Validation and Update of the Sinkhole Index
- Phase 2 -
(BED26 TWO 977-10)

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Outline

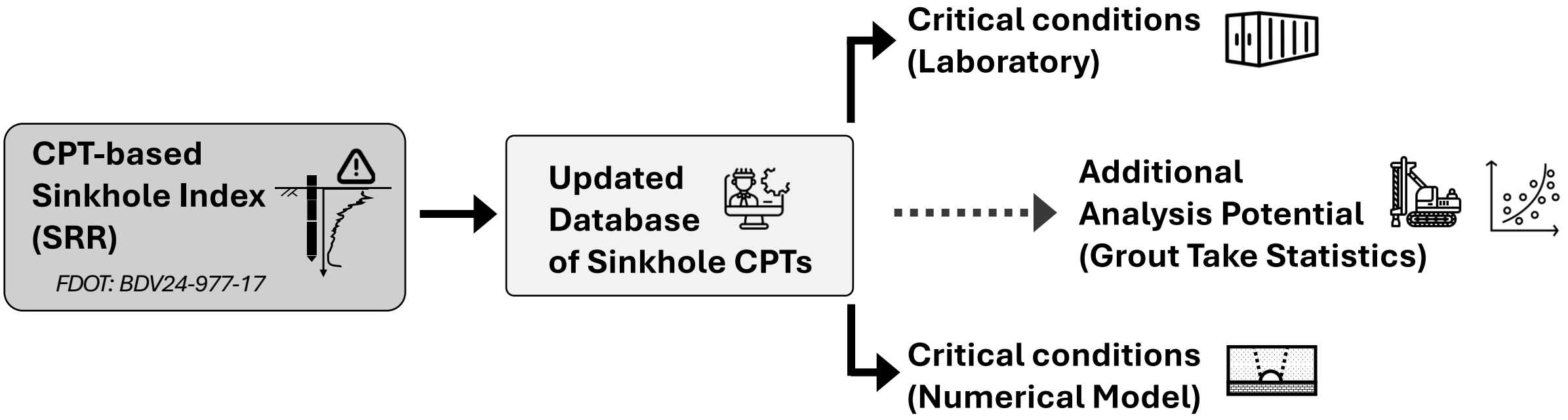
- Brief Project Overview
  - Objectives
  - Benefits

- Florida Sinkhole Refresher
- Sinkhole Index Refresher

- Progress
  - Physical Modeling
  - Grout Take Correlation

Project Objectives [Phase 2]

1. Validate the **sinkhole index** via large-scale sinkhole simulation testing
2. Validate **sinkhole index thresholds** proposed in Phase 1, using:
   a) Finite Element (FE) modeling, and
   b) Large-Scale Sinkhole testing using LSSB
3. Investigation into Sinkhole Indices' ability to **estimate grout volume** (empirical)



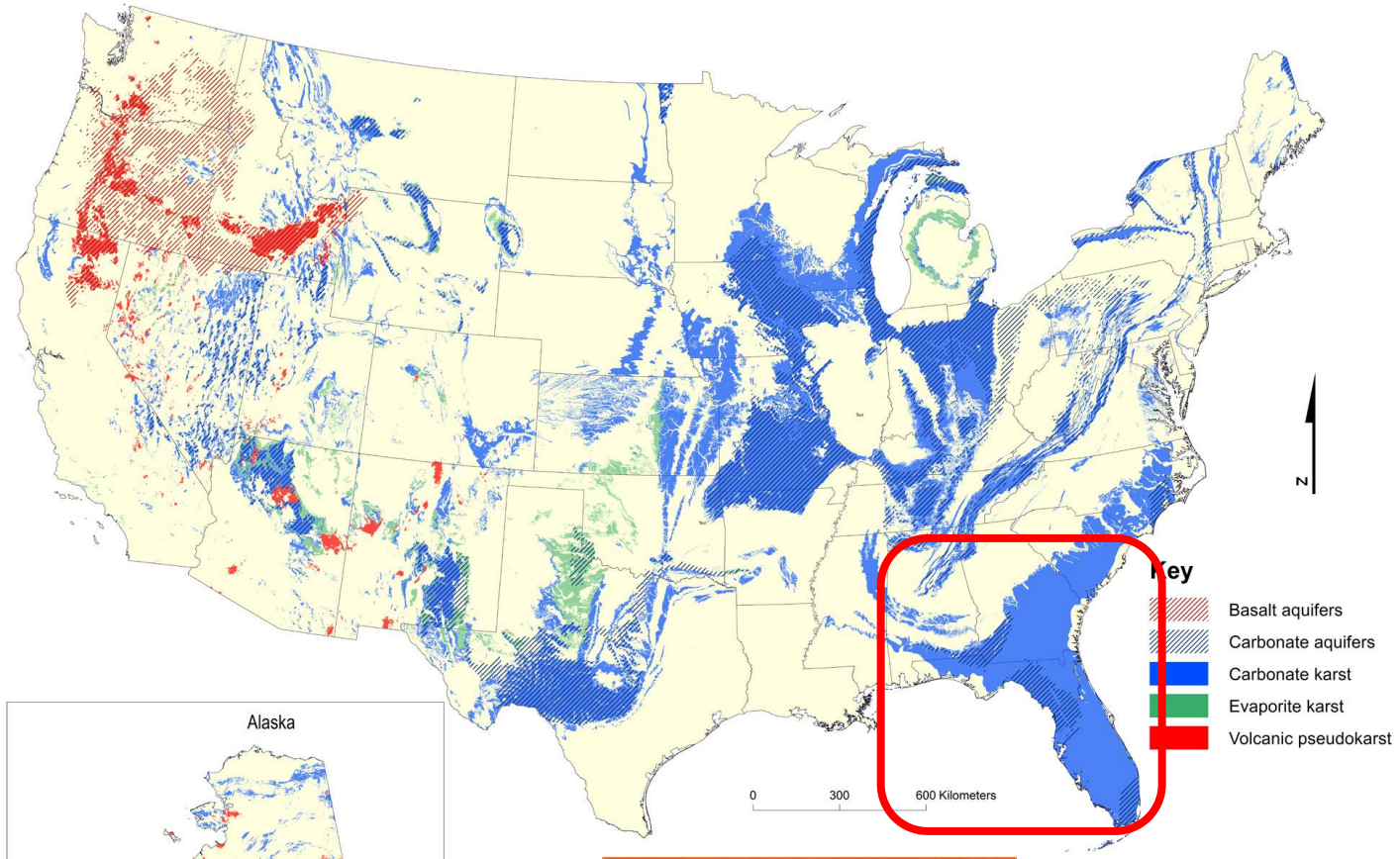
Project Benefits

- *Qualitative*

  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*

  Help engineers perform more effective sinkhole assessment; thus, save time and reduce repair cost (e.g., optimumize repair/mitigation scheme). The correlation between the index and grout-take volume can provide quantitative information of est mitigation plan.

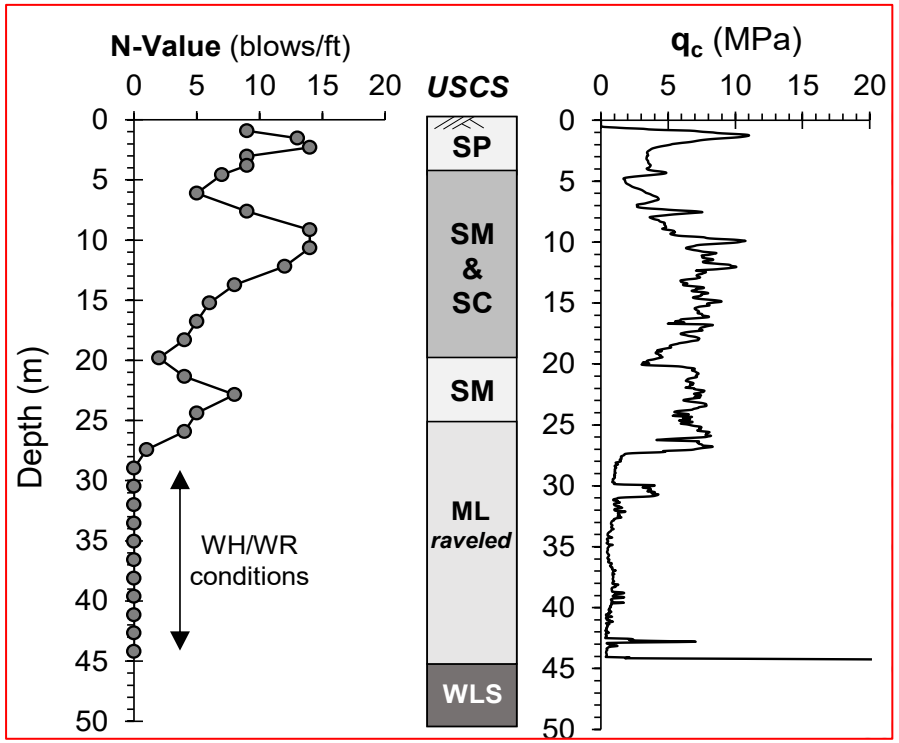


Karst:

Landscape developed by the dissolution of sediment and rocks.

"Eogenetic" karst:

- *youngest* karst (55mya)
- Extensive primary porosity
- "undisturbed" overburden



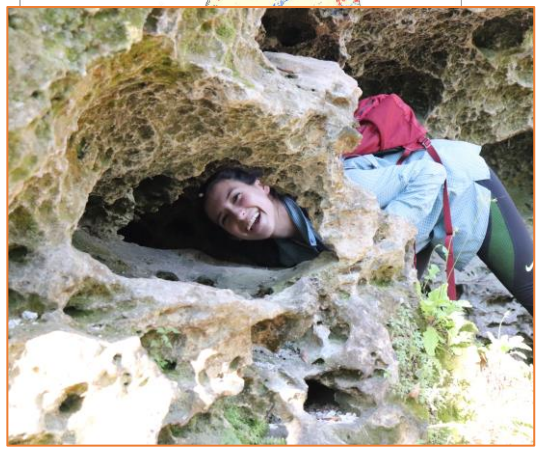


Photo: Exposed Karst near Gainesville, FL. Wife to scale. Personal archival

✓ Provides clean drinking water to the state.

✗ Creates a landscape vulnerable to sinkholes.

Sinkhole Indices

Sinkhole Resistance Ratio (SRR)

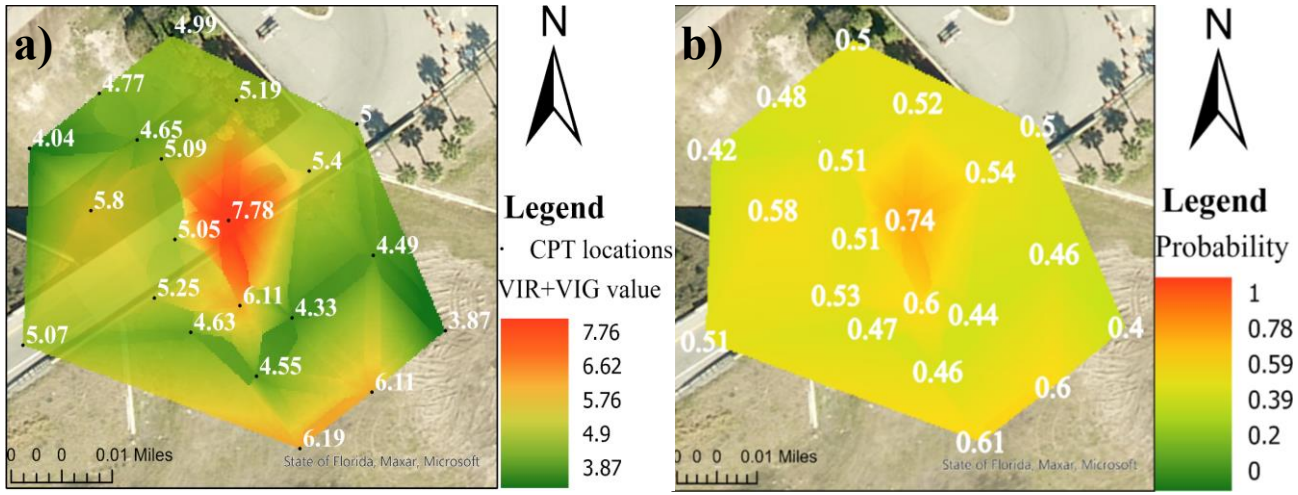
Nam et. al - FDOT: BDV24-977-17

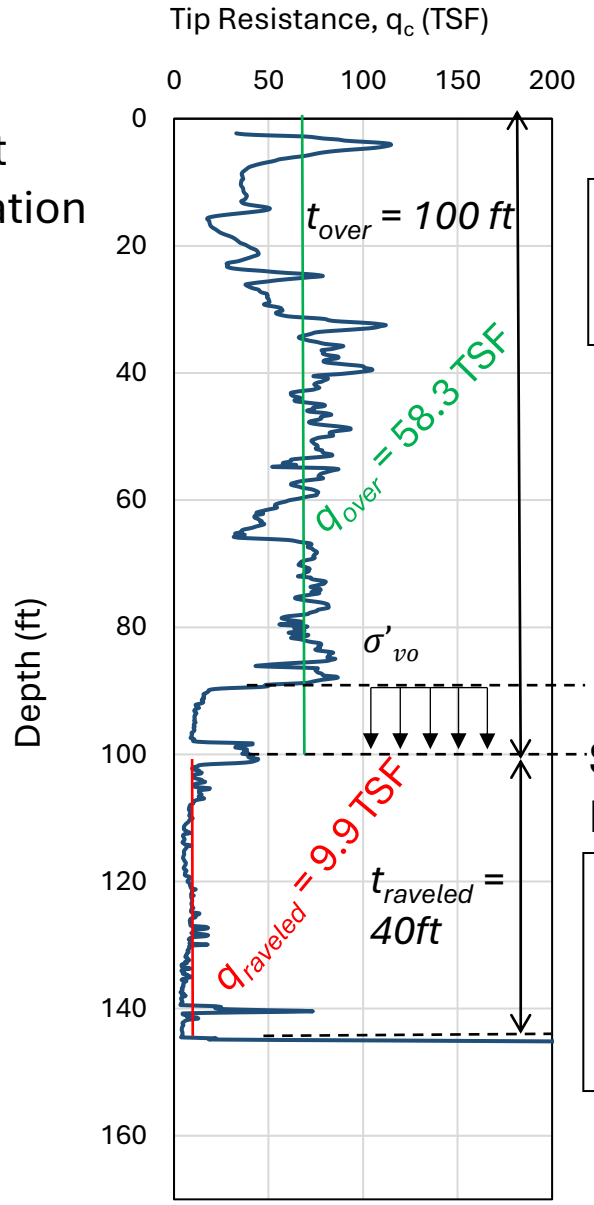
$$\text{SRR} = \left(\frac{q_{over} + q_{ravel}}{100 * \sigma'_{vo}}\right)\left(\frac{t_{over}}{t_{ravel}}\right)$$

SRR ⇧ = "**safer**" against sinkhole formation

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)





Raveling Index (RI)

$$RI = t_{ravel}/t_{over}$$

$$RI = \mathbf{0.4}$$

Sinkhole Resistance Ratio (SRR)

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

$$\boldsymbol{SRR = 0.622}$$

Task 1: Sinkhole Physical Testing using the LSSB

- Simulation of large-scale sinkhole raveling and collapse to identify critical ratio of encountered stratigraphy geometry and reduction of soil resistance due to sinkhole formation (SRR parameters).

Large-Scale Soil Box (LSSB) Testing at UNF

Modifications for Sinkhole Simulation

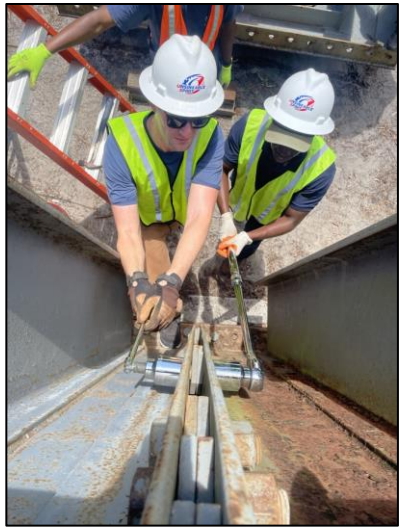
- Pressure cell array
  - Density, arching and horizontal stress during collapse.
- Inflatable void options (yacht fender)
- Boundary conditions (plastic liner and waterproof)

Part / Orientation	Marking	Suspended weight* (lbs)
1) Base – middle	n/a	1,500
2) Base – end	n/a	3,500
3) Base – end	n/a	3,500
4) Side – Middle	2	2,000
5) Side – Middle	5	2,000
6) Side – edge	3	4,000
7) Side – edge	6	4,000
8) End	B	6,000
9) Side – edge	1	4,000
10) Side – edge	4	4,000
11) End	A	6,000

*Provided by crane operator during assembly, not verified by researchers

~21 ton structure

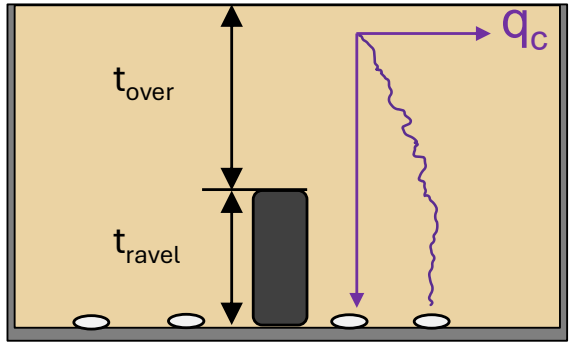
(excluding roof!)



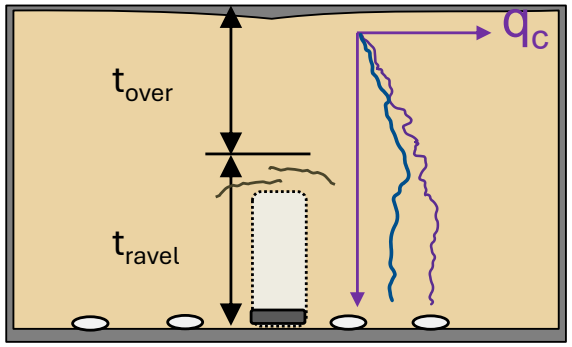
Task 1: Sinkhole Physical Tests using the LSSB

Profile View

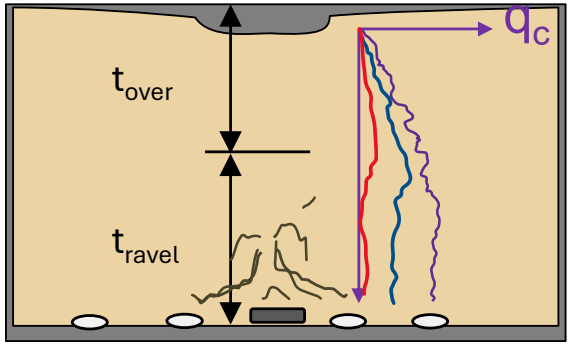
Inflated, sand filled, base-line DCP performed



Deflated, subsidence measured, DCP performed

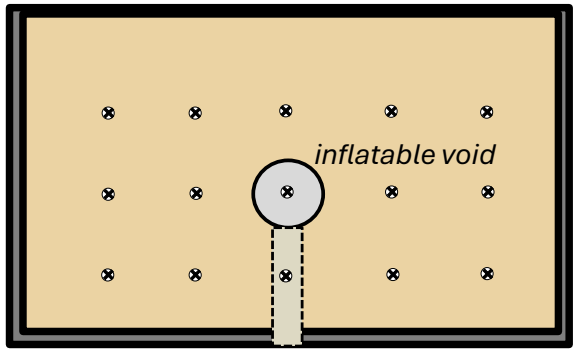


Deflated, watered, DCP performed

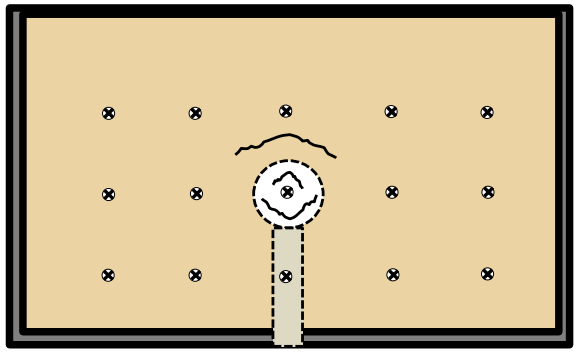


Pressure plate array

Plan View



⊗ DCPT "PANDA" test grid



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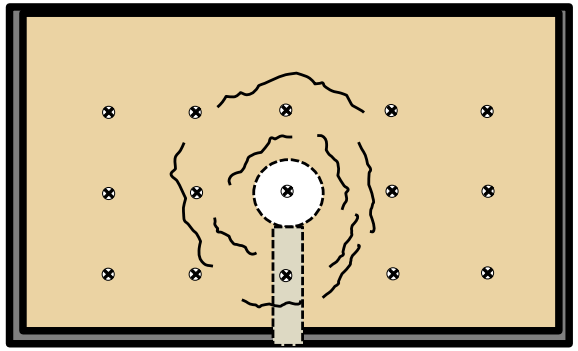


⊗ DCPT "PANDA" test grid

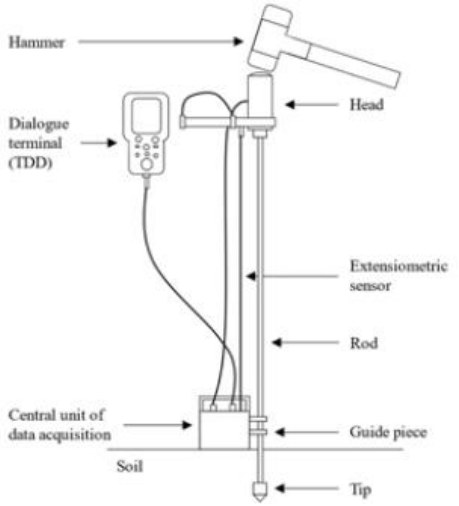
Planned Steps:

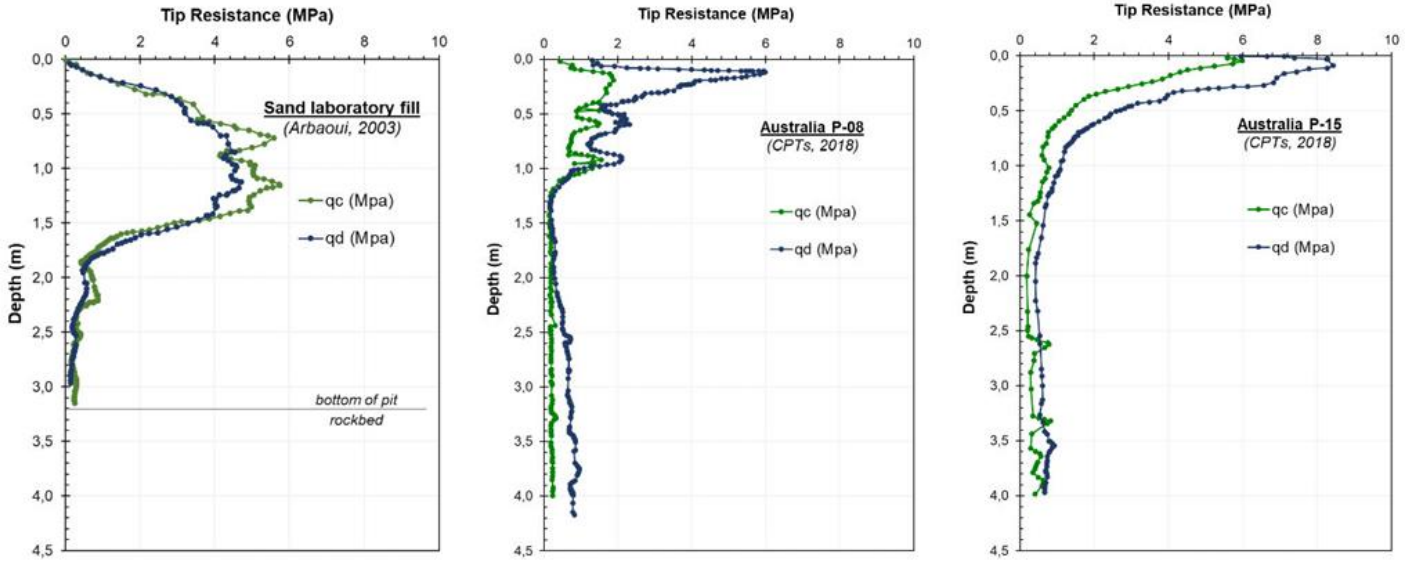
1. Subsurface void: installation of in situ (controllable) volume and drainage port
2. Soil fill and density check (baseline)
3. reference q_c profiling (DCPT PANDA®)
4. Erosion monitoring, Post-collapse forensics → **Sinkhole Indexing**

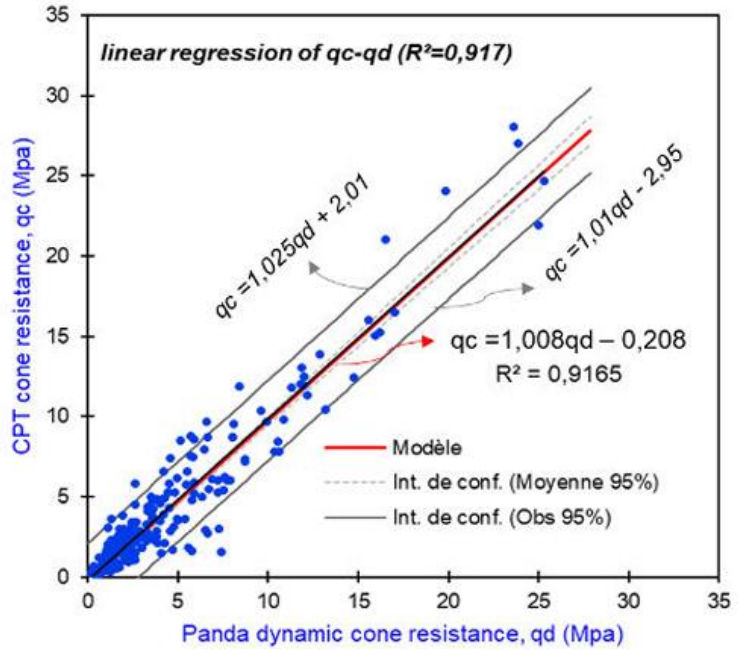
Task 1: Sinkhole Physical Tests using the LSSB

Soil testing will be performed using the PANDA variable energy Dynamic CPT.

- Variable Energy allows user to control penetration depth
- French standard for compaction control of subgrade
- Used in liquefaction assessment and mitigation testing
  Hubler and Hanley (2021) and Retamels et al. (2021)







SRR = *f*(cone tip resistance) → q_c

Dynamic CPT → q_d

$$q_c = 0.87 q_d \; to \; 1.11 \; q_d$$

Benz-Navarrete et. al (2020)

Retamels et. al (2021)

Task 2: Establish the severity criteria of the sinkhole index and correlate the index to the grout-take volume

1. Qualitative meaning of the SRR values will be assigned and the corresponding severity criteria will be established.
   - SRR based on database and numerical modeling (e.g., probability of collapse, Factor of Safety)
   - Use of LSSB testing results to validate the SRR → $SRR_{critical?}$
2. Correlation between Index and the grout-take volume in mitigated sites.

Task 2: Establish the severity criteria of the sinkhole index and correlate the index to the grout-take volume

Task 2: Establish the severity criteria of the sinkhole index and correlate the index to the grout-take volume

2. Correlation between indices and the grout-take volume.

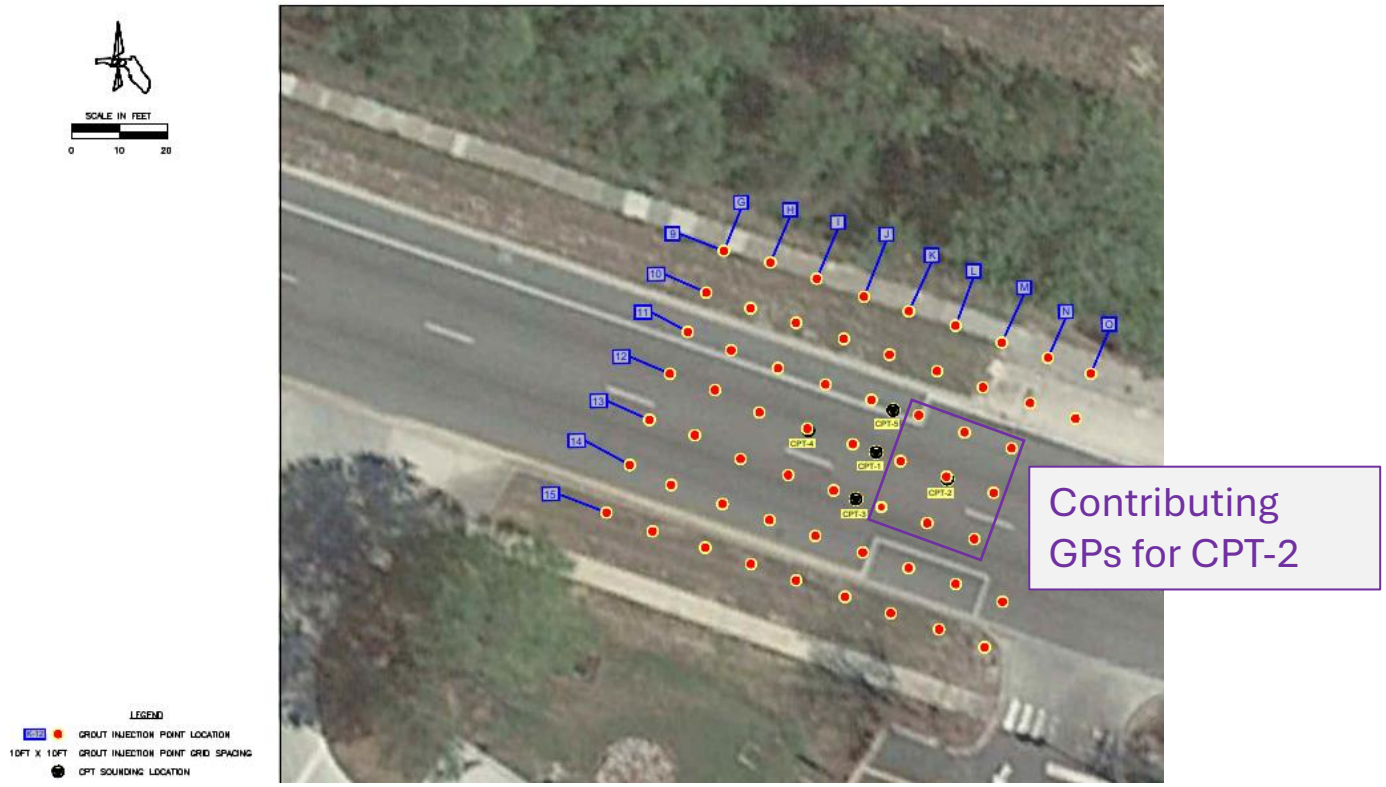
Site ID	Sinkhole Type	County (District)	lat	long	# Grout Points	Total Grout Volume (CY)
Wekiva Parkway Sec.6 STA 775 2019	Collapse	Lake (5)	28.812882°	-81.464594°	274	3109
SR50 Groveland 2020	Depression	Lake (5)	28.561992°	-81.858400°	60	1130
I4 Rest Area 2011	Collapse	Polk (1)	28.174157°	-81.767350°	27	1100
US27 Polk S 2010	Collapse	Polk (1)	27.847627°	-81.585336°	19	384
US27 Polk N 2010	Collapse	Polk (1)	27.861023°	-81.588964°	14	260
Wekiva Parkway Sec.6 STA 1130	Collapse	Lake (5)	28.813058°	-81.463690°	203	5354
US19 Sealawn 2011	Depression	Hernando (7)	28.478269°	-82.611443°	65	569

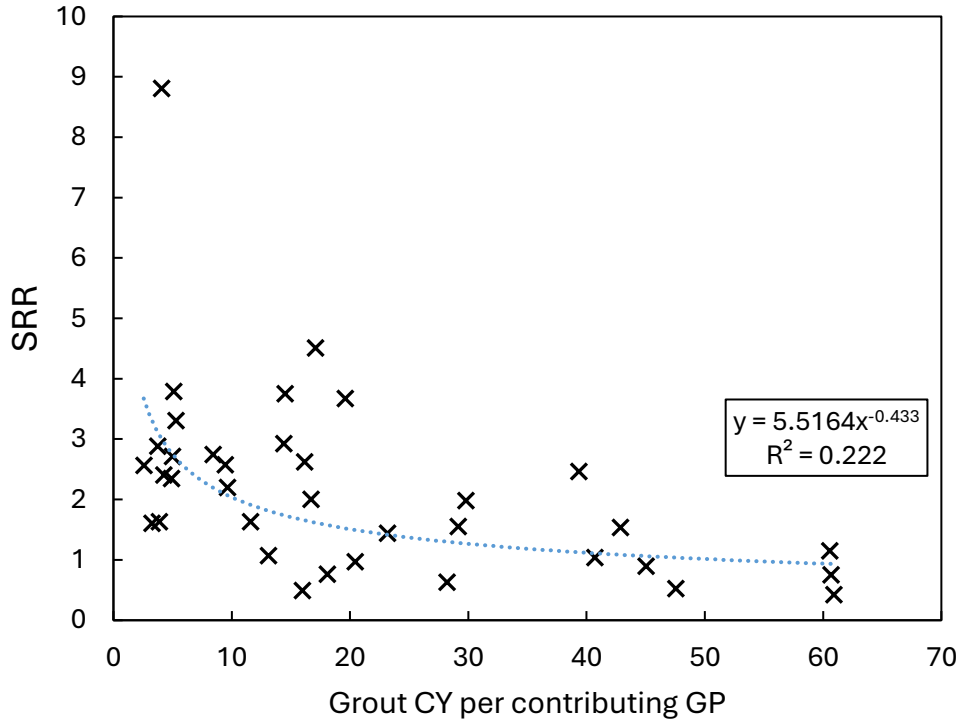
2024: Seven (7) CPT sites

2. Correlation between SRR and the grout-take volume.

Individual CPT-based assessment

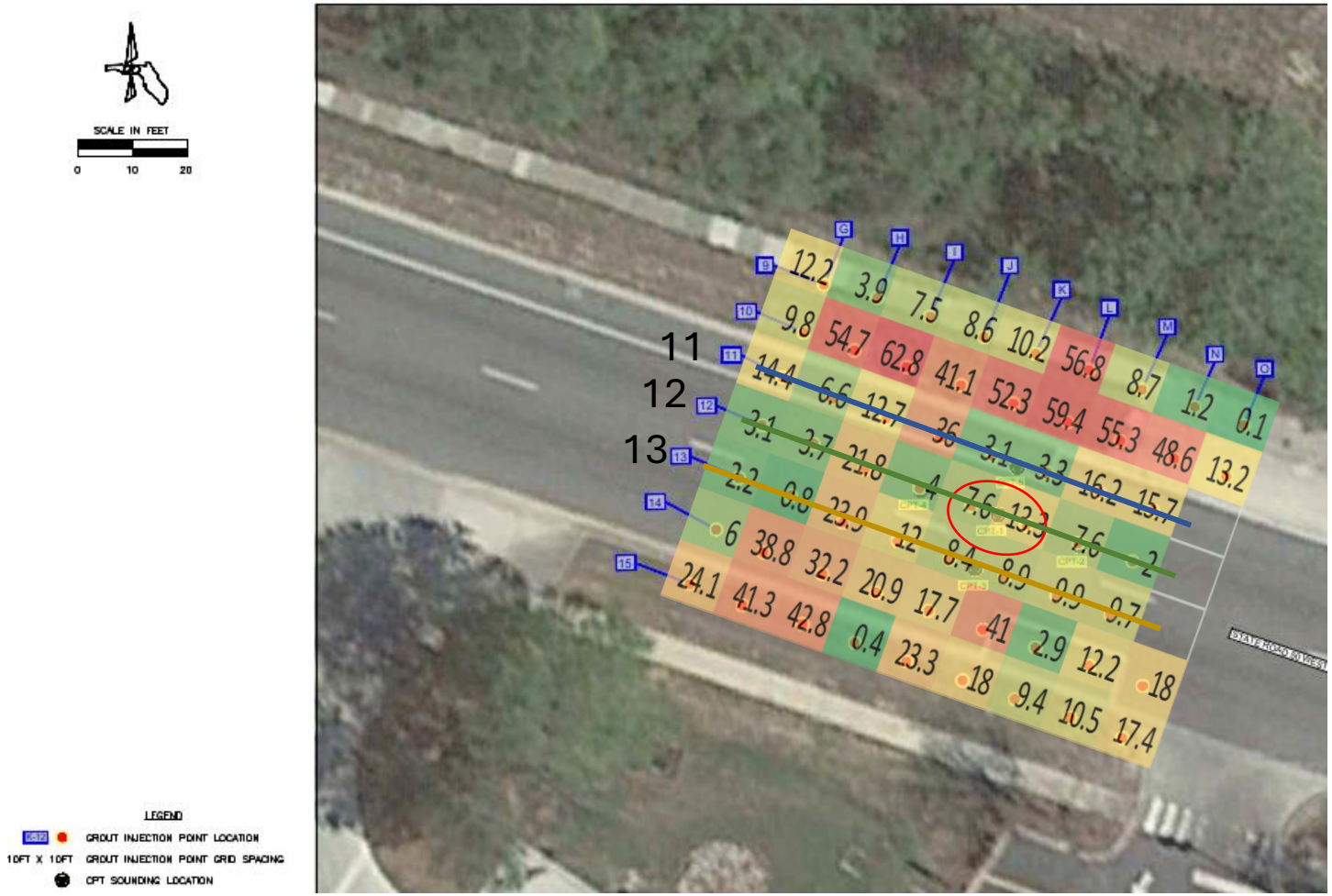
- SRR calced from individual CPT
- Summation of Grout Volumes from within *vicinity* of CPT.
  - Nearest Neighbor
  - Even Split
  - Tributary Distance



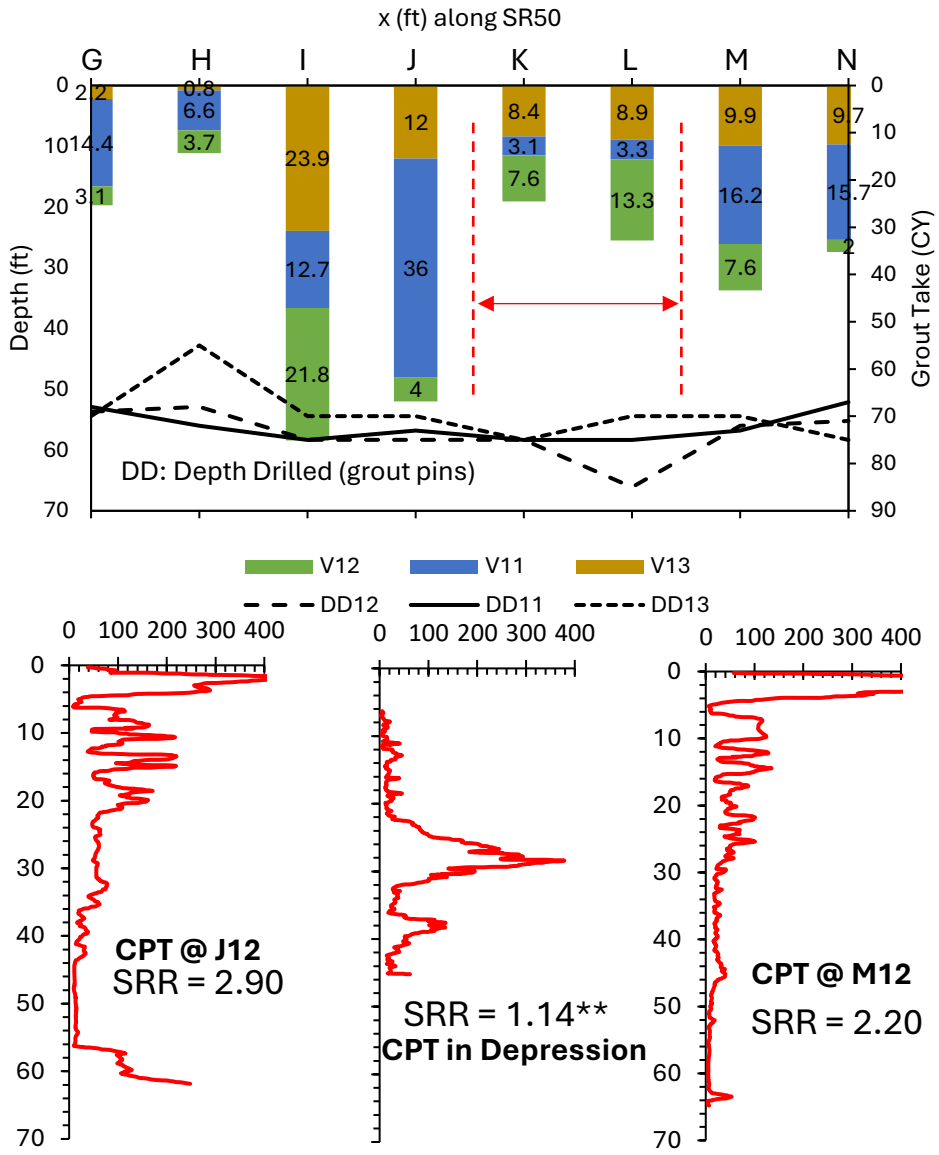


- Tributary Distance and Area?
- Grout Take as function of depth / stratigraphy?

2. Correlation between SRR and the grout-take volume.



Grout Takes along **Line 12**, **Line 11**, **Line 13**



<u>Variable Karst</u> = Grout Takes (volume) do not correspond with severe CPTs or surface feature

Task 2: Establish the severity criteria of the sinkhole index and correlate the index to the grout-take volume

2. Correlation between indices and the grout-take volume.

Site ID	Sinkhole Type	County (District)	lat	long	# Grout Points	Total Grout Volume (CY)
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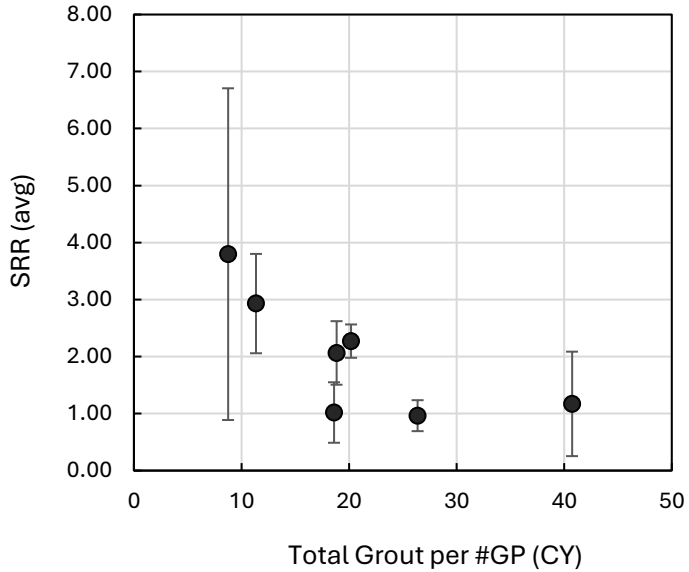
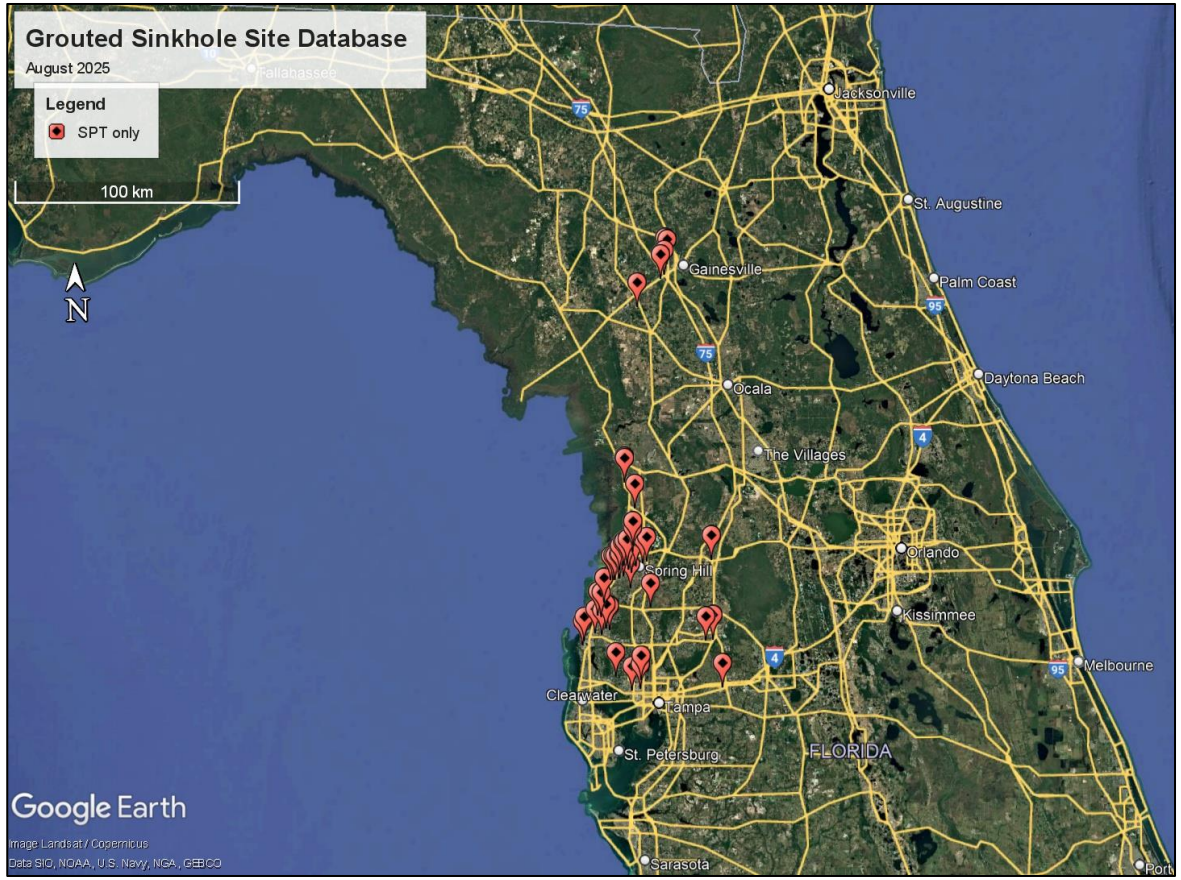


2024: Seven (7) sites in 2024

2025: Forty-Four (44) sites

Task 2: Establish the severity criteria of the sinkhole index and correlate the index to the grout-take volume

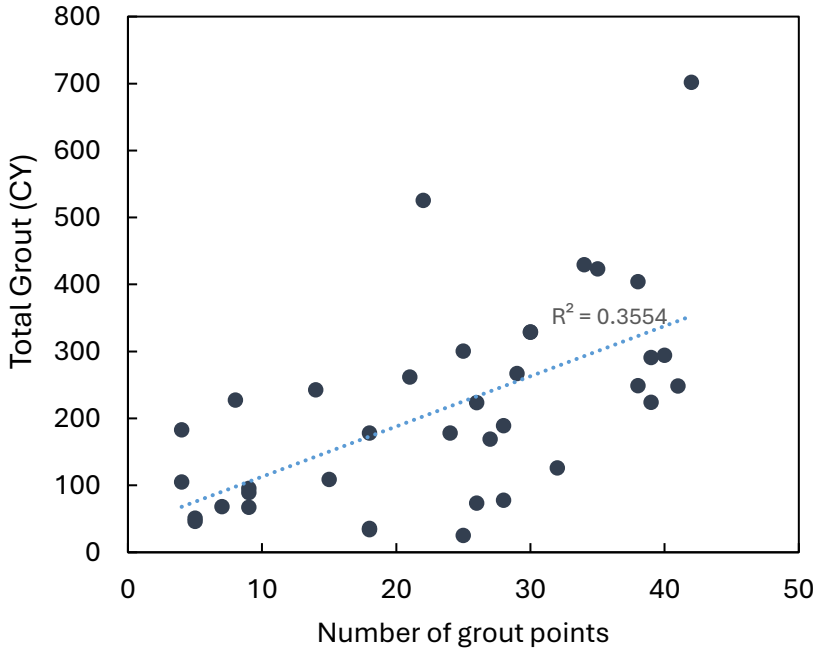
Site ID	Sinkhole Type	County (District)	lat	long	# Grout Points	Total Grout Volume (CY)	Total Grouted Length (ft	Grouted S.A (ft2)
I4 Rest Area 2011	Collapse	Polk (1)	28.174157°	-81.767350°	27	1100	3033	2827
US27 Polk N 2010	Collapse	Polk (1)	27.861023°	-81.588964°	14	260	1428	1590
US27 Polk S 2010	Collapse	Polk (1)	27.847627°	-81.585336°	19	384	1779	5655
SR574Euclid 2010	Collapse	Polk (1)	28.010611°	-82.156664°	4	183	288	400
Wekiva Parkway Sec.6 STA 1130	Collapse	Lake (5)	28.813058°	-81.463690°	203	5354	11929	15200
2019	Collapse	Lake (5)	28.812882°	-81.464594°	274	3109	9900	9325
SR50Hernando 2020	Collapse	Hernando (7)	28.508070°	-82.197500°	8	227	473	800
US19Goshawk 2020	Collapse	Citrus (7)	28.811662	-82.576695	15	109	560	700
US98Oakvillage 2020	Collapse	Citrus (7)	28.711130°	-82.532136°	25	300	4144	900
3534NW7th 2021	Collapse	Alachua (2)	29.658701	-82.375767	4	105	222	300
SW43RD 2018	Collapse	Alachua (2)	29.617465	-82.389362	5	46	185	144
SR52PascoTrails1 2018	Depression	Pasco (7)	28.324650°	-82.468567°	9	67	540	400
SR56Pasco 2018	Depression	Pasco (7)	28.508070	-82.197500	9	89	456	400
US301Pasco311 2019	Depression	Pasco (7)	28.198045°	-82.195455°	9	96	385	400
SR50 Groveland 2020	Depression	Lake (5)	28.561992°	-81.858400°	60	1130	4079	2000
i4Mango 2019	Depression	Hillsborough (7)	28.005706°	-82.303572°	14	243	722	1500
US19 Sealawn 2011	Depression	Hernando (7)	28.478269°	-82.611443°	65	569	1813	5400
Mazzuco-Alshin.11	depression	Hernando (7)	28.54207	-82.54417	42	702	3439	7920
US19HomosassaMarine 2019	Depression	Citrus (7)	28.816911	-82.577309	7	68	254	700
SW63RD BLVD 2017	Depression	Alachua (2)	29.600785	-82.406163	5	51	146	100
Corr.10	insurance	Pasco (7)	28.196287	-82.763232	18	34	500	2305
Curcio-berry.09	insurance	Pasco (7)	28.178882	-82.770352	26	74	695	3063
Grotto.11	insurance	Pasco (7)	28.426350	82.617890	29	267	2561	2400
Haskell.10	insurance	Pasco (7)	28.294560	-82.702340	32	126	1163	3220
Lopez.12	insurance	Pasco (7)	28.244560	-82.665680	39	224	1559	5670
McCarthy.10	insurance	Pasco (7)	28.225700	-82.714920	34	430	1134	3838
Sears.12	insurance	Pasco (7)	28.238860	-82.650330	35	423	1910	5260
Siberman.11	insurance	Pasco (7)	28.432780	-82.624190	21	262	1027	3240
Stacy.12	insurance	Pasco (7)	28.431998	-82.643906	24	178	1489	4850
Cardenas.07	insurance	Hillsborough (7)	28.043321	-82.514358	18	36	863	2346
Currie.08	insurance	Hillsborough (7)	28.056960	-82.625450	38	404	2085	5476
Denova.08	insurance	Hillsborough (7)	28.056960	-82.625450	25	25	555	3290
Dexter.08	insurance	Hillsborough (7)	28.290459	-82.686619	39	291	2263	4202
Morejon.12	insurance	Hillsborough (7)	28.002190	-82.555380	18	178	936	2640
Roque.12	insurance	Hillsborough (7)	28.009580	-82.518160	28	78	1307	2738
Bennett.12	insurance	Hernando (7)	28.565860	-82.542973	40	294	1671	8420
Carey.13	insurance	Hernando (7)	28.497370	-82.568970	28	189	1138	4396
Groesbeck.11	insurance	Hernando (7)	28.448620	-82.585820	30	329	2110	4820
McCluskey.08	insurance	Hernando (7)	28.486040	-82.530880	41	248	2315	5090
Oliveria.08	insurance	Hernando (7)	28.489494	-82.583720	22	525	3024	3370
Serafin.08	insurance	Hernando (7)	28.485570	-82.588610	26	224	1498	4076
Simpson.11	insurance	Hernando (7)	28.472864	-82.563504	30	328	1760	4045
Steele.10	insurance	Hernando (7)	28.439424	-82.603208	27	169	997	3600
Wilkinson.11	insurance	Hernando (7)	28.504216	-82.482914	38	249	2088	5950

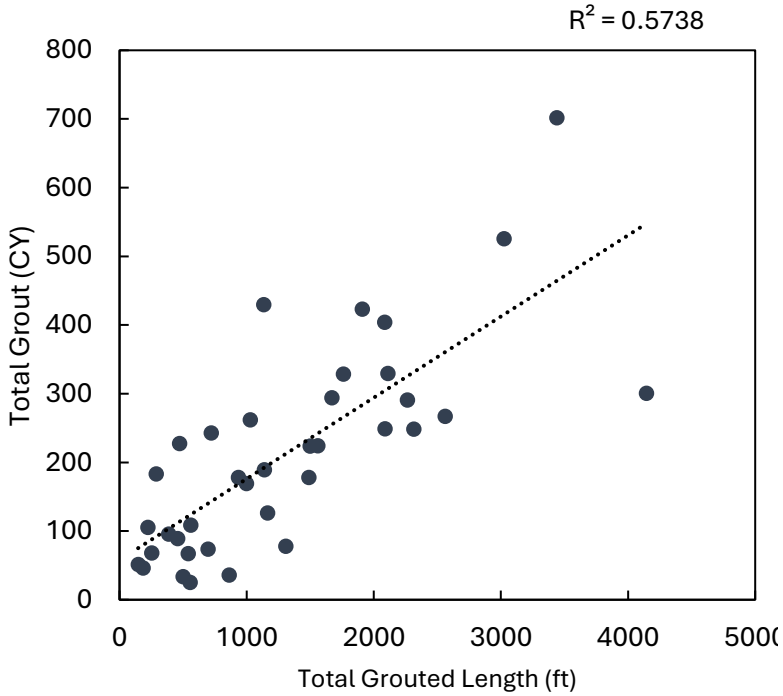


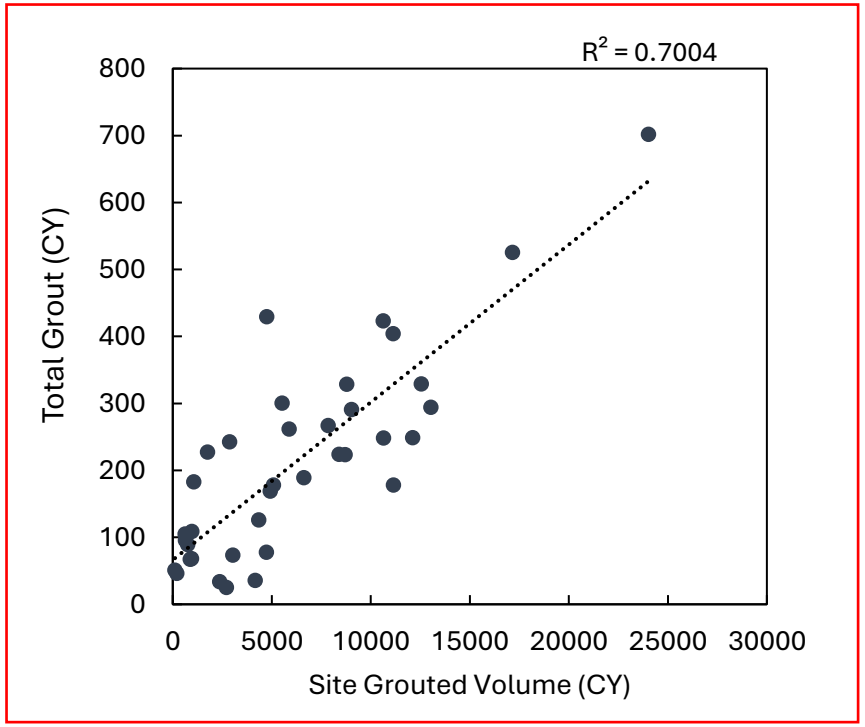
2. Correlation between SRR and the grout-take volume.

Site-based assessment **(n = 44)**

- *Averaged Subsurface indices near sinkhole will show some trend of overall anticipated grout volume at site.*
  - IF SPT/CPT performed near collapse showed residual soil; removed.
- Stratigraphy Considerations averaged per site (1-4 SPTs per site)







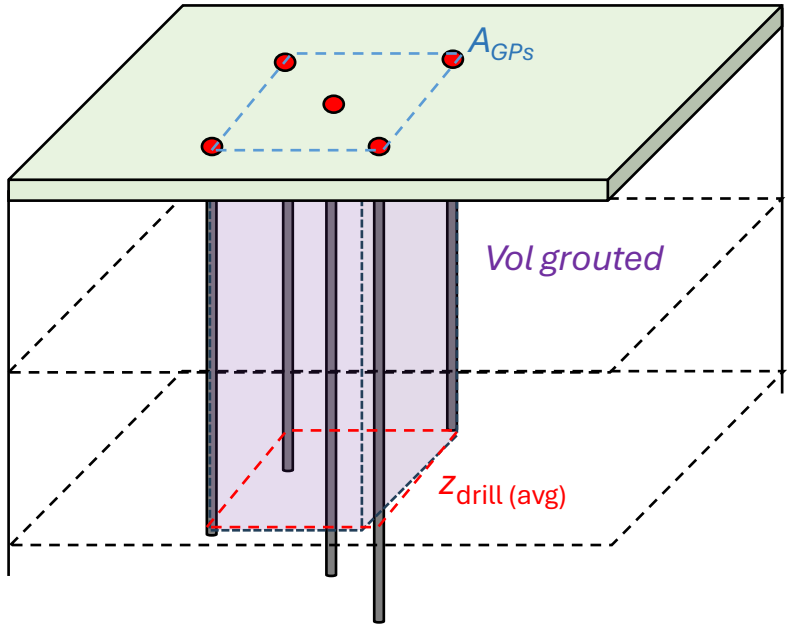
(Average depth of drilled GPs) x (Surface area of Grout Plan)

2. Correlation between SRR and the grout-take volume.

Site-based assessment

Grout Variables

- Total Grout Volume
- Number of Grout Points (GPs)
- Grout per GP
- Length of Grout Points
- **Effective Volume of grouted site (CY/CY)**



$$\text{Effective Volume Grouted (\%)} = \frac{Total\ Grout\ Volume}{(Area\ of\ GP) * (Average\ Drill\ Depth\ of\ GPs)}$$

Geotech Variables

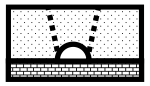
- **H_SAND (AVG)**
  N_SPT_ SAND (AVG)
- **H_CLAY (AVG)**
- **N_SPT_CLAY (AVG)**
- **N_SPT_LIMESTONE (AVG)**
- **N_SPT_LIMESTONE (SD)**
- **T_RAVELING (ft)**
  - Raveling Index (RI)?
  - Sinkhole Resistance Ratio(SRR)

(n = 19 / 44)

Pearson's Correlation	H_SAND	H_CLAY	H_Ravel	N-SAND	N-CLAY	N-LIMESTONE	Depth of LIMESTONE	Collapse Type	RI	SRR
Total Grout	0.044	0.343	0.129	-0.156	0.249	0.234	0.237	-0.084	-0.225	-0.221
Total Grout per GP	0.173	0.387	0.129	-0.224	0.142	0.340	0.167	0.601	-0.092	-0.232
Total Grout per LF	-0.077	0.166	-0.065	-0.164	0.169	0.110	-0.188	0.580	0.172	-0.071
%Eff. Vol Grouted	-0.338	-0.082	0.083	0.055	0.120	-0.245	-0.226	0.441	0.706	0.201

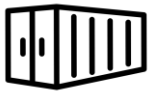
Summary of Findings & Progress – Summer 2025

Critical conditions (Numerical Model)



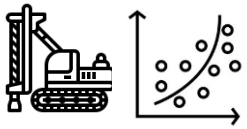
- Field data from Cover Collapse sinkholes suggests $SRR_{critical} = 2.0$
- 115 FEM stability to find SRR simulated in various soil and geometry conditions.
- Bottom-end $SRR_{FS=1.0}$ between 0.3 - 0.5
- Stability Style Chart shows promise when comparing $SRR_{FS=1.0}$ to field data

Critical conditions (Laboratory)



- Viable method determined to test SRR using large scale soil box with simulated void and failure.
  - PANDA DCPT → q_d
- Failure mechanism will be observed and SRR_{Lab} will be measured at various stages.
- Deliverable End of August

Additional Analysis Potential (Grout Take Statistics)



- Field Data shows grout take highly variable in karst conditions in all sinkhole area types.
- **More drilling = more grout** *(duh)*
- **Raveling Index (RI) highly correlated to *Effective Grouted Volume***
- Geologic formation may play a role; multivariable, “region-based” parameters.

  Machine learning application?

- Draft Report End of September
- Close out December

Thank you!

Questions/Suggestions/Feedback?

Photo: 2004 Sinkhole Howland Blvd / Barbara Perez, Orlando Sentinel

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