

# **Pile/Shaft Design Using Artificial Neural Networks (i.e. Genetic Programming) with Spatial Variability Considerations**

FDOT Contract No.:

BDK-75-977-68

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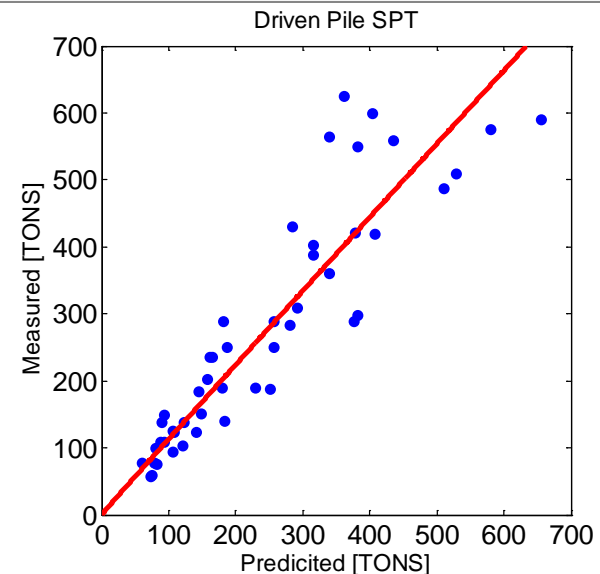
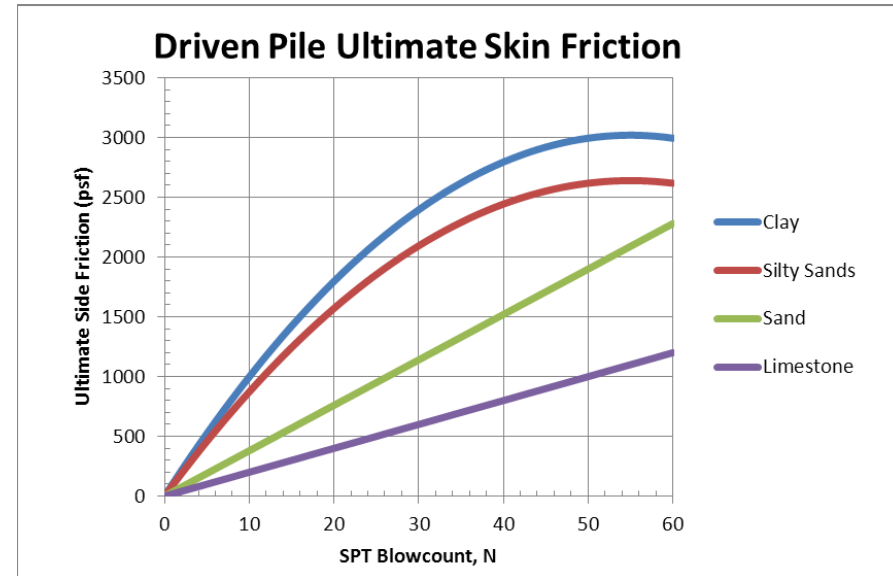
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# Scope

- Improvement of prediction equations (side and tip resistance) used by FB-DEEP for both prestressed concrete piles and drilled shafts.
- Optimizing prediction equations by use of a Genetic Program (GP) from site insitu and load test data.



# Research Tasks

1. Data Collection
2. Development of Genetic Code to improve Pile/Shaft predictions
3. Inclusion of Spatial Variability in assessment of Pile/Shaft Capacity Equations
4. Development and Evaluation of Pile Capacity Equations from Insitu Data
5. Final Report and Database Upload

# Data Collection

- Geotechnical Reports
  - SPT Boring Logs
  - Lab Test for Rock
    - $q_u$  - unconfined compressive strength
    - $q_t$  - split tensile
    - E - Modulus
    - REC/RQD – Recovery
- Load Test Reports
  - Drilled Shafts and Driven Piles
  - Static
  - Osterberg
  - Statnamic

# FDOT Database

- Standardize format
- Organize site data based on hierarchy structure
  - Project
    - Bridge
      - Pier
        - Pile/Shaft
          - Load Test
  - Subsurface
    - Borings
    - Lab Data
- [fdot.ce.ufl.edu](http://fdot.ce.ufl.edu)

# Formatting Insitu Data

Insitu\_v2-01 [Compatibility Mode] - Microsoft Excel

File Home Insert Page Layout Formulas Data Review View

Clipboard Font Alignment Number Styles Cells Editing

17 1

Company

Project Name: Buckman Bridge

Section

Township

Range

Coord. System

Vertical Datum

Project #: 72001-3462

county: Duval

hole name: B-21

test date

report date

GWT elev: 2 (ft)

top of boring: -20 (ft)

ground elev: -20 (ft)

latitude

longitude

station #: 285+50

offset: 94

Reference

x coord: #N/A (ft)

y coord: #N/A (ft)

x coord: 28550.00 (ft)

y coord: 94.00 (ft)

SPT # 21 of 36

Generate elev from depth

Generate depth from elev

CLEAR CONTENTS

DELETE THIS RECORD

line #	elev. (ft)	depth (ft)	N blows	interval (in)	Soil Pre-descriptor	Soil Type	Soil Post-descriptor	USCS	AASHTO	Note
1	-22.00	2.00	0	12	BROWN	Muck/Peat	SOFT	Pt		
2	-27.00	7.00	0	12	BROWN	Muck/Peat	SOFT	Pt		
3	-32.00	12.00	0	12	BROWN	Muck/Peat	SOFT	Pt		
4	-37.00	17.00	1	12	BROWN	Muck/Peat	SOFT	Pt		
5	-42.00	22.00	1	12	BROWN	Muck/Peat	SOFT	Pt		
6	-47.00	27.00	2	12	BROWN	Muck/Peat	SOFT	Pt		
7	-52.00	32.00	2	12	BROWN	Muck/Peat	SOFT	Pt		
8	-55.00	35.00				Stratum Change				
9	-57.00	37.00	10	12	DARK TO LIGHT BROWN FINE	Sand	TO DENSE	SP		
10	-62.00	42.00	15	12	DARK TO LIGHT BROWN FINE	Sand	TO DENSE	SP		
11	-67.00	47.00	33	12	DARK TO LIGHT BROWN FINE	Sand	TO DENSE	SP		
12	-70.00	50.00				Stratum Change				
13	-72.00	52.00	20	12	GRAY FINE	Sand	COMPACT	SP-SC		
14	-77.00	57.00				Stratum Change				
15	-77.00	57.00	10	12	GRAY	Clay	STIFF	CH		
16	-80.00	60.00				Stratum Change				
17	-82.00	62.00	39	12	GRAY TO BROWN FINE	Sand	VERY	SP		
18	-87.00	67.00	35	12	GRAY TO BROWN FINE	Sand	VERY	SP		
19	-92.00	72.00	70	12	GRAY TO BROWN FINE	Sand	DENSE TO V	SP		
20	-97.00	77.00	70	12	GRAY TO BROWN FINE	Sand	DENSE TO V	SP		
21	-102.00	82.00	52	12	GRAY TO BROWN FINE	Sand	DENSE TO V	SP		
22	-105.00	85.00				Stratum Change				
23	-107.00	87.00	14	12	BLUE	Clay	STIFF	CH		
24	-110.00	90.00				Stratum Change				
25	-112.00	92.00	31	12	BLUE	Clay	WITH SAND,	CH		
26	-115.00	95.00				Stratum Change				
27	-117.00	97.00	49	12	GRAY	Sand	WITH CLAY	SP-SC		
28	-122.00	102.00	51	12	GRAY	Sand	WITH CLAY	SP-SC		

SPT N

Average: -1.75 Count: 9 Sum: -7 90% 6

# Formatting Load Test Data

**Sample**

Project No.  Name

Bridge No.

Pier Name

Pile Name   As Built

Pile Type

Description

Pile Elastic Modulus (ksi)

Void Diameter (in)

Width or Diameter (in)

Cross Sectional Area (in^2)

Total Length (ft)

Embedment Length (ft)

Pile Weight (kip)

Concrete Strength (ksi)

Station

Offset

Company  LT Type

Load	Disp 2	Disp 4
0.00		0.00
13.00		0.00
18.40		0.01
32.80		0.01
51.00		0.02
67.20		0.03
85.20		0.03
103.00		0.04
121.80		0.05
138.80		0.07
156.60		0.08
175.20		0.10
194.00		0.11
210.80		0.13
227.80		0.16
246.60		0.19
265.60		0.24
283.40		0.31

Select Record :

- Pier = 14, Pile = LT2
- Pier = 16, Pile = LT4
- Pier = 25, Pile = LT3
- Pier = 3, Pile = LT1

Static LT Comments :

Load Vs Disp4

# Driven Pile Datasets

Project Site	Project Number	Borings (Firm)	Load Tests (Firm)	No. Borings	No. Load Tests	Foundation		
						Dimension (in.)	Pile (Concrete/Steel)	Length (ft)
5th St. Bascule Bridge	412808-1-52-01	Mactec	Applied Foundations	7	4	18	Concrete	55
Acosta Bridge	72160-3506	Law Engineers	Schmertmann & Crapps	53	3	24	Concrete	39-67
Apalachicola Bay	49010-3536	F.D.O.T.	Schmertmann & Crapps	28	5	18-24	Concrete	68.2-123.7
Apalachicola River	49010-3533	F.D.O.T.	Schmertmann & Crapps	33	4	18-30	Concrete	65.2-93.2
Bayou Chico	48050-3536	F.D.O.T.	Williams Earth Sciences Inc.	7	3	24	Concrete	46-87
Blackwater Bridge (I-10)	58002-3449	Williams Earth Sciences Inc.	Williams Earth Sciences Inc.	4	2	24	Concrete	115
Buckman Bridge	72001-3462	Ardaman & Associates	Schmertmann & Crapps	40	8*	30	Concrete	104.5-121
Caminida Bay	061-01-0040	Applied Foundations	LA D.O.T.	4	2	30	Concrete	55-60
Choctawhatchee	60040-3527	F.D.O.T.	Schmertmann & Crapps	35	10	24-30	Concrete	69-125
Dixie Highway	230656-1-52-01	PSI	Applied Foundations	22	3	24	Concrete	850

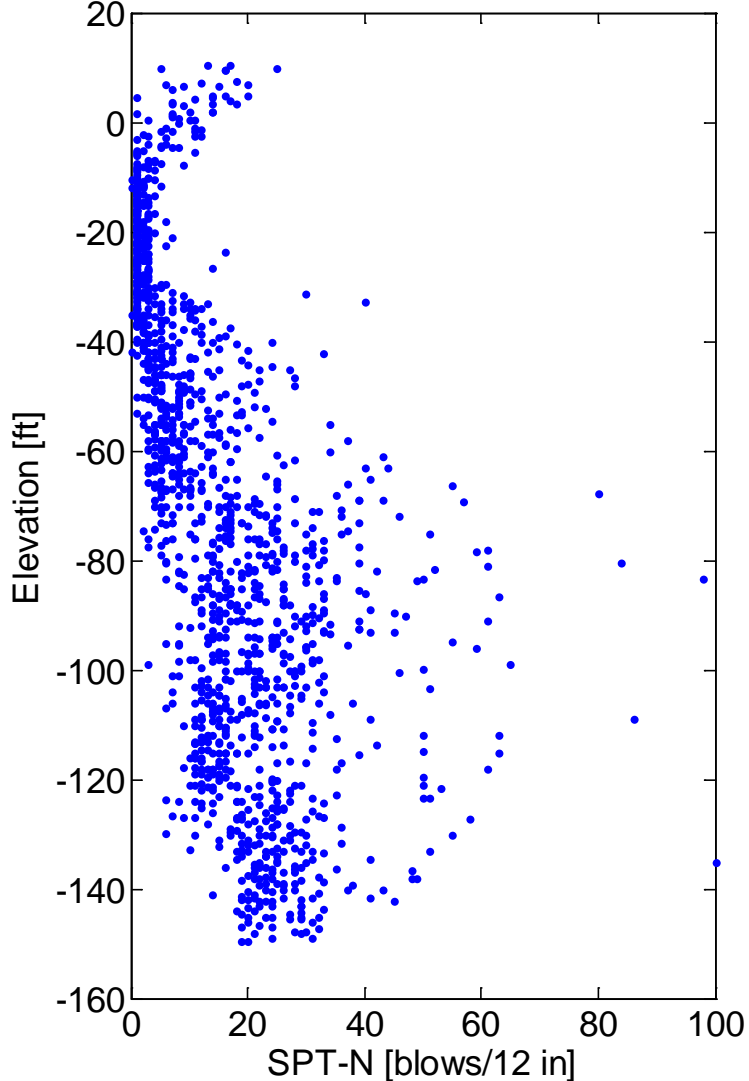
Project Site	Project Number	Borings (Firm)	Load Tests (Firm)	No. Borings	No. Load Tests	Foundation		
						Dimension (in.)	Pile (Concrete/Steel)	Length (ft)
Dodge Island	87000-3675	Law Engineers	Law Engineers	6	3*	30	Concrete	65-110
Escambia River	48140-3509/ 58080-3516	F.D.O.T.	Schmertmann & Crapps	53	2	24	Concrete	65-92
Fort Myers	12001-3513	Ardaman & Associates	HDR	5	1	14	Concrete	34.3
Howard Frankland	15190-3479	Williams and Associates	HDR	49	4	30	Concrete	52.9-101.8
Julington Creek	78070-3517	PEC	Ardaman & Associates	29	3	24	Concrete	80-95
Mantanzas River (SR 312)	78002-3509	F.D.O.T.	Williams Earth Sciences Inc.	8	4*	24	Concrete	140-150
Port Orange	79180-3514	Franco/Williams/ Dawson	Schmertmann & Crapps	11	2	18	Concrete	32.8-34.3
Roosevelt Bridge	89010-3541	Law Engineers	Law Engineers	41	2	30	Concrete	62.5-70
Sunshine Skyway	15170-3421	Williams and Associates	Schmertmann & Crapps	22	7	20-24	Concrete/Steel	38.2-79.6
West Bay Bridge	217911-5-52-01	F.D.O.T.	Dames & Moore	19	2	30	Concrete	105-130
White City Bridge	51020-3514	F.D.O.T.	Dames & Moore	16	2	24	Concrete	31-125.6
* = includes tension tests				Borings	Load Tests			
			Totals:	492	61			

# Drilled Shaft Datasets

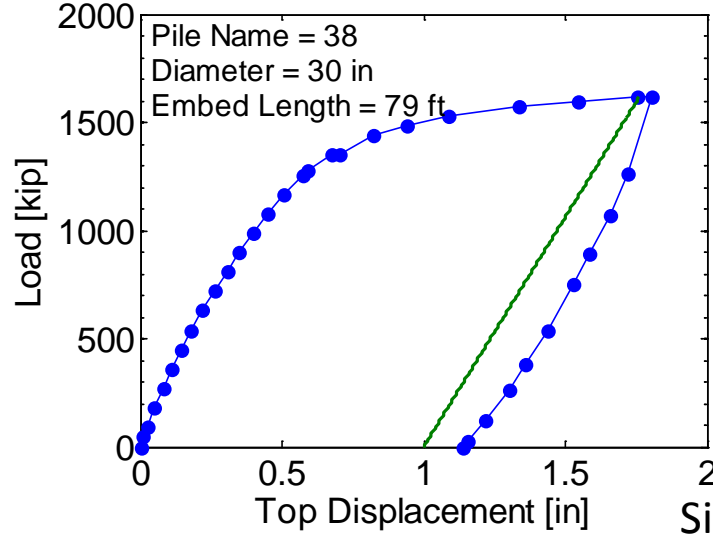
Project Site	Project Number	Borings (Firm)	Load Tests (Firm)	No. Borings	No. Load Tests	Foundation	
						Dimension (in.)	Length (ft)
Appalachicola River (S.R.20)	47010-3519/ 56010-3520	Ardaman and Associates	Schmertmann & Crapps	148	8	108	80-160
Fuller Warren	72020-1485	Law Engineering	N/A	26	4	36-72	74.5-201.5
Gandy Bridge	10130-1544	Beiswenger, Hoch & Assoc.	Williams and Associates	116	6	48	43.1-83
Macarthur Causeway	87060-1549	Law Engineering	Law Engineering	44	5	48	30.5-150
17th Street	86180-1522	Williams and Associates	LOADTEST Inc	95	3	48	40-100
Sunshine Skyway	15170-3421	Williams and Associates	Schmertmann & Crapps	22	10	24-48	38.2-79.6
Venetian Causeway	11120-158-141	Dames & Moore	Florida Testing & Engineering, Inc	17	10	48	50-82
Victory Bridge	53020-3540	F.D.O.T.	Schmertmann & Crapps	28	6	48	69-100
Lee Roy Selmon	10190-1416	PSI	Applied Foundation	504	13	48	46.7-79.9
				<b>Borings</b>	<b>Load Tests</b>		
			<b>Totals:</b>	<b>1000</b>	<b>65</b>		

# Data for Genetic Program

60040-3527 Choctawhatchee

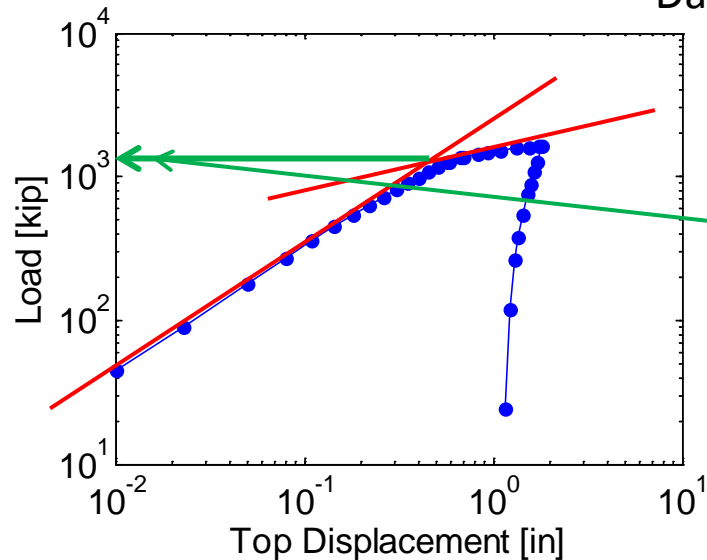


60040-3527-Choctawhatchee



Side = 1050 kips

Davisson Tip = 445 kips

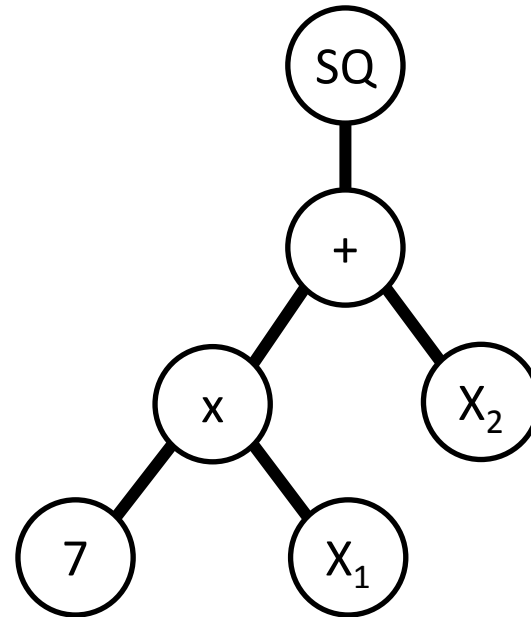


Compared to  
Telltale Data

# Genetic Program

- Optimization tool based on natural selection and evolutionary algorithms.
- Optimizes a prediction model based on a set of inputs (insitu data) and corresponding outputs (load test).
- Previous work done for driven pile models using CPT- $q_t$ , and shallow foundation settlement from SPT-N.
- Begins with generation of random population of models.

- Model represented by tree structure

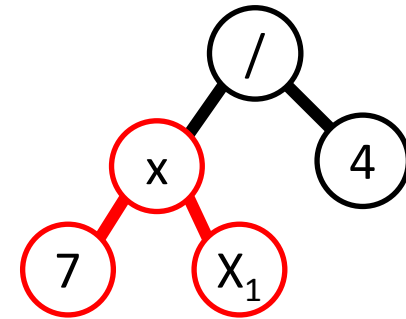
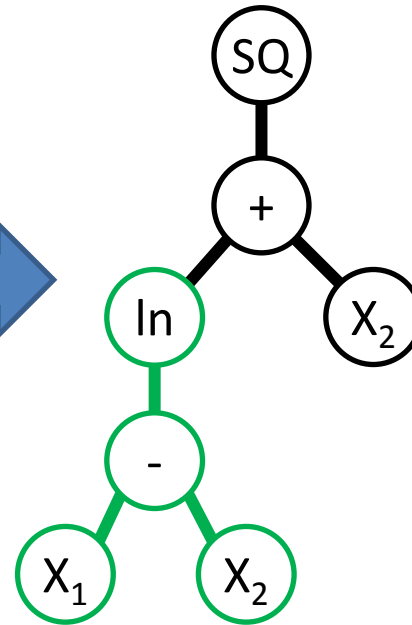
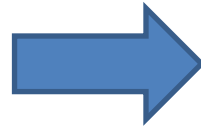
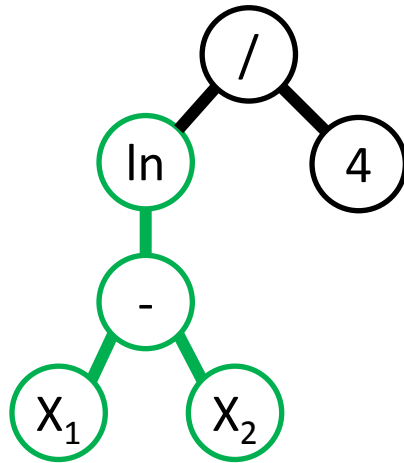
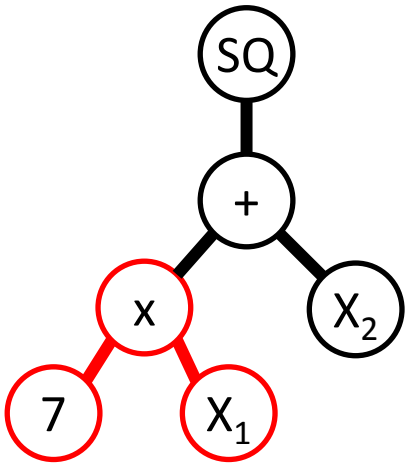


$$[7X_1 + X_2]^2$$

# Crossover

Selection of two models from the population

Resulting new models for next generation



$$[7X_1 + X_2]^2$$

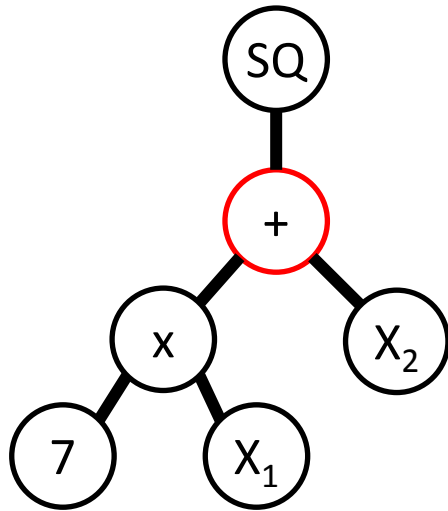
$$\frac{\ln(X_1 - X_2)}{4}$$

$$[\ln(X_1 - X_2) + X_2]^2$$

$$\frac{7X_1}{4}$$

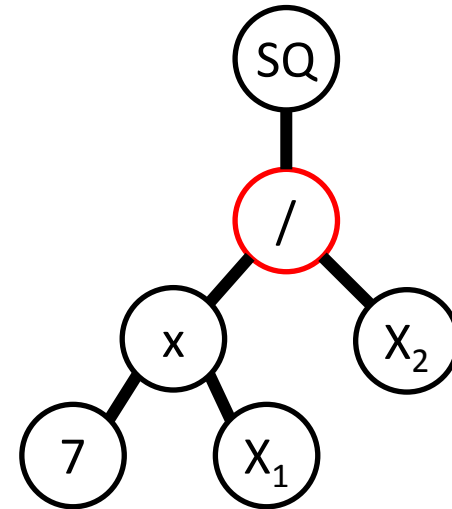
# Mutation

Selection of one model from the population



$$[7X_1 + X_2]^2$$

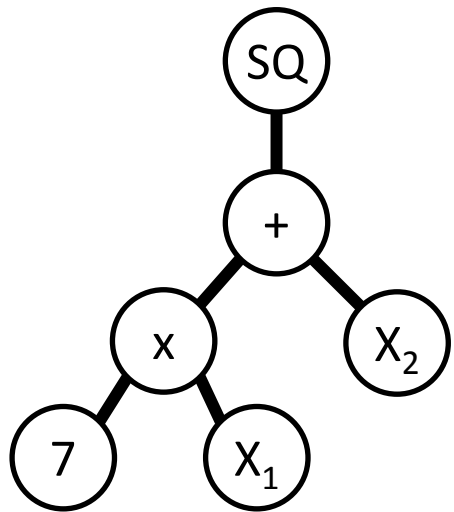
Resulting new model for next generation



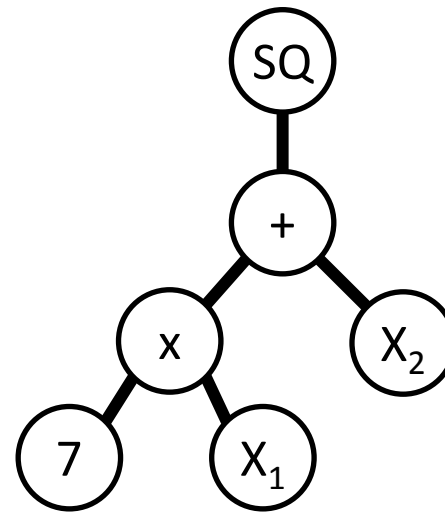
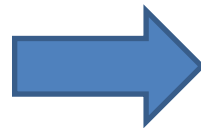
$$\left[ \frac{7X_1}{X_2} \right]^2$$

# Reproduction

- One model is selected from the population and copied over to the next generation.



$$[7X_1 + X_2]^2$$



$$[7X_1 + X_2]^2$$

# Selection Criteria/Fitness

- Need a basis for which models are selected for use in evolutionary algorithms.
- For symbolic regression can use  $R^2$ , mean squared error (MSE), etc. to quantify how well the predict model fits the measured data.
- Assign a probability of selection for model based on fitness score relative to entire.
  - i.e. Better fitting models have a higher chance of being selected.
- Repeat this process for multiple generations until optimal solution is determined.

$$MSE = \frac{1}{N} \sum (M - P)^2$$

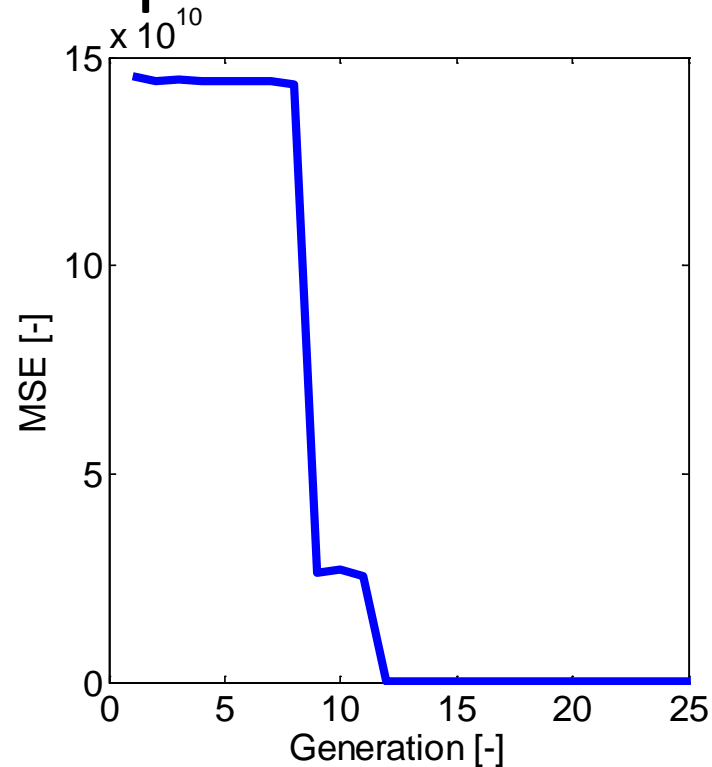
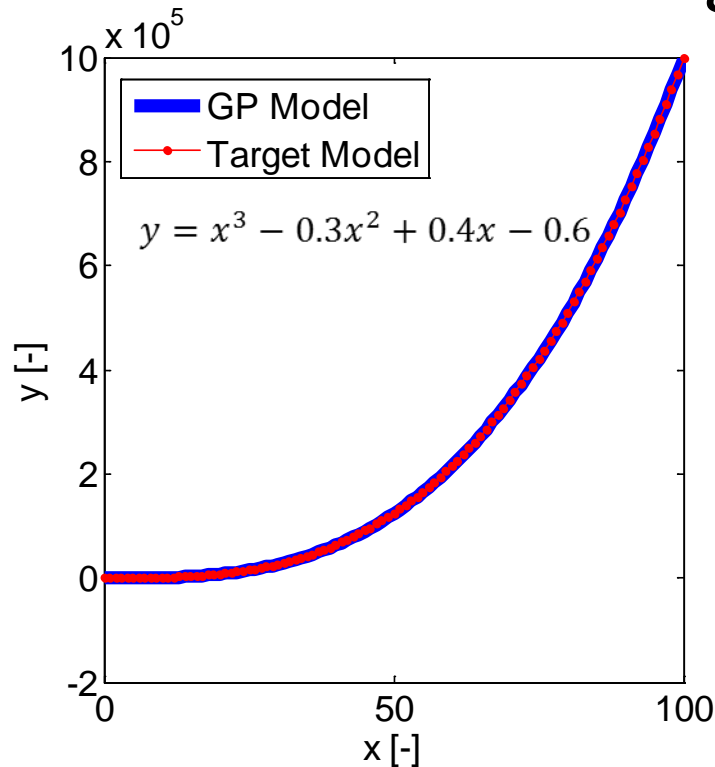
$M$  – measured value

$P$  – corresponding model prediction

$N$  – number of data points

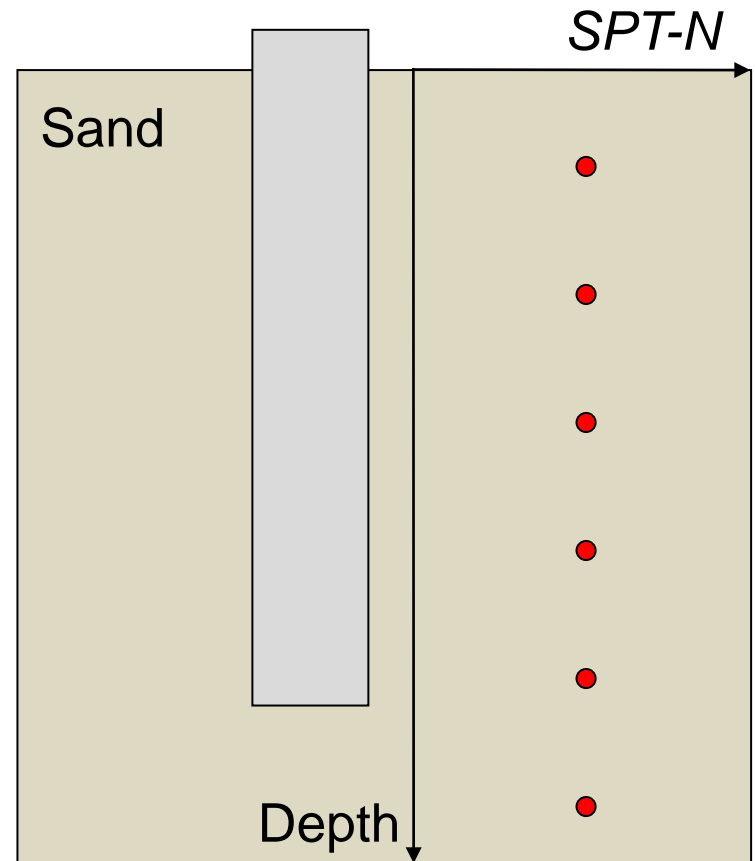
# Implementation and Validation

- Coded in MATLAB using data downloaded from the FDOT database.
- Validation for solving 1 equation.



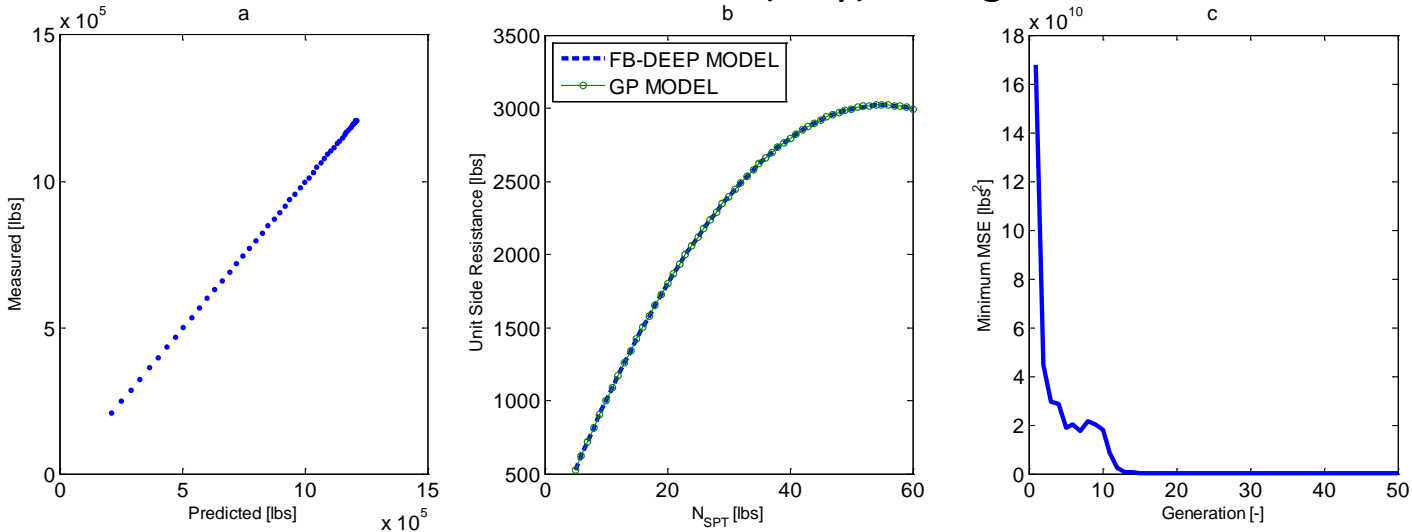
# Validation cont.

- See how well GP predicts FB-DEEP models.
- Create borings logs of uniform SPT-N blow count and soil type.
- Generate multiple profiles with different SPT-N.
- Use FB-DEEP calculation to be representative load test.

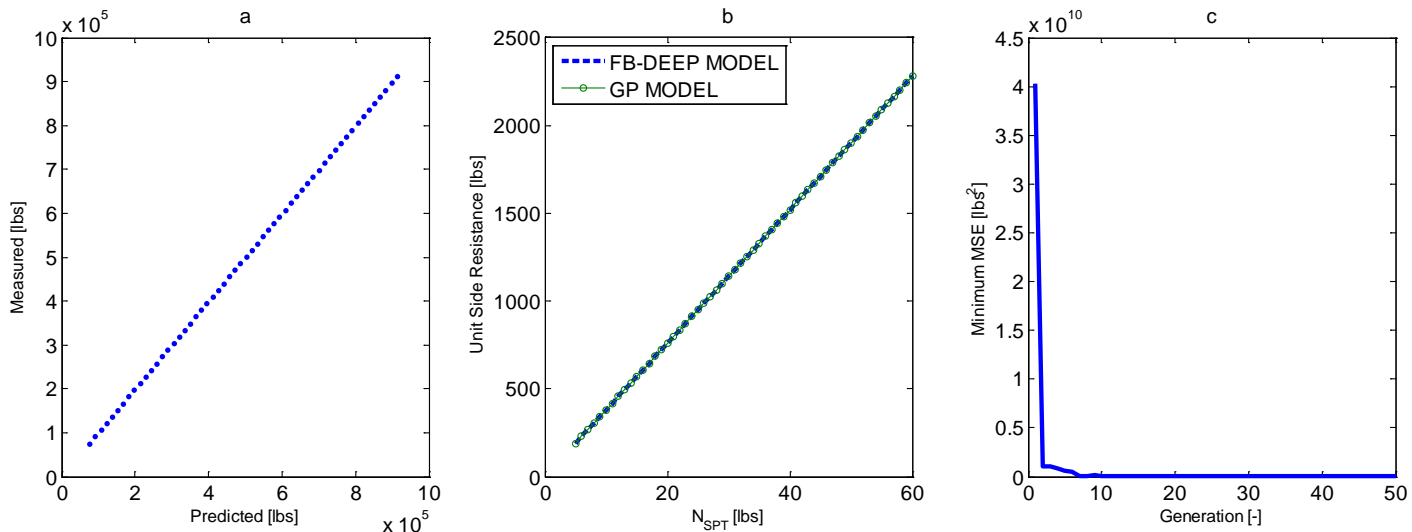


# Validation cont.

## FB-DEEP SOIL TYPE 1 (Clay) Fitting

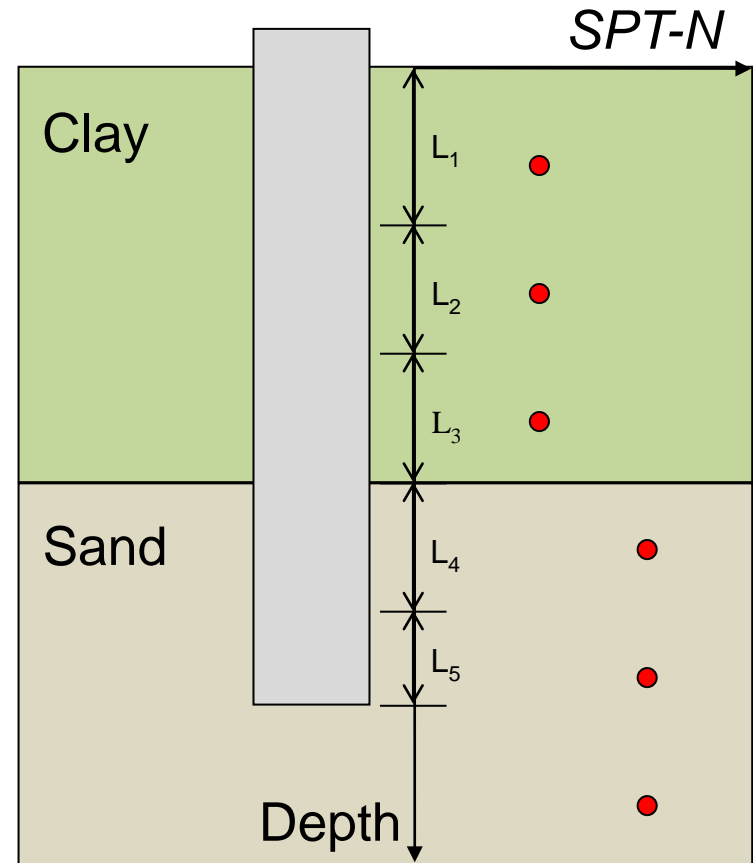


## FB-DEEP SOIL TYPE 3 (Sand) Fitting



# Validation cont.

- See how well GP predicts 2 FB-DEEP models at the same time.
- Create borings logs with 2 uniform layers of SPT-N blow count and soil type.
- Generate multiple profiles with different layering and SPT-N.
- Determine  $L_i$ , to evaluate SPT-N's contribution to side resistance.



# GP Capacity Prediction

- GP needs to account for different layering sizes as well as sample spacing.
- $L_i$  provides means to determine a weighted average.
- Driven Pile data set only provides total resistance, which side and tip can be derived from.
- GP then has to evaluate fitness based on total side resistance, when optimizing multiple soil type models.

$$\bar{f}_s = \frac{1}{\sum L_i} \sum f_{s_i} L_i$$

$$USF = P \sum \bar{f}_s \sum L_i$$

$\bar{f}_s$  – mean unit side friction of soil type

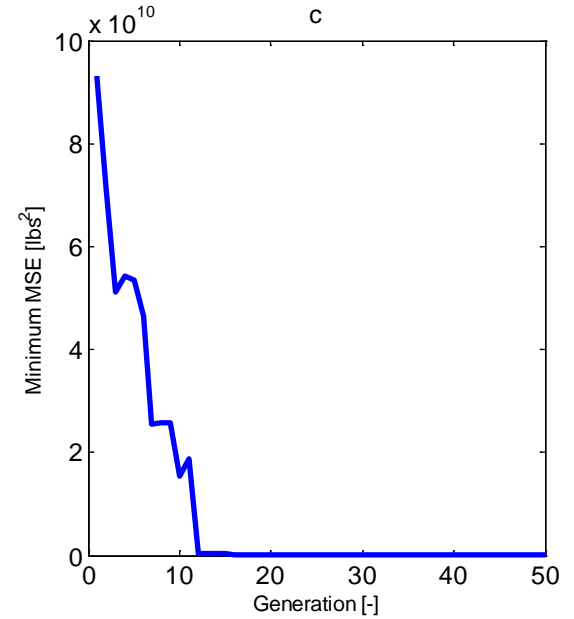
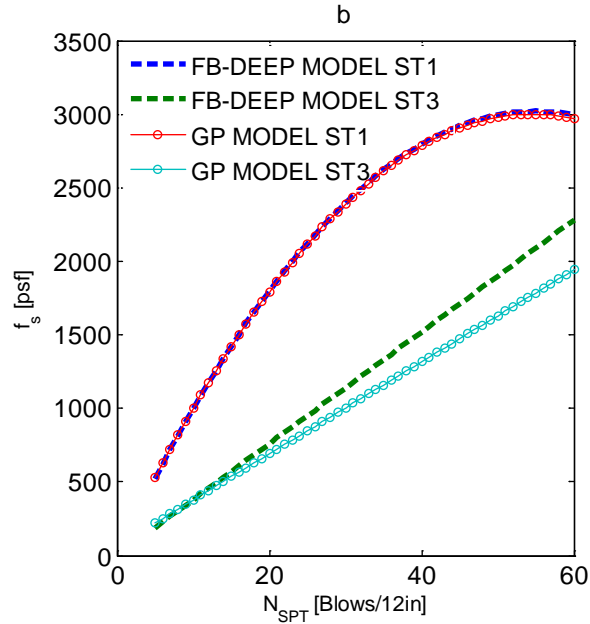
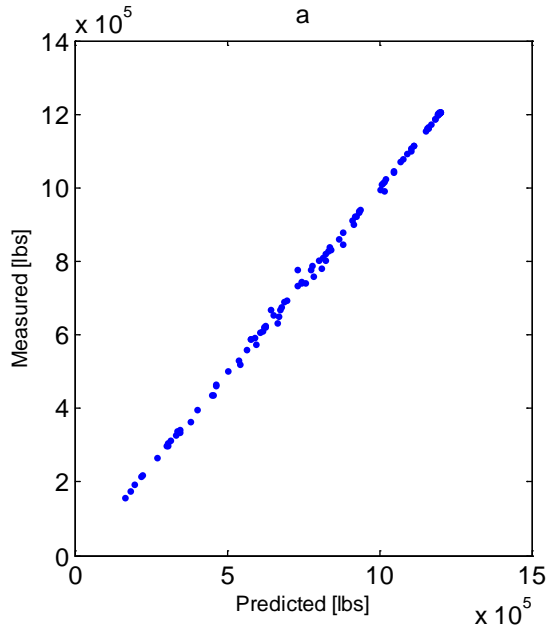
$f_{s_i}$  – unit side friction, function of soil type and SPT-N

$L_i$  – samples attributed length

$USF$  – Ultimate Side Friction of Pile

$P$  – Pile's perimeter

# Validation cont.



GP Run	ST 1 Model	ST 3 Model	MSE (lbs <sup>2</sup> )
	$f_s = 109.8N_{SPT} - N_{SPT}^2$ (psf)	$f_s = 38N_{SPT}$ (psf)	
1	$109.8N_{SPT} - N_{SPT}^2 + 5.28$	$31.3N_{SPT} - \sin(N_{SPT} + 65.5) + 65.1$	1.14e+08
2	$65.9N_{SPT}$	$38.1N_{SPT} - 3.6/\ln(N_{SPT}) + 26.6$	2.07e+10
3	$109.6N_{SPT} - \sin(\sin(14.3 - N_{SPT})) - N_{SPT}^2$	$33.2N_{SPT}$	1.25e+08

# GP with Real Data

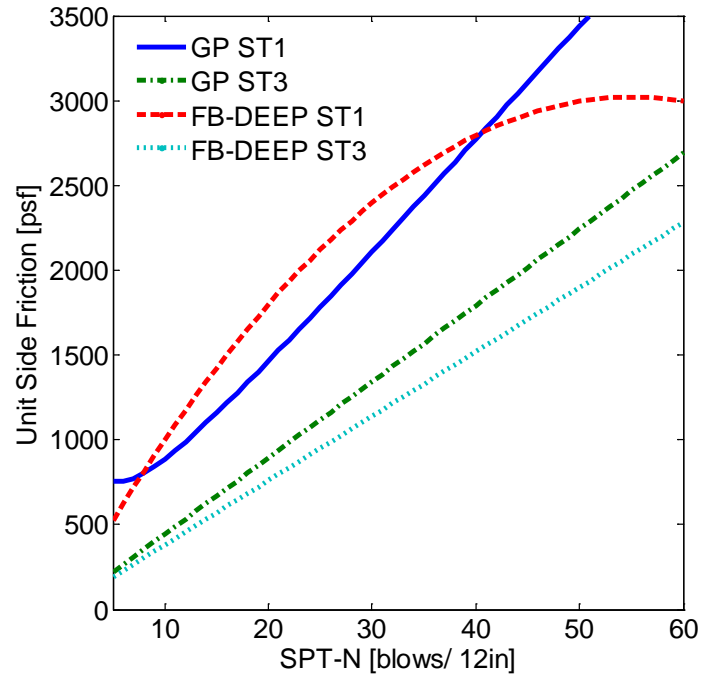
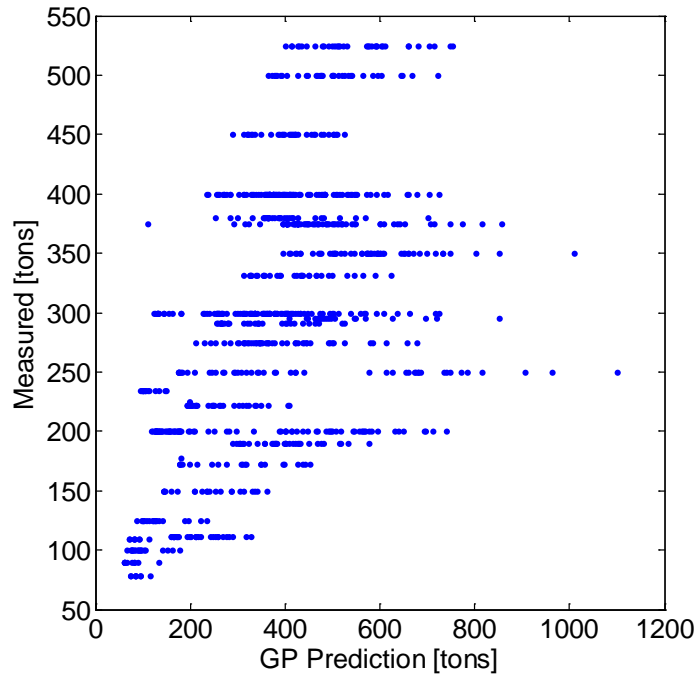
- 9 sites totaling 233 boring 34 load test.
- Ultimate side friction from load test data.
- Optimizing 2 soil type models
- Limited SPT-N to max value of 60
- For each site, ultimate side friction is evaluated for each boring and compared to the corresponding load test piles.

# Assignment of Soil Type

- First attempt fitting for cohesion and cohesionless models.
- Binning based on either USCS classification or boring log soil description.
- Automatically sorted using database fields.
- Advantages:
  - less computation time
  - Learn how GP works with real data

Soil Type 1	Soil Type 3
CL	GW
ML	GP
CL-ML	GM
CH	GC
MH	GC-GM
OL	GW-GM
OH	GW-GC
SC	GP-GM
SW-SC	GP-GC
SP-SC	SW
SM-SC	SP
SW-SM	SM
SP-SM	
Pt	

# Results



Large scatter can partially be to GP's model error and spatial variation across the site.

# Next Phase of GP Work

- Entering Additional FDOT sites into Online database
- Investigation of Different Soil/Rock descriptors
  - Refining of USCS binning.
- Task 3, inclusion of spatial variability in error assessment.
- Investigate the separation of site into multiple zones due to stratigraphy or anisotropy

# Next Phase of GP Work -cont

- Evaluate Tip resistance based on soil & rock type.
- Develops Models based on Davisson and Ultimate
- Evaluate Skin and Tip Resistance for Drilled shafts using GP

Questions?