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SINKHOLE REPAIR UNDER HIGHWAY EMBANKMENT

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ABSTRACT: In March of 2002, a depression was discovered in the eastbound lane of SC22 near Conway, South Carolina. Within hours, a hole developed that revealed a void beneath the asphalt pavement approximately 8 feet deep by 10 feet wide. As a safety precaution, the SCDOT filled the void with flowable fill and patched the asphalt while further investigations were conducted. Further investigation revealed that a collapse type sinkhole had developed beneath the relatively new roadway. Geophysical testing data along with several Soil Test Borings were performed to evaluate the potential cause of the sinkhole as well as potential for future sinkhole development in the area. Although the potential for sinkhole development has always existed in the area due to the Coquina Limestone that underlies the relatively thin overburden, the absence of large-scale development has limited the occurrence of sinkholes in the area to subsidence type. As many of these sinkholes go unreported or unnoticed, this phenomenon is not well understood in the immediate area. Using the field investigation tools available, potential solutions to this sinkhole have been developed as well as precautionary measures to reduce the risk exposure as large-scale infrastructure projects continue to be constructed throughout the area.

INTRODUCTION

In March of 2002, a depression was discovered and reported by a passing South Carolina highway patrolman to the local South Carolina Department of Transportation (SCDOT) maintenance office. The area was immediately cordoned off while an attempt was initially performed to patch what was first considered a surficial depression. However, in a matter of hours following the patch, the depression in the pavement "opened" to reveal a void beneath the pavement. The size of the void was estimated to be 8 feet deep by 10 feet wide. As a safety

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precaution, the SCDOT immediately filled the void with flowable fill (lean concrete) and patched the asphalt pavement until a detailed investigation could be performed to determine the extent of what was now identified as a sinkhole, and possible repair procedures to solve the problem. Figure 1 presents a photograph of the sinkhole prior to filling with flowable fill and asphalt patching.

Fig. 1 - Veterans Highway Sinkhole Shortly Before Initial Patching

The location of the sinkhole is along Veterans Highway (South Carolina 22) between the SC19 overpass and the bridge over Kingston Lake Swamp (Bridge 17) near the town of Conway as shown in Figure 2. The Veterans Highway is a relatively new roadway, having been constructed within the last three years. The opening of the sinkhole developed within the fast lane of the eastbound side of the highway at approximate STA 865+34. Slightly east of the sinkhole, two additional surface depressions were also identified on the side of the roadway. At the time of their first detection, these additional depressions appeared relatively shallow in nature and not of immediate concern of collapse.

LOCAL GEOLOGY

The site is located in the Atlantic Lower Coastal Plain Physiographic Province, which is bordered to the northwest by the Upper Coastal Plain and the Atlantic Ocean (and Continental Shelf) to the southeast. The basement rock in the Lower Coastal Plain is typically 2,500 feet below the existing ground surface and slopes upwards towards the fall line, where it is encountered as outcroppings in the vicinity of Columbia, SC.

The near surface marine deposits generally encountered in the vicinity of the Veterans Highway sinkhole are primarily Recent deposition consisting of sands, silts, and low permeability clays. These deposits overlie the Bear Bluff Formation, which consists of cemented calcareous sands, known locally as Coquina Limestone. The upper boundary of this formation varies quite a bit across the area due to past erosion and solutioning of the limestone. Calcium carbonate content in these soils typically ranges between 40% and 60%. Beneath this geologic unit is the PeeDee Formation, which is comprised of fine sands and dark silts and clays deposited in open marine conditions. It is not uncommon to find interbedded layers of the cemented coquina in the upper PeeDee Formation.

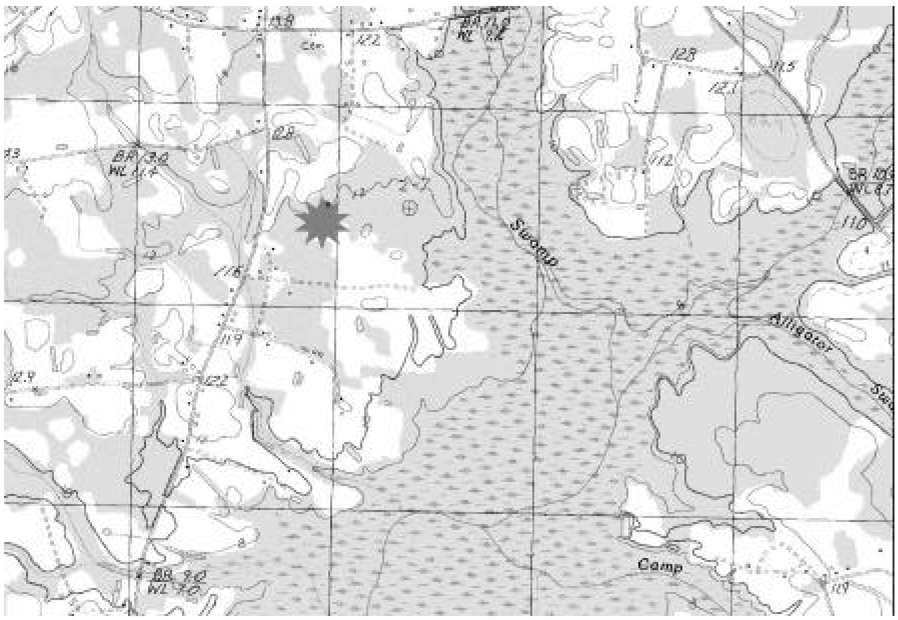

Fig. 2 – Approximate Site Location on USGS Topographic Map (courtesy of Delorme, Inc)

INVESTIGATION SCOPE

Upon discovery of the sinkhole formation by the SCDOT, the contractor involved with the project was contacted. Through the contractors engineering firm, an initial investigation was performed involving a limited number of soil test borings and Electric Resistivity Testing (ERT) in the sinkhole vicinity. Through this initial investigation the collapse within the roadway was verified as being a sinkhole. The nearby surface depressions did not exhibit any voids within the embankment, which would indicate an immediate concern. Based on this initial discovery, the SCDOT embarked on a detailed investigation to answer the following questions:

- Has the existing sinkhole been adequately repaired?
- Is there an immediate concern for further sinkhole development in the area of the existing sinkhole?

- Are the anomalies encountered during the Electric Resistivity Testing (ERT) provided by the contractor traceable to actual soil defects such as sinkhole development, lower compaction or consistency, extreme changes in soil type and properties, etc.?

- What are the typical insitu texture, porosity, geomorphology constituents of the underlying limestone in the vicinity of the sinkhole and the effect they may have on sinkhole development?

- Are there surficial features that may appear on aerial photographs that would be helpful in correlating the existing sinkhole to the potential for sinkhole development elsewhere along the roadway?

- Are the adjacent surface depressions related to sinkhole activity or is some other mechanism at work?

In order to answer these concerns, a multi-phase approach was planned. These phases consisted of additional geotechnical investigation in the field with soil test borings and an evaluation of existing data and input from local geologists with knowledge of the local karst geology.

GEOTECHNICAL FINDINGS

Subsurface Conditions

In general, the soil conditions were similar within the general vicinity of the sinkhole. However, some differences in thickness of overburden do exist and are presented separately as two general areas: immediate sinkhole vicinity and adjacent surface depression area.

Sinkhole Vicinity

In general, our subsurface exploration encountered 6 feet of poorly graded sands identified as embankment fill (SP or SM) underlain by soft to firm, sandy to silty clay to an average depth of 28 feet. Below the clay is the coquina limestone, which extends to the PeeDee Formation encountered at a depth of 96 feet.

The exception to this generalization is within the centerline of the sinkhole, where below the approximate 10 feet of cementious flowable fill are very loose sands to a depth of approximately 27 feet. Organic debris (wood chips) and organic laden soils were encountered at a depth of 12 feet and continued to a depth of 20 feet. Rod drops were noted immediately below the flowable fill, as well as at depths of 18.5 feet and 24 feet. Rod drops are defined as zones where a void or extremely loose soils exist that allow the drilling tools to "free fall." Drilling fluid loss was also observed immediately below the flowable fill. Below the sand is a very soft clay which transitions to the coquina limestone at a depth of 31.5 feet. This boring was terminated within the coquina.

Adjacent Surface Depression Area

In general, the borings performed in this area encountered 12 feet of embankment fill (SP or SM) underlain by interbedded layers of soft to firm, silty clay and loose to medium dense, clayey sands to an average depth of 28 feet where the coquina was encountered. Some variation in the depth to the coquina limestone does exist as it was encountered as shallow as 22 feet within one of the borings.

Laboratory Testing Results

Laboratory testing was limited to Calcium Carbonate Content testing (ASTM D 4373) of select samples of the coquina. Testing revealed calcium carbonate content ranged from 42% to 65% for the selected samples, which indicates that the limestone is moderately to highly solutionable in an acidic environment. Spot-checking select samples in the field with a weak muratic acid solution (diluted HCL) indicated that the coquina was highly reactive.

Review of Existing Data

The review of existing data included the geotechnical investigations performed during the development of the project and after the initial sinkhole collapse. Information was also provided by SCDOT inspectors that were present during the construction of the roadway. In general, the boring logs performed previously matched the ones performed during this study. ERT testing revealed many areas of higher relative conductivity and correspondingly lower relative resistivity, which indicates the potential for a soil defect. These defects may be in the form of, but are not limited to, large voids, increased porosity, or soft saturated clays. The ERT does not, however, indicate what type of anomaly. Based on the review of documentation, it appears that geogrid was used at the base of the embankments between STA 865+00 to 866+50 to bridge what was described as a wet area.

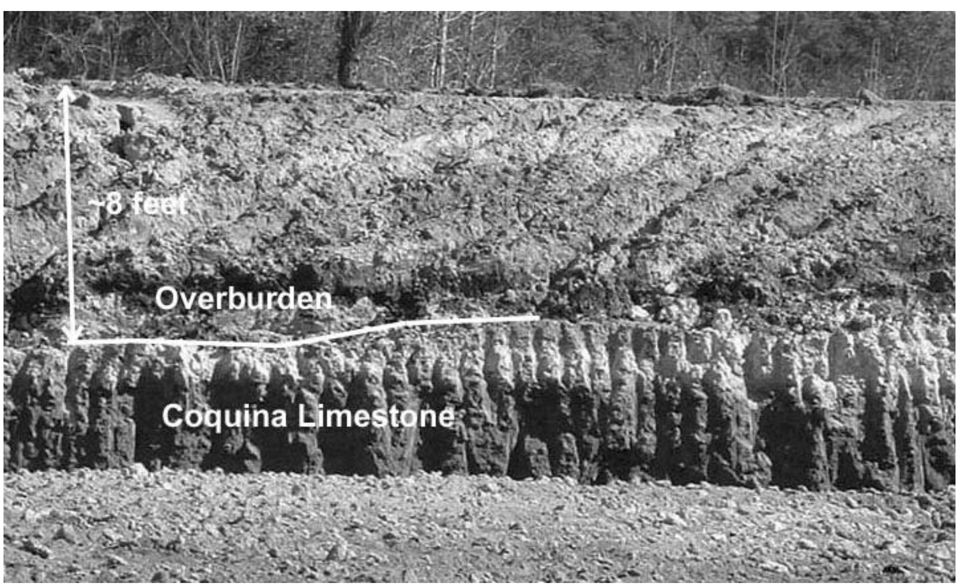

Fig. 3 – Nearby Strip Mine Excavation Showing Local Stratigraphy

The high concentration of Coquina Limestone in the Conway area can lead to problems associated with dissolutioning, which is typically a very slow process (Harris, 2003). Generally, the sinkhole type most prominent in the area is a subsidence type due to the thin overburden and the coquina's high porosity and past dissolution activity. Two ponds, Clear Pond and The Vineyard, located nearby, are examples of local subsidence type sinkholes that are very deep and have been filled with organics over time (Wright, 2003). Figure 3 presents a view of the local stratigraphy at a nearby strip mine excavation.

SUMMARY

After implementing the multi-phase investigation, the following conclusions were defined based on the original questions that were posed prior to beginning the project.

Has the existing sinkhole been adequately repaired? Evidence of continued sinkhole activity exists as evidenced by rod drops and fluid loss immediately below the flowable fill "plug" that was placed approximately twelve months prior to this investigation. This conclusion indicates a long-term solution needs to be developed. Without remediation, the soils beneath the roadway and flowable fill plug will likely continue to subside and result in either a depression forming or in another collapse type failure of the roadway adjacent to the original.

Due to the relatively long period of time for the dissolutioning process to occur, it appears that the sinkhole was already present prior to the construction of the road. It was most likely present in the form of a highly porous cemented structure as opposed to a cavern or void, which is typically encountered in the Floridian aquifers. The relatively clayey overburden and the geogrid supported embankment acted as a reinforced cap to temporarily bridge over the weakened soil structure during construction. With time, the structure finally collapsed resulting in loss of the embankment soils. This was probably compounded by the past drought activity in the state. As the groundwater table is lowered, the effective unit weight of the overburden soils increase as buoyancy decreases.

Is there an immediate concern for further sinkhole development in the immediate area of the existing sinkhole? It is practically impossible to predict when and if new collapse-type sinkholes will develop along the highway. However, based on the slow process of limestone solution and the field exploration undertaken for this project, it is unlikely that multiple new collapse sinkholes would form in the near future unless there is drastic change in environmental factors. However, steps should be taken to evaluate the long term stability of the roadway.

Are the anomalies encountered during the Electric Resistivity Testing (ERT) traceable to actual soil defects such as lower compaction or consistency, extreme changes in soil type and properties, sinkhole development, etc.? The evaluation performed during this project suggests that a properly designed ERT program can prove to be a useful tool in evaluating soil defects as they relate to embankment stability and pavement serviceability in the area.

What are the typical insitu texture, porosity, geomorphology constituents of the underlying limestone in the vicinity of the sinkhole, and the effect they may have on *sinkhole development?* In general, the high calcium carbonate content of the coquina and the relatively porous structure lends itself to dissolution. However, these properties are similar to coquina elsewhere in the region, therefore this phenomenon is not site specific.

Are there surficial features that may appear on aerial photographs that would be helpful in correlating the existing sinkhole to the potential for sinkhole development elsewhere along the roadway? At this time there does not appear to be a direct correlation to surface features, namely Carolina Bays, which are prevalent in the nearby area, and the development of sinkholes.

Are the surface depressions related to sinkhole activity or is some other mechanism at work? Based on the observed surface features and results of the field exploration, it is our opinion that the sinkhole and surface depressions are two different phenomena. The surface depressions appear to be the results of compression and nesting of organics and erosion of the embankment fill into the voids within the organics below the filled embankment.

RECOMMENDATIONS

At the time of this paper, the solution to repairing the sinkhole is currently being finalized. During this project, several common techniques to provide a permanent repair were evaluated. These included excavation and replacement, a high mobility grouting (HMG) program, and a low mobility grouting (LMG) program. Due to the lack of large specific voids, it was determined that an LMG program has a significant chance at long-term success and is relatively economical with minimum traffic disruptions. The exact components of the program would consist of compaction grouting near central sinkhole locations and possible compensation grouting away from the central core. Additional subsurface investigations surrounding the active sinkhole are planned to help define the limits more thoroughly. This field-testing will include a combination of closely spaced soil test borings and higher resolution electrical resistivity testing (ERT) in the immediate vicinity of the sinkhole. The additional information will be used to formulate the final plan and develop specifications.

The compaction grouting is intended to fill larger void spaces and densify the softer soils. This method has the effect of breaking the poorly cemented Coquina structure and reducing the overall porosity by forcing the in-place soil particles closer together. The resulting change in porosity will decrease the permeability, and therefore the solutionability, of the coquina. The grout-reinforced soil also provides a strength gain for the upper soils, which have been weakened by the formation of the sinkhole.

FUTURE CONSIDERATIONS

In the area of the active sinkhole, the plan calls for long-term monitoring points be established to measure deformations that may occur after the repair. This will be done to ensure that the sinkhole activity has not shifted to other portions of the roadway, as well as ensure the existing roadway is not negatively affected by the repair work. Follow up Geophysical testing, such as ERT or GPR testing, may be performed at some length of time after repairs have been made to evaluate the effectiveness of the repairs and to help determine if new voids have formed.

CONCLUSIONS

As the first recorded collapse sinkhole in this area, which is developing rapidly, this problem reveals a new concern for future infrastructure development as well as newly constructed roadways. Until now, surface pavement depressions have typically been associated with normal maintenance problems with embankments constructed on soft soils. Some of these areas may need to be reassessed and evaluated to eliminate the potential for active sinkhole development.

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APPENDIX I. CONVERSION TO SI UNITS

Feet (ft) X 0.305 = meter (m)

Pounds per cubic foot (pcf) X 0.157 = kilonewton per cubic meter (kN/m^3)

U.S. ton per square foot (tsf) X 95.7 = kilopascal (kPa)