THE WINTER PARK SINKHOLE AND CENTRAL FLORIDA SINKHOLE TYPE SUBSIDENCE

S.E. Jammal, P.E.
President, Jammal and Associates, Inc.
Consulting Geotechnical Engineers
P.O. Box 339, Winter Park, Florida, USA, 32790

Abstract
The karst topography of Central Florida, with marine calcareous sediments overlain by clays and sands, has experienced much sinkhole activity. During the past 20 years, approximately 70 sinkholes have formed in the two major Central Florida counties (Orange and Seminole). Most occurred in April and May, when rainfall is reduced and aquifer withdrawal is high. Sinkholes are typically small, from a few meters in depth to 10 meters in diameter. An occasional large hole forms, which may cause substantial damage, such as the Winter Park sinkhole. It grew to about 106 meters in diameter and 30 meters deep.

Engineering in potential sinkhole areas involves a careful examination of site conditions, geologic and hydrogeologic characteristics, subsurface soil conditions and construction influences. Prediction that a specific sinkhole will occur is not possible, but engineering can offset potential dangers. Evaluation of sinkholes after the fact can lead to a better understanding and effective corrective measures.

Geology of Central Florida
The Florida Platform, about 480 x 800 kilometers in size, consists primarily of sedimentary deposits laid down in a nearly horizontal manner. The oldest sediments are shallow water marine deposits formed on continental shelves; no sediments formed in deep oceanic basins are recognized. Sediments in peninsula Florida consist essentially of fragmental and pasty marine limestones, sandstones, and shales. An uplift along the longitudinal peninsular spine created an elevated topography, with subsurface longitudinal and transverse fractures, thus allowing subsurface drainage. The latter accentuates cavern formation along the fracturing. At the Winter Park sinkhole site below ground surface at about 27 meters above Mean Sea Level (MSL), lie about 18 meters of loose to dense deposits of sands, clayey sands, and slightly cemented sands (Pleistocene). Below these lie about 27 meters of loose to very dense clayey sands, with silt, shell phosphate and dolomite fragments (Hawthorn formation), bedded on limestone of the Ocala Group. This latter layer overlays the Avon Park limestone formation. Solution cavities occur in the Ocala and Avon Park limestone beds. This stratigraphy has been laid down in successive marine exposures. The geology is similar in the Central Florida region to that cited, with variation in depths to limestone and the groundwater piezometric surface, and surface elevation. Figure 1 indicates the Florida Platform with comments; Figure 2 is a profile of the subsurface conditions at the Winter Park site with comments on the hydrology and the sinkhole.

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Figure 1. The Florida Platform

Figure 2. Stratigraphy - Winter Park sinkhole site
Environmental Conditions in Central Florida

Central Florida receives about 130 centimeters of rain each year of which about 70% is lost to evapotranspiration. Thus there is a substantial flow which passes into or over the ground. Since upper levels are sands, extensive infiltration occurs, with recharge of the limestone aquifer through fractures, sinkholes, solution pipes, or porous formations. Western Orange County, in which Winter Park lies, is an excellent recharge area. The Floridan Aquifer in the limestone has a piezometric level of about +14 meters (MSL). It is overlain by the Hawthorn aquiclude. A non-artesian aquifer lies above the Hawthorn.

The climate of Central Florida is subtropical and during geologic ages solution cavities have formed. Subsurface cavern development is extensive as demonstrated by the many large springs and lakes. The countryside is dotted with lakes and cypress bayheads due to various types of subsidence in the past.

Water supply in Central Florida is derived from subsurface wells drawn from the Floridan or overlying aquifer. Thus there are many local disturbances of the subsurface hydrology, which become particularly important in the normally dry months of April and May. Pumpage is a factor of significance in sinkhole formation. In addition, numerous drainage wells, installed over many decades for storm water disposal, affect the local flow patterns as well as the chemical condition of the water inserted into the aquifer.

Local Geology and Sinkhole Activity

In Orange and Seminole Counties subsidence is due to at least five important factors, each vary with the local site conditions.

1. Fault patterns
2. Surface and subsurface drainage patterns
3. Groundwater table fluctuations
4. Soil permeability and its impact on recharge
5. Water chemistry

Winter Park and adjacent areas lie at the terminus of at least three faults. The City is in a topographically closed area which means that stormwater flows into the area. Various water supply wells exist, pumping large volumes, as well as drainage wells delivering corrosive water to the limestone. Recharge does occur, particularly in faulted conditions. Cavities in the underlying limestone, developed over geologic ages, are interconnected with piping into the Hawthorn layer and overlain by sand. Gradual solution and erosion of sands and clays, can lead to surface layer penetration and a sinkhole. Several sinkholes have occurred in the vicinity since 1961 and sinkhole activity is expected to continue. Identified faulting patterns in the area are depicted in Figure 3.

Winter Park Sinkhole

Penetration of the surface sands at the sinkhole site in Winter Park occurred about 8:00 p.m., Eastern Standard Time on May 8, 1981. A resident of a nearby house, which was subsequently lost in the hole, noted a swishing noise and a large sycamore tree disappearing into a hole. Police secured the area overnight. Over the next few days the hole grew to about 106 meters in diameter and 30 meters deep.
Recorded Sinkholes since 1962

Area of Porous Soil and Fort Preston Aquiclude

Area of High Water Level Fluctuation (5-6 m in 1960 to 1962)

Figure 3. Identified faulting patterns in the area.

Initially it was a dry hole, as can be seen in early photographs. At that point the central aven through the Hawthorn was well defined. Later the hole filled to the piezometric level of the Floridan Aquifer (about +14 meters (MSL)). During formation, the sinkhole destroyed streets, utilities, recreational facilities, one house, several businesses, and six vehicles. It seriously interrupted local traffic. There were no personal injuries. Substantial community impact occurred, with demands on police, city and county governments, and news media. The site required surveillance and restricted access, which continues to this day. Figure 4 is an aerial photograph of the sinkhole at time of maximum growth. Figure 5 shows its location with respect to local sinkhole occurrences in the past.

Investigation - Winter Park Sinkhole

The sinkhole had an immediate detrimental effect on the City of Winter Park, its traffic, businesses, utilities, as well as a resident whose house fell into the hole and was destroyed. As the hole grew it threatened a major traffic artery and interrupted well-traveled City streets. The City was unsure just how much additional damage would occur immediately or over a long period, since the future stability and growth of the hole was uncertain. Hence the City retained Jammal and Associates for initial advice as the hole was growing, then instructed Jammal to investigate and
Figure 4. Aerial photograph of Winter Park sinkhole about 3 p.m., May 11

Figure 5. Location and distribution of sinkholes around Winter Park
report on the collapse, the possibility of disastrous long-term effects, and proposals for corrective measures. Jammal investigated the sinkhole site for ten months. A detailed, written report was made to the City.

Investigation proceeded in the following general order:

1. Observations on formation of the sinkhole. A substantial number of photographs were taken (photographs by the news media were available).
3. Review of subsurface data for the area.
4. Documenting the topography of the sinkhole by means of photogrammetric surveys using color, black and white aerials, and infra-red color.
5. Standard penetration test borings, with four bordering the hole and one inside on a side slope after it stabilized. Initially the slopes were in a "quick" condition.
6. Auger borings to the north and west (toward the nearest lakes, at higher piezometric levels) to identify near surface soil conditions and the shallow aquifer.
7. Soundings and later fathometer readings in the hole to establish the bottom profile.
8. Installing shallow observation wells on north and west lines toward adjacent lakes.
9. Examination of water quality.
10. On-going review of data to adjust the investigative plan as needed.

The sinkhole stabilized with vertical banks in various rim areas and steep slopes in others. These were in surficial sands, (the Ft. Preston layer) hence the sinkhole after stabilizing was still expected to grow substantially due to rain and weathering unless corrective measures were taken. Figure 6 shows the hole and the various boring positions around the initial rim.

The borings indicated that there was a non-artesian surficial aquifer, conically depressed around the sinkhole. Below this, above the Hawthorn, was a secondary piezometric aquifer not interconnected with the surficial aquifer, again circumferentially depressed around the hole. Separated by a few hundred feet, two other areas of depression were found indicating possible future sinkhole sites.

Five standard penetration test borings were made to depths of 52 meters below ground surface. None of the five showed the presence of soft zones that would have indicated potential unfilled voids within the subsoil.

Twenty auger borings drilled to depths of 9 meters provided information on the texture and stratigraphy of the upper sandy soils and allowed determination of the non-artesian water table level. Nothing unusual was encountered for these soils. The primary objective for these borings was to make water table observations and provide guidance for installing the shallow observation wells.

Water was first observed in the sinkhole about noon, May 9, at an estimated depth of 30 meters below ground surface. It slowly rose to the piezometric level of the Florida Aquifer (about +14 meters (MSL)), then continued rising, indicating the aven had been plugged. The water surface was at elevation of +19.5 meters (MSL)
on July 19, when it suddenly cycled down to piezometric level, +13.4 meters (MSL). Subsequently, it cycled up to +19.5 meters (MSL) and again dropped down to +13.4 meters (MSL) on September 20. Following this second draining the water level rose, indicating a plug, and remained at about a normal lake level in the area. Nearby Lake Killarney has an elevation of +25 meters (MSL). A definite subsurface gradient was observed between Lake Killarney and the sinkhole pool. Fathometer readings and soundings in the sinkhole pool indicated a definite bottom, but the plug was full of debris, e.g., a house, six automobiles, and trees. The sinkhole pool contained extensive floating debris.

Water quality sampling in the sinkhole indicated no unusual results for groundwater.

Technical Conclusions - Winter Park Sinkhole
The Winter Park sinkhole was formed as a result of long-term erosion and ravelling of overburden material into cavernous limestone, not a roof collapse in limestone. Even though the sinkhole developed rapidly, it was a progressive erosion of overburden starting with a small ground depression. The aven was 13 to 17 meters in diameter and by observation penetrated 9 to 12 meters into the Hawthorn formation. It was Jammal's opinion that the sinkhole had been forming over a long time period, but that formation was accentuated over a period of about 50 years, resulting from a progressive
decline of the piezometric level of the Floridan aquifer. About 50 years ago this level was about +20 meters (MSL) and now is about +14 meters (MSL). Decline can be attributed both to extended below average rainfall and areal pumping of wells. No evidence was found of contributing factors such as local plumbing leaks. A profile of the sinkhole as it existed and with projected erosion is shown in Figure 7. The sinkhole was stable in 1982 and continued stable through 1983.

Alternatives for Correction of Damage
The City was interested in alternatives to offset damage. Correction would be complex since the sinkhole was in part on City owned property, and in part on the private property of several owners. By law, the City could not expend public funds on private property.

A total of seventeen alternatives were considered in the report to the City. Alternatives included bank stabilization to prevent further erosion, a drainage well for lake level control, restoration of Denning Drive, (a major street) and recommendations on a systematic investigative program to document sinkhole changes in the future. The alternatives were expensive, so action was delayed. Through 1983 the private owners commenced bank filling to stabilize
and recoup their business property. The City had previously closed several businesses because of dangerous bank conditions. The City initiated construction modifications on their property—steep banks and Denning Drive. Complete filling of the sinkhole was initially rejected because of the amount needed, about 150,000 cubic yards, and cost. To date, substantial filling of the edges has occurred using construction debris. Hence, filling may be the final solution.

**Impacts**

There was intense media coverage extending internationally. Thousands of visitors observed the sinkhole and crowd control and safety burdened the City. Beyond the public information aspect, there was increased demand for sinkhole speakers both in schools, professional societies, service clubs, and other organizations. Further, it was apparent that, while many agencies were involved, no central depository existed for sinkhole or relevant geologic and hydrologic data. Therefore, a Sinkhole Research Institute was established at the University of Central Florida, Orlando, by the State of Florida. Lastly, it rapidly became apparent that sinkhole insurance coverage was deficient in Florida. Only the family home lost in the Winter Park sinkhole was covered against damage. All other losses were not protected. The 1981 Florida Legislature rapidly redressed this situation, expanding the availability of insurance coverage.

**Engineering in Potential Sinkhole Areas**

The consulting engineer, particularly in geotechnical engineering, is constantly faced with the potential for sinkholes throughout Central Florida. Since this is a fact of life subsurface investigations and engineering must be approached cautiously. Based on existing information, the future occurrence of an individual sinkhole on a proposed construction site cannot be predicted with certainty. However, the site can be evaluated for potentially dangerous areas, which may be avoided during land planning. Or, if it is necessary to develop a less than perfect site, subsurface investigations must be thorough enough to allow engineering to a reasonable risk.

Investigation of a site requires a systematic examination of the features outlined below.

1. **Site Conditions**
   a. Topography.
   b. Site surface features. Examine for depressions, leaning trees or poles, stressed vegetation.
   c. Drainage patterns.
   d. Occurrence of sinkholes, on site or in the region.

2. **Geologic and Hydrogeologic Conditions**
   a. Geology of the area.
   b. Fault lines and lineament maps.
   c. Groundwater levels.
   d. Quality of groundwater in the Floridan Aquifer.

3. **Subsurface Soil Conditions**
   a. Stratification.
   b. Consistency — Look particularly for soft zones in drilling and loss of drilling fluid.
c. Texture.
d. Groundwater level - Search for cones of depression.

4. Influence From Construction
a. Wells, drains, and storage ponds may enhance potential in an otherwise stable situation.

Once a thorough evaluation is made, the engineering will be focused on offsetting possible effects, whether by using piling, spread footings, grouting subsurface formations, or similar techniques.

Beyond engineering for initial construction of larger facilities, is the evaluation and correction of damage once subsidence starts, or a hole occurs. This damage may be due to a sinkhole in open land or one impacting a structure. Florida has many small sinkholes. When these stabilize the typical practice is to fill them. Further, there are many structures where the cost of geotechnical investigation and the low frequency of sinkhole formation do not warrant initial detailed analysis such as roads and subdivisions. The latter may be as large as several thousand houses and investigation under each is not practical nor economical. In cases such as these, reconstruction becomes a way of life, or damage can cause abandonment in severe cases. Where cracking starts, indicating subsurface movement grouting has been a common solution. In many cases in subdivisions, the home owner has caused the problem by improperly installing an irrigation well. Post construction tasks are varied and are approached on an individual evaluation basis.

Summary
In Central Florida, geologic history has created a karst environment with great potential for sinkhole development. Sinkholes are a way of life as evidenced by the many lakes, springs, and sinks, and the recent documentation of the phenomenon in more detail. In this region the geotechnical engineer must be particularly competent and vigilant in dealing with potential problems on development sites, and in correction of damage after occurrence.