GEOPIER®

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October 13, 2023

TO: Johnston Architects

SUBJECT: Design Submittal - Geopier Soil Reinforcement REVISED
Mercer Island Mixed-Use Development
Mercer Island, WA

This letter and the attached documents represent our design submittal for Geopier® soil reinforcement at the site of the Mercer Island Mixed-Use development located in Mercer Island, WA. The following paragraphs document our design of the Geopier-Rampact reinforcement system for support of the mat foundations. Based on the geotechnical report and project documents it is assumed that the ground improvement will only be required west of Gridline G and that east of Gridline G the mat foundation and spread footings will be founded on competent native soils.

Geopier Reinforcement Design

Subsurface information, as documented in the geotechnical report completed by Hart Crowser Inc., has been used as a basis for our design. Below are the simplified soil soil conditions:

- Loose to medium dense silty granular FILL, soft SILT and PEAT to variable depths between El.87ft and El.60ft.
- Underlain by interbedded layers of medium to hard SILT and silty CLAY and medium dense to dense SAND and silty SAND to the maximum exploration at about El.40ft.
- At about El.71.5 ft, where finished floor elevation (FFE) is defined, soils predominantly consist of very soft and soft SILT to about El. 60ft. In the southeast portion of building footprint, soils consist of very stiff to hard SILT and dense to very dense SAND.
- Groundwater was encountered at variable depths between 7.5 and 35 feet (assumed to be perched water).

In view of the loose/soft to medium dense/stiff sandy and silty soils, the Geopier-Rampact system or "displacement process" will be used to install the Geopier elements. The Geopier-Rampact system which we propose to utilize consists of a hollow mandrel with an internal compaction surface which is driven into the ground using a powerful static down force augmented by dynamic vertical impact energy. After driving to the design depth, the hollow mandrel serves as a conduit for aggregate placement. As the mandrel is raised and redriven downward thin lifts of compacted aggregate are formed and compacted both vertically and laterally. The process is repeated until the rammed aggregate pier is constructed. We anticipate installing Geopier elements from the approximate elevation between 75 and 76 ft. The mandrel will be driven to the dense to very dense soil conditions. Geopier elements will be installed to 20 feet or refusal below the planned FFE. Practical refusal is considered less than 1 foot of mandrel advancement in 30 seconds.

The Geopier reinforcement has been designed to support the structure based on the loading provided by the structural engineer plans with a maximum allowable bearing capacity of up to 4,000 psf which can be increased by 1/3 for short duration loading due to the ground improvement system but the ground improvement system has been designed for the actual pressures provided by the structural engineer. Actual loading of the mat provided by the structural engineer reveals an average bearing pressure of 1,000 psf. The design cell capacity (combination of the Geopier element and surrounding matrix soil) for each Geopier element supporting foundations is 50 kips.

Our Geopier elements will be installed directly beneath the mat foundations to provide adequate static support and beneath the mat foundation in a grid pattern with an approximate maximum spacing of 5 feet on-center.

Spread Foundation Settlement

For our analysis, settlements are first calculated for a zone extending from the bottom of the footing to the depth of the reinforcement. Additional settlement may occur in the “lower zone” or in the unimproved soil beneath the reinforced zone. The lower zone settlement is calculated using an elastic or consolidation approach depending on the soil type. For the area of the deeper ground improvement we estimate a total settlement of approximately 1 inch and and for the area of shallower ground improvement we are estimating approximately ½ to ¾ of an inch of settlement. Differential settlement over 40 feet will be less than ½ of an inch. Please see our attached calculations for additional information.

Geopier Mechanics Analysis

We have provided analysis regarding the Geopier Mechanics Analysis. Below are our calculated factors of safety:

- Shearing Below Single Element: 12.8
- Shearing Within Improved Soil: 25.9
- Shearing Below Improved Soil: 31.9

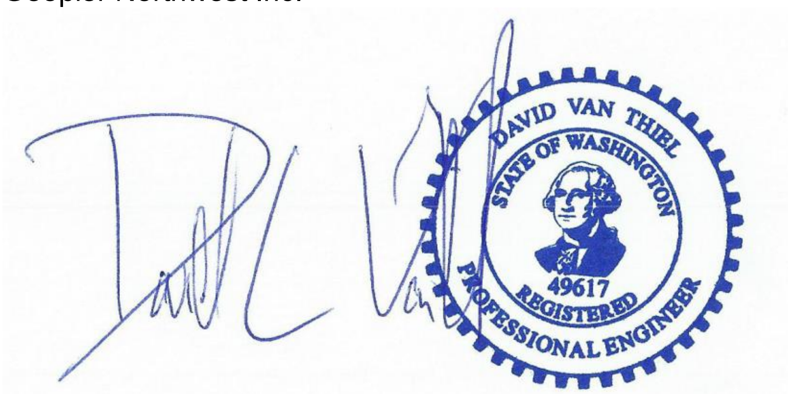
All factors of safety are acceptable to us as the ground improvement engineer and are high enough where additional deformation would not be anticipated. Calculations are attached to this design submittal.

Geopier Installation and Modulus Testing

The installation of the Geopier reinforcement, including a downward modulus test, will be completed in general accordance with the specifications. The installation and the modulus test will be conducted under the supervision of an experienced geotechnical engineer from Geopier Northwest. The modulus test will consist of loading the Geopier element in increments to 150% of the design load while measuring deflections to verify the design parameters. The modulus test will also incorporate a creep test at 115% of the design load.

We appreciate the opportunity to work with you on this project. If you have any questions or require further information, please call.

Sincerely,
Geopier Northwest Inc.



David Van Thiel, P.E., G.E.

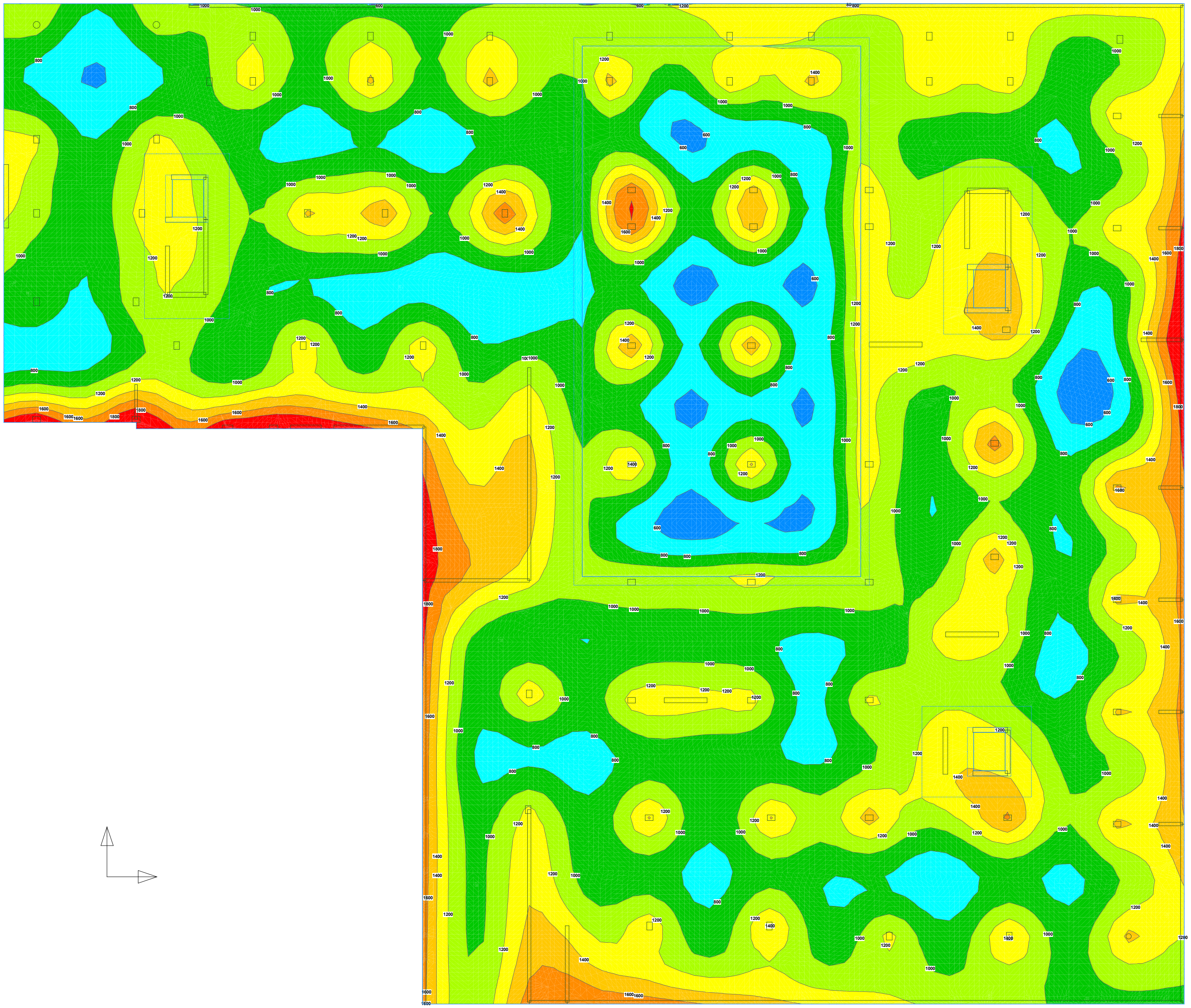
Appendix A: Structural Loading

Service LC: D + L: Std Soil Bearing Pressure Plan

Service LC: D + L: User Lines; User Notes; User Dimensions;
Element: Wall Elements Below; Wall Elements Above; Wall Element Outline Only; Column Elements Below; Column Elements Above; Slab Elements; Slab Element Outline Only;
Scale = 1:450
Service LC: D + L - Area Spring Vertical Reactions Plot

200 400 600 800 1000 1200 1400 1600 1800

Min Value = 0 psf @ (21.47,206.3)   Max Value = 2270 psf @ (39.37,105.9)

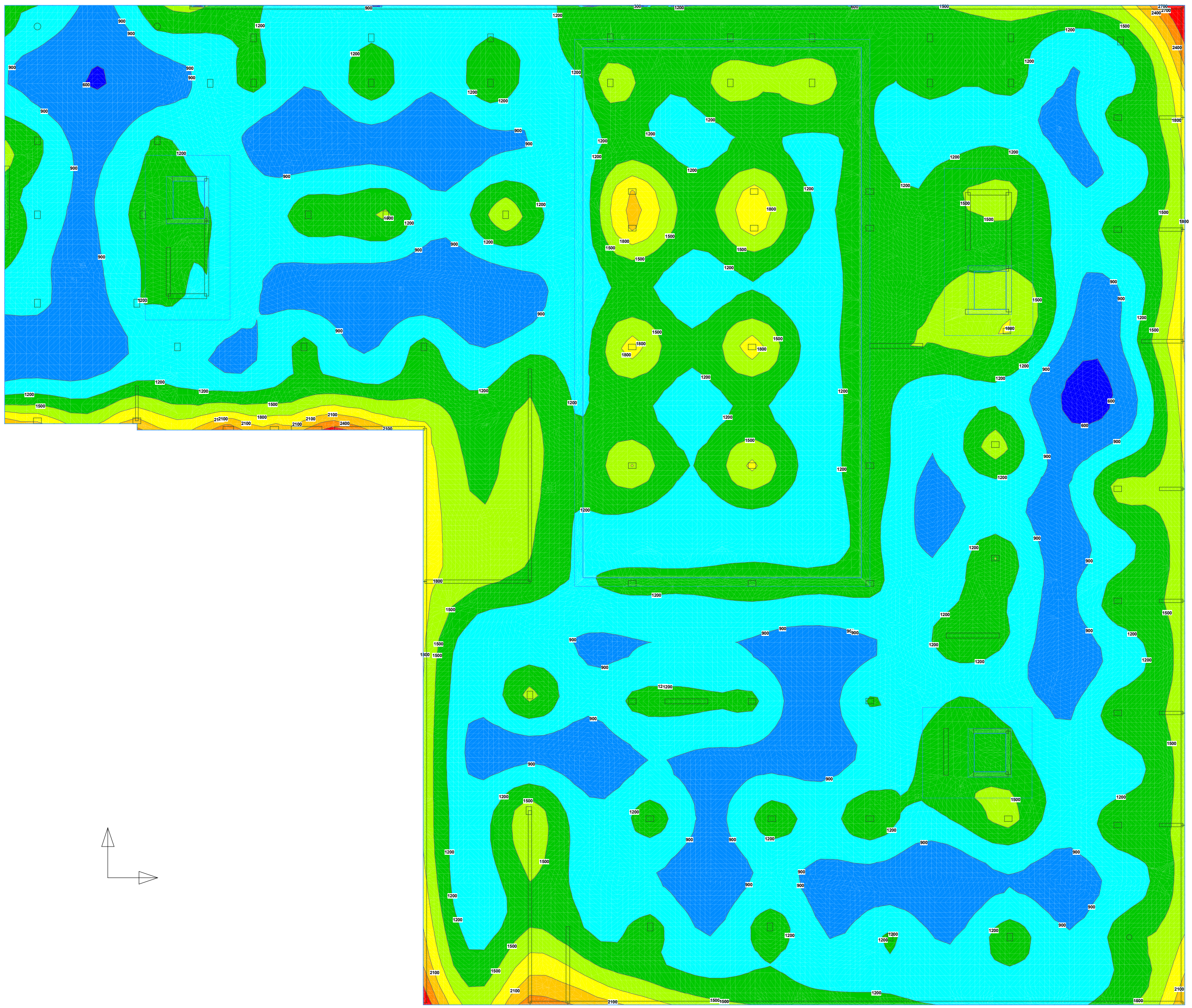


Soil Bearing Design: Max Soil Bearing Pressure Plan

Soil Bearing Design: User Lines; User Notes; User Dimensions; Latitude Span Designs; Longitude Span Designs; Latitude DS Designs; Longitude DS Designs; PC Designs;
Element: Wall Elements Below; Wall Elements Above; Wall Element Outline Only; Column Elements Below; Column Elements Above; Slab Elements; Slab Element Outline Only;
Scale = 1:450
Soil Bearing Design - Area Spring Vertical Reactions Plot (Maximum Values)

300 600 900 1200 1500 1800 2100 2400 2700

Min Value = 0 psf @ (21.47,206.3)   Max Value = 3289 psf @ (254.5,206.3)



Appendix B: Bearing Calculations

PROJECT: Mecer Island Mixed Use *Deep
NO:
DATE: 10/13/2023
ENGINEER: DVT

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RAMMED AGGREGATE PIER ® DESIGN FOR MATS

Equivalent B = 185.7 ft.

Mat Width	115	ft
Mat Length	300	ft
Mat Area	34500	sq. ft.
Equiv Width, B	185.7	ft
Floor Pressure	1000	psf
Dgw	8	ft
γ soil	125	pcf
Hs	15	ft
Pier Diameter	24	inches

Rammed Aggregate Pier® Design:

								Center			Edge		
Spacing (feet o-c)	Layer Thickness	Ra	Em (ksf)	Eg (ksf)	Ecomp (ksf)	z (ft)	z/Beq	Influence Factor	ΔP (ksf)	S (inches)	Influence Factor	ΔP (ksf)	S (inches)
5.00	4	0.13	100	1400	263	2.0	0.01	1.00	1.00	0.2	0.98	0.98	0.2
5.00	4	0.13	100	1400	263	6.0	0.03	1.00	1.00	0.2	0.83	0.83	0.2
5.00	4	0.13	100	1400	263	10.0	0.05	1.00	1.00	0.2	0.73	0.73	0.1
5.00	3	0.13	100	1400	263	13.5	0.07	1.00	1.00	0.2	0.67	0.67	0.1
5.00	2	0.13	400	5000	978	16.0	0.09	1.00	1.00	0.0	0.64	0.64	0.0
	17												

Selected for Design:	5.00	0.13	0.8	0.6
	Spacing (ft)	Ra	Ctr UZ (in)	Edge UZ (in)

Lower Zone:

											Center			Edge		
Layer	Soil Type		Esoil ksf	Cεr	Cεc	OCP ksf	Thickness ft	z ft	σ'v psf	z/Beq	Iσ Center	ΔP ksf	S (Center) in	Iσ Edge	ΔP ksf	S (Edge) in
UZ	GP-CL						17.0	8.5					0.8			0.6
1	ML			0.005		18.76	10	22.00	1876	0.12	0.99	0.99	0.11	0.61	0.61	0.1
2	ML			0.005		25.02	10	32.00	2502	0.17	0.97	0.97	0.09	0.57	0.57	0.1
3	ML			0.0025		100.75	71	72.50	5038	0.39	0.81	0.81	0.14	0.47	0.47	0.1
							108.0									

Center		Edge	
UZ (in) =	0.8	UZ (in) =	0.6
LZ (in) =	0.3	LZ (in) =	0.2
Total Center (in) =	1.1	Total Edge (in) =	0.8

PROJECT: Mecer Island Mixed Use *Shallow
NO:
DATE: 10/13/2023
ENGINEER: DVT

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RAMMED AGGREGATE PIER ® DESIGN FOR MATS

Equivalent B = 185.7 ft.

Mat Width	115	ft
Mat Length	300	ft
Mat Area	34500	sq. ft.
Equiv Width, B	185.7	ft
Floor Pressure	1000	psf
Dgw	1	ft
γ soil	125	pcf
Hs	1	ft
Pier Diameter	24	inches

Rammed Aggregate Pier® Design:

								Center			Edge		
Spacing (feet o-c)	Layer Thickness	Ra	Em (ksf)	Eg (ksf)	Ecomp (ksf)	z (ft)	z/Beq	Influence Factor	ΔP (ksf)	S (inches)	Influence Factor	ΔP (ksf)	S (inches)
5.00	0.5	0.13	100	1400	263	0.3	0.00	1.00	1.00	0.0	1.00	1.00	0.0
5.00	0.5	0.13	100	1400	263	0.8	0.00	1.00	1.00	0.0	1.00	1.00	0.0
5.00	0.5	0.13	100	1400	263	1.3	0.01	1.00	1.00	0.0	1.00	1.00	0.0
5.00	0.5	0.13	100	1400	263	1.8	0.01	1.00	1.00	0.0	1.00	1.00	0.0
5.00	1	0.13	400	5000	978	2.5	0.01	1.00	1.00	0.0	0.98	0.98	0.0
	3												

Selected for Design:	5.00	0.13	0.1	0.1
	Spacing (ft)	Ra	Ctr UZ (in)	Edge UZ (in)

Lower Zone:

											Center			Edge		
Layer	Soil Type		Esoil ksf	Cεr	Cεc	OCP ksf	Thickness ft	z ft	σ'v psf	z/Beq	Iσ Center	ΔP ksf	S (Center) in	Iσ Edge	ΔP ksf	S (Edge) in
UZ	GP-CL						3.0	1.5					0.1			0.1
1	ML			0.005		5.63	10	8.00	563	0.04	1.00	1.00	0.27	0.77	0.77	0.2
2	ML			0.005		11.89	10	18.00	1189	0.10	1.00	1.00	0.16	0.63	0.63	0.1
3	ML			0.0025		78.25	77	61.50	3912	0.33	0.87	0.87	0.20	0.49	0.49	0.1
							100.0									

Center		Edge	
UZ (in) =	0.1	UZ (in) =	0.1
LZ (in) =	0.6	LZ (in) =	0.5
Total Center (in) =	0.7	Total Edge (in) =	0.6

Appendix B: Settlement Calculations

GEOPIER BEARING CAPACITY ANALYSI

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Run Date: 10/13/2023 7:55

PROJECT: Mercer Island Mixed Use

Reference: Technical Bulletin No. 2, "Bearing Capacity of Geopier-Reinforced Founhdation Systems", by Geopier Foundation Co., Inc. (1999)

Footing Data:

Design Bearing Pressure	q	=	3,000	(psf)
Footing Length	L	=	300.00	(ft)
Footing Width	B	=	115.00	(ft)
Footing Depth	D_f	=	2.00	(ft)
Pier Diameter		=	24	(in)
Number of Piers		=	1,380.0	
Pier Modulus	K_{Gp}	=	125	(pci)
Depth to GWL Below Finish Floo		=	1.0	(ft)

Total Column Load (kips)	=	103,500
Footing Area (sq. ft)	=	34,500.00
Total Pier Area (sq. ft)	=	4,333.20
Area Ratio	=	0.126
Stess Applied to Piers (psf)	=	14,082
Stress Applied to Matrix Soil (psf)	=	1,408
Relative Stiffness Ratio	=	10
Individual Pier Load (kips)	=	44.22

Matrix Soil Data:

					Lower Zone:	
UZ Soil Modulus	K_s	=	13	(pci)		
Allowable Bearing Pressure		=	1,500	(psf)		
Undrained Strength	S_u	=		(psf)		(psf)
Cohesion	c	=	200	(psf)	500	(psf)
Friction Angle	Φ_s	=	26	(degrees)	34	(degrees)
Unsubmerged Unit Weight:						
Above D_f	γ_2	=	120	(pcf)		
Below D_f	γ_1	=	120	(pcf)		

Geopier Data:

Pier Diameter	d	=	2.0	(ft)	
Effective diam.	d_e	=	2	(ft)	*** effective shaft diam. = nominal diam. + 6"*
Shaft Drill Depth		=	15	(ft.)	** Assumed Average Shaft Lengtl
Effective Shaft	$H_{eff.}$	=	17.0	(ft.)	*** effective pier length for soil bearing capacity a*
Modulus	k_{gp}	=	125	(pci)	
Friction Angle	Φ_{gp}	=	48	(degrees)	
Unit weight:					
Unsubmerged	γ_{gp}	=	135	(pcf)	
Design	γ_{gp}	=	73	(pcf)	
Pier Area	A_{gp}	=	4,333.20	(sq. ft.)	
Area Ratio	R_A	=	0.126	(Af/Agp)	
Stiffness Ratio	R_s	=	10		
Top-of-pier Stress	σ_{gp}	=	14,082	(psf)	

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A. Shearing Below the Tip of Individual Geopier Elemer

predominantly clayey soils where essentially **undrained** *conditions apply*

Ultimate Top-of-pier stress	q_{ult}	=	0	psf	$q_{ult} = 4s_u d_e H_{eff.}/d^2 + 9s_u$ *(Eq.11.)*
For Design Pier Stress = 14082 psf		**=**	**0.00**		

predominantly silty and/or sandy soils where essentially **drained** *conditions apply*

Effective shaft diameter	d_e	=	2.5	ft	*(effective shaft diam. = nominal diam. + 6")*
Crossectional area of Geopier element	A_g	=	3.1	ft2	$Ag = \Pi d_2/4$
Average unit shaft friction (drained)	f_s	=	755	psf	$f_s = (d_f+H_{eff.}/2)\gamma \tan(\Phi_s)\tan^2(45+\Phi_s/2)$ *(Eq.12)*
Effective area of Geopier element shaft	A_{shaft}	=	134	ft2	$A_{shaft} = \Pi d_e H_{eff.}$
Ultimate shaft frictional capacity (drained)	q_{shaft}	=	32,107	psf	$q_{shaft} = f_s A_{shaft}/A_g$
	Qshaft	=	100,868	pounds	$Qshaft = f_s A_{shaft}$
Effective overburden stess @ pier tip	σ_{vtip}	=	1157	psf	
Bearing Capacity Factors: Φs = 34 degrees					*(Use Meyerhof factors for bearing capacity below individual piers)*
cohesion	N_c	=	145		
friction	N_γ	=	0		
embedment	N_q	=	65		
Ultimate bearing Capacity at pier tip (drainec	q_{tip}	=	147,692	psf	$q_{tip} = cN_c+(0.5)d_e\gamma N_\gamma+\sigma_{vtip}N_q$ *(Eq.9)*
Ultimate tip capacity (drained):	Q_{tip}	=	463,988	pounds	$Q_{tip} = q_{tip} A_g$
Ultimate Top-of-Pier Stress	q_{ult}	=	179,799	psf	$q_{ult} = (Q_{shaft} + Q_{tip})/A_g$
For Design Pier Stress = 14082 psf		**FS =**	**12.77**		

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B. Shearing Within The Geopier-Reinforced Soil Matrix

Composite Soil Strength Parameters:

R_a Reduction Factor	=	0.4		Effective R_a = 0.05
Soil Stress Concentration Factor	=	2.5		(Reduced R_s to account for vert. stress decrease with depth)
$\Phi_{comp.}$	=	30	degrees	
$C_{comp.}$	=	0	psf	(based on value entered for Su)
	=	175	psf	(based on value entered for C)

$$q_{ult.} = k_1(C_{comp.}N_c) + k_2(\gamma_1 B N_\gamma) + \gamma_2 D_f N_q$$

where:

k_1 = 1 — k_1 = 1.3 for square and rectangular footings; and 1.0 for continuous footings

k_2 = 0.5 — k_2 = 0.5 for sauare, rectangular and continuous footings

N_c = 36
N_γ = 20
N_q = 22
(Terzaghi General Shear Factors)

$q_{ult.}$ = $k_1(C_{comp.}N_c)$ + $k_2(\gamma_1 B N_\gamma)$ + $\gamma_2 D_f N_q$

$q_{ult.}$ = 6,296 66,240 5,280

$q_{ult.}$ = 77,816 psf

For Design Footing Stress = 3000 psf **FS = 25.9**

C. Shearing Below The Bottom of The Geopier-Reinforced Soil Matrix

Depth below FF to btm.of Geopier-reinforced zone	H	=	19.0	feet	
Effective stress at btm.of Geopier-reinf. zone	σv-uz/lz	=	1157	psf	
Stress induced from footing @ UZ/LZ plane	q_{bottom}	=	2,421	psf	q_{bottom} = q{BL/[(B+H)(L+H)]} *(Eq. 15)*

predominantly clayey soils where essentially **undrained** *conditions apply*

Undrained strength of soil below UZ/LZ plane	S_u	=	0	psf	
Stress induced from footing @ UZ/LZ plane	q_{bottom}	=	2,421	psf	q_{bottom} = q{BL/[(B+H)(L+H)]} *(Eq. 15)*
For Design Footing Stress = 3000 psf		**FS =**	**0.0**		

predominantly silty and/or sandy soils where essentially **drained** *conditions apply*

Bearing Capacity Factors: Φs = 34 degrees *(Use Terzaghi local shear factors for shearing below the reinforced zone)*

cohesion	N_c	=	21		
friction	N_γ	=	8		
embedment	N_q	=	10		
Ultimate bearing capacity @ UZ/LZ (drained)	$q_{ult.}$	=	77,268	psf	qult = $cN_c + (0.5)B\gamma N_\gamma + \sigma_{v\text{-}uz/lz} N_q$ *(Eq.9)*
Stress induced from footing @ UZ/LZ plane	q_{bottom}	=	2,421	psf	q_{bottom} = q{BL/[(B+H)(L+H)]} *(Eq. 15)*

For Design Footing Stress = 3000 psf **FS = 31.9**