 |
| | 11 | 0.179 | 1 | 82.20 |
| | 12 | 0.19527 | 1 | 82.20 |

# LLP Livorno case history with Robertson 1989 method

## Optional plots of P-Y curves every 1 m



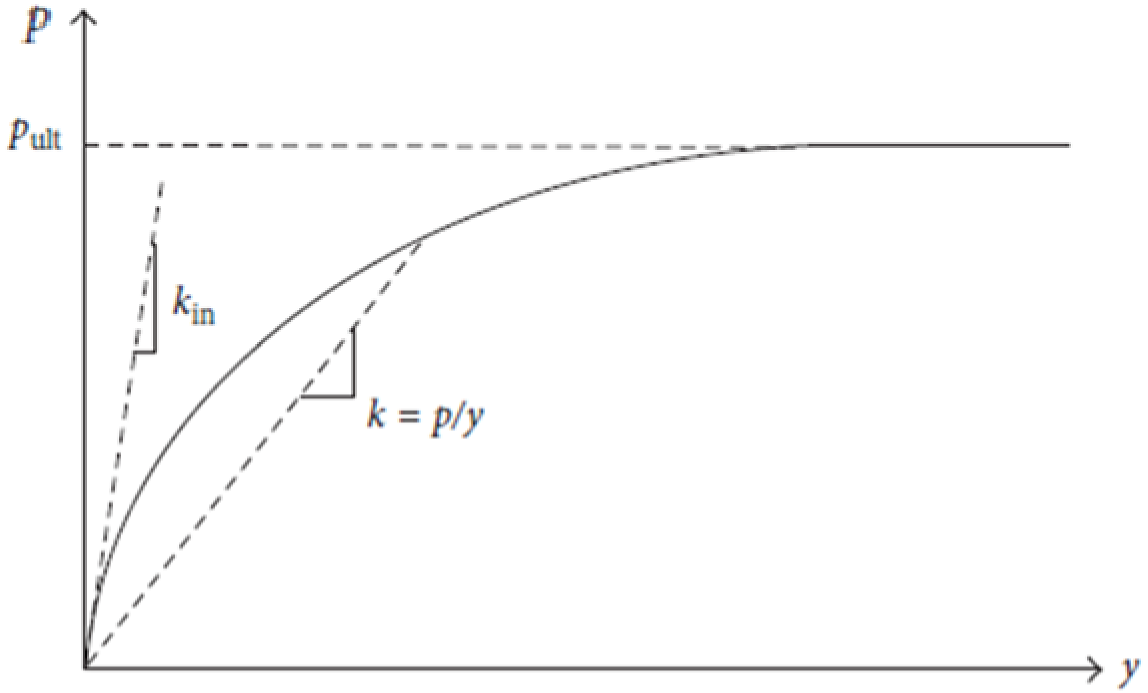



# Marchetti 1991 method for P-Y curves from DMT data

(for clay only)

# Marchetti 1991 method

This method **simplifies** previous methodologies and **improves** them by adopting tangent hyperbolic curve (Gabr and Borden 1988) and DMT compressibility parameter $E_D$ (Robertson 1989)




Parameters:

- p : soil reaction
- y : pile deflection
- $p_{ult}$ : ultimate soil resistance

# Marchetti 1991 method

$$\frac{\mathbf{P}}{\mathbf{P}_{\mathbf{ult}}} = \mathbf{tanh}\left(\frac{\boldsymbol{E}_{\boldsymbol{s1}}\,\boldsymbol{y}}{\mathbf{P}_{\mathbf{ult}}}\right)$$

Ultimate soil resistance ($P_{ult}$)

$\mathrm{P_{ult}} = \alpha\ \mathrm{K1}\ (\mathrm{P_0} - \mathrm{U_0})\ \mathrm{d}$

$\alpha = \text{reduction factor} = \frac{1}{3} + \frac{2}{3}\left(\frac{Z}{7d}\right) \leq 1$

$\mathrm{K1} = 1.24$

$\mathrm{Z} = \text{depth, d} = \text{pile diameter}$

$P_o = \text{Corrected DMT-A reading}$

$U_0 = \text{in-situ hydrostatic pressure}$

Initial Tangent Modulus ( $E_{s1}$)

$E_{s1} = \alpha\ K2\ E_D$

$E_{s1} = \text{initial tangent soil modulus,}$

$K2 = 10\left(\frac{d}{0.5}\right)^{0.5}$

$E_D = \text{dilatometer modulus}$

y significant for y/d ≤ 4%

# LLP Livorno case history with Marchetti 1991 method

- DMT data exported from SDMT Pro (Z, $P_0$, $U_0$, $E_D$)
- Evaluate or input all other parameters ($K_1$=1.24, $K_2$, α, Pu, $E_{s1}$)

| Pile Length [m] | 18 |
|---|---|
| d [m] | 0.5 |
| K1 | 1.24 |
| K2 | 10 |

| Z [m] | $P_0$ | $U_0$ | $E_D$ | α | $P_{ult}$ | $E_{s1}$ |
|---|---|---|---|---|---|---|
| [m] | [kPa] | [kPa] | [MPa] | [] | [kN/m] | [kPa] |
| 0.8 | 206 | 0 | 6.2 | 0.49 | 62.04 | 30114 |
| 1 | 211 | 0 | 5.6 | 0.52 | 68.52 | 29333 |
| 1.2 | 223 | 0 | 5.3 | 0.56 | 77.69 | 29781 |
| 1.4 | 207 | 0 | 5.5 | 0.60 | 77.00 | 33000 |
| 1.6 | 194 | 0 | 4.0 | 0.64 | 76.75 | 25524 |
| 1.8 | 192 | 0 | 2.4 | 0.68 | 80.49 | 16229 |
| 2 | 225 | 0 | 3.4 | 0.71 | 99.64 | 24286 |
| 2.2 | 285 | 0 | 3.7 | 0.75 | 132.95 | 27838 |
| 2.4 | 317 | 0 | 6.0 | 0.79 | 155.36 | 47429 |
| 2.6 | 243 | 0 | 5.1 | 0.83 | 124.83 | 42257 |
| 2.8 | 231 | 0 | 3.1 | 0.87 | 124.12 | 26867 |
| 3 | 216 | 0 | 3.0 | 0.90 | 121.17 | 27143 |
| 3.2 | 196 | 0 | 2.8 | 0.94 | 114.58 | 26400 |
| 3.4 | 178 | 0 | 1.7 | 0.98 | 108.26 | 16676 |
| 3.6 | 173 | 0 | 1.5 | 1.00 | 107.26 | 15000 |
| 3.8 | 179 | 0 | 0.9 | 1.00 | 110.98 | 9000 |
| 4 | 179 | 0 | 0.6 | 1.00 | 110.98 | 6000 |
| 4.2 | 173 | 2 | 1.1 | 1.00 | 106.02 | 11000 |
| 4.4 | 179 | 4 | 0.8 | 1.00 | 108.50 | 8000 |
| 4.6 | 184 | 6 | 0.8 | 1.00 | 110.36 | 8000 |
| 4.8 | 183 | 8 | 1.3 | 1.00 | 108.50 | 13000 |
| 5 | 188 | 10 | 1.1 | 1.00 | 110.36 | 11000 |

# LLP Livorno case history with Marchetti 1991 method

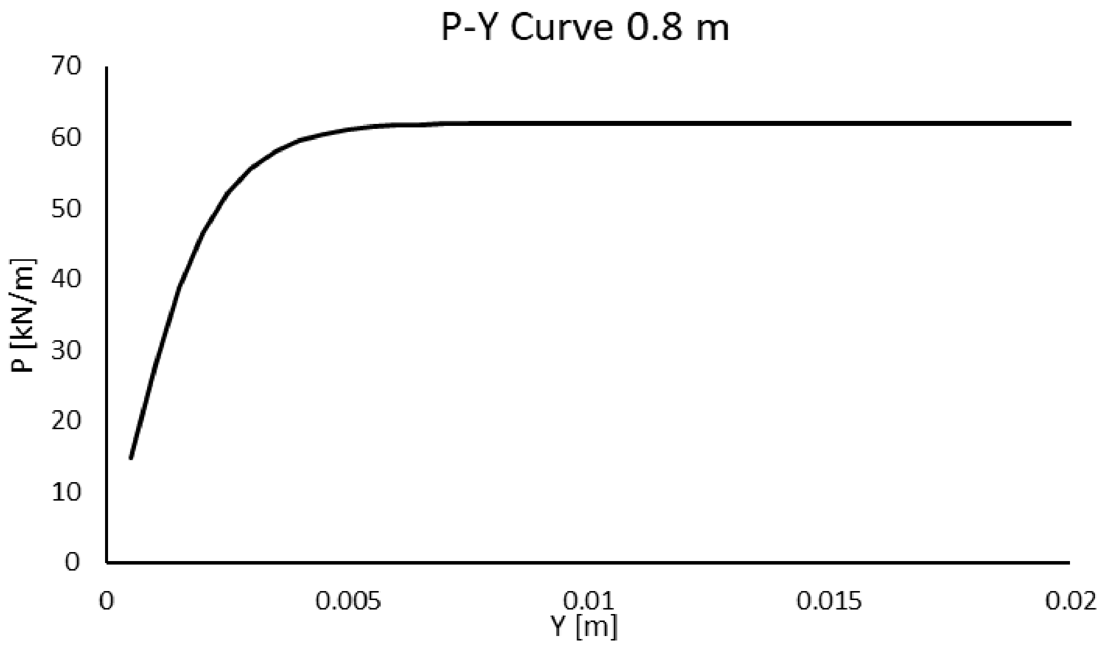
## Evaluate P-Y values: calculation every 1 m depth and selection of Y/D as in the table below

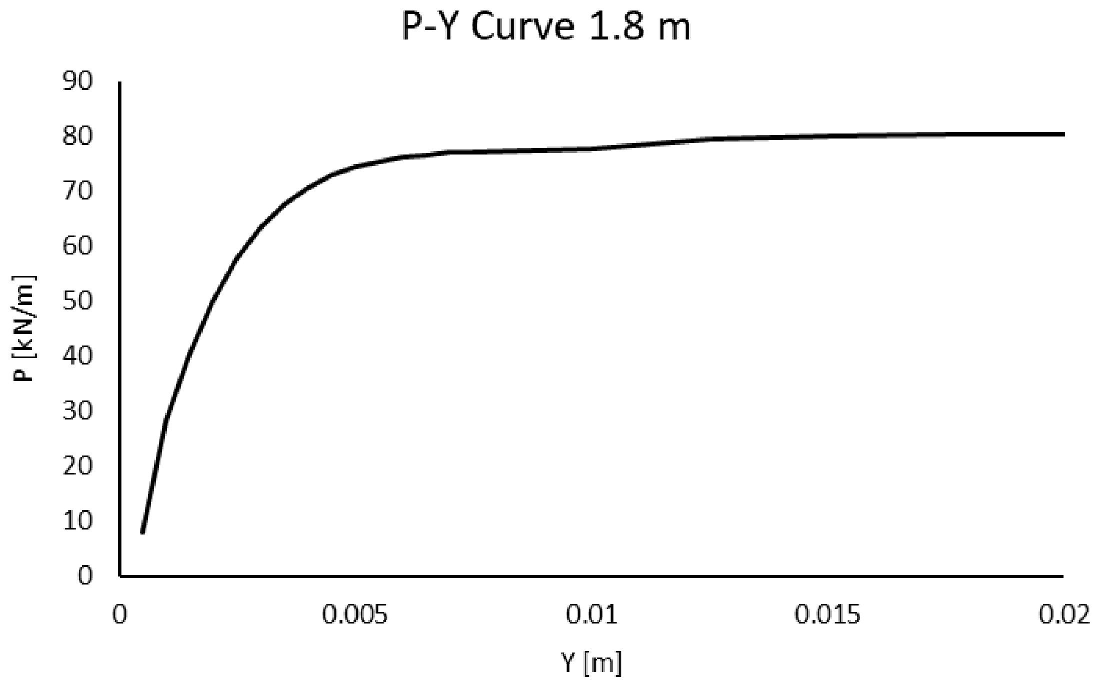
| P-Y Graph | | | |
|---|---|---|---|
| Depth [m] | Y/D [%] | y [m] | P [kN/m] |
| 0.8 | 0.1 | 0.0005 | 14.77 |
| | 0.2 | 0.001 | 27.95 |
| | 0.3 | 0.0015 | 38.58 |
| | 0.4 | 0.002 | 46.47 |
| | 0.5 | 0.0025 | 51.97 |
| | 0.6 | 0.003 | 55.64 |
| | 0.7 | 0.0035 | 58.02 |
| | 0.8 | 0.004 | 59.53 |
| | 0.9 | 0.0045 | 60.48 |
| | 1 | 0.005 | 61.08 |
| | 1.1 | 0.0055 | 61.44 |
| | 1.2 | 0.006 | 61.67 |
| | 1.3 | 0.0065 | 61.81 |
| | 1.4 | 0.007 | 61.90 |
| | 1.5 | 0.0075 | 61.95 |
| | 2 | 0.01 | 62.03 |
| | 2.5 | 0.0125 | 62.03 |
| | 3 | 0.015 | 62.04 |
| | 3.5 | 0.0175 | 62.04 |
| | 4 | 0.02 | 62.04 |

| Depth [m] | Y/D [%] | y [m] | P [kN/m] |
|---|---|---|---|
| 1.8 | 0.1 | 0.0005 | 8.09 |
| | 0.2 | 0.001 | 16.01 |
| | 0.3 | 0.0015 | 23.63 |
| | 0.4 | 0.002 | 30.81 |
| | 0.5 | 0.0025 | 37.45 |
| | 0.6 | 0.003 | 43.51 |
| | 0.7 | 0.0035 | 48.94 |
| | 0.8 | 0.004 | 53.74 |
| | 0.9 | 0.0045 | 57.94 |
| | 1 | 0.005 | 61.57 |
| | 1.1 | 0.0055 | 64.69 |
| | 1.2 | 0.006 | 67.34 |
| | 1.3 | 0.0065 | 69.58 |
| | 1.4 | 0.007 | 71.46 |
| | 1.5 | 0.0075 | 73.03 |
| | 2 | 0.01 | 77.69 |
| | 2.5 | 0.0125 | 79.46 |
| | 3 | 0.015 | 80.11 |
| | 3.5 | 0.0175 | 80.36 |
| | 4 | 0.02 | 80.4431 |

# LLP Livorno case history with Marchetti 1991 method

## Optional plots of P-Y curves every 1 m

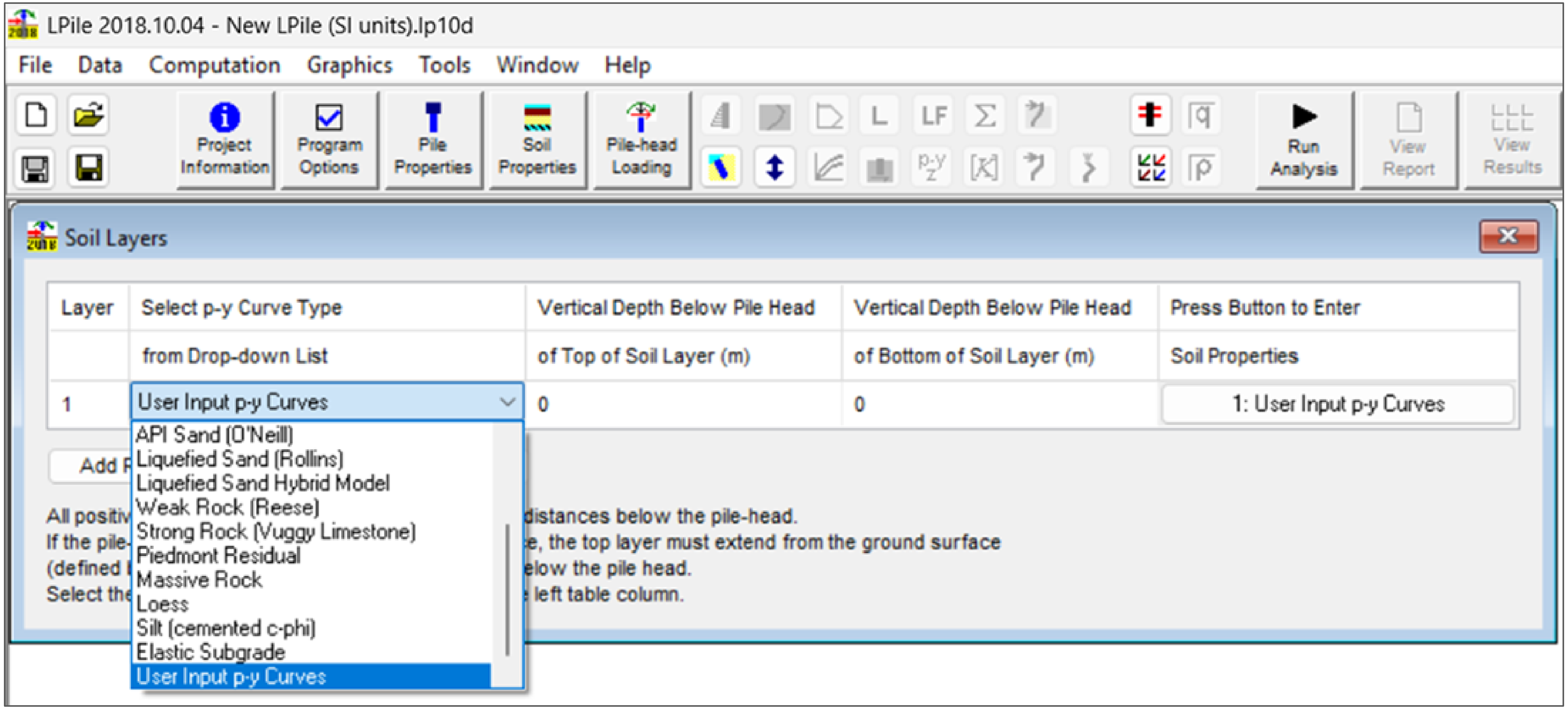


# Ensoft Lpi 2018 software for LLP - Input and Processing

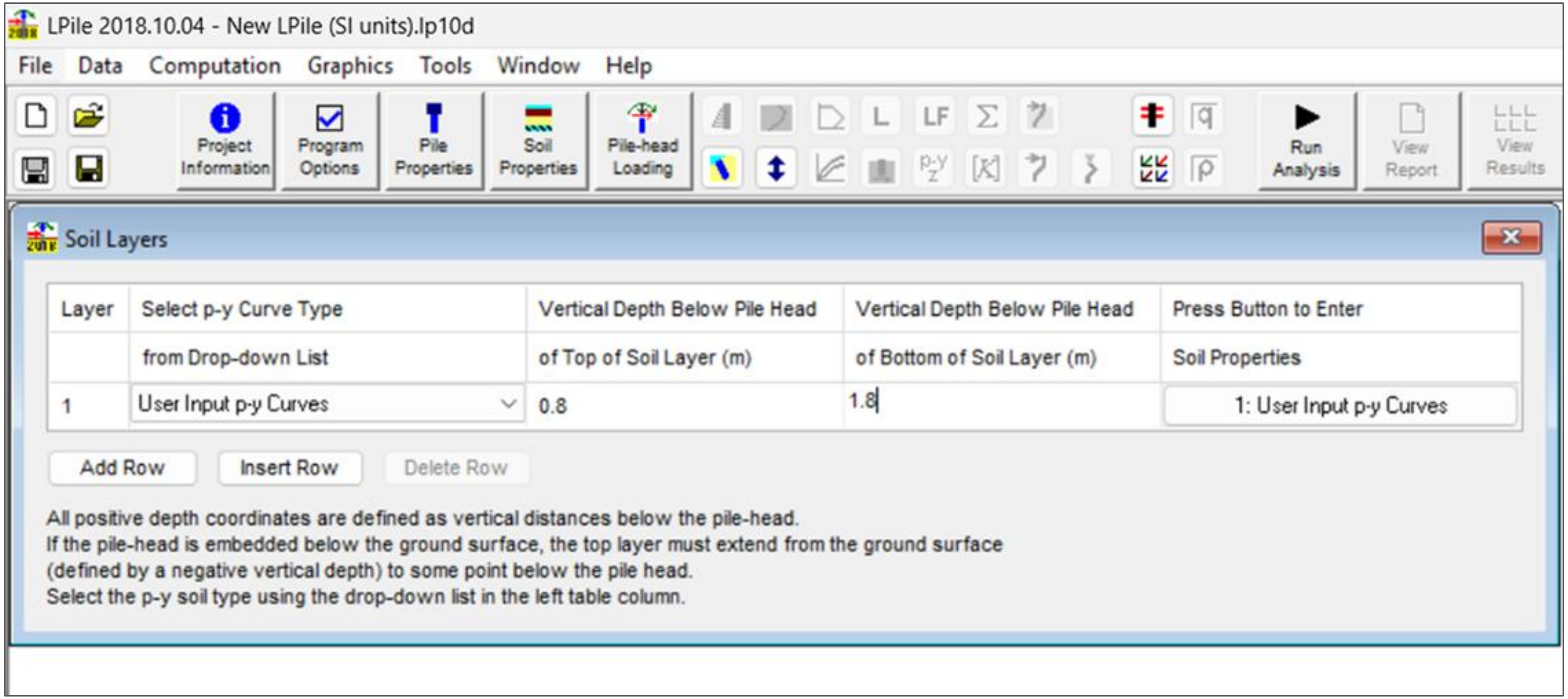
# Input P-Y curves in Ensoft Lpi 2018 software

**Step 1** Create the subsoil profile by using user input P-Y curves



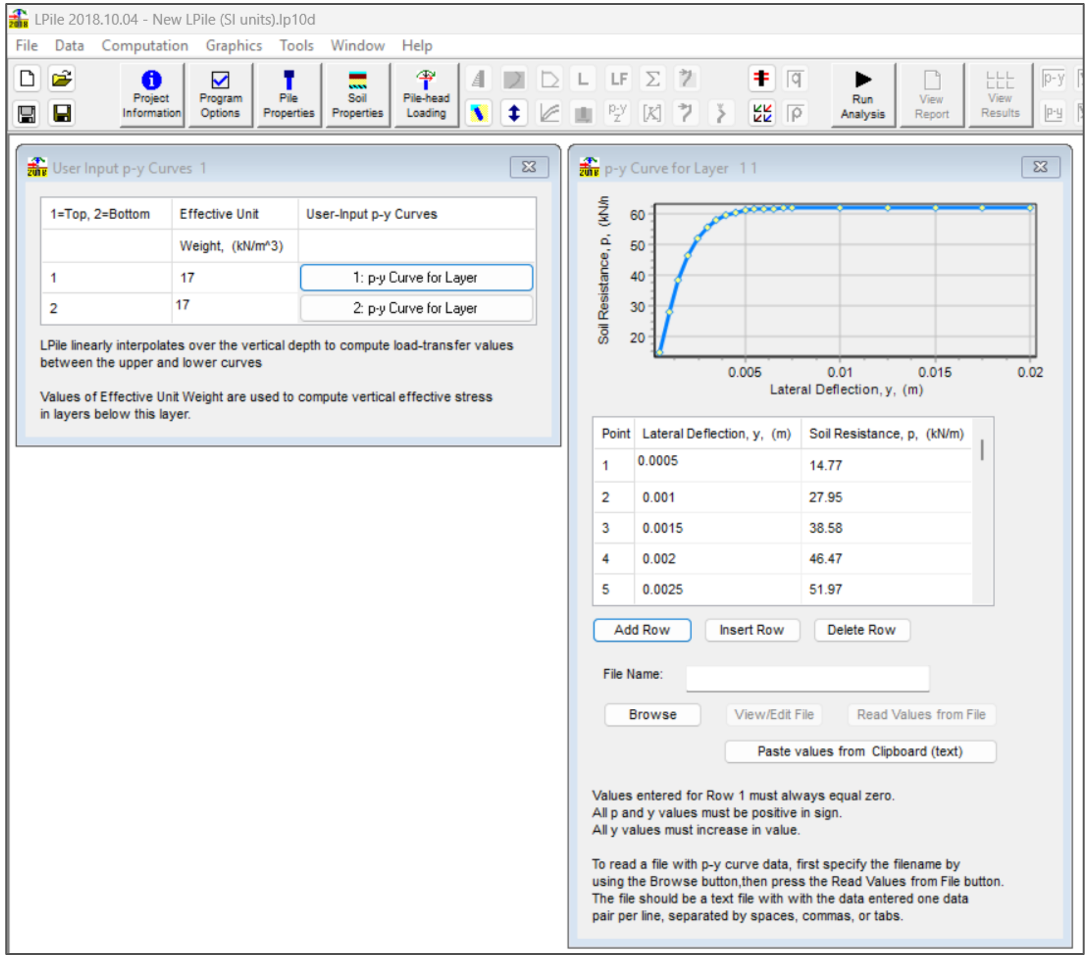
# Input P-Y curves in Ensoft Lpi 2018 software

**Step 2** Create layers starting from first test depth (generally 1.0 m interval – max 20 layers)



# Input P-Y curves in Ensoft Lpi 2018 software

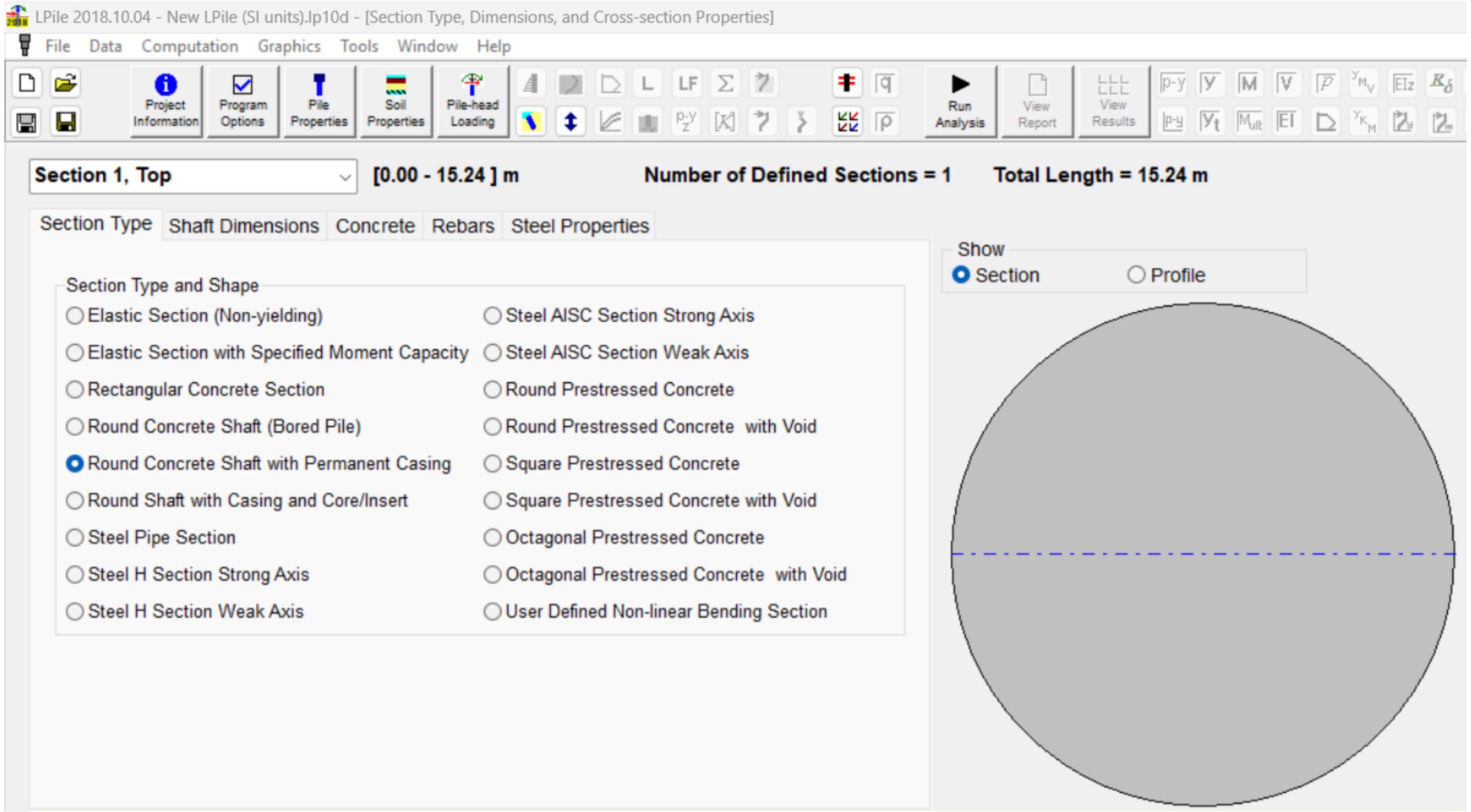
**Step 3** For each layer, input unit weight for top and bottom depth of layer and P-Y curves




| P-Y Graph | | | |
|---|---|---|---|
| **Depth [m]** | **Y/D [%]** | **y [m]** | **P [kN/m]** |
| 0.8 | 0.1 | 0.0005 | 14.77 |
| | 0.2 | 0.001 | 27.95 |
| | 0.3 | 0.0015 | 38.58 |
| | 0.4 | 0.002 | 46.47 |
| | 0.5 | 0.0025 | 51.97 |
| | 0.6 | 0.003 | 55.64 |
| | 0.7 | 0.0035 | 58.02 |
| | 0.8 | 0.004 | 59.53 |
| | 0.9 | 0.0045 | 60.48 |
| | 1 | 0.005 | 61.08 |
| | 1.1 | 0.0055 | 61.44 |
| | 1.2 | 0.006 | 61.67 |
| | 1.3 | 0.0065 | 61.81 |
| | 1.4 | 0.007 | 61.90 |
| | 1.5 | 0.0075 | 61.95 |
| | 2 | 0.01 | 62.03 |
| | 2.5 | 0.0125 | 62.03 |
| | 3 | 0.015 | 62.04 |
| | 3.5 | 0.0175 | 62.04 |
| | 4 | 0.02 | 62.04 |

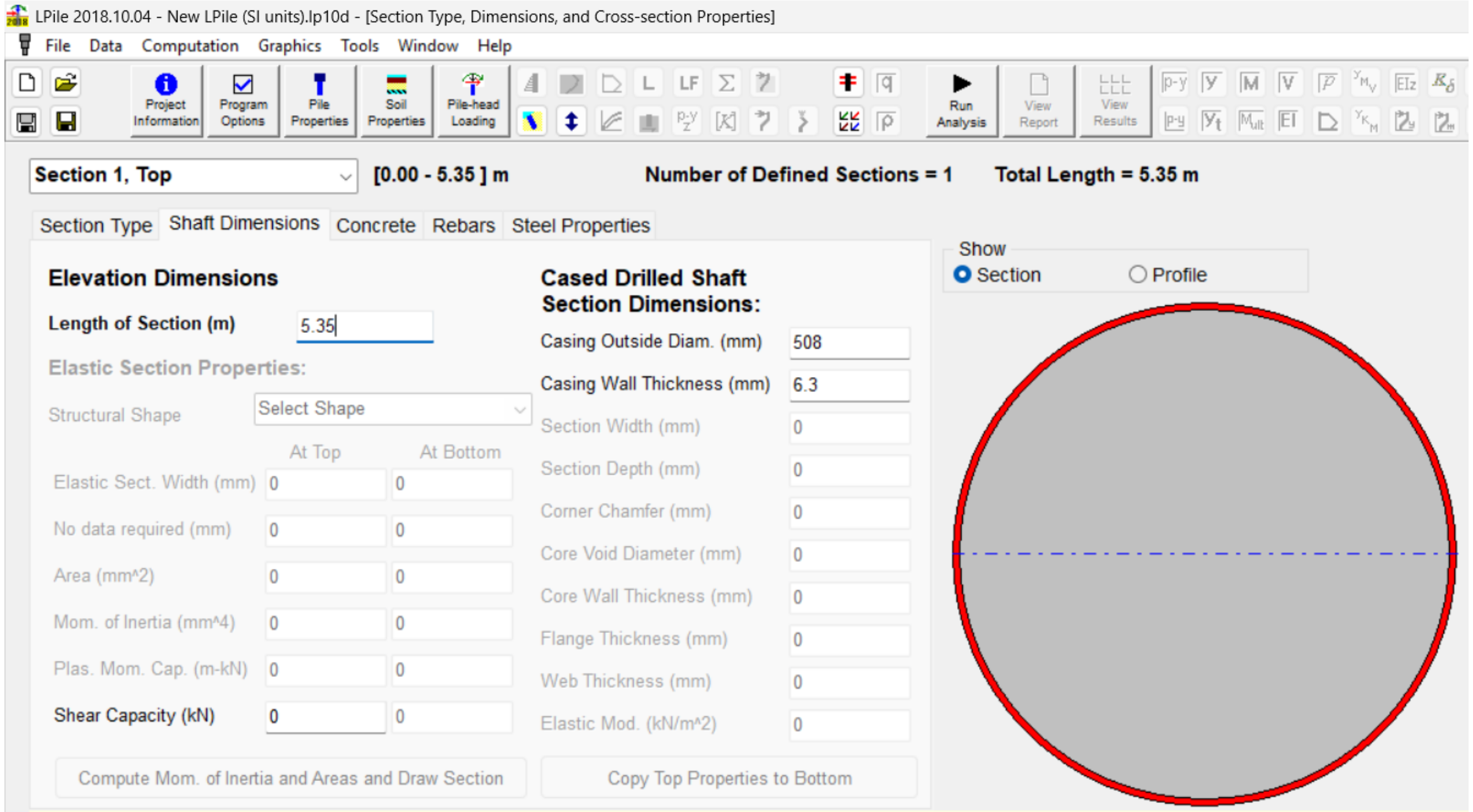
# Input Pile properties in Ensoft Lpi 2018 software

## Step 4 Choose pile type from the list



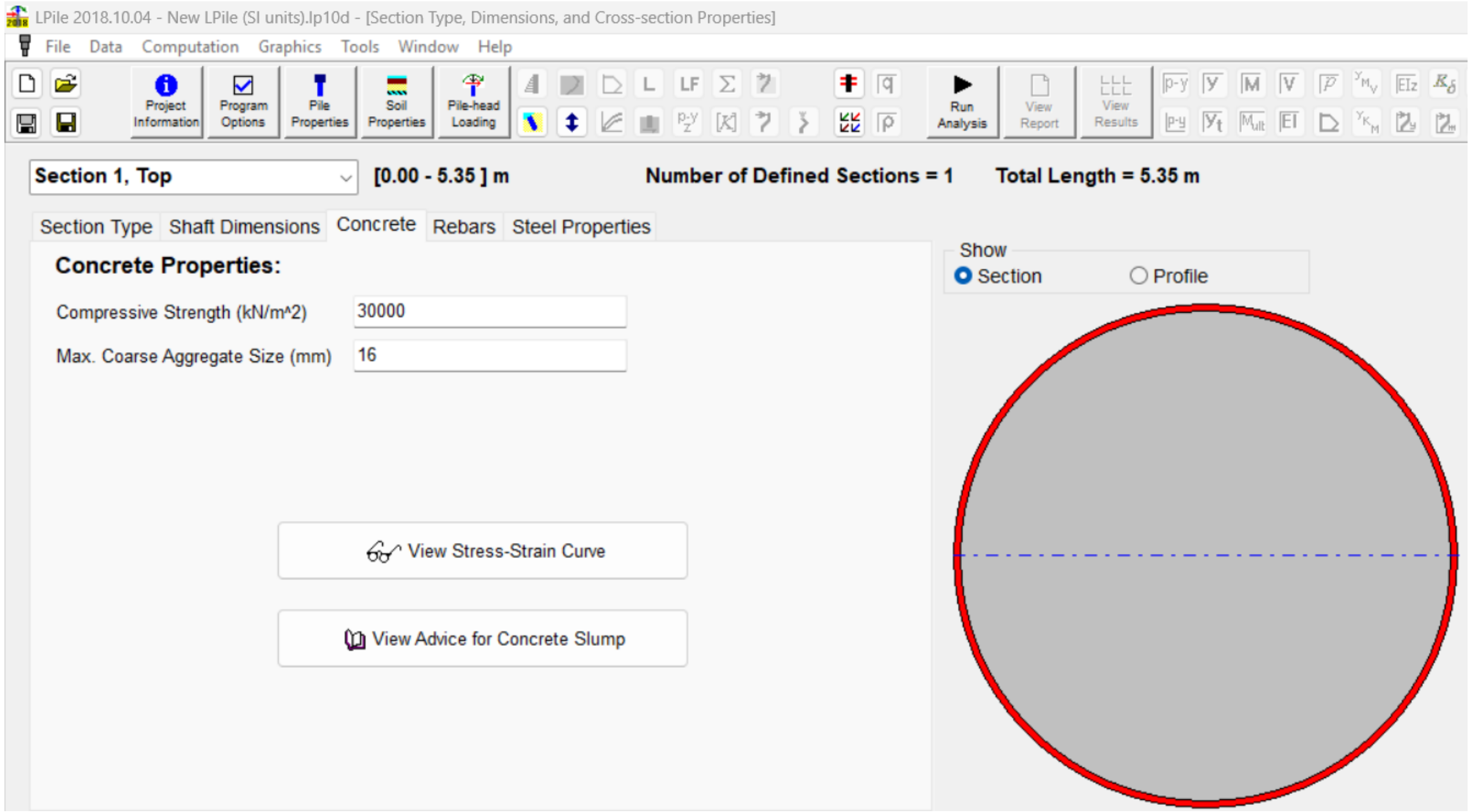
# Input Pile properties in Ensoft Lpi 2018 software

**Step 5** Input shaft dimensions



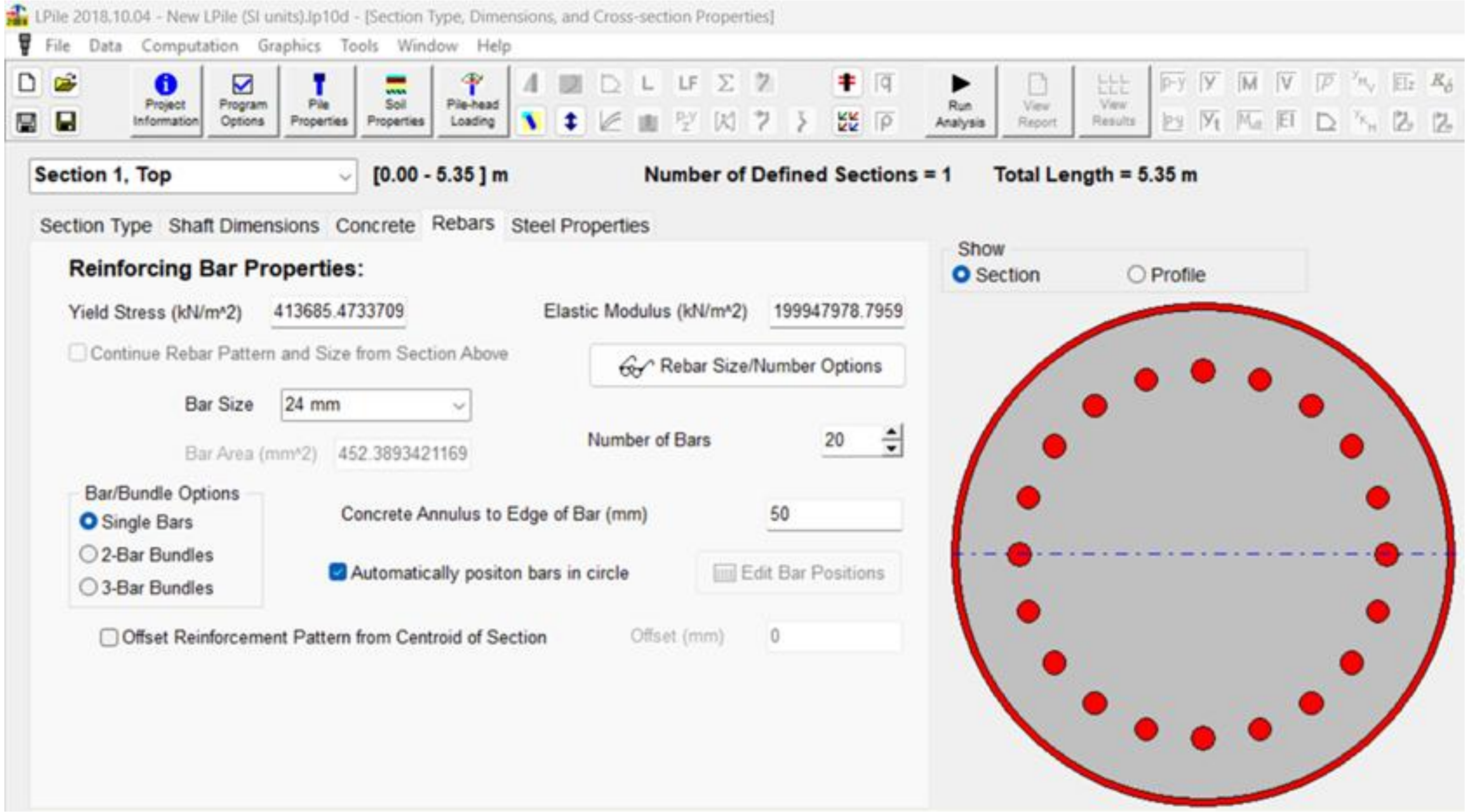
# Input Pile properties in Ensoft Lpi 2018 software

**Step 6** Input concrete properties, Max. coarse aggregate size of the employed concrete



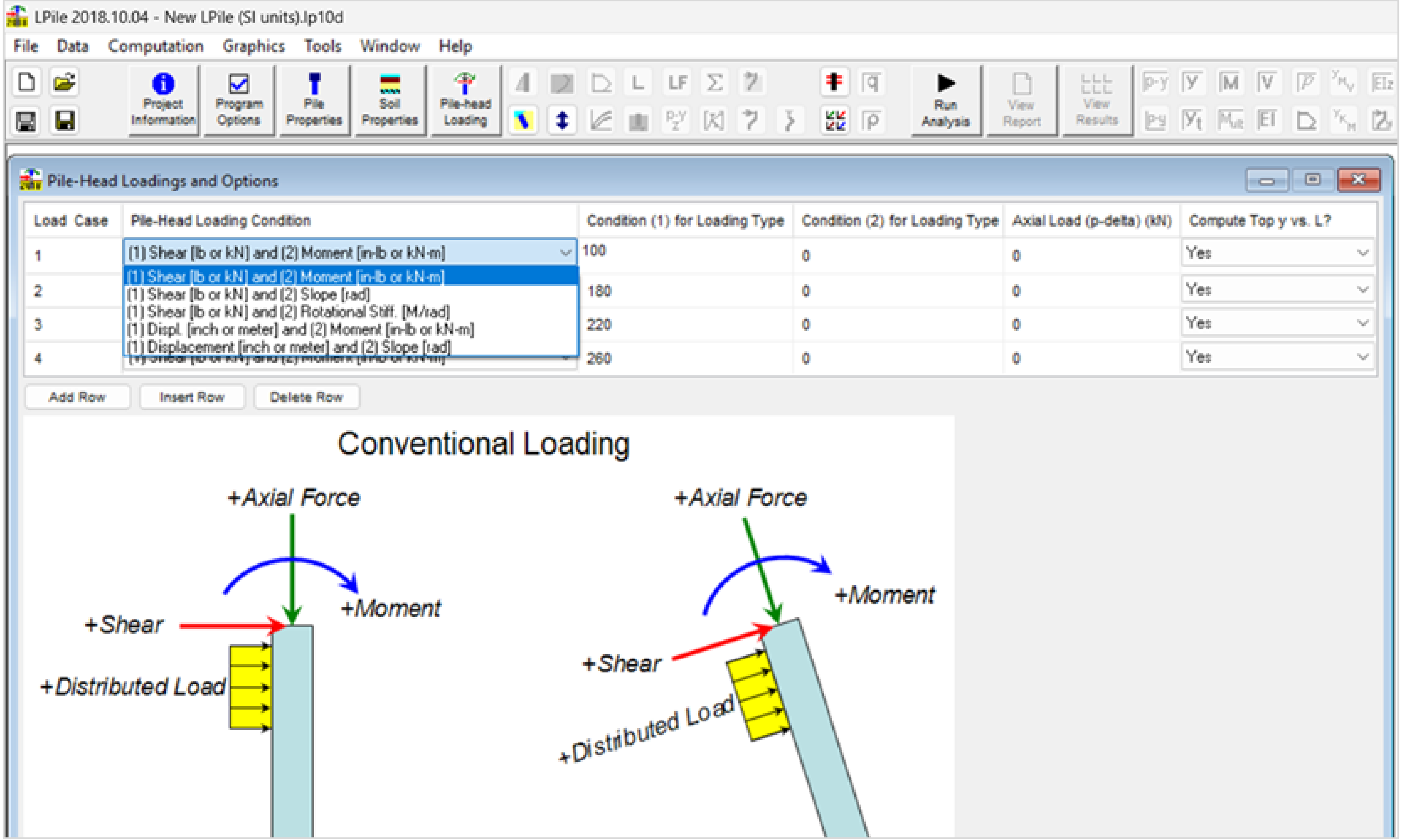
# Input Pile properties in Ensoft Lpi 2018 software

## Step 7 Input reinforcing bar properties



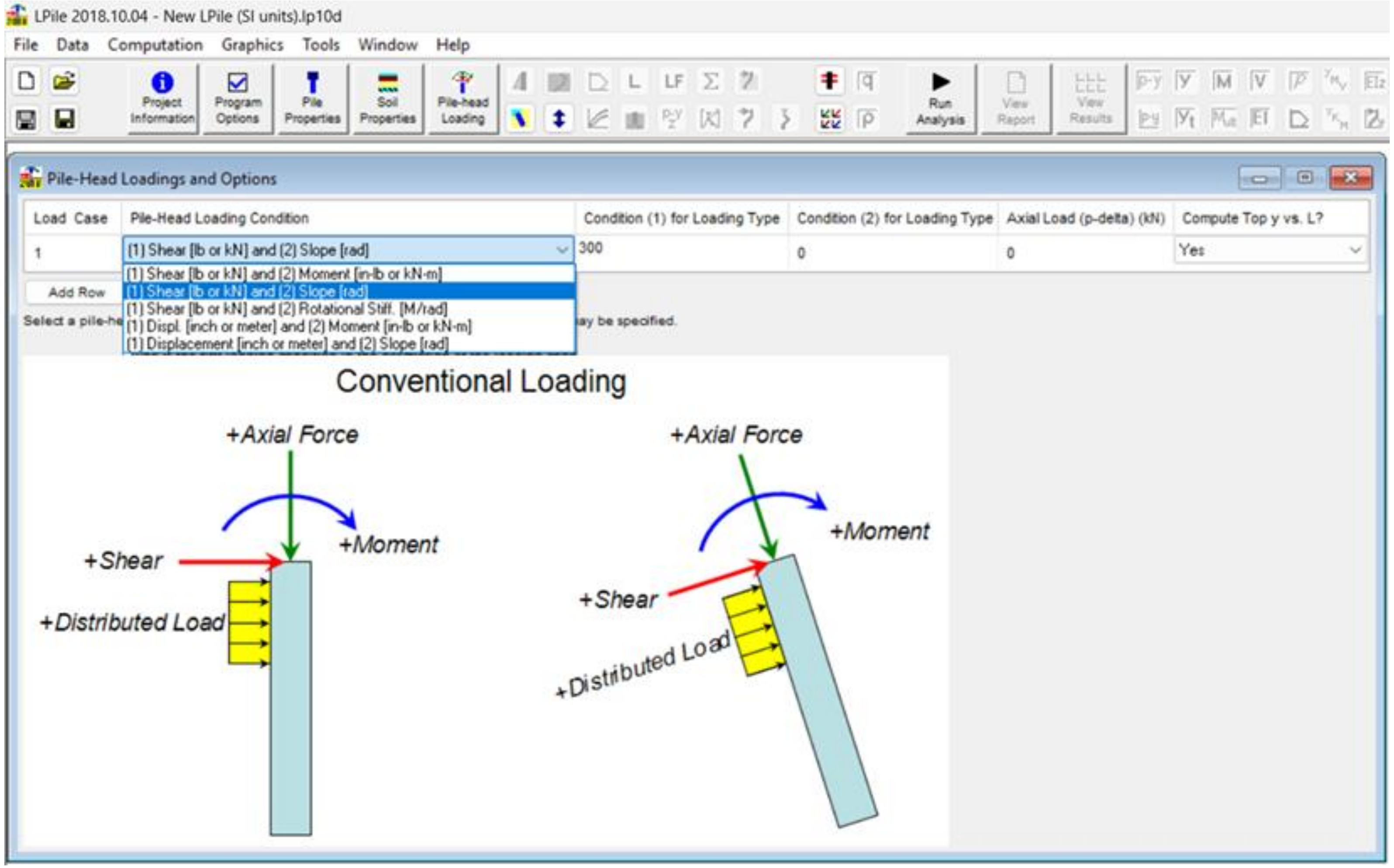
# Input Pile properties in Ensoft Lpi 2018 software

**Step 8a** In section 'Pile Head Loading', select condition 1 for free head and input loads



# Input Pile properties in Ensoft Lpi 2018 software

**Step 8b** In section ‘Pile Head Loading’, select condition 2 for fixed head and input loads

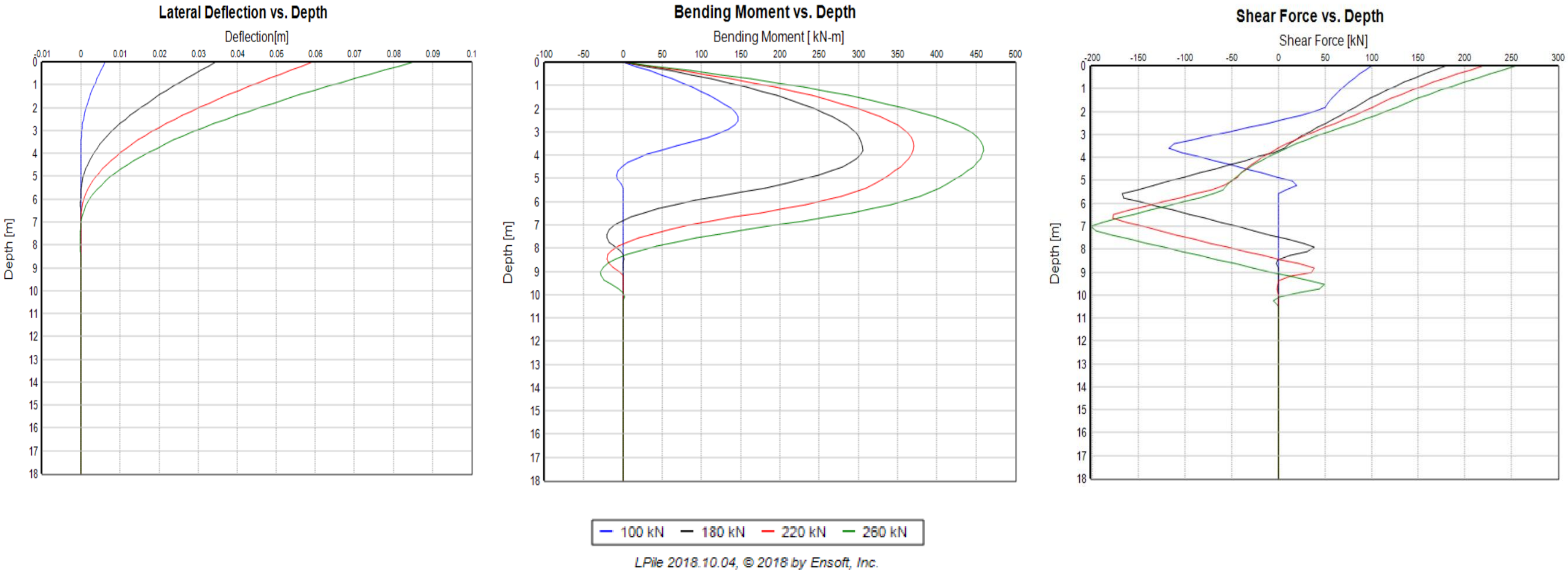


# Details of LLP case history in Livorno (CH clay)

- Pile diameter = 0.5 m
- Pile length = 18 m
- Two different pile conditions:
  - Free head loading (kN): 100, 180, 220, 260
  - Fixed head loading (kN): 50, 100, 140, 180, 220, 260, 300
- Pile casing: OD = 508 mm, ID = 495.4 mm
- Compressive strength of concrete = 30 MPa
- Reinforcement steel:
  - 20 bars Φ 24 mm up to depth 5.35 m
  - 8 bars Φ 24 mm from depth 5.35 m to 18 m

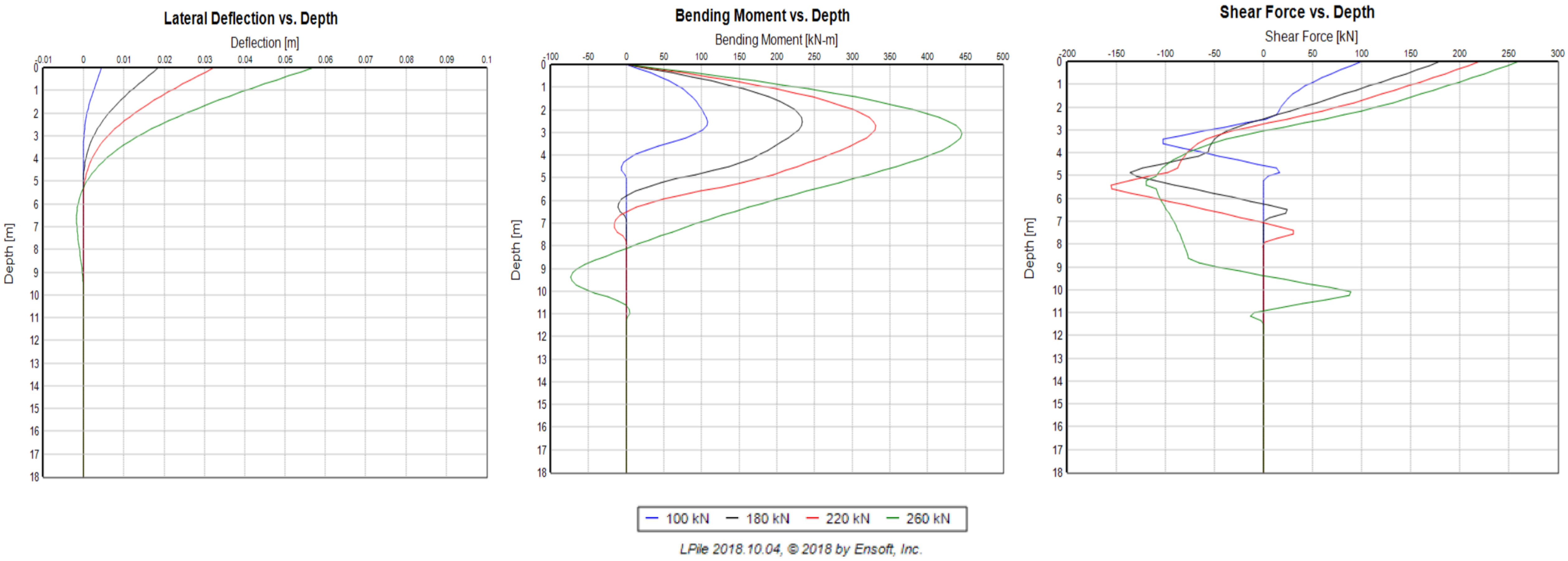
# LLP analysis output P-Y curves Robertson 1989

## **LLP Livorno case history** free head condition



# LLP analysis output P-Y curves Marchetti 1991

## **LLP Livorno case history** free head condition



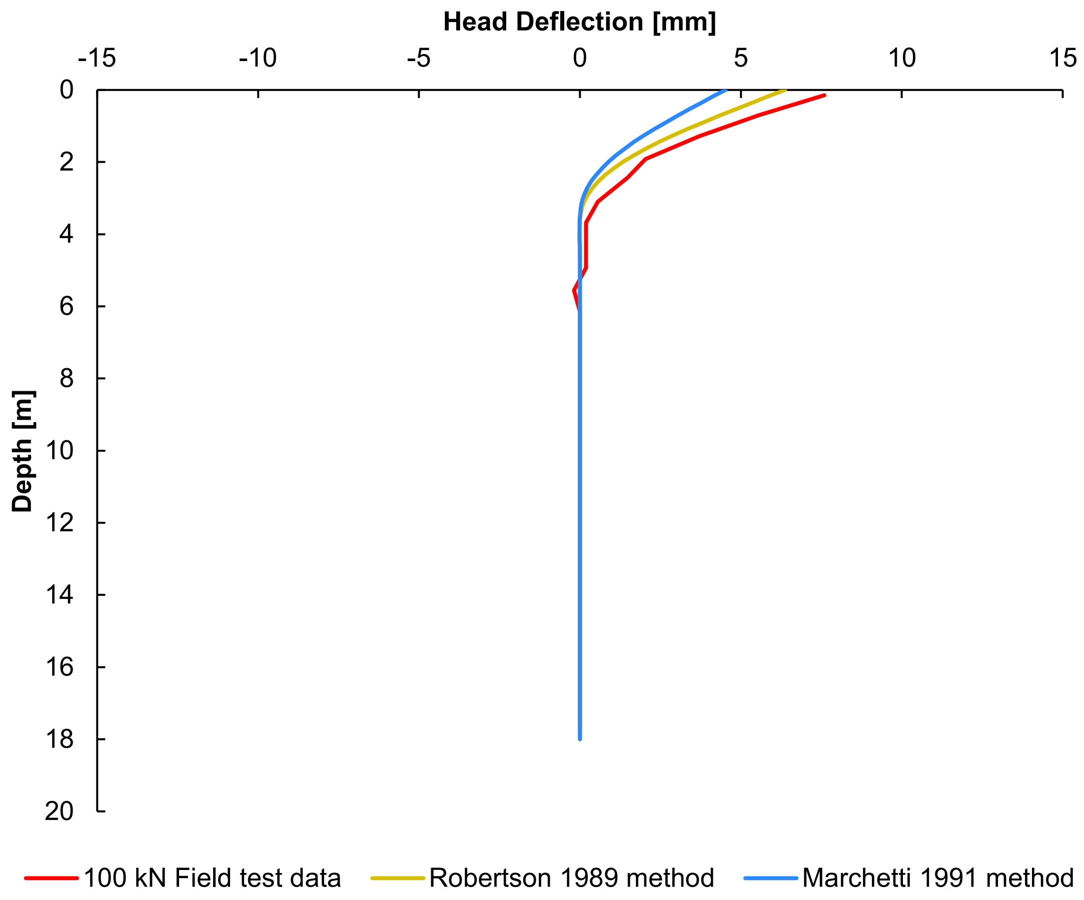
# LLP Livorno case history: validation of Robertson 1989, Marchetti 1991 compared with field test measurements

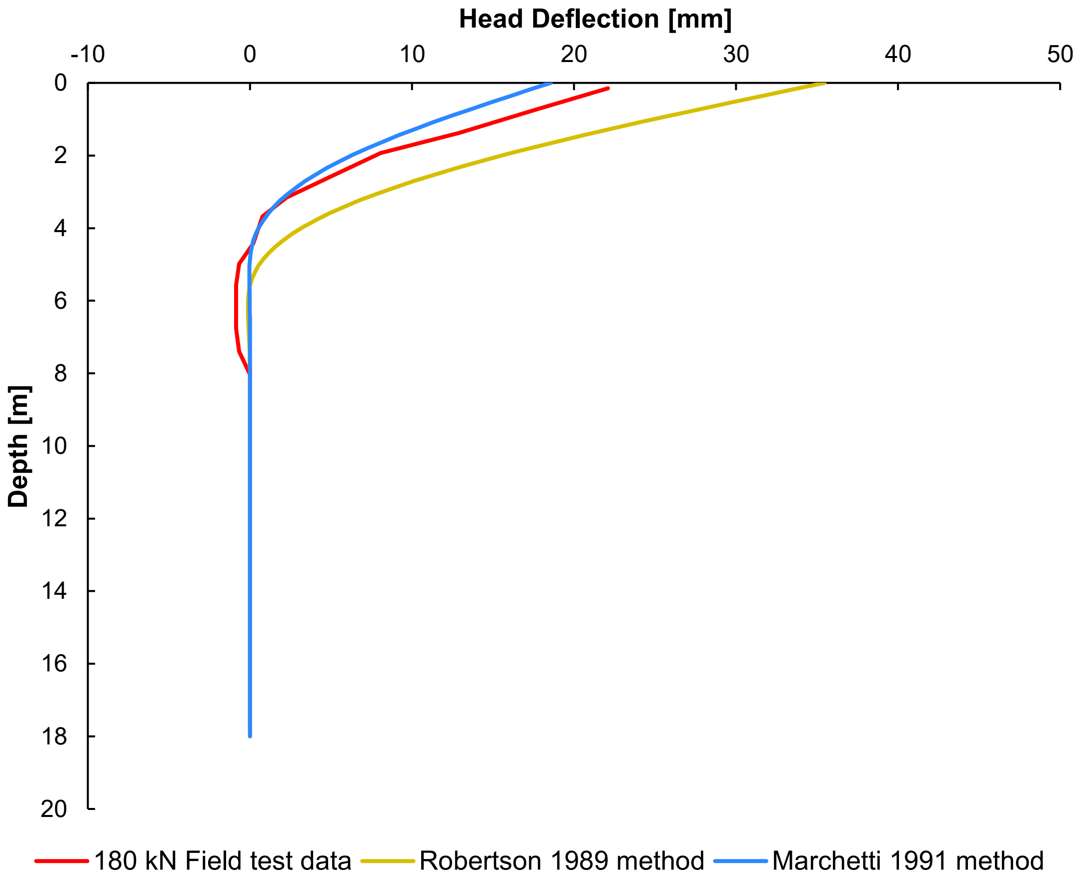
# Free Head Pile Robertson 1989 - Marchetti 1991 - measured

100 kN horizontal load

LLP tests Livorno

180 kN horizontal load



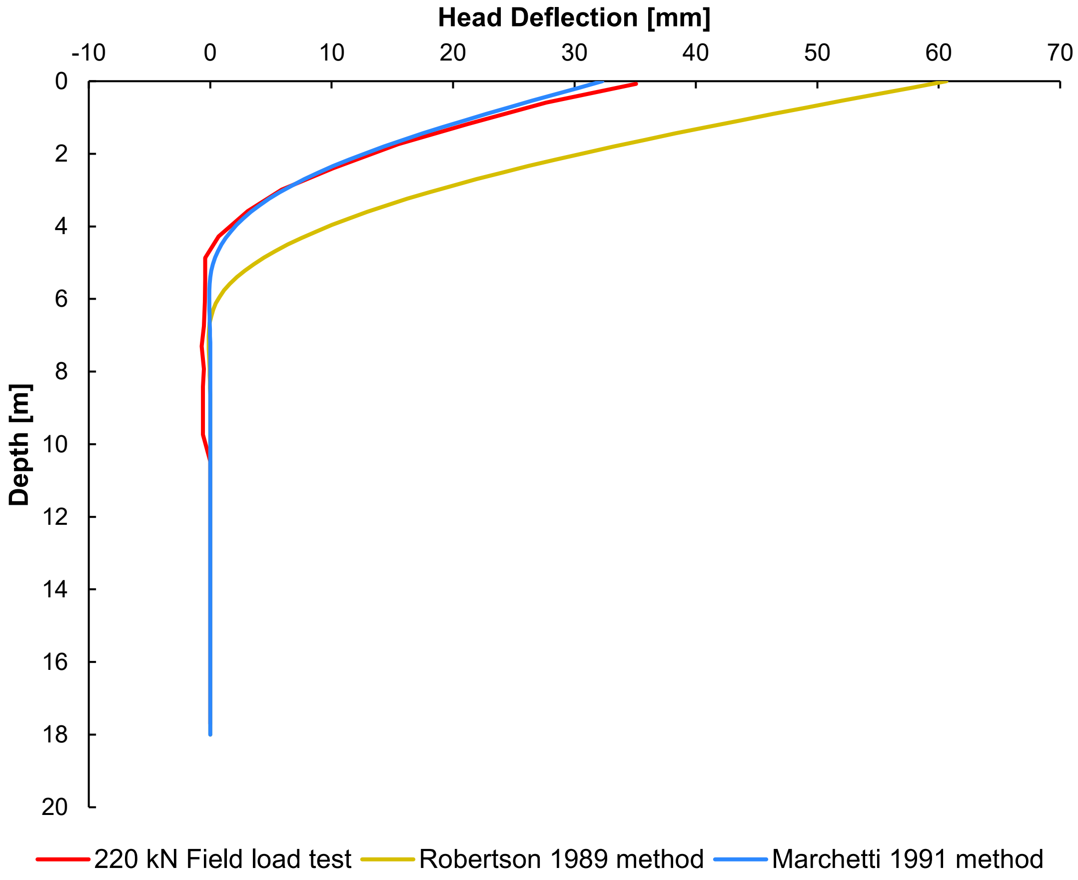



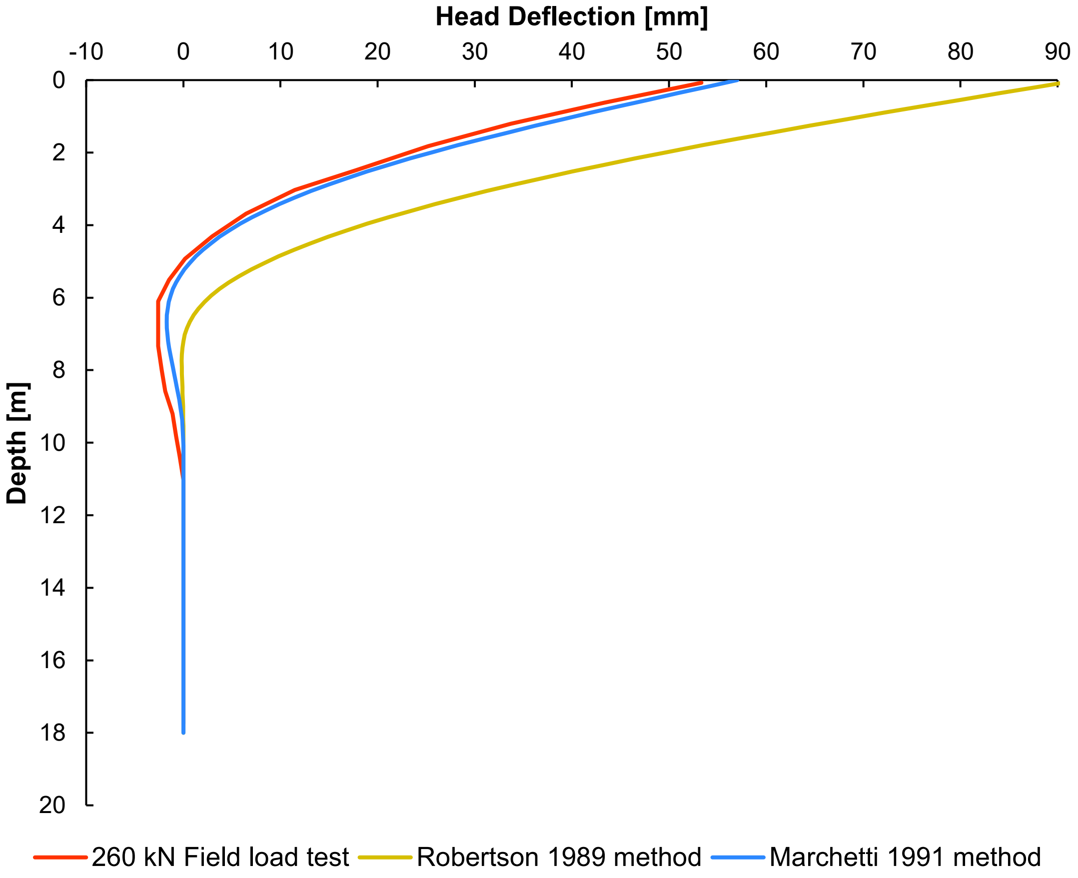
# Free Head Pile Robertson 1989 - Marchetti 1991 - measured

220 kN horizontal load

LLP tests Livorno

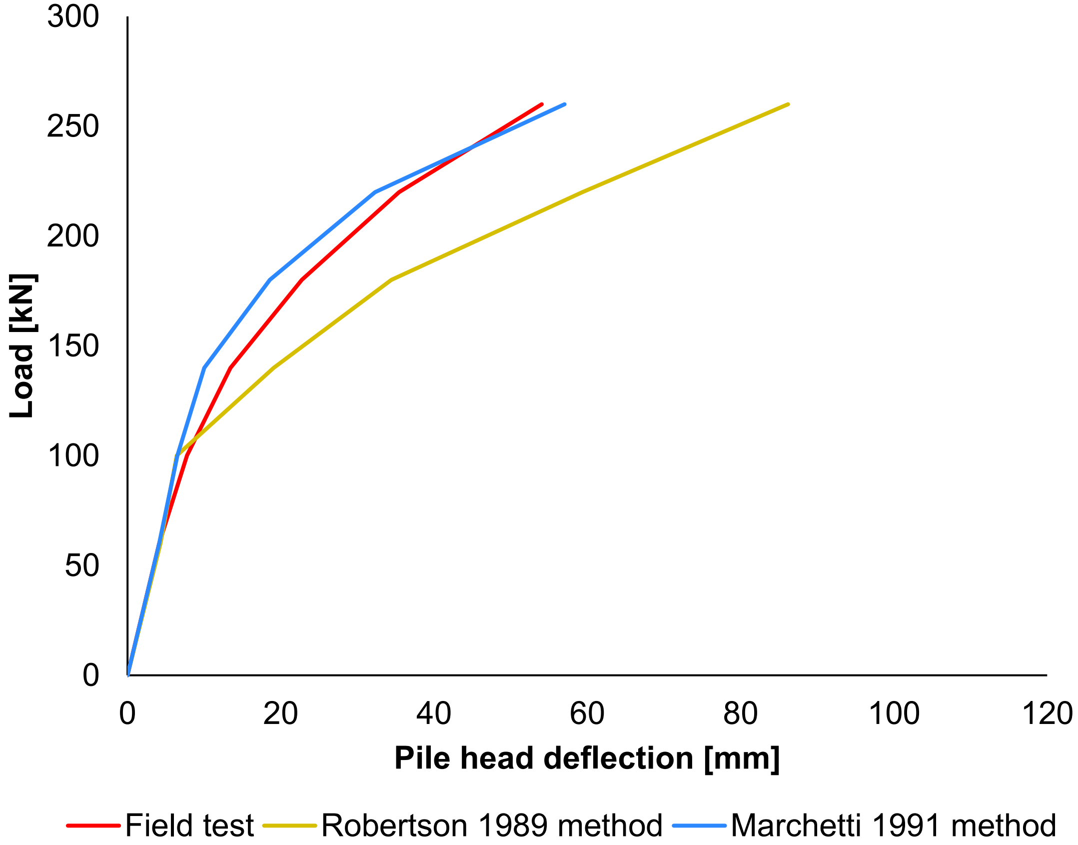
260 kN horizontal load



# Free Head Pile Robertson 1989 - Marchetti 1991 - measured

## LLP tests Livorno

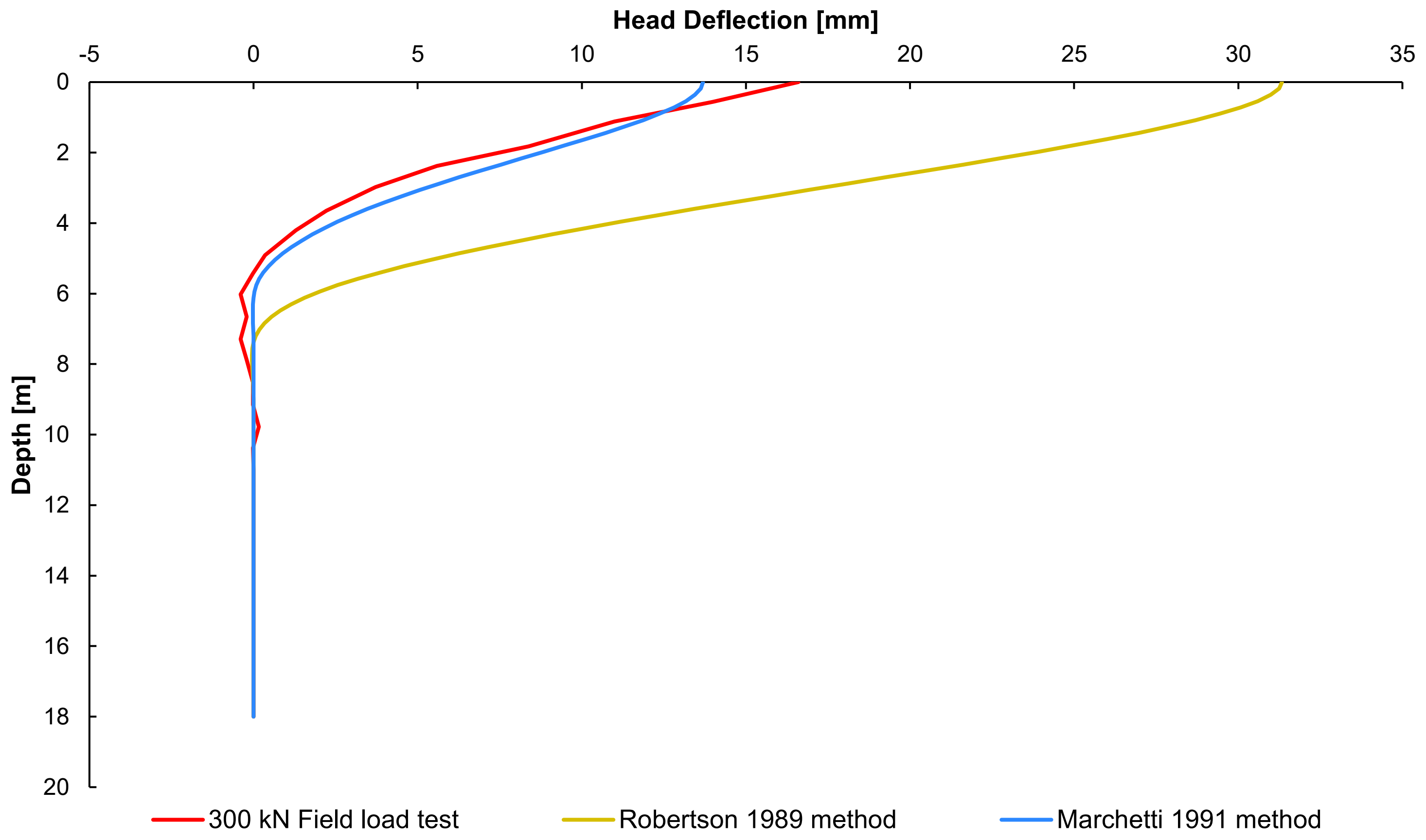



| Applied Load | Field measure | Robertson (1989) | Error Robertson | Marchetti (1991) | Error Marchetti |
|---|---|---|---|---|---|
| [kN] | [mm] | [mm] | [%] | [mm] | [%] |
| 0 | 0 | 0 | **0** | 0 | **0** |
| 60 | 4 | 4 | **0** | 4 | **0** |
| 100 | 8 | 6 | **-25** | 7 | **-13** |
| 140 | 13 | 19 | **46** | 10 | **-23** |
| 180 | 23 | 34 | **48** | 19 | **-17** |
| 220 | 35 | 59 | **41** | 32 | **-9** |
| 260 | 54 | 86 | **59** | 57 | **5** |

# Fixed Head Pile Robertson 1989 - Marchetti 1991 - measured

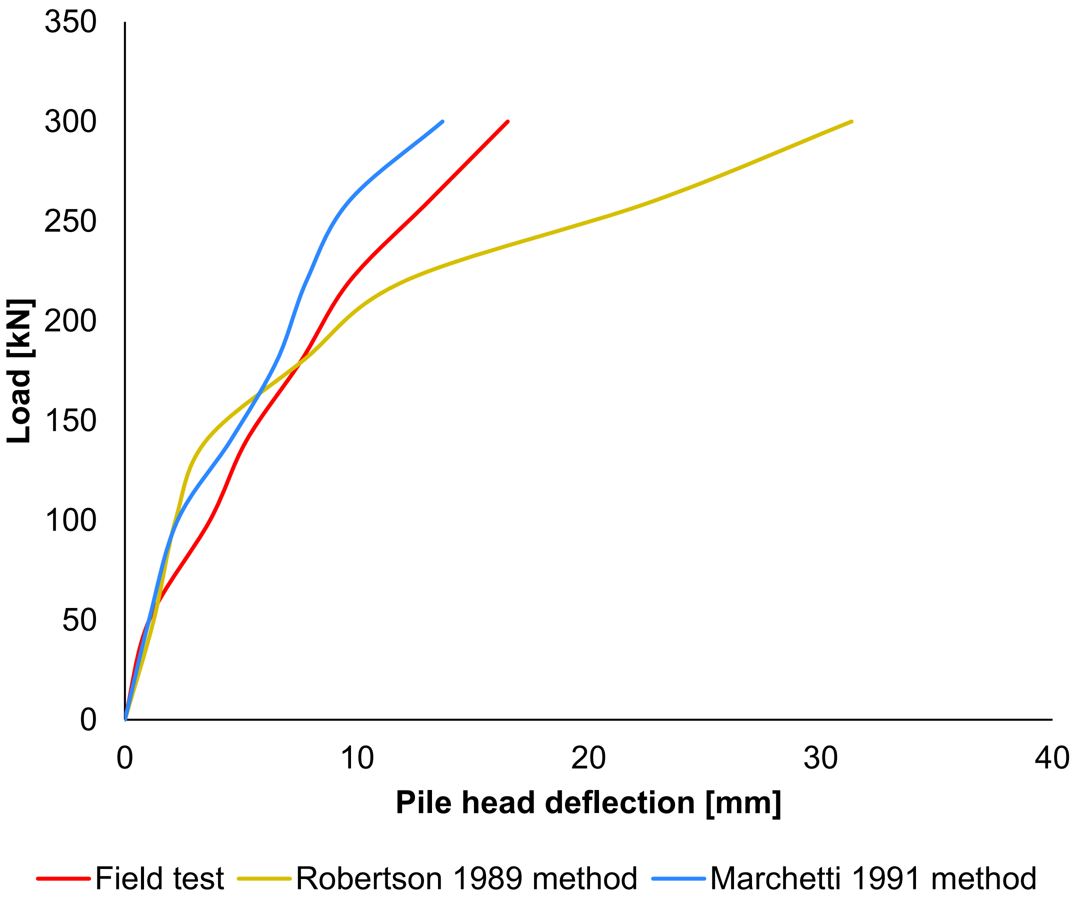
LLP tests Livorno

## 300 kN horizontal load



# Fixed Head Pile Robertson 1989 - Marchetti 1991 - measured

## LLP tests Livorno




| Applied Load | Field measure | Robertson (1989) | Error Robertson | Marchetti (1991) | Error Marchetti |
|---|---|---|---|---|---|
| [kN] | [mm] | [mm] | [%] | [mm] | [%] |
| 0 | 0 | 0 | **0** | 0 | **0** |
| 50 | 1 | 1 | **0** | 1 | **0** |
| 100 | 4 | 2 | **-50** | 2 | **-50** |
| 140 | 5 | 4 | **-20** | 5 | **0** |
| 180 | 8 | 8 | **0** | 7 | **-13** |
| 220 | 10 | 12 | **20** | 8 | **-25** |
| 260 | 13 | 23 | **76** | 10 | **-23** |
| 300 | 17 | 31 | **82** | 14 | **-18** |

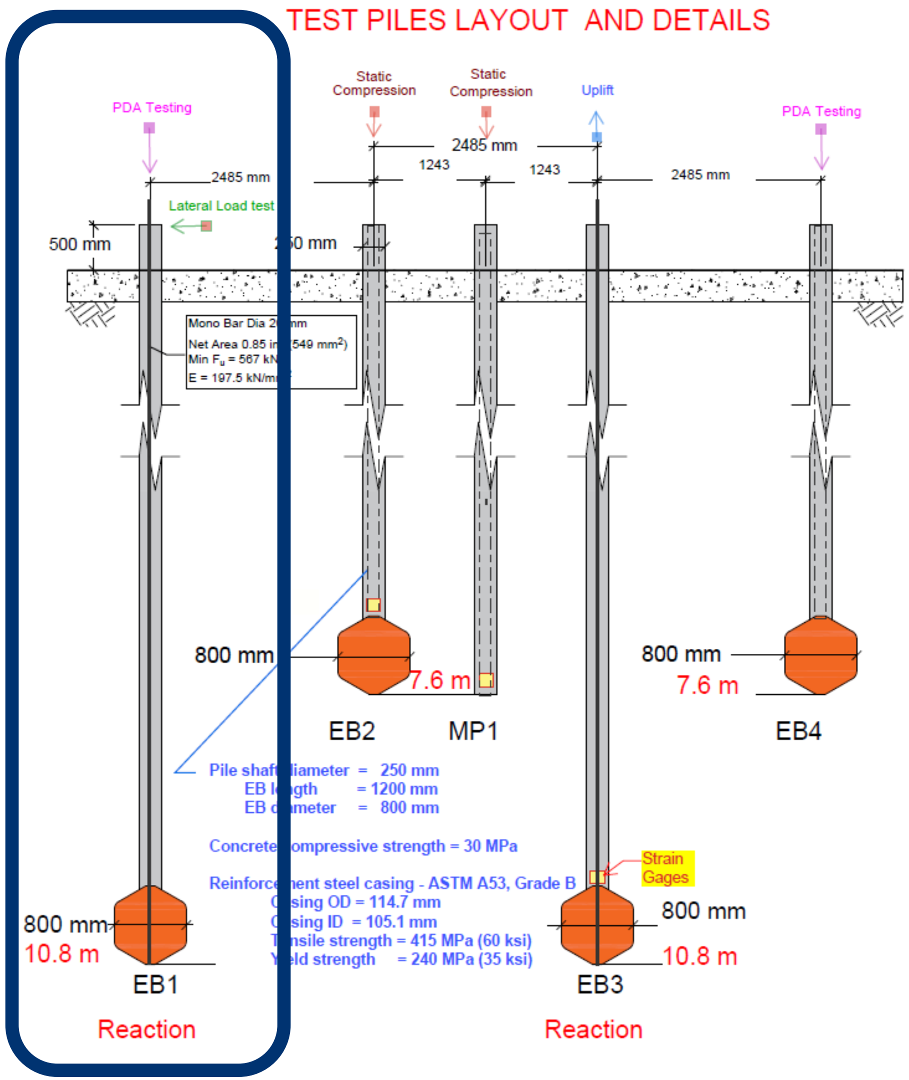
# LLP test in Livorno (1991)

Comments on Robertson (1989) and Marchetti (1991) performance:

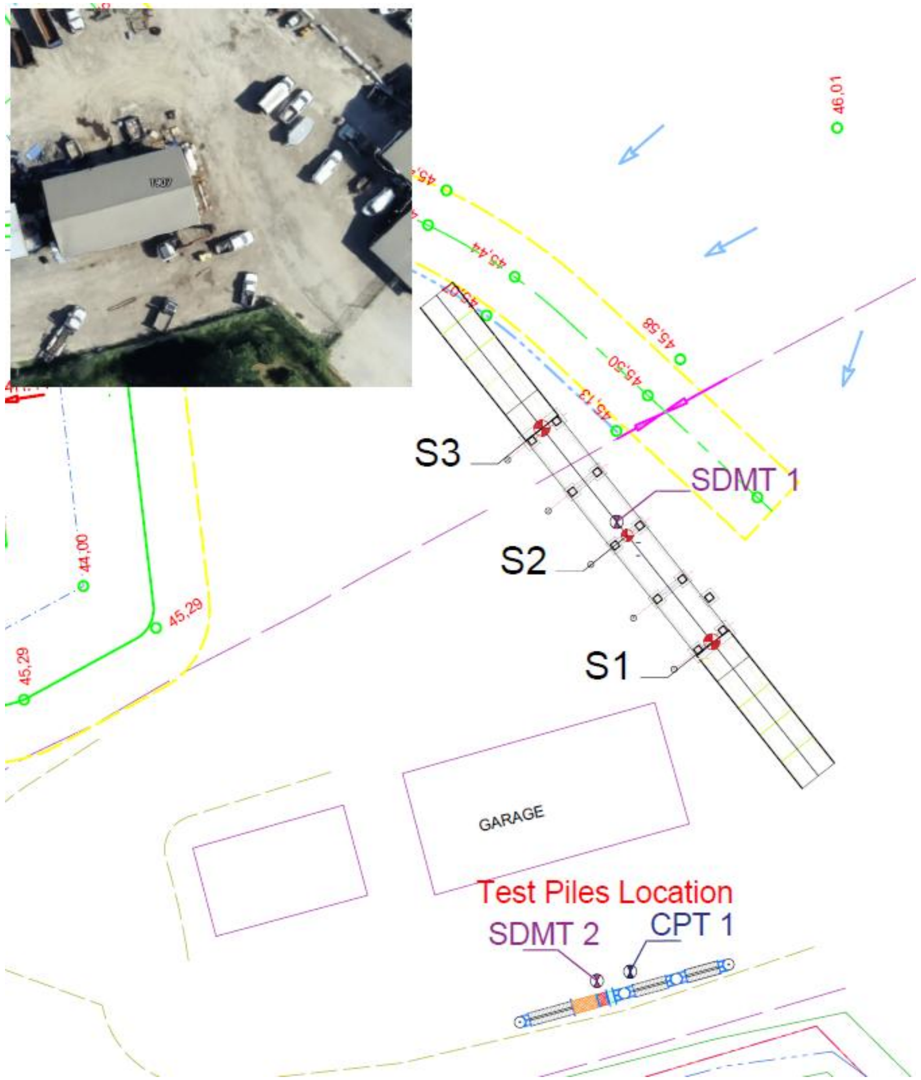
- At the lowest load, where initial tangent modulus is estimated by $E_D$, Roberston method provides good prediction
- At medium to high loads, Robertson method overpredicts deflections. Possible reason: $p = p_{ult}$ only for $y/y_{50} \geq 8$, too conservative !!
- Marchetti method (tanh function) provides very good predictions at all loads in the LLP test of Livorno

# LLP tests in Gatineau (2025)

# Pile testing Specifications for the Gatineau Pile Testing Event (2025)



# Site characterization tests for the Gatineau Pile Testing Event (2025)

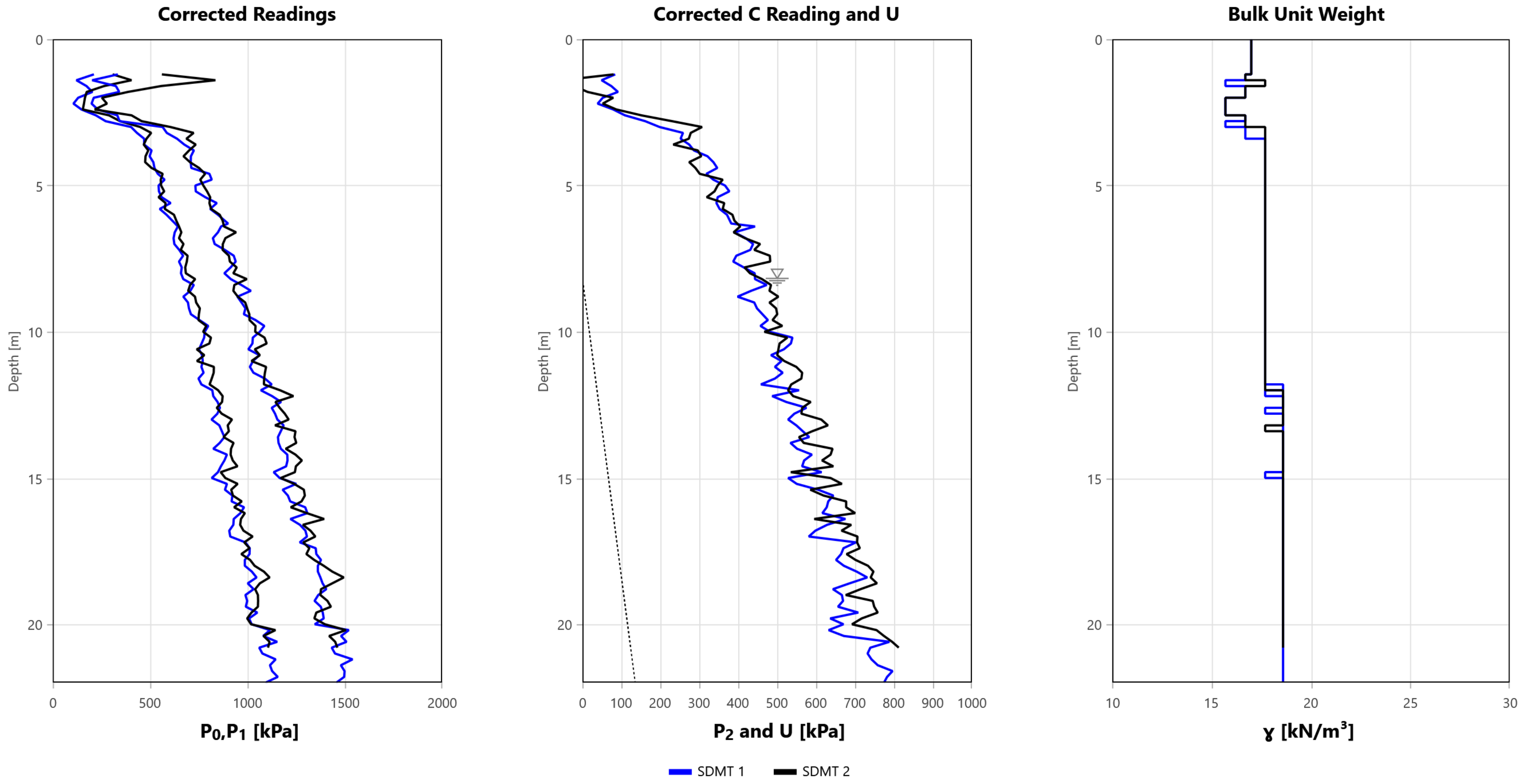


# Summary of information for the LLP prediction in Gatineau

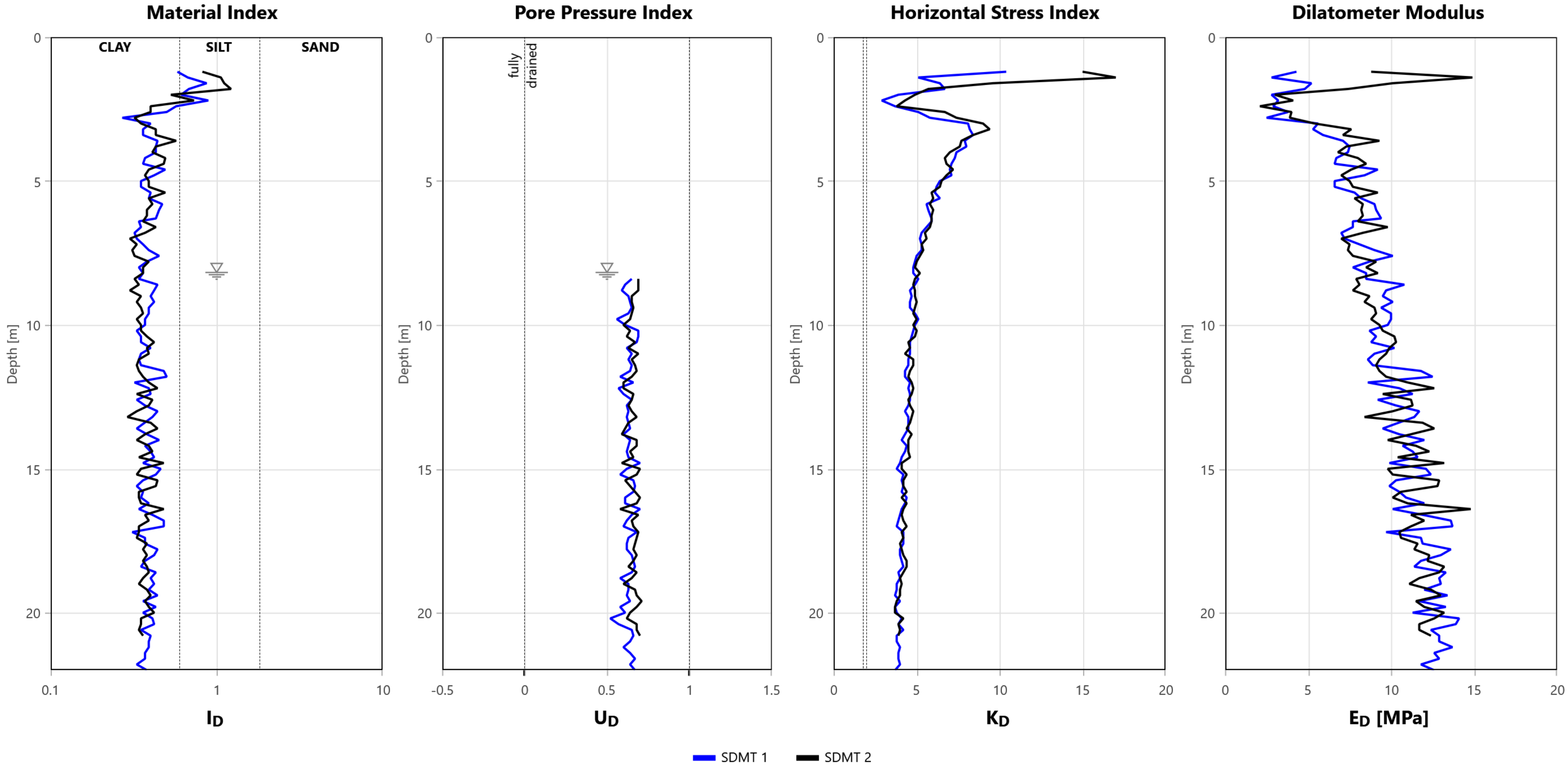
- DMT (CPT and Boreholes) detect mostly a stiff silty clay subsoil
- Robertson 1989 and Marchetti 1991 are both applicable
- Pile EB1: LLP with expanded base (pile toe geometry assumed irrelevant)
- Pile diameter 0.25 m
- Pile reinforcement: 4 inch steel pipe (101.9 mm)
- The concrete and grout compressive strength is 30 MPa
- Steps discussed in the previous slides will be adopted for the LLP simulation

# Gatineau LLP test site (September 2025): DMT test results

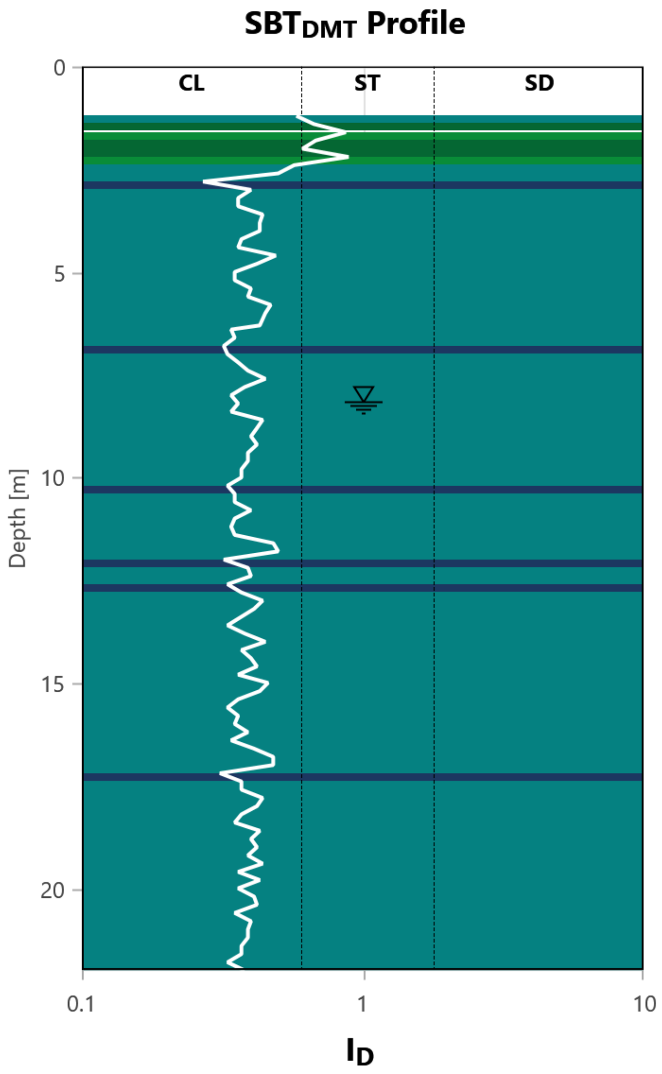
# Medusa DMT tests results in Gatineau (2025/9)

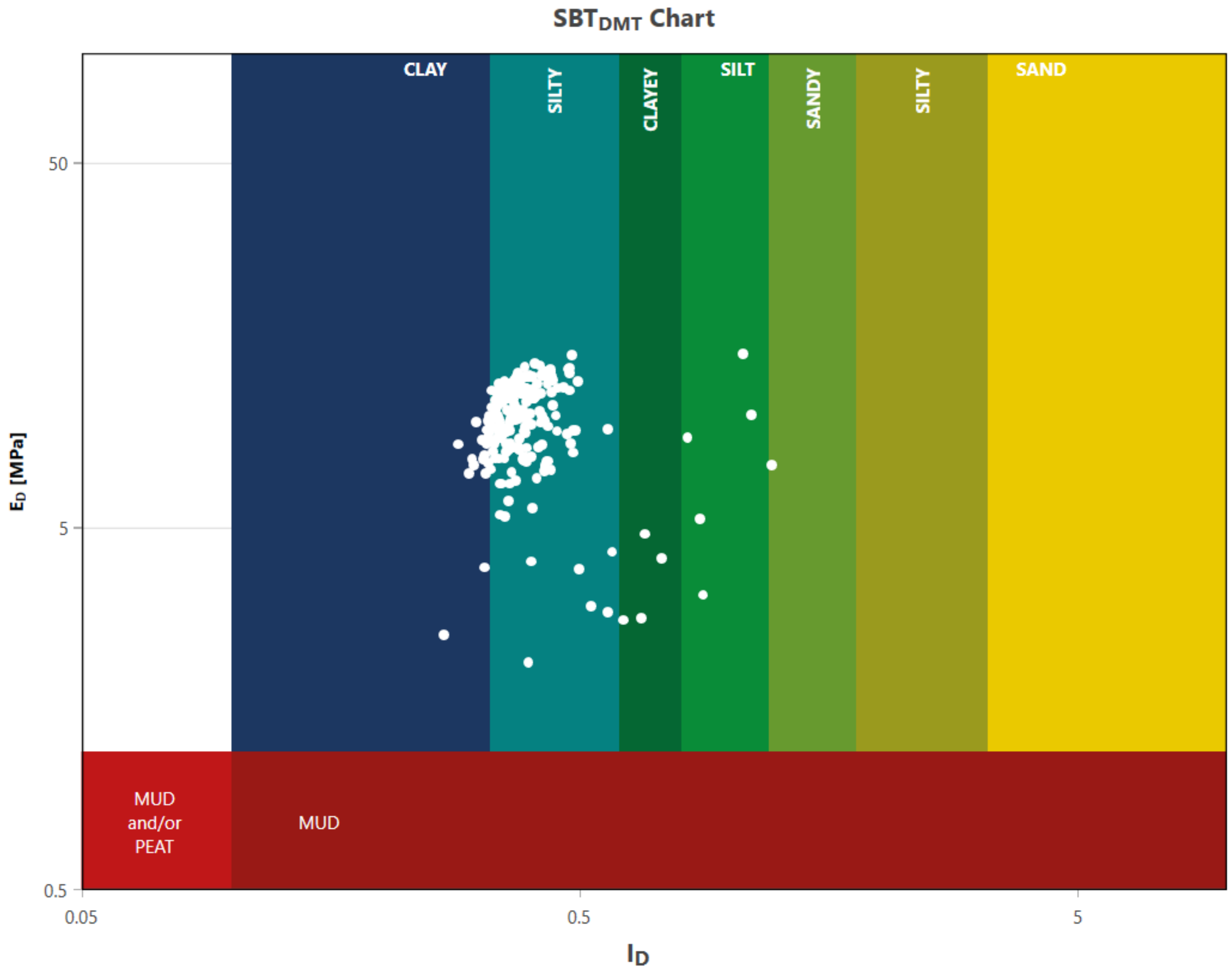


# Medusa DMT tests results in Gatineau (2025/9)

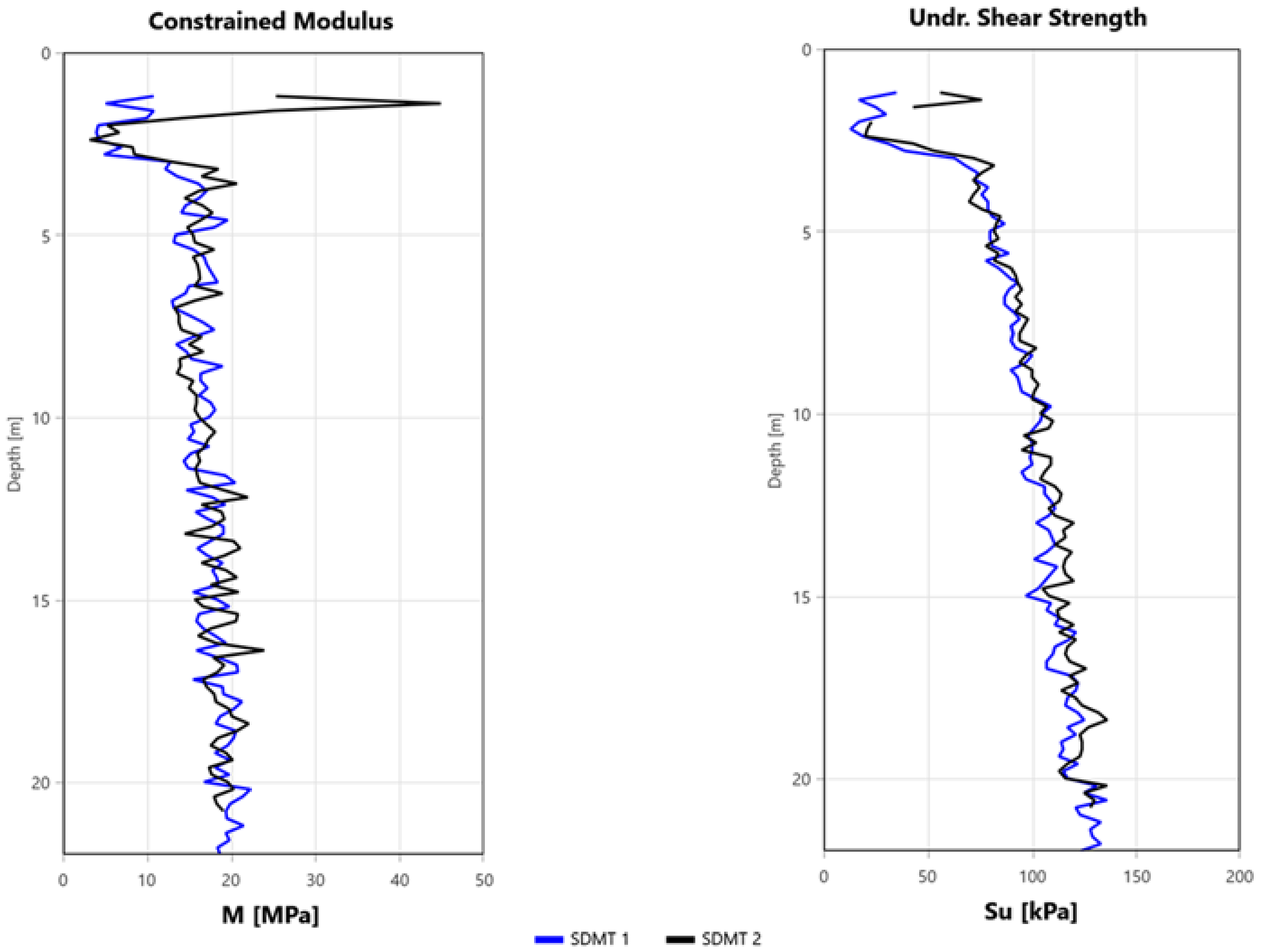


# Medusa DMT tests results in Gatineau (2025/9)

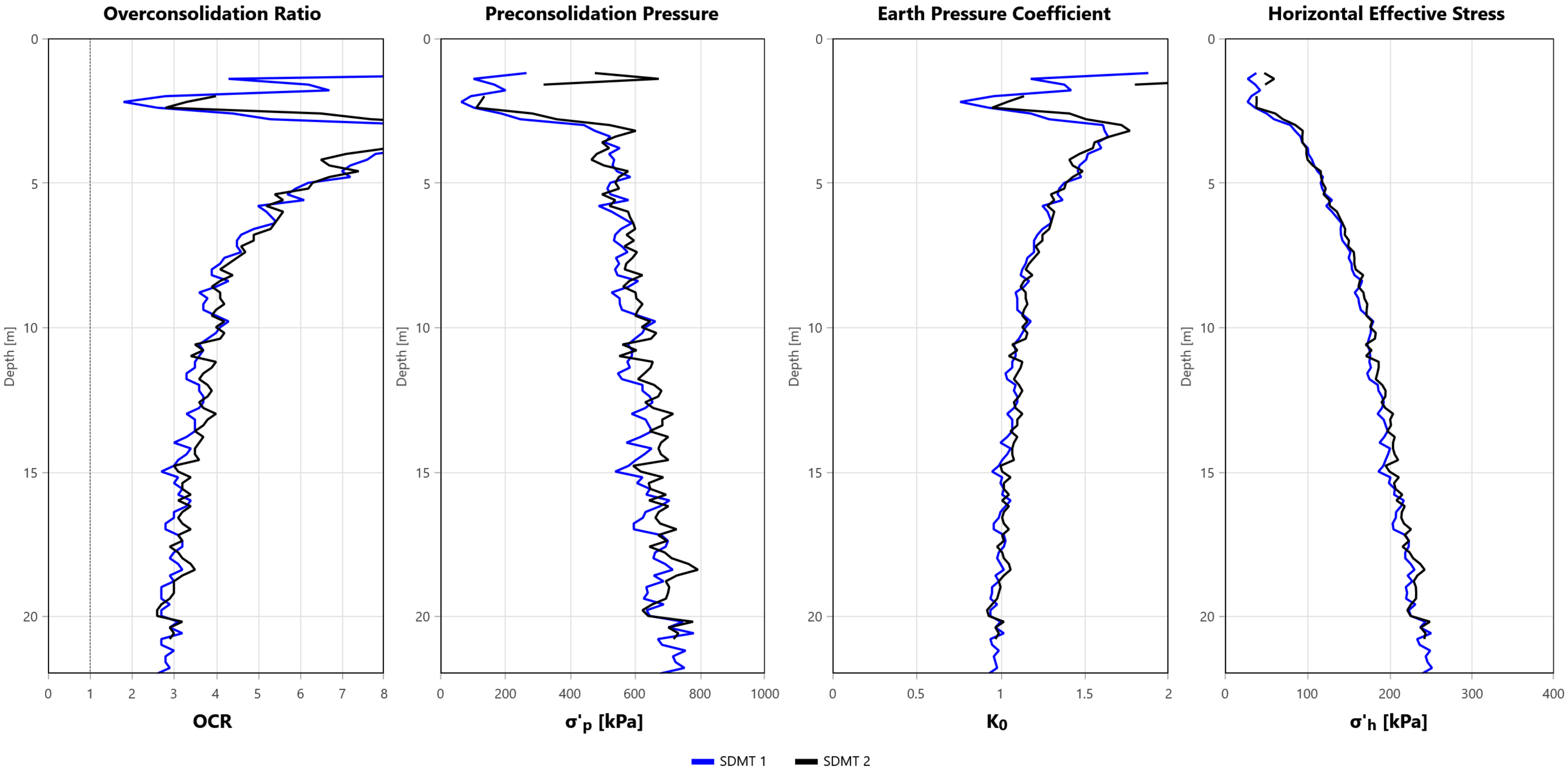


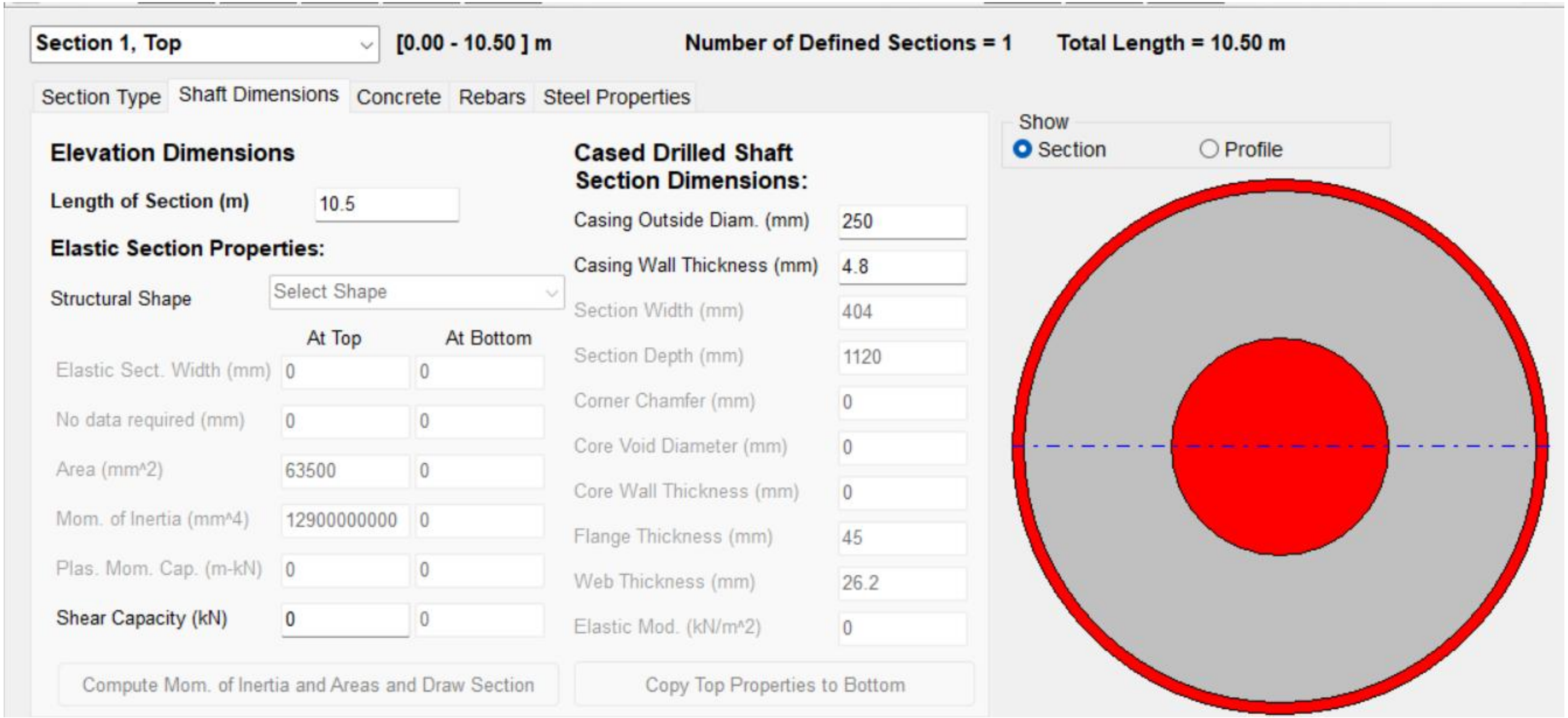
# Medusa DMT tests results in Gatineau (2025/9)



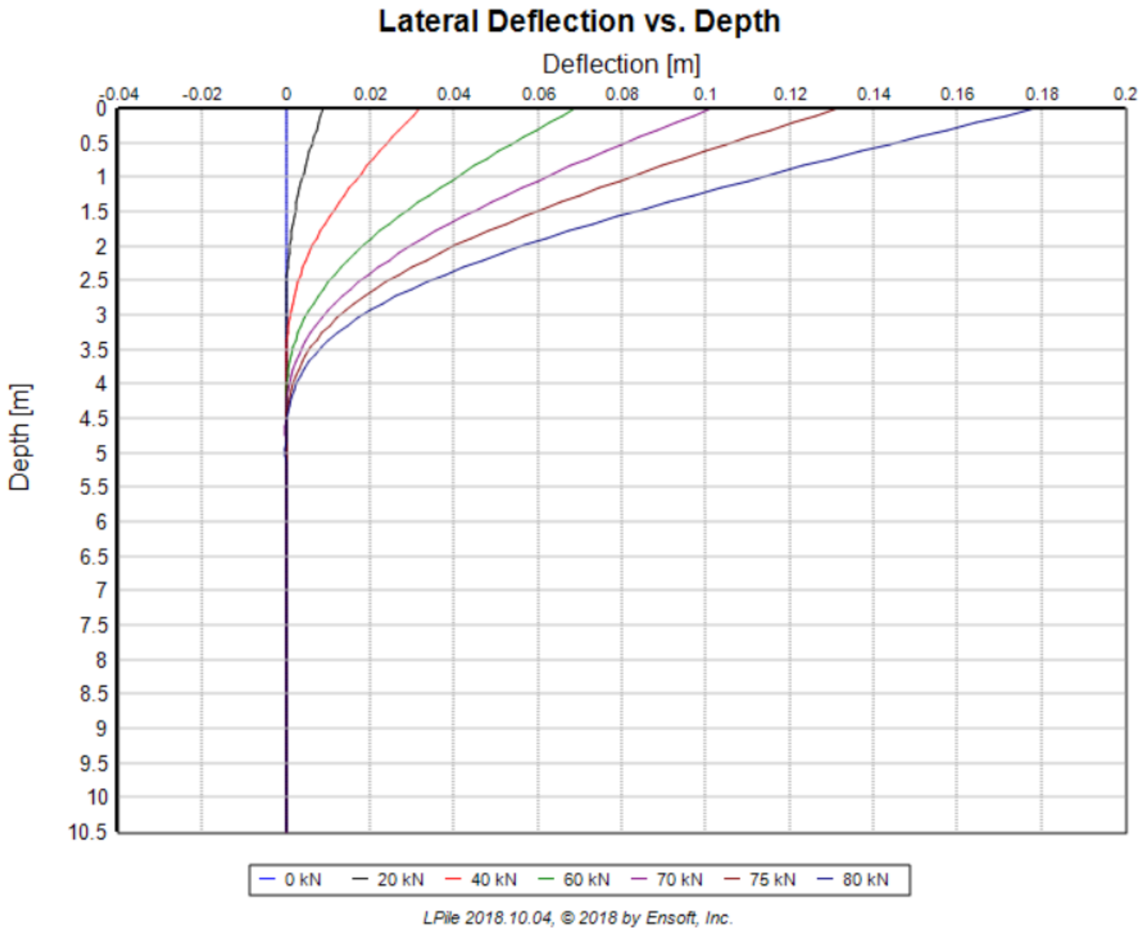
# Medusa DMT tests results in Gatineau (2025/9)



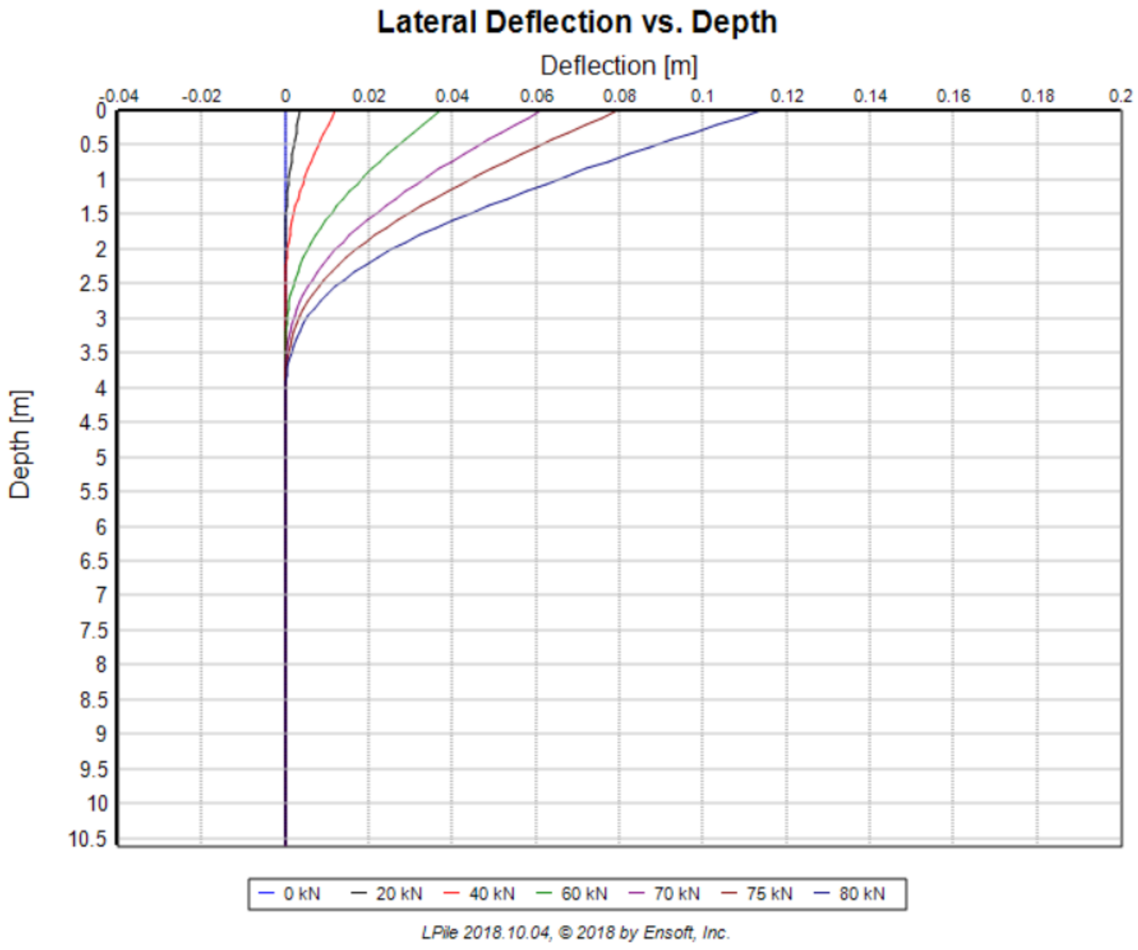
# Input LL Pile properties in Ensoft Lpi 2018 software (Gatineau 2025)



# EP1 Free Head LLP pile deflection using Ensoft Lpi 2018



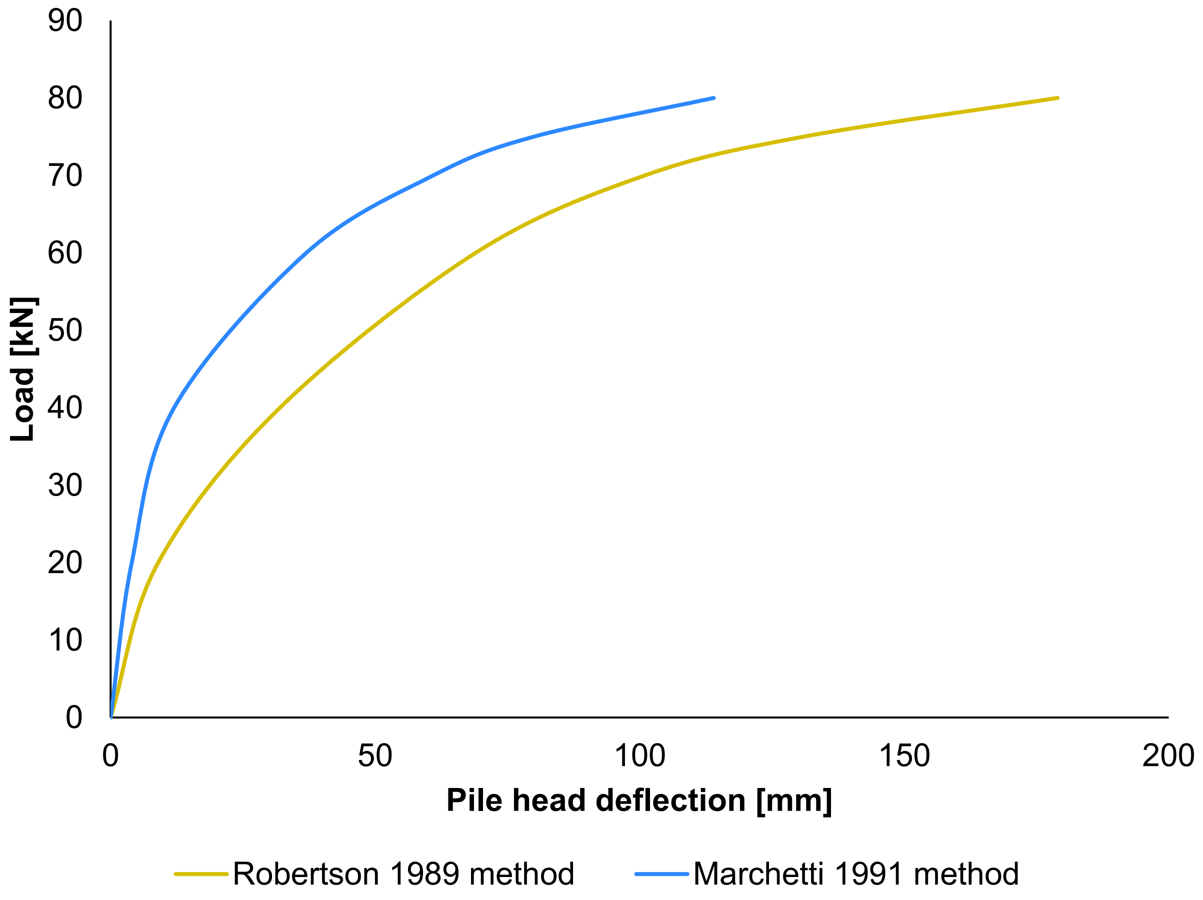

Robertson 1989 method




Marchetti 1991 method

# EP1 Free head Sample LL Pile prediction (Gatineau 2025)

**warning: assumed pile conditions may be different from final pile test conditions !**




| Applied Load | Robertson (1989) | Marchetti (1991) |
|---|---|---|
| [kN] | [mm] | [mm] |
| 0 | 0 | 0 |
| 20 | 9 | 4 |
| 40 | 32 | 12 |
| 60 | 69 | 37 |
| 70 | 101 | 61 |
| 75 | 131 | 80 |
| 80 | 179 | 114 |

# Summary-Conclusions-Discussion

- Gabr & Borden (1988): first method with hyperbolic expression, but ignoring $E_D$
- Robertson (1989): introduced $E_D$ for initial tangent modulus, cubic parabola
- Several comparisons and case histories (Robertson (1989), Briaud, J.-L. et al. (2018), Auburn University / B-424–2 style report and FHWA / DOT(2024)) concluded Robertson 1989 method underestimates soil reaction (p-values) with overprediction of pile-head deflection
- In Livorno LLP test case history
  - Robertson 1989 prediction overestimated measured deflections
  - Marchetti 1991 prediction agreed with measured deflections

# Summary-Conclusions-Discussion

- Differences Robertson 1989 vs Marchetti 1991 (P–Y relationship)
  - Robertson 1989
    - non-hyperbolic, soil stiffness too low in small-medium strain range, ‘delaying’ ultimate resistance $\mathrm{p_{ult}}$
    - $p$ approaches $p_{ult}$ only after very large displacements = $8y_{50}$
    - Excess computed deflection, mostly in the pre-yield regime
  - Marchetti 1991
    - Hyperbolic tangent captures smooth transition from initial stiffness to ultimate resistance
    - Soil nonlinearity more realistic
    - Achieves $\mathrm{p/p_{ult}} \approx 1$ at smaller more reasonable displacements

# Summary-Conclusions-Discussion

- Ensoft Lpi 2018 software simple tool for processing pile behavior (including LLP)
- Pile properties must be corresponding to in situ conditions (important as P-Y curves)
- Gatineau LLP test predictions valuable for additional validation

**Special thanks to Robert Edde and all event organizers**