M E M O R A N D U M

Date: September 17, 2006

Re: Geotechnical Investigation Specification
for a
Composite Elevated Water Storage Tank

The specification referenced above provides guidelines to the engineer performing a geotechnical investigation for a composite elevated tank.

The entity responsible for arranging a geotechnical investigation should be knowledgeable with respect to minimum requirements. An agreement should be structured that will provide for an adequate investigation and result in adequate information. We recommend that the agreement reflect the requirements of the specification referenced above, and define other standard contractual requirements such as access, timing, insurance and compensation.

Planning the appropriate geotechnical investigation requires a general knowledge of the anticipated geological conditions at the site and an understanding of the structure size and anticipated loads. The geotechnical engineer should be provided with preliminary structure and load information including anticipated height, diameter of the pedestal, structure and water weight, and service level shears and moments at grade that are associated with wind and earthquake loads. Please contact a Landmark representative to obtain this information.

The specification requirements for analysis and recommendations are general and may be adjusted to suit the specific geological and geographical conditions. The geotechnical engineer should be prepared to adjust the exploration depths and testing during drilling, depending on the subsurface conditions encountered.

It is recommended that the geotechnical engineer be involved during final foundation design and construction, in order to confirm recommendations and provide further testing and inspection as required. This allows the geotechnical engineer to be particularly aware of unusual or unforeseen conditions that may affect the recommendations or performance of the foundation.

GUIDE FOR GEOTECHNICAL INVESTIGATION
FOR A
COMPOSITE ELEVATED WATER STORAGE TANK

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GUIDE FOR GEOTECHNICAL INVESTIGATION FOR A COMPOSITE ELEVATED WATER STORAGE TANK

1. General

1.1 Scope

This is a guideline for obtaining a geotechnical investigation for a composite elevated tank. The work includes field investigation, laboratory testing, engineering analysis, and recommendations.

1.2 Purpose

The purpose of the geotechnical investigation is to obtain information on the subsurface conditions at the site for design and construction of foundations and related earthwork.

1.3 Procurement

The geotechnical investigation is usually procured by the owner or his engineering representative during the planning of a project, and the report is typically included with project documents. A geotechnical engineer familiar with geological conditions at the site should be retained to provide the geotechnical investigation and report. The geotechnical engineer should also be involved during final foundation design and construction, in order to confirm recommendations and provide further testing and inspection as required. This allows the geotechnical engineer to be aware of unusual or unforeseen conditions that may affect his recommendations in regard to performance of the foundation.

1.4 Responsibilities

The geotechnical engineer is responsible for developing and coordinating the field investigation and testing program. The geotechnical engineer should consider imposed loads, topography, subsurface conditions, and soil and rock properties to provide design, construction and inspections recommendations.

The geotechnical engineer should be provided with preliminary structure and load information including anticipated height, support wall diameter, dead and water loads, and shear and moment at grade due to wind and seismic loads.

The owner or his engineering representative should locate the center of the tank in the field and provide a convenient benchmark referenced to mean sea level. Layout of individual boring and determining their elevation is usually the responsibility of the geotechnical engineer.

2. Design Criteria

2.1 Strength

A factor of safety of 3.0 or greater is required for bearing capacity of shallow foundations. Minimum factor of safety for pile foundations should comply with the following.

- 3.0 where capacity is determined by analysis using engineering principles.
- 2.25 where capacity is determined by dynamic testing of driven piles in accordance with ASTM D 4945 .
- 2.0 where capacity is determined by static load testing in accordance with ASTM D1143 or other in-situ tests that measure end bearing, side friction, or both.

2.2 Settlement

The combined foundation and concrete support wall form a rigid structure that will experience negligible out-of-plane settlement. Subsurface deformations that require consideration are total settlement, and differential settlement that causes tilting of the structure. The following settlement limits are typically specified for composite elevated tanks.

- 3.0 in. total settlement for shallow foundations.
- 3/4 in. total settlement for deep foundations.
- 1/800 tilting of the structure. Larger tilting is permitted when the effects of tilting are included in the structural design. Maximum tilt should not exceed 1/300.

3. Field Investigation

3.1 General

Field investigation should include sufficient sampling, testing, and observations to determione site conditions and engineering properties of the supporting soils for design and construction of the foundation. Consult available geological literature to determine characteristics of the formations that may be encountered during the field investigation.

Field investigation shall be conducted in accordance with applicable ASTM standards or other accepted procedures.

3.2 Borings

The minimum number of borings should comply with the following:

- 1.0 MG capacity and smaller: 3 equally spaced borings on anticipated support wall diameter.
- 1.0 to 1.5 MG capacity: 3 equally spaced borings on anticipated support wall diameter plus 1 boring at the tank center.
- 1.5 MG capacity and larger: 4 equally spaced borings on anticipated support wall diameter plus 1 boring at the tank center.

Borings should extend sufficient depth to identify strata that may be significantly affected by imposed foundation loads.

Cone penetration testing or other in-situ tests may be used to replace or augment conventional borings. The number, spacing and location, and depth of borings may need to be adjusted as the field investigation progresses if unanticipated subsurface conditions are encountered.

3.3 Sampling and Field Testing

Sampling should be performed at 2.5 ft intervals for the first 10 ft to 15 ft, and at 5 ft intervals thereafter. Split-spoon sampling in accordance with ASTM D 1586 should be used for granular soils, and the type of hammer used should be reported on the boring log. Predominantly cohesive soils should be sampled using thin-wall Shelby tube samplers in accordance with ASTM D 1587. Field testing with pocket penetrometer, shear vane, cone penetration, pressuremeter, and other recognized in-situ tests may be used to determine physical properties of subsurface soils.

Rock cores should be NX-size or larger. The recovery, expressed as a percentage, and the rock quality designation should be reported on the boring log. Any zones of rock not recovered should be identified on the boring log and discussed in the report.

Samples should be sealed and packaged to preserve their integrity, and handled and transported in a manner to minimize disturbance. Samples should be labeled with the following: job number, boring number, sample number, sample depth, and any pertinent information regarding sample disturbance.

3.4 Groundwater

Boreholes should be bailed and water levels measured. Groundwater information should include date, bailed depth, water level depth, caved depth, and any surface or subsurface-related condition that may influence the water level elevation.

3.5 Completion

At completion of field operations, all boreholes should be filled and plugged in accordance with applicablel regulations. The site shall be left reasonably close to its original condition.

3.6 Boring Logs

Ground surface at boring locations should be referenced to a datum elevation. A detailed field log of each boring should be kept which identifies the materials encountered and provides details of drilling procedures. Samples should be classified in accordance with the Unified Soil Classification System and ASTM D 2488.

Final boring logs incorporated into the report should include the boring number, date and time of start and finish, approximate relative surface elevation and methods of borehole drilling used. Each log shall contain a graphical presentation of the materials and shall include results of laboratory testing. Other information required are the results of sample penetrations at each interval, number of blows required to advance the sampler, water infiltration observation, subsequent water level observation and presence of gas or other unusual conditions.

4. Laboratory Testing

4.1 General

Laboratory testing should be conducted on representative samples to determine physical characteristics of the subsurface materials. Testing should be in accordance with applicable ASTM standards.

4.2 Soil Classification

Soils should be classified in accordance with the Unified Classification system. Deleterious materials, chemically active materials, or other special conditions should be noted.

Laboratory tests include Atterberg limits (ASTM D 4318), grain size analysis (ASTM D 422), moisture content (ASTM D 2216) and dry unit weight.

4.3 Soil and Rock Strength

Shear strength and angle of internal friction for bearing capacity should be determined by testing or indirect methods. Potential strength change with moisture content variation should be considered.

Laboratory tests for soil may include unconfined compressive strength (ASTM D 2166), direct shear test (ASTM D 3080) or triaxial compression test (ASTM D 4767).

Laboratory tests for rock may include unconfined compressive strength (ASTM D 2938) and splitting tensile strength tests (ASTM D 3967).

4.4 Soil Settlement and Volume Change

Testing to evaluate deformation and volume change characteristics of soils should be conducted.

Settlement and consolidation - Tests should be conducted to define the coefficient of consolidation, compression index and initial void ratio of soils for estimating total and differential settlement of shallow foundations. Laboratory tests may include tests for consolidation (ASTM D 2435) and specific gravity (ASTM D 854).

Soil Expansion – Tests should be conducted as applicable to determine the expansion potential of soils to determine the effect on foundation elements. Laboratory tests may include pressure swell and/or free swell tests (ASTM D 4546), Atterberg limits tests (ASTM D 4318), moisture content determinations (ASTM D 2216), soil suction tests (ASTM D 5298), grain size analyses (ASTM D 422), or other recognized tests

4.5 Other Tests

Additional tests for deleterious materials, chemically active materials or other special soil conditions may be required, depending on the regional location and history of the site.

5. Engineering Analysis and Recommendations

5.1 General

Shallow and/or deep foundation systems should be evaluated based on the results of field inspection, laboratory testing, structural loading conditions, and minimum design criteria for strength and settlement in requirements in Section 2.

5.2 Shallow Foundations

Shallow foundations are annular ring or circular raft (mat) configurations. Approximate maximum diameter of an annular ring foundation is 1.4 times the support wall diameter. Where required bearing area would result in a larger foundation diameter a raft configuration is used.

Ultimate bearing capacity and net allowable bearing capacity should be determined based on the design criteria in Section 2. The effect of short duration loads, such as wind or seismic should be considered in evaluating allowable bearing capacity. Resistance to lateral loads by friction, adhesion and passive earth pressure shall be determined.

The following should be reported.

- Recommended net allowable bearing capacity for long-term loads, and the permissible increase for short duration loads.
- Estimated total and differential (tilting) settlement.
- Minimum and maximum founding depths for recommended bearing pressure.
- The effect of foundation size on allowable bearing pressure and estimated settlement.
- Recommendations for resistance to lateral loads by friction, adhesion, and passive earth pressure.
- Potential for soil movement due to volume change of expansive soils.
- Soil improvement methods and procedures, if applicable.
- Recommendations for construction and inspection.

5.3 Deep Foundations

Deep foundation elements are driven piles, and cast in-situ piles or drilled piers that typically are arranged in one or more circular rows. A pile or pier cap connects the deep foundation elements to the tank support wall.

Ultimate axial compression and uplift capacity, and allowable service level capacity of pile or pier foundations should be determined based on the design criteria in Section 2. The effect of short duration loads, such as wind or seismic should be considered in evaluating capacity. Tip or end bearing and side friction resistance for the applicable soil and rock strata should be determined. The relationship of displacement and the relative mobilization of side and tip resistance should be considered when establishing allowable pile or pier capacity.

The following should be reported.

- Recommended ultimate and allowable tip or end bearing resistance and side friction resistance for long-term compression and uplift loads of pile or pier types considered. Permissible increase in compression and uplift resistances for short duration loading.
- Estimated total and differential (tilting) settlement.
- Minimum pile or pier penetration into bearing strata.
- Minimum pile or pier spacing.
- Reduction in axial capacity due to pile or pier group efficiency. Reduction in axial capacity for spacing closer than recommended minimum spacing.
- Soil resistance parameters for lateral loads, or estimated lateral load capacity of pile or pier types considered.
- Recommended testing.
- Estimated uplift forces on piles or piers due to volume change of expansive soils.
- Estimated negative skin friction forces due to consolidation of soft soil layers.
- Recommendations for pile or pier installation, and inspection. Discussion of installation equipment and procedures such as: pile hammers, pre-drilling, jetting, driving shoes, and concrete placement methods

5.4 Other considerations

The following should be considered and discussed in the report, where applicable.

- In seismic areas, the Site Class determined in accordance with procedures in ASCE 7.
- Minimum foundation depth for frost penetration.
- Presence of permanent high water table for stability calculations.
- Construction dewatering requirements.
- Recommendations for excavating and backfilling. Earthwork requirements for constructing slab-on-grade floors.
- Presence of sulfates in soil or groundwater and the potential for concrete degradation.
- Recommendations for construction on a sloping site or adjacent to earth cuts.
- Recommendations for special conditions such as karst topography, faults, and soil liquefaction.

- Trench and excavation parameters to satisfy OSHA standards during construction.

6. Geotechnical Report

A report that documents the results of the field investigation, laboratory testing, analysis and recommendations should be prepared. The report should include the following.

- A description of the structure and loading conditions considered in the geotechnical investigation. Any limitations should be identified.
- Descriptions of the site, regional geology, field investigation methods, and laboratory testing. Test results and supporting documentation.
- A plan of the site indicating boring locations and proposed structure location. A section drawing of boring logs.
- Analyses, recommendations, and discussion of foundation alternatives. Foundation descriptions, founding materials, founding depths, soil and rock capacity parameters, and estimated settlement and volume changes.
- Discussion of foundation construction and inspection requirements

7. References

The following ASTM standards are referenced in this guideline.

ASTM D 422	Standard Test Method for for Particle-Size Analysis of Soils
ASTM D 854	Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
ASTM D 1143	Standard Test Method for Piles Under Static Axial Compressive Load
ASTM D 1586	Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils
ASTM D 1587	Standard Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes
ASTM D 2166	Standard Test Method for Unconfined Compressive Strength of Cohesive Soil
ASTM D 2216	Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
ASTM D 2435	Standard Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading
ASTM D 2488	Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)
ASTM D 2938	Standard Test Method for Unconfined Compressive Strength of Intact Rock Core Specimens
ASTM D 3080	Standard Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions
ASTM D 3967	Standard Test Method Splitting Tensile Strength of Intact Rock Core Specimens
ASTM D 4318	Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
ASTM D 4546	Standard Test Methods for One-Dimensional Swell or Settlement Potential of Cohesive Soils
ASTM D 4767	Standard Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive S
ASTM D 4945	Standard Test Method for High-Strain Dynamic Testing of Piles

ASTM D 5298	Standard Test Method Measurement of Soil Potential (Suction) Using Filter Paper