Development of Sinkhole Risk Evaluation Program
(BDV24 TWO 977-17)

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Presented to:
FDOT GRIP Meeting
July 15, 2016
Presentation Outline

• Introduction
• Task 1 – Subsurface characterization by CPT
• Task 2 – In-situ groundwater sensing
• Task 3 – Development of groundwater model for high-resolution recharge map
• Future plan
Introduction

• Research objective:
  • to develop a procedure to evaluate the level of sinkhole vulnerability based on in-situ CPT
  • to develop a high-resolution recharge map
  • to explore in-situ groundwater sensing/monitoring

• Research methodology
  • In-situ tests (SPT, CPT, etc.)
  • Piezometer sensor installation
  • Numerical analysis (finite difference, finite element)
UCF Sinkhole Research Team

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Geotechnical Eng.
- Sinkhole stability analysis for risk evaluation
- Subsurface characterization of geotechnical system
- Laboratory evaluation of geomaterials

Dr. Dingbao Wang
Water Resource Eng.
- Surface water and groundwater interaction
- Water resources systems analysis
- GIS and remote sensing applications in water resources

Dr. Andrew H. Yun
Structural Eng.
- Sinkhole sensing and prediction algorithm
- Signal processing & data mining; Civil infrastructure monitoring
- Multi-physics modeling

Dr. Manoj Chopra
Geotechnical Eng.
- Physical groundwater model test
- Soil erosion and sedimentation
- Nonlinear soil consolidation & stress analysis
Task 1. Subsurface characterization by CPT (at Wekiva pwky site)
Wekiva Parkway Project – Site Description

• Lake County
• About 40 minutes North of Downtown Orlando.
• Focus Section: North end of SR 46 to Mt. Plymouth Rd connector toll road.
• Located north of wekiva springs and south of Seminole springs. Numerous relic sinkholes.
• Interchange consists of 3 bridges, 4 earth-embankment ramps
Field investigation performed by FDOT and Professional Services Inc.
- 74 CPT soundings performed till refusal
- 14 SPT borings through performed till

🌟 Focus thus far on constructed bridge over sinkhole anomaly.
• 3 Total Grids of 15 or more CPTs performed on/near sinkhole anomaly areas.

• Bridge grid (shown right) consists of 17 CPT and 4 SPT performed within roughly an acre.

• Depth to Limestone varies from 60 to 130 feet.

• Borings show very loose soil (WH/WR & Tip resistance < 10 TSF) directly above the limestone bedrock.
CPT data are plotted along the lines to visualize soil strata stiffness profile and possible sinkhole anomaly along each profile line shown in the figure above.
2D CPT Imaging (tip resistance data)

- 2D CPT imaging was created in MATLAB to visualize soil strata stiffness profile and possible sinkhole anomaly along each profile line.
- 3D Surface plot with interpolated shading. Color scale from 0 to 200 TSF.
- Very low tip resistance within the “bowl” or “valley” of limestone surface suggest that subterranean erosion of overburden soils has occurred (Raveling).
• Soil raveling

The groundwater from unconfined aquifer to confined aquifer weathers the carbonate limestone and erodes the overburden soils causing sinkholes. The overburden soils can be raveled before any noticeable subsidence or sinkhole-like identifiers are shown on the ground surface. Best time to perform mitigation measures

**Cover-subidence sinkhole**

Sediments spall into a cavity. As spalling continues, the cohesive covering sediments form a structural arch. The cavity migrates upward by progressive roof collapse. The cavity eventually breaches the ground surface, creating sudden and dramatic sinkholes.

**Cover-collapse sinkhole**

Granular sediments spall into secondary openings in the underlying carbonate rocks. A column of overlying sediments settles into the vacated spaces (a process termed "piping"). Dissolution and infilling continue, forming a noticeable depression in the land surface. The slow downward erosion eventually forms small surface depressions 1 inch to several feet in depth and diameter.

From Tihansky 1999
Raveling Index (RI)

- Proposed by Gray and Bixler, the raveling index is the ratio of thicknesses of raveled soil to harder “undisturbed” overburden soil. Best when calculated using CPT data because of high resolution of data.

\[
RI = \frac{\text{Thickness of raveled zone}}{\text{Depth to top of raveled zone}}
\]

\[
RI = \frac{40}{55} = 0.727
\]
Raveling Index plot of the Wekiva Pwky site
Task 2. Sensor layout & in-situ installation
Sensor layout for Wekiva pkwy

- Ground water table from MSL
  - Low: 63 feet
  - High: 70.5 feet
- Number of Zone: 4
  - No. of sensor in zone 1: 7
  - No. of sensor in zone 2: 4
  - No. of sensor in zone 3: 7
  - No. of sensor in zone 4: 2
- Type of sensor: 4500S-350kPa
- Number of Datalogger: 5
  - 4-channel datalogger: 4
  - 16-channel datalogger: 1
Sensor layout for fdot retention pond

- Ground water table
  - Low: 13.5 ft
  - High: 16 ft
- Number of sensor: 16
- Type of sensor: 4500S-350kPa
- Number of datalogger: 1
- Type of datalogger: 16-channel
Equipment

- **Piezometer sensor**
  - Make: Geokon
  - Model: 4500S-350kPa
  - Resolution: 0.025% F.S
  - Accuracy:
    - ±0.1% F.S.

- **4-Channel datalogger**
  - Make: Geokon
  - Measurement Accuracy: ±0.05% F.S.
  - Data Memory: 320K EEPROM
  - Storage capacity: 10666 arrays

- **16-Channel datalogger**
  - Make: Geokon
  - Measurement Accuracy: ±0.05% F.S.
  - Data Memory: 320K EEPROM
  - Storage capacity: 3555 arrays
Sensor preparation and installation

Step 1: Checking sensors and dataloggers in lab
Step 2: Install sensor using CPT/SPT trucks
Step 3: Install sensor using CPT/SPT trucks
Step 4: Connect sensors to datalogger and start logging
Process of sensor Installation

1. Cones Penetration Test (CPT) Soundings and Measurement of Ground Watertable
2. Determine Raveling Layers to place sensors
3. Conduct Sensors' Initial reading of Pressure and Temperature
4. Install sensors using CPT/SPT trucks
5. Collect Data and Post-Process
6. Start logging
7. Check Sensors after Installation
8. Install sensors using CPT/SPT trucks
9. Input Sensors' Properties into software called "Logview"
10. Burry Cables and Connect Sensors to Dataloggers
Adapter and Sacrificial cone-tip
Task 3. Development of a high-resolution groundwater recharge map
Procedures to develop the high-resolution groundwater model

1. Identify the Study Area
2. Determine the Model Domain
   - Natural Boundary
   - Artificial Boundary
3. Collect the Hydrogeological Data
   - Land Surface Elevation
   - Depth to Clay Layer
   - Depth to Limestone Layer
4. Collect the Hydrological Data
   - Rainfall
   - Evaporation
   - Transpiration
   - Surface Runoff
   - Depth to Water Table
   - Depth to Potentiometric Level
   - Lake Stage
   - Stream Stage and Discharge
   - Spring Discharge
5. Collect the Soil Property Data
   - Hydraulic Conductivity
   - Anisotropy
   - Porosity
   - Soil Moisture Content
   - Infiltration Capacity
   - Soil Compressibility
     - Specific Yield
     - Specific Storage
6. Determine the Simulation Code
7. Build Up the Conceptual Model
8. Convert the Conceptual Model to Numerical Model
9. Calibrate and Validate the Numerical Model
10. Sensitivity Analysis
11. Execute the Numerical Model and Visualize the Output
Study Area

• Mt. Plymouth, FL
  • Wekiwa Pkwy Bridge
  • Construction Site

• Newberry, FL
  • Detention Pond
Model Domain

Water Table Contour 2010
(SJRWMD Special Publication SJ95-SP7)
Model Horizontal Discretization

248 Rows and 218 Columns => 54,064 elements

Grid Size: 30 m x 30 m
Model Vertical Discretization

- **Surficial Layer (Surficial Aquifer)**
  - Primarily composed of sand

- **Clay Layer (Upper Confining Unit)**
  - Primarily composed of clay

- **Limestone Layer (Floridan aquifer)**
  - Primarily composed of limestone and dolostone
Boundary conditions

Surficial Layer
- Inactive Area
- General-head Boundary

Limestone Layer
- Inactive Area
- Pumping Well Boundary
- General-head Boundary
Simulation Code

• MODFLOW – 2005
  • Three-Dimensional Finite-Difference Groundwater Model
  • Most Current Release of MODFLOW
  • The Most Frequently Used Groundwater Model Tools
  • Developed by Harbaugh (2005) From U.S. Geological Survey
Recharge

Wekiwa Pkwy Bridge
Recharge

Wekiwa Pkwy Bridge
Recharge

Wekiwa Pkwy Bridge
Future work plan

• Sinkhole risk assessment
  • Reconstruct the threshold to determine soil raveling
  • Improve the Raveling Index
  • Sinkhole stability analysis (seepage-stress FE model)

• In-situ groundwater sensing
  • Continue to install the sensors in both sites
  • Monitoring the data

• Groundwater recharge work
  • Develop the groundwater model for Newberry Pond site
  • Construct the recharge map
Acknowledgement:
Special Thanks to SMO and District 5 teams for all their drilling support thus far!

Thank you!
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Questions?