GEOPIER FOUNDATION CO INC
TECHNICAL BULLETIN

No. 1

BEHAVIOR OF GEOPIER-SUPPORTED FOUNDATION SYSTEMS DURING SEISMIC EVENTS

This Technical Bulletin discusses the engineered behavior of Geopier-supported foundation systems during earthquakes. During earthquake loadings, Geopier-supported foundation systems are designed to behave similar to shallow foundations but exhibit greater bearing capacities and greater resistance to lateral forces. When anchors are incorporated into the Geopier elements, uplift resistance is provided. Additionally, the installation of Geopier elements should provide for a substantial reduction in the potential for liquefaction within the Geopier-enhanced soil layer.

1. BACKGROUND: DEMANDS ON CONVENTIONAL FOUNDATIONS DURING SEISMIC EVENTS

During seismic events, building foundations are subject to increased vertical and lateral loading demands compared to static conditions. Earthquake shaking results in the development of vertical and horizontal inertial forces as the mass of the structure responds to vertical and horizontal accelerations. The applied inertial forces must be resisted by the building foundation system.

1.1. SHALLOW FOUNDATION BEHAVIOR

Buildings constructed on shallow spread footings resist the increased downward inertial force by available resistance to shear on bearing capacity failure planes extending below the footing. Because soil shear resistance increases with load application rate, foundation bearing capacity during short term dynamic loading conditions is greater than bearing capacity during long-term slowly-applied static loading conditions (UBC, 1994). Shallow spread footings resist horizontal inertial forces through friction between the footing bottom and underlying soil and through passive resistance developed within the soil adjacent to the footing. Conventionally constructed spread footings resist uplift forces by the dead weight of the structure and foundation system.

1.2. DEEP FOUNDATION BEHAVIOR

Deep foundations resist the increased downward inertial force by available shaft friction and resistance to shear below the foundation tip (Figure 1). Uplift vertical loads are resisted by friction along the foundation shaft. Horizontal inertial forces are resisted by interaction between the deep foundations and surrounding soil. If, during shaking, the ultimate bending moment or shear capacity of the deep foundation elements are exceeded, the piles will break, leading to a loss of load carrying capacity relative to long-term future downward static loads.

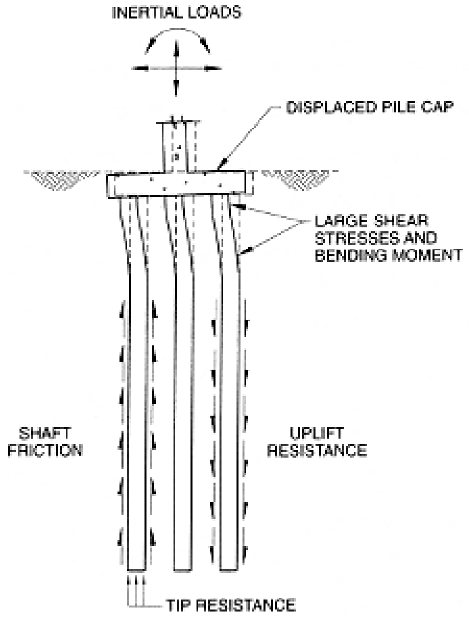

Figure 1. Behavior of Deep Foundations.

2. ENGINEERED PERFORMANCE OF GEOPIER-SUPPORTED FOUNDATIONS DURING SEISMIC EVENTS

Geopier-supported foundations are engineered to resist applied inertial forces with mechanisms similar to those for conventionally supported shallow foundations. Downward vertical inertial forces are resisted by available shear resistance along bearing capacity failure planes. Horizontal initial forces are resisted by friction between the footing bottom and underlying materials as well as through passive resistance developed within the soils adjacent to the footing.

The increase in shear strength and stiffness of foundation materials enhanced with Geopier elements results in significantly higher allowable bearing capacities relative to conventionally supported spread footings. Because the coefficient of friction between the footing bottom and Geopier aggregate is greater than the coefficient of friction between the footing bottom and native soils, and because of stress concentration on the stiffer Geopier elements, Geopier-supported foundation systems exhibit a greater lateral load resistance than conventionally-supported spread footings (Figure 2). Unlike conventionally-supported spread footings, Geopier-supported footings may be constructed to include uplift anchors which are embedded in the Geopier elements to provide resistance to uplift loads. Uplift anchors provide resistance to uplift loads and additional resistance to lateral loads.

Geopier elements are ductile and may experience both elastic and plastic deformations without a subsequent loss of strength in contrast to relatively brittle conventional deep foundation systems. Thus, Geopier-supported foundation systems offer a greater confidence in the retention of post-earthquake integrity than conventional deep foundations.

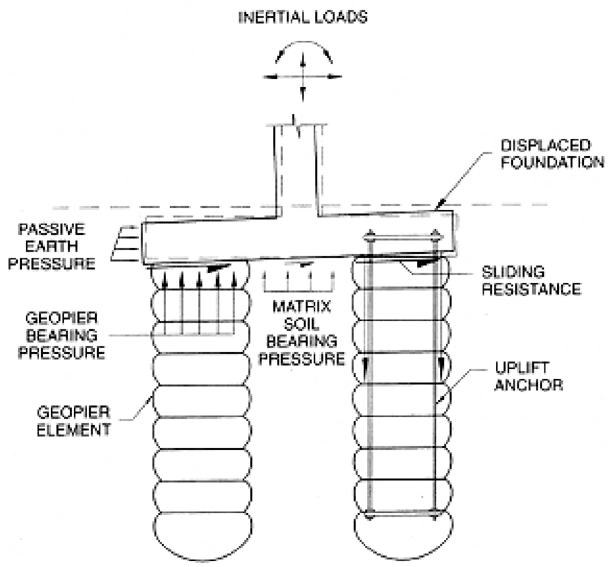

Figure 2. Behavior of Geopier-Supported Foundations.

3. BACKGROUND: IMPACTS OF SOIL LIQUEFACTION ON FOUNDATIONS

Soil liquefaction may occur when loose deposits of saturated cohesionless soil are subject to shaking. If the level of shaking is of sufficient intensity and duration, loose sand deposits contract, thereby increasing the pore water pressures within the saturated material. An increase in pore water pressure results in a decrease in effective stress and a corresponding decrease in soil shear strength. Liquefaction results in a loss of soil shear strength and then a subsequent reduction in soil volume as the excess pore water pressures dissipate.

The potential impacts of liquefaction on conventional foundation systems include bearing capacity failure or excessive settlement due to loss of shear strength in the bearing deposits, and subsequent settlement that occurs due to the dissipation of excess pore water pressure in the soil layers subject to liquefaction. Additionally, deep foundation systems such as driven piles or drilled shafts may be subject to excessive bending moments and shear stresses that develop from horizontally-applied inertial forces in conjunction with the loss of soil support in liquefied materials.

4. REDUCTION IN THE POTENTIAL FOR LIQUEFACTION WITHIN GEOPIER-REINFORCED SOIL LAYERS

The installation of Geopier foundation elements results in a significant reduction in the potential for soil liquefaction within Geopier-reinforced soil layers. Geopier foundation elements reduce the potential for soil liquefaction in four ways (Figure 3).

1. Geopier aggregate is compacted to a density sufficient to preclude liquefaction of the aggregate and of the matrix soil in the primary reinforced zone, extending 6 inches from the Geopier cavity perimeter. Thus, the percentage of non-liquefiable bearing material below Geopier-supported footings is generally 50 to 70 percent of the footing area.

2. During installation, horizontal stress within the adjacent soil mass is increased by ramming Geopier aggregate into the cavity. Horizontal stress has been shown by Ferguson et al. (1993) and Handy (1998) to range between two times the preconstruction in-situ lateral pressure and the passive earth pressure at a distance of about three feet from the Geopier element perimeter. After installation, the maximum principal stress (σ_1') within the soil mass adjacent to the Geopier is oriented horizontally and may be 2 to 5 times the overburden vertical stress at that depth. For a soil deposit of a given relative density (usually characterized by standard penetration test N-values), the available resistance to cyclic shearing (τ) is directly proportional to the maximum principal stress (Seed and Idriss, 1982). Thus, if the principal stress increases by a factor of two, the available cyclic shear resistance also increases by a factor of two.

3. Because Geopier elements are stiffer than the surrounding soil, Geopier elements will absorb a greater percentage of shear stresses that occur within the soil deposit during seismic loading. Assuming that shear stresses induced in the soil mass and Geopier elements are proportional to stiffness, the ratio of the applied shear stress resisted by the unimproved matrix soil (τ_s) to the free-field shear stress (τ) induced by the earthquake could be expressed as:

$$\frac{\tau_s}{\tau} = \frac{1}{(1-R_a+R_a\,R_s)} \qquad \textit{Eq. 1.}$$

where R_a is the percent area coverage of Geopiers elements below the footing and R_s is the ratio of the stiffness of the compacted Geopier aggregate to the stiffness of the native unimproved soil. Depending on the nature of existing soil deposits, the ratio of the stiffness of Geopier elements to existing soil has been found to range from 8 to 35. This stiffness ratio is even greater for soil that exhibits liquefaction potential.

Using Eq.1, if Geopier elements and the associated primary reinforced zone (6 inches from the Geopier cavity perimeter) cover 60 percent of the footing area and exhibit a stiffness ratio of 10, the shear stress that should occur within the foundation soil will be limited to 16 percent of the average shear stress applied by seismic shaking. If Geopier elements and the associated primary reinforced zone cover 70 percent of the footing footprint area and exhibit a stiffness ratio of 25, the shear stress that should occur within the foundation soil will only be 6 percent of the average shear stress applied by seismic shaking. This reduction in applied shear stress is significant in computing the reduction in liquefaction susceptibility of the Geopier-reinforced soil.

4. Depending on the gradations of the existing soil materials and the Geopier stone, Geopier elements may serve as a drainage path for the dissipation of excess pore water pressure and act as gravel drains.

In summary, the installation of Geopier foundation elements is considered to significantly reduce the potential for soil liquefaction in Geopier-reinforced soil layers. This reduced liquefaction potential results in a significant decrease in the potential for bearing capacity failure and excessive settlement during and following major seismic events. The ductility of Geopier-supported foundation systems allows the Geopier elements to deform with the soil mass and thus provides for greater post-earthquake integrity.

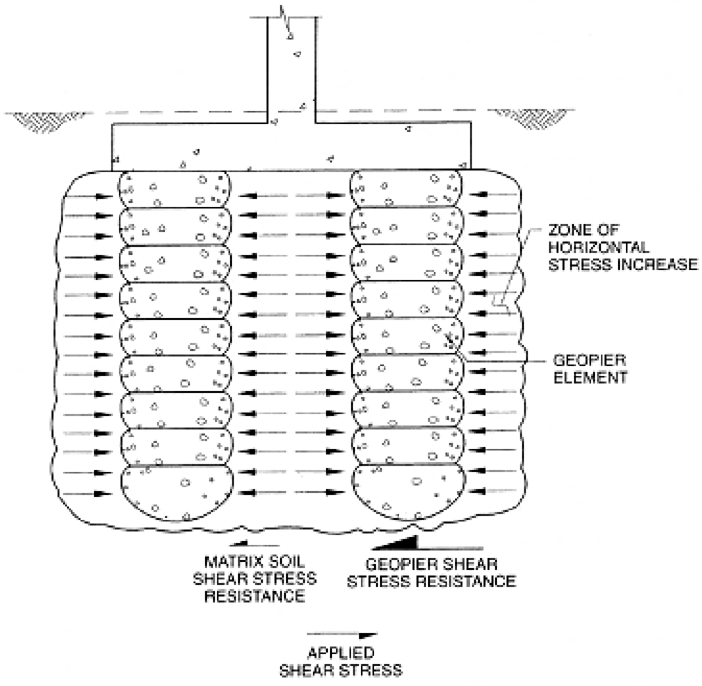

Figure 3. Reduction of Liquefaction Potential.

5. SPECIAL PROVISION FOR USE OF GEOPIER SOIL REINFORCEMENT FOR SEISMIC CONSIDERATIONS

The use of Geopier-supported footings will reduce earthquake-induced shear stress on foundation bearing soils to about 6 to 16 percent of the original shear stress applied by seismic shaking. This will significantly reduce the potential for soil liquefaction and the associated potential for large footing movements of the foundation system.

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