An Alternative Approach to Foundation Support

King County, WA, engineers used innovative soil reinforcement technology to support a mechanically stabilized earth wall along a major highway.

By Brendan T. FitzPatrick

With a total land area of 2,130 sq mi and a population in excess of 1.7 million (up 15 percent since 1990), King County is the largest metropolitan county in Washington and the 12th largest in the nation. The county transportation system relies heavily on freeways and arterials to move both people and freight. As federal and state highways become more congested, the importance of the arterials has increased; however, many are themselves congested to critical proportions.

In unincorporated King County, home to 350,000 people, King County DOT is implementing a strategic roadway and bridge improvement program, under the King County Comprehensive Plan, to upgrade its network of regional arterials. A critical part of this program is the reconstruction and widening of 140 Avenue SE, a key north-south link located in the southeast of the county. Upgrades include expanding the existing two-lane road to five lanes and constructing bike paths, as well as the normal curb and gutter installation and landscaping.

In one section of a 1.4-mi stretch of the highway under construction in the second phase of the overall project, roadwork was complicated by adjacent wetlands and the presence of liquefiable soils.

Limited Options

The original roadway had been constructed by placing a fill in the wetland swale and installing a culvert beneath to accommodate run-off. However, with such a practice no longer acceptable, the civil engineering prime, David Evans and Associates Inc. (www.deainc.com) specified the construction of a mechanically stabilized earth (MSE) wall to retain the fill for support of the additional lanes. The 150-ft long, maximum 19-ft high wall was designed by Tensar Earth Technologies Inc. (www.tensarcorp.com) to support the road widening and minimize wetland impacts.

However, during the preliminary site investigation by geotechnical engineers Shannon and Wilson (www.shannonwilson.com), borings encountered up to 14 ft of loose, granular soils overlying dense, gravelly, silty sand beneath the retaining wall footprint. Given these conditions, and a high water table, Shannon and Wilson Senior Associate Stan Boyle, Ph.D., P.E., determined that liquefaction could occur under seismic loading, threatening wall stability.

With the sensitive wetlands on one side, and a busy highway on the other, the choice of liquefaction remediation was driven by safety issues and the need to avoid wetland encroachment. "We initially considered several options," says Boyle, "including excavating a shear key trench. Ultimately, we determined that in terms of safety, ease of installation and comparative cost, a Geopier® system was the best approach to reinforce the potentially liquefiable soils and increase the factor of safety of the wall for global stability."

Stability analyses were conducted, from which Shannon and Wilson, with support from Geopier Foundation Company (www.geopiers.com), devel-

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oped a preliminary design and layout based on a magnitude 7.5 earthquake generating a peak ground acceleration of 0.3g. The design called for 88, 30-in. diameter Geopier elements to be installed in a triangular grid pattern at 64 in. on center beneath the central, and highest, portion of the proposed wall. James Johnson, a designer with Geopier Foundation Company-Northwest, confirmed this approach and it was accepted by King County DOT engineers.

Fast Installation

Following modulus testing to verify design parameters, production piers were installed 12 ft to 15 ft below grade to reinforce and stiffen the loose soils and increase the shear resistance beneath the wall. All 88 piers were installed in just four days.

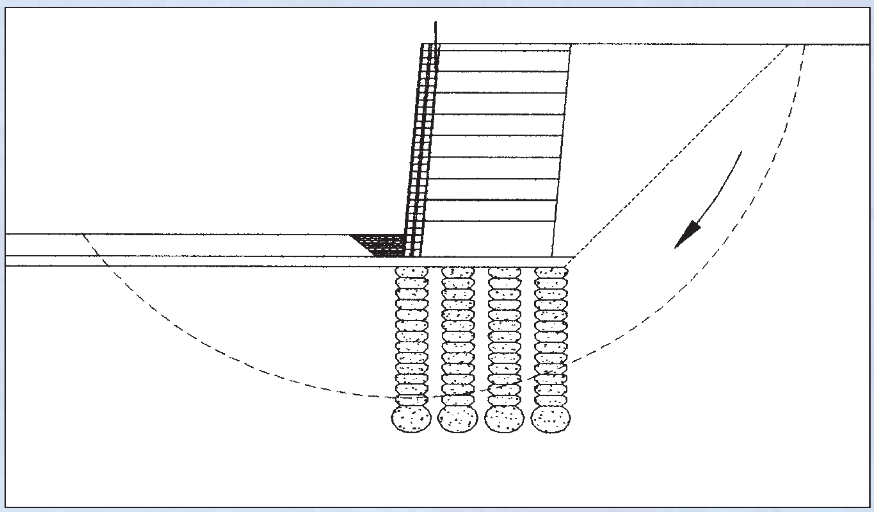
According to Alan Corwin, P.E., a materials engineer with King County DOT who was involved with the project, Geopier Rammed Aggregate Piers™ (RAPs) are "a promising alternative to complete removal of low-bearing soils. We have considered them on numerous projects where intermediate depth soft soils were encountered."

Developed in the late 1980s, Geopier intermediate soil reinforcement quickly established itself as an economic and effective method of supporting foundation loads for commercial and industrial construction. In recent years, this technology has also gained ground in transportation applications. RAPs are increasingly being used to strengthen and stabilize weak or soft soils beneath earthen embankments, MSE walls, and box culverts, and to stabilize slopes. The system is also effective in mitigating liquefaction potential.

Installed under retaining walls or embankments, these RAPs increase the composite stiffness of the soft surrounding soils to reduce settlement and provide additional shear reinforcement, increasing the factor of safety for bearing capacity and global stability. When constructed using open-graded aggregate, consolidation times are accelerated as a result of radial drainage to the elements.

RAPs can be installed within unstable or marginally stable slopes to intersect potential or active failure planes and provide additional shear reinforcement to increase the factor of safety for slope stability. RAPs are commonly used to reinforce soft, compressible soils to support box culverts and new fill. The piers provide superior stiffness to control both total and differential settlement of the culverts.

Soil liquefaction can have devastating effects on structures in seismically active regions. The installation of RAPs reduces the potential for liquefaction by providing a stiff, non-liquefiable inclusion in the liquefiable soils and reduces the magnitude of shear stresses in the matrix soil between the piers to levels sufficiently low to preclude liquefaction triggering. The use of open-graded aggregate to construct the Geopier elements allows the piers to act as vertical drains to aid in the dissipation of excess pore water pressure generated from seismic, as well as vertical, loading.



Geopier Rammed Aggregate Piers exhibit friction angles from 49 degrees to 52 degrees, increase the composite stiffness of the soft foundation soil, and provide additional shear reinforcement that increases the factors of safety for bearing capacity and global stability.

Straightforward Construction

RAPs are installed by constructing successive layers of densely compacted aggregate in a drilled or excavated shaft, measuring between 24 in. and 36 in. in diameter. Depth of installation typically ranges between 10 ft and 30 ft below working grade.

The construction process is simple and fast. A cavity is drilled to design depth and a 12-in. thick lift of open-graded aggregate is placed at the bottom of the cavity. The aggregate is compacted using a patented beveled tamper that delivers high-energy vertical ramming action to densify the aggregate and pre-stress the surrounding soils. The process continues with successive lifts of rammed aggregate to form the completed pier.

The ramming process forces the aggregate laterally into the matrix soil, producing significant lateral pre-straining and pre-stressing of the surrounding soils. The horizontal movement results in a large increase in lateral stress in the matrix soil. The reinforced soils essentially "grab and hold" the very stiff element and thus improve the strength and stiffness of the combined pier-soil system.

Because of the high internal angle of friction (48 to 52 degrees) exhibited, the elements not only reduce the magnitude of settlement but also increase the factor of safety against slope instability. As a result of the stiffening of the matrix soil and inclusion of stiff RAPs, the allowable bearing pressures are increased by two to three times the un-reinforced-bearing pressures and the composite reinforced zone can support high loads (over 3,000 kips) while controlling settlement.

The replacement installation process affords the opportunity to visually inspect and verify the soils at each location. In addition to quality control testing performed during individual pier installation, a modulus load test is performed on nearly all projects to verify

The finished wall in King County, WA, is shown here. In addition to MSE and embankment support, Geopiers can be used for shallow foundation support, slope stabilization, floor slab support, tank support, liquefaction mitigation, and uplift control.

the design stiffness and pier behavior. The use of steel tell-tales at the bottom of the pier provides additional design assurance that the pier is able to resist the applied stresses.

Effective Alternative

The reinforcement of soils for highway construction or upgrade constitutes an increasing percentage of transportation-related Geopier work to date. These projects have primarily been for support of embankments and MSE retaining walls for grade separation and highway access ramps.

It is well understood that facilitating grade separations and constructing access ramps by the placement of embankments or MSE retaining walls can present stability and settlement problems when weak, compressible, or liquefiable soils are present. The historical approaches of over-excavating, surcharging, or constructing toe-berms to alleviate these problems, while effective, have significant drawbacks in today's transportation construction arena.

Complete removal of the problem soils is typically an expensive exercise and may require shoring, dewatering, or other cost approaches. Surcharging is extremely time-consuming. Toe-berm construction typically requires extending large right-of-ways, which can present acquisition and cost problems in already developed urban areas. And in the light of heightened awareness and increasingly stringent federal, state, and local regulations, development in or near wetlands is an important consideration.

Geopier soil reinforcement is designed to overcome these problems by specifically targeting the weak, compressible, or liquefiable soils *in situ*. The system is installed beneath the proposed embankment or MSE wall, therefore limiting the impact on environmentally sensitive adjacent areas and eliminating right-of-way issues. Installation is fast and clean, and typically the work can be accomplished without unduly impeding traffic flow. GE

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