# GEOPIER® Ground Reinforcement

## Foundation Design Concepts for the Structural Engineer

*Rimas M. Veitas, P.E. and James R. Wheeler, P.E.*

*Poor site subsurface conditions such as soft, compressible soils, uncontrolled fill, and/or "Urban Fill" deposits are all too common at today's building construction sites... Removal and replacement of the problem soils typically involves massive over-excavation, or requires the construction of deep foundations and structural floor slabs. Both options are costly and time-consuming. However, developments in ground improvement technology have made it possible to reinforce unsuitable soils in place. With current technologies it is possible to convert building foundations from pile supported structural slabs to conventional foundations with non-structural slabs-on-grade.*

Understanding the basic structural design concepts used with these ground improvement alternatives allows the structural engineer to design conventional shallow foundations bearing on the improved ground, thereby significantly reducing overall project complexity, schedule and cost. One such ground improvement technique is the *Geopier® Rammed Aggregate Pier™* ground reinforcement system, an innovative intermediate foundation solution developed in 1989. *Geopier®* elements have been used to support building structures in soft clays and silts, sands and gravels, organic silts and peat as well as urban fills.

### A Straightforward Approach to Settlement Evaluation

*Geopier®* elements are vertical columns of aggregate, placed in thin lifts and mechanically tamped in augered holes. These inclusions develop lateral stress in the surrounding soils to stiffen and reinforce the composite soil matrix. Individual pier elements are typically 30 inches in diameter and are constructed to depths ranging from 6 to 23 feet using the simple construction process shown in *Figure 1*. In practice, each pier is designed to act as a stiff element in the reinforced soil mass, attracting most of the applied foundation or slab loads while in most cases permitting the matrix soil between the elements to support a portion of the applied load. The end result is a man-made soil which has been improved to safely support the new structure with a prescribed bearing pressure. A contrast can be drawn between a reinforced concrete column and a pier reinforced soil mass. The steel reinforcing elements and pier elements both stiffen and add strength to the axial load resisting element.

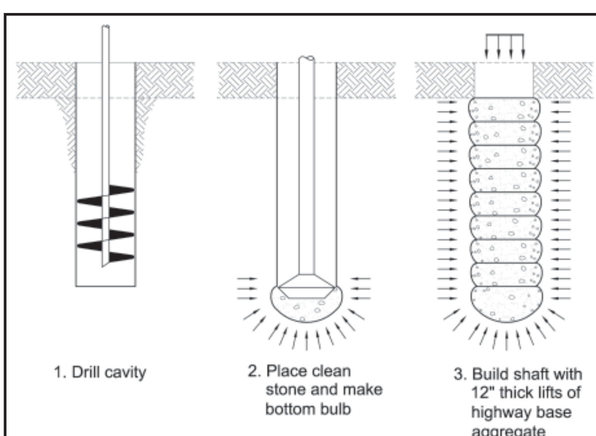


*Figure 1. Geopier Rammed Aggregate Pier (RAP) Construction Process*

The geotechnical engineer evaluates the settlement of the *Geopier*-reinforced soil strata and recommends an allowable bearing pressure that fulfills the project settlement criteria. The structural engineer then designs a conventional spread footing foundation, with some minor modifications.

To evaluate anticipated settlement of pier-supported foundations, the footing is modeled as a rigid plate supported on a system of stiffer piers and softer matrix soil springs, and assumes that the stiff piers and matrix soil settle uniformly beneath the rigid footing, as shown in *Figure 2*. Using the principle of static equilibrium, stresses concentrate at the top of the stiff piers in proportion to the stiffness ratio between the piers and the surrounding matrix soil and the area coverage ratio of the stiff piers beneath the footing. In practice, the stiffness of the piers is found to be typically 10 to 50 times greater than the stiffness of the matrix soils, and the area coverage ratio is typically at least 30 percent for foundations. Settlement in the *Geopier*-reinforced ground is then estimated by dividing the pier stress by its stiffness. The pier stiffness and corresponding load-carrying cell capacity are estimated based on past experience in similar soils and are typically verified at each project through the completion of a full-scale modulus load test.

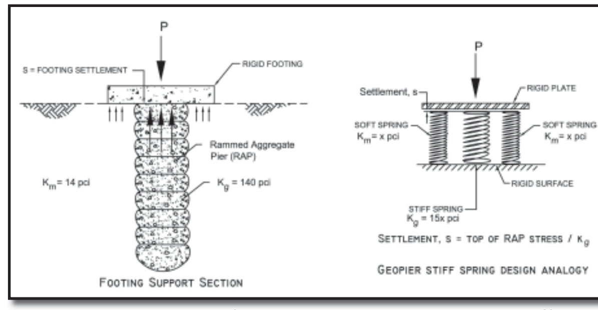


*Figure 2. Geopier Foundation Support Design Concept: Stiff Spring Design Analogy*

### Site Conditions Dictate Structural Design Evaluation Alternatives

Although *Geopier* design theory is simple to understand in relatively competent soils, further consideration must be given to situations in which foundation elements are to be supported on or above extremely soft compressible soils, including soft clay or organic deposits. As such, the design of foundations and floor slabs supported on *Geopier* elements requires a basic understanding of geotechnical design procedures for various soil conditions, as shown in *Figure 3*, and summarized as follows:

- A continuous stratum of relatively weak soils such as natural clays, silts and sands or non-organic granular or cohesive fills. These soils may be assumed to provide some structural support.
- A compacted structural fill layer placed to raise the grade over a layer

of relatively weak soils. The underlying soils are assumed to provide some structural support.

- Peat or organic soils that may extend up to the foundation bearing level. These soils cannot be relied upon for long-term vertical support of foundations or floor-slabs.
- A layer of compacted fill placed above the piers to raise grade over a layer of peat or organic soils. In this case the fill soils arch to the piers and provide structural support.

## Simple Concepts Govern Shallow Foundation Design

The design of the *Geopier* ground reinforcement for footing support is straightforward. However, close cooperation with the structural engineer and the geotechnical engineer is critical to determine the design approach for a conventional spread footing foundation system.

### *Isolated Spread Footing Design*

The design of isolated footings supported on Geopier-reinforced ground is no different than footing design on undisturbed, naturally deposited soils or on engineered compacted fill. The structural engineer should understand the soil conditions and design for the appropriate allowable footing bearing pressure.

Where foundations are in contact with the pier element, the footing is designed to bear directly on the piers and the surrounding, reinforced ground. Thus, an increased allowable bearing pressure of the pier-reinforced ground, typically two to three times the allowable bearing pressure of the unreinforced soils, is used to size the footing. In cases where the footings are not in direct contact with the pier elements, the footings are sized for the allowable bearing pressure of the fill.

It should be noted that the size of footings must be selected to ensure full coverage of the piers. In cases where there is a net uplift due to wind or seismic loads, a structural steel anchor may be designed and incorporated into the *Geopier* element to construct a tension element capable of supporting up to 70 kips of allowable uplift load. This eliminates the need for increased concrete footing mass, additional bracing or shear walls.

### *Wall or Strip Footing Design*

Design of wall footings falls into two distinct categories. Heavily loaded footings are supported with piers spaced at less than three pier diameters and are designed as isolated footings. Lightly loaded footings are those under which piers are spaced at greater than three pier diameters, and may have to structurally span between the piers. As such, for weak soil conditions the lightly loaded wall footing may be designed as a beam on an elastic foundation, incorporating the corresponding spring stiffness of the piers and the matrix soils. Alternatively, the footing bending steel could be conservatively sized as required for a continuous beam. Experience has indicated that shear steel is usually not required. In peat and organic soil conditions, it is assumed that the matrix soil does not provide any vertical support. Thus, for lightly loaded footings constructed in these soil conditions, the wall footing and wall must be designed as a continuous beam. Again, experience has shown that only bending steel is usually required.

The design of *Geopier* - supported retaining wall footings does not differ greatly from conventional footing design. In cases where major constraints exist on footing geometry, the use of tension or uplift piers may be considered.

## Cost-Effective Slab-On-Grade Support

A major cost and project schedule saving benefit offered by *Geopier* ground support is in the support of slabs-on-grade. Over the last ten years, *Geopier* systems have been designed to support floors ranging from heavily loaded warehouse slabs to lightly loaded residential floors. In most cases, the slabs were designed essentially as unreinforced slabs-on-grade, in accordance with ACI 360.R-92. Partially reinforced and fully reinforced slabs have also been used over organic and extremely weak soils.

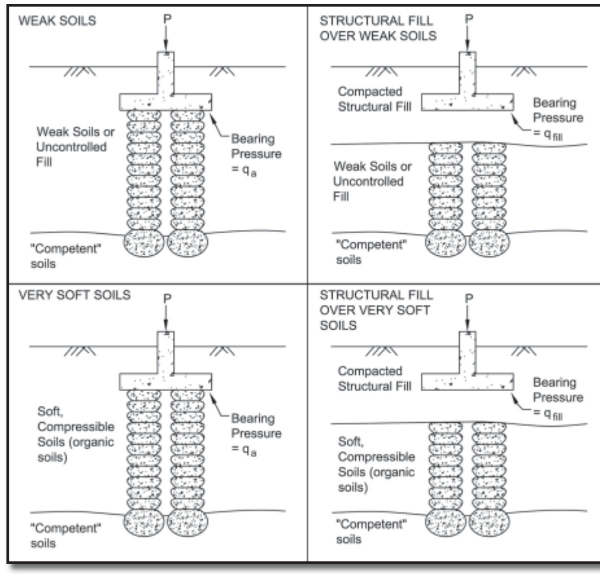


*Figure 3. Conditions Governing Geopier RAP Foundation Support Design Alternatives*

### *Weak Soil Conditions*

Heavily loaded floor slabs in weak soils can be engineered to support load requirements without the need to resort to the use of a structurally reinforced slab. As shown in *Figure 4*, piers may be spaced on an 8-foot to 16-foot grid to provide uniform slab support. However, a key element of the slab design is the coordination of the slab control joints (non post-tensioned slabs). Experience with unreinforced, conventional slab-on-grade construction has shown that joint spacing of 10 to 16 feet limits curling issues and shrinkage cracks. Given these serviceability limitations, the pier grid must generally conform to the spacing of control joints. To facilitate slab design, a finite element model, similar to that shown in *Figure 5*, is typically created using stiffer soil springs at the pier locations and softer springs between the piers to model the matrix soils. Due to the reinforcing effect from pier installation, the support spring stiffness is decreased by about one half of the previous spring stiffness for each 12-inch increment away from the edge of the pier. The unreinforced slab is then designed to limit principal bending stresses in the concrete to a value less than the modulus of rupture divided by an appropriate safety factor. The structural engineer typically works closely with the geotechnical engineer to consider if the slab weight should be addressed in the finite element calculation of stresses. Lightly loaded slabs can also be supported on *Geopier*-reinforced ground.

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### Peat and Organic Soil Conditions

A heavily loaded slab bearing on peat and organic soils should be designed as a structurally reinforced slab-on-grade, per ACI-318. It is assumed that the matrix soils provide no long-term support for the slab. The concept of utilizing the decayed spring supports around the piers may be considered in the analysis of the structural slab support, depending on the soil conditions.

### Utilizing a Raise in Site Grade

When site grades are raised, the concept of soil arching is considered to support the slab-on-grade. At a pier spacing of twice the fill thickness plus the diameter of the pier, it is assumed that soil arching provides continuous support for the slab-on-grade resting on the pier-supported fill. The piers are designed to support the floor dead and live loads and the weight of a cone of arched soil above the pier itself. If piers are spaced at a distance such that the zones of pier-supported soil arches do not overlap, a finite element analysis should be completed to verify slab reinforcement design.

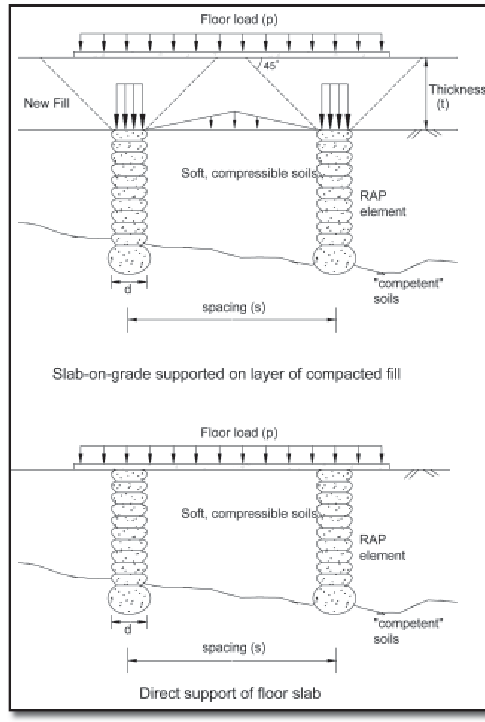


*Figure 4. Geopier Floor Slab Support Alternatives*

## Cost and Schedule Advantages

There is no mystique associated with *Geopier* ground reinforcement. Nevertheless, this is a specialty technique and, as such, requires a structural engineer familiar with the geotechnical design properties and system construction. Close cooperation between all parties involved is essential, particularly in the early stages of the project. For the structural engineer, the benefit is in a simplified, shallow foundation design. For the general contractor, speed and ease of *Geopier* installation enhances the foundation construction schedule. And for the owner, the saving is in both time and money. ▪

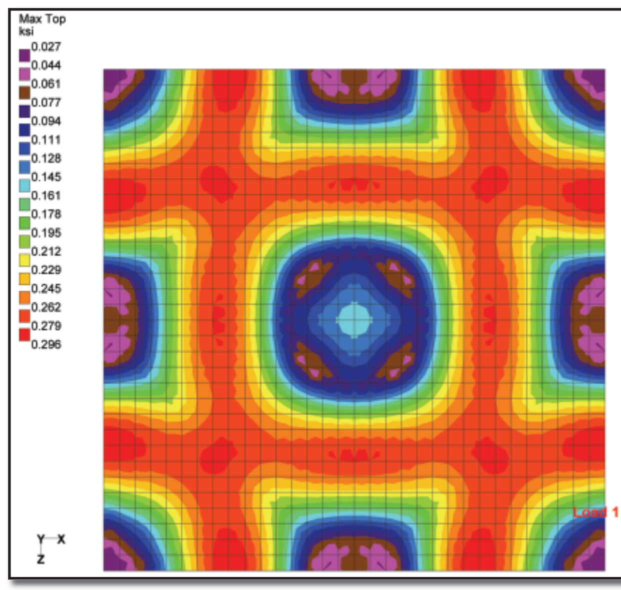


*Figure 5. Maximum Flexural Stress due to Uniform Loading of 950 psf*

For more information on *Geopier® Rammed Aggregate Pier*™ technology, log on to **www.geopiers.com/sm**

*Rimas M. Veitas, P.E., is President of Veitas & Veitas Engineers Inc., in Braintree, MA, and the New England licensee for Geopier Foundation Company. Mr. Veitas has over 20 years of experience in structural engineering design and specialty geotechnical contracting expertise.*

*James R. Wheeler, P.E. is Principal and founder of Design/Build Geotechnical, LLC, located in Stow, MA, and is the New England area design associate for Geopier Foundation Company. He has more than 28 years of geotechnical design and construction experience.*