GRIP 2022
Project: Validation and Update of the Sinkhole Index (BDV24 TWO 977-41)

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Outline

- Brief Project Overview
  - Benefits
  - Objectives
  - Scope
- Technical Background
- Data Collection
- Data Analysis
- Timeline

Project Benefits

- *Qualitative*
  - The updated index and chart that quantitatively characterize the raveling condition and depth characteristics will enable more accurate and effective sinkhole assessment, thus geotechnical engineers can make better decision in emergency response (e.g., lane closure), repair/mitigation plan, etc.
- *Quantitative*
  - The updated index and chart will help engineers perform more effective sinkhole assessment; thus, save time and reduce repair cost (e.g., optimum repair/mitigation scheme). The correlation between the index and grout-take volume can provide quantitative information of grout cost, amount, etc.

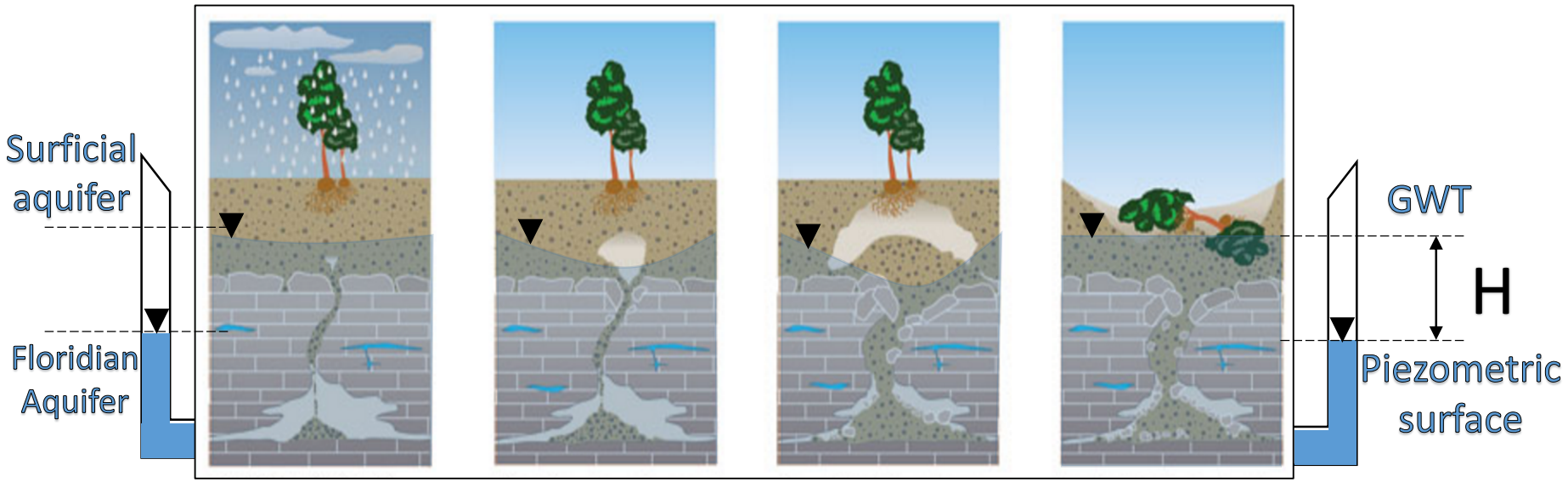
Project Objectives

1) **Validate** and **Update** the sinkhole index and chart by both large-scale sinkhole simulation test and the updated dataset containing other geological formations and geotechnical conditions,
2) **Develop** a set of **criteria** and **guidance** for the sinkhole index and vulnerability assessment,
3) **Evaluate** the raveling progression and the correlation between the sinkhole index and grout-take volume.

Project Scope

- Task 1 – Data Collection and Case Studies
- Task 2 – Validation and update of the sinkhole index and chart
- Task 3 – Set-up of the Large-Scale Soil Box (LSSB)
- Task 4 – Sinkhole physical test using the LSSB
- Task 5 – Establish the severity criteria of the sinkhole index and correlate the index to the grout-take volume
- Task 6 – Draft Report and Closeout Teleconference
- Task 7 – Final Report

Florida Sinkholes – Raveling Formation

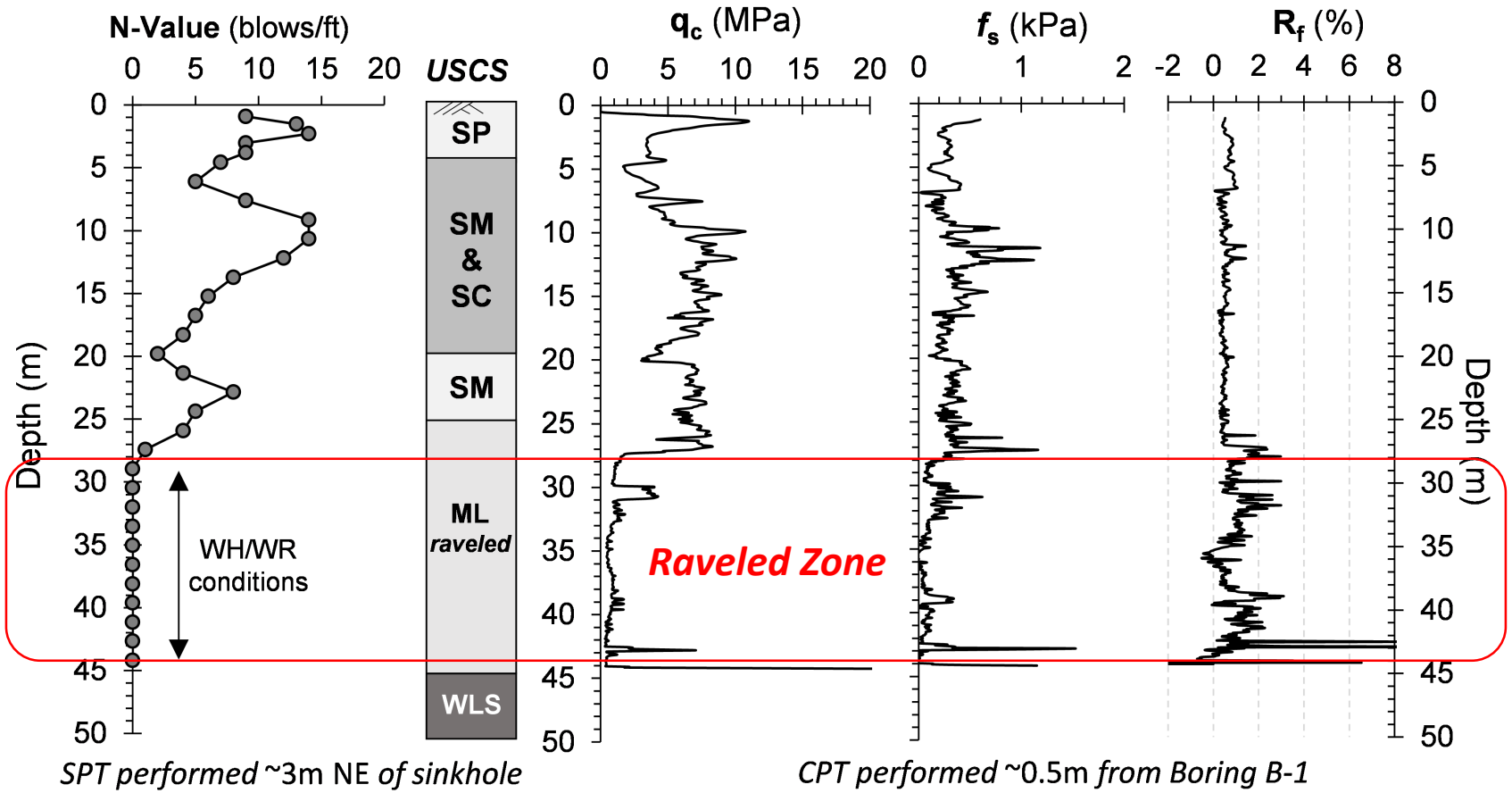


- Product of soluble, porous, carbonate-based bedrock conducive of groundwater flow.
- Migration of soil sediment into rock cavities as downward infiltration (recharge) of groundwater occurs.
- Depending on residual soil type, “void” formation (raveling) and expansion in overburden may occur.
- Collapse of soil into raveled material, creating a sinkhole

CPT and SPT

CPT

SPT



Cone penetration test (**CPT**): **0.16 ft** [60ft ~ **> 1 hr**]

Standard penetration test (**SPT**): **2.5 ft** [60ft ~ **half day**]

Important for ground verification

Sinkhole Index

Sinkhole Resistance Ratio (SRR)

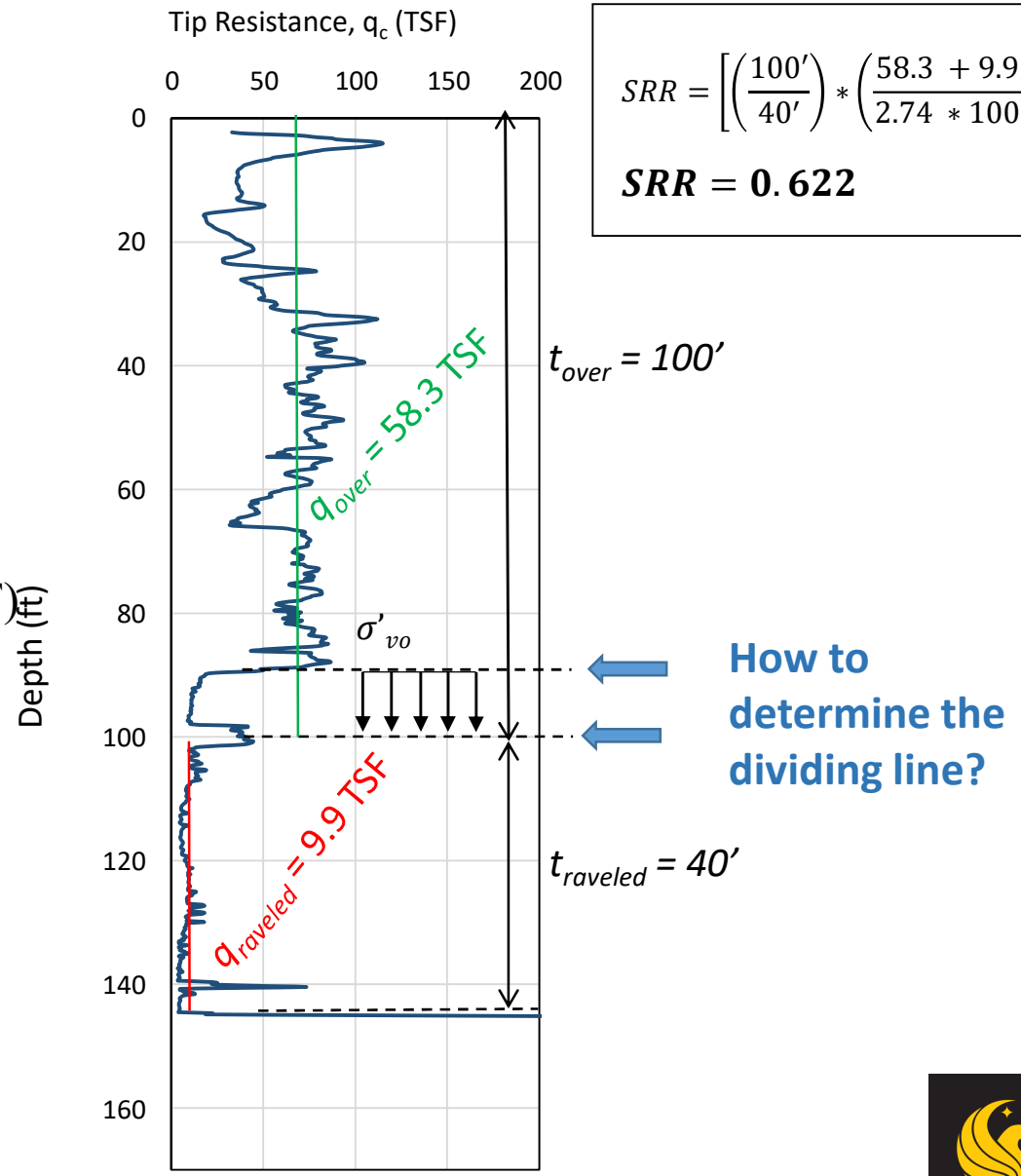
$$\text{SRR} = \left(\frac{q_{over} + q_{ravel}}{100 * \sigma'_{vo}}\right)\left(\frac{t_{over}}{t_{ravel}}\right)$$

Where:

q_{over} = average q_t measured in overburden soils (TSF)
q_{ravel} = average q_t measured in Raveled soils (TSF)
σ'_{vo} = effective vertical stress at depth raveled soils start (TSF)
t_{over} = thickness of overburden (ft)
t_{ravel} = thickness of raveled zone (ft)
q_t = Corrected cone tip resistance (corrected for p.w.p)

Needs estimates of:

- Vertical stress calculated using estimated unit weight: (Robertson and Cabal 2010)
- GWT → effective stress



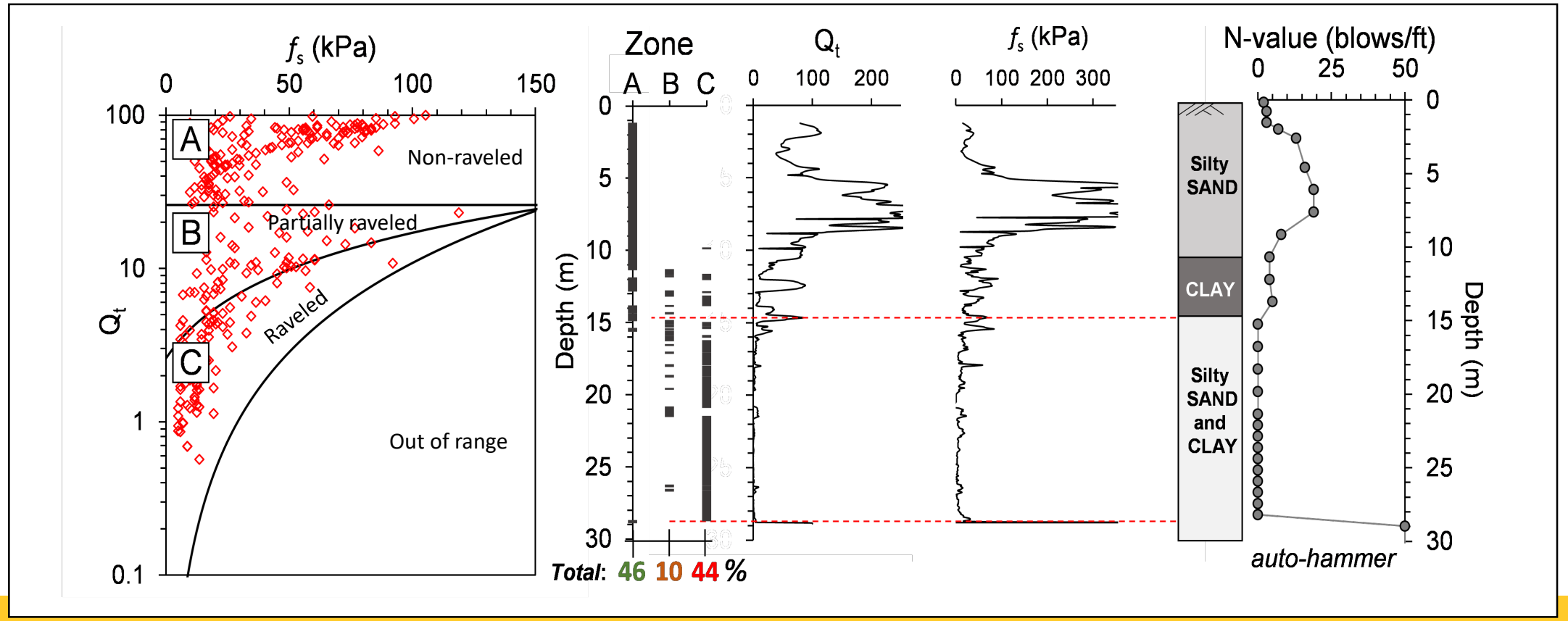
$$SRR = \left[\left(\frac{100'}{40'}\right) * \left(\frac{58.3 + 9.9}{2.74 * 100}\right)\right]$$

$$\boldsymbol{SRR = 0.622}$$

CPT-based Raveling Chart

Application

- Identify soils which exhibits raveling behavior.
- Identify the depths of raveled zone → profile of zones → much like Soil Behavior Type (SBT) charts

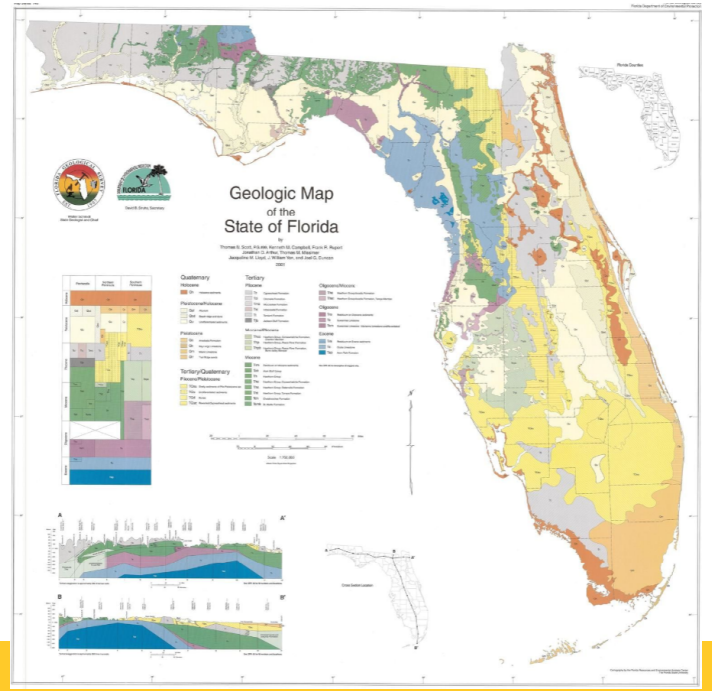


Project Background

- The sinkhole index (SRR) and raveling chart were developed from the previous project, entitled “Development of a Sinkhole Risk Evaluation Program”.
- However, the index and chart were developed based on the limited number of datasets involving four sites with only Cypresshead geological formation. Thus, both index and chart need to be validated and updated with sufficient number of datasets collected throughout the state of Florida, particularly with different geological formations (e.g. Ocala LS/Hawthorn formation) and geotechnical conditions.
- In addition, the criterion to determine the dividing line of raveled and overburden zone is unclear and subjective.

Task 1: Data Collection Summary

- **49** sites (47 contained the desired CPT data)
- **237** total CPTs
  - Number of CPTs per site varied from 1 to 13
- **36** sites contained information on CPT location relative to the sinkhole.
- Surficial Geology Unit determined from USGS Geological Map



Geologic map of Florida (Thomas Scott 2001)

District	Site Info/File Name	SPT Data	Grout Information
1	I-4 Rest Area Polk County 2011	Yes	Yes
	Recker Highway 2005	No	No
	US 27 Polk County 2010 North	Yes	Yes
	US 27 Polk County 2010 South	Yes	Yes
	US 92 Memorial Cracked CP 2012	No	No
2	I-10 Columbia County 2007	No	No
	I-75 Northbound Depression Alachua 2005	Yes	Yes
	I-75 Southbound Depression Alachua 2005	No	Yes
	SR 55 Taylor County 2021	Yes	No
	US 27 Perry 2021	Yes	No
	US 441 Micanopy Depression 2012	No	No
	US 441 Micanopy Depression 2015	No	No
3	FDOT Ponce Operations Facility 2006	No	No
	SR 319 Leon County 2004	No	No
	SR 77 Roadway Depression 2020	Yes	Yes
5	Deland 15A North 2016	No	No
	Deland 15A South 2016	No	No
	Deltona Howland 2004	No	No
	I-4 CR 46 Depression 2002	Yes	No
	I-4 Lake Mary Blvd Depression 2002	No	No
	I-4 Maitland Blvd Depression 2004	Yes	No
	I-4 Rest Area Seminole County 2003	No	No
	I-4 Seminole County Irma 2017	No	No
	Rose Down Blvd Debary 2018	No	Yes
	Silver Star Road 1990	No	No
	SR 35 Silver Springs Marion County Irma 2017	No	Yes
	SR 400 Lake Mary Depression 1996	No	No
	SR 434 EB Depression 2012	No	No
	SR 44 Depression 2014	Yes	No
	SR 50 Groveland 2020	No	Yes
	SR 500 Lady Lake Irma 2017	No	Yes
	SR 535 Meadow Creek 2006	Yes	No
	US 17 Ponce Deleon Springs 2005	No	No
	US 17-92 Debary VFW 2005	No	Yes
	US 27 Lake County 2008	No	No
	US 27 Ocala 2004	No	No
	US 27 Villages Sinkhole 2015	No	No
	US 301 Depression 1 Oxford 2015	No	No
	US 301 Depression 2 Oxford 2015	No	No
	US 301 Depression 3 Oxford 2015	No	No
	US 301 Depression 4 Oxford 2015	No	No
	US 441 North Ocala 2005	No	No
	US 441 Reddick Marion County Irma 2017	No	Yes
7	I-275 Green St. 2020	Yes	Yes
	PSI Pasco County Land O' Lakes 2018	Yes	No
	SR 33 USF 2012	No	No
	US 19 Sealawn 2011	Yes	No
Turnpike	Mile Post 299 Pavement Settlement 2020	Yes	Yes
	Western Beltway Sinkhole 2010	Yes	Yes

Project Site Map

- Deland 15A North 2016
- Deland 15A South 2016
- Deltona Howland 2004
- FDOT Ponce Operations Facility 2006
- I-10 Columbia County 2007
- I-275 Green St. 2020
- I-4 CR 46 Depression 2002
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- SR 44 Depression 2014
- SR 50 Groveland 2020
- SR 500 Lady Lake Irma 2017
- SR 535 Meadow Creek 2006
- SR 55 Taylor County 2021
- SR 77 Roadway Depression 2020
- Silver Star Road 1990
- US 17 Ponce Deleon Springs 2005
- US 17-92 Debary VFW 2005
- US 19 Sealawn 2011
- US 27 Lake County 2008
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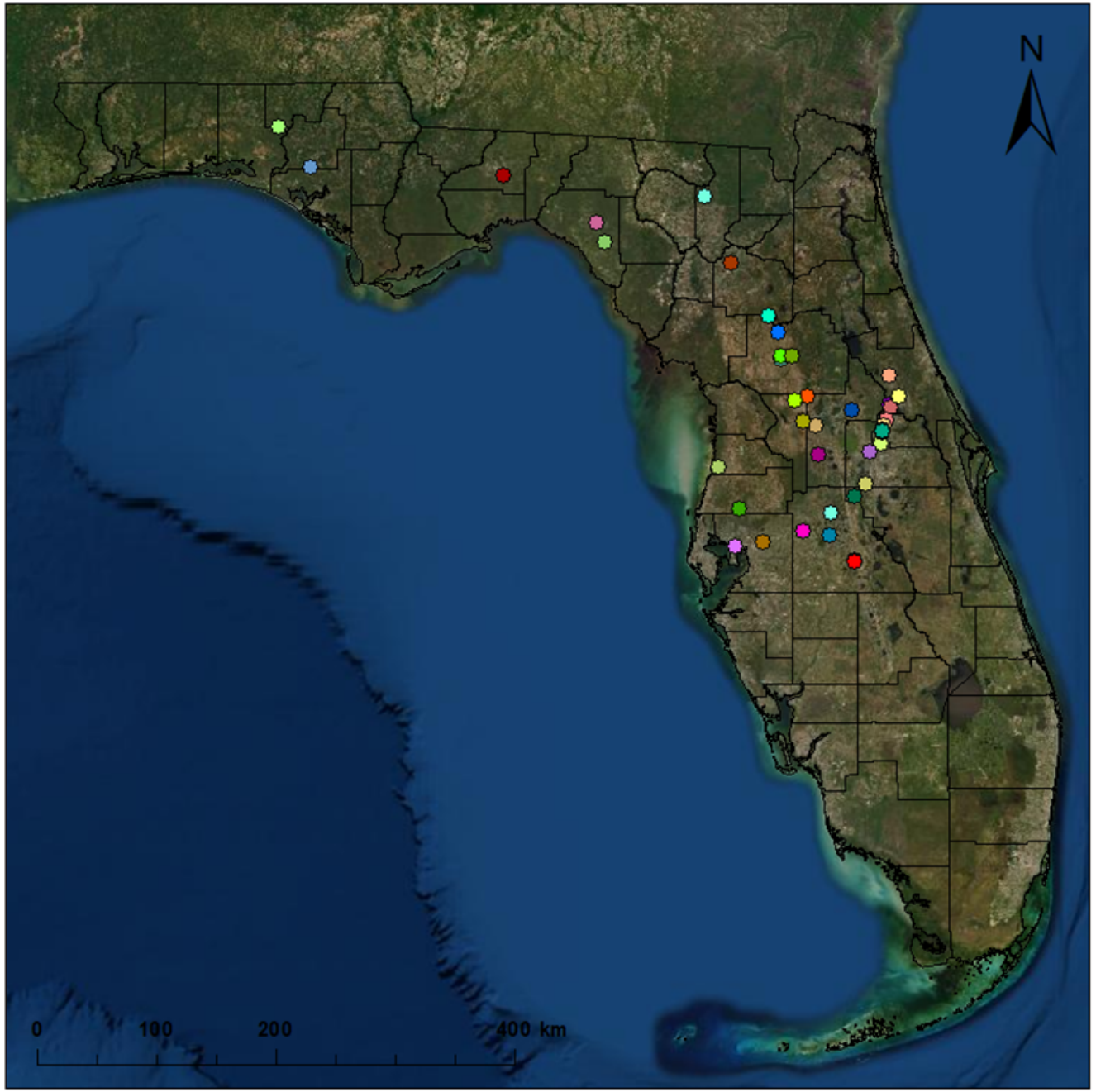
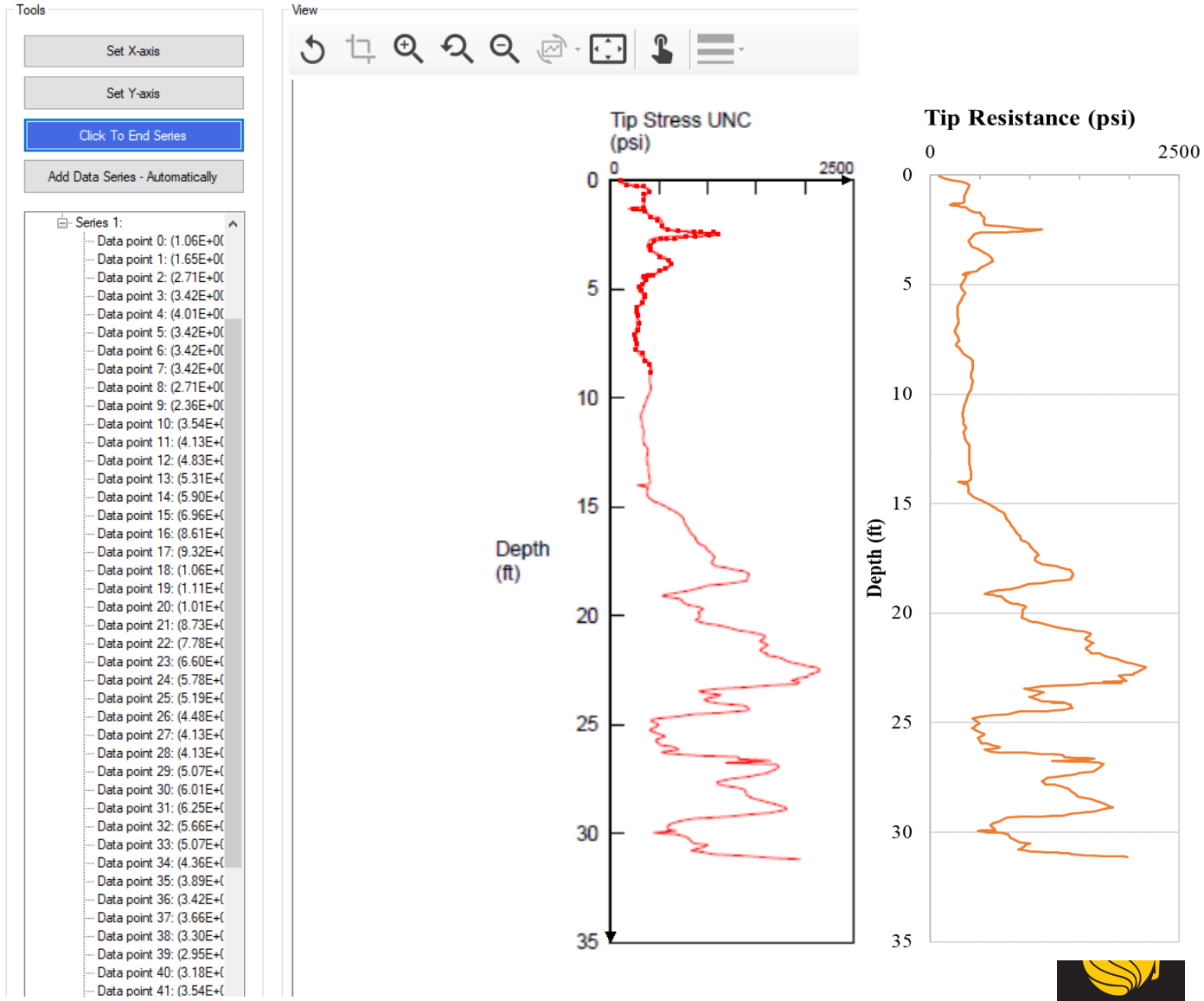


Task 1: Data Collection & Digitization

- In cases where the data was not digitized (either a picture or PDF of graphic information), the data was digitized.
- *Graph Grabber* program was used to digitize all CPT data including tip resistance (q_c), sleeve friction (f_s) and pore waster pressure when available.
  - CPT profile was imported into the software and the cursor was moved along the line and manually clicked to obtain data points.
- To aligning the tip resistance, sleeve friction and pore pressure values with depth an interpolation program was written to allow for consistent readings of each parameter per depth for each CPT data set.
- The digitized data was then compared with the PDF graphic to determine accuracy.



https://www.quintessa.org/software/downloads-and-demos/graph-grabber-2.0.2

Task 1: Data Collection Summary Cont.

- 29 sites with SPT data
- 14 sites with Grouting Information
  - 12 contain CPT data
  - Lower number of grouting information most likely due to various methods of mitigation or dealing with sinkholes.
  - Not all sinkhole locations required mitigation but were instead abandon and left in place such as the PSI Pasco County Land O'Lakes 2018 sinkhole.
- Grouting information will be used to determine a correlation between the determined SRR from the CPT data and the grout intake (Task 5)

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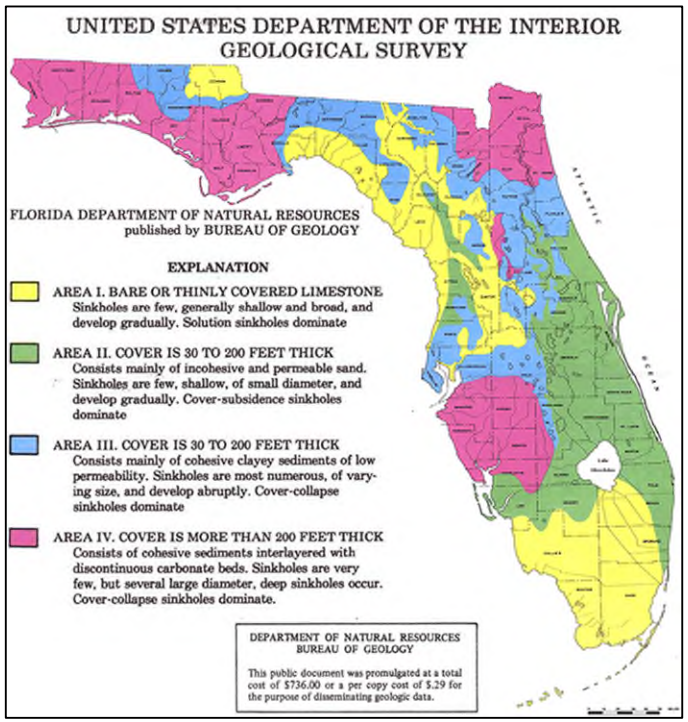
	PSI Pasco County Land O' Lakes 2018	Yes	No
	SR 33 USF 2012	No	No
	US 19 Sealawn 2011	Yes	No
Turnpike	Mile Post 299 Pavement Settlement 2020	Yes	Yes
	Western Beltway Sinkhole 2010	Yes	Yes

Task 1: Data Collection Summary Cont.

- Using the reports and other miscellaneous information additional sinkhole characteristics were identified including size, type, and surficial geological unit.
- Sinkhole size ranged from approximately 12.6 ft^2 to 16,000 ft^2
- The type of sinkhole was determined for each site based on the Florida Geological Survey (FGS) sinkhole map:
  - Type 1 – 11
  - Type 2 – 6
  - Type 3 – 31
  - Type 4 – 1
- Note: This database will continue to grow as more sinkhole sites developed across the state.



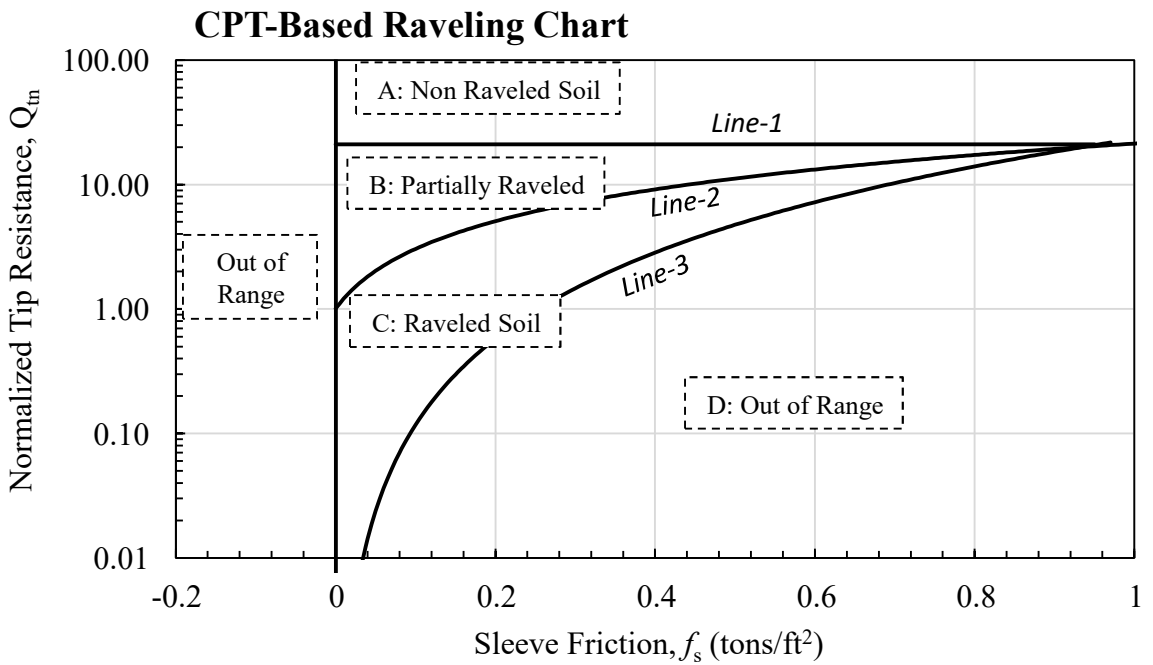
Sinkhole type map (DNR 1985)

Task 2: Validation and update of the sinkhole index and chart

- To update the raveling chart via the newly updated datasets. The chart is used not only (a) to help determine the dividing line from the raveled (t_{ravel}) to the non-raveled zone (t_{over}) but also (b) to provide the raveling severity characteristics along depth.
- To develop the criteria and a standard procedure to determine the dividing line between raveled (t_{ravel}) and non-raveled overburden (t_{over}) zone.
- To validate and evaluate the performance of the SRR through the new datasets. If needed, the PIs will modify the index (e.g., adjustment factor).

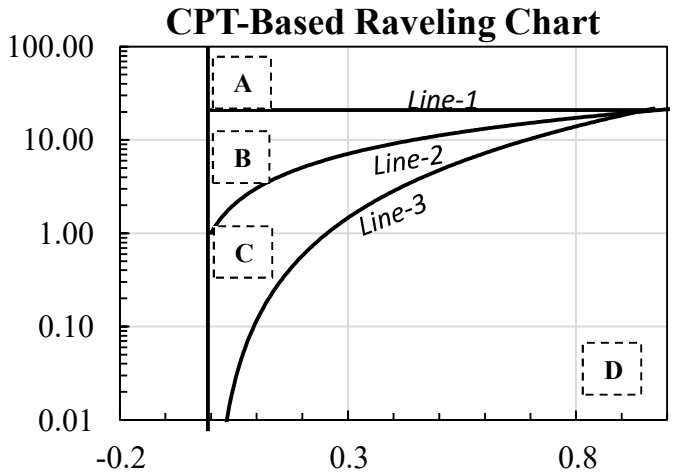
Raveling Chart

- A helpful tool to identify potentially raveled soil from the Q_{tn} and f_s values obtained from the CPT.
- Practitioners can quickly plot the CPT parameters along this chart to estimate the likelihood of sinkhole forming raveling soils, during the site investigation.
- The zones making up the CPT-raveling chart are labeled A through D, with zones B and C pertaining to the raveled soils, A associated with non-raveled soil, and D being the lower range of data, demarcating the raveled soil.
- Previous Limitations:
  - Validation of chart with varying subsurface geology and anticipated sinkhole type
  - Normalized tip resistance (Q_{tn}) as part of input value for chart



CPT Location

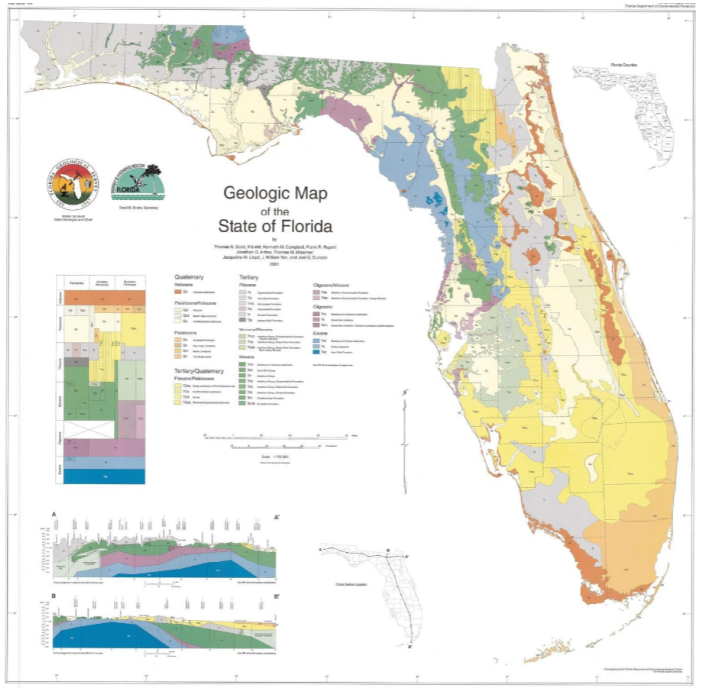
- Used sub-set of 118 CPTs (Inside – 23 CPTs, Edge – 36 CPTs, Outside – 33 CPTs, & Unknown – 26 CPTs)
- Calculated SRR for each CPT
- The CPTs were then evaluated on a point by point basis along the depth in reference to the raveling chart:
  - CPTs located inside and edge of sinkhole have more easily definable raveled zones. Those outside tend to not follow the trends seen inside.
  - Inside CPTs had the highest percentage of points, 43%, within the raveling zone, as expected.
  - Additionally, inside CPTs also had the highest percentage located within the more severely raveled zone C.
  - Edge CPTs have a slight larger overall percentage of raveled points than those outside and a higher percentage within the more severely raveled zone C.
  - Overall, the CPT designations align with our expectations, largest percentage of points within the raveled zone for the inside designation and smallest for the outside.

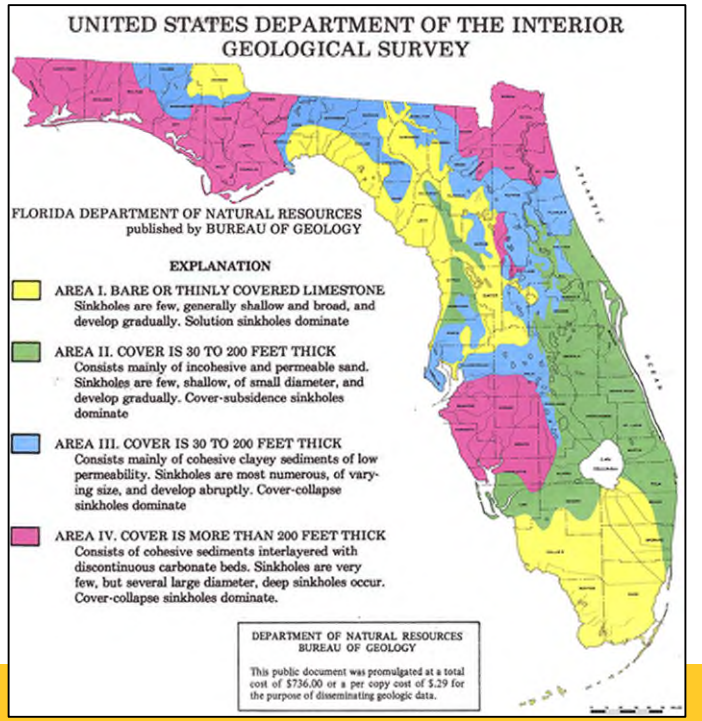


	Zone	Total	Total Percent
INSIDE	A	6446	47%
	B	3200	23%
	C	2671	20%
	D	1319	10%
	Sum	13636	
EDGE	Zone	Total	Total Percent
	A	12276	59%
	B	3506	17%
	C	3001	14%
	D	2151	10%
	Sum	20934	
OUTSIDE	Zone	Total	Total Percent
	A	11698	62%
	B	3697	20%
	C	1878	10%
	D	1644	9%
	Sum	18917	

Sub Categorization of CPTs

- Reviewed both USGS Geology Map and FGS Sinkhole Ma
- Found that the FGS Sinkhole Map provides the best method for analyzing our raveling chart
  - The different types of sinkholes provide a better insight into the effectiveness of our raveling chart as well as provide insight into the different geologic condition throughout Florida.
  - While the surficial geological unit does help us understand what the surface does in relation to sinkholes we believe that the sinkhole map inherently takes into consideration the soils characteristic based on the type of sinkhole possible to develop.
  - Using this knowledge as well as our designation of CPT location relative to the sinkhole we next determined the overall effectiveness of the raveling chart.



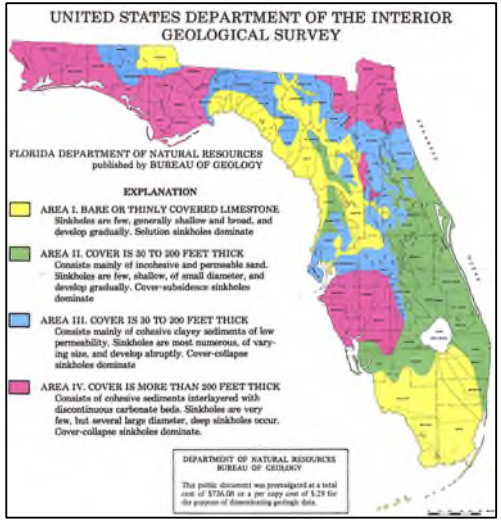


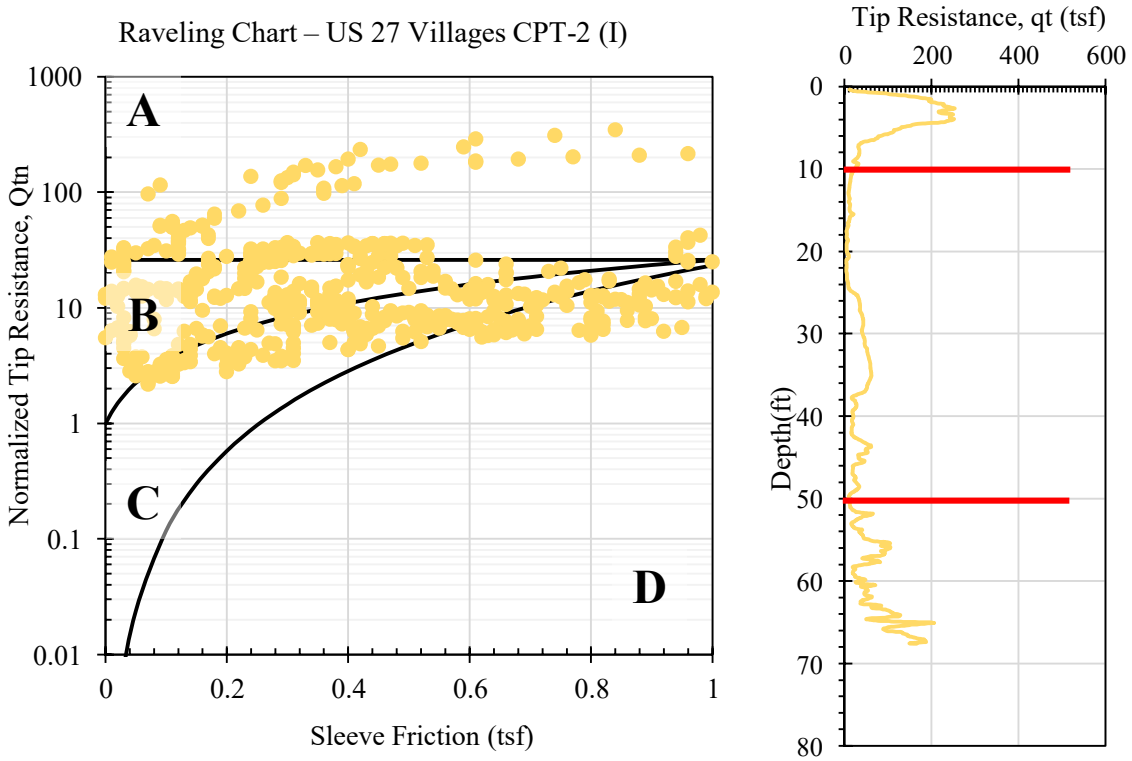
Evaluation of Raveling Chart

- Using the designated zones of the raveling chart (A – Not Raveled, B - Partially Raveled, C- Raveled, D – Out of Range) we determine the statistical chance that the points along the depth of the CPT were located within the correct zone of the raveling chart.
  - Positive – CPT point located in raveled zones, B or C, of the chart and the raveled zone of the CPT profile
  - False Positive – CPT point located in raveled zones, B or C, of the chart but not the raveled zone of the CPT profile.
  - Negative – CPT point located outside raveled zones, B or C, of the chart and the raveled zone of the CPT profile
  - False Negative – CPT point located outside raveled zones, B or C, of the chart and but in the raveled zone of the CPT profile

	CPT Location				Type			
	I	E	O	U	1	2	3	4
Positive	61%	61%	64%	67%	35%	84%	67%	0%
False Positive	39%	39%	36%	33%	65%	16%	33%	100%
Negative	73%	86%	83%	80%	87%	83%	80%	100%
False Negative	27%	14%	17%	20%	13%	17%	20%	0%

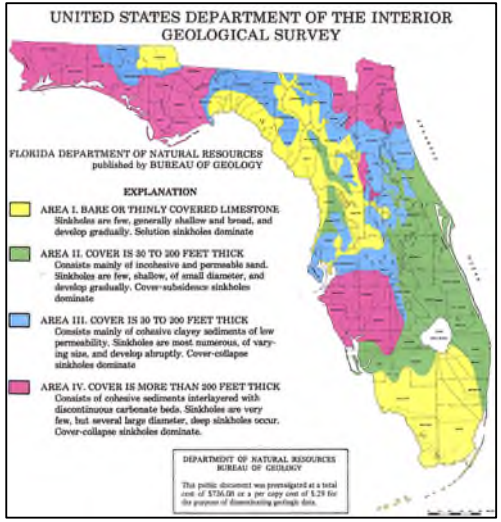
Type 1 – US 27 Villages Sinkhole CPT-2

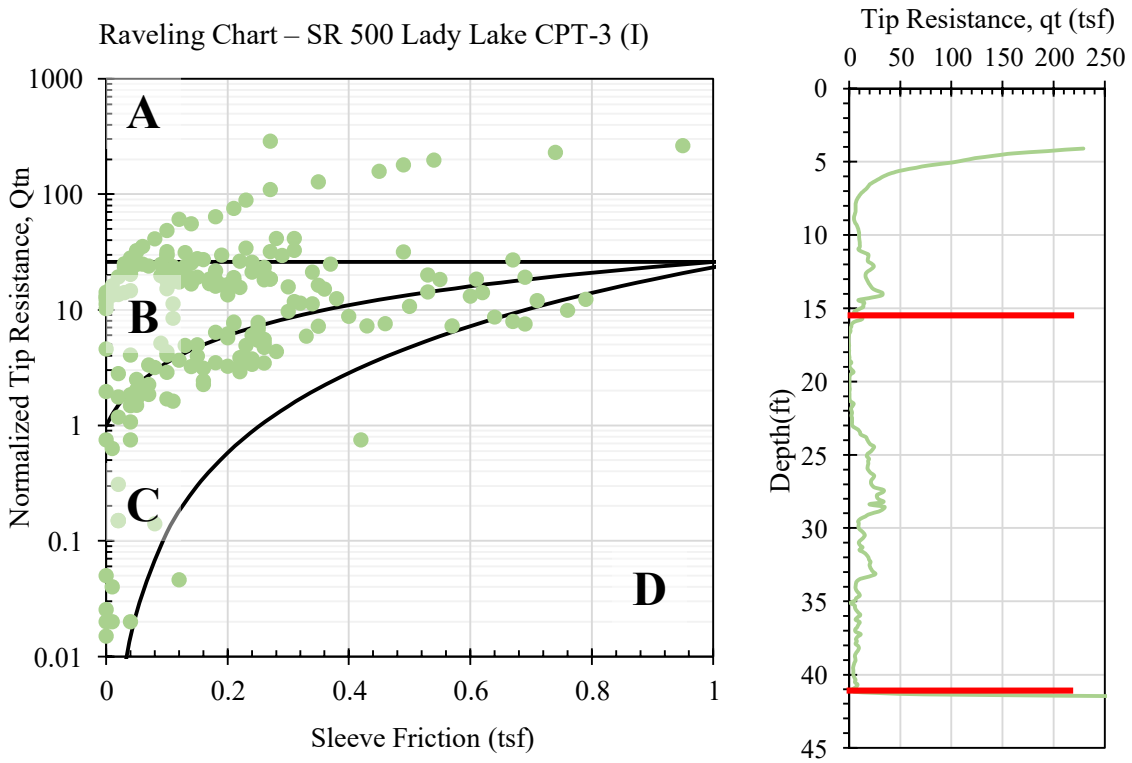




Name (CPT Location)	Ravel Start (ft)	Ravel End (ft)	Positive	False Positive	Negative	False Negative
US 27 Villages CPT-2 (I)	10	50	67.00%	33.00%	85.30%	14.70%

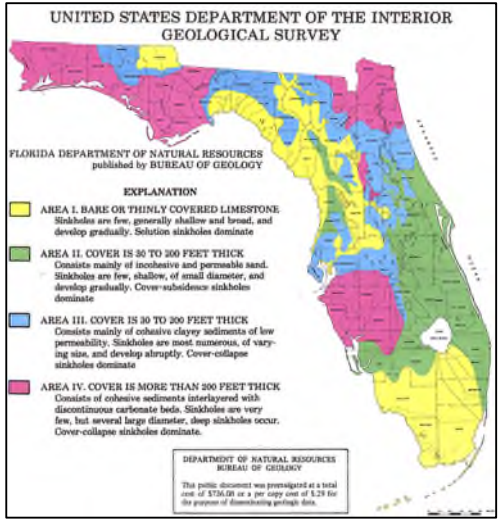
Type 2 – SR 500 Lady Lake Irma 2017 CPT-3

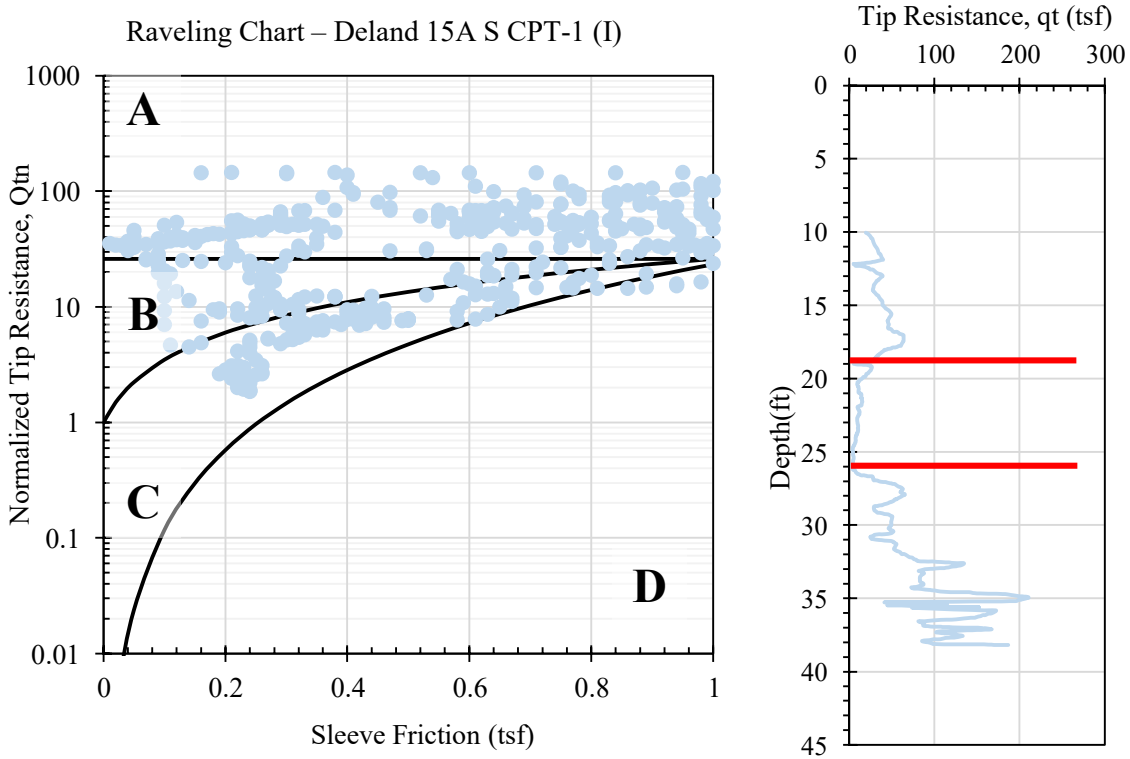




Name (CPT Location)	Ravel Start (ft)	Ravel End (ft)	Positive	False Positive	Negative	False Negative
SR 500 Lady Lake Irma 2017 CPT-3 (I)	15.3	41.2	81.10%	18.90%	42.10%	57.90%

Type 3 – Deland 15A South 2016 CPT-1





Name (CPT Location)	Ravel Start (ft)	Ravel End (ft)	Positive	False Positive	Negative	False Negative
Deland 15A South 2016 CPT-1 (I)	19	26	97.50%	2.50%	88.40%	11.60%

Task #2 General Recommendations

- Based on our analysis of the updated database of CPT-sinkhole sites, the researchers have determined that the existing raveling chart is still a moderately accurate way to identify whether soil is exhibiting raveling behavior or not – regardless of the subsurface geological conditions or the anticipated sinkhole mechanism type (i.e., “area”).
- The existing raveling chart was found to accurately identify raveled soil 63% of the time, and identify non-raveled soil 82% of the time, within the updated database.
- However, the anticipated sinkhole type and subsurface geology in the testing location is important to consider when implementing the chart as an investigation tool.

Task 3: Setup of the Large-Scale Soil Box (LSSB)

Deconstruction (**UF**), transportation, and re-construction at campus of **UNF**

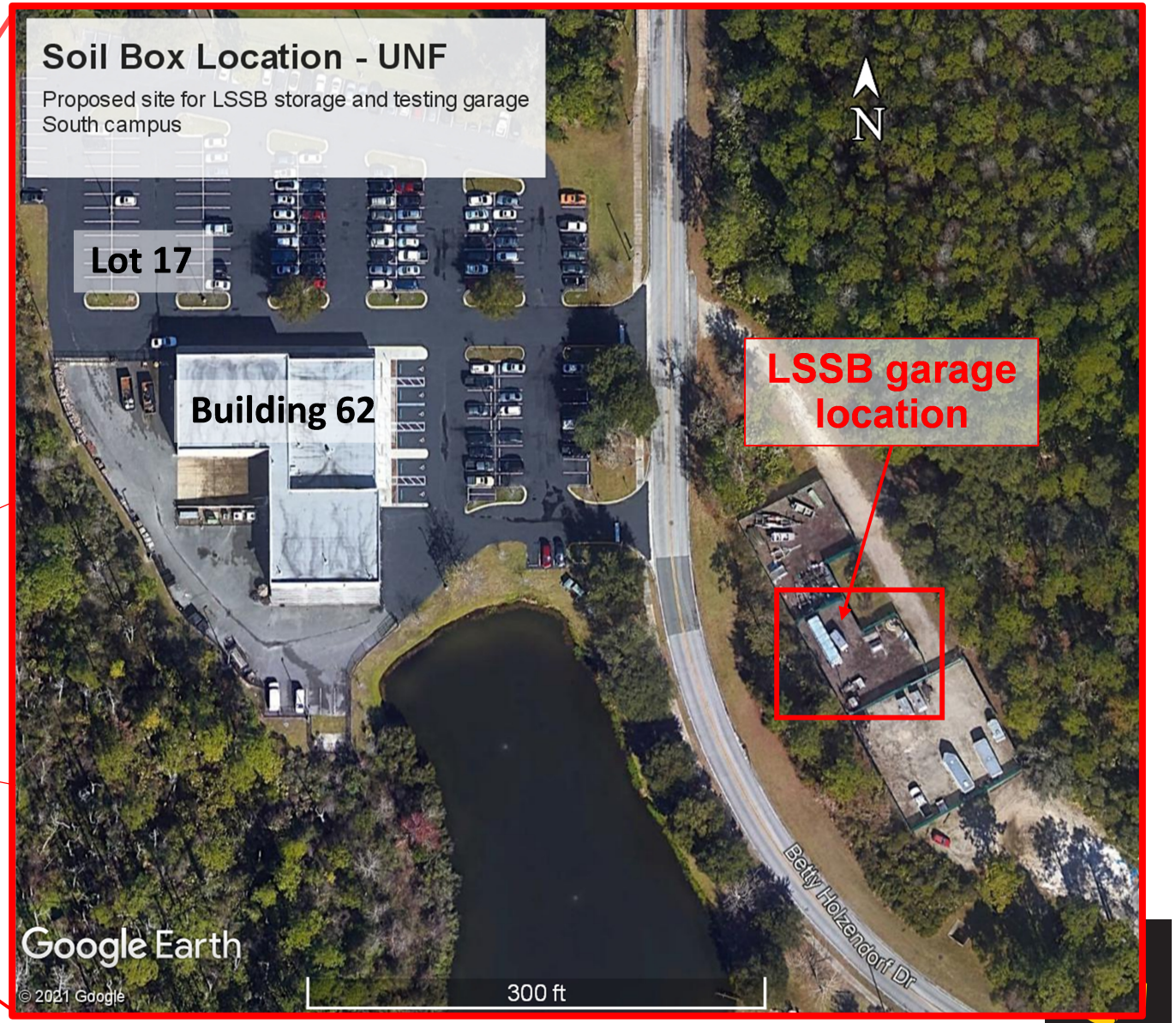
- Concrete slab, gated/locked area, tarped and covered with parking canopy
- LSSB preparation for sinkhole testing.

Deliverable **3**:

(a) Summary of the testing set up and review of site simulation

(b) Detailed description of the LSSB modification for sinkhole testing

University North Florida – Jacksonville, FL



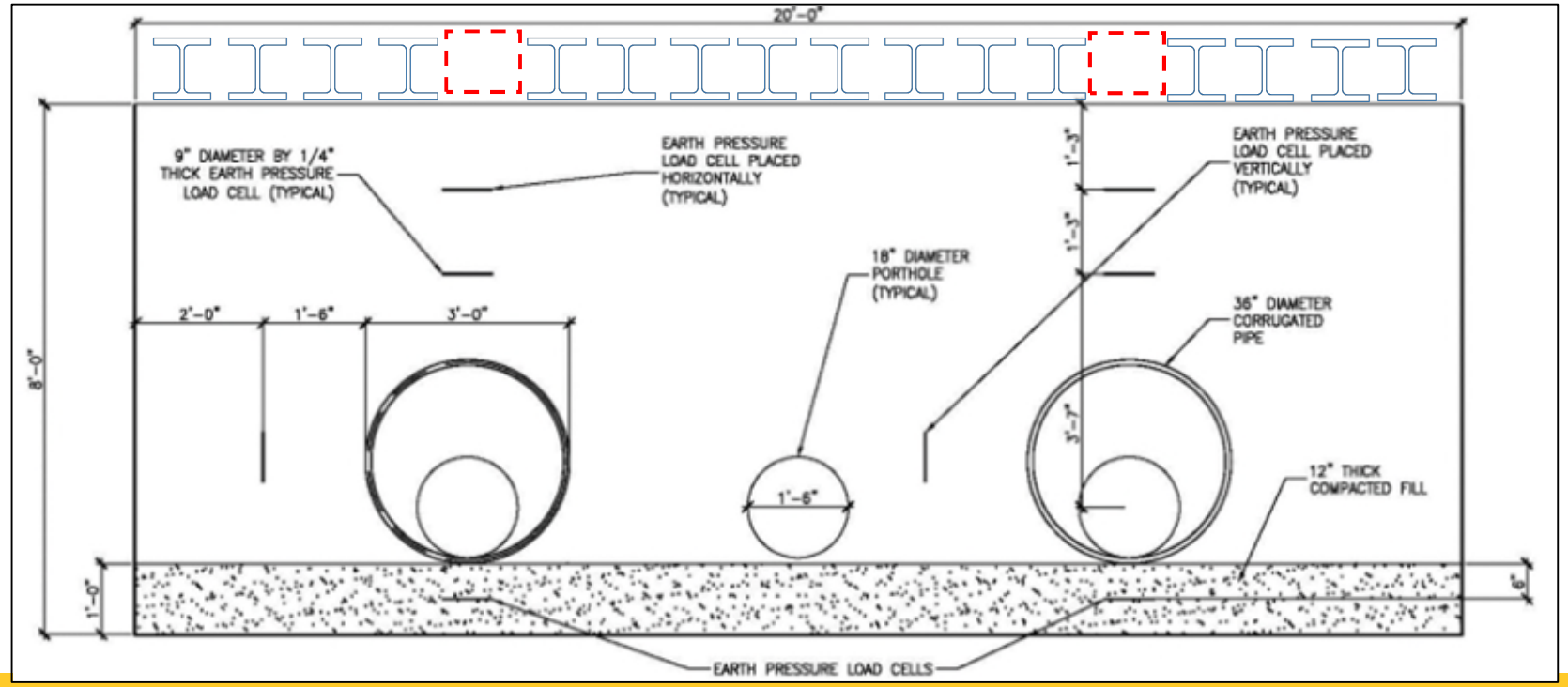
Inflated airbag to simulate overburden pressure **(ABOVE)**

Entry port for “void” installation and sediment transport **(BELOW)**

(LEFT) Installation of I-Beam roof for reaction force of airbags and overburden simulation

Planned modifications for Sinkhole Testing

- Pressure cell installation
- Piezometer installation
- Boundary conditions (plastic liner and waterproof)
- Roof plate removal/rearrange
- Catchment basin for effluent eroded slurry



(LEFT) Installation of I-Beam roof for reaction force of airbags and overburden simulation

Task 4: Sinkhole Physical Tests using the LSSB

Previous accidental sinkhole formation:
UF Thesis, Faraone 2012

Simulate: site conditions – overburden thickness, soil type, density
Control: internal erosion – recharge via falling head
Monitor: raveling progression – collection and measurement of effluent
Identify: critical variables in relationship to sinkhole index field testing (CPT)

Deliverable **4**:

(a) Detailed testing procedure
(b) Results of physical model tests of sinkhole raveling using the LSSB

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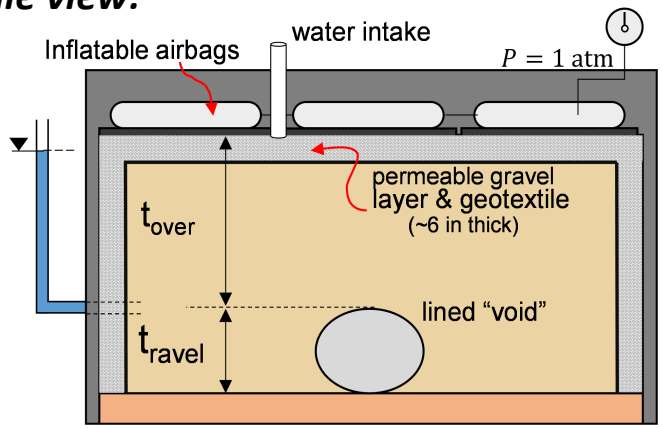
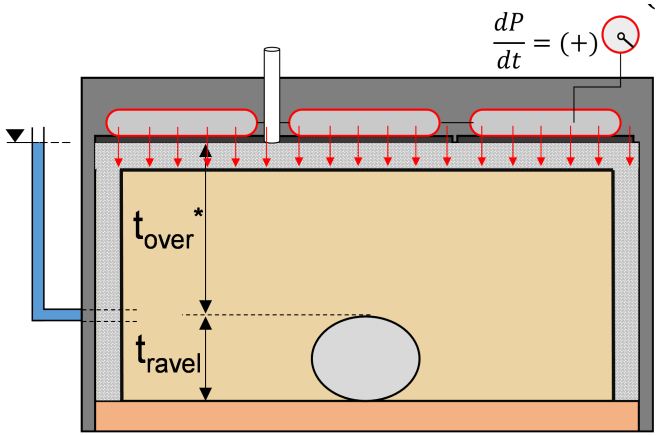
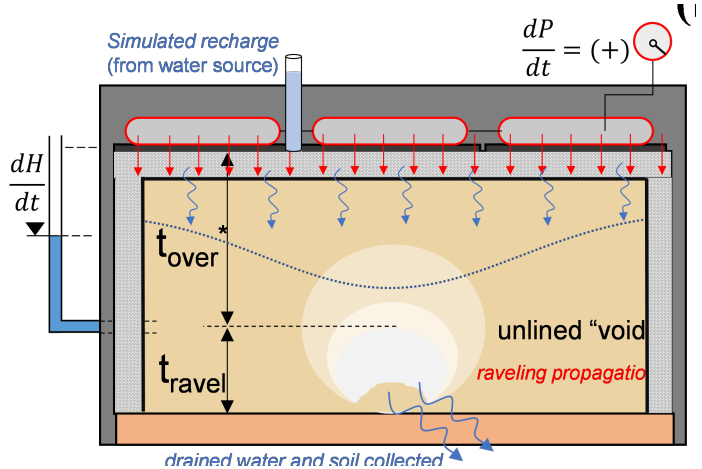
Task 4: Sinkhole Physical Tests using the LSSB

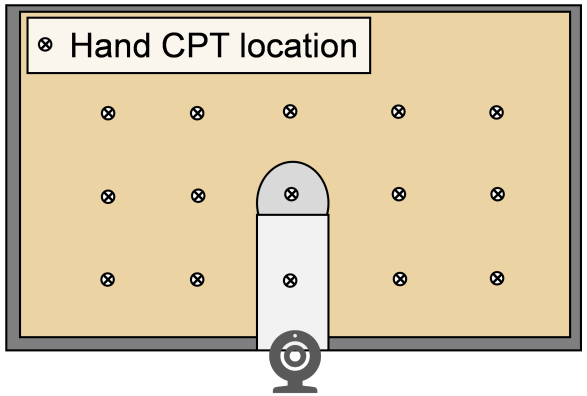
Profile view:

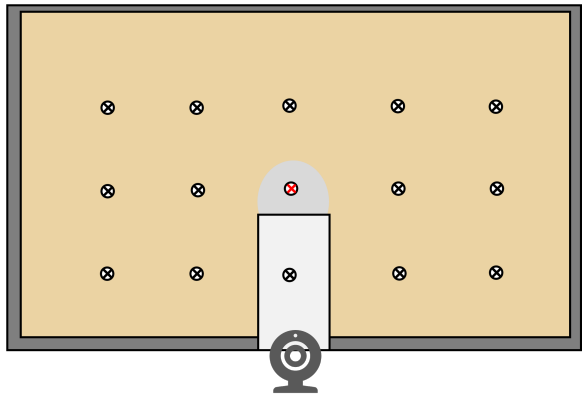


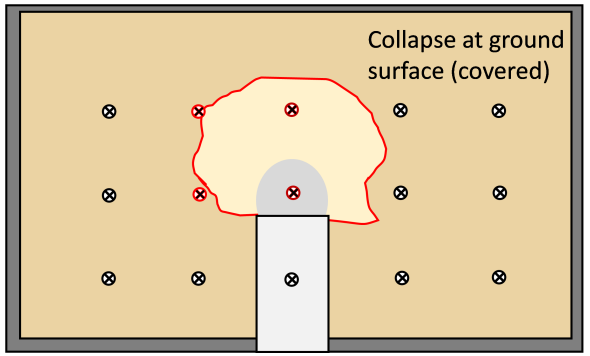




Top view:







Proposed Steps:

1. Subsurface void: installation of in situ (controllable) volume and drainage port
2. Soil fill and overburden simulation (airbag inflation)
3. reference q_c profiling (hCPT)
4. Recharge simulation, erosion monitoring, post-collapse forensics → **Sinkhole Indexing**

Task 5: Establish the severity criteria of the sinkhole index and correlate the index to the grout-take volume

- Physical meaning of the SRR values will be assigned and the corresponding severity criteria will be established.
  - Correlation between SRR and other indices (e.g., RI, probability of collapse)
  - Use of LSSB testing results to validate the SRR
- Correlation between SRR and the grout-take volume

Project Timeline

Deliverable # / Description as Provided in Scope (Associated Task)	Anticipated Date of Deliverable Submittal Month/Year	Comments
Project Kickoff Teleconference/Presentation	June 2021	Completed
Deliverable 1: A written report of the findings from Task 1, including: (a) summary of data collection and (b) summary of expert group meetings	January 2022	Completed
Deliverable 2: A written report on the findings from Task 2, including: (a) updated and enhanced sinkhole raveling chart, (b) criteria and standard procedure of the index calculation, and (c) results of the validation and modification (if necessary) of the index	August 2022	In Progress
Deliverable 3: A written report on the findings from Task 3, including: (a) the summary of the LSSB setup and (b) detailed description of the LSSB.	February 2023	Delayed

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Project Timeline Cont.

Deliverable # / Description as Provided in Scope (Associated Task)	Anticipated Date of Deliverable Submittal Month/Year	Actual Submittal Date
Deliverable 4: A written report on the findings from Task 4, including (a) testing procedure and (b) results of physical model tests of sinkhole raveling using the LSSB	May 2023	Delayed
Deliverable 5: A written report on the findings from Task 5, including: (a) severity criteria of the SRR, (b) correlation of the SRR to other indices (RI, factor of safety), and (c) evaluation of the effects of grout-take.	April 2023	Pending
Deliverable 6a: Draft Final Report	June 2023	Pending
Deliverable 6b: Closeout teleconference and PowerPoint presentation	September 2023	Pending
Deliverable 7: Final Report	September 26, 2023	Pending

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Thank you!

Question?