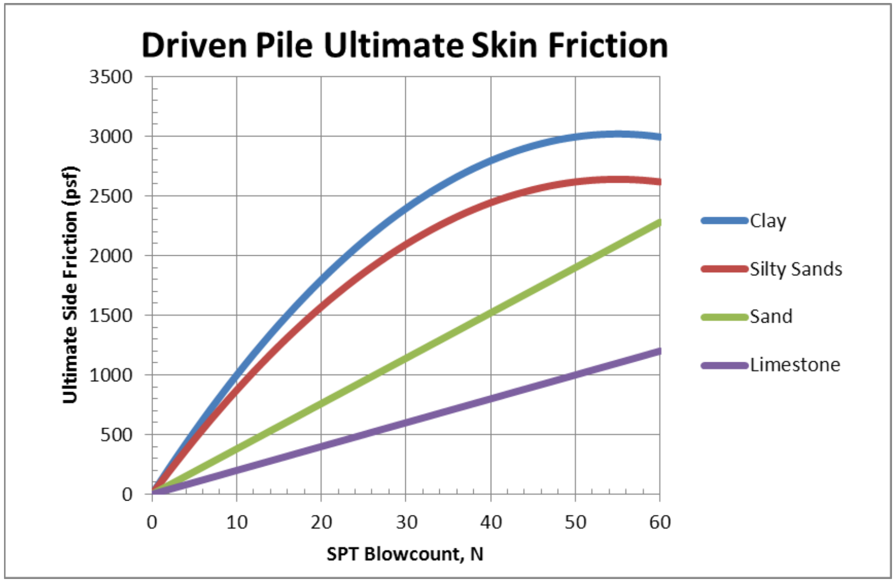
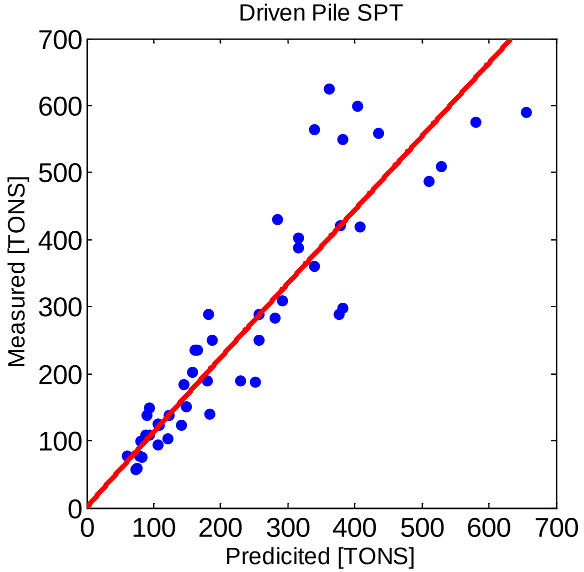
Pile/Shaft Design Using Artificial Neural Networks (i.e. Genetic Programming) with Spatial Variability Considerations

FDOT Contract No.:	BDK-75-977-68
Project Manager:	Rodrigo Herrera, PE Peter Lai, PE
Principal Investigator:	Michael McVay, PhD Khiem Tran, PhD
Primary Researcher:	Harald Klammler, PhD Michael Faraone, EI

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

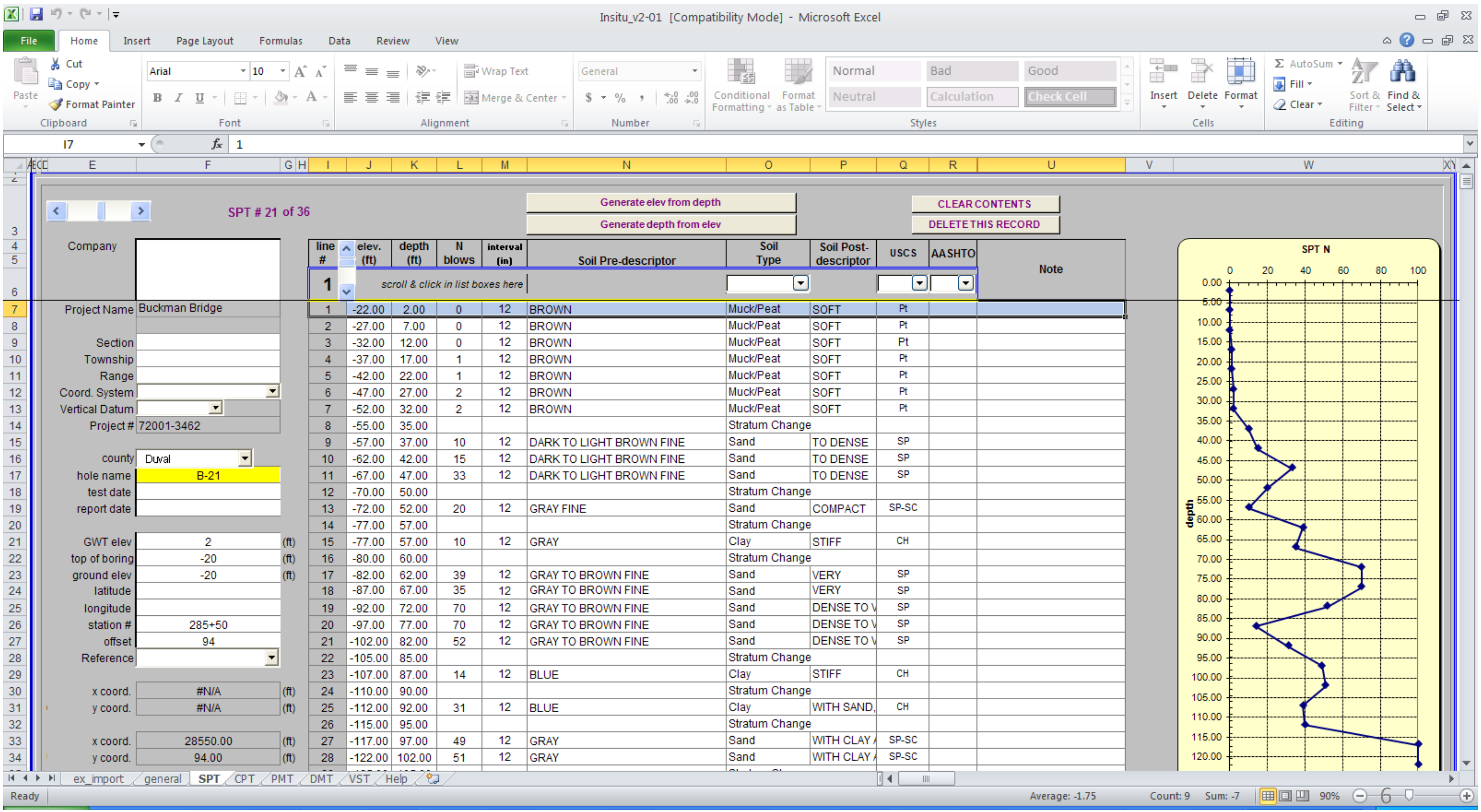
Data Collection

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

FDOT Database

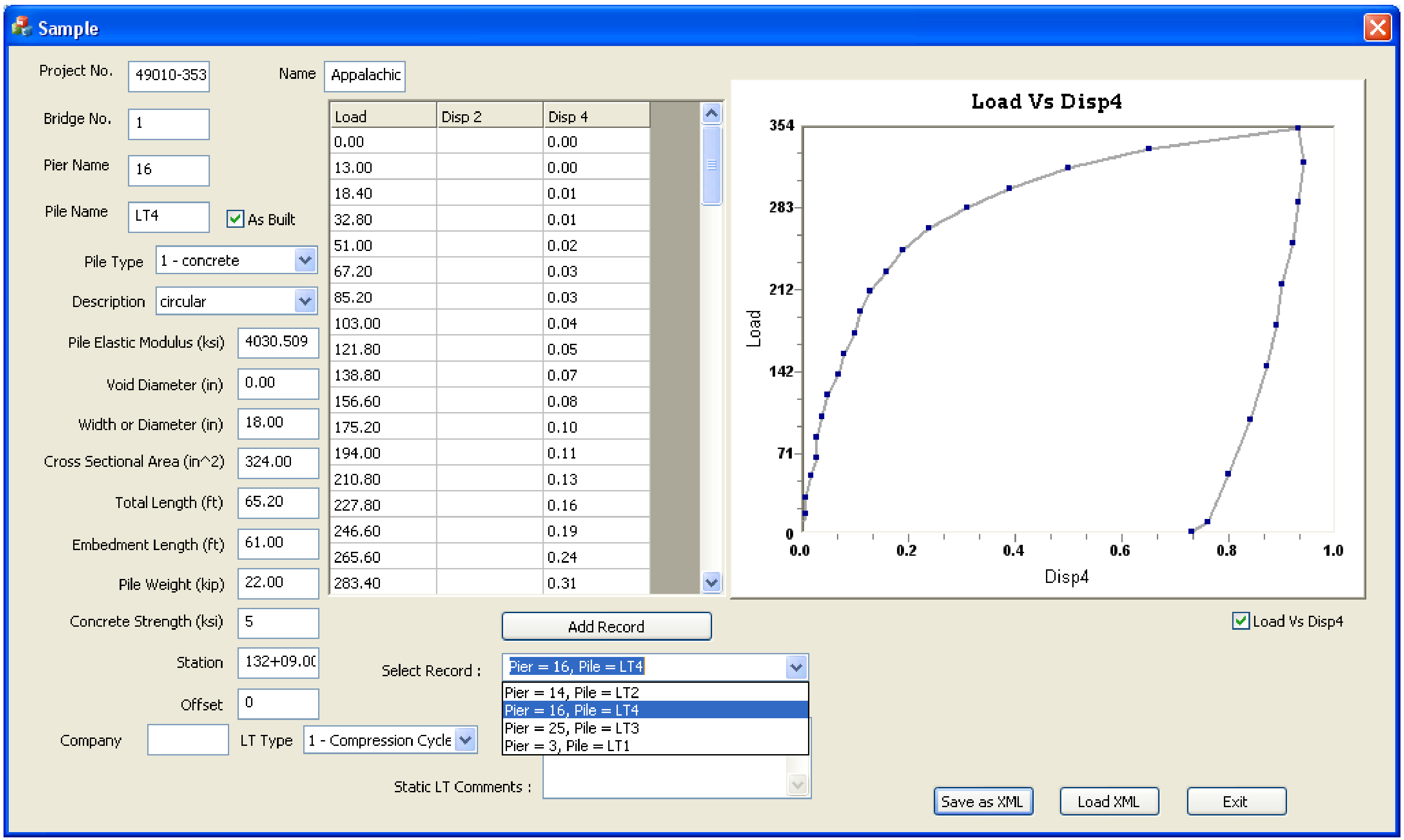
- Standardize format
- Organize site data based on hierarchy structure
  - Project
    - Bridge
      - Pier
        - Pile/Shaft
          - Load Test
    - Subsurface
      - Borings
      - Lab Data
- fdot.ce.ufl.edu

Formatting Insitu Data



line #	elev. (ft)	depth (ft)	N blows	interval (in)	Soil Pre-descriptor	Soil Type	Soil Post-descriptor	USCS	AASHTO
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	

Formatting Load Test Data



Driven Pile Datasets

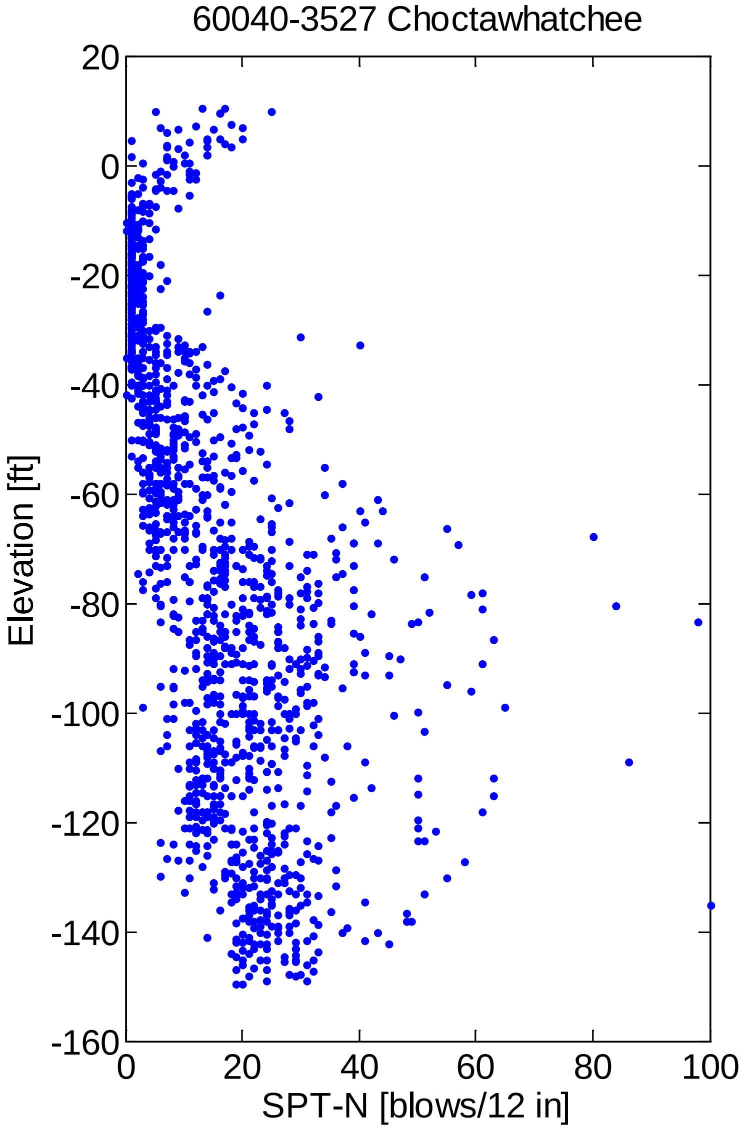
Project Site	Project Number	Borings (Firm)	Load Tests (Firm)	No. Borings	No. Load Tests	Foundation		
						Dimension (in.)	Pile (Concrete/Steel)	Length (ft)
5th St. Bascule Bridge	412808-1-52-01	Mactec	Applied Foundations	7	4	18	Concrete	55
Acosta Bridge	72160-3506	Law Engineers	Schmertmann & Crapps	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	50

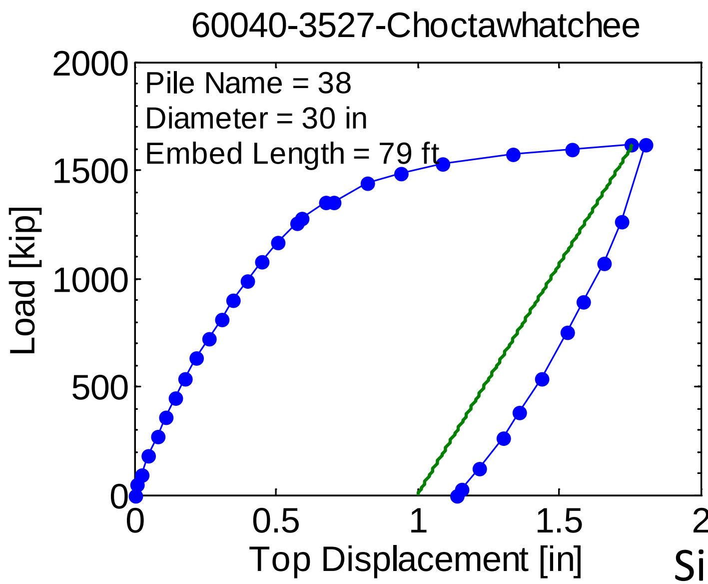
Project Site	Project Number	Borings (Firm)	Load Tests (Firm)	No. Borings	No. Load Tests	Foundation		
						Dimension (in.)	Pile (Concrete/Steel)	Length (ft)
Dodge Island	87000-3675	Law Engineers	Law Engineers	6	3*	30	Concrete	65-110
Escambia River	48140-3509/ 58080-3516	F.D.O.T.	Schmertmann & Crapps	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
				Borings	Load Tests		
			Totals:	1000	65		

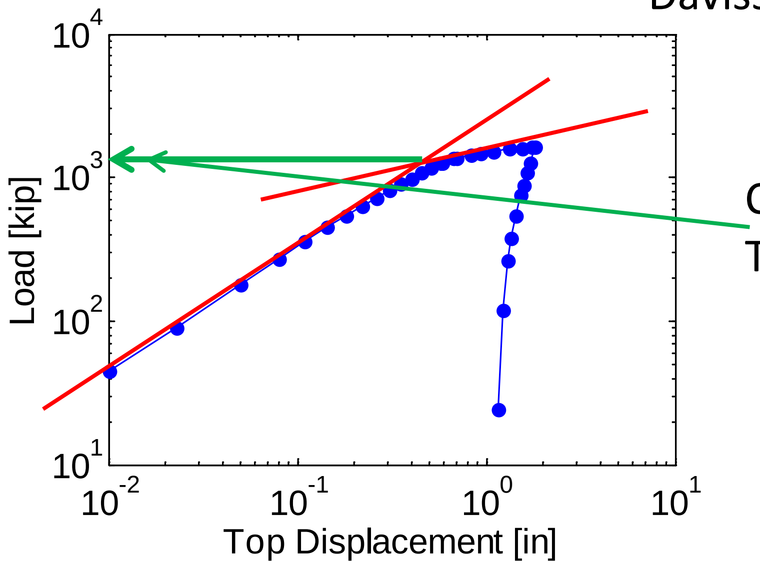
Data for Genetic Program





Side = 1050 kips

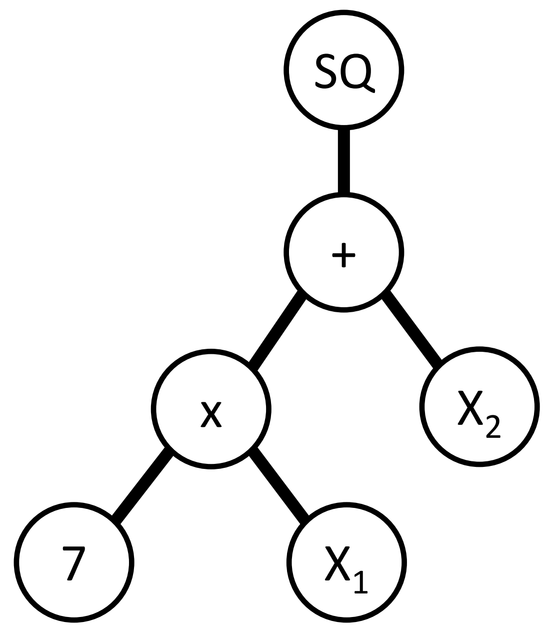
Davisson Tip = 445 kips



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

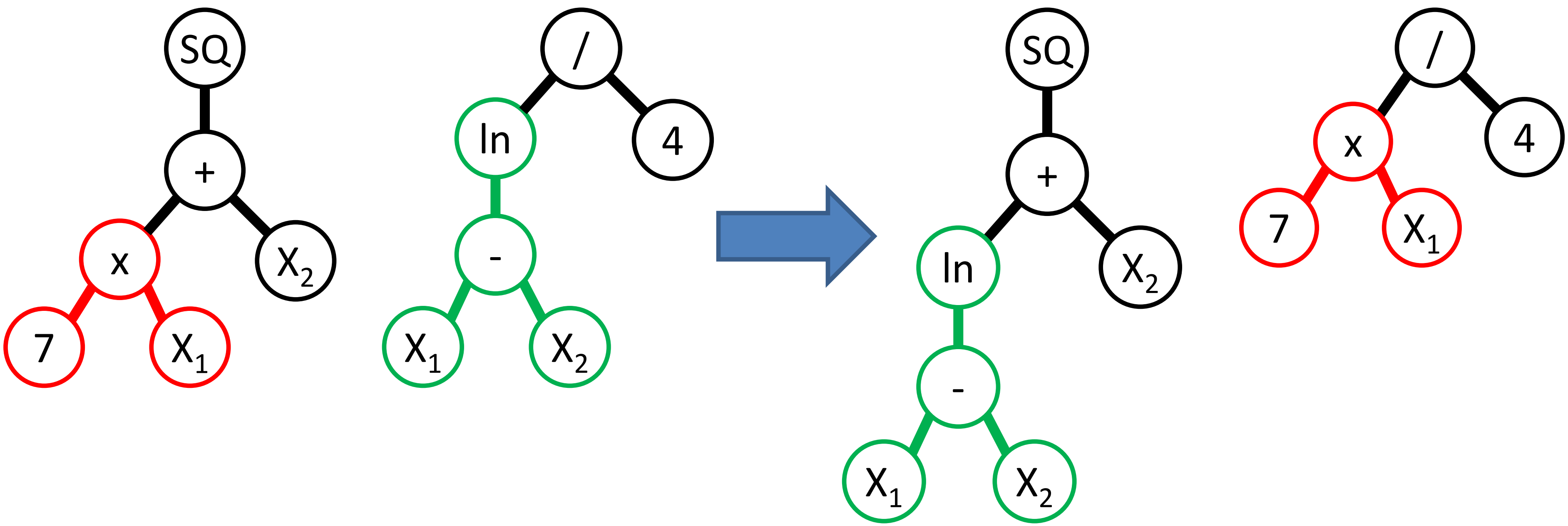


$$[7X_1 + X_2]^2$$

Crossover

Selection of two models from the population

Resulting new models for next generation

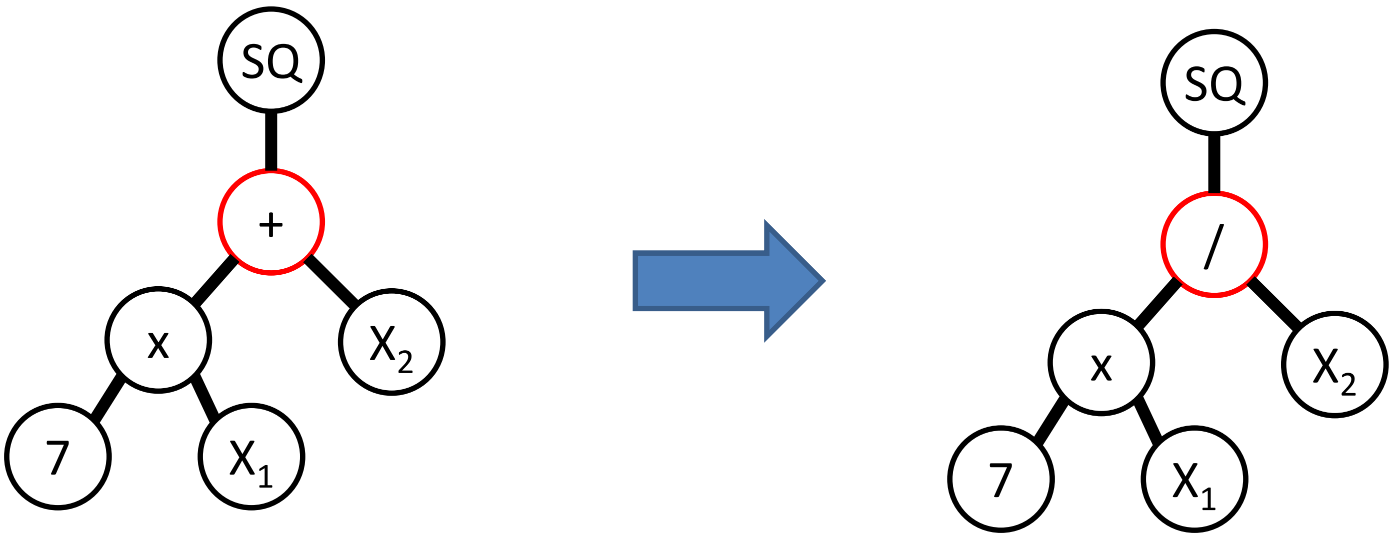


$$[7X_1 + X_2]^2 \qquad \frac{\ln(X_1 - X_2)}{4} \qquad [\ln(X_1 - X_2) + X_2]^2 \qquad \frac{7X_1}{4}$$

Mutation

Selection of one model from the population

Resulting new model for next generation

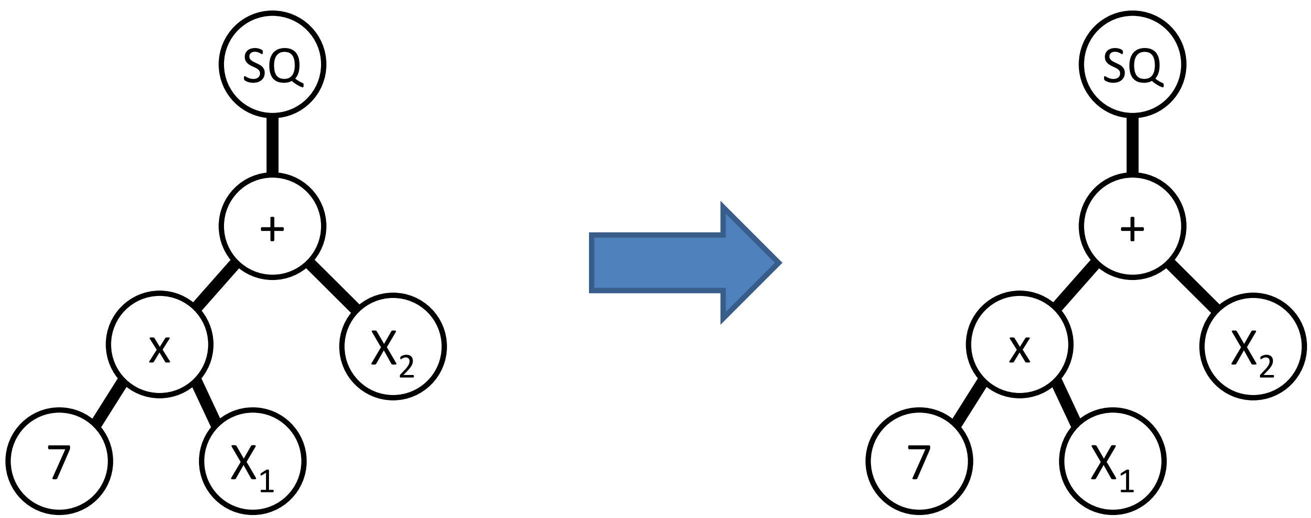


$$[7X_1 + X_2]^2$$

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

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

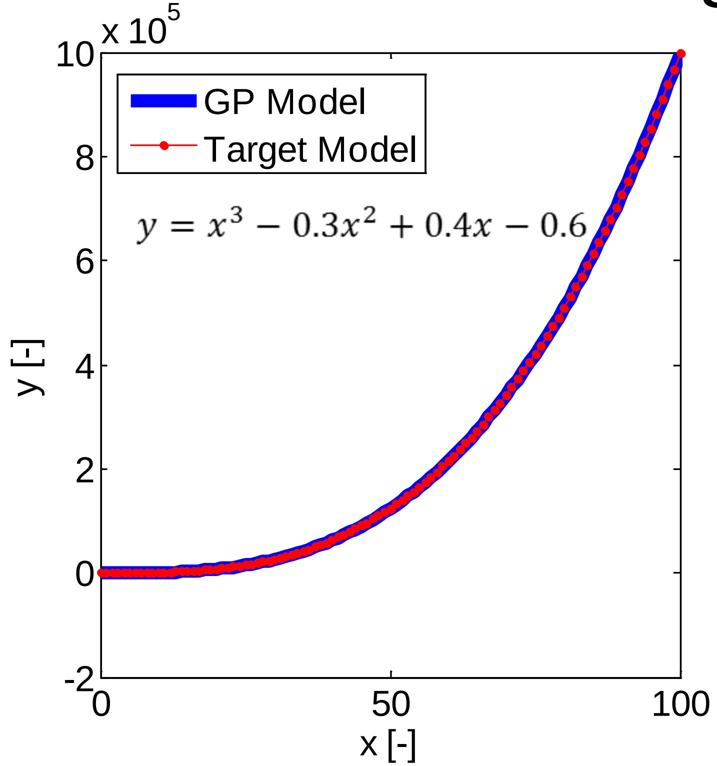
- Need a basis for which models are selected for use in evolutionary algorithms.
- For symbolic regression can use R^2, mean squared error (MSE), etc. to quantify how well the predict model fits the measured data.
- Assign a probability of selection for model based on fitness score relative to entire.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

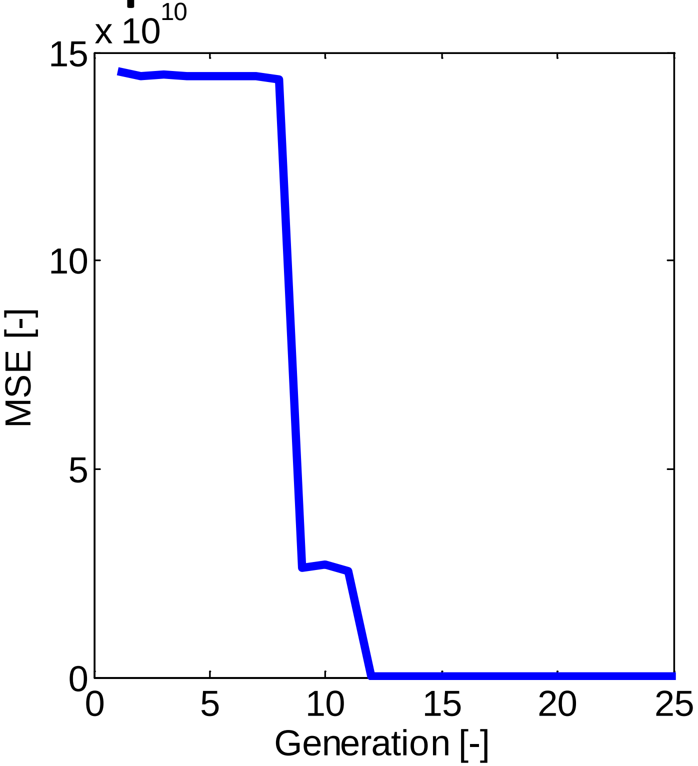
$$MSE = \frac{1}{N}\sum(M - P)^2$$

M– measured value
P– corresponding model prediction
N– number of data points

Implementation and Validation

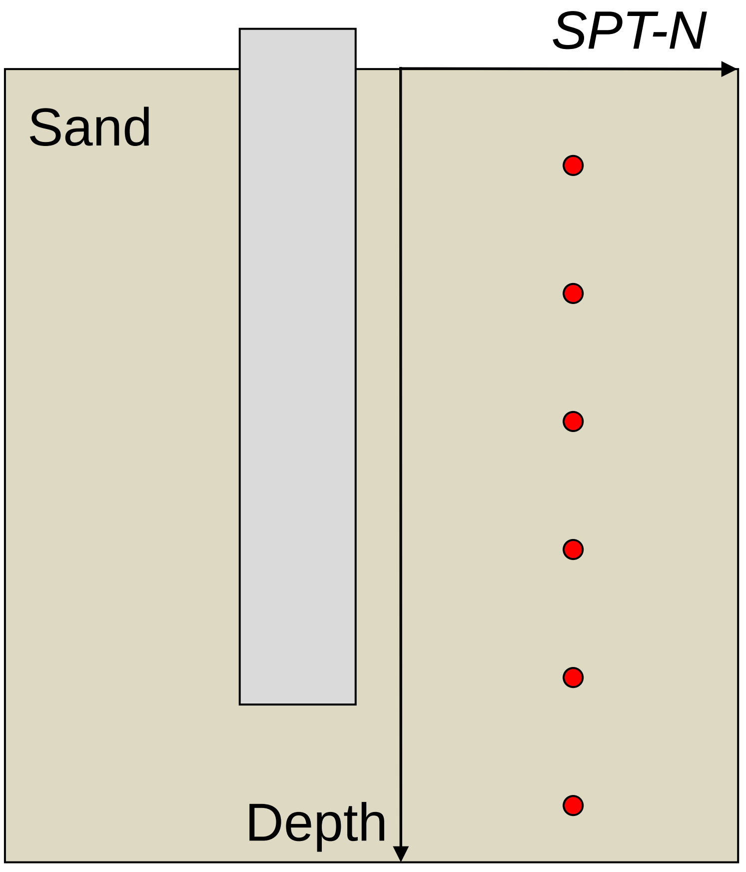
- Coded in MATLAB using data downloaded from the FDOT database.
- Validation for solving 1 equation.





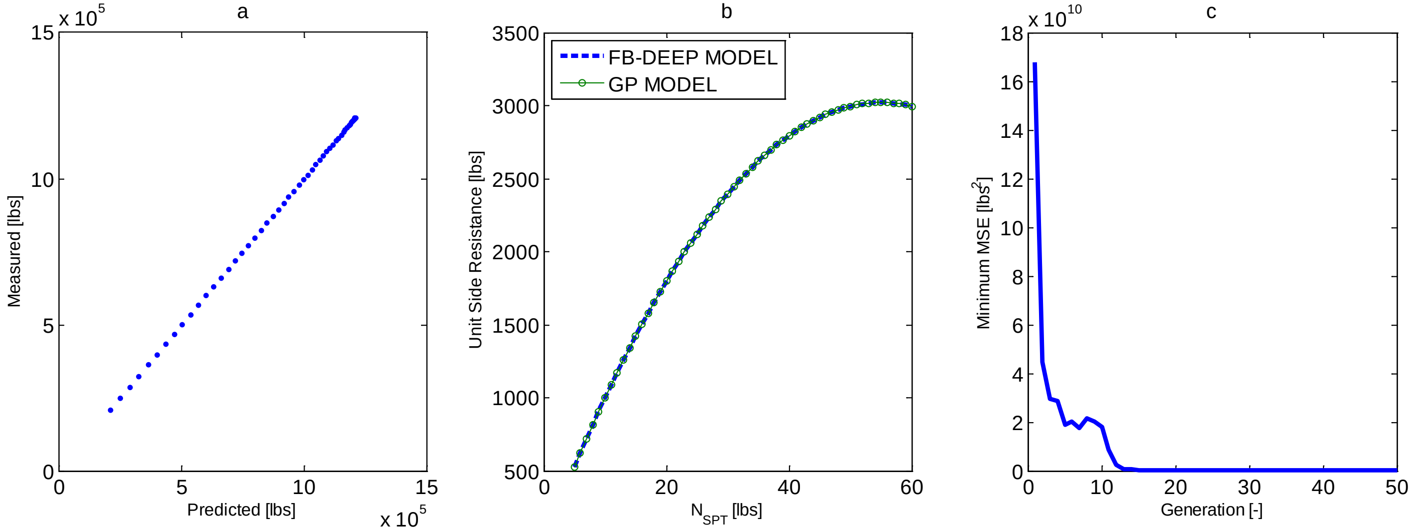
Validation cont.

- 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.

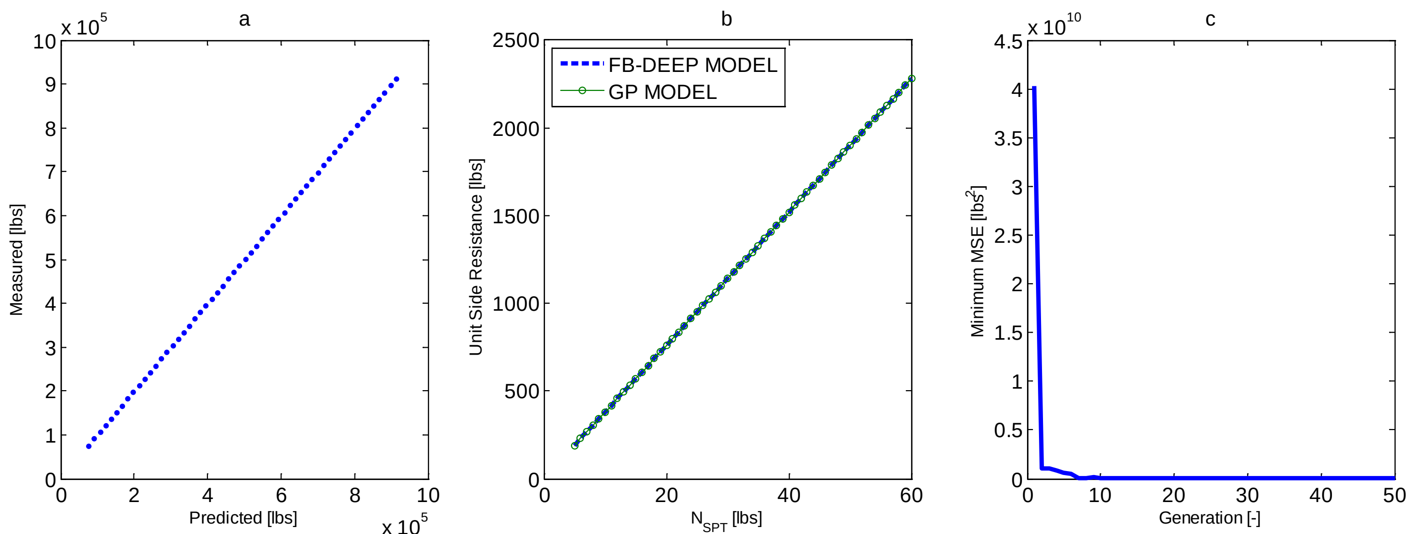


Validation cont.

FB-DEEP SOIL TYPE 1 (Clay) Fitting

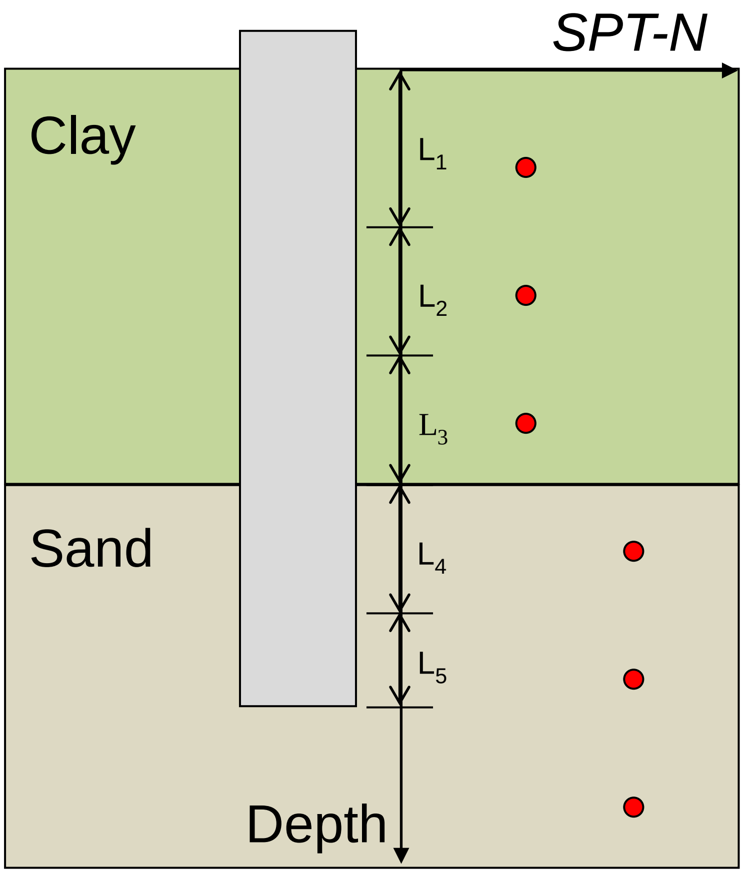


FB-DEEP SOIL TYPE 3 (Sand) Fitting



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 Li, to evaluate SPT-N's contribution to side resistance.



GP Capacity Prediction

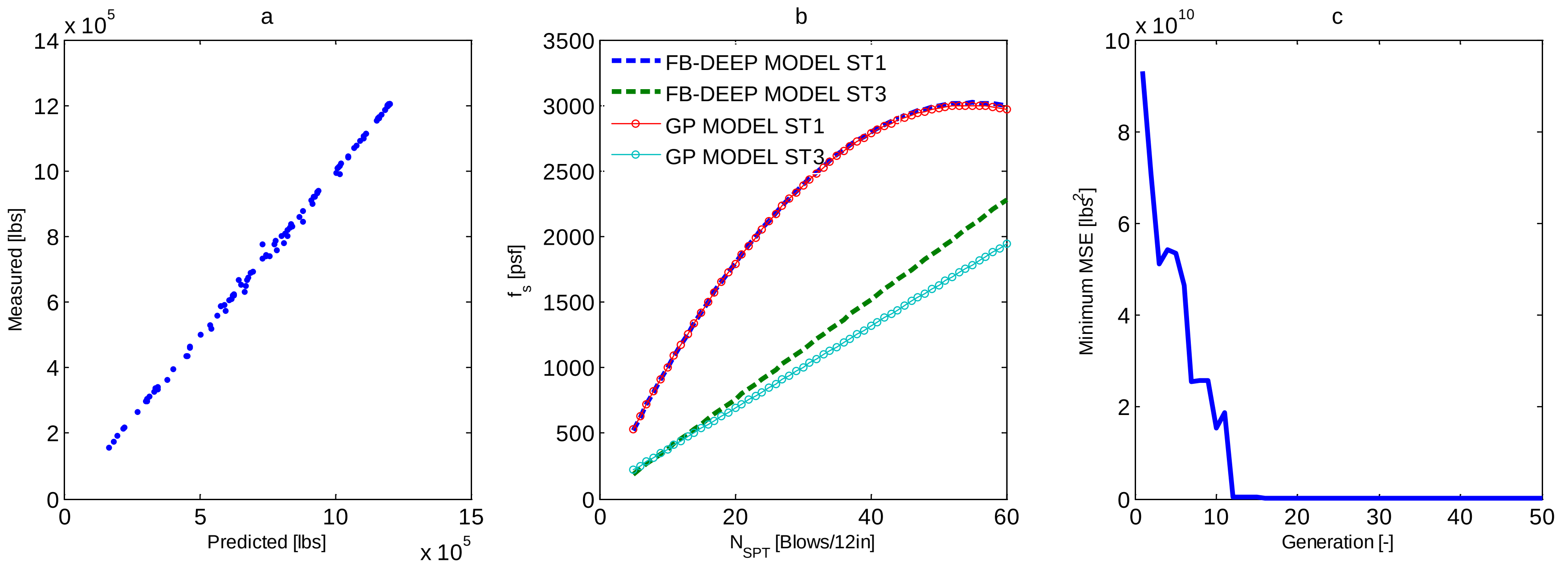
- GP needs to account for different layering sizes as well as sample spacing.
- Li provides means to determine a weighted average.
- Driven Pile data set only provides total resistance, which side and tip can be derived from.
- GP then has to evaluate fitness based on total side resistance, when optimizing 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 $f_s = 109.8N_{SPT} - N_{SPT}^2 \ (psf)$	ST 3 Model $f_s = 38N_{SPT}(psf)$	MSE (lbs²)
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

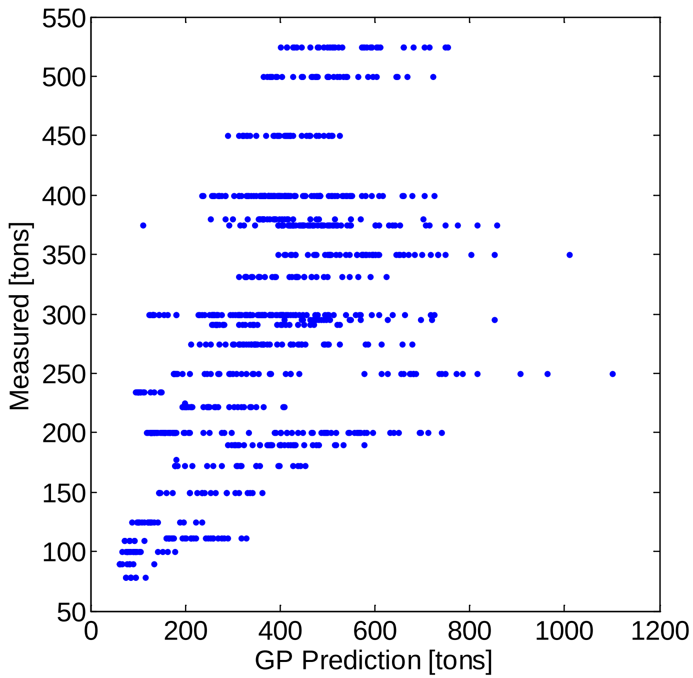
- 9 sites totaling 233 boring 34 load test.
- Ultimate side friction from load test data.
- Optimizing 2 soil type models
- Limited SPT-N to max value of 60
- For each site, ultimate side friction is evaluated for each boring and compared to the corresponding load test piles.

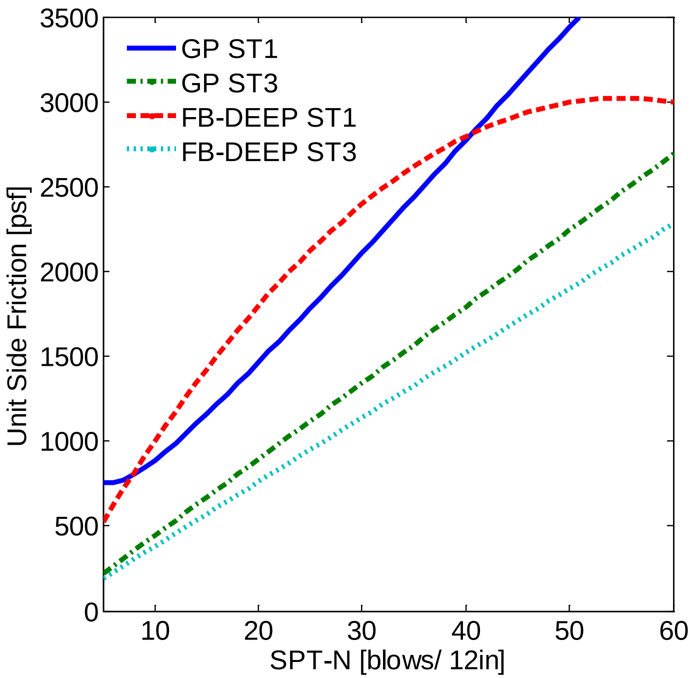
Assignment of Soil Type

- 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?