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Special Contribution

Detection and Geotechnical Characterization of Sinkhole: Central Florida Case Study

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ABSTRACT

Sinkholes are a major geohazard in Karst formed from the dissolution of soluble bedrocks. Due to limestone bedrock and groundwater flow, many sinkholes have been formed, resutling in structural damages to buildings and infrastructure. In this article, types and mechanisms of sinkholes in Florida are presented. In addtion, current practice in detection and characterization of sinkhole subsurface and sinkhole research of Florida Sinkhole Research Institute (FSRI) at University of Central Florida (UCF) are introduced.

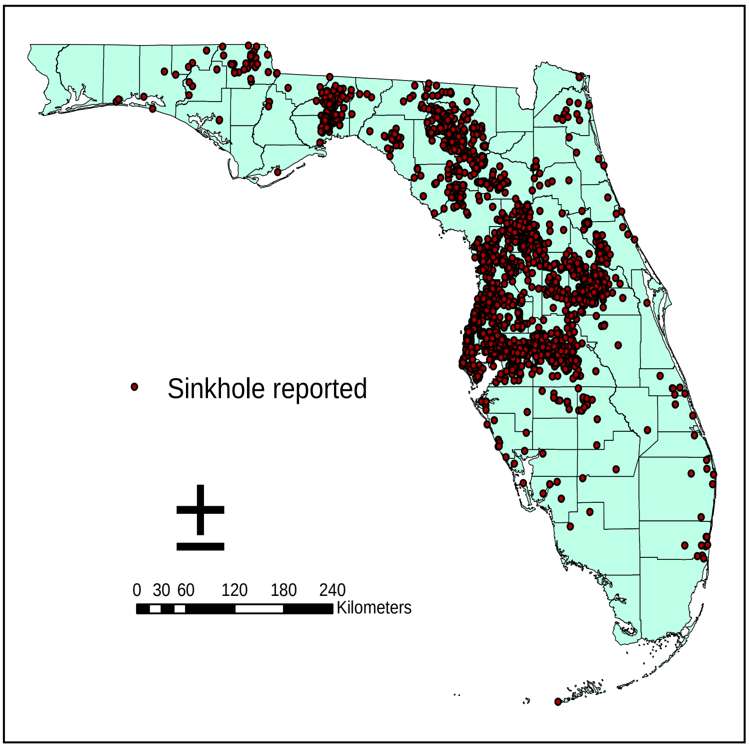
Key Words: Sinkhole, Raveling, Cone Penetration Test, Sinkhole Resistance Ratio

1. Introduction

Sinkholes are a geologic hazard that occurs in areas underlain by soluble bedrock such as limestone, gypsum, marble, anhydrite, or dolomite. Although roughly 15% of the United States is underlain by rock susceptible to sinkhole development (Sinclair 1986), the discussion here after refers to sinkhole occurrence in limestone, which underlays the bulk of Florida's Peninsula (Lane 1986). Example photos showing Florida's karst features are shown in Fig. 1.

Fig. 1. Photo showing typical Florida's karst formation

Sinkholes can cause serious damage to properties and infrastructure, and sometimes human casualties occur, in severe cases. Considerable damage from natural sinkholes is particularly common in Florida, Texas, Alabama, Missouri, Kentucky, Tennessee, and Pennsylvania (Kuniansky et al. 2016). Insurers in Florida, the most vulnerable state to sinkhole damage, received a total of 24,671 claims for sinkhole damage between 2006 and 2010, totaling $1.4 billion (FOIR 2010). According to the Florida Office of Insurance Regulation (FOIR) report, the insurers' expense has been gradually growing with increases in both frequency and severity of sinkholes.



(a) Florida sinkhole map

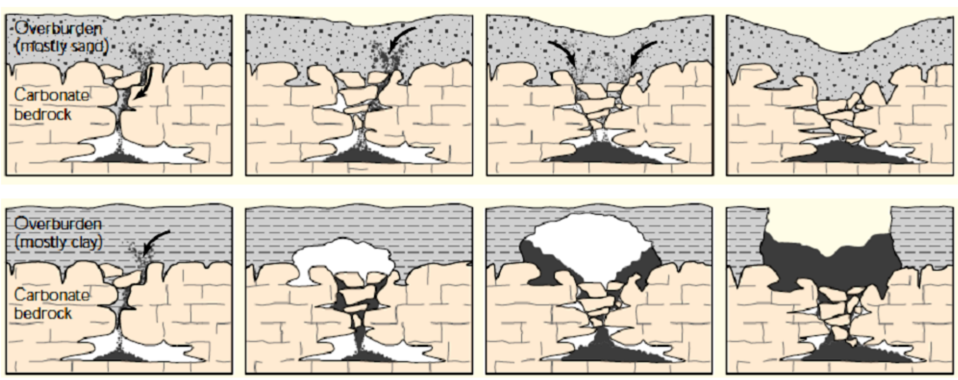
(b) Winter Park sinkhole (in 1981)

(c) Sinkhole near Walt Disney World (in 2013)

Fig. 2. Florida's sinkholes

2. Sinkhole Type and Mechanisms in Florida

In general, sinkholes in Florida are classified into three types, which are cover-collapse, cover-subsidence and dissolution sinkholes. The two sinkhole types that can damage building and infrastructure are the subsidence and collapse types (see Fig. 3). Dissolution sinkholes, also named as cover-sagging sinkholes, commonly take place in mantled karst areas where gradual settlement of the cover by passive sagging may occur due to the progressive corrosional lowering of the rock-head. Sinkholes produced by this mechanism are usually shallow, and they may not be considered a direct threat to human lives due to their significantly slow deformation rates (Gutiérrez et al., 2008). In cover-subsidence (cover-suffusion) sinkholes, the soil depth is large enough for arching to take place, but the high overburden pressure leads the soil to flow into the cavity, resulting in excessive surface settlement. These subsidence sinkholes gradually form over a long period of time. In cover-collapse sinkholes, a subsurface cavity increases due to hydrogeological conditions (e.g. downward seepage) until the overburden depth above the cavity becomes too shallow for arching to develop, then a surface collapse suddenly.



(a) Cover-subsidence sinkholes tend to develop gradually where the covering sediments are permeable sand.

(b) Cover collapse sinkholes may develop abruptly over a short period of time and can result in catastrophic damages.

Fig. 3. Formations of two types of sinkholes common in Florida (from Tihansky, 1999).

3. Sinkhole Detection and Characterization

There have been sinkhole multiple geophysical and geotechnical subsurface methods for sinkhole assessment. In order to identify and estimate subsurface voids, such Ground Penetrating Radar (GPR), surface resistivity, and seismic (or stress) wave methods are commonly used. Advanced data processing technique (e.g. full wave inversion) are also used for 2D or 3D imaging of subsurface cavity. These nondestructive methods are useful as an initial check to identify underground cavity but limited to provide more in-depth engineering information such as soil type, strength(or resistance), stability, and so on.

Therefore, traditional geotechnical subsurface exploration methods such as SPT and CPT are still commonly used for sinkhole geotechnical assessment, particularly for raveling assessment. The natural migration of sandy soil into the cavities within the limestone resulting in the deterioration of overburden soil stiffness is known as the soil raveling concept (Foshee and Bixler 1994). Soil raveling is believed to an initial, and detectible, stage of a sinkhole. The raveling sinkhole concept has been previously studied and supported using SPT and CPT. SPT borings performed within these sinkhole sites, found zones of very low N-value blow counts as well as zones where SPT shows "weight-of-rod (WR)" or "weight-of-hammer (WH)" conditions. In addition, loss of circulation of drilling fluid as well as zones of no recovery from the split spoon sampler were also encountered within these areas. Commonly found directly above the limestone, these soft anomaly zones of sandy material area considered to be due to raveling or subterranean erosion. A typical raveling due to sinkhole activity is presented in Fig. 4. Foshee and Bixler (1994) proposed a CPT-based index, Raveling Index (RI) to quantitatively measure the sinkhole vulnerability. RI is defined as thickness of overburden/thickness of raveled, however, the RI does not account for the magnitude of soil resistance (qc and fs) and has shown some limitations in accuracy and applications.

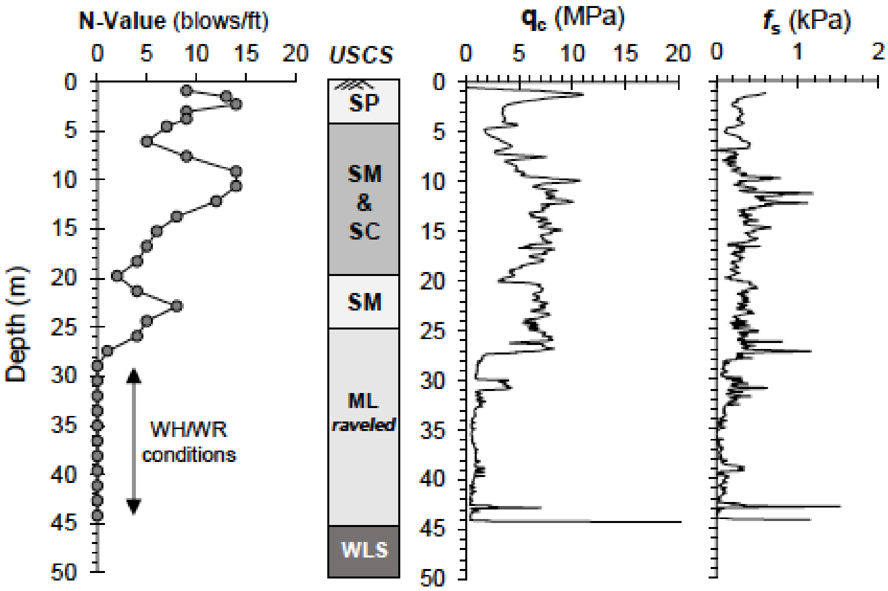
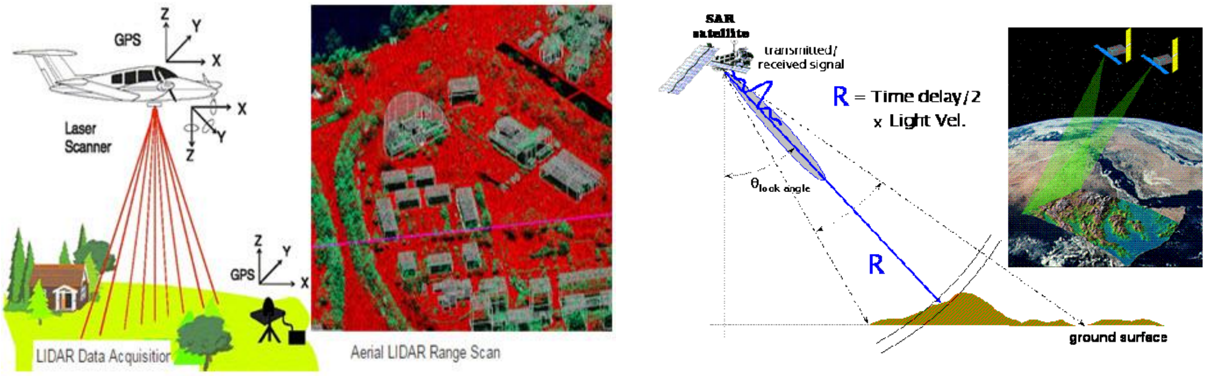


Fig. 4. Sinkhole raveling detected by SPT and CPT.

In addition, remote sensing techniques and methods have been introduced for sinkhole assessment (Kim et al. 2019; Wu et al. 2016). Fig. 6 shows the example figures of LiDAR and InSAR that are used to characterize landform and surface topography. In sinkhole active areas, subsurface soil erosion continues due to groundwater recharge flow, and probably leads to subsidence on the ground. Rainfall events create runoff that can cause significant near surface erosion in the areas of shallow bedrock. Thus, magnitude and rate of subsidence and their shape/trend can be used to detect potential sinkhole in large scale.



(a) LiDAR (b) InSAR

Fig. 5. Remote sensing techniques for sinkhole assessment

4. FSRI's Sinkhole Research

Florida Sinkhole Research Institute (FSRI) at University of Central Florida was established in 1982 after Winter Park Sinkhole, which was opened up in May 1981 with 350 ft wide and 75 ft deep, and have conducted a number of sinkhole research projects. The FSRI constructed sinkhole database, and the database was transferred to Florida Geological Survey (FGS). Recently the FSRI was reactivated with research focus on engineering characterization and mitigation. The institute is also expanding the research to urban ground/road collapse due to aging of underground infrastructure. Example sinkhole research projects of the FSRI are presented in the following sections.

4.1 CPT-based sinkhole vulnerability evaluation

This section presents a CPT-based raveling chart that is used in identifying and classifying raveled soils in Central Florida during initial subsurface exploration. The raveling-chart was developed by collecting a large sample of CPT data (i.e cone tip resistance, qc, and sleeve frictional resistance, fs) from multiple sites within the same geological formation. CPT data was grouped within three categories: collapsed sinkholes, suspected raveling, and no1n-raveled, and plotted using a scatter of data points with coordinates (fs, Qtn,); that is sleeve friction resistance, and normalized tip resistance. A simple statistical analysis was applied for the resulting data group to create envelopes, or threshold lines, which bound the data to create certain categories. The resulting chart provides quantifiable measure of sinkhole raveling due to soil erosion.

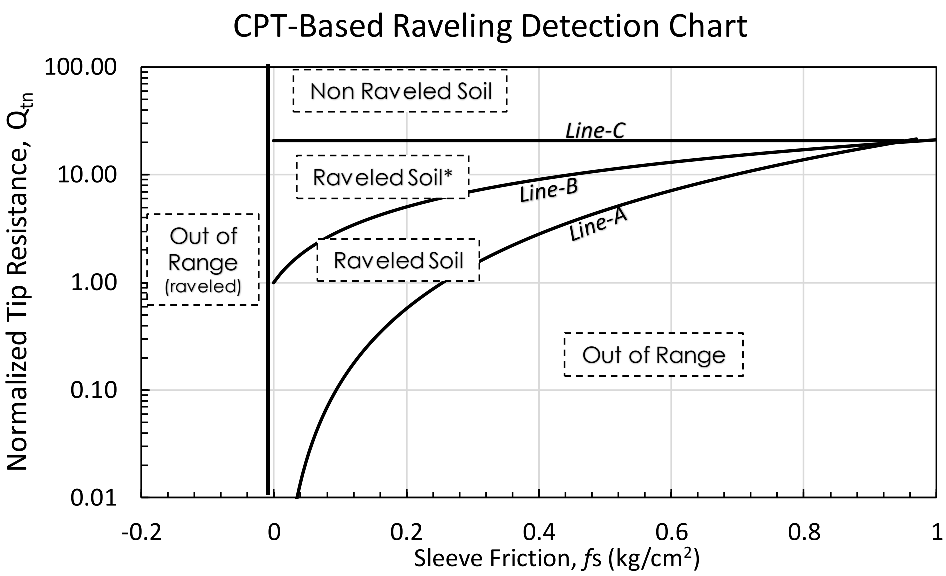
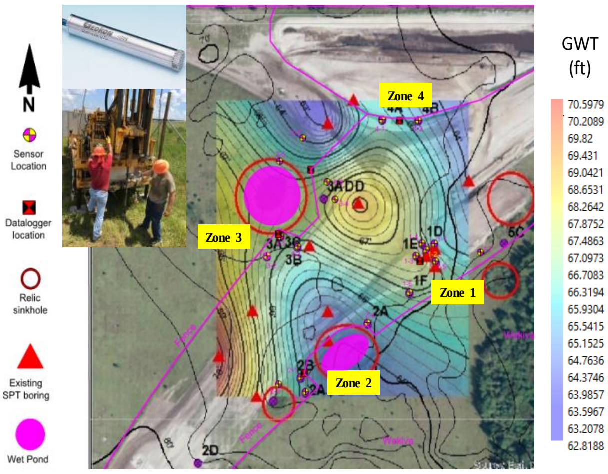


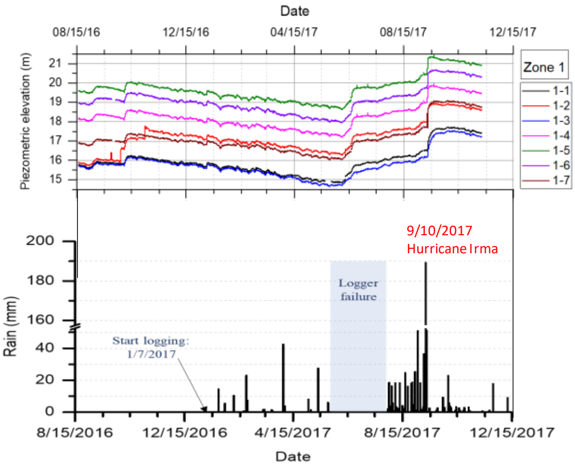
Fig. 6. Sinkhole raveling classification chart (from Shamet et al. 2018)

4.2 In-situ Groundwater monitoring

Hydrogeological approach has been employed because groundwater recharge flow (or seepage downward) is one of major triggering mechanism of sinkhole in central Florida. Multiple piezometer sensors are installed in a pilot study site where SPT and CPT demonstrated active sinkhole activities. The purpose of these piezometer installation is to identify a location of point of recharge, which is assumed as sinkhole source due to higher potential of internal soil erosion. In addition, any sudden change in groundwater table or hydraulic gradient can be a sign of upcoming sinkhole, thus those changes can be detected by continuous monitoring of groundwater. Figures 7a and 7b show the examples how groundwater measurement and monitoring can be used for sinkhole risk evaluation.



(a) Groundwater contour



(b) Groundwater table monitoring

Fig. 7. Groundwater sensing and monitoring for sinkhole risk assessment

4.3 Sinkhole hazard mapping

Mapping of natural hazards has been widely adopted in the areas of earthquakes, tsunamis, flooding, volcanoes, and landslides to help prevent significant damages in vulnerable areas from those specific hazard types. Relatively, sinkhole hazard mapping is not well studied. FSRI has been constructing regional-scale sinkhole vulnerability maps. The probabilistic methods (e.g. Frequency Ratio and Logistic Regression) were used to construct sinkhole hazard models from the statistical analysis of spatial relationships between sinkhole occurrence and a group of contributing factors. The input factors used in computing sinkhole susceptibility index (SSI) include hydraulic head difference, recharge rate, soil permeability, overburden thickness, aquitard layer thickness, depth to water table, and proximity to karst features. Fig. 8 shows the sinkhole vulnerability map of Central Florida area using the Frequency Ratio method. Currently, the authors are exploring a spatio-temporal-magnitude sinkhole hazard approach, which can probabilistically predict location, time, and size of sinkhole.

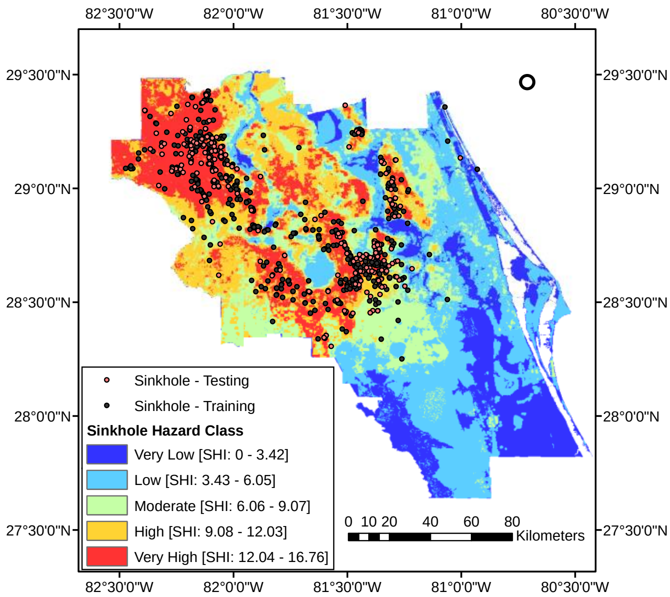


Fig. 8. Regional-scale sinkhole hazard map by FR method

5. Conclusion

Sudden ground/road collapse due to sinkhole (both natural and manmade sinkholes), particularly in urban areas, can cause loss of lives and significant structural damages to buildings and infrastructure. These sinkholes problems have been one of geoscience phenomenon, and thus the topic has received a great attention to geoscience community. Extensive studies, particularly mechanism study, have been carried out from geological, hydrogeologist, geophysical viewpoints, however geotechnical engineering understanding and engineering assessment tools are not well studied. Currently sinkhole problems in the field are mainly based on engineer's knowledge and experience with limited in-situ and lab tests. No systematic and quantitative approaches are available for the sinkhole assessment; therefore quantitative engineering methods are necessary in sinkhole risk assessment. Particularly, engineering methods of cavity detection, stability diagnose, mitigation and reinforcement are crucial in geotechnical engineering community. The authors believe that the role of geotechnical engineers is crucial in the success of sinkhole mitigation and prevention, thus more attention from geotechnical community is necessary.

REFERENCES

Sinclair, B. F. (1986). Sinkholes in Florida. Orlando: The Florida Sinkhole Research Institute.
Lane, E. (1986). Karst in Florida. Tallahassee: Florida Geological Survey.
Florida Office of Insurance Regulation. (2010). Report on Review of the 2010 Sinkhole Data Call. Availabe online: http://www.floir.com/siteDocuments/Sinkholes/2010_Sinkhole_Data_Call_Report.pdf (accessed on July 3).
Foshee, J., & Bixler, B. (1994). Cover-Subsidence Sinkhole Evaluation of State Road 434, Longwood Florida. ASCE journal of Geotechnical Engineering, 2026-2040.
Kuniansky, E.L.; Weary, D.J.; Kaufmann, J.E. The current status of mapping karst areas and availability of public sinkhole-risk resources in karst terrains of the United States. Hydrogeology Journal 2016, 24, 613-624.
Gutiérrez, F.; Guerrero, J.; Lucha, P. A genetic classification of sinkholes illustrated from evaporite paleokarst exposures in Spain. Environmental Geology 2008, 53, 993-1006, doi:10.1007/s00254-007-0727-5.
Kim, Y.J.; Nam, B.H.; Youn, H. Sinkhole Detection and Characterization Using LiDAR-Derived DEM with Logistic Regression. Remote Sens. 2019, 11, 1592.
Wu, Q., Deng, C., Chen, Z. Automated delineation of karst sinkholes from LiDAR-derived digital elevation models. Geomorphology 266 (2016) p 1-10.
Shamet, R., Nam, B. H., Horhota, D, "Development of sinkhole raveling chart based on cone penetration test (CPT) data," The Sinkhole Conference, April 2-6, 2018, Shepherdstown, West Virginia.

◆ A brief CV of Associate Professor Boo Hyun Nam

Dr. Boo Hyun Nam is an Associate Professor in Civil, Environmental, and Construction Engineering (CECE) and Interim Director of Florida Sinkhole Research Institute (FSRI) at University of Central Florida (UCF). He received his Ph.D. in Civil Engineering at The University of Texas at Austin in 2010 and has been working at UCF since 2011. Over the years, Dr. Nam has conducted research in the areas of sinkhole detection and engineering characterization, civil engineering materials (e.g. cement, concrete, and various geo-materials), and interdisciplinary research. He has authored over 120 publications in prestigious international peer-reviewed journals and conferences. Dr. Nam also currently serves in multiple technical committees of ASCE Geotechnical-Institute (GI) and Transportation Research Board (TRB).