

Foundation Pile Example: Helical Pile Design

Deep Excavation LLC Software program: DeepFND, HelixPile Document version: 1.0 January 14, 2019 www.deepexcavation.com www.deepex.com

DEEP EXCAVATION

A. Project description

In this example we will design a helical foundation pile. The Figure below presents the project model. Tables 1 and 2 present the soil properties and the stratigraphy respectively. Table 3 presents the external loads applied on the pile head. Table 4 presents the pile section properties that we are going to use. The general ground surface is at El. Oft and the general water table is at El. -15 ft.

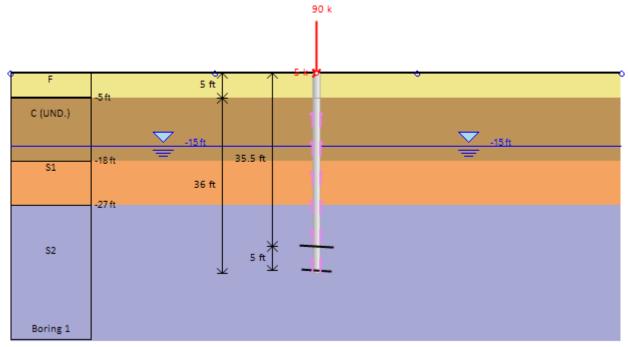


Figure: Project model.

Soil			G	eneral p	oroperti	es		Lateral properties			
Layer	Soil Type	ф' (deg)	C'/Su (psf)	γ (pcf)	γ _{dry} (pcf)	E _{LOAD} (ksf)	E _{reload} (ksf)	k (pci)	e50	Krm	
F	Fill	25	0	120	120	300	900	60	-	-	
С	Clay (Undrained)	-	1300	116	116	400	1200	-	0.005	-	
S1	Sand	32	0	130	130	600	1800	60	-	-	
S2	Sand	34	10	135	135	900	2700	90	-	-	

Table 1: Soil properties.

Soil Layer Elevation (ft) OCR Ko									
F	-0	1	0.577						
С	-5	1	0.515						
S1	-18	1	0.47						
S2	-27	1	0.441						

Stage	Axial Load (kips)	Moment (k-ft)	Lateral Load (kips)
Stage 0 (Compression)	90	0	5
Stage 1 (Tension)	-70	0	5

Table 3: External loads.

Table 4: Pile parameters.

Pile Type	Helical Pile
Pipe Width	4 in
Pipe Thickness	0.5 in
Number of Helixes	2
First Helix Diameter	18 in
Tip Offset	0.5 ft
First Plate Thickness	0.375 in
First Plate Ult. Capacity	100 kips
Second Helix Diameter	20 in
Plate Spacing	5 ft
Second Plate Thickness	0.375 in
Second Plate Ult. Capacity	100 kips

B. Modeling with DeepFND/HelixPile

Our software programs DeepFND and HelixPile are identical. They share the same user-friendly interactive interface, and they include the same analysis options. The only difference is that DeepFND can do the lateral and vertical design of all pile types (helical and non-helical). On the other hand, HelixPile includes only helical pile sections. This example was created using the Helical Pile component of the DeepFND software, but the exact same options should be followed to create the model in HelixPile.

In DeepFND software, we should define initially the soil properties of all soils according to the geotechnical report, the model stratigraphy, the pile head loads and the pile initial depth and structural section.

• Define soil properties:

From the General tab of DeepFND we can select the option "Edit Soil Type Data". In the dialog that appears, we can modify the existing soils database or add new soils, and then for each one of them, we have to define the general soil properties, the soil model and the lateral soil properties. The soil parameters can be defined manually, or with the use of the software SPT estimator or local parameter estimation tools.

DEEPFND/HELIXPILE EXAMPLE: HELICAL PILE DESIGN

	Soil Types	? ×
Soil Types F S1 C S2	1. Name and Basic Soil Type Soil Name F Description Miscellaneous fill 2. Soil Type - Behaviour ③ Sand ③ Silt ③ Rock ○ Clay ③ IGM (intermediate geo mat.) Gravel 3. Default drained-undrained behavior for clays (See Theory Manual) Undrained ④ Drained A. General B. Elasto-plastic Lateral E. Adv. 4. Unit Weights - Density Y 120 pcf ③ Y dry	Test Data SPT Estimator Notes Other Nspt 0 10 20 30 40 50 60 r_{z} 0 10 20 30 40 50 60 r_{z} 0 100 110 120 130 140 r_{z} 0 30 40 50 60 c' 0 0 50 60 c'
Add New Soli Copy Soli Delete Selected Soli Delete all solis	5. Strength Parameters and Poisson Ratio Drained strength properties c [*] 0 psf ≥ d* 25 degrees ≥ v [*] 0.35 ≥ 5. At-rest coefficients KoNC 0.577 ≥ nOCR 0.5 ≥ Ko = KoNC* (OCR)*nOCR 6. Ultimate bond (grouted piles when bond option is selected) q skin.u 20 psi ≥	0 500 1000 1500 2000 Su 0 2000 4000 6000 8000 ☐ Elasticity modulus Important Note: The ultimate skin friction can be used to calculate the geotechnical capacity of tiebacks. To do this, you have to switch on the Use Soil Bond Strengths Options for the tiebacks. Otherwise, the program will either average the vertical and horizontal confining stresses or use the bond stress as defined in the Geotech tab from the tieback section option.
Paste Soil	Rock joints are open filled with gouge	
		OK Cancel

Figure: Edit Soil Type Data Dialog.

• Define stratigraphy:

From the General tab of DeepFND we can select the option "Edit Boring". In the dialog that appears, we can define the top of the soil layer elevation and the soil type for each soil layer.

Soil Layers								53				
Available Borings	-1. Gen	eral Boring Inf	ormation - Coordina	ates								
Boring 1		Name Borir	ng 1									
	Coord	inates X	50 ft Y	0	ft							
	The x coordinate controls where the boring is shown in your design section view. Each design section uses one boring (soil strata). You can use a different boring on each design section.											
2. Boring Layers - Layer Elevations												
		Тор	Soil type		OCR	Ко	Edit					
	•	0	F	¥	1	0.577	Edit					
		-5	С	¥	1	0.5151	Edit					
		-18	S1	~	1	0.47	Edit					
		-27	S2	~	1	0.441	Edit					
				~								
Add New Boring												
Delete Selected Boring (Stratigraphy)	In	sert Layer	Delete Lay	er								
						0	к	Cancel				

Figure: Edit Soil Layers Dialog.

• Define external loads on pile head:

In any model in DeepFND we can add several stages. In our deep foundation software these can work as loading stages, so in each stage we can define a different load (load type, magnitude etc). In this example, we will use Stage 0 to define our maximum compression load, and Stage 1 to define our maximum tension load on the pile head.

First of all, we right-click on the Stage 0 tab right below the model area and we select to Add Stage (so Stage 1 is added):

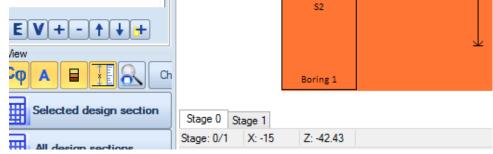


Figure: Stages in DeepFND.

After we create the stages, we double-click on the load in the model area. In the dialog that appears, we can add several loads in the list and define the load type and the magnitude of each load, in each stage. The summary of all loads will be applied on the pile head. If we apply a design standard (i.e. AASHTO LRFD), the loads will be factored depending on the load type (dead, live, wind, ice, vehicular etc.).

			l	oads on pile.					×			
List of loads Load 1, DL, DL: Dead load	Load properties 1. Name Load 1, DL 2. Load Type											
		3. Load magnitude Apply same load on all stages Activate for current stage										
	✓ Activate for current stage											
	Γ	oad for every stage	Active	Axial force(k)	Moment(k-ft)	Horizo	ontal					
	►	Stage 0	✓	90	0	5						
Add new load		Stage 1	✓	-70	0	5						
Delete selected load												
Apply to all design sec	tions	Pile	weight Igr	nore pile weight		~	ОК	Cano	el			

Figure: Define loads on pile head.

• Define pile section and initial length:

In DeepFND we have to define the pile type, structural section (pipe dimensions and helix configurations) and original depth. Later, based on the analyses results, we can choose to optimize the pile section and the pile embedment. The required pile length can also be calculated by the software. We have to double-click on the pile and define the pile parameters in the dialog that appears. By pressing "Edit" on this dialog, we can define the pile type and the pile structural section.

Edit Pile Dimensions and Data, Stage: 0									
A. General B. Prestress-Unbraced C. Corrosion D. Results P-y Lateral									
Pile Properties 1. Selection of Support Type General pile type 2. Support Structural Section Used Structural Section Pipe 4* 3. Dimensions 1.1 Coordinates at Top of Pile 2.0 1.2 Angles «190 deg 4. Shaft grouting Shaft sgrouted 5. Activate/Deactivate pile - Permanent or Temporary ✓ Activate support for this stage	Section Pile Side View 41ft 41ft 4 Graphics Control Fit to image scale	th							
Show full calculations		ОК	Cancel						
Figure: Define pile dimensions and data dialog.									
Helica	l anchor sections		×						
Pipe A"	I capacity options C. Concrete). External casing							
Pipe 4"									

Helical sections	A. General	B. Geotechnical	capacity options	C. Concrete D.	External casing					
Pipe 4"	1. Name			_						
	Pipe 4"			Manufactu	Manufacturer					
	Т	el:		web						
	2. Shaft-pip	e dimensions an	d properties							
		fy 65	🖌 ksi	lxx 8.59 ir	14 E	29000 ksi				
		fu 80	🗸 ksi	Sxx 4.3	1 ³ Torsion	nal pipe capacity				
	Se	ction Pipe	~	Zxx 6.167 in	13 Telastic	46.53 k-ft				
	Dian	neter 4	in	rx 1.25 ii						
	Thick	mess 0.5	in	J 17.18058 in		le shaft capacity 1 357.5 k				
	Area pipe /	Apipe 5.5	in^2	Sxy 8.59 in	13 Qultimate	a 357.5 k				
	Perin	neter 12.5663	70 in		Define me tension st	chanical connection rength				
Add new helical section										
Delete all	3. Helix dim	ensions and pro	perties							
	✓ Use diff	ferent size plate	es Available o	onfigurations Nor	ie	✓ Select				
Delete selected helical section					End offset	0.5 ft				
CFANCE	1	Diameter <mark>(</mark> în)	Spacing (ft)	Thick (in)	Effective Area (ft2)	Ult. Capacity (k)				
	▶ 1 ¹		5	0.375	1.68	100				
Pideal	2 2	0	5	0.375	2.094	100				
MAGNUM										
	Add a ne	ew plate De	elete selected plate	Save configura	tion Delete config.	Add configuration				
Database 🖬 Databa										

Figure: Define pipe size and helix configurations.

C. Define Analysis Options

After we create the model in DeepFND, we have to define several analysis parameters.

• Pile length automatic optimization:

In the general tab of DeepFND we can select to optimize the pile length. In this case, we need to define the maximum pile depth and the step. The software will use the step to calculate the pile tensional and compressional capacity in several depths and compare them with the applied tension and compression loads respectively. It will stop the analysis when both capacities exceed the applied loads and return as a result the pile depth, the calculated capacities and the pile structural results (moment, shear, displacement etc.). If the software reaches the maximum depth and fails to find a suitable solution, it will stop the analysis and return as a result the calculated capacities etc. of the maximum depth.

If we leave this option unselected, the software will use the pile depth we manually specified for the analysis and return all analysis results.

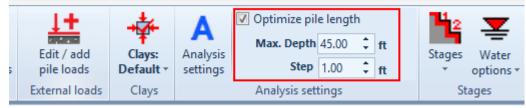


Figure: Option to optimize pile length in the General tab.

• Analysis equations and settings:

In the Analysis tab of DeepFND, all analysis parameters are automatically defined according to the pile type (helical or non-helical) and the pile installation method (drilled, driven, caisson, micporile etc.).

Ge Ge	neral	Propertie	s Analysis	Torque	Design	Settlement	Lateral	Results	Report	View	Help	
Method Meyer	hof/Hans	en 🔻	🔽 Include shaft	resistance		🔲 Use additional r	nultipliers	Factors on c'	Trilinear c' or	Su	*	method Mitsch-Clemence 0.09 e^ 🔻
Equation Gene	ral: Nc c' +	- (Nq- *	δ on concret	e 100	%			Addition	I factor at sha	ft		Rock Use specified soil bond 🔹
🔽 Consider di	sturbance	Ed	δ on stee	50	%							
Bearing C	pacity Me	thod		S	haft resistar	nce			Reductions or	n side c'		Cylinder method

Figure: Analysis settings, automatically selected.

• Design standards and Safety factors:

In the Design tab we can define the structural codes and the safety factors applied on the bearing, shaft and structural capacities. Alternatively, we can select a load combination of a specific geotechnical design standard (we will not use one in the current example).

4		General	Properties	Analysis	Desi	gn	9	Settle	ment		Late	ral	Res	ults	Report	View	Help
	0	DES	2	DES	🔲 Use m	ob.	axial	for S	FR ch	ecks		Custo	m STR	V A	djust ultimat	e STR capa	tity by FS
_	E ode	Steel-Desi	-	Members:	Safety Fa	ctor	Shaft	2			STR	.des	0.6	Safety	y Factor 1.6		
	ions *	AISC 360-10	ALL. * Settings	US Sizes *	Safety Fa	ctor	Beari	ng 2						Meth	od Internati	onal Buildi	ng Cor 🔻
		Struc	tural code or	otions	×			Safe	ty fac	tors					Structu	ral factors	
	Concre	te Code Option		5110113		Г											
	0011010														Base	model	
	1:ACI 3	318-11			~	E.	Su	ď	Ksub	e50	Qu	RQD	krm				
						251) 0	(pst)	(deg) 25	(pci) 30	•	(ksf)	(%)	-				
-	Steel C	ode Options				-	1300	0		0.005	•	•	-				
	17-419	C 360-10 ALL.			~	0	•	32 34	50 90	•	•	•	-				
	17.740	G SUB TOTALL.															
	Timber	Code Options															
	Service	e, a=0.36			~										150 k		
					<u> </u>												
				ок	Cancel	F						5 ft	ŕ		-20 x 💞		

Figure: Define structural codes and structural/geotechnical safety factors.

Design	Select Load Combination or Design Approach 🔼	×		
Use mob. axial	Design Approach	٦	Single 🔹 Mult. 🔹	Examine corrosion effects
afety Factor Shaf	🔘 Do Not Use A Code			
afety Factor Bear	Analyze only one Code Case		Approach: Service	
			Load combinations	Design Life
	Design Code			
<mark>Ι γτ < Su</mark>	AASHTO LRFD (2010)			·
te (pcf) (psf) (psf) 120 0 -	Load Case			
ID.) 116 - 1300 130 0 -	Strength Ib			
135 10 -	When you are analyzing a wall with LRFD or ULS procedures you will need to define the appropriate load combination or design approach. Select 1st the design code, and then select the appropriate case. Load combinations can be applied at each stage or you can create different design sections where dirrent load combinations are assumed.			

Figure: Option to assign a design standard load combination.

• Settlement analysis options:

In the Settlement tab we can select the option to perform settlement analysis. Also there, we can define pile settlement acceptance criteria.

🤹 Gener	al Propert	ties Analysis	Design	Settlement	Lateral	Results	Report	View	Help		
Perform settlem Calculate design Include corrosic	n capacity from on effects in PY		lection fact M Effective an	Edit pile settlement acceptance criteria							
Settlement analysis						_	Pile acceptance criteria				
Units		Base model			Pile acc	ceptance	criteria			×	
English Units (ft, inch Design sections Cost Base model	ee view			ia ew criteria	Average p	e/visible a active (to b s visible (on s + 0 + 0 ate diameter viate size ad criterion a criterion cod criterion cod criterion cod criterion cod criterion cod criterion cod criterion	graphs) D _{PL} + 0 r D v tettlement (Criteria determ riterion) _S = Sha sines ultima	ift diamete		
		h						OF	<	Cancel	

Figure: Option to perform settlement analysis and pile settlement acceptance criteria.

• Lateral pile analysis options:

In the Lateral tab we can select the lateral pile analysis method. The available options are either to calculate pile moment, shear and displacement for the defined lateral loads, or perform a pushover analysis and report the required load to achieve a specific displacement.

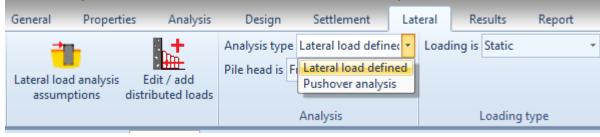


Figure: Lateral load options.

• Torque options:

In the Torque tab of DeepFND, we can either select one of the existing Torque factor profiles, or we can define new profiles:

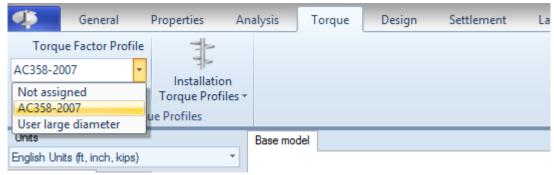


Figure: Torque profiles.

			Torque Installat	ion Profiles	x						
Profiles	1. Gen	eral Load Test	Information - Coordina	tes							
AC358-2007	Name User large diameter										
User large diameter TEST 3	Torque Installation Profiles are used to estimate the required installation torque to meet required helic: capacity. Torque Installation Profiles have traditionally been reported based on the installation shaft diameter. 2. Torque Installation Profile data										
		Diameter (in)	Torque Installation Factor kT (1/ft)		^						
	•	0	10								
		1.75	10								
		2.875	9								
		3	8								
		3.5	7								
		4.5	5								
		6	4								
Add New Profile		8	3		v						
Delete Selected Record	In	isert point	Delete point	Delete all points							
				OK Cance	ł						

Figure: Edit torque profile factors.

D. Analysis and Results

. . .

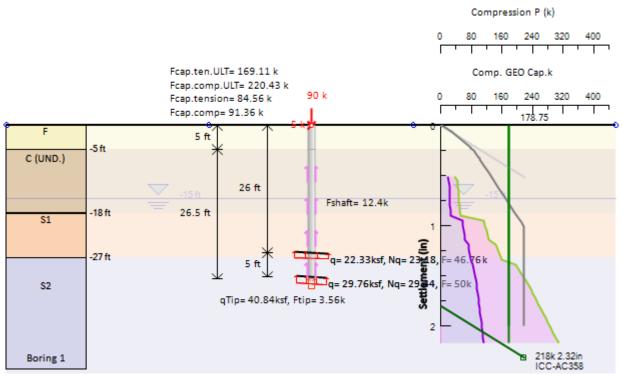
Since the model is ready, we can choose to calculate the design section. After the analysis is succeeded, the Summary table appears. The table below includes the calculated compression and tension capacities, the optimized pile depth, the lateral pile results and more. With red we can see some values that are critical. In this case, we can see that at least one stress check is above the limit "1". We can locate the issue by closing the summary table and reviewing the results graphically on the model area for every stage. In this case, the pile structural capacity and moment capacity are not enough to cover the combination of the tension and lateral load applied on the pile head. In this case we need to somehow increase the pile capacity (increase pipe section or use an external casing on the top of the pile).

		Calculation	Pile type	Fmax compression (k)	Cap. compression (k)	Fmax tension (k)	Cap. tension (k)	Max. stress check	Pile length (ft)	Pile OD (in)	Bearing
Base model		Calculation succ	Helical	90	91.4	70	84.6	1.182	31.5	4	18S20S
		cap.ten.ULT= 16		k			0 	80 16	ression P 30 240 I I I . GEO Caj	320	400
	F	cap.tension= 84 cap.comp= 91.3	.56 k	90 k			0 [80 16	50 240 178.3	·	400
F		5 ft	\uparrow			`	° 🔨				
C (UND.)	-5ft	-15 ft	ft	Fsh	naft= 9.31k						
\$1	-18 ft	26.5 ft	۴	1	Fcylinder =	t (in)		5			
\$2		*	\mathbf{A}		29.76ksf, 1		4, F= 50				
Boring 1										18k 2.32 CC-AC3	

Table: Analysis and Checking Summary table.

Figure: Pile bearing capacity (cylinder method) and settlement.

DEEPFND/HELIXPILE EXAMPLE: HELICAL PILE DESIGN





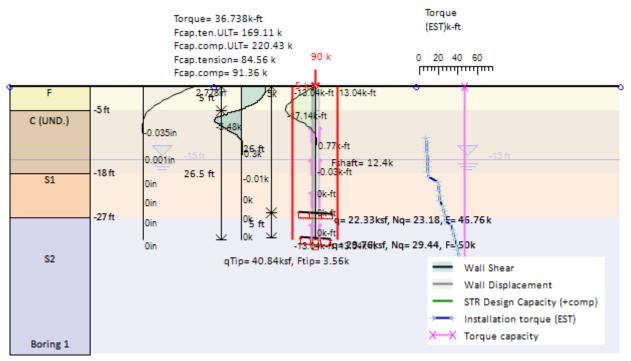


Figure: Pile displacement, shear and moment diagrams, and estimated torque.