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SHOPPING CENTER SAVED BY SHORT AGGREGATE PIERS

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ABSTRACT

We were faced with an extraordinary geotechnical challenge; our client wanted to support large tilt wall buildings and pavements for a 32 acre Commercial Shopping Center on 5 to 8 feet of saturated, 1 to 3 blow/foot hydraulically placed fill. To make matters more difficult, the site was in the seismically active Napa Valley.

We offered 3 solutions; 2 conventional, and 1 unconventional. Our conventional solutions consisted of: 1) piers founded in the normally consolidated clay below the hydraulic fill, or, 2) over-excavation and replacement of the upper 5 to 8 feet of highly unstable soil. Our *unconventional* solution consisted of Short Aggregate Piers (Geopier or SAP) to mitigate settlement for moderate building loads. Because of economics, speed and fear of the unknown over-excavation costs, our client chose Geopiers to support the large buildings.

KEY WORDS

Short Aggregate Piers, Geopier, Alternative Foundation, Upper Zone Settlement, Lower Zone Settlement, Stress Bulb

INTRODUCTION

South Napa Marketplace (SNMP) is a Commercial Shopping Center in Napa, California. SNMP sits on an approximately 32 acre site with 6 major tenant building pads and 7 minor tenant building pads. Three of the major tenant pads were leased prior to the start of construction, and the remaining pads were built on speculation. FHK Developers retained Anderson Consulting Group of Roseville, California to prepare a geotechnical report for the vacant site in November 1994.

Initially, Anderson Consulting Group (ACG) studied the site history, researched the seismic response, and evaluated the geotechnical feasibility of developing the South Napa Market Place Regional Shopping Center. After the feasibility work, ACG met with the developer and prepared a work scope for the final geotechnical report. In the final geotechnical report, ACG prepared innovative design and construction recommendations to develop the challenging site. ***The Challenge:*** support medium structural loads and pavements on wet, soft and unstable soil.

RECENT SITE HISTORY

The 32 acre site was originally part of a Spanish Land Grant. Mr. Gasser purchased the property in 1947. Previously a wetland marsh, Tulocay Creek bisected the 32 acre site north to south. Between about 1955 and 1988 the site was used to deposit Napa River dredge tailings. Dredge contractors hydraulically deposited the upper 5 to 8 feet of sand, silt, and clay using a series of dikes and weirs with no mechanical compaction. Mr. Gasser also allowed occasional fill and construction debris dumping (large concrete chunks, wood, brick, and asphalt) primarily on the southern portion of the property.

In the late 1960's, Toulocay Creek was redirected from its original north-south direction to run directly west to the Napa River across the north end of the site. Mr. Gasser filled the original creek channel with uncompacted fill in 1971.

SITE CONDITIONS

ACG performed the geotechnical investigation when the site was relatively flat, vacant, and covered with annual grasses. ACG observed some construction debris on the south side of the site. Between the investigation and the start of construction, the Napa region received over 50 inches of rain. The site was essentially saturated to the ground surface by the time of construction in July 1995.

SOIL AND GROUND WATER CONDITIONS

ACG drilled 29 borings and excavated 14 backhoe trenches to explore the subsurface soil/ground water conditions. ACG encountered hydraulic fill from the ground surface down to 5 to 8 feet across the site. The hydraulic fill was erratic in density and classification. Blow counts in the hydraulic fill varied from 1 to 30 blows/foot; the drill rods occasionally advanced under their own weight. The hydraulic fill varied from relatively clean gravel (GP) and sand (SP), to silt (ML) and highly expansive clay (CH), with various mixtures of each in random locations. Beneath the hydraulic fill ACG observed, native, normally consolidated clay (CL/CH).

ACG noted construction debris fill consisting of concrete, masonry, etc., during the field exploration. The debris encompassed an area approximately 300 by 600 feet along the south boundary of the site. The debris was 2 to 6 feet in thickness.

ACG encountered static ground water about 13 feet below the surface (which is about 0 mean sea elevation). We encountered perched ground water in the exploratory trenches above the static groundwater. The clay below the fill was relatively impervious, and water that seeped into the fill perched on top of the clay. This combined with the loose/soft fill made the bottom 3 to 4 feet of hydraulic fill essentially saturated.

PROJECT DESCRIPTION

SNM has 14 building pads, 6 of those are major tenants. Three major tenants, Target, Raleys, and Office Depot, have constructed their buildings, covering about 330,000 square feet, on Short Aggregate Piers. Column loads ranged from about 40 kips to 200 kips. Strip footing loads ranged from about 2000 plf to 5000 plf.

INNOVATIVE SOLUTION, GEOPIERS

In December 1994, ACG discovered the article "Short Aggregate Piers Defeat Poor Soils" in ASCE Civil Engineering magazine. The inventor, Dr. Nathaniel Fox of Geopier Foundation Company (GFC) flew out from Stone Mountain, Georgia to review the SNMP and our geotechnical data. Collectively, we decided Short Aggregate Piers were a potential cost saving option for structural load support. As a result, ACG included the Short Aggregate Piers as an option and alternative to conventional concrete piers or over-excavation/replacement in the geotechnical report.

The design team, including ACG, developers, general contractor, subcontractor, and Architect, met and discussed the strengths and weaknesses of each option. Based on our meetings, the general contractor bid both over-excavation and Short Aggregate Piers. The bids came in relatively close, however, the owner chose Short Aggregate Piers. FHK indicated that historical over-excavation cost over-run experiences and the unknown potential delays with conventional over-excavation / replacement made Short Aggregate Piers attractive. Also, conventional concrete piers were much more expensive than Short Aggregate Piers.

History of Short Aggregate Piers (GEOPIERS)

Dr. Nathaniel Fox is the lead inventor of Short Aggregate Piers and president of the Georgia based Geopier Foundation Company, Inc. Beginning in 1984, Dr. Fox began thinking of a system to improve the bearing capacity of shallow foundations without the expense of large cranes and other massive equipment. The ultimate system, Geopiers, generally uses bobcats and inexpensive aggregate base for construction. Since 1988, Short Aggregate Piers have seen increased use each year. Over 30,000 Geopiers support structures in 22 states in the USA and 2 countries. The highest column loads on Geopiers come from the Portland Trailblazers parking Garage at 2,200 kips. To date, measured settlement has never exceeded predicted values.

Geopier Technical Approach

The technique for constructing the Geopiers is simple and fast. Basically, aggregate is compacted both vertically and horizontally using the patented beveled tamper, thus horizontally stressing and densifying the matrix soil. The Geopier innovation improved (densified) the soil in the upper loose fill zone at SNMP, and reduced stress transferred to the more competent lower zone. In other instrumented applications, Geopiers have transferred over 90% of the load to the upper zone (upper and lower zones are defined below). The system is analogous to adding stiff springs to a soft/loose spring system to transfer and absorb stress. By adding Geopiers (stiff springs) the lower zone soil realizes less stress from foundation loads. Burmister showed for layered elastic systems, that the stress transferred to a lower layer can be significantly reduced if the lower layer is overlain by a much stiffer upper layer (Burmister 1958, 1967).

The settlement of a Geopier-supported footing or mat is a complex soil-structure interaction consisting of interaction between 1) footing and Geopier, 2) footing and matrix soil, and 3) matrix soil and Geopier. These complex interactions and mechanisms are not completely understood, however, load test data show close agreement with settlement predictions. In fact, most Geopier supported foundations have settled less than predicted settlements (Lawton and Fox, 1994).

ACG designed the Short Aggregate Pier solution with the assistance of Dr. Fox and Geopier Foundation Company, Inc. Design generally included:

1. Identify the Upper Zone and Lower Zone soil types and properties.

   Upper Zone (UZ) = pier length + 1 pier diameter
   Lower Zone (LZ) = soil beneath upper zone

2. ACG estimated settlement with design loads using elastic settlement prediction in the UZ. UZ settlement was predicted using the assumption of a perfectly rigid footing and a subgrade modulus approach. Subgrade moduli for the matrix soil were determined from laboratory tests and estimated allowable bearing pressures. We conservatively estimated Geopier moduli from previous load tests in soft soil. This approach is conservative because the load test does not consider the beneficial effect of confining pressures produced from the loaded footing acting on the matrix soil (Lawton, Fox, and Handy 1994). ACG estimated the unreinforced soil UZ settlement = 2 to 2 ½ inches and Geopier reinforced UZ settlement = 0.4 to 0.5 inches.

3. ACG estimated settlement of the LZ using 1) consolidation theory, and 2) Schmertmann's strain

influence factor method (Schmertmann 1970; Schmertmann et al. 1978) and 3) Bowles' modified elastic theory method (Bowles 1988). Foundation stress transferred from the UZ to the LZ was estimated using a modification of the 2:1 method and engineering judgment. ACG estimated LZ settlement = 0.1 to 0.2 inches.

4. After this analysis, ACG conservatively recommended 30 inch diameter Geopiers, embedded 6 to 8 feet beneath the strip and spread footings.
5. An allowable reinforced soil bearing capacity is established using the combined Geopier and matrix soil subgrade moduli and engineering judgment. ACG conservatively recommended an allowable bearing capacity = 3,000 psf for the Geopier reinforced soil at SNMP.
6. ACG presented the Geopier analysis and conclusions to the structural engineer. After discussions, the structural engineer planned and specified Geopier supported foundations for three major tenants at SNMP.
7. Because the system was new in California, ACG had to educate the structural engineer, developer, construction manager, and most importantly the City of Napa building officials and their plan checkers. The City of Napa hired both structural and geotechnical plan checkers just for us! Education mostly consisted of teaching the basic concepts, the conservative assumptions we used, and how settlement would be controlled.

Geopier Earthquake Considerations

Our research indicated that a maximum credible seismic event could result in mean peak horizontal accelerations at the site up to 0.57g. Since the Geopiers were not connected to the foundations, (we had no uplift requirement) the Geopiers did not positively or negatively influence the seismic susceptibility of the foundation. Although, one could argue that vertical accelerations could cause more damage to piers/piles connected to caps; much like the damage noted in the Northridge event. To date, these vertical accelerations do not require mitigation in the codes.

Geopier Load Tests

ACG monitored 2 load tests prior to Short Aggregate Pier production installation at SNMP. Much like small pile/pier load tests, our SAP load test simply consist of 4 reaction Geopiers (2 at each end) and 1 compressive Geopier. Reaction Geopiers mobilize pullout friction with a steel anchor system that consists of a 1-inch thick, 12 inch by 24 inch steel plate welded to 2 threaded rods. The anchor is placed on top of the bottom stress bulb. The load test procedure is modified from ASTM D1143.

ACG observed UZ settlement = 0.25 inches for the 12 ksf load on a 6-foot deep pier in adequate soil (N ~ 20). ACG observed UZ settlement = 0.38 inches in poor soil (N~1 to 5) for the 8-foot deep pier.

Geopier Construction / Performance

GFC drilled 30 inch diameter cavities to the design depth (actually 9 to 11 feet from subgrade elevation). GFC used their patented proprietary tamping system to compact, densify, and displace matrix soil at the bottom of the cavity to create a "stress bulb". Then aggregate base (the same used in road construction) or crushed rock was added to the stress bulb until no deflection of the tamping system was observed. The aggregate was then placed into the cavity in 12 inch lifts. The shape of the compaction head is essential for success; it must distribute the compactive energy down-vertically and out-horizontally. As each lift was tamped into place, it formed into a bulb, so that a stack of bulbs was ultimately created making up the Geopier. Not only was the aggregate compacted, but the surrounding native soil was stressed. Conventional strip and spread footings were then constructed on top of the Geopiers.

The following construction procedure was generally followed by GFC:

1. A conventional auger rig excavated 30-inch diameter cavities between 9 and 11 feet below pad grade.
2. An 853 Bobcat pre-stressed the bottom of the cavity with the patented tamper, creating a stress bulb.
3. A 753 Bobcat placed 12-inch loose lifts of open graded gravel in the bottom of the hole. GFC used open graded gravel because ground water was present in most excavations; the open graded gravel allows more effective energy transfer to the gravel and surrounding soil when under water.
4. The 853 Bobcat densified the first lift of open graded gravel with the tamper.
5. If ground water was still present, GFC repeated steps 3 and 4.
6. If ground water was not present, the 753 Bobcat placed a 12 inch lift of Class 2 aggregate road base.
7. The 853 Bobcat densified the 12 inch lift with the tamper.
8. The process was repeated until the pier was terminated at bottom of footing elevation.

ACG randomly measured the dimensions of pier holes and performed density and dynamic cone penetration tests on various lifts of the aggregate piers.

GFC installed about nine hundred interior and exterior Geopiers at SNMP in the summer of 1995. Target, Raley's, and Office Depot structures were built, no settlement has been reported, although we did not install settlement monitors.

SUMMARY AND CONCLUSIONS

Generally, the South Napa Marketplace (Napa, California) was not feasible to build without the innovative and cost effective Short Aggregate Pier system. Geopiers were used to reinforce 5 to 8 feet of very soft / loose hydraulically placed fill. The Geopier system was much more cost effective when compared to conventional concrete piers and the unknown risks of over-excavation / replacement. At SNMP Geopiers decreased the construction schedule, and the Geopier contractor was able to work in wet weather with no delays. The general contractor was able to excavate and pour the strip and spread footings the day after the piers were installed.

ACG won the 1995 California Geotechnical Engineers Association Most Outstanding Project Award for the innovative Geopier foundation system used at SNMP.

REFERENCES

Bowles, J.E. [1988]. "*Foundation Analysis and Design,*" 4th edition. McGraw-Hill, New York, New York.

Burmister, D.M. [1958]. "Evaluation of pavement systems of the WASHO road test by layered system methods." Highway Research Board Bulletin 177, pp. 26-54.

Lawton, E.C. and Fox, N.S. [1994]. "Settlement of structures supported on marginal or inadequate soils stiffened with short aggregate piers." Geotechnical Special Publication No. 40: Vertical and Horizontal Deformation of Foundations and Embankments, ASCE, Vol. 2, pp. 962-974.

Lawton, E.C., Fox, N.S., and Handy, R.L. [1994]. "Control of Settlement and Uplift of Structures Using Short Aggregate Piers." Proceedings. of *In-situ Deep Soil Improvement,* ASCE National Convention, pp. 121-132.

Schmertmann, J.H. [1970]."Static cone to compute static settlement over sand." J. Soil Mech. And Found. Div., Proc. ASCE, 96(SM3), pp. 1011-1043.

Schmertmann, J.H., Hartman, J.P., and Brown, P.R. [1978]. "Improved strain influence factor diagrams." J. Geotech. Eng. Div., 104(GT8), pp. 1131-1135.