GEOPIER FOUNDATION CO INC
TECHNICAL BULLETIN

No. 5

GEOPIER® SHEAR REINFORCEMENT FOR GLOBAL STABILITY AND SLOPE STABILITY

This Technical Bulletin discusses the increase in the soil shear strength afforded by the installation of *Geopier®* elements. Increases in shear strength are often required in weak soils where construction of Mechanically Stabilized Earth (MSE) retaining walls, concrete retaining walls, and earthen embankments may result in global instability. Increases in shear strength are also required for natural slopes subject to sliding. *Geopier* construction results in very dense aggregate pier elements that exhibit high angles of internal friction. This Technical Bulletin describes design methods used for the improvement of soil shear strength with *Geopier* soil reinforcing elements.

1. BACKGROUND: GLOBAL STABILITY AND SHEAR STRENGTH

Construction of MSE retaining walls, concrete retaining walls, and earthen embankments often results in high shearing stress in the underlying soil. If the shear strength of the foundation soils is less than the applied shear stress, failure will occur as the structure rotates on slip surfaces extending through the foundation soils. Similarly, if the shear strength of natural or fill slopes is less than the shear stress in the inclined soil mass, a landslide will occur.

Geopier soil reinforcing elements are installed in weak matrix soil to improve the composite shearing strength and increase the factor of safety against global instability or sliding. Depictions of *Geopier* elements to reinforce matrix soils beneath an MSE wall, an embankment, and within a sliding soil mass are illustrated in Figures 1a, 1b, and 1c, respectively.

geopier®

Figure 1a.
Geopier
Soil Reinforcement
of MSE Wall.

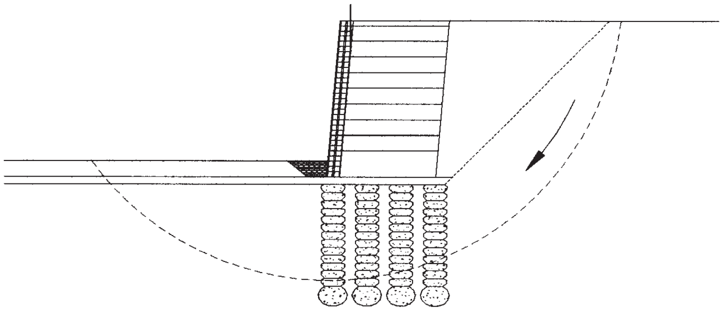


Figure 1b.
Geopier
Soil Reinforcement
of Embankment.

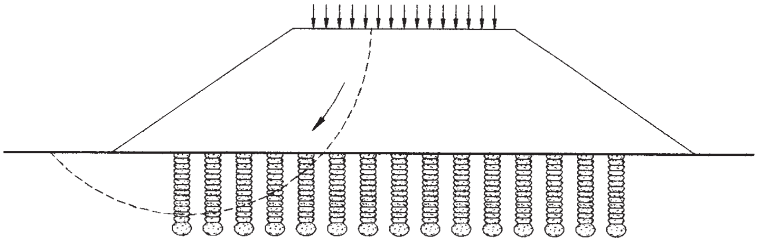
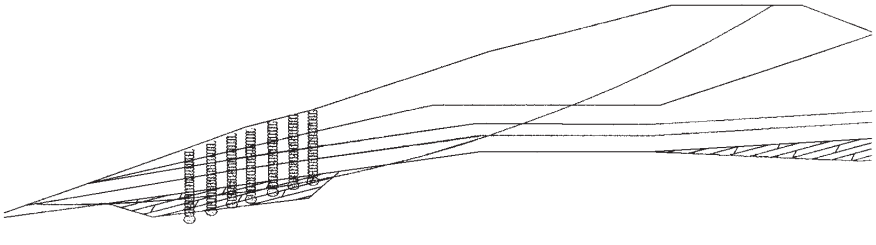


Figure 1c.
Geopier
Soil Reinforcement
of Natural Slope.



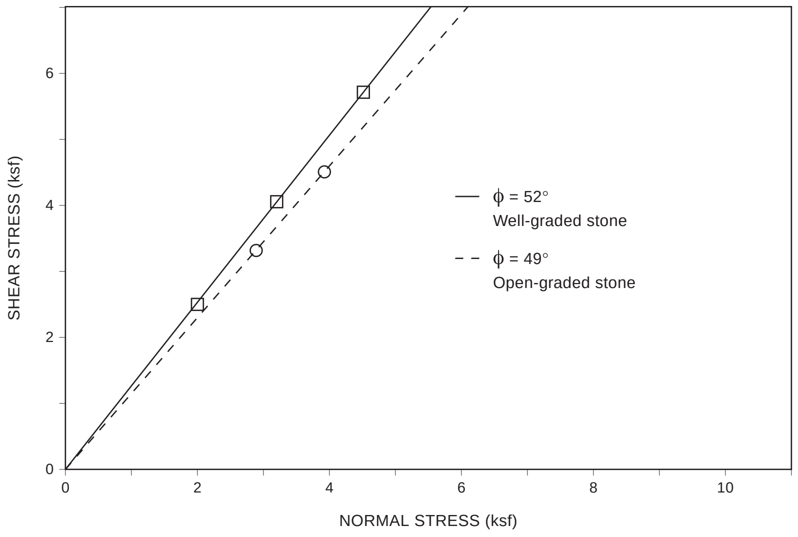
2. *GEOPIER* CONSTRUCTION

Geopier construction is described in detail in the *Geopier* Reference Manual (Fox and Cowell 1998). The elements are constructed by drilling out a volume of compressible soil to create a cavity and then ramming select aggregate into the cavity in thin lifts using the patented beveled tamper. The ramming action causes the aggregate to compact vertically and to push laterally against the matrix soil, thereby increasing the horizontal stress in the matrix soil. *Geopier* construction results in a very dense aggregate pier with high stiffness and high angle of internal friction resulting from the dilation of the aggregate when subject to shearing stresses. The construction process allows for a high level of confidence in the design friction angle used for rammed *Geopier* aggregate.

3. *GEOPIER* SHEAR STRENGTH

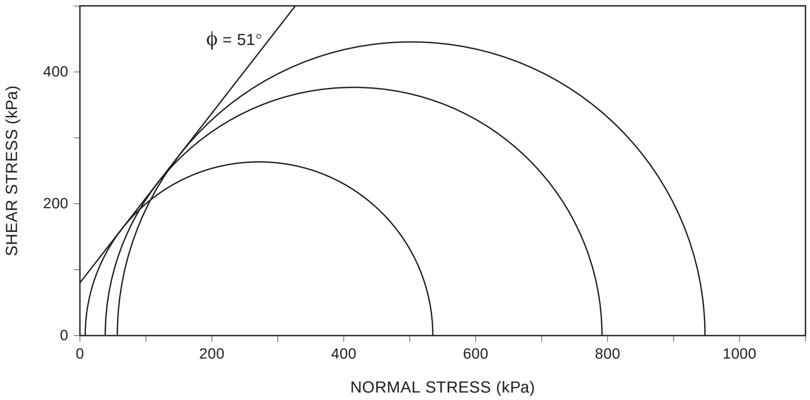
Full-scale field shear tests performed on 30-inch diameter *Geopier* elements and small-scale laboratory triaxial tests performed on reconstituted samples demonstrate that the angle of internal friction for *Geopier* aggregate ranges from 49 degrees to 52 degrees, depending on gradation. Results obtained from the full-scale direct shear tests performed on *Geopier* elements (Fox and Cowell 1998) are shown in Figure 2. The tests were performed by applying incremental normal loads to the top of installed *Geopier* elements followed by the application of horizontal loads until shear failure. *Geopier* elements constructed using both well-graded base course stone and open-graded (#57) stone were tested.

Figure 2.
Results of Full-scale Field Shear Testing
Performed at the Tops of Geopier Elements.



Small-scale laboratory triaxial tests were performed at Iowa State University on reconstituted samples of well-graded *Geopier* aggregate compacted to densities consistent with those measured for installed *Geopier* elements (White 2001). Test results, illustrated in Figure 3, indicate an angle of internal friction of 51 degrees. The high friction angles measured in the field and laboratory tests are attributed to the high density and the dilatent behavior of the very stiff aggregate produced during the high-energy ramming of the crushed aggregate.

Figure 3.
Results of Triaxial Testing
of Compacted Geopier Aggregate.



4. SHEAR REINFORCEMENT DESIGN METHODS

The design of shear reinforcement for slopes, embankments, and walls is performed by determining the factor of safety against global instability. The factor of safety against instability is the ratio of the resisting moment to the destabilizing moment (Duncan 1987). Many computer programs, such as PCSTABL, UTEXAS, SLOPE/W, and GSLOPE, are currently available for performing these conventional analyses. The input parameters required to perform the analysis include slope or wall geometry, soil unit weight, soil shear strength (cohesion and friction angle), and the level of the phreatic surface.

4.1 COMPOSITE SHEAR STRENGTH PARAMETERS

The composite shearing strength of *Geopier*-reinforced soils is computed using the conventional method of calculating the weighted average of the shear strength components of the *Geopier* elements and matrix soil materials (FHWA 1999). The composite shear strength is expressed in the following equation:

$$\tau_{comp} = \sigma'_v \tan \phi'_{comp} + c'_{comp}. \qquad Eq.1.$$

The composite cohesion intercept (c'_{comp}) is computed with the expression:

$$c'_{comp} = c'_g R_a + c'_m (1 - R_a), \qquad Eq.2.$$

where c'_g is the cohesion intercept of the *Geopier* aggregate, c'_m is the cohesion intercept of the matrix soils, and R_a is the ratio of the *Geopier* area to the gross footprint area of the reinforced soil zone. Because the cohesion intercept of the *Geopier* aggregate is zero, Equation 1 reduces to:

$$c'_{comp} = c'_m (1 - R_a). \qquad Eq.3.$$

The composite friction angle (ϕ'_{comp}) is computed with the expression:

$$\phi'_{comp} = \arctan [R_a \tan \phi'_g + (1 - R_a) \tan \phi'_m], \quad Eq.4.$$

where ϕ'_g is the friction angle of the *Geopier* aggregate and ϕ'_m is the friction angle of the matrix soils.

4.2 COMPOSITE SHEAR STRENGTH PARAMETERS INCORPORATING STRESS CONCENTRATION

In situations where *Geopier* elements supporting MSE walls or embankments extend through weak soils to a firm bearing layer, the significant difference between the matrix soil stiffness and the *Geopier* element stiffness results in a concentration of stress to the tips of the *Geopier* elements. This results in a significant further increase in the composite shear strength (Mitchell 1981).

The composite shear strength of the *Geopier*-reinforced zone is computed in a manner similar to that discussed above utilizing a weighted average approach as presented in Equation 1. However, the calculations to determine the composite friction angle and cohesion values incorporate additional terms to account for the stress concentration:

$$\phi'_{comp} = \qquad Eq.5.$$

$$\arctan \left[\frac{R_s}{R_a R_s - R_a + 1} R_a \tan \phi'_g + \frac{1}{R_a R_s - R_a + 1} (1 - R_a) \tan \phi'_m \right],$$

$$c'_{comp} = \qquad Eq.6.$$

$$\frac{1}{R_a R_s - R_a + 1} (1 - R_a) c'_m,$$

where R_s is the ratio of the *Geopier* element stiffness to the matrix soil stiffness (Mitchell 1981). Typical stiffness ratio values range from 10 to 40 when considering traditional foundation support applications (Lawton and Fox 1994, Fox and Cowell 1998, Lawton 2001). Design values of stiffness ratio must be selected with care.

4.3 INCORPORATION OF COMPOSITE PARAMETERS

The *Geopier*-reinforced zone is designed to intersect the critical shearing surfaces located beneath the retaining walls and the embankment slopes. Within the reinforced zone, the composite cohesion and friction angle values (Equations 2 through 6) represent the composite shear strength of the soil zones reinforced by the aggregate elements. Analyses are performed on a trial and error basis; the area coverage (R_a) of the *Geopier* elements is varied until the acceptable factor of safety is reached.

5. EXAMPLE CALCULATIONS

Example calculations for estimating the composite shear strength parameter values using the procedures outlined above are shown in Figures 4a and 4b. The matrix soil and *Geopier* aggregate shear strength parameter values are provided in the figure. An area ratio (R_a) of 0.20 is assumed for the calculations.

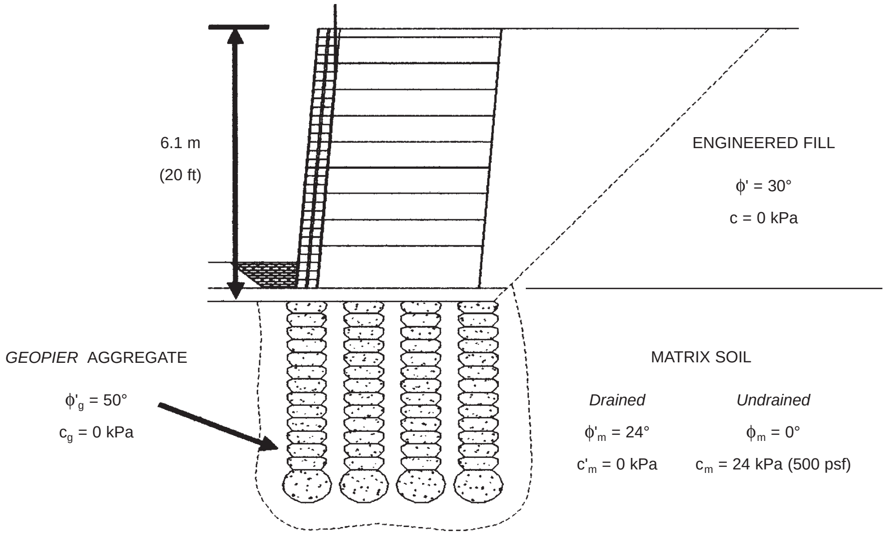


Figure 4a.
Determination of
Composite Shear Strength
Parameter Values.

COMPOSITE SHEAR STRENGTH PARAMETER VALUES (NO STRESS CONCENTRATION)

Drained Composite Parameter Values

$c'_{comp} = (1 - 0.20)\ 0\ \text{kPa} = 0\ \text{kPa}$

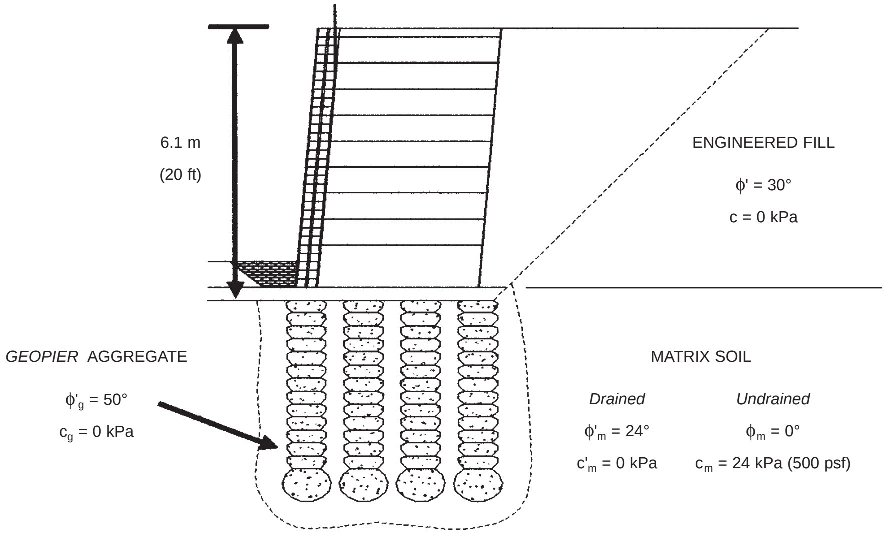
$\phi'_{comp} = \arctan\ [0.20 \tan 50° + (1 - 0.20) \tan 24°] = 30.7°$

Undrained Composite Parameter Values

$c_{comp} = (1 - 0.20)\ 24\ \text{kPa} = 19.2\ \text{kPa}\ (400\ \text{psf})$

$\phi_{comp} = \arctan\ [0.20 \tan 50° + (1 - 0.20) \tan 0°] = 13.4°$

Figure 4b.
Determination of Composite Shear Strength Parameter Values
Using Stress Concentration.



COMPOSITE SHEAR STRENGTH PARAMETER VALUES (STIFFNESS RATIO = 5)

Drained Composite Parameter Values

$$c'_{comp} = \left[\frac{1}{10(0.20) - 0.20 + 1}\right] (1 - 0.20)\ 0\text{ kPa} = 0\text{ kPa}$$

$$\phi'_{comp} = \arctan\left[\left[\frac{10}{10(0.20) - 0.20 + 1}\right] 0.20 \tan 50° + \left[\frac{1}{10(0.20) - 0.20 + 1}\right] (1 - 0.20) \tan 24°\right] = 44.4°$$

Undrained Composite Parameter Values

$$c_{comp} = \left[\frac{1}{10(0.20) - 0.20 + 1}\right] (1 - 0.20)\ 24\text{ kPa} = 6.9\text{ kPa (143 psf)}$$

$$\phi_{comp} = \arctan\left[\left[\frac{10}{10(0.20) - 0.20 + 1}\right] 0.20 \tan 50° + \left[\frac{1}{10(0.20) - 0.20 + 1}\right] (1 - 0.20) \tan 0°\right] = 40.4°$$

Figure 5a (page eight) presents the results of an undrained global stability analysis performed using the same wall geometry and matrix soil properties as provided in Figure 4. The results of the analysis for *unreinforced* conditions indicate that the factor of safety is on the order of 1.0. The results of the analyses incorporating a *Geopier*-reinforced zone to intersect the critical failure surface are presented in Figures 5b and 5c (page eight). Using an area ratio of 0.20 and a stiffness ratio of 1.0 (no stress concentration), the factor of safety is increased to 1.3 (figure 5b). The factor of safety increases to approximately 1.7 when a stiffness ratio of 5 is incorporated into the analysis (Figure 5c).

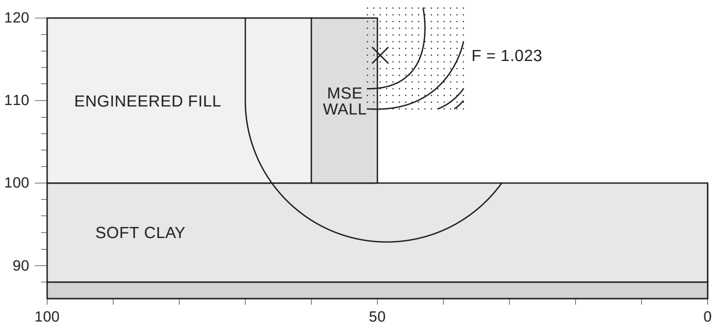


Figure 5a.
Unreinforced Slope Stability Analysis.

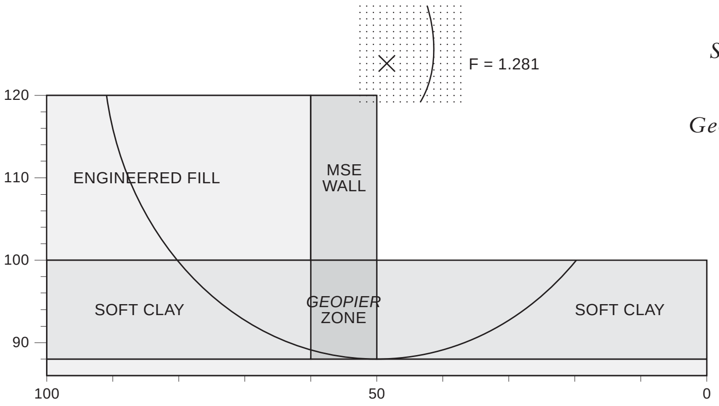


Figure 5b.
Slope Stability Analysis Incorporating Geopier-reinforced Zone.

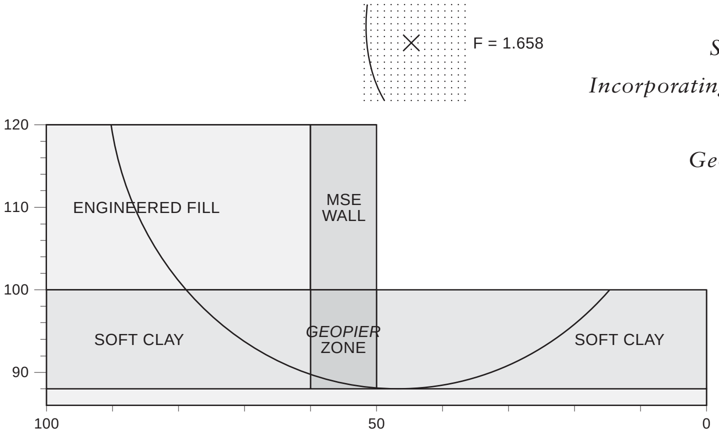


Figure 5c.
Slope Stability Analysis Incorporating Stress Concentration within the Geopier-reinforced Zone.

6. SUMMARY

Geopier soil reinforcement effectively increases the factor of safety against global instability of retaining walls, embankments, and slopes. Global instability occurs when the destabilizing moment exceeds the resisting moment. When *Geopier* elements are installed within the zone of critical shearing surfaces, the high angle of internal friction exhibited by the *Geopier* elements provides significant increases in the shear resistance.

REFERENCES

Duncan, M.J., A.L. Buchignani, and M. DeWet. (1987). An Engineering Manual for Slope Stability Studies. Virginia Polytechnic Institute and State University. Blacksburg, Virginia. March.

Federal Highway Administration (1999). Ground Improvement Technical Summaries, Volume II. Demonstration Project 116. Publication No. FHWA-SA-98-086.

Fox, N.S. and M.J. Cowell (1998). *Geopier® Foundation and Soil Reinforcement Manual*, *Geopier* Foundation Company, Inc., Scottsdale, AZ.

Lawton, E.C. and N.S. Fox. (1994). “Settlement of structures supported on marginal or inadequate soils stiffened with short aggregate piers.” *Geotechnical Specialty Publication No. 40: Vertical and Horizontal Deformations of Foundations and Embankments*, ASCE, 2, 962-974.

Lawton, E.C. (2000) “Performance of *Geopier* Foundations During Simulated Seismic Tests at South Temple Bridge on Interstate 15, Salt Lake City, UT.” Final Report, No. UUCVEEN 00-03, University of Utah, Salt Lake City, UT.

Mitchell, J.K. (1981). “Soil Improvement: State of the Art.” Session 12, Tenth International Conference on Soil Mechanics and Foundation Engineering, Stockholm, Sweden, June 15-19.

White, D.J. (2001). Letter to *Geopier* Foundation Company. Iowa State University. November 20, 2001.

AUTHORS

Brendan T. FitzPatrick, Associate Project Engineer, *Geopier* Foundation Company, Inc.

Kord J. Wissmann, Ph.D., P.E., Chief Engineer, *Geopier* Foundation Company, Inc.

SYMBOLS USED

c'_{comp} = Composite cohesion intercept of the *Geopier*-reinforced zone.
c'_{g} = Cohesion intercept of *Geopier* aggregate.
c'_{m} = Cohesion intercept of matrix soil.
ϕ'_{comp} = Composite angle of internal friction of the *Geopier*-reinforced zone.
ϕ'_{g} = Angle of internal friction of *Geopier* element.
ϕ'_{m} = Angle of internal friction of matrix soil.
R_a = Ratio of sum of the cross-sectional area of *Geopier* elements to the gross reinforcement area.
R_s = Ratio of *Geopier* element stiffness to matrix soil stiffness.
τ_{comp} = Composite shear strength.
τ_m = Matrix soil shear strength.

GeoStructures, Inc. and GeoConstructors, Inc.
107 Loudoun Street, SE
Leesburg, Virginia 20175
Telephone: (703) 771.9844
Fax: (703) 771.9847
e-mail: gsi@geostructures.com

GeoStructures, Inc. – Northeast
2866 Mummasburg Road
Gettysburg, Pennsylvania 17325
Telephone: (717) 677.4835
Fax: (717) 677.6646
e-mail: wsmith@geostructures.com

GeoStructures, Inc. – Southeast
6548 Vintage Ridge Lane
Fuquay-Varina, North Carolina 27526
Telephone: (919) 557.9069
Fax: (919) 557.9709
e-mail: nhothem@geostructures.com

Peterson Contractors, Inc.
Box A, 104 Blackhawk
Reinbeck, Iowa 50669
Telephone: (319) 345.2713
Fax: (319) 345.2991
e-mail: corkpci@staroute.com

Foundation Service Corp.
Box 23, 302 Blackhawk
Reinbeck, Iowa 50669
Telephone: (319) 345.2277
Fax: (319) 345.2658
e-mail: djclark@gcmuni.net

Design/Build Geotechnical
151 Randall Road
Stow, Massachusetts 01775
Telephone: (978) 567.9222
Fax: (978) 567.8888
e-mail: jwheeler@DBGeotech.com

Helical Drilling / Geopier
639 Granite Street
Braintree, Massachusetts 02184
Telephone: (781) 848.2110
Fax: (781) 848.2065
e-mail: rimas@veitas.com

CORPORATE OFFICE

Geopier Foundation Company, Inc.
8283 North Hayden Road, Suite 291
Scottsdale, Arizona 85258
Telephone: (480) 998.3522
Fax: (480) 998.3542
e-mail: geopier6@aol.com.com
Web: www.geopiers.com

DESIGN OFFICE

Geopier Foundation Company, Inc.
200 Country Club Drive SW, Suite D-1
Blacksburg, Virginia 24060
Telephone: (540) 951.8076
Fax: (540) 951.8078
e-mail: geopier@earthlink.net

Geopier Global Corporation
3183 Liberty Bell Road
Green Bay, Wisconsin 54313
Telephone: (920) 434.8847
Fax: (920) 434.8721
e-mail: geopierglobal@aol.com

Geopier International Corporation
Josef-Leistenschneider-Str.23
63628 Bad Soden-Salmunster, Germany
Telephone: 49(0)6056/912716
Fax: 49(0)6056/912717
e-mail: geopier10@aol.com

GEOPIER TEAM

Geopier Foundation Company – Northwest
40 Lake Bellevue, Suite 100
Bellevue, Washington 98005
Telephone: (425) 646.2995
Fax: (425) 646.3118
e-mail: jamesj@geopier.com

Geopier Foundation Company of Northern California
685 Placerville Drive, PMB #382
Placerville, California 95667
Telephone: (530) 621.4867
Fax: (530) 621.4837
e-mail: 4tom@farrellinc.com
Web: www.geopiernca.com

Geopier Foundation Company – West
2102 Business Center Drive, Suite 130
Irvine, California 92612
Telephone: (949) 253.5853
Fax: (949) 752.9318
e-mail: info@geopier.com
Web: www.geopier.com

Geopier Foundation Company – West
9385 SW Heikes Drive
Hillsboro, Oregon 97123
Telephone: (503) 628.0341
Fax: (503) 628.8806
e-mail: johnm@geopier.com
Web: www.geopier.com

Geopier Foundation Company – West
8283 North Hayden Road, Suite 291
Scottsdale, Arizona 85258
Telephone: (480) 998.3522
Fax: (480) 998.3542
e-mail: geopier6@aol.com

Geopier Foundation Company – Great Lakes
P. O. Box 421
1368 South Broken Arrow
New Palestine, Indiana 46163
Telephone: (317) 861.9361
Fax: (317) 861.9362
e-mail: gfcgl@earthlink.net

Geopier Foundation Company – Midwest
5818 Admiral Lane
Minneapolis, Minnesota 55429
Telephone: (763) 592.5340
Fax: (763) 592.5339
e-mail: geopiermnwi@qwest.net

The Pro Firm
1370 NW 141st Drive
Clive, Iowa 50325
Telephone: (515) 223.9326
Fax: (515) 225.4483
e-mail: geopier1@msn.com

Geopier Foundation Company – Houston
8314 Atascocita Lake Way
Humble, Texas 77346
Telephone: (281) 852.5878
Fax: (281) 852.5879
e-mail: tlw90@aol.com

Geopier Foundation Company – MidSouth, LLC
9160 Highway 64, Suite 12, No. 134
Lakeland, Tennessee 38002
Telephone: (901) 309.3363
Fax: (901) 309.3373
e-mail: Geopier@att.net

Geopier Foundation Company – Southeast
5665 Highway 9, Suite 103-178
Alpharetta, Georgia 30004
Telephone: (770) 667.9864
Fax: (770) 343.9963
e-mail: geopier@mindspring.com