JANUARY 18-19, BERKELEY, CA

PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

2018 Annual Meeting

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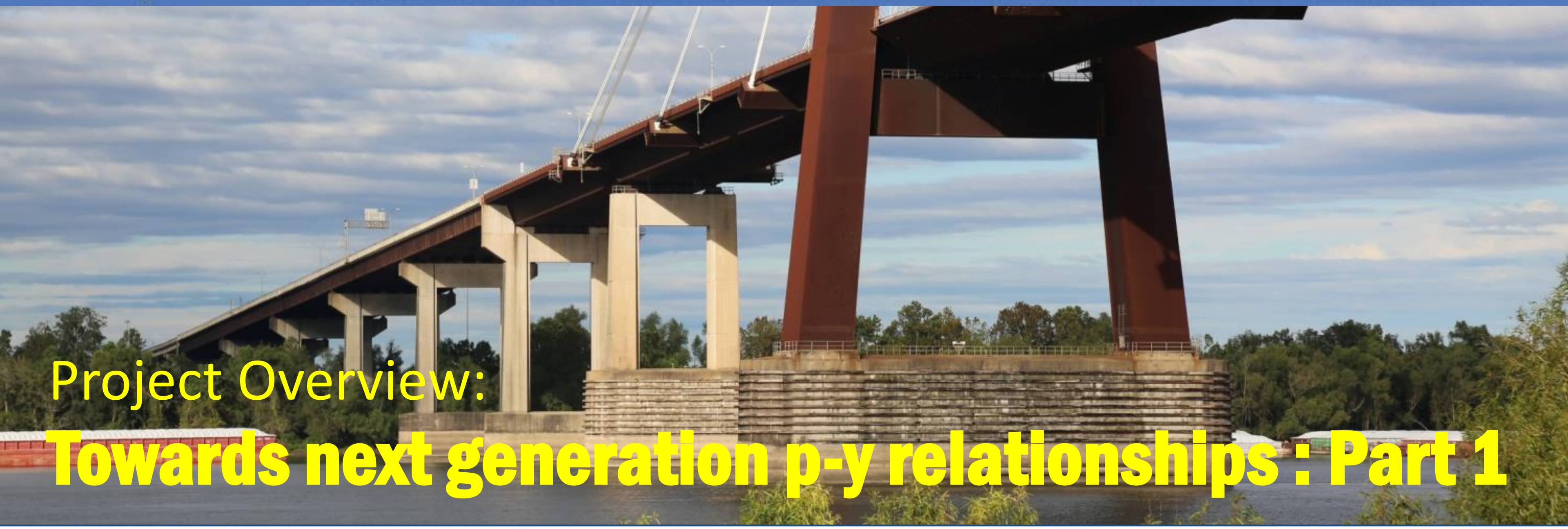


Project Overview:

Towards next generation p-y relationships : Part 1

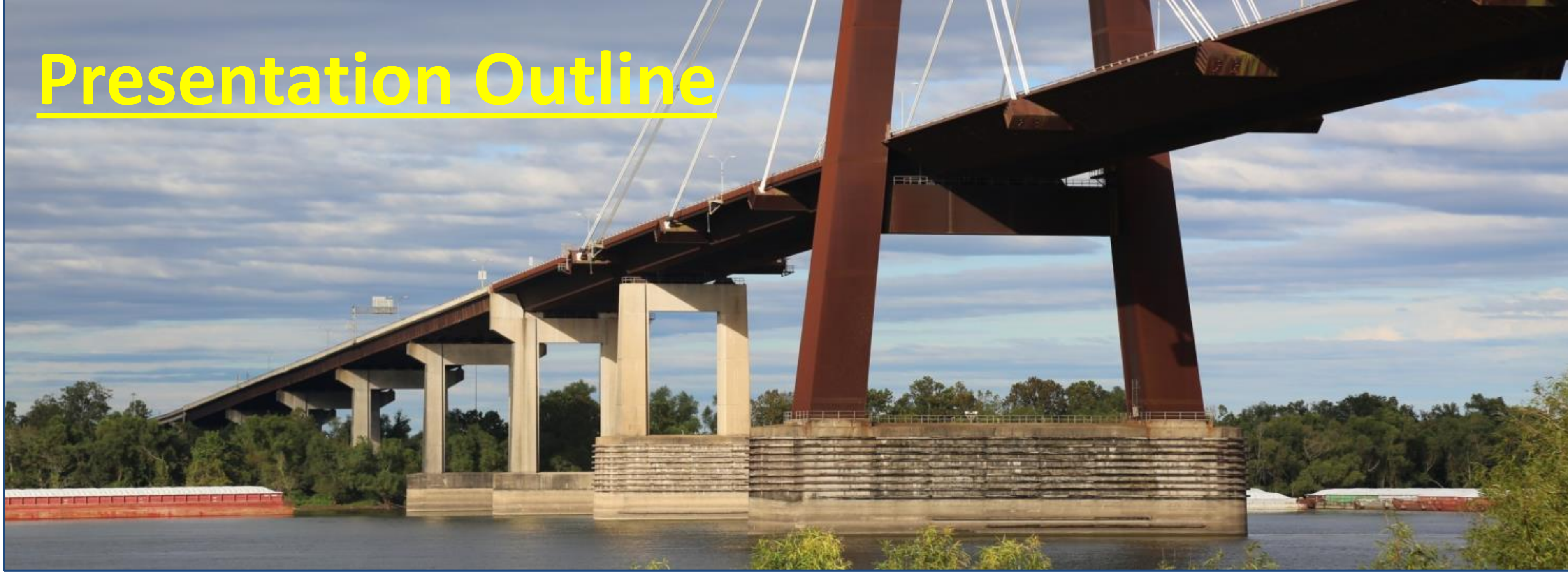
Report Part 1: State of Practice – State of the Art

Presenter: Anne Lemnitzer

Graduate student contributor: Camilla Favaretti

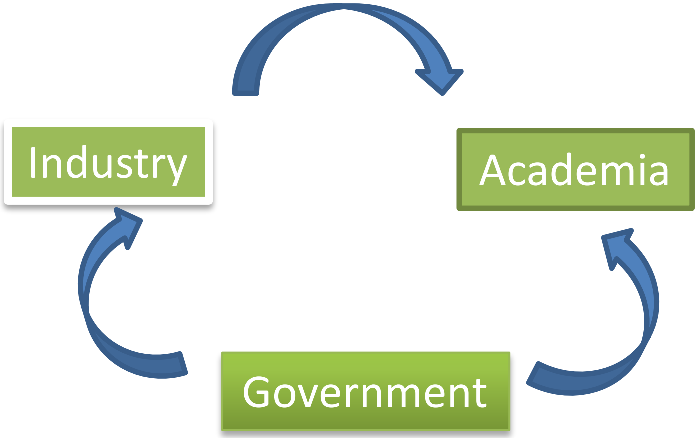
University of California, Irvine

Presentation Outline



- **Brief review of project objectives, background & motivation**
- **Content of report to be published / p-y issues**
- **Discussion**

Current Project Team



Project Members

Anne Lemnitzer (UC Irvine, PI, Lead)
Pedro Arduino (Univ. of Washington)
George Anoyatis (Univ. of the West of England)
Scott Brandenberg (UCLA)
Tara Hutchinson (UCSD)
George Mylonakis (Univ. of Bristol)

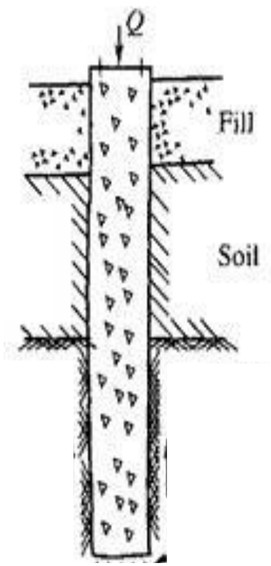
Advisory Panel

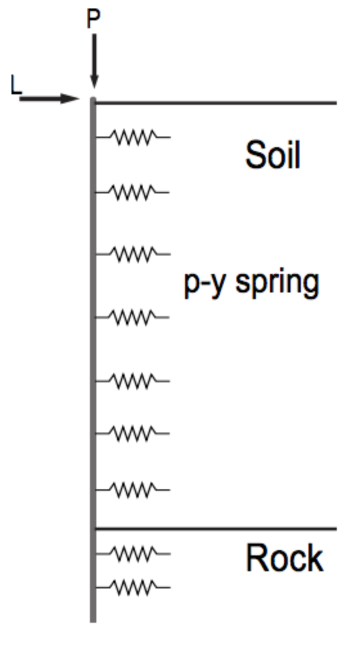
Peter Robertson (Gregg Drilling)
Jonathan Stewart (UCLA)
Tom Shantz (Caltrans)

Extended Project Members and expert board

Diane Fiorelli (Langan)
Haze Rodgers (Langan)
Kyle Rollins (BYU)
Armin Stuedlein (Oregon State Univ.)
Ben Turner (Dan Brown & Associates)
John Turner (Dan Brown & Associates)
Shin-Tower Wang (Ensoft)
Silas Nichols (FHWA)

P-Y Curves – what motivates this design tool?





Advantages

- Predicts the full, nonlinear lateral load-deformation response;
- Can incorporate multiple layers of soil and/or rock;
- Accounts for nonlinear *M–EI* behavior of reinforced concrete shaft;
- Provides structural analysis (shear, moment, rotation, and displacement) of the drilled shaft;
- Accounts for the effects of axial compression load on the structural behavior of the shaft;
- Can be implemented easily on a desktop computer with available software.

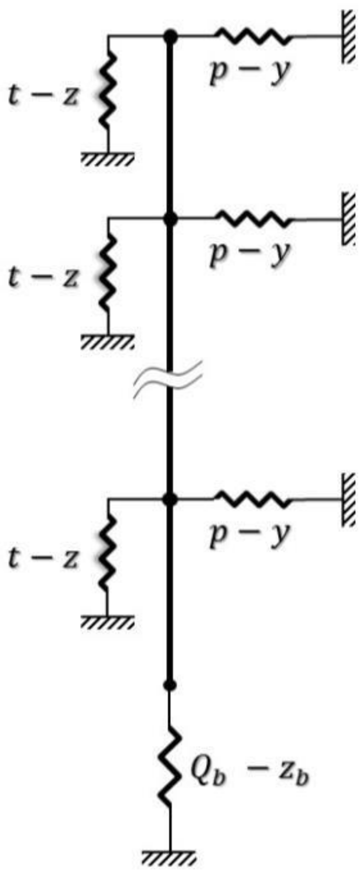
Limitations

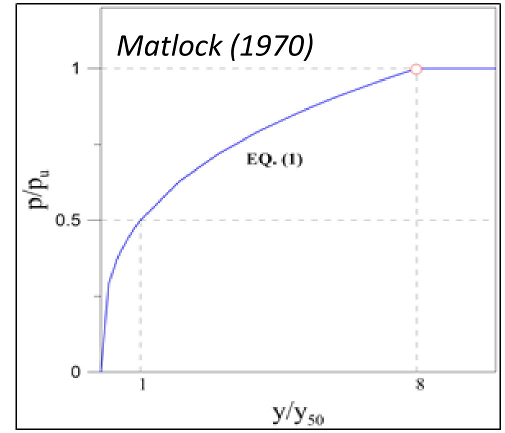
- Lack of a strong theoretical basis for *p-y* curves
- Requires back analysis of instrumented load tests to verify and validate *p-y* curves; such verification is currently lacking or limited to a few cases.
- Discontinuity of response results

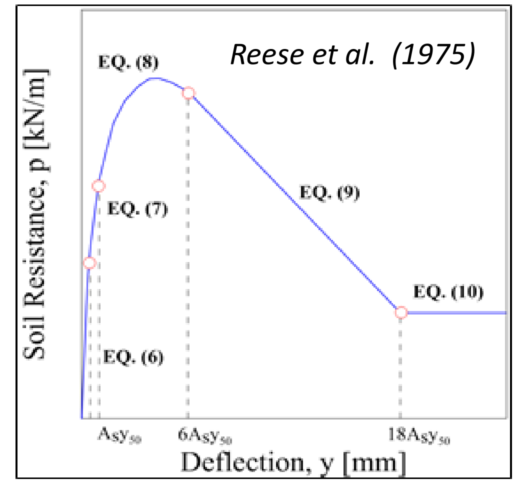
P-Y Models – where are we coming from?

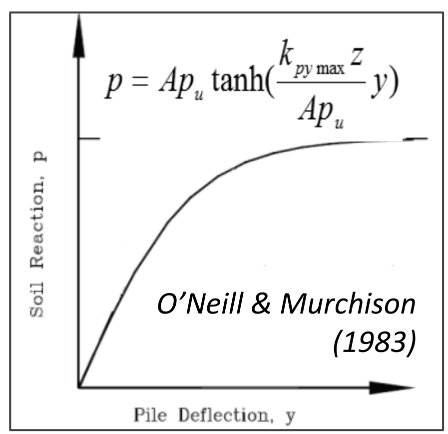
Matlock 1970 – Soft clay with free water
Reese et al 1975 – Stiff clay with free water
Reese et al 1974 – Sand
O'Neill & Murchison (1983) - Sand

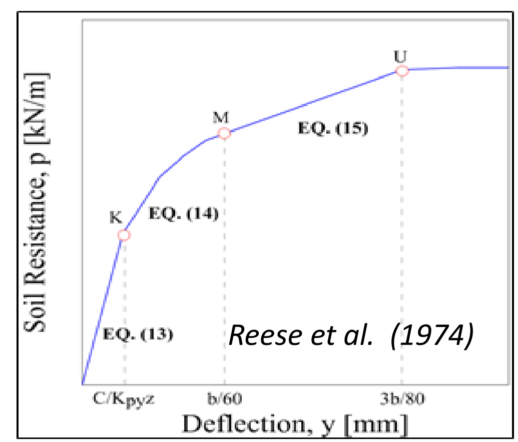
API



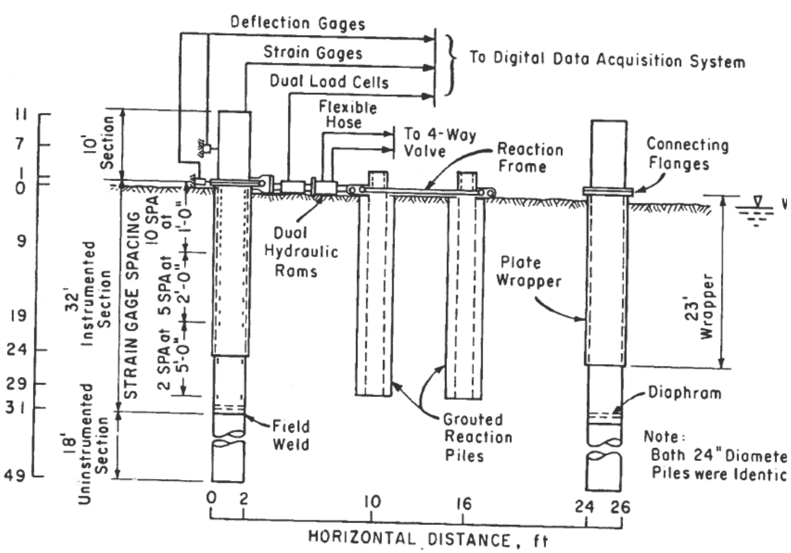


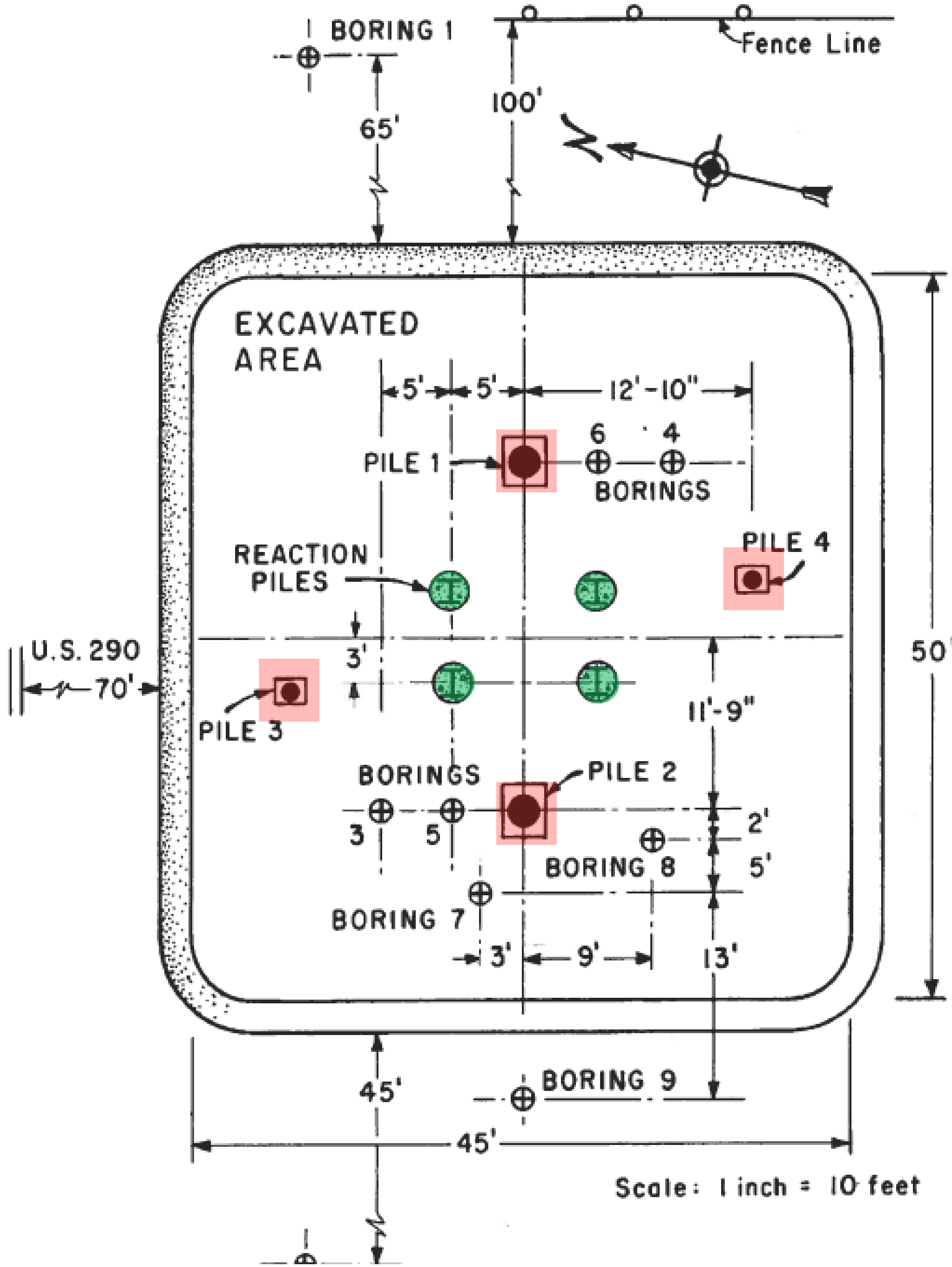




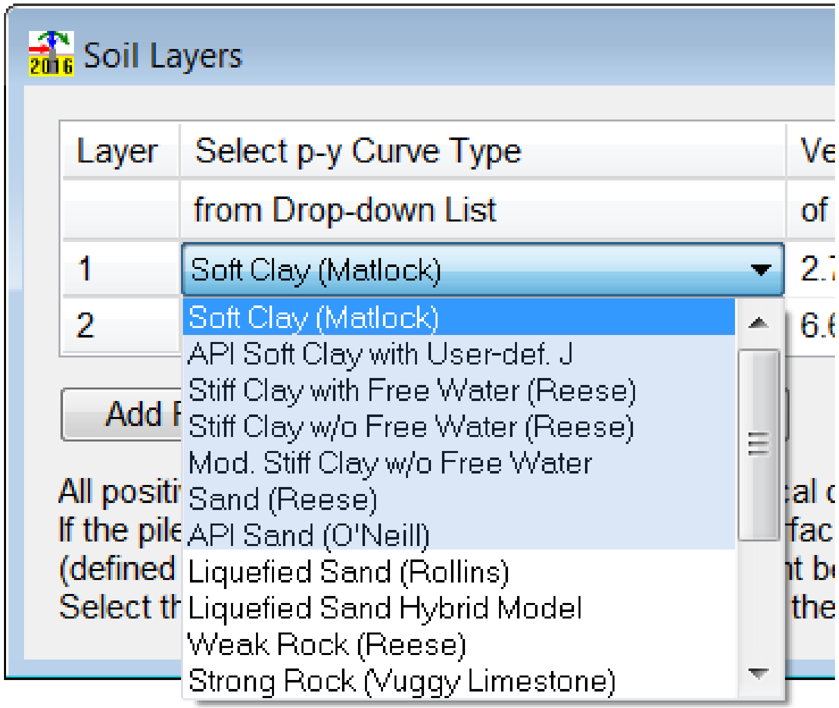


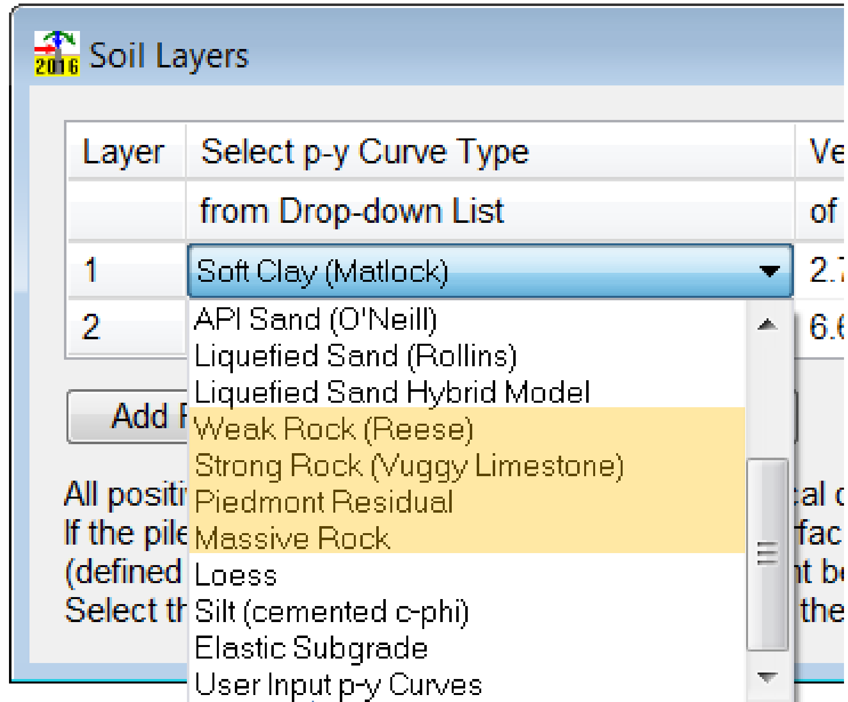
Example: Reese & Cox, 1975
(Stiff Clay Study)





Screenshot of the p-y formulations available in Lpile.





User defined py curve option is used less than 10% of the time
[personal communication with Ensoft, Inc.]

1 General Introduction to the PY analysis

2 State of the Practice Survey

3 State of the Practice Review

4 State of the Art Review

5 Recommendations for Immediate and Long Term Future Research

Working group meeting: September, 2017

State of the Art Issue to be discussed in the report:

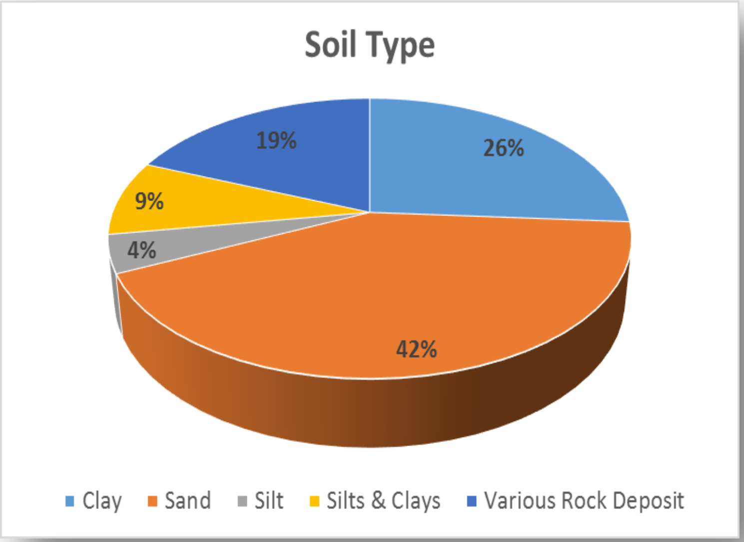
- Diameter studies
- Inertial & kinematic loading effects
- Fixity conditions (at the pile head and pile tip – e.g., rock socketing)
- Pile nonlinearity & structural performance issues
- Influence of loading: cyclic and dynamic loading, torsion
- Effects of batter
- Behavior of pile groups
- Effect of soil layering
- Installation effects
- Py relationships from advanced insitu testing

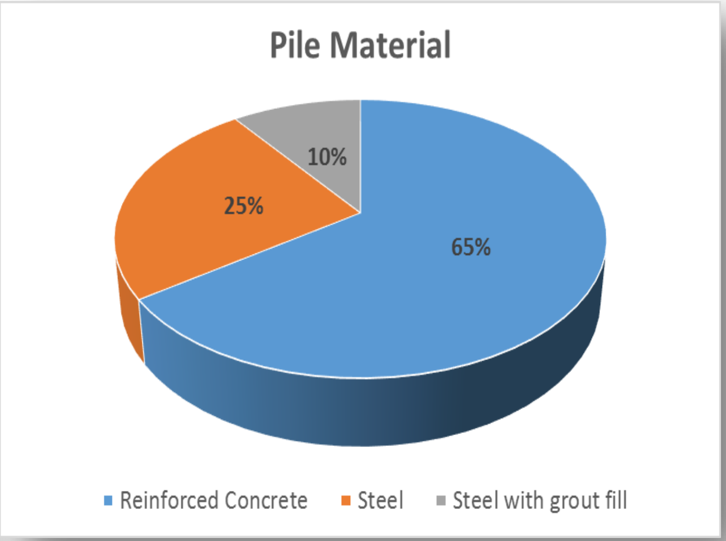
P-Y Models – what has been done since the 1960s?

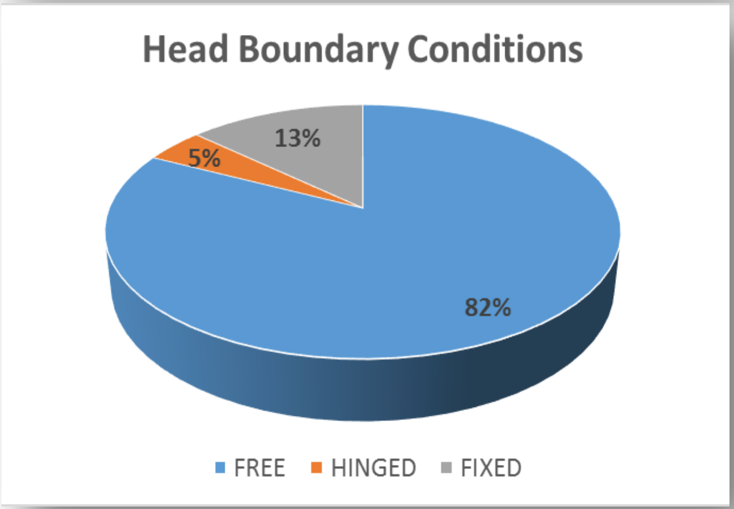
Our initial review showed that since the early studies, we have approximately:

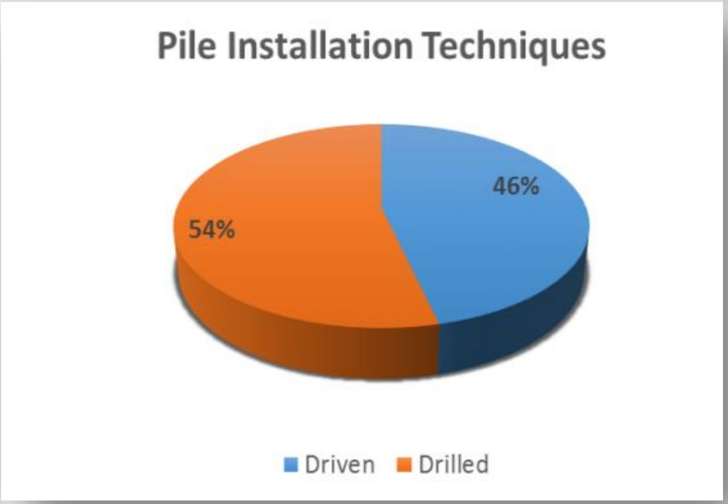
- More than 200 analytical studies on py relationships
- More than 30 studies in centrifuge
- More than 80 studies on large scale experimental pile behavior

Statistics of > 65 large scale tests reviewed

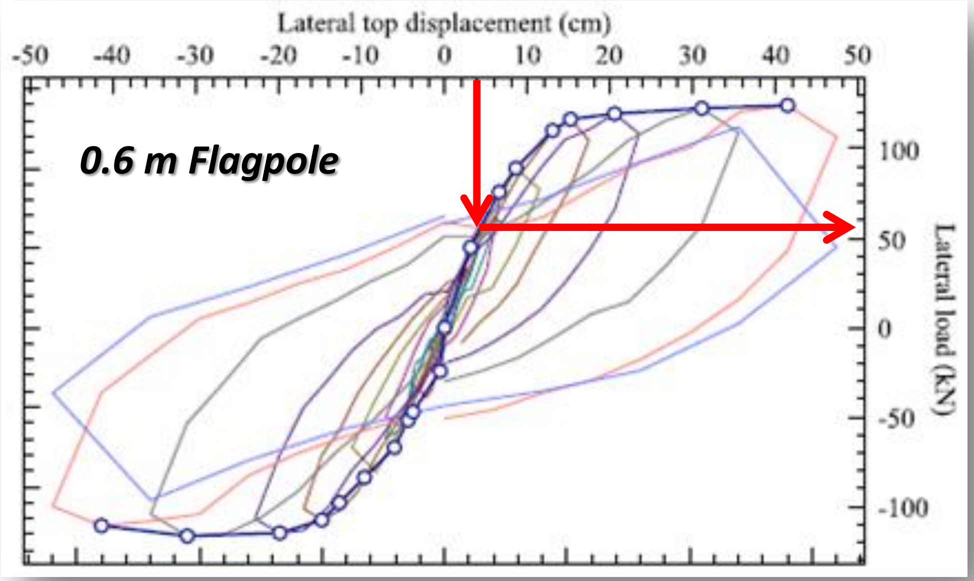


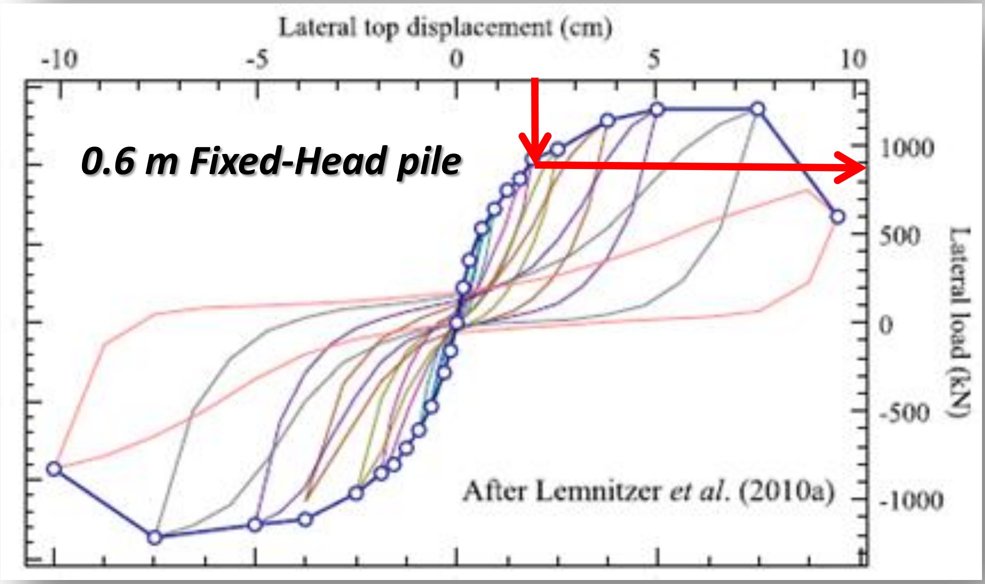




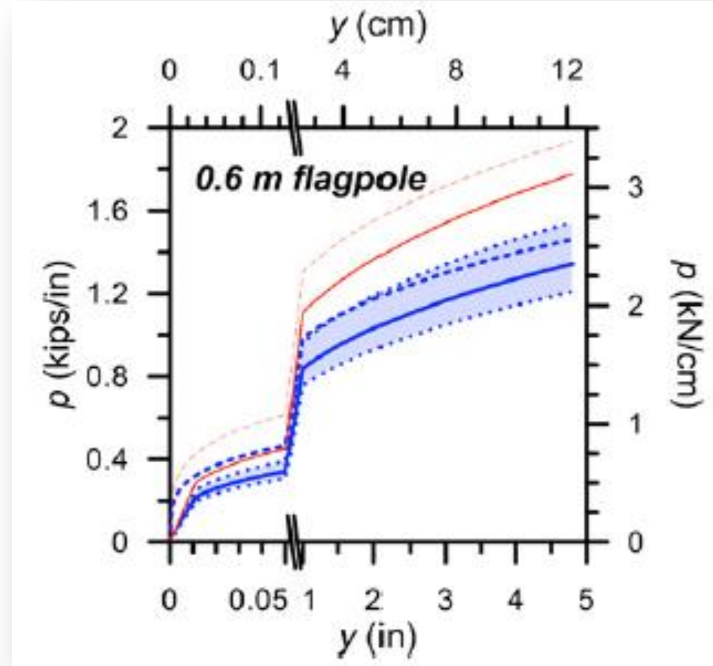


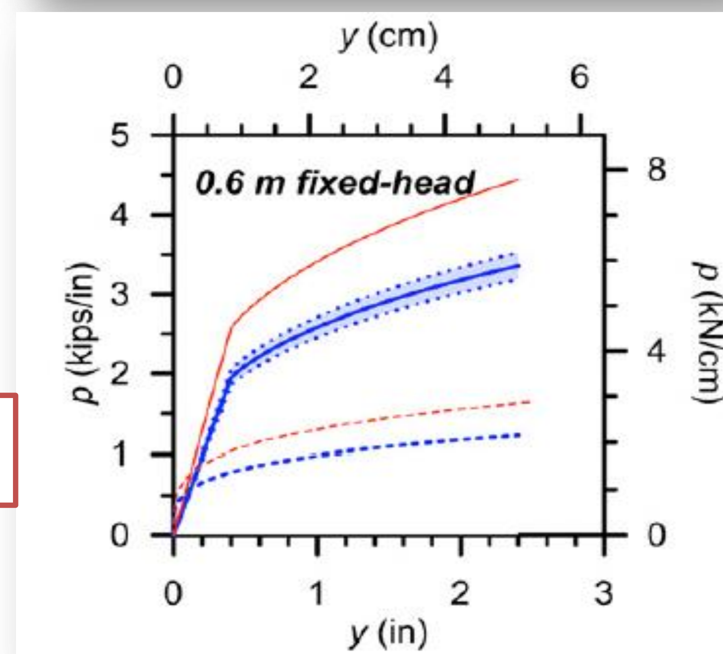
Example:
Research on Head Fixity





Khalili Tehrani et al. (2014) compared test results from RC **fixed & free head** pile researched by *Stewart et al (2007).*





Experimental curves

API curves

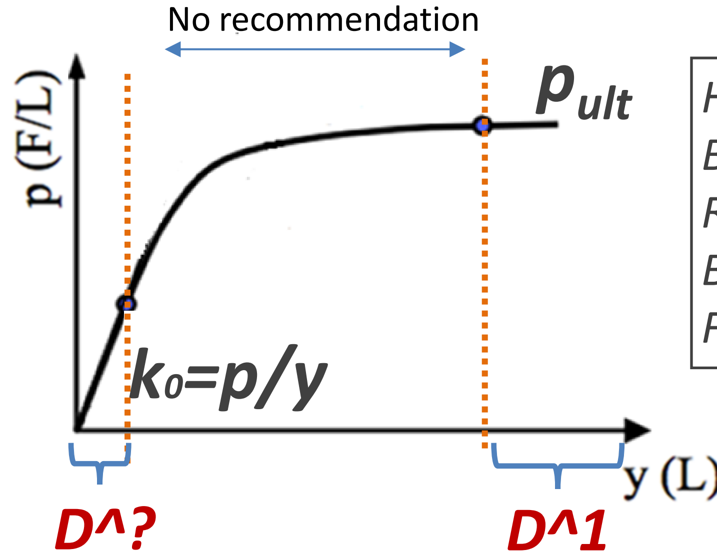
- Fixed-head capacity is **50% greater** than flagpole.
- The fixed-head pile has **100%** larger capacity than API.
- Initial stiffness is overestimated by **30%** by API.

Reese et al. (1974)
Reese et al. (1975)
Lam & Cheang (1995)
Fan (1996)
Ashford &Juirnarongrit (2005)

k_{ind}

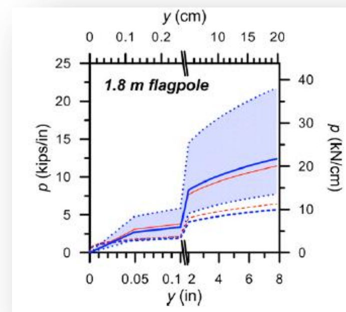
Stevens & Audibert (1979)
Wiemann et al. (2004)
Sorensen (2010)

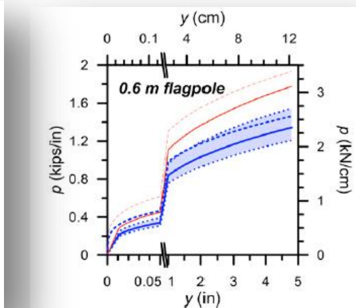
k_{dep}



Hansen (1961)
Broms (1964)
Reese et al. (1974)
Briaud & Smith (1983)
Fleming et al. (1992)

Experiments:



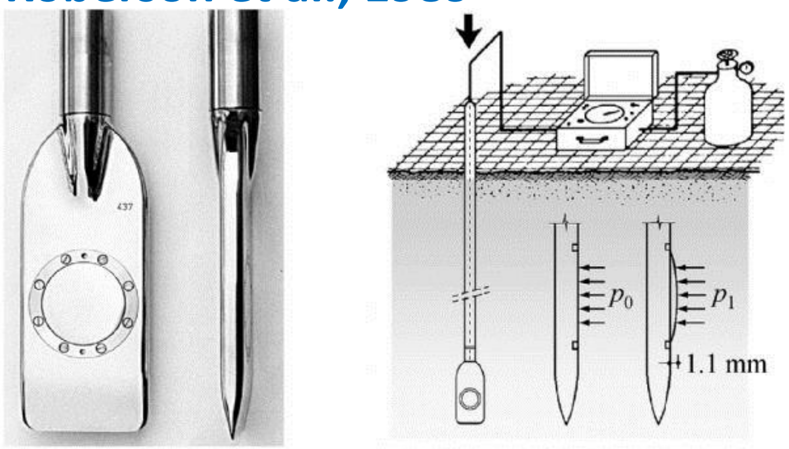


Stewart et al. 2007, Khalili-Tehrani et al. 2014

PY Curves from In-Situ Testing: DMT, PMT, CPT

Huang et al. 2001

Roberson et al., 1989



(a) (b)

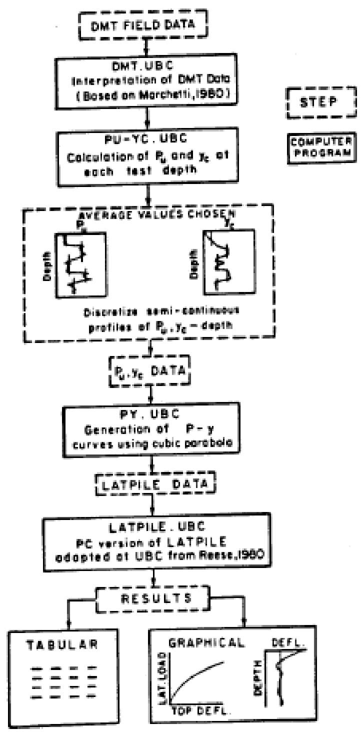
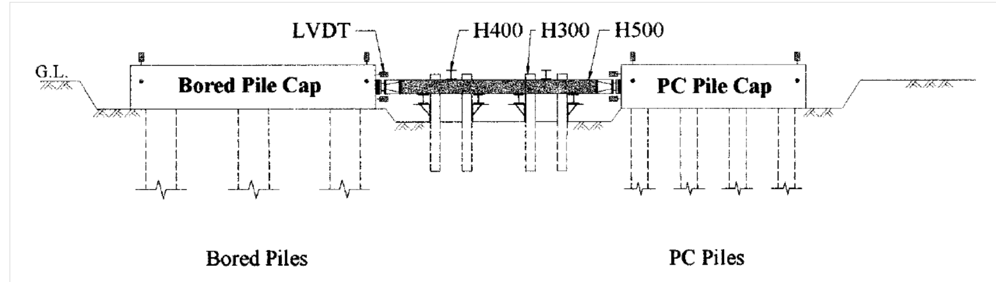
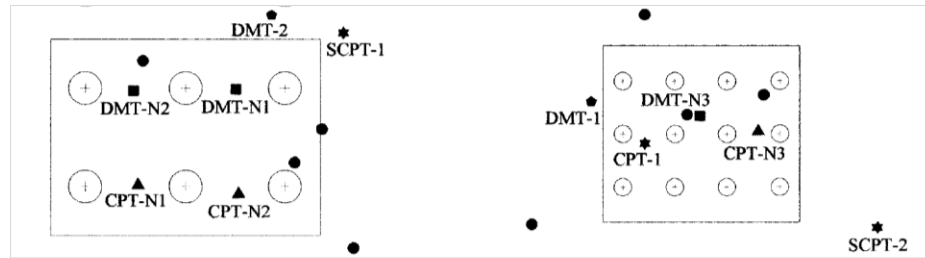
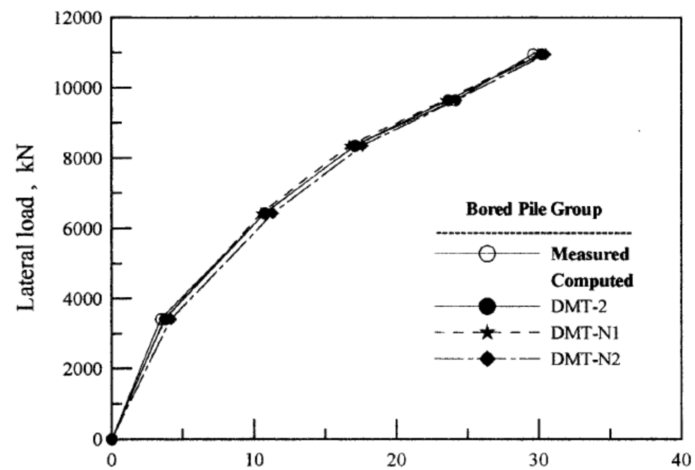


FIG. 3—Flowchart for determining P-y curves from DMT data.



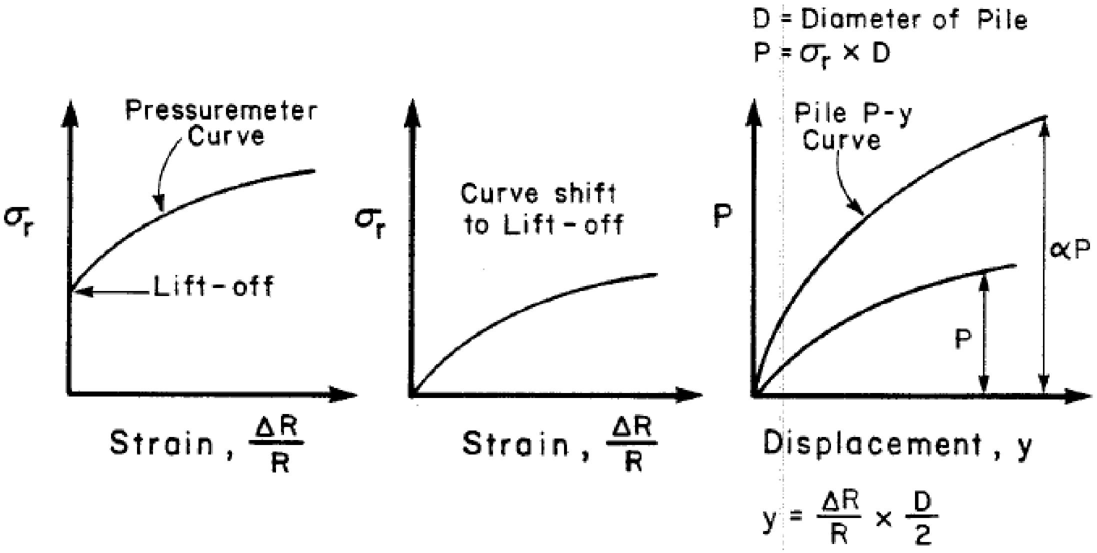




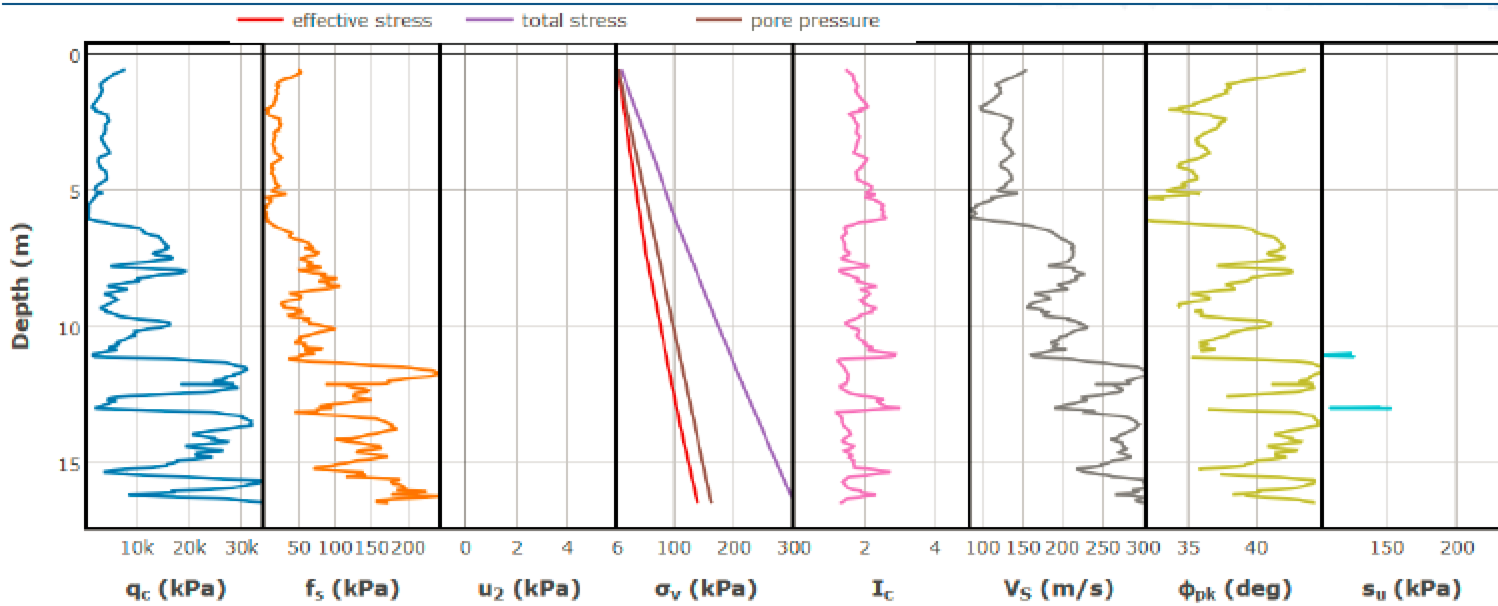
PY Curves from In-Situ Testing: DMT, PMT, CPT

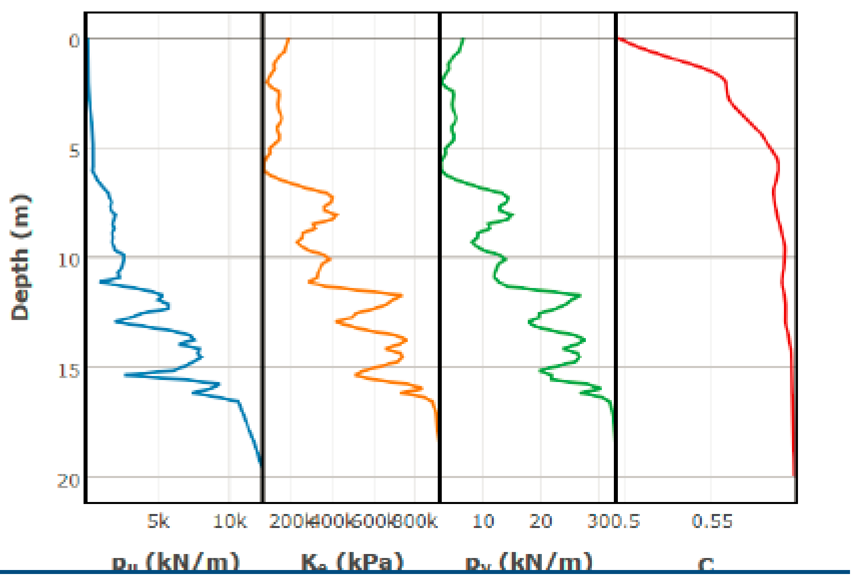
Robertson et al., 1986

Pressuremeter Concept:

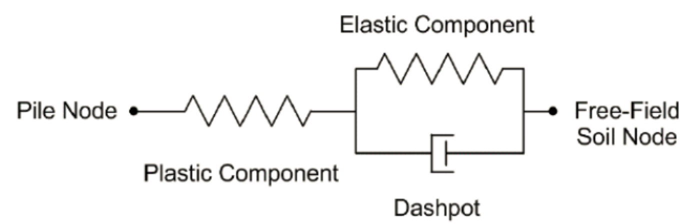


Brandenberg and Arianna (2017) uclageo.com/CPTpy/





(b) Updated *PySimple3* (current study)



- Use of the pySimple3 material model
- Computing p-y properties from CPT data (continuous)
- Special Focus on Intermediate Soils ($2.3 < I_C < 2.7$)
- Incorporation of layering effects
- Use of small strain stiffness

Courtesy of Brandenberg and Arianna

Testing with new materials

- **Main Concern**: Seismic. Increased seismic loads necessarily require increased steel reinforcement using current design specifications
- The density of steel in the rebar cage can cause difficulty during concreting, leading to voids and loss of cover

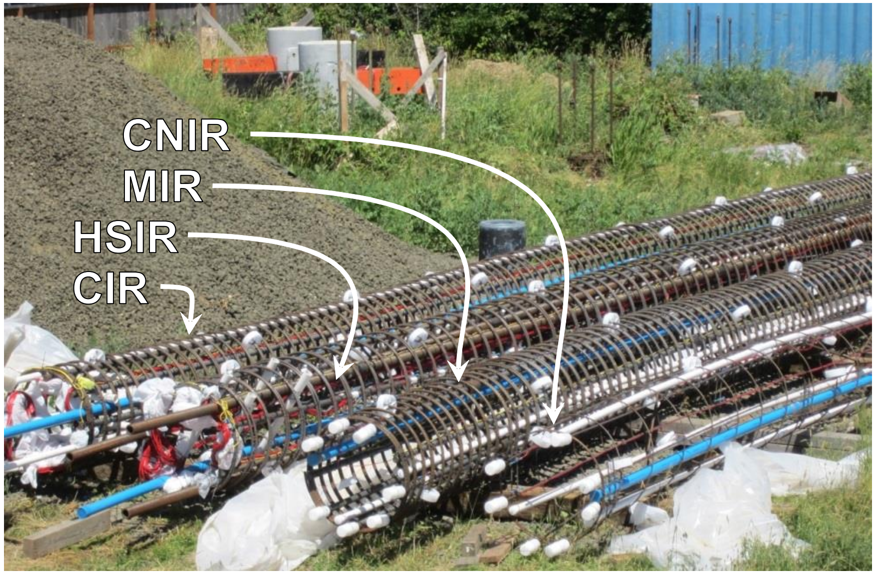
- high strength (550 MPa) steel as an alternative to 420 Mpa

- use of permanent steel casing in design for flexure, lateral load transfer

- Evaluate use of hollow bar as dual purpose elements (structural, CSL access), compare to TIP Thermal Wires

Example: Stuedlein et al. 2017, 2018

ODOT-ADSC WCC Study: Axial and Lateral Response of Drilled Shafts with High-strength Steel and Steel Casing



MIR: mild steel, uncased

HSIR: high strength, uncased

CIR: mild internal steel, cased

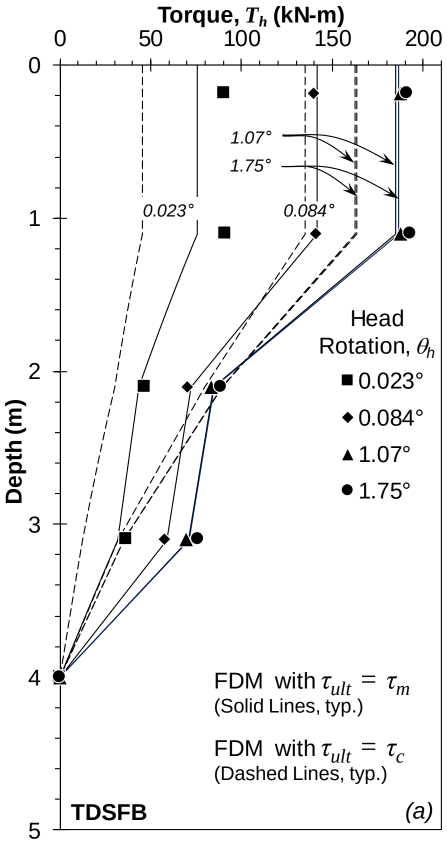
CNIR: no internal steel, cased

Slide Courtesy of Prof. Armin Stuedlein

Lateral Loading Tests: Test Setup

Slide Courtesy of Prof. Armin Stuedlein

Stuedlein et al. 2017: Torsional Response of Drilled Shafts



Supporting Survey – State of Practice – Preliminary Results (Survey is currently expanded towards east coast and outside CA)

Sample questions

In which Sector do you practice?

Which industrial application is your work/design mostly related to (please circle):

Are you structural/geotechnical. Which degree and licenses do you hold?

What type of deep foundations do you design and <u>how often</u> (in % of total amount of deep foundation design)? (e.g., drilled shafts, driven piles, monopiles, auger cast piles, etc.)

Which type of analysis methods (%) do you use for your lateral deep foundation design?

Which Software do you typically use? Please indicate the %.

How are the results of your lateral pile analysis used?

What type of lateral loading do you primarily use in your analysis? Please circle your answer.

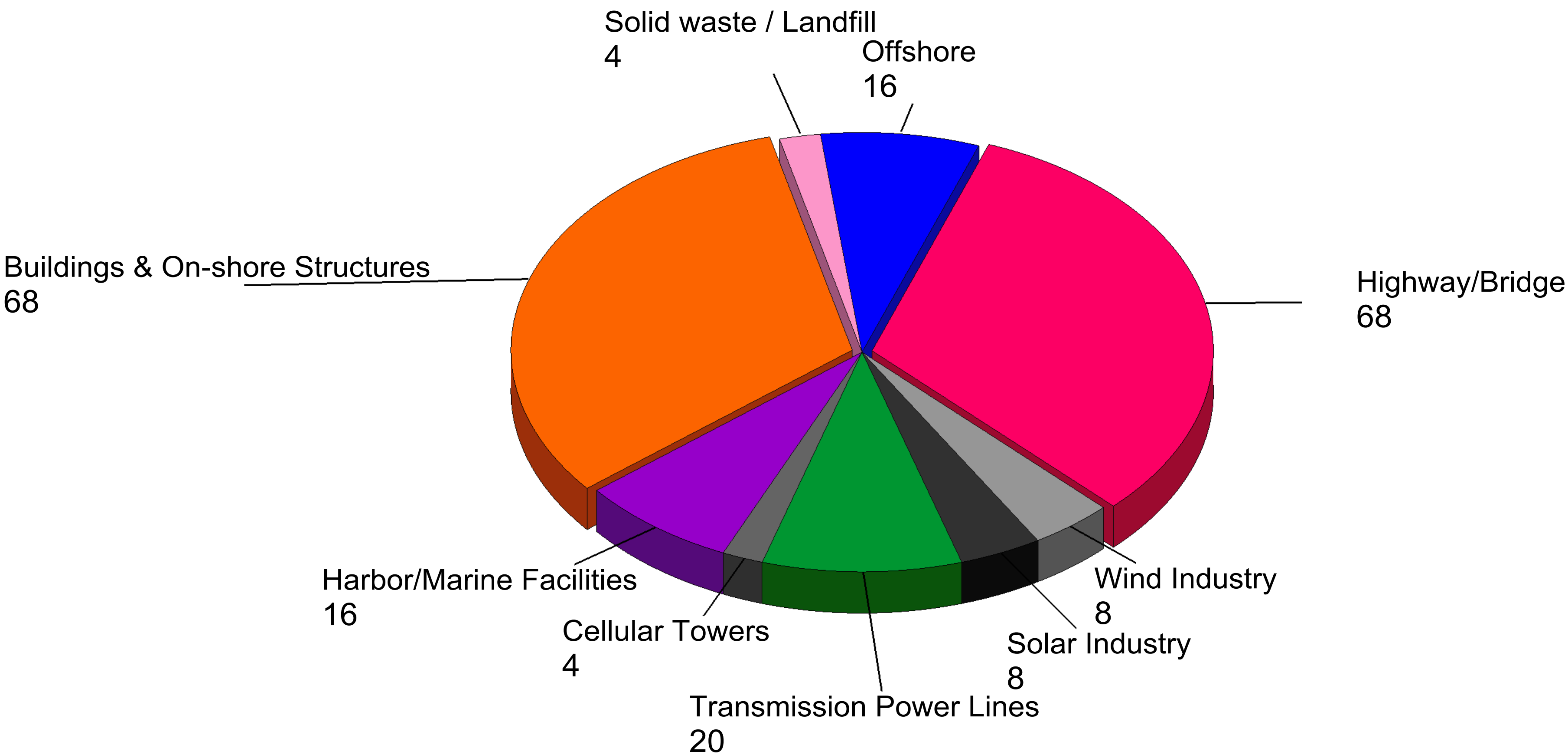
How do you determine your EQ loads:

What are the primary sources of uncertainty during your lateral foundation analysis and design?

What type of site investigation methods do you primarily use? Where do you get your strength parameters from?

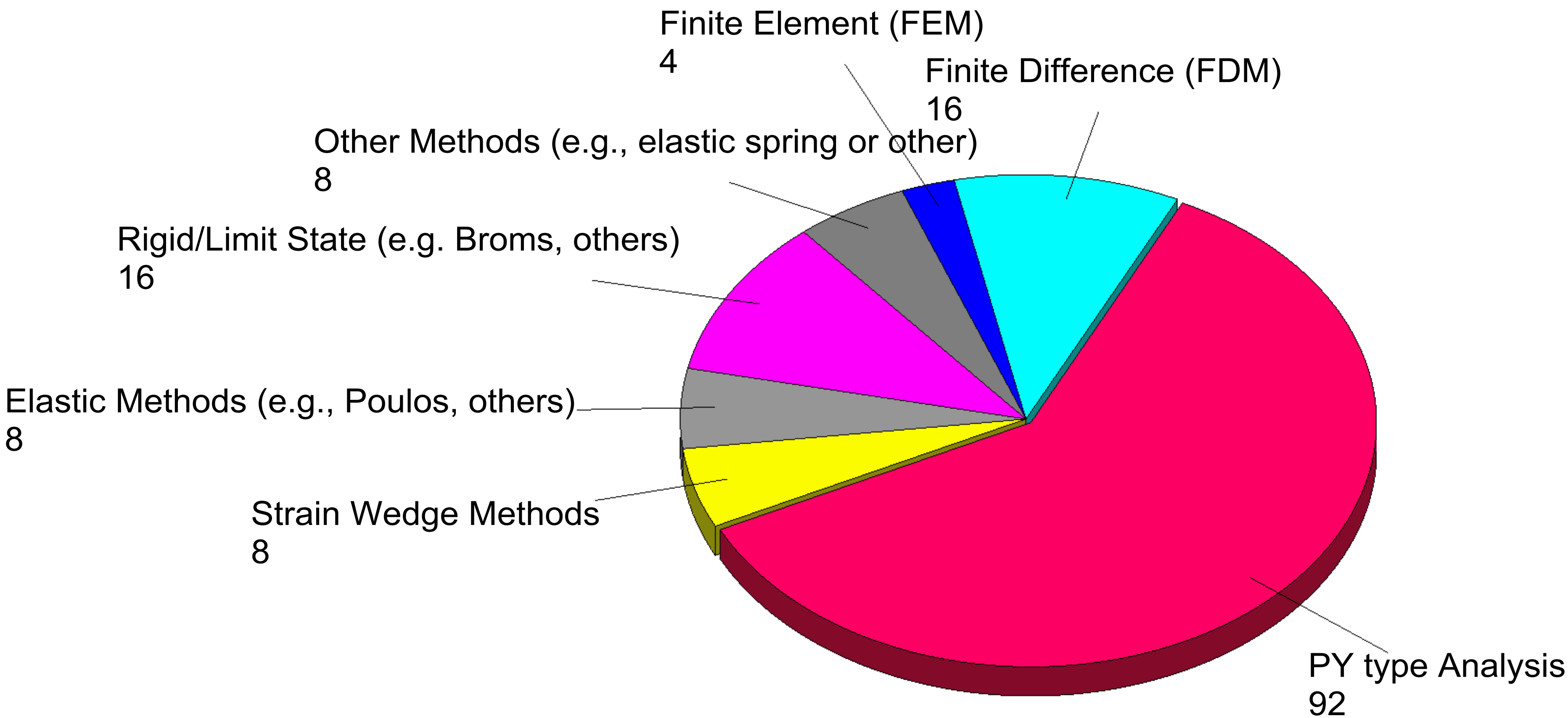
Which industrial application is your work/design mostly related to?

Answers in % of all responders, multiple choice



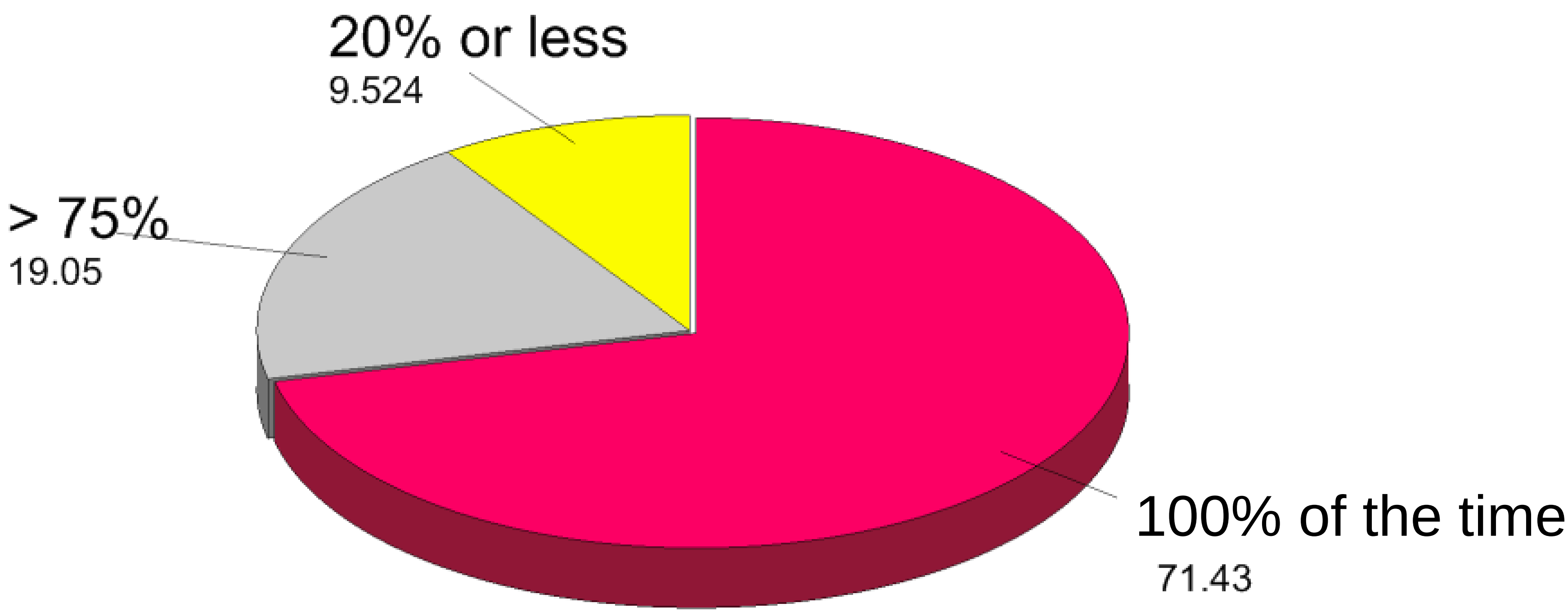
** Please note: responders were able to select multiple answers (chart will not add up to 100%)*

Which type of analysis methods do you use for your lateral deep foundation design?



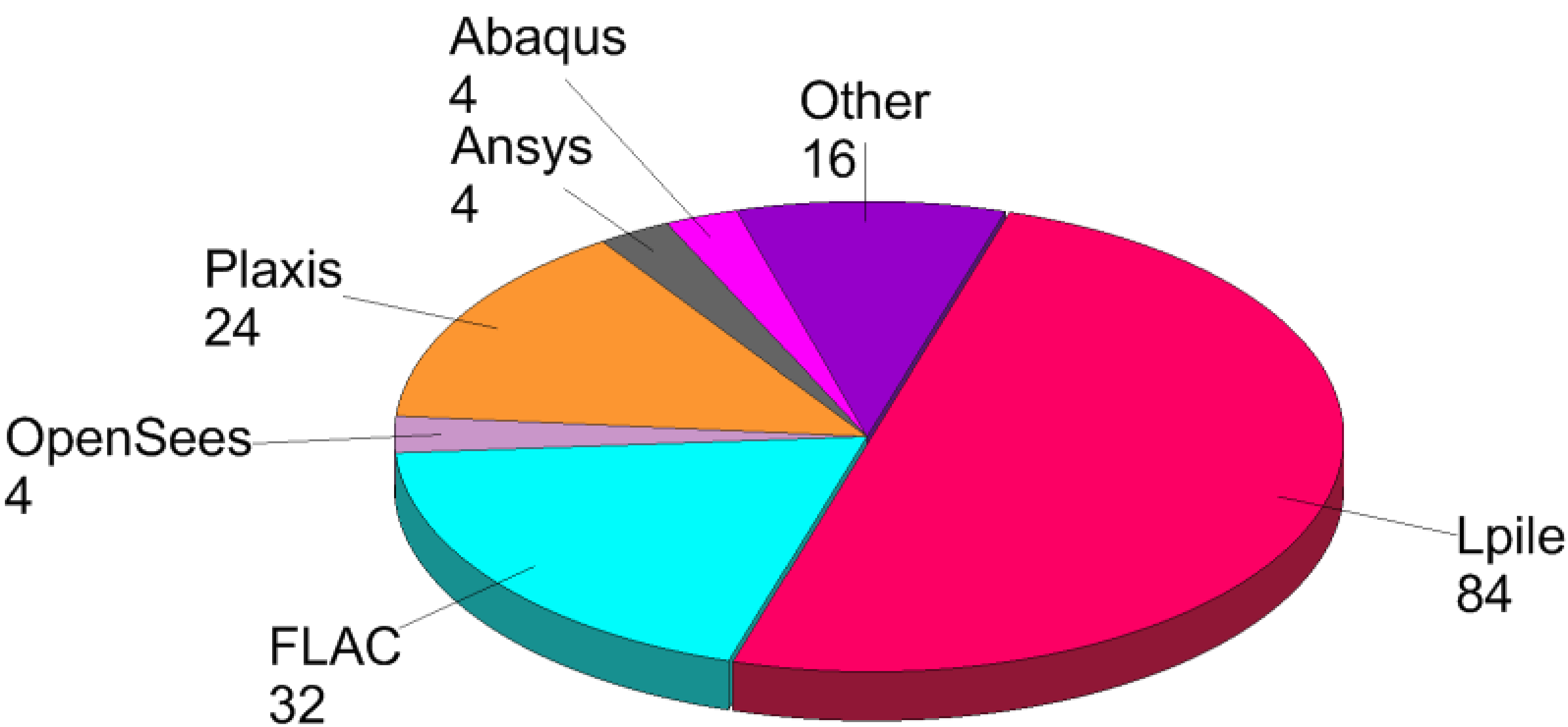
** Please note: responders were able to select multiple answers (chart will not add up to 100%)*

If you use the p-y method, to which % of the time to you employ this method?



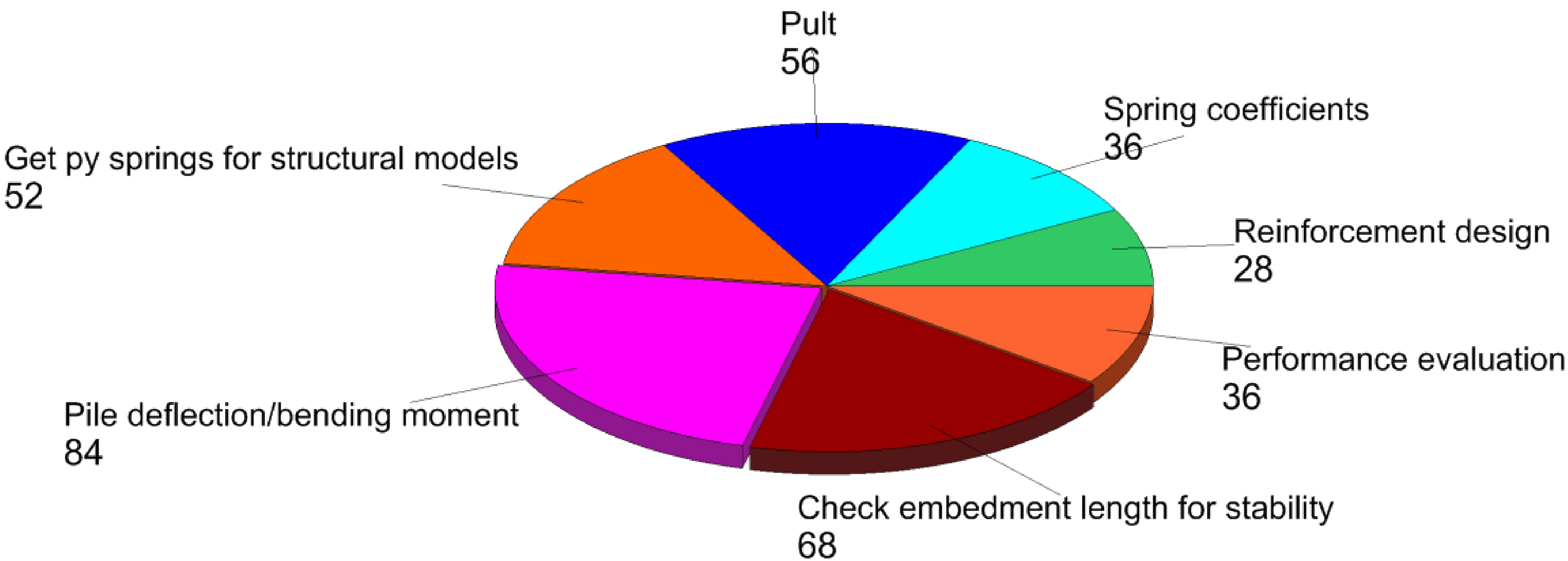
Which software do you typically use for **Single Pile** design?

Lpile
Strain Wedge
FLAC
OpenSees
Plaxis
MFAD
Ansys
Abaqus
Other



** Please note: responders were able to select multiple answers (chart will not add up to 100%)*

How are the results of your lateral pile analysis used?



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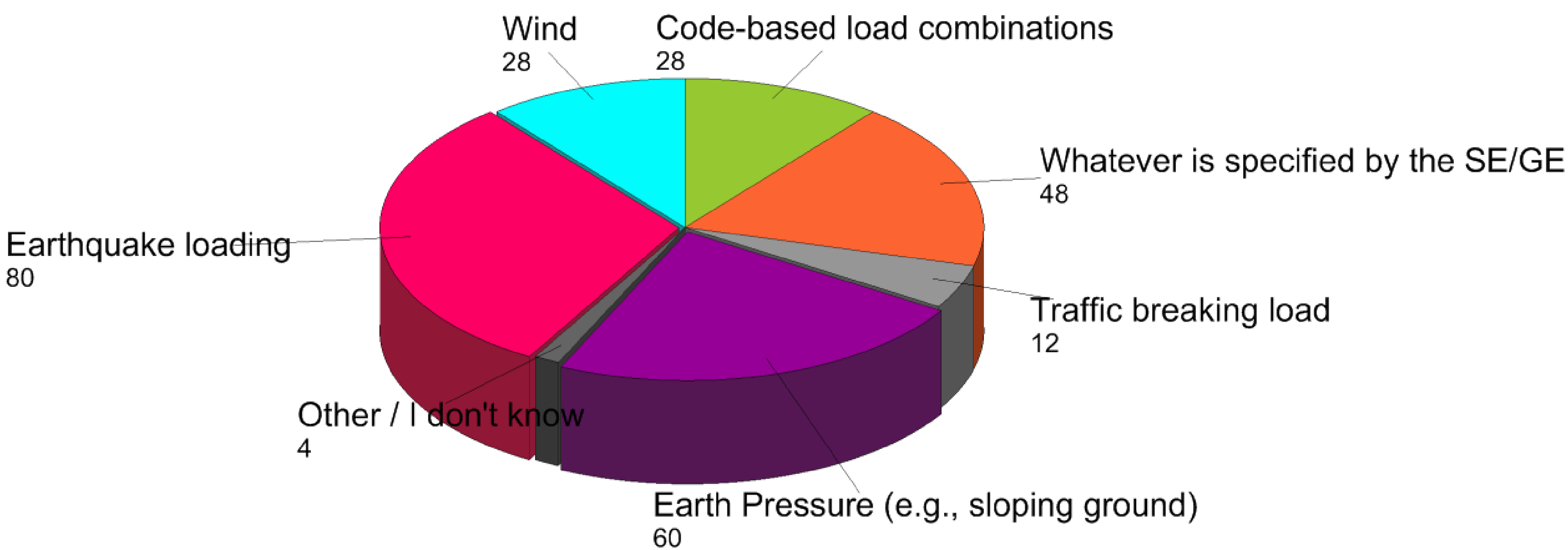
What type of lateral loading do you primarily use in your analysis?



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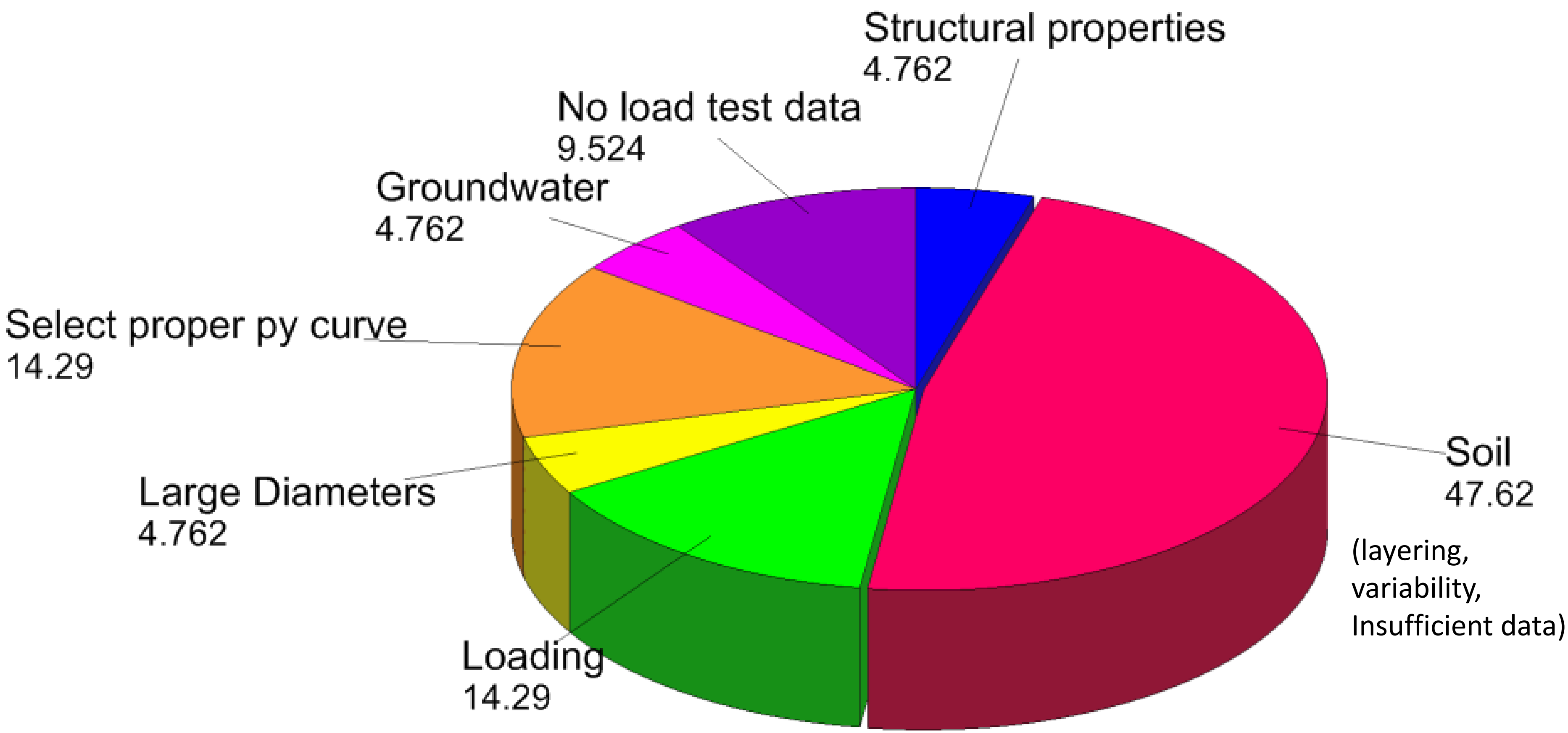
What are the primary sources of uncertainty during your lateral foundation analysis and design? (open ended question)



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GEOTECHNICAL ENGINEERING CIRCULAR: DESIGN, ANALYSIS, AND TESTING OF LATERALLY LOADED DEEP FOUNDATIONS THAT SUPPORT TRANSPORTATION FACILITIES - 90% DRAFT REPORT

CONTRACT NO. DTFH6114D00047-5013
SEPTEMBER 2017

U.S. Department of Transportation
Federal Highway Administration

Online tool for literature review: Database of lateral load tests