Development of a Sinkhole Risk Evaluation Program

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FDOT State Materials Office

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UCF Sinkhole Research Team

Dr. Boo Hyun Nam
Geotechnical Eng.

- Sinkhole stability analysis for risk evaluation

-Subsurface characterization of geotechnical system

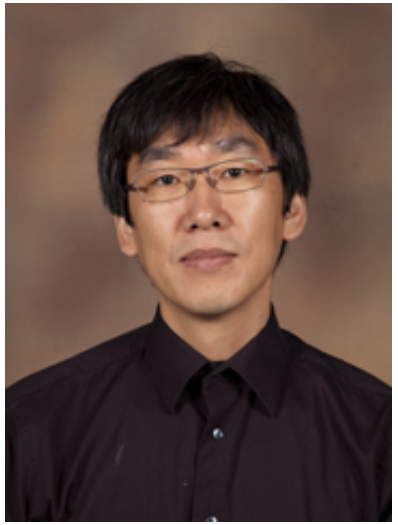
- Laboratory evaluation of geomaterials

Dr. Manoj Chopra
Geotechnical Eng.

- Physical groundwater model test

-Soil erosion and sedimentation

- Nonlinear soil consolidation & stress analysis



Dr. Andrew H. Yun
Structural Eng.

- Sinkhole sensing and prediction algorithm

- Signal processing & data mining; Civil infrastructure monitoring

- Multi-physics modeling

Dr. Dingbao Wang
Water Resource Eng.

-Surface water and groundwater interaction

- Water resources systems analysis

- GIS and remote sensing applications in water resources

UCF Sinkhole Research Team (cont.)

- Four Graduate Students
  - Adam Perez (M.S. student)
    - Sinkhole stability analysis
  - Ryan Shamet (M.S. student)
    - Sinkhole identification by using CPT
  - Xia Han (Ph.D student)
    - Groundwater modeling
  - TBD
    - In-situ groundwater monitoring

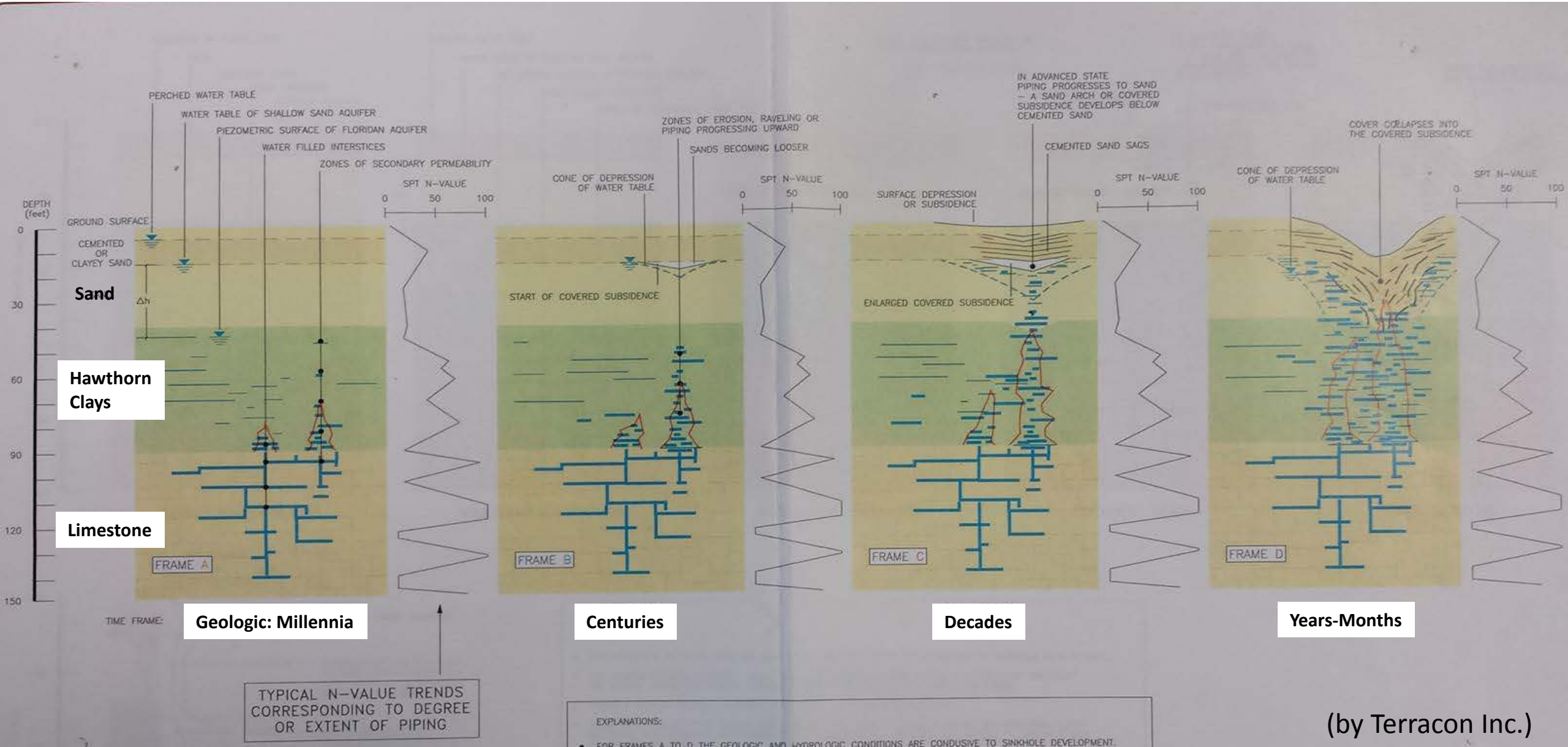
Status of UCF Sinkhole Research

- The Florida Sinkhole Research Institute (FSRI)
  - Expertise in the fields of geotechnics, sensing and monitoring, and groundwater modeling
- Collaboration with FDOT District 5
  - Development of sinkhole research ideas
- Collaboration with Florida Geological Survey (FGS)
  - Sinkhole mapping project
- Terracon Foundation Support
  - To buildup testing setup for sinkhole research

Presentation Outline

- Sinkhole mechanism
- Current practice of sinkhole study in Florida
- Literature review
- Work plan
  - Task 1 - Development of in-situ groundwater monitoring system
  - Task 2 - Development of high-resolution recharge map (model development)
  - Task 3 – Improved identification method for detecting raveled soil zone (by using CPT)
  - Task 4 – Development of sinkhole stability analysis model and stability chart
  - Task 5 – Guideline of sinkhole evaluation procedure

Sinkhole Mechanism (from geotech perspective)



(by Terracon Inc.)

Key Parameters for Sinkhole Study

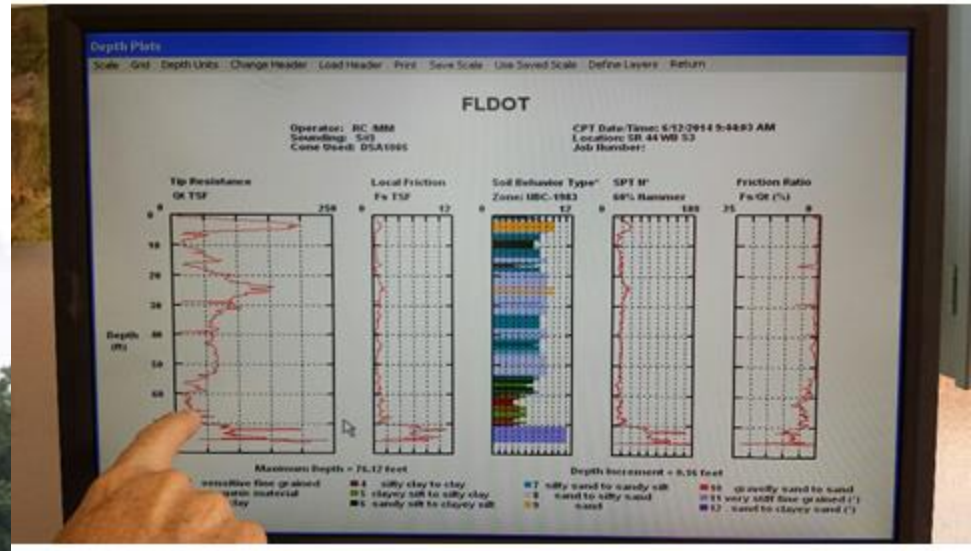
- Recharge rate
- Head difference
- Soil profile and properties
- Thickness of overburden soil
- Raveled zone of soil
- etc.

Affect sinkhole stability

SR 434, Deland, FL

Cone Penetration Test (CPT)
Performed by District 5

CPT data



Lake formed by Sinkhole

SR 434, Deland, FL – Sinkhole Site

Pore water pressure measurement (Piezometer)

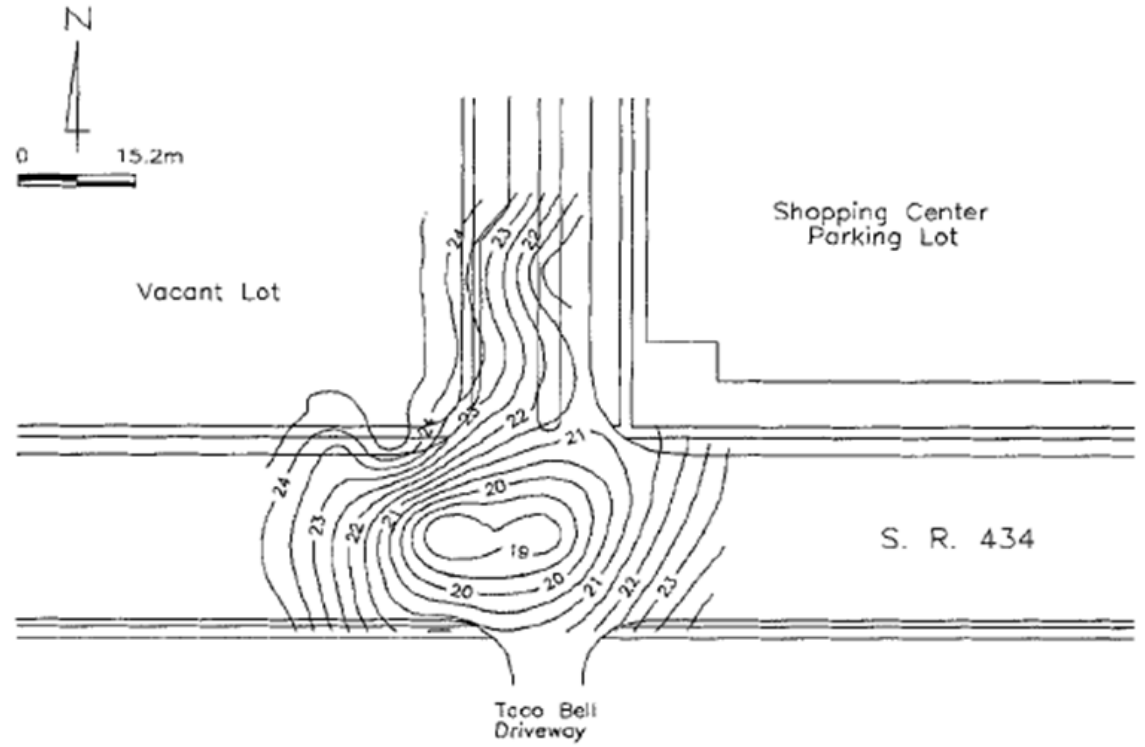
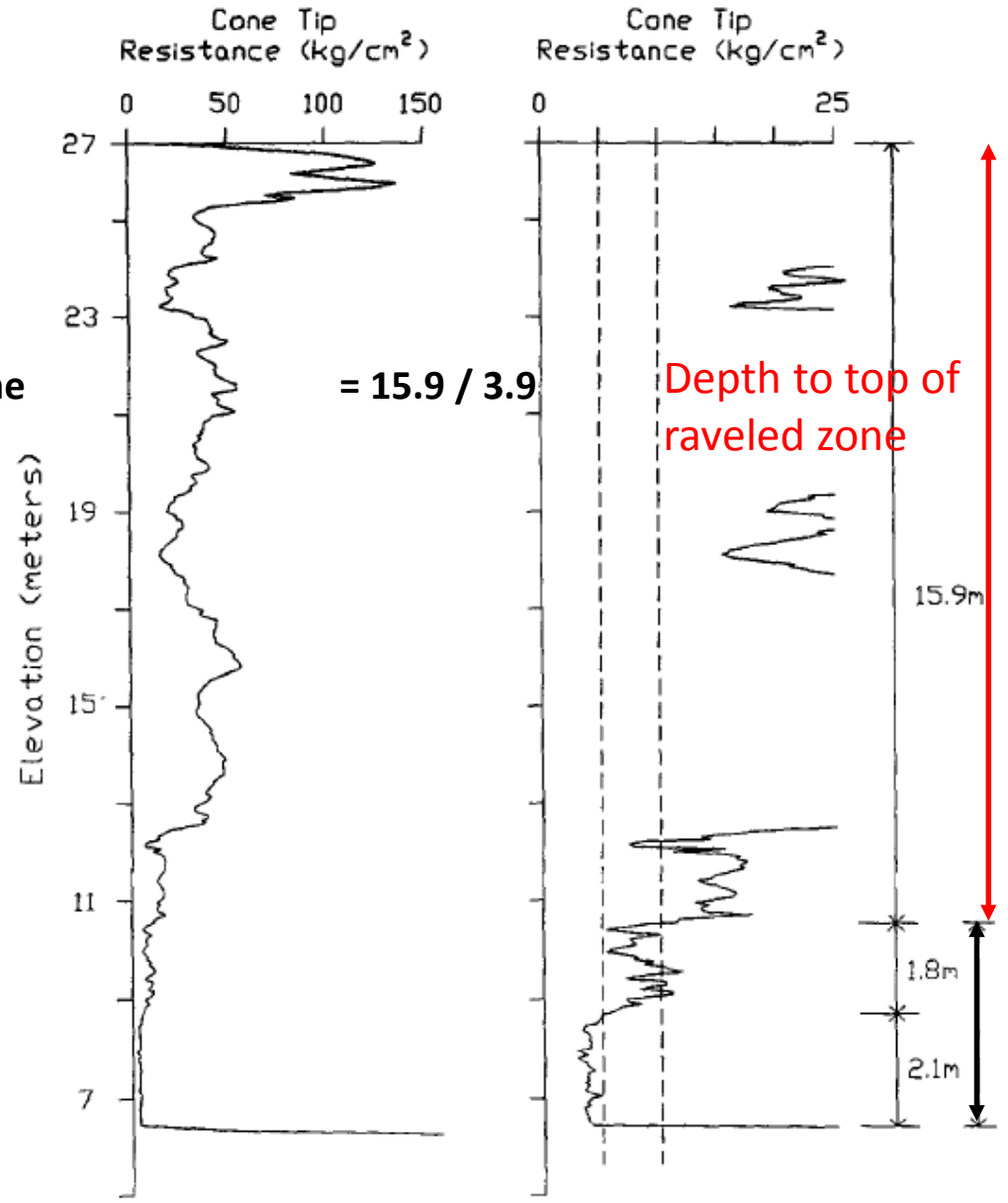


FIG. 15. Piezometric Head Contours based on November 6, 1990 Readings

Raveling Index

Raveling Index (RI) = Thickness of raveled zone / Depth to top of raveled zone

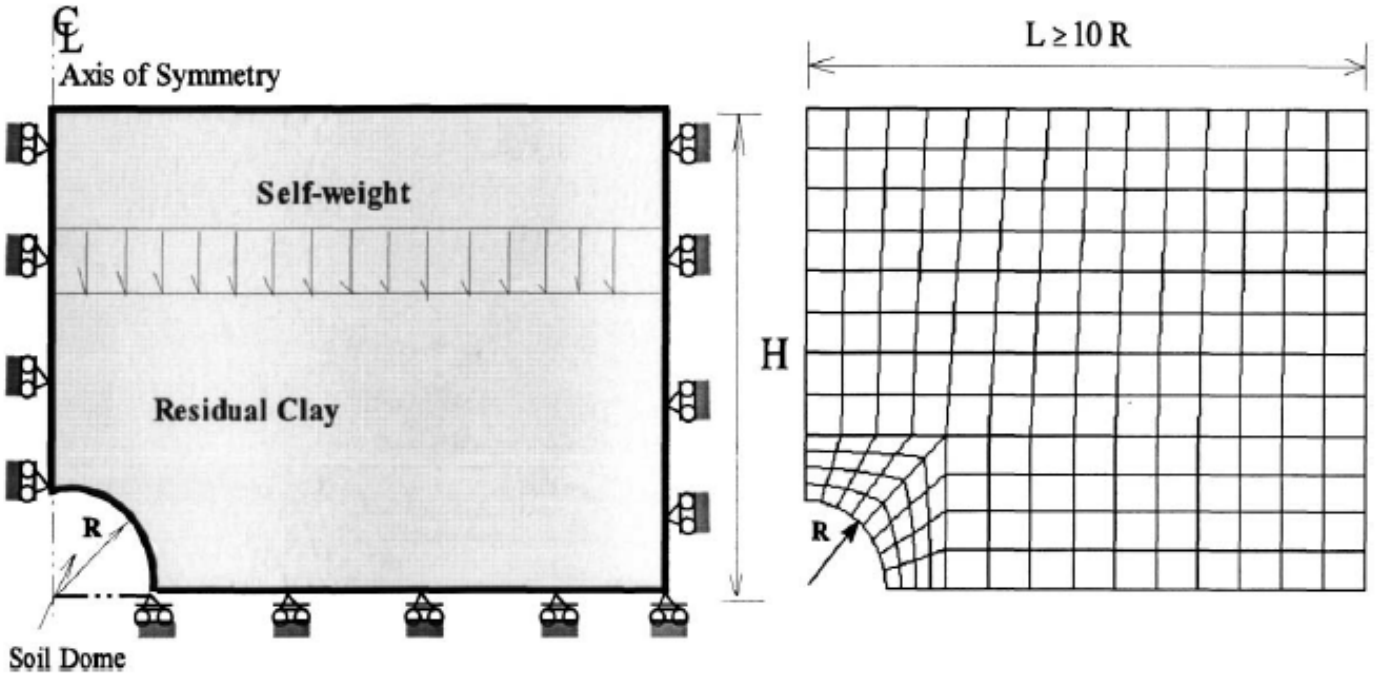
= 15.9 / 3.9



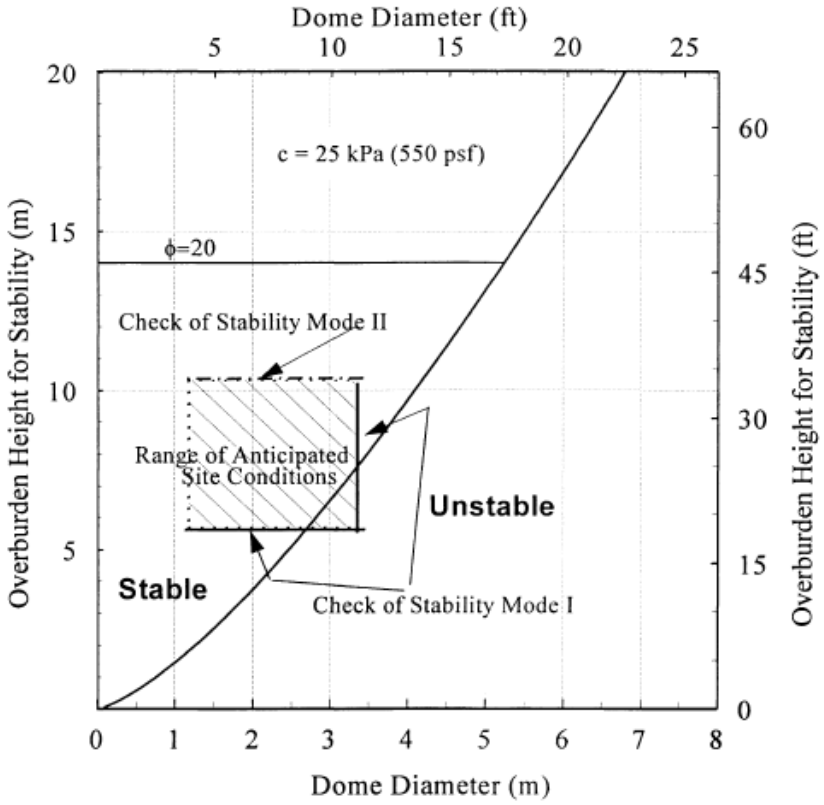
(suggested by K. Gray)

Stability Analysis - Literature review

FEM Modeling

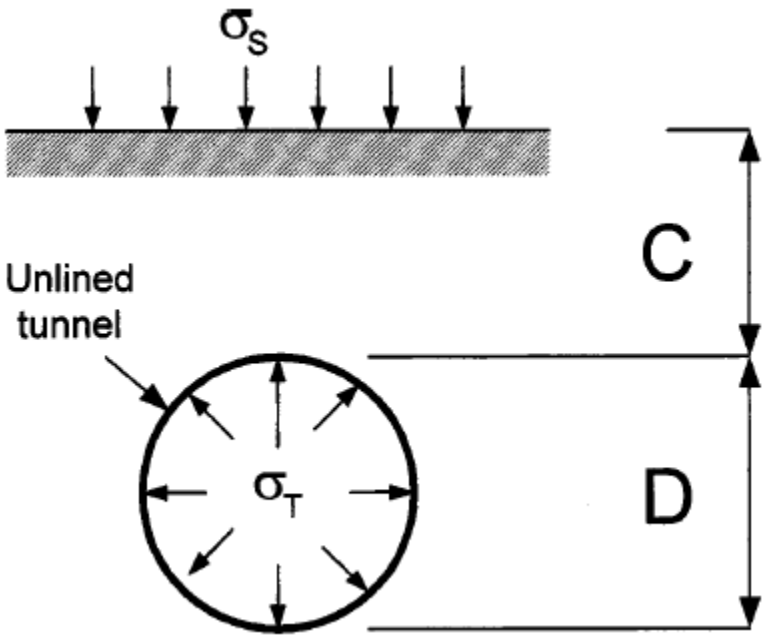


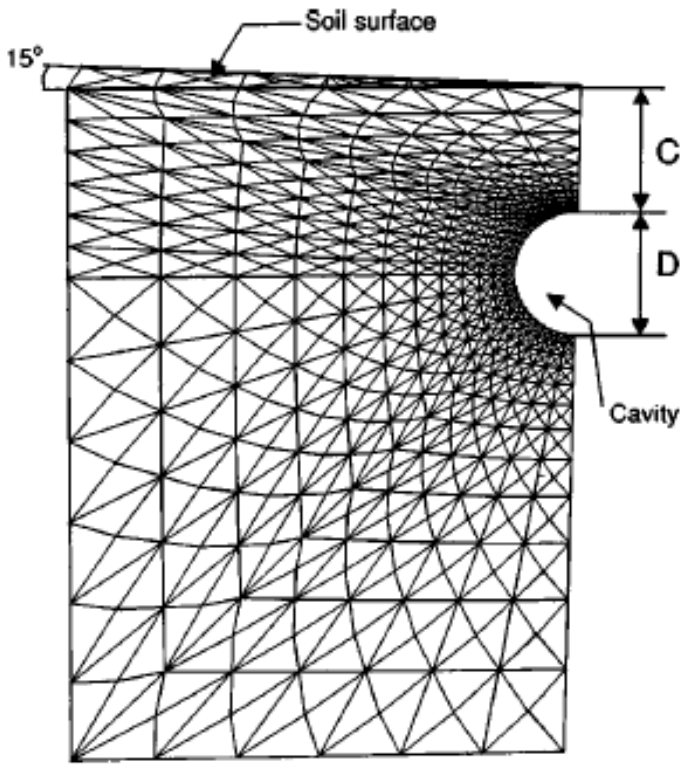
Stability Chart

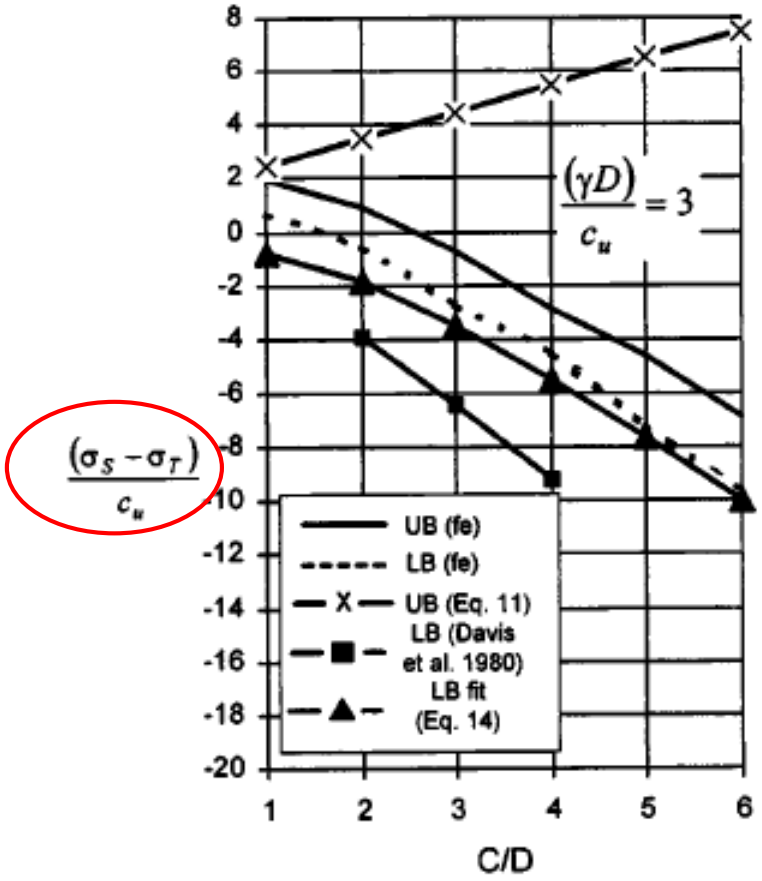


Yang and Drumm 2002_Eng. Geology 2002

Stability Analysis - Literature review

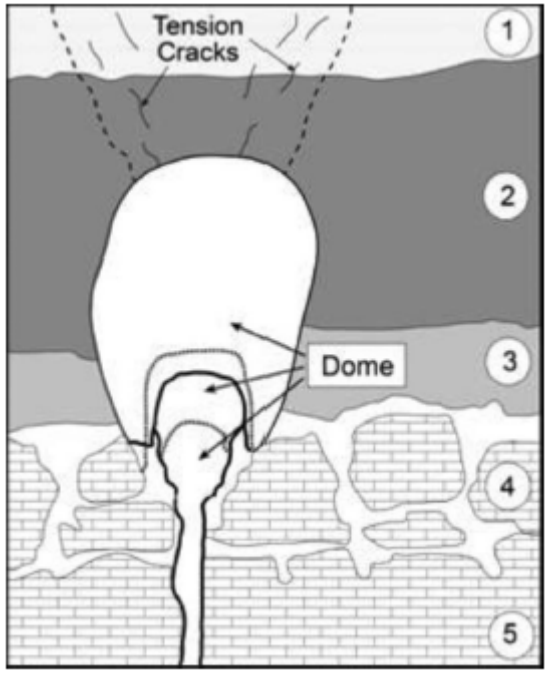






Drumm et al. 2009_ASCE JGGE

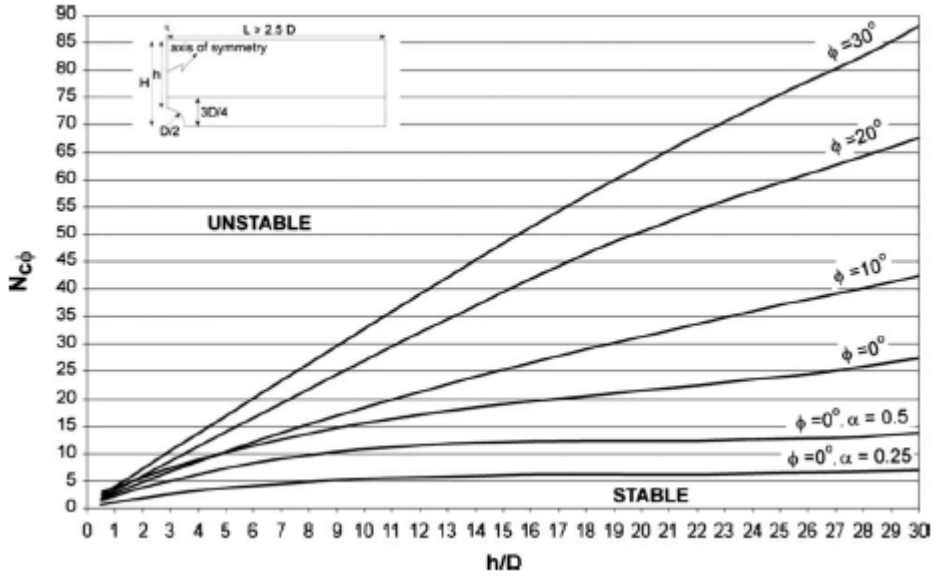
Stability Analysis - Literature review



Stability Ratio, N

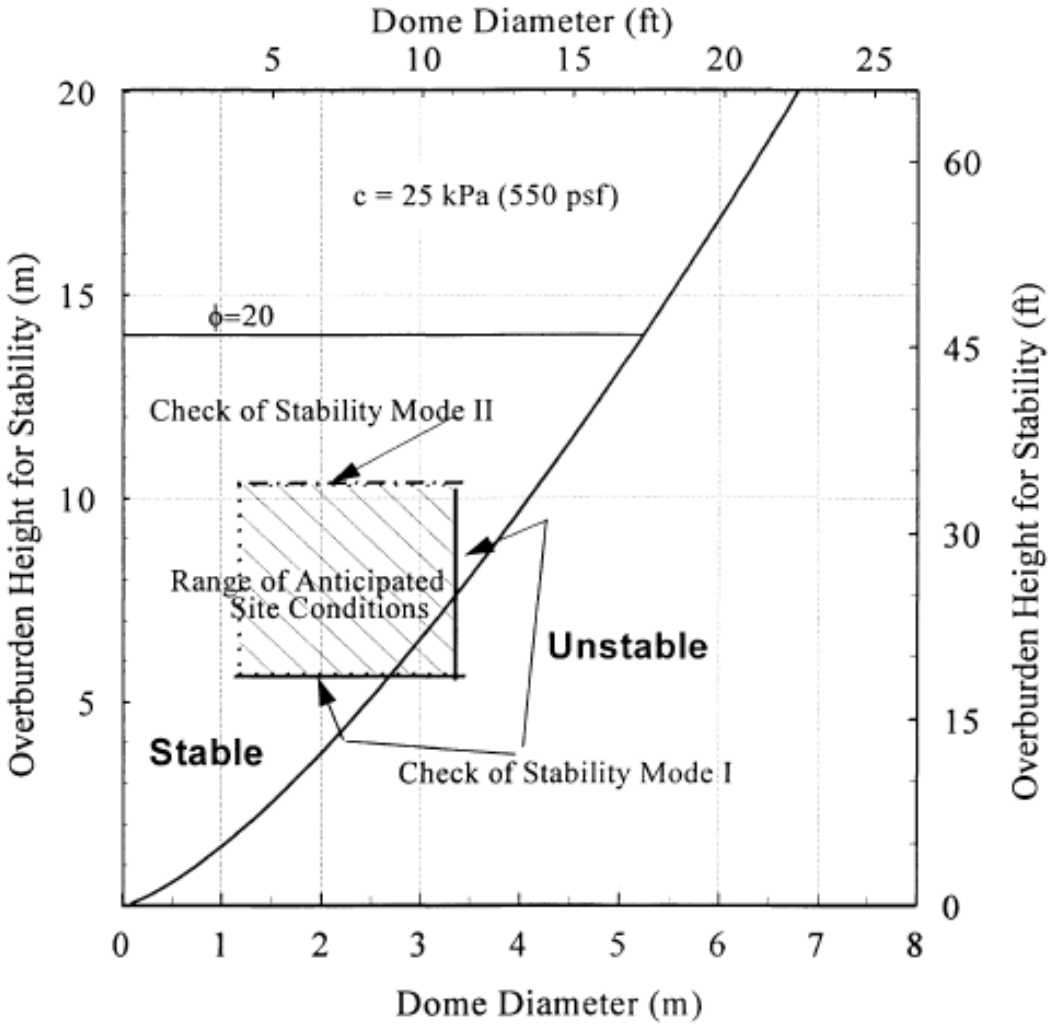
$$N = \left[\frac{\sigma_S - \sigma_T + \gamma(h + D/2)}{c_u} \right] \quad (1)$$

where σ_T=internal cavity or tunnel pressure; σ_S=surface surcharge; h=soil thickness above the cavity; D=diameter of circular openings; γ=unit weight of the clay soil; and c_u=undrained shear strength.



Drumm et al. 2009_ASCE JGGE

Potential Research Topics?



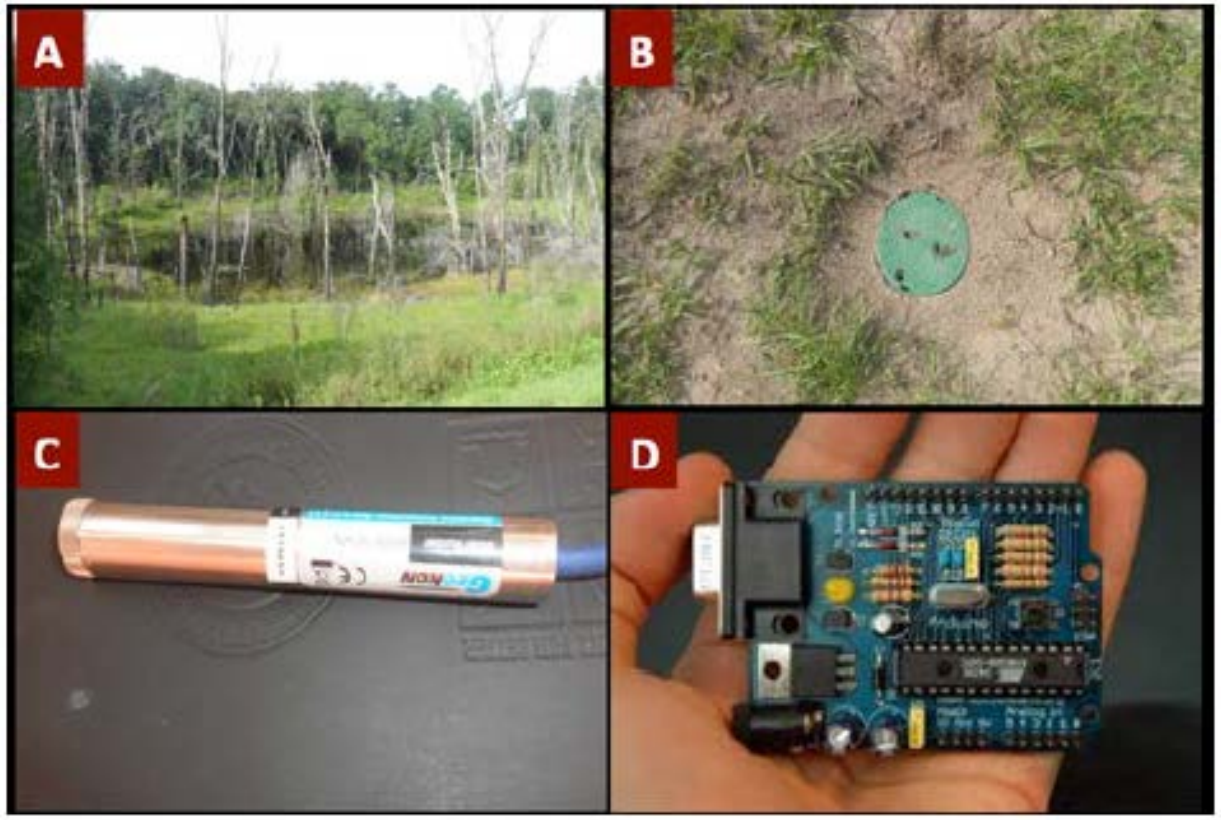
1. Site-based stability analysis by using field (or lab) tests
2. Stability analysis under varied groundwater recharge conditions
3. Correlation between Raveling Index vs. Stability chart

Work Plan

- Task 1 - In-situ groundwater monitoring system
- Task 2 - High-resolution recharge map (model development)
- Task 3 – Improved identification method for detecting raveled soil zone (by using CPT)
- Task 4 – Development of sinkhole stability analysis model and Stability chart
- Task 5 – Guideline of sinkhole evaluation procedure

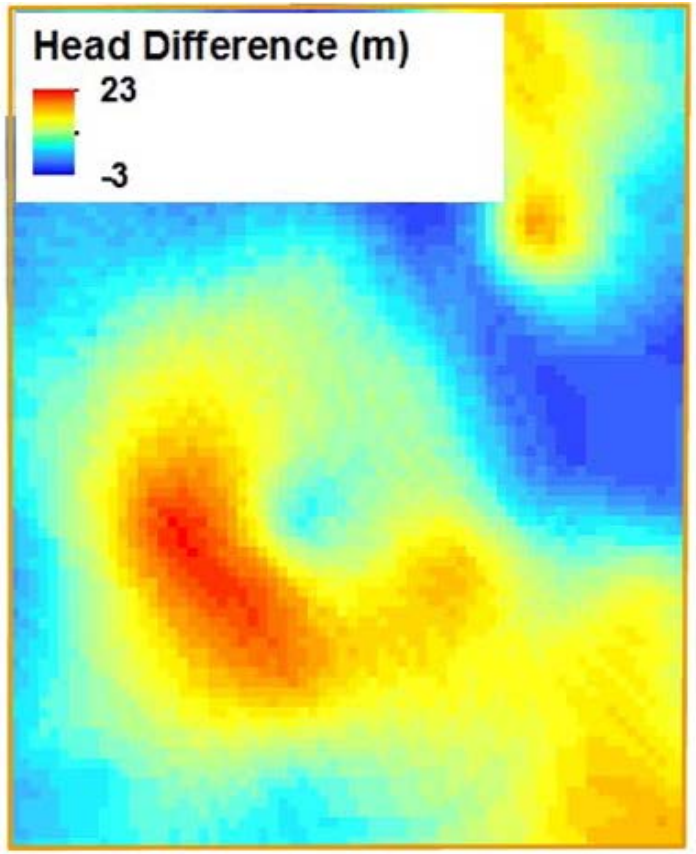
Task 1 – In-situ monitoring

- Piezometer sensor at multiple locations
- Long-term monitoring of GWT
- Develop the algorithm of data processing (e.g. event-based analysis)

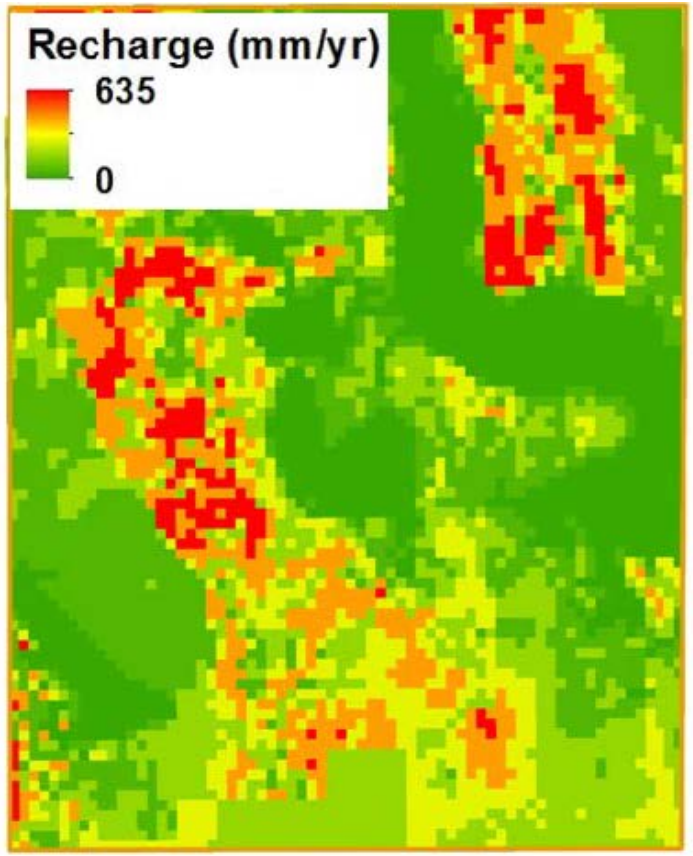


Task 2 – High-resolution recharge map

- Development of groundwater model (by using MODFLOW)
- Development of high-resolution recharge map for the study sites



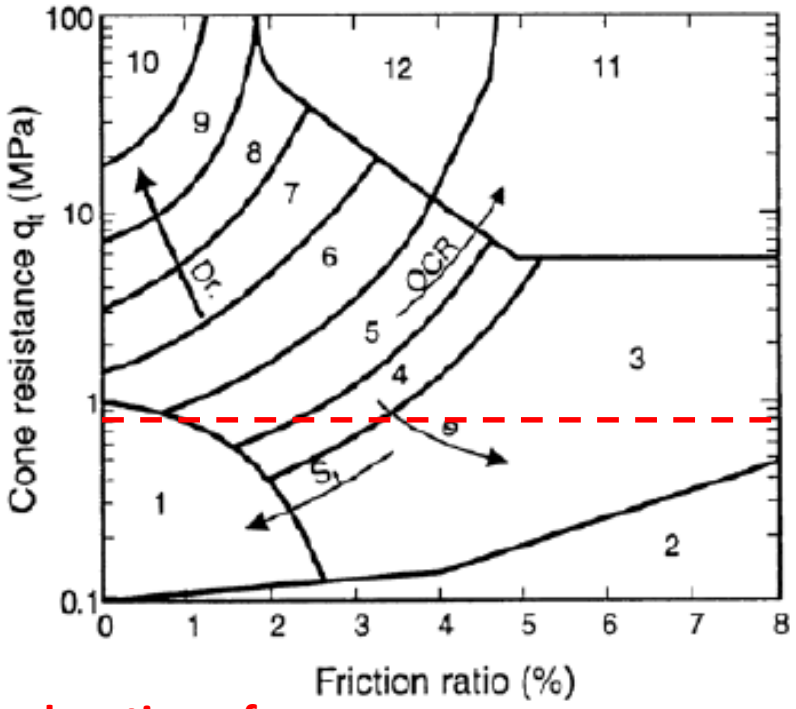
Head difference between surficial and upper Floridan aquifer



Estimated recharge at the spatial resolution of 30 m by 30 m (for the grid size)

Task 3 – Improve the RI Index

- RI = Thickness of raveled zone/depth to raveled zone
- The RI is empirical and solely based on tip resistance of CPT. Tip resistance readings less than 10 kg/cm^2 (10 tsf) are typical conditions of raveled zone.



Zone	Soil Behavior Type
1	Sensitive fine grained
2	Organic material
3	Clay
4	Silty Clay to clay
5	Clayey silt to silty clay
6	Sandy silt to clayey silt
7	Silty sand to sandy silt
8	Sand to silty sand
9	Sand
10	Gravelly sand to sand
11	Very stiff fine grained*
12	Sand to clayey sand*

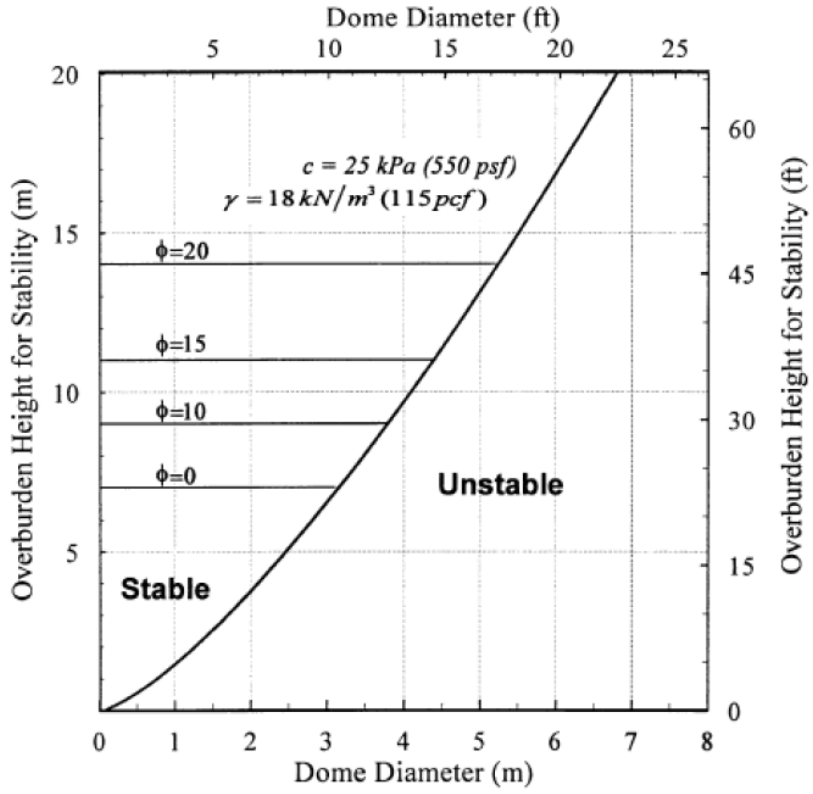
* Overconsolidated or cemented

(Robertson et al. 1990)

Where is the location of raveled zone?

Task 4 – Sinkhole Stability Analysis Model and Stability Chart

- Development of sinkhole stability analysis model
  - coupled seepage and stress analysis
- Sinkhole stability chart
  - Accounting for varied hydrogeological and soil conditions



Task 5 – Develop the guideline for sinkhole risk evaluation

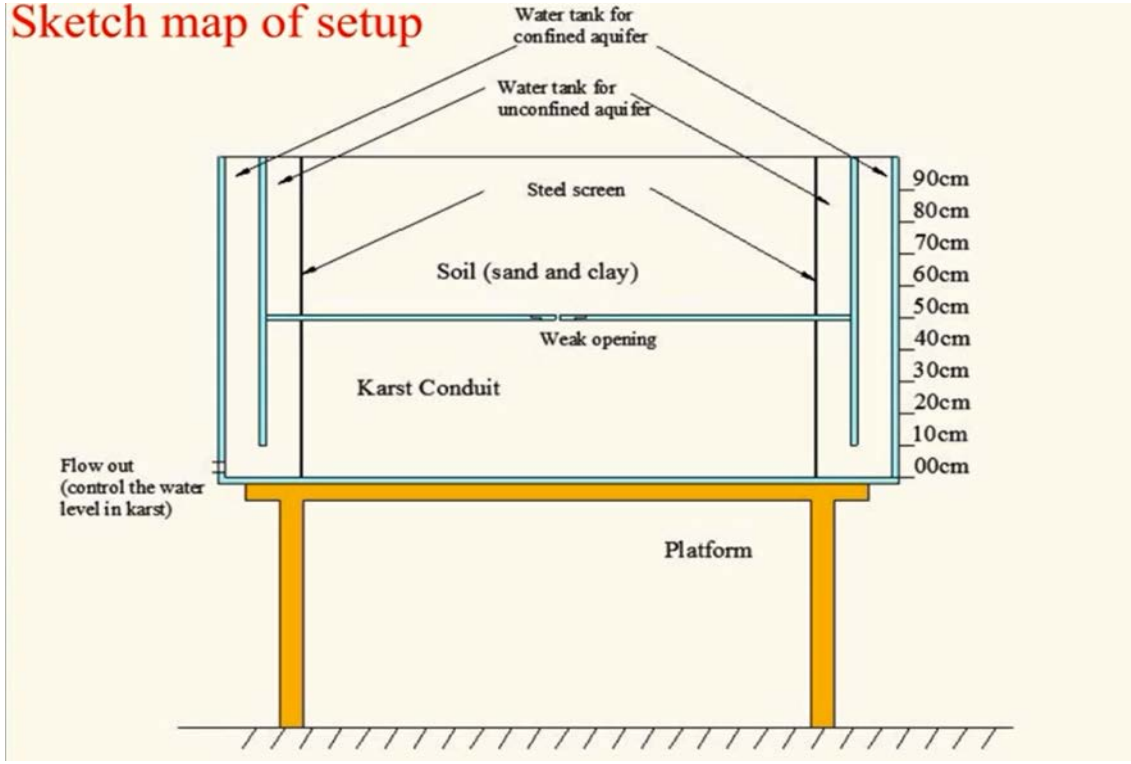
- Guidelines (or manuals) regarding the details of:
  1) Installation and monitoring methods for in-situ GWT sensors
  2) Identify the raveled soil zone based on CPT or SPT
  3) Use of FEM-based sinkhole stability analysis

Thank you!

Questions ?

Development of Sinkhole Vulnerability Index

- Research methodology
  - Physical model test
  - Numerical simulation
  - Field subsurface exploration



- Sinkhole Vulnerability Index (SVI)
  - SVI = f (raveled zone, soil properties, overburden thickness, recharge, etc.)