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ABSTRACT

Claims for sinkhole damages have increased significantly since the passage of legislation in 1969 requiring Florida insurance companies to provide sinkhole coverage for residential properties. At many sites, there is little surficial evidence of karst activity (ie. Areas of subsidence and depressions) to provide a direct link between a suspected sinkhole and damage to the structure. Whatever the cause of the damage, sinkhole damage investigations are becoming increasingly important.

The karstic terrain and limestone bedrock typical of west-central and central Florida make the area susceptible to sinkhole activity. However, the geologic setting and potential impacts to structures is complicated by the presence of shrink-swell clays that cover the limestone materials, organic infilled paleokarst features or poor construction site grading practices.

Subsidence-like damage to houses can result from other mechanisms such as decay and compaction of buried organic debris and organic-rich sediments, or movement of shrink-swell clays. This paper will present investigative methods and case histories that detail the extent of the field investigations, often with conflicting conclusions.

Keywords

Sinkhole studies
Subsidence
Shrink-swell clays

INTRODUCTION

Claims for sinkhole damages have increased significantly since the passage of legislation in 1969 requiring Florida insurance companies to provide sinkhole coverage for residential properties. In part, this may be due to factors such as expanded development in formerly rural areas (multiplying the number of reported sinkholes), increasing ground water withdrawals and the result of drought conditions in central Florida. Increasingly, damage claims are being submitted for relatively small property losses involving non-structural damage that may, or may not, be the result of sinkhole activity (minor wall cracking and floor settlement). At many sites, there is little surficial evidence of karst activity (ie. Areas of subsidence and depressions) to provide a direct link between a suspected sinkhole and damage to the structure. Whatever the cause of the damage, sinkhole damage investigations are becoming increasingly important; both to verify that sinkhole claims are correctly diagnosed and to ensure that a proper remedy to repair the damage is recommended.

Local Geologic Conditions and Uncertainties

The limestones that form the foundation of Florida's geologic column are several hundred meters thick. They were formed during geologic periods of submergence, much like limestone deposits currently forming in the Caribbean Sea and Atlantic Ocean areas around the Bahamas (Sinclair, et.al., 1985). The limestone beds were then periodically exposed and subject to erosion and solutioning. It was during these periods of emergence that paleokarst features started and/or formed.

The upper 30 to 60 meters (100 to 200 feet) of the tertiary sediments consist of interbedded clays, clayey sands, and limestone (dolosilt) materials, known as the Hawthorn Group (Sinclair, 1985). The underlying Floridan aquifer system consists primarily of fractured, weathered, and karstic limestone.

The upper portion of the Hawthorn Group materials is the phosphate ore bearing zone. The three to four meter thick ore interval is locally known as the Bone Valley Formation. A typical geologic cross-section is shown in Scott (1989). The Hawthorn Group materials are typically overlain by a variable thickness of Recent to Pleistocene beach and estuarine deposited sands with little or no clay fines. Because of the long geologic periods of emergence and the disconformable stratigraphic layering in the limestone materials, there is a high probability of the presence of karst features. These buried geologic features often remain undetected by either remote or direct detection methods.

The major types of sinkholes have been discussed by various authors (Sinclair, 1985; Wilson, 1995; Culshaw and Waltham, 1987). The two major categories of sinkholes are the solution (dissolution or doline) sink features and the collapse type (See Figure 1)

Cover-collapse sinkholes form where a thick, competent, and generally impermeable clay layer overlies limestone bedrock. Initially the clay has sufficient strength to bridge a developing cavity in the underlying limestone. A cover-collapse sinkhole occurs as a result of sudden failure of the clay unit and catastrophic downward movement (ie. Raveling) of the overlying sandy soils into the cavity. Cover-subsidence sinkholes form by the gradual downward raveling of noncohesive sediments (usually sand and silt) into actively forming cavities. The raveling reduces soil density, which is manifested at the surface by an area of slow, gradual subsidence.

Sinkhole density is simply the number of mappable or visible natural closed depressions per unit area (Wilson, 1995). Visible sinkhole densities of about 50 per square mile are common in central Florida.

Buried sinkhole densities, in known karst areas of central Florida, may be in the thousands per square mile. Wilson (1995) estimates that six to 50 percent of all buried sinkholes are currently eroding or raveling and are potentially unstable.

From a recent GPR survey in central Florida he estimated the number of potential buried sinkholes to be on the order of 7,000 per square mile for this area.

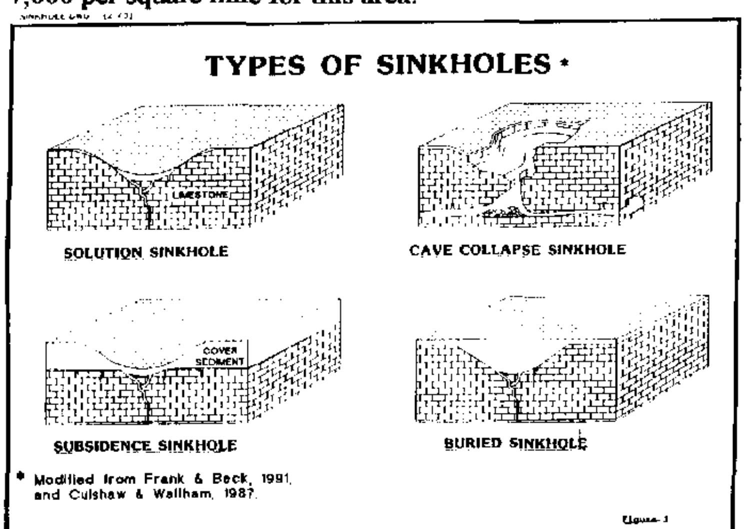

Fig. 1

Karst Investigative Methods

The investigative methods used to locate sinkholes range from remote sensing techniques to surficial geophysical methods to the direct approach of drilling and sampling. In many cases, all the techniques are used.

The remote sensing and historical data review methods, such as the interpretation of maps, photographs, and reports, are often the first steps taken as part of a sinkhole investigation. If suspicious features and/or historical evidence of sinkholes are present or strongly suspected, the next step would likely involve more direct techniques.

Most sinkhole damage investigations involve determination of the probability of cover-subsidence sinkholes, as the catastrophic nature of cover-collapse (and limestone-collapse) sinkholes leave little doubt as to their identity. Because slow, gentle subsidence can result from other mechanisms such as decay and compaction of buried organic materials or movement of shrink-swell clays, identifying cover-subsidence sinkhole development can be difficult. A key element is to establish the presence of a raveling zone of soft or loose soils that extends from the top of limestone bedrock sufficiently close to the surface to cause subsidence. Alternatively, evidence of downward movement of soils into deep solution features is significant. Ground penetrating radar (GPR) and other indirect and direct techniques are useful for exploring geologic uncertainties such as buried or suspected karst features. One of the advantages of some of the indirect methods is that they can cover large areas at much lower costs and much faster than drilling and sampling. This area-wide assessment can help identify buried or observed karst features, help pinpoint test boring locations and provide repeatable signatures of certain key stratigraphic units.

Benson (1993) gives some statistical rationale for using indirect methods for sinkhole studies. "If a one acre site contains a spherical cavity with a projected surface area of 0.1 acre, 10 borings spaced over a regular grid will be required to provide a detection probability of 90 percent." Traditional approaches still often only use test borings to locate or discount the presence of karst features. These limited spatial sampling approaches, however, are probably inadequate.

Ground penetrating radar surveys are relatively inexpensive, nonintrusive surface surveys that can be used to define shallow lithologic contracts and features, such as buried sinkholes. GPR surveys are done using surface equipment or downhole probes (Barr 1993, Church 1986 and Hunt 1984). Because clay soils typically show higher conductivity values than sands, they often become the depth of maximum penetration of a GPR survey (Barr 1993).

Interpretation of GPR survey data may indicate breaches in clayey units. However, due to the higher conductivity of the clay and the typically saturated, near-surface conditions in central Florida, surface GPR surveys may not provide a reliable presentment of a buried karst that has not yet caused collapsed.

Smith (1986) describes the use of electrical resistivity as a tool for assessing karst terranes. "The karstic terrane in north-central Florida is essentially geoelectrically uniform and subsurface dissolution cavities, whether air-filled or water-filled exhibit detectable resistivity analomies."

As also outlined in Hunt (1984) electrical resistivity methods appear to have some applicability for karst studies. However, its effectiveness to find buried voids may be severely limited by the presence of overlying clays and/or saturated soils that have a similar conductivity as the infilled sink feature.

Because drilling and sampling is a pinpointed method of investigation, it is best that sites chosen for drilling are selected with the aid of the other remote sensing and indirect methods. One benefit of drilling and sampling as part of a karst investigation is that it can help confirm the type of sink feature that has been identified by these other methods. The confirmation of cover-collapse features will likely activate different design criteria and may even stop a project. The typical types of investigative methods are summarized in Table 1 below.

TABLE 1 - Typical Karst Investigation Methods

Method	Land Coverage	Advantages	Disadvantages
Remote Sensing	A few hectares to several square kilometers	•Provides wide area coverage •Helps delineate existing sinks and possible future sinks •Typically inexpensive and quick	•Needs ground truthing •Get false positives •Can miss existing features due to vegetative or urban cover
GPR Electrical Restivity and Shallow Seismic	A few to several hectares	•Cover relatively large areas quickly •Can help see buried sinks •Relatively inexpensive •Improves field sampling programs	•Needs drilling to confirm •Can give false positives •Limited depth of penetration through clays •May not see small voids
Drilling and Sampling	Several square meters to a few hectares	•Obtain physical samples •Can detect presence of voids •Can be used in conjunction with down hole geophysics •Can help confirm suspected buried features	•Limited horizontal coverage •May miss nearby feature •Relatively expensive
Probablistic Methods	A few hectares to several square kilometers	•Cover a large area •Uses existing data base information •Relative inexpensive •Improves field sampling and testing	•Based on probability •May give false impressions of frequency •Does not pinpoint features

Insurance Requirements

In Florida, a sinkhole loss for insurance purposes is defined as "...actual physical damage to the property covered arising out of or caused by sudden settlement or collapse of the earth supporting such property only when such settlement or collapse results from subterranean voids created by the action of water on limestone or similar rock formation." Florida statutes require insurance companies to directly investigate sinkhole damage claims. Claims can be denied only after certification by a qualified professional that the "...scope of analysis was sufficient to eliminate sinkhole activity as the cause of the damage within a reasonable professional probability." Based on an insurance company survey by Eastman et al. (1995), sinkhole claims have escalated from a low of 35 in 1987 to 426 in 1991. There has been a corresponding increase in litigation associated with these claims.

Case Histories

No. 1. The site consists of a concrete block house located in western Citrus county. The property abuts a natural channel of the Homosassa River, the headwaters of which is a large spring discharging groundwater from the Floridan Aquifer and the Ocala limestone. Significant settlement damage was present in the garage at the southwest corner of the house, along with an area of settlement in the front yard (eight to ten m from the house). Previous work at the site consisted solely of an electrical resistivity survey. The resistivity data was interpreted to indicate the presence of possible deep porous and cavernous zones in the limestone bedrock. The damage was attributed to a recent flooding event, as no evidence of "linkage" of the deep cavities to the surface was found

A subsequent investigation included a site inspection, soil probings, and two SPT borings. The most obvious damage was occurring as settlement cracking in the garage area, with less significant cracking along the west and east exterior walls. The homeowner indicated that the settlement in the garage had started shortly after the flood. The depression in the front yard occurred over a period of several years. SPT borings were located to test the area of subsidence in the front yard (SPT-1) and the area of damage at the southwest corner of the house (SPT-2). The first boring encountered a thin layer of surficial sand, followed by soft peat and organic silty sand. These organic sediments were underlain by hard limestone, followed by a sequence of interbedded silty sand, clayey sand and sandy clay. Moderately hard limestone was present at the bottom of the boring (18 m). A significantly different stratigraphy was encountered in boring SPT-2, consisting of a thin veneer of surficial sands underlain by a zone of hard limestone to a depth of seven m. An abrupt loss of circulation was then encountered, followed by a zone of very soft, silty sand. The silty sand was generally similar in appearance to the surficial sand unit. Due to caving of the soft sediment and the inability to establish circulation, the driller was not able to advance the boring past a depth of 8.2 m.

These boring data clearly indicated that karst activity was the likely cause of the damage to the house. Important evidence included the presence of localized cracking damage, along with a significant sediment-filled void or cavern in the limestone bedrock. The sediment fill was similar in appearance to the surficial soils, providing an important indicator of downward movement (raveling) into a karst solution feature(s). Small to large diameter solution pipes are common structures in the Ocala limestone and may be interconnected to a more extensive cavern and spring system. The area of sinkhole activity was limited, however, and did not appear to extend to the area of subsidence in the front yard. The settlement in this area was the result of the decay and compression of the shallow peat and organic silty sand units which were likely deposited in a paleokarst feature that developed in the limestone prior to deposition of the overlying surficial sands.

No. 2. Two previous geotechnical investigations were completed to determine the cause of moderate to severe cracking damage in the east exterior wall of the house. Tasks completed included a GPR survey, seven SPT borings, and laboratory testing of selected soil samples. Based on these borings, the shallow stratigraphy consists of a thin layer of surficial sand, underlain by a sequence of clay and sandy clay. Two limestone units were encountered deeper in the borings with interbedded units of calcareous clayey sand. Atterberg limits tests indicated the shallow clay unit had a moderate to high plasticity. Although the shallow plastic clays were cited as a possible contributory factor to the damage, a program of subsurface compaction grouting was completed to stabilize deep, "..isolated zones..of lose and raveled.." soils. The primary evidence cited for karst activity consisted of thin intervals (0.3 to 0.6 m) of soft clay sediment encountered deep in two of the SPT borings. These soft zones were overlain by 11 to 12 m of competent clayey sediment and limestone.

Within a short period, additional cracking and distress occurred. Initially, aerial photographs and soil survey maps were reviewed. Soil units in the area of the site include well-drained sandy soils and poorly drained, sandy and clayey soils.

An updated damage assessment was completed, along with several hand auger borings to obtain samples of the shallow clay unit. Review of monitoring data from several crack gauges installed on the eastern wall of the house indicated total displacements of one mm to 3.8 mm along individual cracks. An SPT boring was completed and a piezometer installed near the area of distress. No unstable soil conditions were indicated in the boring. Partial circulation losses were recorded in two narrow zones (6.7 – 7.3 m, 13.4 – 13.7 m). Atterberg limits tests were performed on clay samples from depths of 1.2 to 1.8 m. Test results indicate the shallow clays at the site are highly plastic (plasticity indexes of 41 to 60). A free-swell test conducted on a sample from a similar depth exhibited a free swell value of 400 percent.

These data were compared to published data on Hawthorn Group clays from Gainesville, Florida, an area where shrink-swell clays are a recognized cause of foundation damage (Schmertmann & Crapps, 1980). Our test results were remarkably similar, supporting the conclusion that the near-surface clayey soils are subject to significant shrink-swell behavior and have a high to very high capacity for expansion. As there was little evidence to indicate a cover-subsidence sinkhole and distress continued after grouting, shrink-swell clay movement appeared to be the cause of the damage.

No. 3. This residential property was also the subject of two geotechnical engineering investigations related to structural damage and subsidence. The first investigation included a GPR survey and several test borings. Both methods revealed a geologic analomy that turned out to be a layer of peat that thickened across the length of this single-story ranch-style house. Sandy soils up to three meters thick were located over the peat deposit, which in turn was upwards of two meters thick. A review of historical information revealed that two nearby neighbors had submitted sinkhole related damage claims to their insurance companies.

The second investigation, performed by our firm, included a detailed review of the previous studies and visual inspection of the damage to the house. Two additional standard penetration test borings were completed adjacent to the house. These generally confirmed the lateral and vertical extent of the peat materials.

The initial investigation concluded that the peat was located in an old sinkhole or paleokarst feature and that because they encountered low standard penetration test blow count values, the peat was settling due to reactivation of the sinkhole.

A review of predevelopment aerial photography revealed a small closed-basin depression about 30 meters north of the subject house. It was obscured in later photographs by filling and house construction.

Because the original investigators had made claims that the damage was likely due to reactivation of an old sink rather than strictly due to soil/peat compression, the insurance company was pressed to pay the homeowner a damage claim or likely face legal action from the owner. Our investigation did not concur that the sinkhole activity had restarted but that the distress was due to long-term compression of the peat deposits beneath part of the house.

If the damage is strictly attributable to soil movement, then the insurance company is not responsible for the damages. However, since the cause of the damage was complicated by the presence of a peat deposit (probably at the edge of an ancient sink feature) it could not be conclusively stated that it was or was not an active sinkhole. Though the observed damage was much more consistent with gradial settlement, typical of peat compression and decay, the insurance company initially decided to assist the homeowner with remedial repairs in lieu of a cash settlement. However, once the cost estimates for repairs, as well as for a two to three month relocation for the homeowner, became finalized, the insurance company and the owner agreed to a cash settlement. (Under current Florida regulations if a homeowner takes a cash settlement for the policy limits, they may be subject to cancellation after six months.)

Conclusions

The incentive to investigate sinkhole damage claims for residential property has sometimes been driven by the "me too" syndrome. Many homeowners see or hear of damage claims being paid and feel their property damage may be sinkhole related. In many cases two or more geotechnical engineering investigations are completed on the same structure for the homeowner and the insurance companies. Even though accepted methods such as GPR and drilling are used, there are often different conclusions as to the cause of the damage. These differing conclusions, even though they may be founded on tentative data interpretation, can result in unjustified insurance settlements, arbitration, or litigation. If a sinkhole case goes to court, the legal and expert witness fees may exceed the policy limits of the house.

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