UNINTENDED CONSEQUENCES

KARST IN SOUTH CAROLINA’s LOW COUNTRY

Stephen Geiger, P.E.
ECS Southeast, LLP
April 9th to 11th, 2018
SOUTH CAROLINA COASTAL PLAIN GEO-HAZARDS
SOUTH CAROLINA COASTAL PLAIN
GEO-HAZARDS IN AREA OF INTEREST

MAP GUIDE

- High Potential for Liquefaction
- Low Potential for Liquefaction
- Potential for Collapse
- Potential for Sinkholes
- Potential for Landslide
- Low geologic hazard potential
- Fall Line

- Liquefaction features caused by 1886 Charleston Earthquake
- Prehistoric Liquefaction features
- Known Sinkhole Occurrences
- Limestone Cave
- Landslide Occurrence

NOT FOR DISTRIBUTION
GEORGETOWN, SOUTH CAROLINA

Third Oldest City in the United States
Spaniards 1526, French 1562, English 1721, Chartered 1729

County Population = 63,000
MHI = $41,500
GEORGETOWN’S “MOST” FAMOUS SON
GEOLOGY SNAP SHOT

Pleistocene <2.5 M

Paleocene 55 to 65 M
# Rotosonic Borings

## Georgetown Drainage Project Investigation
Georgetown County, South Carolina

**Date Drilled:** 11/30/2011  
**Supervisor:** J. Stewart  
**Casing Length (ft):**  
**Approx. Ground Elevation:**  
**Hammer Type:** Gravity, Automatic, Other:  
**Water Level:** Not Recorded  
**Drilling Method:** Rotosonic

### Material Description

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Material Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 to 2.0</td>
<td>Brown/Gray, Dark Gray, Silty Fine to Medium SAND (SM)</td>
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<tr>
<td>2.0 to 3.0</td>
<td>Brown/Gray, Fine to Medium SAND (SM)</td>
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<td>4.0 to 5.0</td>
<td>Light Gray, Clayey Fine to Medium SAND (SM)</td>
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<td>6.0 to 7.0</td>
<td>Dark Gray, Fine to Medium SAND (SM)</td>
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<tr>
<td>59.0 to 60.0</td>
<td>Pale Yellow Clay, Gray, Fine to Medium SAND (SM)</td>
</tr>
</tbody>
</table>

## LOG OF BORING No. Pump Station #1

**Noting:** 583780.359  
**Easting:** 2522083.975  
**Notes:** Continuous Rotosonic Sample

### Sample Type
- SS - Split Sample
- ST - Shelly Tule
- RG - Rock Core 1-7/8”
- RGW - Rock Core, 1-5/8”
- CT - Continuous Tube
- GSA - Geologic Sample Tube

### Drilling Method
- HSA - Hollow Stem Auger
- DRA - Drilled Auger
- RWA - Rotary Wash
- DF - Downward Flow
- PC - Rock Core
- HMD - Percussion Hammer Drill

### Standard Penetration Test Data (Bolton’s)

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>SPT N-values</th>
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</thead>
<tbody>
<tr>
<td>5.0</td>
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<td>12.0</td>
</tr>
<tr>
<td>40.0</td>
<td>20.0</td>
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</tbody>
</table>

**Legend:**
- SS - Split Sample
- ST - Shelly Tule
- RG - Rock Core 1-7/8”
- RGW - Rock Core, 1-5/8”
- CT - Continuous Tube
- HSA - Hollow Stem Auger
- DRA - Drilled Auger
- RWA - Rotary Wash
- DF - Downward Flow
- PC - Rock Core
- HMD - Percussion Hammer Drill

- **Urban Fills**
- **Pleistocene (Estuarine)**
- **Williamsburg Formation**
- **Very Stiff to Hard (CL/CH)**
- **Paleocene**
- **Limestone**
Simplified GeoLogic Profile

Characterized Subsurface Stratigraphy

Ground Surface

Sands & Clays
Geologically Recent Deposits (Tertiary)

Very Dense/Cemented Silts & Clays

Limestone (Carbonates)

Urban Fills & Estuarine Deposits
Pleistocene

Williamsburg Formation
Paleocene

Limestone
SKETCH 2

CHARACTERIZED GROUNDWATER HYDROLOGY

GROUND SURFACE

[SURFACE AQUIFER]
OPEN TO ATMOSPHERE; OCCURRING IN SOILS WITH LOW TO MODERATE HYDRAULIC CONDUCTIVITY

AQUIFARD – DOES NOT READILY TRANSMIT WATER; VERY LOW HYDRAULIC CONDUCTIVITY

LOWEY CONFINE AQUIFER – NOT HOMOGENEOUS OR ISOTROPIC. CONTAINS LIMESTONE DEPOSITS WITH HIGH VOID CONTENT AND SOLUTION CAVITIES. VERY HIGH HYDRAULIC CONDUCTIVITY

*THE PRE-CONSTRUCTION HEAD PRESSURE IN THIS [LOWER CONFINED AQUIFER] IS EQUAL TO OR SLIGHTLY HIGHER THAN THE [SURFACE AQUIFER]

Discontinuous

High Void Content

Solution Cavities

Very High Hydraulic Conductivity
STORMWATER DRAINAGE PROJECT

Significant Flooding During Heavy Rainfall and High Tide
Confluence of 2 Major River Systems
In Area Bounded by Blue Line
WET WELL DESIGN
KING PILE SYSTEM

Design Phase Study
CPT Refusal +/-35’

PLAN

SECTION

30” O.D. @ 7.25’ O.C.

Tip 47’

23’
KING PILE SYSTEM INSTALLATION

Temporary Steel Casing Installation
Vibratory Hammer

Temporary Casing Clean Out
KING PILE SYSTEM INSTALLATION

Pile Shell Installation

Steel Shell Driven To Design Tip Elevation
KING PILE SYSTEM INSTALLATION

Installed System
Prior to Concreting and Excavation

Concrete Placement
Tremie Method
KING PILE SYSTEM INSTALLATION

Artesian Conditions At Base of Wet Well Excavation
KING PILE SYSTEM INSTALLATION

Finally A Dry Excavation!!
KING PILE SYSTEM INSTALLATION

Discharge Rates From Flowmeter
+/-90,000 Gallons Per Hour
+/-2M Gallons Per Day
“REAL” GEOLOGIC CROSS SECTION

Open Pit Limestone Mine – Holly Hill, SC

Open Cut @ Quarry
< 20 Miles NW of Georgetown
HYDRO-GEOLOGIC CONSIDERATIONS

SHALLOW DWATERING
March/October 2011

DEEP DATERING
October/November 2011

SKETCH 3
Schematic of Karst Geology Prior to De-Watering of Lower Aquifer

- Ground Surface
- Shallow Ground Water
- Geologically Recent Surface Deposits
- Aquitard - Very Low Permeability
- Upward Pressure of Ground Water Below the Aquitard
- Solution Cavities
- Limestone (Calcareous)

King Piles +/-47'
Conditions Prior To Wet Well Dewatering

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DEWATERING EFFECTS

1956 Duke Street Sinkhole

Hazard Sink Hole
Highmarket Sink Hole
Parrish Place Parking Lot Depression
Parrish Place Sink Hole on Fraser Street
Wet Well
COLLAPSE/SINK HOLE MECHANISM

Phenomena Documented In Coastal South Carolina Since 1975
Jamestown Quarry +/-35M Gallons Per Day – Widespread Subsidence
PARRISH PLACE PARKING FEATURE

Opportunity for A Safety Minute?
UPS BUILDING COLLAPSE
PARRISH PLACE

Collapse Occurred +/- 10pm November 17, 2011
### WET WELL PROJECT TIMELINE

#### SIGNIFICANT EVENTS

<table>
<thead>
<tr>
<th>Activity</th>
<th>Date</th>
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<tbody>
<tr>
<td>Artesian Conditions</td>
<td>June 2011</td>
</tr>
<tr>
<td>Consultant Endorsement</td>
<td>Nov. 2011</td>
</tr>
<tr>
<td>Construction Activity of Note</td>
<td></td>
</tr>
<tr>
<td>Consequence of Construction</td>
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</tbody>
</table>

#### Timeline

- **September 1, 2010**
  - Artesian Conditions

- **November 18, 2011**
  - Consultant Endorsement

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**NOT FOR DISTRIBUTION**
Steel and Masonry, 3-Story, 79,300 SF County Judicial Center
Completed Spring 2008
Construction Value +/- $18,000,000
THE “PROJECT”
GEOTEchnical Design

Site formerly occupied multiple generations of structures

Grades raised approximately 4 to 6 feet

8” Tip Southern Pine Timber Piles** (VE)

35 feet minimum embedment
35 blows per foot at EOD

30 tons compression
10 tons uplift
4 tons lateral

Ground level concrete slab-on-grade ** (VE)

Geotechnical Exploration Methods?
Geotechnical Testing Protocol?
Conflicting Geotechnical Reports?
For The Sake of $?
GEOTECHNICAL CHALLENGES

E.O.D. Resistances: 6 bpf to > 100 bpf
GEOTECHNICAL CHALLENGES

First Floor Slab On Grade
+/- 4' to 6'
New Fill

Pile Supported Load Bearing Elements

+/- 35' to 40'

GEO VIRGINIA 2018

SKETCH 4
SCHEMATIC OF SINKHOLE FORMATION FOLLOWING DE-WATERING OF LOWER AQUIFER

GROUND

SHALLOW GROUND WATER

AQUIFAR

NO AND/OR VERY LOW UPWARD PRESSURES BELOW AQUIFAR

SURFACE SOIL FLOWS INTO SOLUTION CAVITIES

LIMESTONE (CALCAREOUS)
SUBSURFACE CONDITIONS POST WET-WELL

Poor Agreement
Mud-Rotary
Forensic Phase

vs.

Hollow Stem Auger
Design Phase

GEO VIRGINIA 2018

Not for Distribution
SUBSURFACE CONDITIONS
POST WET-WALL
WHERE ARE WE NOW?

Lawsuits Related To Drainage Project (>25)
Lawsuits Against Judicial Center Design Team
Protracted Litigation (> 6 Years)

Geotechnical and Structural Deficiencies

ECS Characterizes Geotechnical Deficiencies for Owner
ECS Undertakes Independent Analyses for Owner
   Forensic Assessment w/REA
   CPT & SCPT Soundings
   Mud Rotary SPT Borings
   Refraction Microtremor
   SSHA
Liquefaction Triggering Analysis
Foundation and Slab Repair Design w/REA
WHERE ARE WE NOW?

Key Geotechnical and Foundation Design Shortcomings

Liquefiable Deposits Upper 35 feet ** (+/-2” to 5”)
Peat & Very Soft Marine Clay Layers (LL’s > 85, PI’s > 45, qt < 5 tsf) **

Installed Pile Lengths 14 to 38 feet **

Working Pile Loads
Actual Compressive As Much As 25% Greater Than Design (REA)
Actual Uplift As Much As 20% Greater Than Design (REA)
Actual Lateral As Much As 75% Greater Than Design (REA)

Interpreted Pile Capacities As Low As 50% of Working Loads (FS=1)

Timber Piles Structurally Inadequate
Working Stresses During Lateral Loading >>>> Allowable
WHERE ARE WE NOW?

Conceptual Geotechnical Repairs
Foundations
  Underpinning w/ Cased Micropiles ($5M per HBI) **

Ground Level Slab
  New Micropile Supported Structural Slab ($2M per HBI) **
  HDPE Grouting of Pleistocene Deposits ($1M) X
  Low Mobility Grouting of Limestone ($2M to $3M) X

Collateral Work
  Remove and Replace Existing Finishes ($3M to $4M)

Definition of “Sinkhole” – Engineering vs. Coverage
County Operations Relocation During Repairs (18 mos. @ $6M to $8M)
Estimated Damages ($15M to $18M or more)
FUN FACTS

Originally Considered Driven 55’ PSC or ACIP & Structural Floor Slab Value Engineered - Driven Timber Piles and Slab On Grade ($600,000 net)

Hollow Stem Auger Borings by GER (Max. Depth 35’)
No Laboratory Testing by GER
Conflicting Versions of GER Design Level Reports (seismic risks????)
Design Level Geotechnical Reports Don’t Bear Firm or EOR Seals

+/-375 Timber Piles Installed September/October 2007
Production Pile Lengths 14 to 38 Feet
2 Pre-Production Static Load Tests w/Questionable Results
6 of 10 PDA Tests During Driving, Axial Capacity Concerns

GER Not Retained For Construction Observations (would it have mattered?)
CMT/SI Firm Refuses To Write Letter “Certifying” Foundations
GER Reviews SI Driving Records, “Certifies” Pile Capacity (FS = 1.5)
THANK YOU!

Shameless Plug!!!!