STA PILE3 COMPARISONS

Technical Note

Revision 0

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STA PROJECT No. 999-04

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1.0 INTRODUCTION

This Technical Note compares STA PILE3 solutions with solutions from other analysis methods

2.0 CASE 1 – Submarine Pipeline Start-Up Suction Anchor

Saipem UK supplied STA with an AGSPANC start-up suction anchor design report in March, 2011. The AGSPANC input page for the base case is shown in Figure 1, below.

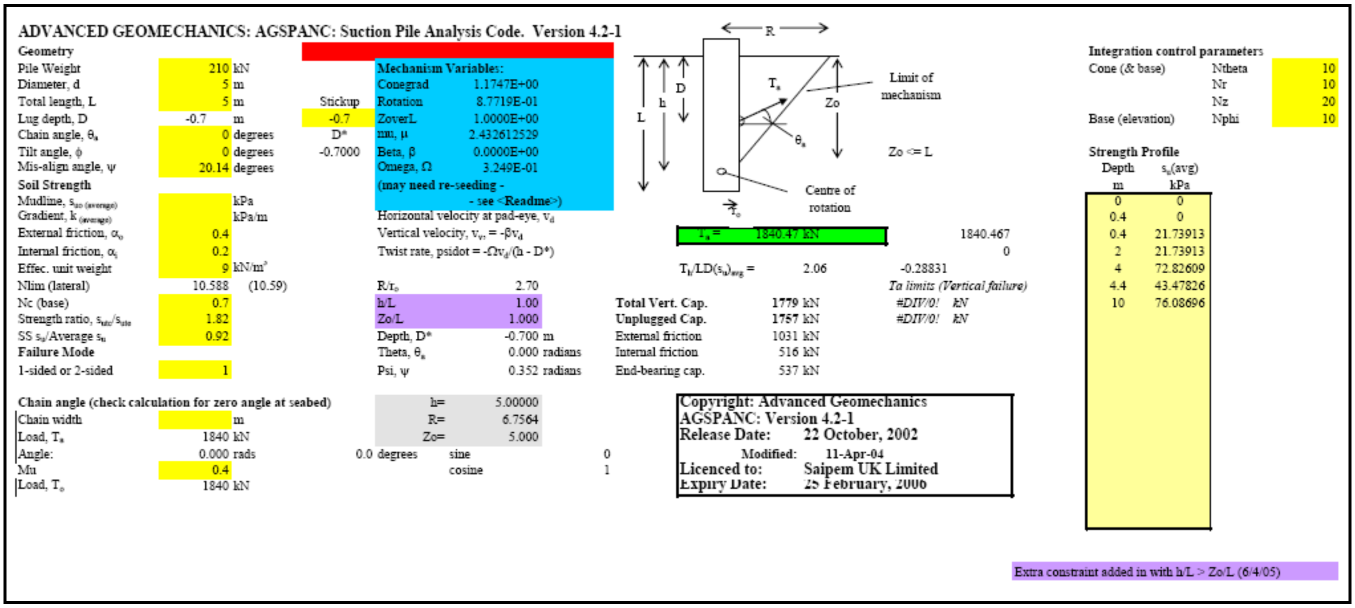


Figure 1 - AGSPANC Input Page for Base Case

Figure 2, below, shows the design soil shear strength profile from the AGSPANC report.

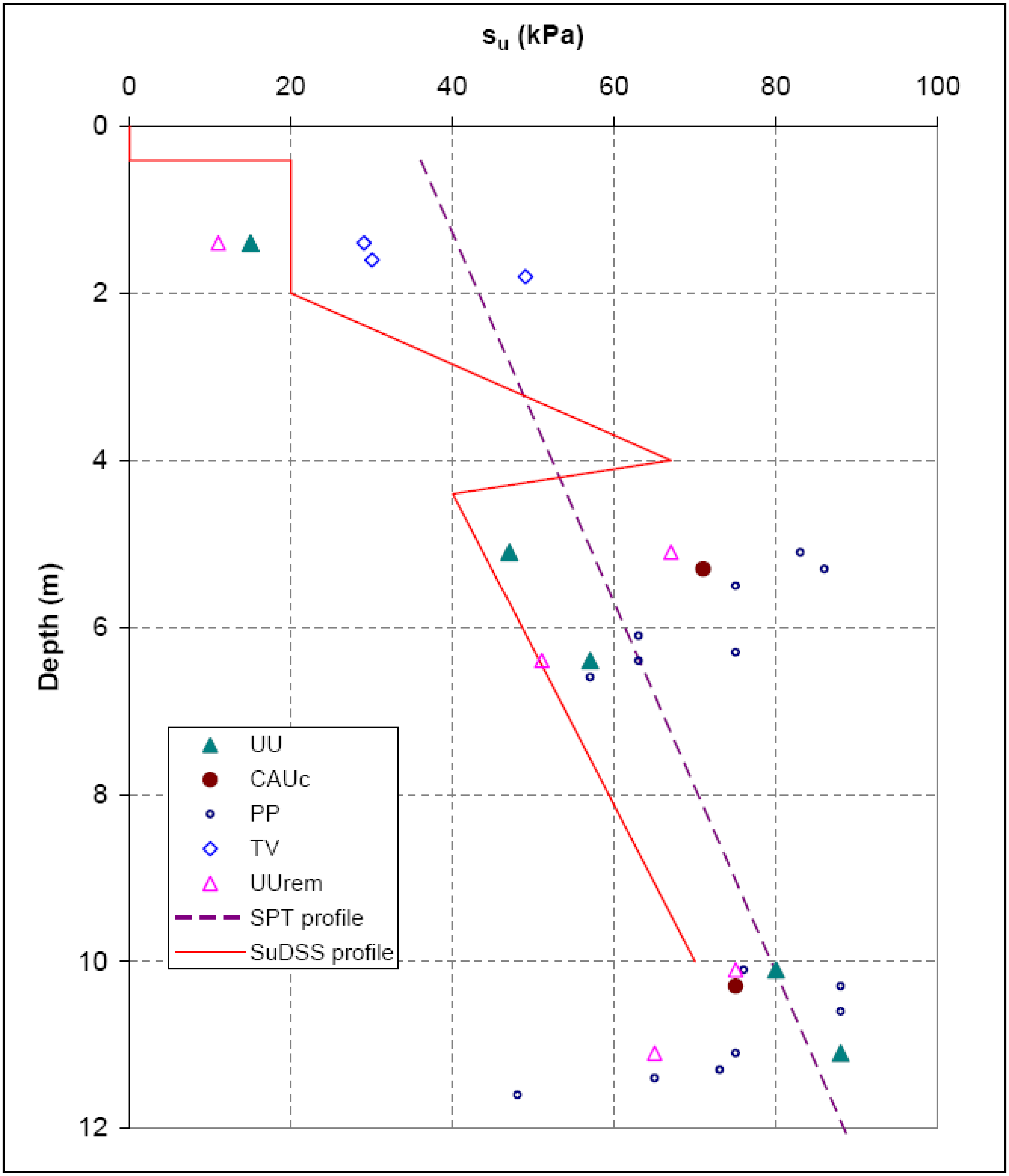


Figure 2 - Design Shear Strength Profile and s_u Data

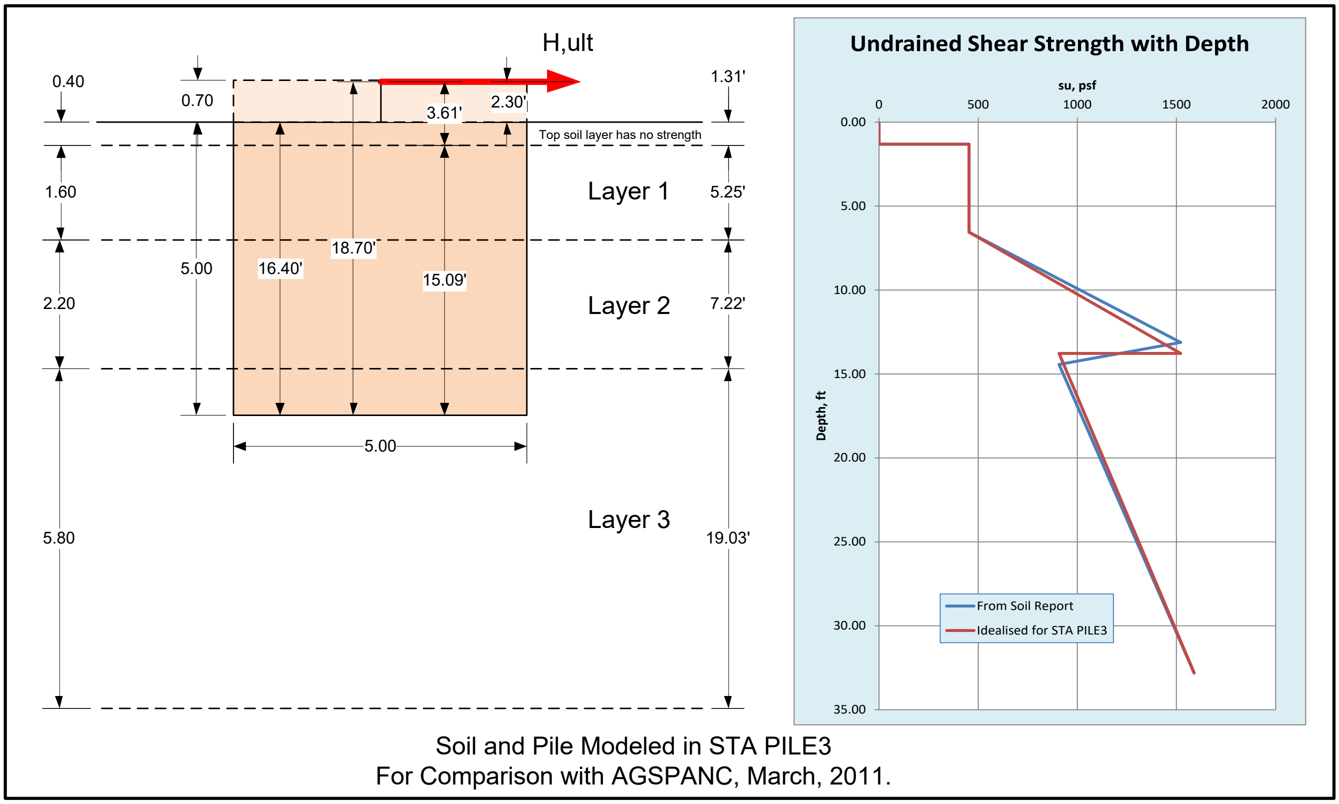


Figure 3 - Pile and Soil as Modeled in STA PILE3

The Imperial (US) dimensions are shown together with the metric dimensions in Figure 3. The AGSPANC pile length is 5.0 meters, or 16.40 feet. The load is applied 0.70 meters above the pile "top", which is at the mudline.

The first 0.40 meters of soil is considered to have zero strength. The next three layers are clay with an undrained shear strength as reported in Figure 2. This reported shear strength profile is shown by the blue line in the graph in Figure 3 in US units. The profile used in STA PILE3 is shown by the brown line in Figure 3. The slight simplification is conservative for the horizontal pile capacity calculation.

The pile model in STA PILE3 is 5.00 meters (196.8 inches) in diameter and 5.70 meters (18.7 feet) in length, with the pile top 3.61 feet above the sea bed. This results in the pile bottom being penetrated the correct depth into the soil and the top 1.31 feet of soil not being modeled (as it has no strength).

Table 1 shows the soil strength table from the AGSPANC analysis in metric and US units.

Table 1 - Soil Strengths from AGSPANC

Depth m	s_u(avg) kPa	Depth ft	s_u(avg) psf
0	0	0.00	0
0.4	0	1.31	0
0.4	21.73913	1.31	454.0
2	21.73913	6.56	454.0
4	72.82609	13.12	1521.0
4.4	43.47826	14.44	908.1
10	76.08696	32.81	1589.1

The soil property input for the STA PILE3 analysis is shown in Table 2.

Table 2 -STA PILE3 Soil Data

SOIL PROPERTIES (up to three layers)		
5.25	Z1, thickness of upper soil layer (ft)	soil-pile
7.22	Z2, thickness of middle soil layer (ft)	friction
19.03	Z3, thickness of lowest soil layer (ft)	angles
0.00	Phi1, 1st layer friction angle (deg.)	0
0.00	Phi2, 2nd layer friction angle (deg.)	0
0.00	Phi3, 3rd layer friction angle (deg.)	0
454.03	cu1, undrained sh. strength top 1st layer (psf)	
454.03	cu2, undrained sh. strength bottom 1st layer (psf)	
454.03	cu3, undrained sh. strength top 2nd layer (psf)	
1521.05	cu4, undrained sh. strength bottom 2nd layer (psf)	
908.06	cu5, undrained sh. strength top 3rd layer (psf)	
1589.11	cu6, undrained sh. strength bottom 3rd layer (psf)	
57.30	Gamma1, 1st layer buoyant weight (pcf)	
57.30	Gamma2, 2nd layer buoyant weight (pcf)	
57.30	Gamma3, 3rd layer buoyant weight (pcf)	open

Table 3 - Pile Properties and Analysis Options for STA PILE3

PILE PROPERTIES and ANALYSIS OPTIONS			
36.00	Fy, Yield stress for pile steel (ksi)	490	pile mass density (lb/cuft)
18.70	Lp, length (ft)	0	no. radial bulkheads
3.61	ztop, top to seabed (-ve if buried) (ft)	1	radial bulhead thickness (in)
0.00	zc, dist.pile head to pad eye (ft)	1	pile top thickness (in)
196.85	pile OD (in)	1	cu reduction factor
1.00	t, pile wall thickness (inches)	2	Installed capacity analysis
29000000	E, Young's Modulus pile (psi)	2	1=closed end, 2=open
414	Hmax, applied lateral load (kip)	1	cu_switch; 1=psi, 2=old API method
1	Vmax, applied vert.load (+ve up) (kip)	2	1=underconsol., 2=normal

The pile is modeled in steel with a 1” wall and a 1” pile top thickness. An applied horizontal load of 414 kips (1840 kN from the AGSPANC input, Figure 1) is specified together with a small uplift of 1.0 kips, to cause a solution for vertical pull out resistance.

The cu reduction factor is set to 1.0 for determining ultimate horizontal capacity.

The pile is specified with an open end and the “psi” method for axial loading is used. The clay is specified as being normally consolidated.

The STA PILE3 “Explain” button gives help for these analysis options:

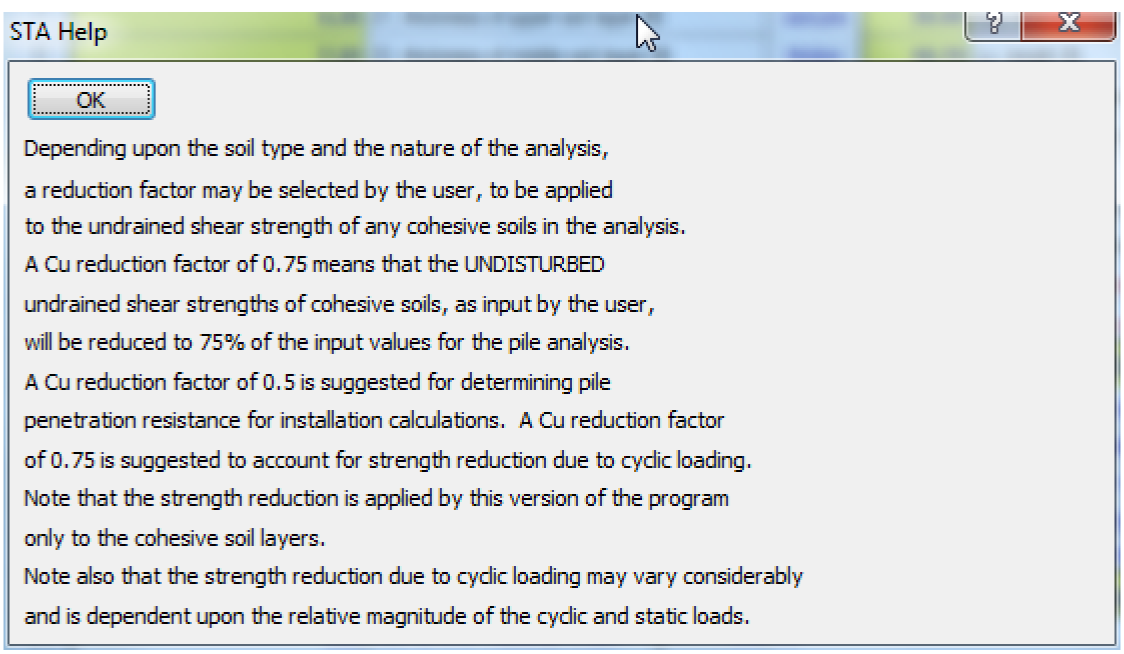
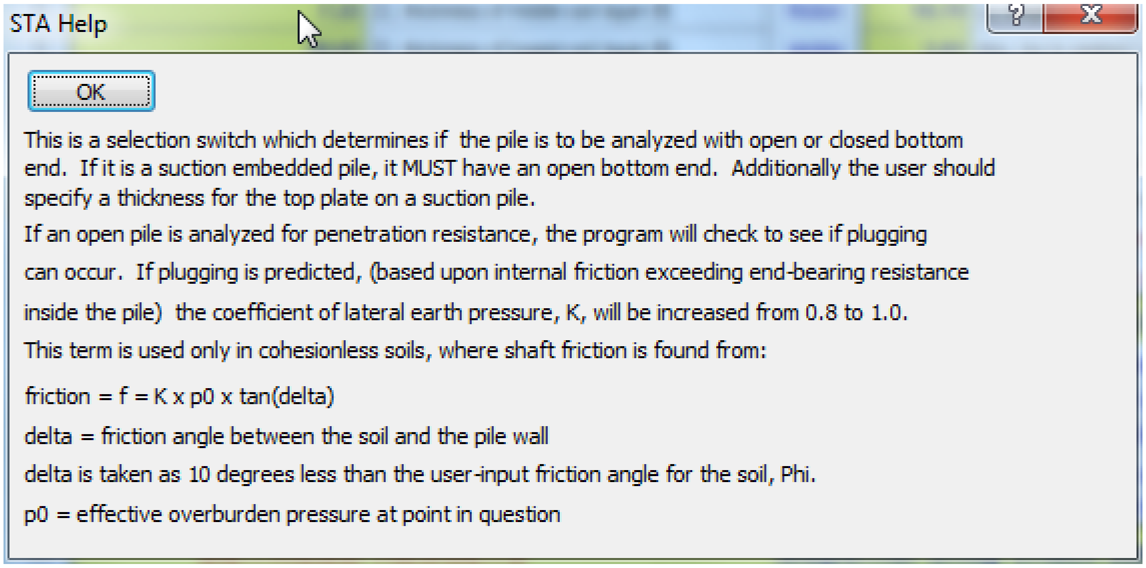


Figure 4 - Help for cu reduction factor



STA Help

OK

This is a selection switch which determines if the pile is to be analyzed with open or closed bottom end. If it is a suction embedded pile, it MUST have an open bottom end. Additionally the user should specify a thickness for the top plate on a suction pile.

If an open pile is analyzed for penetration resistance, the program will check to see if plugging can occur. If plugging is predicted, (based upon internal friction exceeding end-bearing resistance inside the pile) the coefficient of lateral earth pressure, K, will be increased from 0.8 to 1.0.

This term is used only in cohesionless soils, where shaft friction is found from:

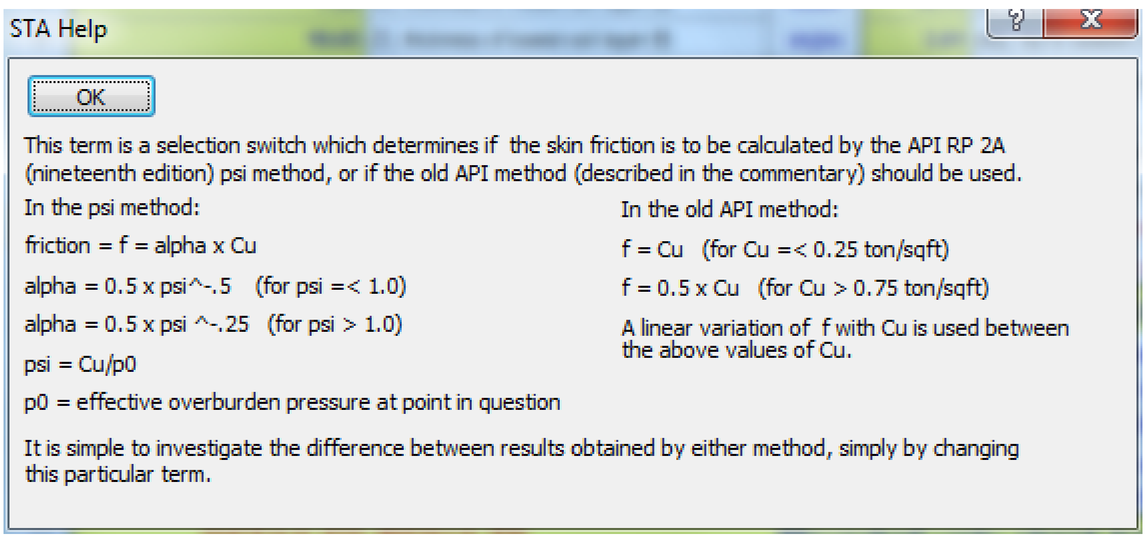
friction = f = K x p0 x tan(delta)

delta = friction angle between the soil and the pile wall

delta is taken as 10 degrees less than the user-input friction angle for the soil, Phi.

p0 = effective overburden pressure at point in question

Figure 5 - Help for closed end or open



STA Help

OK

This term is a selection switch which determines if the skin friction is to be calculated by the API RP 2A (nineteenth edition) psi method, or if the old API method (described in the commentary) should be used.

In the psi method:

friction = f = alpha x Cu

alpha = 0.5 x psi^-.5 (for psi =< 1.0)

alpha = 0.5 x psi ^-.25 (for psi > 1.0)

psi = Cu/p0

p0 = effective overburden pressure at point in question

In the old API method:

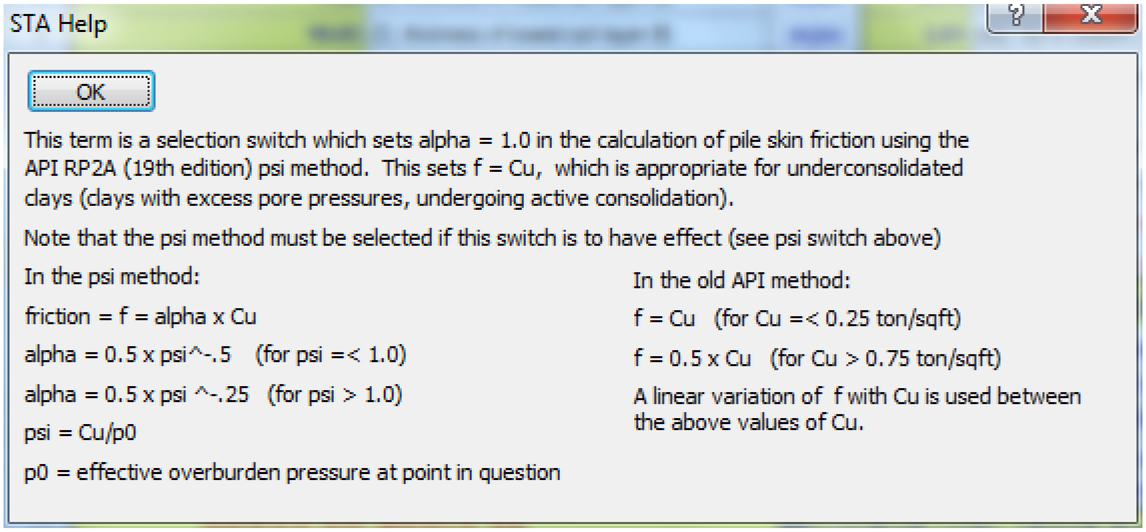
f = Cu (for Cu =< 0.25 ton/sqft)

f = 0.5 x Cu (for Cu > 0.75 ton/sqft)

A linear variation of f with Cu is used between the above values of Cu.

It is simple to investigate the difference between results obtained by either method, simply by changing this particular term.

Figure 6 - Help for psi method


STA Help

OK

This term is a selection switch which sets alpha = 1.0 in the calculation of pile skin friction using the API RP2A (19th edition) psi method. This sets f = Cu, which is appropriate for underconsolidated clays (clays with excess pore pressures, undergoing active consolidation).

Note that the psi method must be selected if this switch is to have effect (see psi switch above)

In the psi method:

friction = f = alpha x Cu

alpha = 0.5 x psi^-.5 (for psi =< 1.0)

alpha = 0.5 x psi ^-.25 (for psi > 1.0)

psi = Cu/p0

p0 = effective overburden pressure at point in question

In the old API method:

f = Cu (for Cu =< 0.25 ton/sqft)

f = 0.5 x Cu (for Cu > 0.75 ton/sqft)

A linear variation of f with Cu is used between the above values of Cu.

Figure 7 - Help for under and normally consolidated

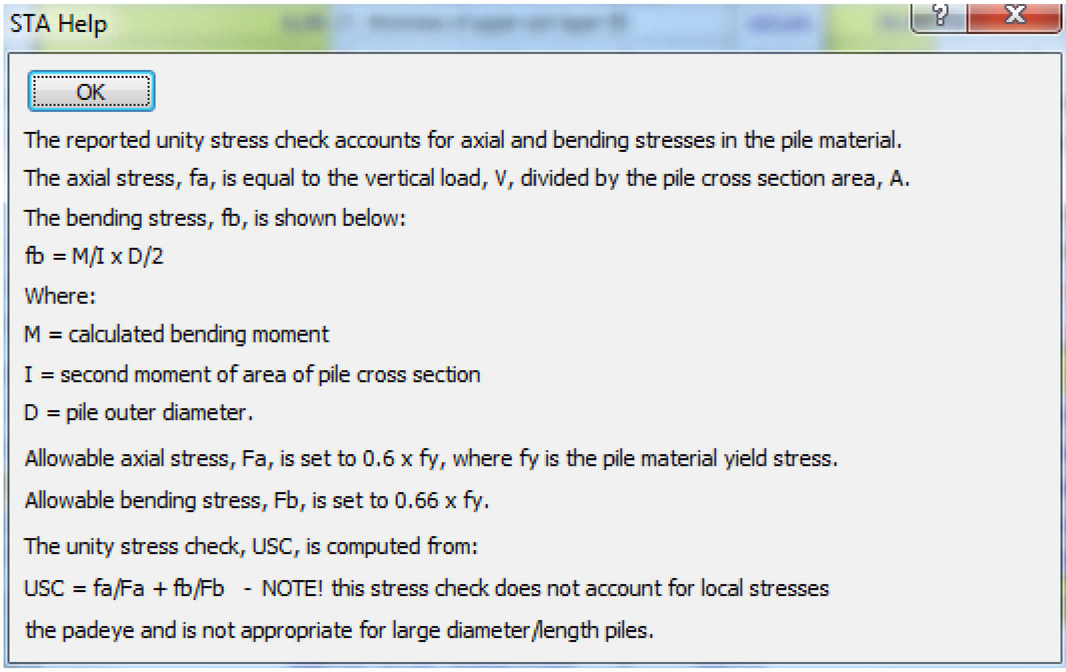
SUMMARY RESULTS	
0.92 Horizontal load safety factor	Explain value
> 100 Vertical load safety factor	
0.02 Unity stress check (app.loads)	
1.76 Ult. capacity unity check (Meyerhof)	
Short pile criteria probably OK	

Figure 8 - STA PILE3 Summary Results

The horizontal load safety factor is 0.92, meaning that the ultimate horizontal capacity of this pile as modeled by STA PILE3 is 92% of the input load, 414 kips, corresponding to that obtained in the AGSPANC analysis (if we have interpreted the AGSPANC data correctly). This is in part due to the conservative interpretation and input of the soil shear strength profile. If the depth of the second soil layer in STA PILE3 was 6.56 feet (as in AGSPANC) and had the same peak value, the result would be 94% of that found in AGSPANC.

The vertical load safety factor is not meaningful as only a horizontal load is being applied.

The steel unity stress check is not appropriate for this pile geometry as it is based on engineers beam bending theory. The “Explain” button gives the user the information shown in Figure 9.



STA Help

OK

The reported unity stress check accounts for axial and bending stresses in the pile material.

The axial stress, fa, is equal to the vertical load, V, divided by the pile cross section area, A.

The bending stress, fb, is shown below:

fb = M/I x D/2

Where:

M = calculated bending moment

I = second moment of area of pile cross section

D = pile outer diameter.

Allowable axial stress, Fa, is set to 0.6 x fy, where fy is the pile material yield stress.

Allowable bending stress, Fb, is set to 0.66 x fy.

The unity stress check, USC, is computed from:

USC = fa/Fa + fb/Fb - NOTE! this stress check does not account for local stresses

the padeye and is not appropriate for large diameter/length piles.

Figure 9 - STA PILE3 Unity Stress Check

STA PILE3 contains this simple material stress check for preliminary evaluation of pile anchors used for mooring systems. These anchor piles generally have larger L/D ratios than this start-up anchor (where L/D =1.0) and with a more optimally located padeye to maximize the pile capacity (maybe at a depth of 0.75 x D). In these circumstances, the STA PILE3 stress check has merit for preliminary pile design.

It should be noted that STA CHAIN may be used to compute mooring line loads at buried padeyes, with an inverse catenary type of solution.

DETAILED RESULTS — **Meyerhof unity check based on a safety factor of 1.5**

382	Hult, ult.horiz. capacity in kips	n/a	n/a
483	Vult, ult.vert. capacity in kips	n/a	n/a
177	f, dist.top to rotation center (in)	n/a	plug resistance (kips)
-0.51	fb, max bend.str.from Hmax (ksi)	0.00	weight radial bulkheads (kips)
0.00	fa, max.ax.str.from Vmax (ksi)	8.63	weight of pile top (kips)
0.51	fmax, comb.str.applied loads (ksi)	41.54	pile weight in water (kip)
47.78	pile weight in air (kips)	64.00	(editable) density of sea water (lb/cuft)
8.56E+13	EI, for pile (lbf-in^2)	1.00	multiplier on base shear: 1=full, 0=none
56.21	T, rel.stiffness (avg. value)	2.95E+06	I, for pile in in^4
0.27	L/T, embed.length/stiff.factor, T	502	average skin friction (psf)
0.92	L/B, embedment length/pile OD	-0.47	fb, max bending stress in pile in ksi from Hult
39	max +ve BM from Hult (ft-kip)	0.79	fa, max. axial stress in pile in ksi from Vult
-1182	max -ve BM from Hult (ft-kip)	1.26	max. combined stress in pile in ksi from ult. loads

Explain value | Select Analysis Type and/or Change Applied Loads

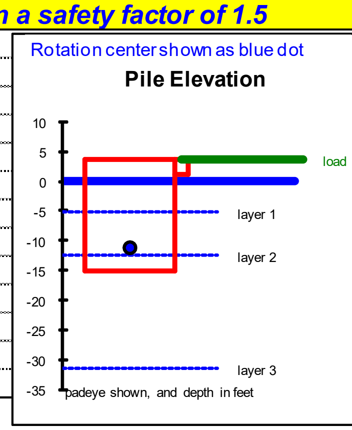


Figure 10 - STA PILE3 Detailed Results

3.0 RESULTS COMPARISON

The Ultimate pile horizontal capacity (Figure 10) is calculated to be 382 kips. The vertical capacity when all soil strength has been regained, sometime after installation, is calculated to be 483 kips. These numbers compare to AGSPANC horizontal of 1840 kN, or 414 kips and AGSPANC vertical of 1779 kN, or 400 kips.

It should be noted that the STA PILE3 weight comes from the user-input material density and pile dimensions, resulting in this case, of a weight in water of 41.54 kips, or 185 kN. It should be noted that the AGSPANC pile weight (assumed to be the weight in water) is specified as 210 kN, or 47.2 kips. If this was reduced to 41.5 kips, the AGSPANC vertical capacity (if it is for uplift) would be reduced to 393.9 kips.

It is not clear that the AGSPANC “Total Vert. Cap.” is for uplift or downwards load.

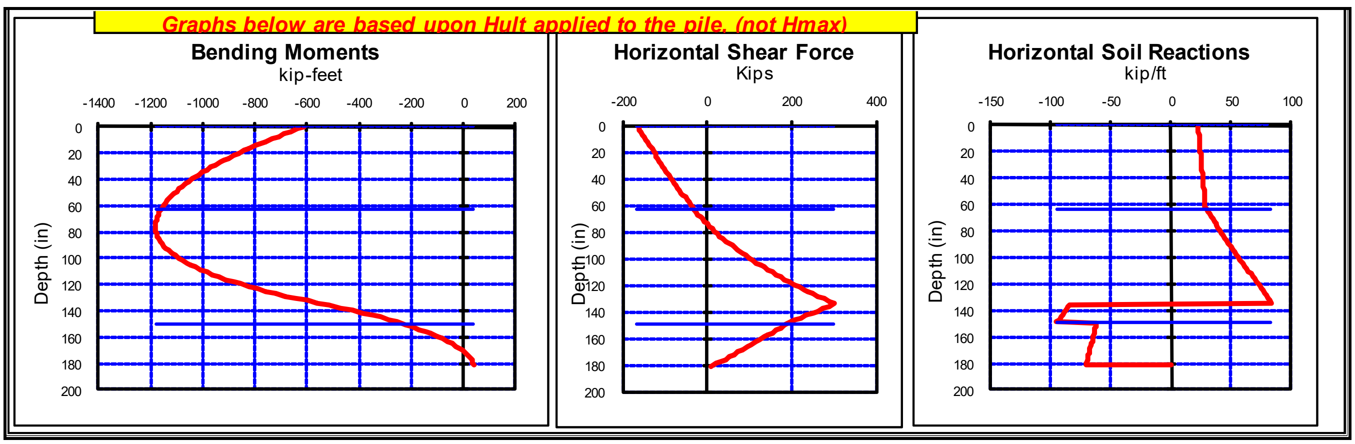


Figure 11 - Bending Moment, Shear Force and Horizontal Soil Reaction Graphs from STA PILE3

Calculate end bearing force for downwards load			
15.09	depth of pile toe (ft)	15.00667	length of radial bulkheads in soil (ft)
1002.00	undrained shear strength of soil at pile toe (psf)	0	area/unit length of radial bulkheads (sqft)
0	phi for cohesionless soil at pile toe (degrees)	615.28	A, pile wall cross section area (sqin)
864.657	overburden pressure at pile toe (psf)		
262.78	external skin friction (kips)		
260.11	internal skin friction if not plugged (kips)	260	
1905.95	end bearing if in cohesive soil and if plugged or closed (kips)	1906	
0	limiting unit end bearing value in cohesionless soil (kip/sqft)		
0	Nq, from table 6.4.3-1 API RP 2A	1	<<-- 1 if plugged in cohesive soil
0	po, end bearing value to use at pile toe in cohesionless soil (ksf)	1	<<-- 1 if plugged in cohesionless soil
0.00	end bearing if in cohesionless soil and if plugged or closed (kips)	0	
4.27	end area in square feet if not plugged or closed, including radial bulkheads		
1905.95	maximum end bearing for this analysis if plugged or closed (kips)		
260.11	minimum of either internal friction or end bearing if plugged or closed (kips)		
38.53	end bearing on annulus in cohesive soil (kips)		
0.00	end bearing on annulus in cohesionless soil (kips)		
298.64	minimum of either end bearing on annulus plus internal skin friction, or end bearing if plugged or closed. (kips)		
298.64	if pile is closed end (cell H12=1) then the plugged or closed value is used here, if open, the value in cell A70 is used.		
298.64	embedment resistance from internal skin friction and end bearing on annulus of suction embedment anchor		

Figure 12 - STA PILE3 End Bearing Calculations

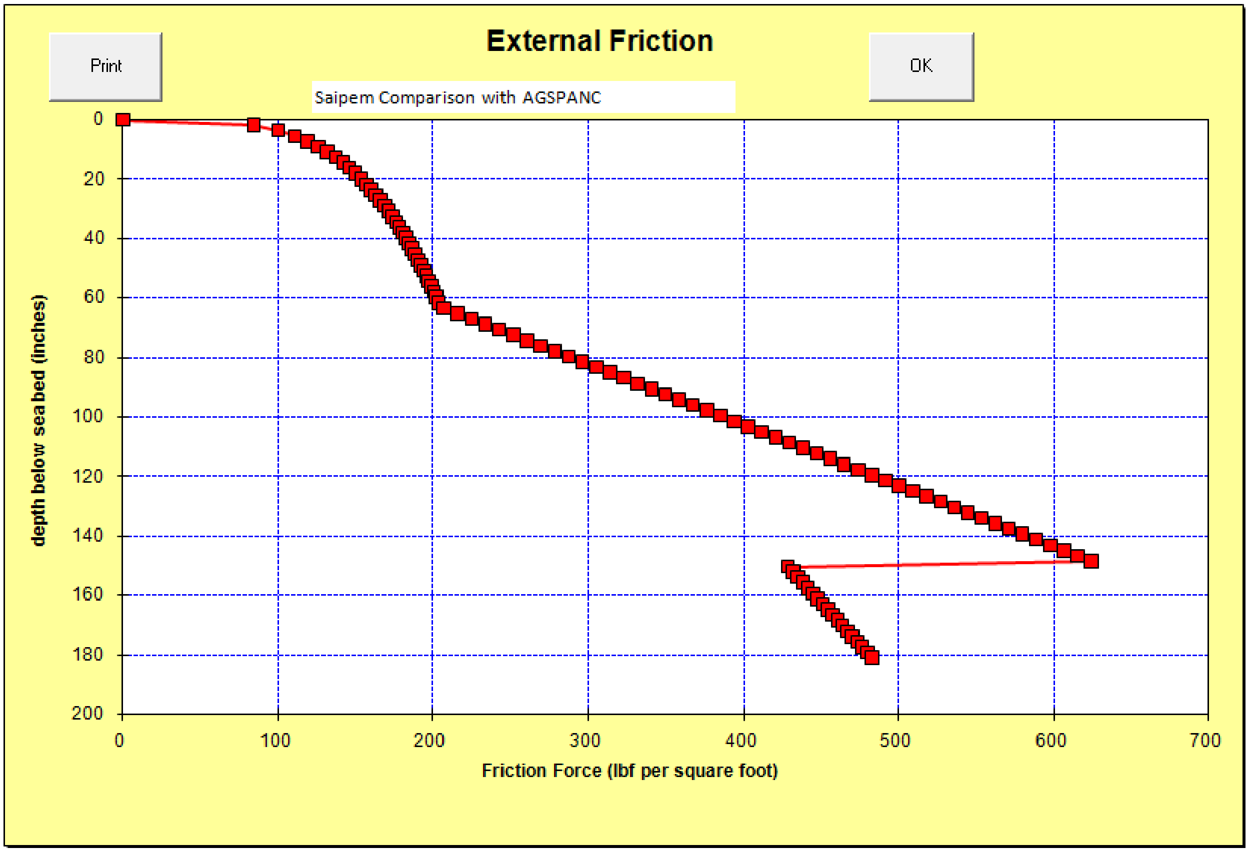


Figure 13 - STA PILE3 External Friction (API psi method)

Look at Base Shear Force for Large Shallow Suction Anchors	
41.54	weight of pile in water (kips)
179.05	weight of soil inside pile (kips)
219.59	effective force over pile base (accounting for uplift, if applied) (kips)
1002.004101	cu at bottom of pile (psf)
0	phi at bottom of pile (degrees)
211.3488868	pile cross sectional area (square ft)
211.7724514	cohesive shear force needed to slide base in cohesive soil (inc. reduction factor =eff. force/soil wt.)
0	frictional sliding resistance of base in cohesionless soil (kips)
211.7724514	base sliding friction used in calculating Hult (kips)

Figure 14 - STA PILE3 Base Shear Calculations.

Two items are also editable in the detailed results area. They are the mass density of water, which affects the pile weight in water and hence the pile vertical capacity, and the "multiplier on base shear". This term is described in Figure 15, which is obtained by clicking the "Explain" button.

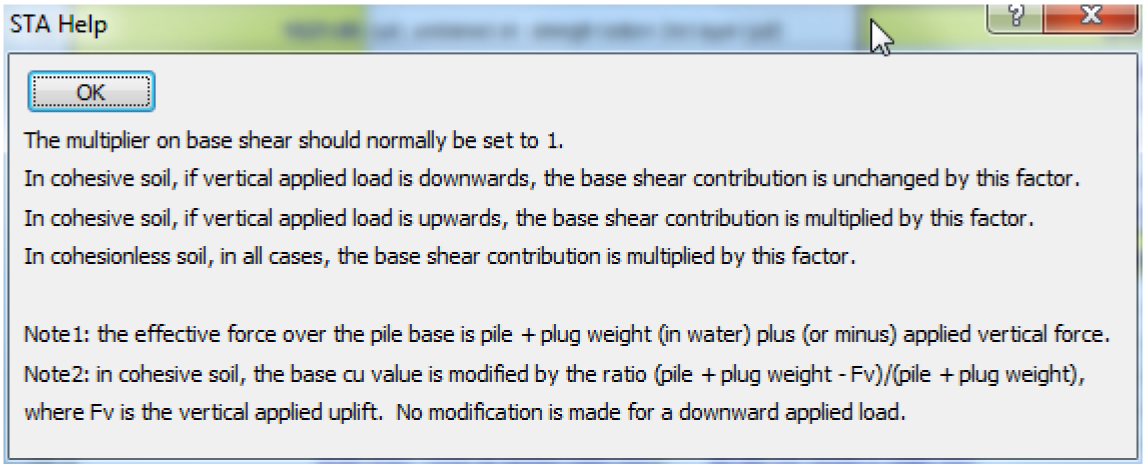


Figure 15 - Help for multiplier on base shear.

Notes on Pile Vertical Capacity in STA PILE3

The ultimate vertical pile uplift capability is reported by STA PILE3 as being 483 kips with the cu reduction factor set to 1.0. In the cohesive soil modeled in this analysis, the soil in contact with the pile inner and outer skin will be disturbed by the pipe embedment. Without more details of the soil engineering properties the time before full undisturbed undrained shear strength is recovered cannot be predicted. It would be prudent to use a c_u reduction factor of 0.5 to estimate the pile's vertical capacity for design for the first few months after embedment. This reduces the vertical uplift capacity to 365 kips.

The ultimate pile downwards capacities are 520 kips with c_u reduction factor of 1.0 and 301 kips with a factor of 0.5.

Notes on Suction Embedment

Installation Probably OK	
10.11 max psi for embedment	Explain value
301.42 plug uplift force (kips)	
340.07 plug resistance (kips)	
301.42 Force required for embedment (kips)	
Short pile criteria probably OK	

Figure 16 - STA PILE3 Summary Results for Suction Embedment

Figure 16 is the table of summary results from STA PILE3, using a c_u reduction factor of 0.5. The program warns that plug uplift is probable if the c_u reduction factor exceeds a value of 0.67.

STA PILE3 — Anchor Pile Design (using API RP 2A) w/Suction Embedment

v.1.8 November 2009 | Run ref: Saipem Comparison with AGSPANC | 03/09/11 22:10

Explain value | Select Analysis Type and Apply Loads | Assumptions | Friction | Print Input & Results

Navy soil design parameters | API Cohesionless soil design parameters

INPUT DATA BELOW

For pile top below sea bed make ztop negative.

SOIL PROPERTIES (up to three layers)			PILE PROPERTIES and ANALYSIS OPTIONS			
5.25	Z1, thickness of upper soil layer (ft)	soil-pile	36.00	Fy, Yield stress for pile steel (ksi)	490	pile mass density (lb/cuft)
7.22	Z2, thickness of middle soil layer (ft)	friction	18.70	Lp, length (ft)	0	no. radial bulkheads
19.03	Z3, thickness of lowest soil layer (ft)	angles	3.61	ztop, top to seabed (-ve if buried) (ft)	1	radial bulhead thickness (in)
0.00	Phi1, 1st layer friction angle (deg.)	0	0.00	zc, dist.pile head to pad eye (ft)	1	pile top thickness (in)
0.00	Phi2, 2nd layer friction angle (deg.)	0	196.85	pile OD (in)	1	cu reduction factor
0.00	Phi3, 3rd layer friction angle (deg.)	0	1.00	t, pile wall thickness (inches)	2	Installed capacity analysis
454.03	cu1, undrained sh. strength top 1st layer (psf)		29000000	E, Young's Modulus pile (psi)	2	1=closed end, 2=open
454.03	cu2, undrained sh. strength bottom 1st layer (psf)		414	Hmax, applied lateral load (kip)	1	cu_switch; 1=psi, 2=old API method
454.03	cu3, undrained sh. strength top 2nd layer (psf)		1	Vmax, applied vert.load (+ve up) (kip)	2	1=underconsol., 2=normal

			SUMMARY RESULTS
1521.05	cu4, undrained sh. strength bottom 2nd layer (psf)		
908.06	cu5, undrained sh. strength top 3rd layer (psf)		0.92 Horizontal load safety factor (Explain value)
1589.11	cu6, undrained sh. strength bottom 3rd layer (psf)		> 100 Vertical load safety factor
57.30	Gamma1, 1st layer buoyant weight (pcf)		0.02 Unity stress check (app.loads)
57.30	Gamma2, 2nd layer buoyant weight (pcf)		1.76 Ult. capacity unity check (Meyerhof)
57.30	Gamma3, 3rd layer buoyant weight (pcf)	open	Short pile criteria probably OK

DETAILED RESULTS

Meyerhof unity check based on a safety factor of 1.5

382	Hult, ult.horiz. capacity in kips	n/a	n/a
483	Vult, ult.vert. capacity in kips	n/a	n/a
177	f, dist.top to rotation center (in)	n/a	plug resistance (kips)
-0.51	fb, max bend.str.from Hmax (ksi)	0.00	weight radial bulkheads (kips)
0.00	fa, max.ax.str.from Vmax (ksi)	8.63	weight of pile top (kips)
0.51	fmax, comb.str.applied loads (ksi)	41.54	pile weight in water (kip)
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0.27	L/T, embed.length/stiff.factor, T	502	average skin friction (psf)
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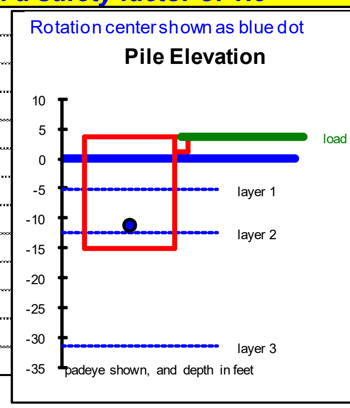

Explain value | Select Analysis Type and/or Change Applied Loads

Graphs below are based upon Hult applied to the pile. (not Hmax)

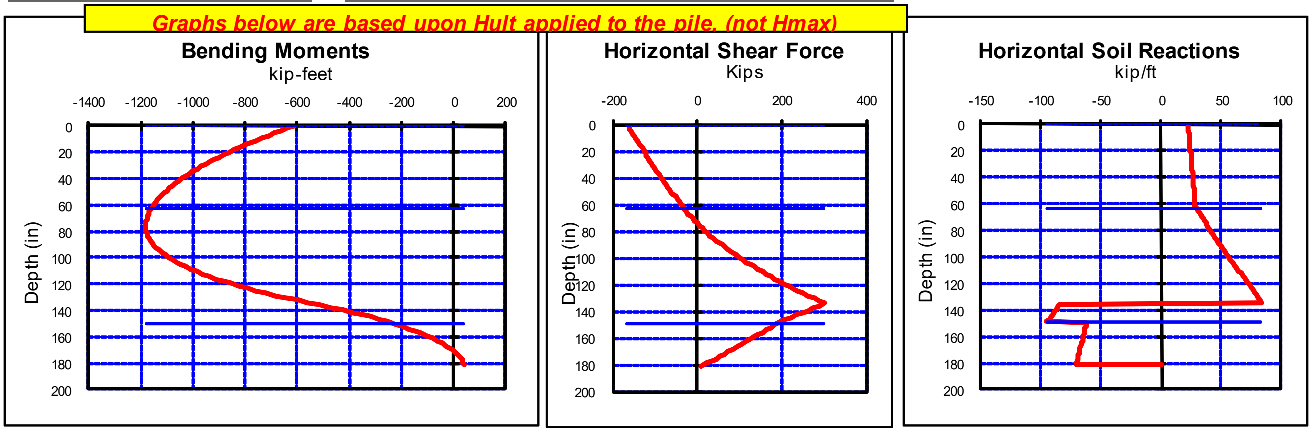

Figure 17 - Single Page of Input and Results.