THREE-DIMENSIONAL ELECTRICAL RESISTIVITY SURVEYS TO IDENTIFY BURIED KARST FEATURES AFFECTING ROAD PROJECTS

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Abstract

The construction associated with road projects In West Central Florida, including the extension of interstate highways and municipal roadways, sometimes activates buried karst features, as the vibration from heavy machinery and increased infiltration from the clearing of vegetation adds stress to unstable subsurface features. When surface depressions form or raveled soils are detected by SPT borings, it is important to evaluate the extent of the subsurface feature to design effective ground stabilization and prevent activation or recurrence of the feature. Ground penetrating radar surveys are rapid but are usually limited in depth to about 15 feet by shallow water tables and the presence of silts and clays. In an effort to model greater depths and cover large areas relatively quickly, Subsurface Evaluations, Inc. (SEI) has developed geophysical techniques to collect three-dimensional resistivity data using a single pole-pole array that covers up to 1.5 acres and models to depths of 70 to 100 feet depending on site conditions. Two case studies from Tampa, Florida are described.

Case 1: The three dimensional resistivity survey technique was used to evaluate subsidence associated with the construction of new lanes for an expressway when a 5-foot diameter surface depression formed. A test boring over the depression showed very loose and very soft material from a depth of 13 feet to 24 feet, where weathered limestone was encountered. A second SPT boring 20 feet away showed very loose and very soft material from 6 feet to 37 feet and a small surface depression formed around the drill rig.

Case 2: Prior to widening of a two-lane bridge over a creek, SPT borings advanced around the bridge revealed that an isolated area of loose organic sands was present.

In both cases, the subsurface features could not be economically or safely delineated by SPT borings. Three-dimensional resistivity surveys were performed to delineate the extents of the subsurface features associated with the surface depressions and raveled soils. In both cases, a volume of potentially deleterious material was calculated based on the 3-D electrical resistivity survey, which was performed in one day.

Introduction

Sinkhole formation is a significant geologic hazard in West Central Florida. The construction associated with road projects sometimes activates buried karst features, as the vibration from heavy machinery and increased infiltration from the clearing of vegetation adds stress to unstable subsurface features. As a result, surface depressions may form at the road project. Test boring programs may also encounter raveled soils. The formation of surface depressions and presence of raveled soils are indicators of karst activity. The subsurface extent of these features cannot be delineated safely or cost-effectively using standard penetration test (SPT) borings. In addition, ground penetrating radar surveys are limited in depth of penetration to about 15 feet by the shallow water table found in the area and the presence of silty and clayey sands. Therefore, Subsurface Evaluations, Inc. (SEI) has developed a technique to collect three-dimensional resistivity data using a single pole-pole array that covers up to 1.5 acres and models to depths of 70 to 100 feet depending on site conditions. Two case studies from Tampa, Florida are described:

Case 1: In 2003, a 5-foot diameter, 5-foot deep surface depression formed during the construction of new lanes for an expressway in Tampa, Florida. The surface depression was backfilled and a SPT boring was advanced at the surface depression location (Sinkhole 1). The boring log showed very loose and very soft material from a depth of 13 feet to 24 feet, where weathered limestone was encountered. A second SPT boring advanced 20 feet from the initial boring showed very loose and very soft material from 6 feet to 37 feet and a small surface depression (Sinkhole 2) formed around the drill rig as the boring was advanced. The boring logs indicated that the small surface depressions were probably related to a larger subsurface feature that could not be economically or safely delineated by SPT borings.

Case 2: In 2003, prior to widening of a two-lane bridge over a small creek, three SPT borings were advanced around the bridge. One of the test borings near the northwest corner of the existing bridge showed the presence of fine sand from 0 to 4 feet, silty fine sand from 4 to 30 feet, and silty, clayey, organic fine sand from 33 to 75 feet, where the boring was terminated without encountering bedrock. Competent bedrock was encountered at depths between 70 and 75 feet in two other borings advanced near the northeast and southeast corners of the existing bridge. The presence of the organic sand and deeper top of bedrock concerned the geotechnical engineer as the organics might represent a filled paleosinkhole with a throat that may or may not contain raveled soil. At depths in excess of 75 feet, delineating the possible paleosinkhole with soil borings was not economically feasible.

Methods

Subsurface Evaluations, Inc. was asked to recommend a geophysical technique to evaluate the subsurface extents of the geologic features that had been encountered. SEI recommended 3-D electrical resistivity imaging (ERI) surveys to evaluate the sites because of the its cost effectiveness and ability to image geologic features in detail to depths of about 70 to 100 feet (Leberfinger et al, 2000).

For three-dimensional modeling, SEI collects resistivity data using a pole-pole array. The pole-pole array provides the maximum number of independent measurements for a given number of electrodes. A pole-pole array uses the first electrode as the current electrode (transmitter) and all of the other electrodes as the potential electrode (sensor) in turn. The process is repeated with the second electrode acting as the current electrode and the third electrode to the end of the line acting as potential electrodes in turn. This process is repeated until a potential reading is obtained between all possible combinations of electrodes. During the survey, two additional electrodes are placed at least 90 degrees apart at least 5 times the maximum distance between any two electrodes in the array to act as infinity electrodes. One infinity electrode is a current electrode (transmitter) and the other is a potential electrode (sensor). A SuperSting R8® Memory Earth Resistivity Meter with up to 121 switches and up to 121 stainless steel electrodes was used to perform the surveys. Advanced Geosciences, Inc. (AGI), Austin, Texas, manufactured the equipment, which was designed for shallow geotechnical and geological applications and was engineered to have a high signal to noise ratio.

Case 1: The 3-D ERI survey grid was rectangular from the edge of the paved shoulder of the expressway to the right-of-way fence. The grid encompassed both surface depressions that had formed at the site. The grid was 100 feet long and 90 feet wide with 110 electrodes and 10-foot spacing (Figures 1 and 2).

Case 2: The 3-D ERI survey grid was a rectangular area around and beneath the bridge. The grid was 165 feet long and 150 feet wide with 114 electrodes and 15-foot spacing (Figures 3 and 4).

Modeling

After each survey was performed, the field data were transferred to a personal computer and converted into data files for modeling. Three-dimensional inverse resistivity modeling was performed using a computer program called RES3DINV, version 2.10 (Loke, 1997). The output is a series of horizontal and vertical slices at different depth ranges across the area of the survey grid. A small, semi-logarithmic contour interval was used to show minor variations in the low resistivity values while covering the entire range of values.

Figure 1: Surface Depression Activated by SPT Boring.

Figure 2: Survey Site Facing Southwest.

Figure 3: Survey Site Facing West.

Figure 4: Survey Site Facing North.

Results and Discussion

In general, possible geologic features related to karst erosion processes in the Tampa, Florida, area are characterized by the following conditions on the ERI profiles:

- *Low resistivity areas that extend to depths greater than the top of bedrock may indicate weathered limestone or clay-filled dissolution features within the limestone; or*
- *High resistivity material consistent with sands that extends toward the bedrock may indicate sand-filled buried depressions*.

Case 1: Three possible geologic features of interest were identified by inspection of the ERI profiles from the 100-foot by 90-foot 3-D ERI survey performed around the surface depressions that formed in the area where new expressway lanes were being constructed.

Feature 1: This is a low resistivity feature that represents possible weathered limestone or clay-filled dissolution features within the limestone. Sinkhole 2 is located at the northwest edge of this feature (see Figure 5). Feature 1 has a length of about 27 feet and a width of about 10 feet. The feature is evident between 24 and 35 feet deep on horizontal layer 4 of Figure 5. Feature 1 appears to correspond to weight-of-hammer weathered limestone identified between 28 and 37 feet in the test boring at Sinkhole 2.

Feature 2: This is a high resistivity feature that represents a possible sand-filled buried depression. The south end of this feature is located between Sinkholes 1 and 2 and the feature extends to the north to the edge of the survey area (see Figure 5). Feature 2 has a length of about 60 feet and a width of about 25 feet. The feature is evident between 7 and 15 feet deep on horizontal layer 2 of Figure 5. Feature 2 appears to correspond to loose sands identified between 4 and 14 feet in the test borings previously

advanced at the site. New sinkholes (surface depressions) like Sinkhole 1 often form at the edge of buried depressions as runoff and infiltrating water begin flowing downward when encountering the more permeable soil at the edge of the feature, thereby, causing downward movement of soils along the edge of the feature.

Feature 3: This is the deepest, moderate to high resistivity material (300 to 700 Ohm-meters), consistent with clayey sand to sand, identified by the ERI survey. Feature 3 represents a possible sand-filled buried depression. Sinkhole 1 is located at the southwest edge of this feature (see Figure 5). Feature 3 has a length of at least 55 feet and is evident between 15 and 24 feet deep on horizontal layer 3 of Figure 5. Feature 3 appears to be related to Feature 2 and may represent deeper sandy soil that filled dissolution features in the weathered limestone when Feature 2 formed. Feature 3 may represent loose mixtures of clay and sand as the data from the test boring at Sinkhole 1 show very soft and very loose material between 14 and 24 feet.

The ERI profiles generated for the 3-D Grid show very uniform, moderate resistivity material (50 to 300 Ohm-meters) at depths of 35 feet and greater. This is consistent with competent limestone.

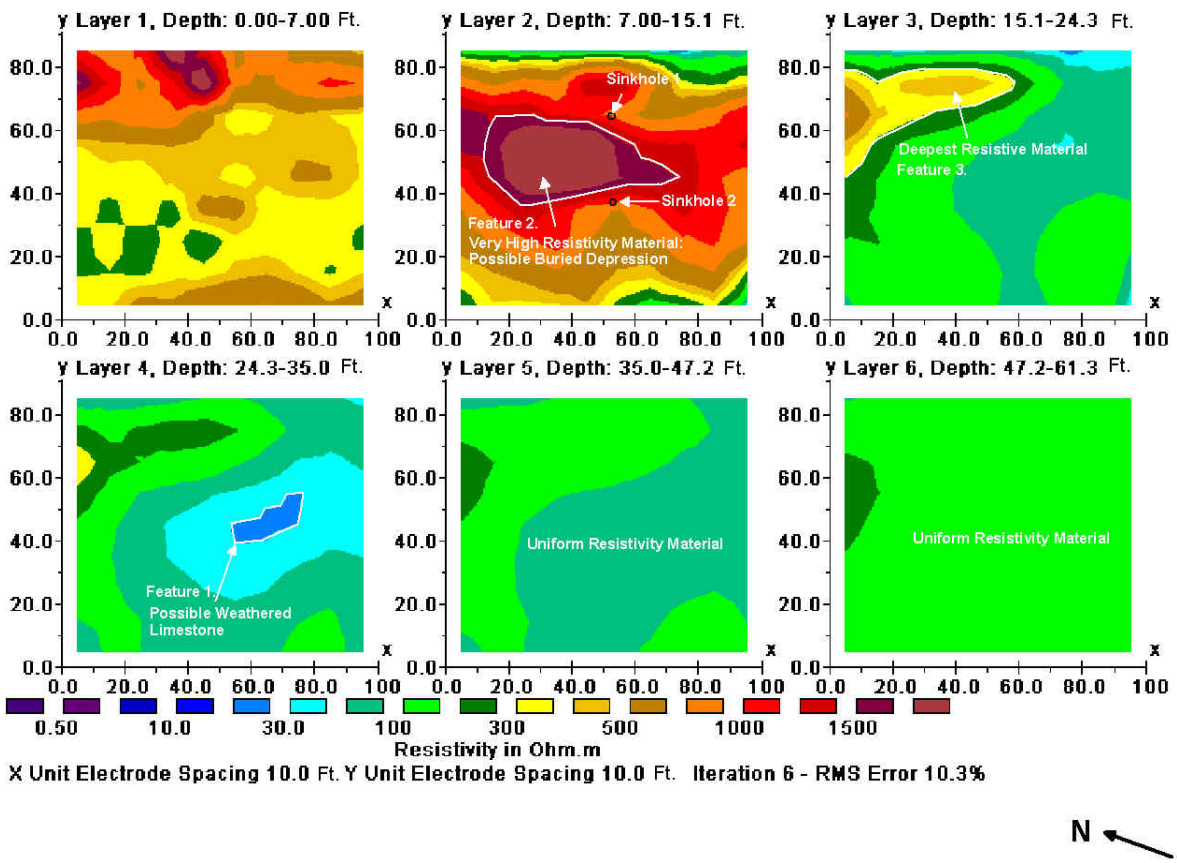

Figure 5: Horizontal Profiles of Depth Slices at the Expressway Widening.

Case 2: Two possible geologic features of interest were identified by inspection of the ERI profiles from the 165-foot by 150-foot 3-D ERI survey performed around the bridge that is scheduled for widening.

Feature 1: This is a relatively low resistivity feature, where moderate resistivity material (225 to 325 Ohm-meters), consistent with mixtures of clay, organic material, and sand is surrounded by higher resistivity material consistent with cleaner sand. Feature 1 is evident within the 36.5 to 52.4 foot depth layer (Figure 6) and has a length of about 70 feet and a width of about 40 feet. The deepest part of the feature, as modeled by the resistivity survey, is located beneath the center of the bridge (Figure 6). The base of the feature appears to be at a depth of about 90 feet. Feature 1 is consistent with a possible

buried depression. The test boring with the organic material at the northwest corner of the existing bridge appears to have been advanced at the edge of this feature.

Following the ERI survey, a test boring was advanced through the bridge deck in the center of the feature. This boring showed the presence of weathered limestone from 63 to 65 feet underlain by weight-of-hammer material and very loose sand and weathered limestone from 65 to 88 feet. This corresponded very well to the 90-foot deep feature identified by the ERI survey (Figure 7).

Feature 2: This is a relatively low resistivity feature, where moderate resistivity material (225 to 325 Ohm-meters), consistent with mixtures of clay, organic material, and sand is surrounded by higher resistivity material consistent with cleaner sand. Feature 2 is evident within the 36.5 to 52.4 foot depth layer (Figure 6). Feature 2 has a length of at least 100 feet and appears to extend beyond the area of the survey to the north and appears to encompass the north edge of the bridge. The base of the feature appears to be at a depth of about 90 feet. Feature 2 is consistent with a possible buried depression.

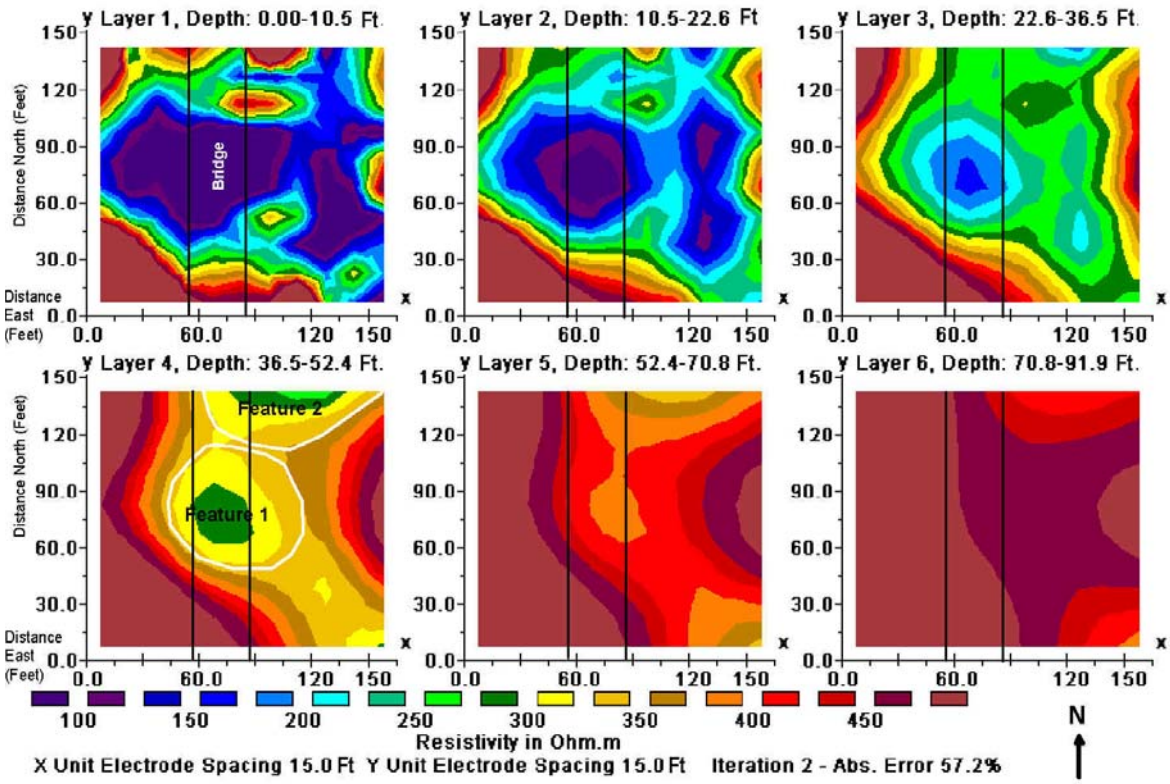

Figure 6: Horizontal Profiles of Depth Slices at the Two-Lane Bridge.

Summary

The three-dimensional resistivity surveys were able to delineate the subsurface extent of the geologic features associated with potentially deleterious materials associated with karst erosion features beneath road projects in the Tampa, Florida, area. The Case 1 survey was performed for $3,500.00 and the Case 2 survey was performed for $4,500.00. In both cases, the 3-D ERI survey was able to provide the geotechnical engineer responsible for the project with an estimate of the volume of the feature to allow an evaluation of design and construction alternatives that reflected real costs based on known conditions. The resistivity models also corresponded remarkably well to the data from soil borings.

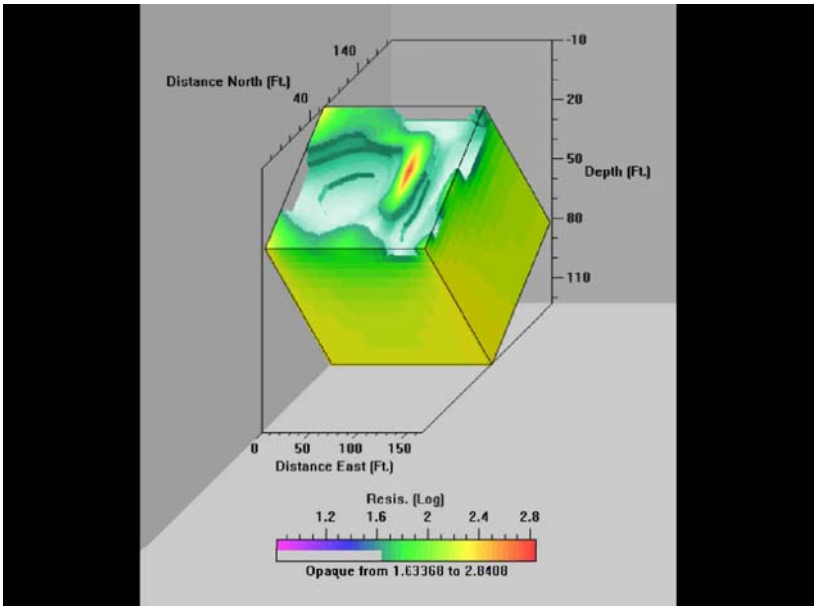

Figure 7: Volume of Resistivity Data Block with Conductive Soils Removed. Block is Tilted about Depth Axis to Illustrate Extent of Possible Buried Depression.

References

Leberfinger JL, Reccelli H, Stahl B, and Warren, J., 2000, Three Dimensional Electrical Imaging. Science Applications International Corporation, 9pp.

Loke, M.H., 1997, RES3DINV version 2.1 from Advanced Geosciences, Inc.