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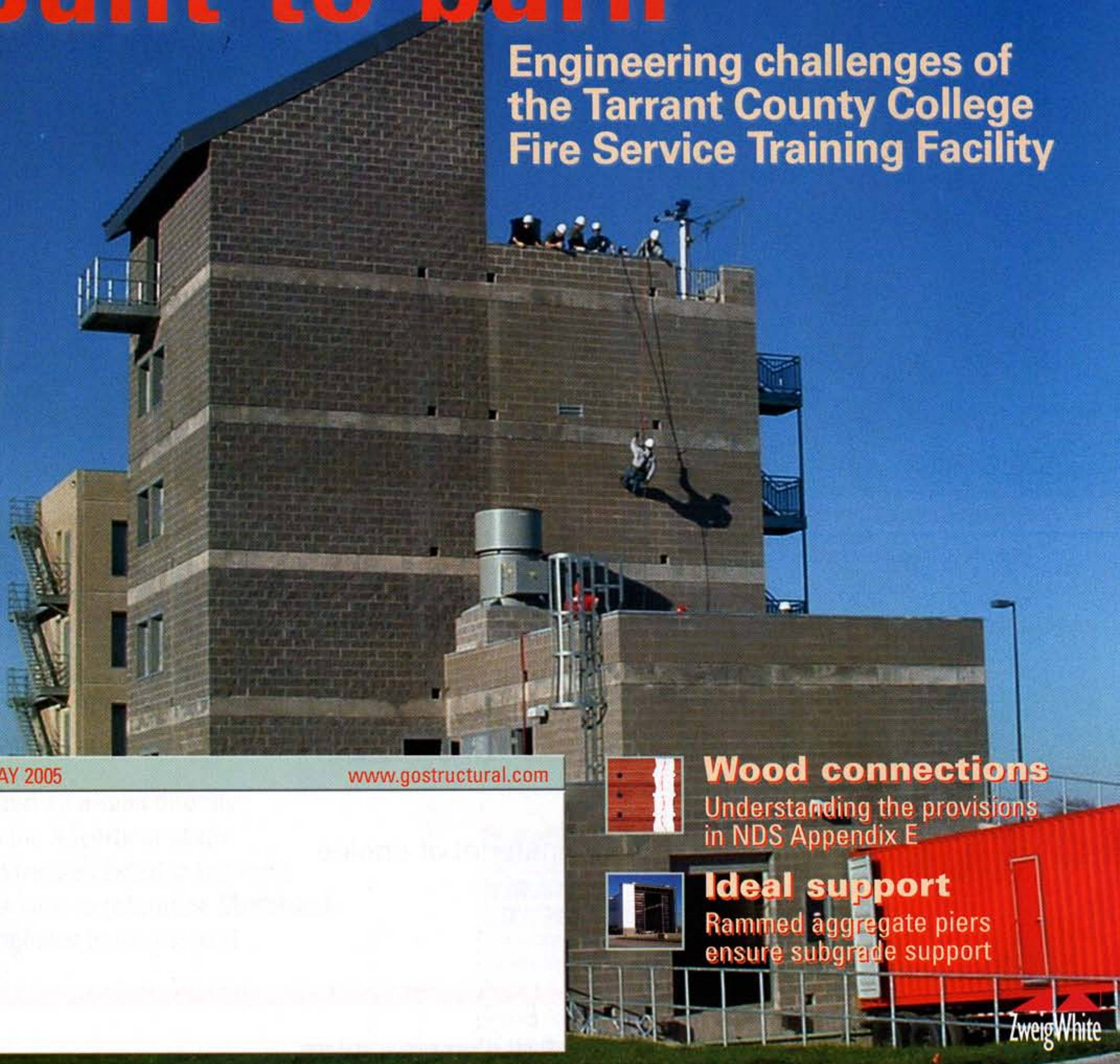

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## Wood connections

Understanding the provisions in NDS Appendix E

## Ideal support

Rammed aggregate piers ensure subgrade support

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# Ideal support

## Rammed aggregate piers ensure subgrade stability

By Brendan FitzPatrick, P.E.

The Delta Marine assembly building in Seattle used Rammed Aggregate Piers for a stable foundation on poor soils.

**Delta Marine, located on the Duwamish River in Seattle, is an industry leader in the design and manufacture of luxury yachts. With its new construction schedule including some of the largest yachts to be built in the United States since the 1920s, the company initiated a three-phase expansion program in 2003. Phase two of the project included the construction of a new, steel frame, high-bay assembly building (360 feet long by 126 feet wide), which doubled the facility's capacity and allowed Delta to commission new and re-fit yachts as long as 325 feet.**

With significant point loads anticipated in the floor slab area from Delta's purpose-built, 400-BFM mobile yacht hoist, a collaborative effort on the part of all the design team members was critical to ensure the optimum geotechnical and structural solution for Delta's owner, Ivar Jones.

### Geotechnical evaluation

The site investigation by Spears Engineering and Technical Services, Auburn, Wash., revealed loose to medium-dense sand with silt fill to a depth of 5 feet, underlain by medium-stiff, organic silt fill as deep as 16 feet below grade. Dense sand was encountered beneath this compressible layer. Standard Penetrometer Testing showed N-values in the silt ranging from 8 to 16. Moisture contents ranged from 34 to 54 percent.

Given foundation loads of 300 to 450 kips, a differential settlement criterion of 0.75 inches, and the presence of the deleterious organic layer, Spears Engineering recommended the Geopier® System to reinforce and penetrate the poor soils in the building footprint area and to support conventional shallow foundations and the floor slab. A piling system and structural floor slab was provided as an alternative. "The soils were loose, but exhibited a high shear angle," said Principal Frank Spears, P.E. "From previous experience, we knew that the Geopier System works well in poor soil conditions and could provide the uniform subgrade improvement that was needed to obtain a higher allowable soil bearing capacity for the site. In terms of time and cost savings, Geopier Rammed Aggregate Piers™ also offer a definite advantage." The structural engineer of record, Thomas Lee, P.E., of Rupert Engineering in Auburn, Wash., agreed. Lee noted that according to the column layout and the span of the shop area, construction costs estimated for the pile foundation option would be greater than for the Geopier System with conventional concrete footings.

### Geopier construction

The Geopier Rammed Aggregate Pier (RAP) construction process is remarkably simple and fast. A 24- to 36-inch-diameter cavity is drilled to design depth, typically ranging from 7 to 30 feet below working grade. Layers of aggregate are then introduced into the cavity in thin lifts of 1-foot compacted thickness. A patented, beveled tamper densifies each layer of aggregate using vertical impact ramming energy, resulting in superior strength and stiffness. The tamper densifies aggregate vertically and forces aggregate laterally into cavity sidewalls. This results in excellent coupling with surrounding soils and reliable settlement control (see Figure 1).

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 unreinforced bearing pressures, and the composite reinforced zone can support high loads (more than 3,000 kips) while controlling settlement.

A modulus load test is performed on nearly all projects, as recommended by Geopier Foundation Company, to verify the design stiffness and pier behavior. Monitoring equipment at the bottom of the pier provides additional design assurance by providing insight into the deformation behavior of the piers.

### Critical point loads

From the soils information, Geopier licensee James Johnson, P.E., of GFC Northwest in Bellevue, Wash., designed 30-inch-diameter reinforcing elements with an allowable cell capacity of 75 kips to support conventional spread footings sized for an allowable bearing pressure of 6,000 pounds per square foot (psf). The support for the conventional footings then was detailed based upon the structural loading information provided by Lee. Since uplift forces would be resisted by the self-weight of the footing and the weight of the braced frame, the Geopier elements were not required to resist uplift loads.

However, the more critical concern was the design and support solution for the floor slab. The rated lifting capacity of the travel hoist is 882,000 pounds. Point loads were calculated by Lee to be approximately 360 kips per leg. Design of the slab needed to take these concentrated loads into account, as well as differential settlement and crack control. Although the hoist was able to move in any direction, its lateral movement was limited to two, approximately 30-foot-wide travel lanes resulting from its own width and the width of the building. Slab design and the Geopier support system was unique for three distinct areas — the heavily loaded travel lanes, the center section of the assembly area not subject to the high point loads, and the relatively lightly loaded floor slab in the office area.

In the travel lane, the RAP spacing was a function of both the floor slab design and the distribution of anticipated wheel loads. A detailed finite element analysis was performed to evaluate the stresses in the floor slab and the distribution of stresses to the RAPs in order to finalize both the slab design and the Geopier solution.

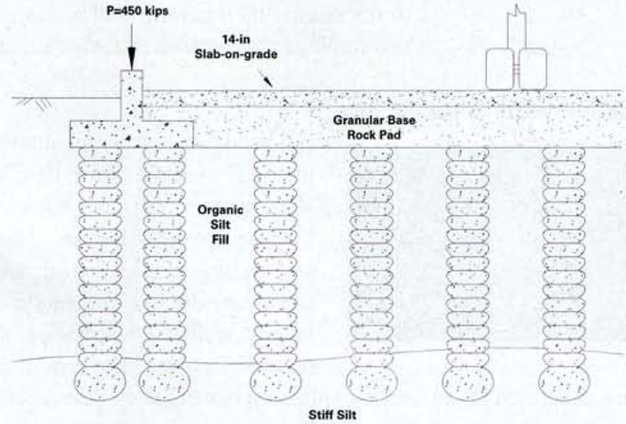


Figure 1: Geopier foundation and floor slab support

This part of the overall design approach involved a collaborative effort between Lee and Greg Gear, P.E. of The Pro-Firm, Des Moines, Iowa, who performed the analysis.

## Finite element analysis

According to Gear, slabs on grade supported by Geopier reinforced soils may be designed based on the American Concrete Institute's Design of Slabs on Grade (ACI 360.R-98). This design reference allows for slabs of varying thickness and varying subgrades. The Geopier reinforced subgrade can be analyzed using a finite element program with the subgrade modeled using spring constants. The spring constant for the RAP is determined by on-site modulus testing. The spring constant of the soils adjacent to the RAP varies based on the distance from the center of the pier and the properties of the adjacent soil. The Geopier installation process improves adjacent soils by prestressing and prestraining the soils radially around the piers. This improvement decreases with radial distance away from the pier, which is conservatively limited to about 6 feet from the centerline of the pier.

The slab thickness is based on the flexural stress allowed by the building design engineer and calculated by the finite element analysis. Other factors that affect the design of the floor slab over Geopier reinforced soils include expansion joints, reinforcing provided, floor concrete strength, and fill thickness between the top of Geopier element and the bottom of slab. The pier spacing is a function of the superimposed loads placed on the floor system and the floor slab design. The support solution and floor slab design is prepared to meet the slab-on-grade design performance criteria as specified by the building design engineer.

## Final configuration

Considering the specific loading and performance criteria for the Delta Marine slab, the collaborative design team developed a solution consisting of Geopier soil reinforcement elements supporting a 3-foot-thick, compacted granular base rock pad overlain by the floor slab. The aggregate pad aided stress transfer to the stiff Geopier elements, provided more uniform slab support, and reduced bending stresses in the slab. The finite element analysis was performed by Gear using a Geopier stiffness modulus value of 150 pounds per cubic inch (pci) that was verified with a modulus test indicating deflections of 0.28 inches at stresses of up to 15,300 psf. Considering the presence of the granular pad and the improvement of the matrix soil surrounding the Geopier elements, a minimum matrix soil stiffness of 80 pci was used between the piers.

The results of the analysis indicated that at Geopier element spacings of 7 feet on-center in the high-traffic areas, the bending stresses in the floor slab were controlled to tolerable levels by using a 14-inch-thick slab-on-grade. In the non-travel areas, a wider element spacing of 8 feet on-center was selected. Finally, in the lightly loaded office area, Geopier elements were spaced at 10 feet on-center to support an 8-inch floor slab-on-grade.

GFC Northwest installed the 30-inch-diameter elements through the upper sand fill and organic silts to the underlying competent sands. With a production rate of approximately 80 to 90 piers per day, the ground reinforcement was completed in approximately 10 days. ■

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