SHORT AGGREGATE PIERS DEFEAT POOR SOILS

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Filling the gap between deep pile foundations and shallow footings, short aggregate piers were originally intended to strengthen poor soils. They're now being installed for a variety of other reasons as well, at sites ranging from an Atlanta milk silo to a Mississippi airplane hangar.

Geopiers—short aggregate piers—provide an economical alternative to the over-excavation/replacement technique that has been widely used to improve the bearing capacity of soils beneath shallow foundations. Geopiers have been used since 1988 to support footings and mats while controlling settlements of structures as tall as 16 stories with column loads from 200 tons to 900 tons. Cost savings—usually 40–60% less than deep foundations—have led to more widespread use in a variety of soils and in seismic areas as well as one project where geopiers provided uplift capacity for an airplane hangar.

Short aggregate piers can control composite footing settlements to less than 1 in. with differential settlements less than 0.5 in. They are also being used where site access is limited, such as at abutting existing buildings or inside basements with low

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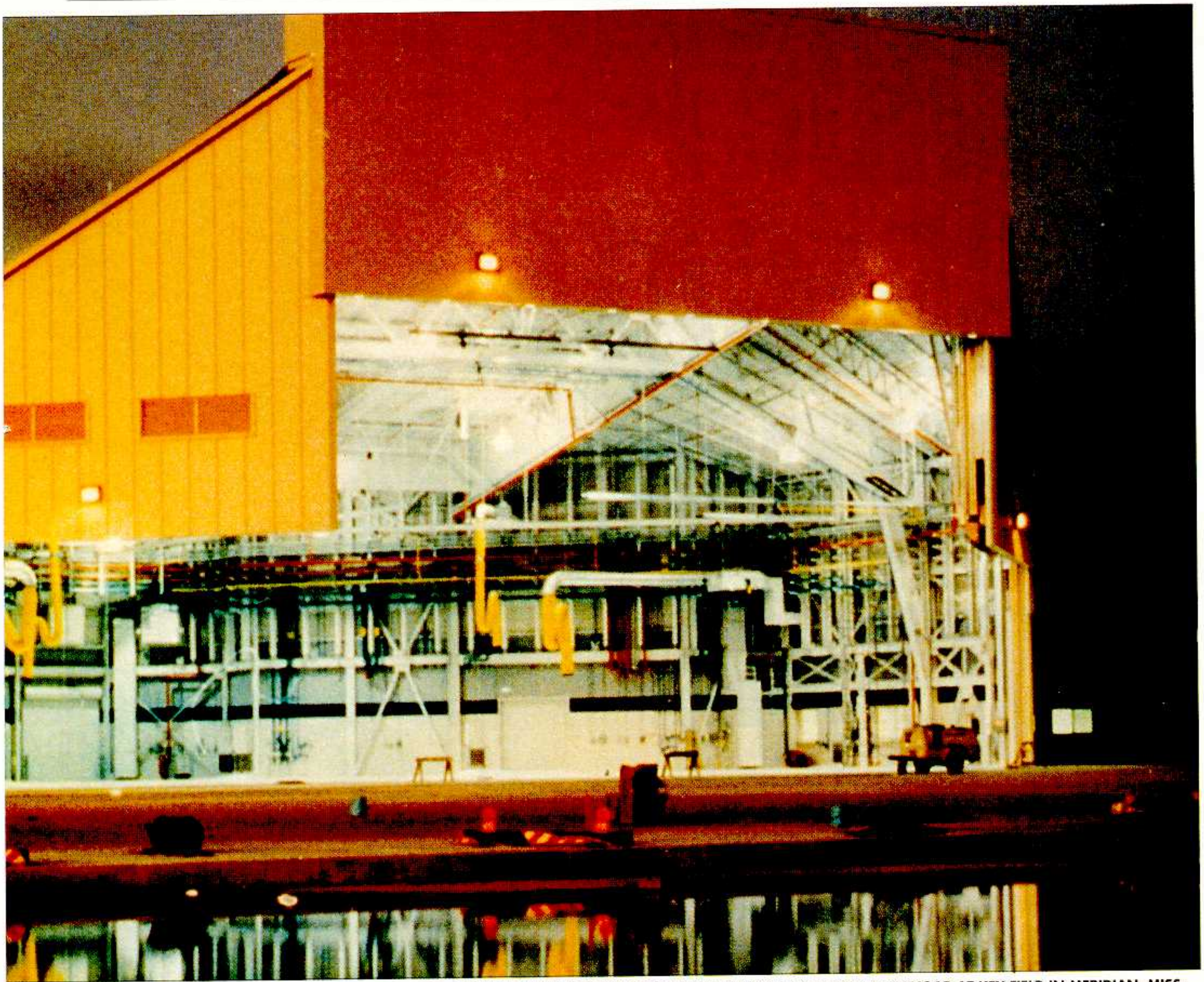

AGGREGATE-PIER UPLIFT ANCHORS WERE CHOSEN TO CONTROL UPLIFT FORCES FROM WIND LOADS AT AN AIRPLANE HANGAR AT KEY FIELD IN MERIDIAN, MISS.

overhead clearances.

Geopiers can be described as stiff springs within a less stiff soil matrix. They enhance the soil through bottom densification and vertical and horizontal prestressing. The patented aggregate piers are constructed of well-graded aggregate, typically stone as used for highway base course material. A pier is formed by creating a cavity in the soil by augering or trenching, then densely compacting the aggregate in thin lifts within the confines of the cavity. The tamper, which has a 45 deg. beveled foot, is a special high-energy, relatively high-frequency unit that applies horizontal and vertical stress on impact, unlike the vibration methods used for other types of piers. During densification, the soil at the bottom of the cavity is prestrained and prestressed, and the aggregate displaces the soil outward, resulting in a buildup of horizontal confining pressures prior to structural loading. The product is a very stiff, very dense short pier with an irregular (undulating) perimeter surface.

The very stiff, very dense short piers are formed as cylindrical columns or prismatic rectangles (linear trench segments). Cylindrical columns are generally 24–36 in. in diameter; rectangles are 18–24 in. wide. Most are 5–10 ft high, set 2 ft below grade level.

Although they might seem similar to stone columns, the geopiers differ in several ways. Aggregate piers are designed primarily to stiffen the subgrade soil; are short rather than being extended to stronger, deeper soils; are formed in a cavity rather than by lateral or vertical soil displacement; include fine and medium sands so they can be highly densified (radial drainage is not a factor); are constructed with high impact frequency rather than vibration; and are impacted in thin lifts to prestrain, prestress and densify adjacent matrix soils. This produces very dense, very stiff foundation elements that reduce vertical displacements from structural loads.

Load transfer to the reinforced soil can be by a single footing of the same or larger diameter as the pier, or more typically a footing supported by two or more aggregate piers. At working loads, the stresses are transmitted to the soil along the pier/soil interface similar to—but much greater than—skin resistance of friction piles. The piers also develop bearing resistance along the underside of the perimeter undulations. As settlement takes place, deformations occur near the top of the pier, displacing soil outward and increasing lateral pressures along the interface. This increased lateral pressure stiffens the pier similar to the stiffening that occurs in a strain-hardening material.

Aggregate piers have improved soils such as soft and loose sandy silts and silty sands, soft and firm silty clays and clayey silts, organic fills, debris fills, uncompacted or erratically compacted fills, very stiff silts and medium dense sands. Ground-water conditions have varied from none to several inches from the ground surface.

PREDICTING SETTLEMENT

The settlement of an aggregate-pier–supported footing or mat is a complex soil-structure interaction between footing and piers, footing and matrix soil, and matrix soil and piers. These complex interactions are not yet completely understood, but we have been able to work out some estimating methods based on two factors: The stiffness of the composite soil (matrix soil plus aggregate piers) within the reinforced zone is stiffer than the unreinforced soil; and the stresses transmitted to the soil beneath the reinforced zone are lower than those transmitted through the comparable unreinforced zone. Settlement predictions are made separately for the upper and lower zones, and the combined values yield the predicted settlement.

To date, more than 1,000 footings, mats and grade beams have been supported by more than 4,000 geopiers in six states. On most projects, the system has replaced the need for deep foundations, although many aggregate piers have been used for their original purpose—improving soils that otherwise would require large footings. Comparison of the actual settlement values with predicted values shows that the system reduces settlement for a variety of loading and soil conditions.

SEISMIC CONSIDERATIONS

Except in areas prone to deep soil liquefaction, geopiers can provide an economic advantage for foundation support in seismic areas. In 1990, geopiers were installed during construction of a five-story office building in Columbia, S.C., where footings support column loads from 50 kips to 800 kips. The soils, virgin residual sandy micaceous silts, were initially rated at an allowable bearing pressure of 1,500–2,000 psf . Geopier support increased composite footing bearing pressure to 66,000 psf, a 300–400% increase.

A SMALL GEOPIER-INSTALLING SYSTEM INVOLVES A SKID LOADER WITH A MODIFIED HYDRAULIC BREAKER AND SPECIAL GEOPIER TAMPER TO COMPACT THE AGGREGATE.

Originally, 70 ft deep piles had been designed and bid for the job. The code required horizontal tie beams to protect the deep foundation from excessive lateral displacements during an earthquake because the piles act as a lever arm, magnifying movements at the pile cap end. Since geopiers are not tied in structurally with the footings they support (except when they act as uplift anchors) and are relatively short, there is no lever-arm shaking effect, and thus no need for the tie beams.

Use of geopiers allowed the structural engineer to eliminate 85% of the tie beams. The savings brought foundation costs well within budget limitations. Settlement readings taken one year after project completion were repeated in three separate surveys. Of 12 instrumented columns, with several representing the greatest load of 800 kips, maximum settlements were less than 0.125 in.

THE MILK SILO

The smallest aggregate-pier project to date was also one of the most challenging. The 40 ft high, 12 ft diameter steel silo was designed to store milk at an Atlanta dairy. Two sides of the single, 15 ft square, 4 ft thick footing are less than 2 in. from the ell of a two-story brick building that showed signs of excessive settlement.

Three geotrenches were constructed, each 2 ft wide and 5 ft deep, diagonally across the footprint of the footing to the edges of the existing wall footings. Use of a small tamper and the relatively high impact frequency of 500 cycles per minute kept vibrations low enough so that none of the existing wall cracks worsened. The known loading from the silo and milk, and subsurface conditions consisting of 25 ft of compressible silts, led to a predicted settlement of 0.5 in. After three months, survey read-