Geological and Geotechnical Investigation Procedures For Evaluation of the Causes of Subsidence Damage In Florida

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Cover Photographs

Upper left – Winter Park Sinkhole, 1981
Upper right – Bartow, Florida, 1967
Lower left – Bartow, Florida, 1967
Lower right – Taylor County, 1967

STATE OF FLORIDA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
Colleen M. Castille, *Secretary*

DIVISION OF RESOURCE ASSESSMENT AND MANAGEMENT
Edwin J. Conklin, *Director*

FLORIDA GEOLOGICAL SURVEY
Walter Schmidt, *State Geologist and Chief*

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Compiled by Walt Schmidt

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PREFACE

FLORIDA GEOLOGICAL SURVEY

Tallahassee, Florida
2005

The Florida Geological Survey (FGS), Division of Resource Assessment and Management, Department of Environmental Protection, is publishing as Special Report No. 57, *Geological and Geotechnical Investigation Procedures For Evaluation of the Causes of Subsidence Damage in Florida.*

This report is a consensus compilation from twenty six professionals who participated in Sinkhole Summit II, a meeting to discuss said issues. The meeting was initiated by the FGS to solicit input as the agency prepared input to assist the Florida State University, College of Business in preparing a report to the Florida Legislature in response to Chapter 627.7077 Florida Statutes. This report should assist the insurance industry, geologic and geotechnical consultants, government agencies, property owners, and the public, in providing a template for sinkhole investigations protocols.

Walter Schmidt, Ph.D.
State Geologist and Chief
Florida Geological Survey

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Geological and Geotechnical Investigation Procedures For Evaluation of the Causes of Subsidence Damage In Florida

A Report Submitted to the Florida State University, College of Business, Department of Risk Management and Insurance, In Response to Requirements of Chapter 627.7077 Florida Statutes

Compiled and Prepared by
Walter Schmidt, P.G. #1
With contributions from the participants of *Sinkhole Summit II, November 2004*

Background

In 1992, the Florida Geological Survey (FGS) hosted a "*Sinkhole Summit*" in response to legislation that requested the Florida State University (FSU) Center for Insurance Research, under the direction of the Florida Department of Insurance to address numerous issues dealing with insurance coverage of sinkhole damages. One small part of that effort dealt with listing what competent professionals do to determine if karst processes are the likely or probable cause of observed damage. In addition, the legislation requested input on recommendations for a continuing research facility on sinkhole science. Our summit was a brainstorming and consensus building session among a cross-section of Professional Geologists, Geotechnical Engineers and other associated experts to compile such a listing and address the questions. A summary of those deliberations were included in the final legislative report, and those specific sections were reproduced by the FGS as Open File Report No. 72, titled: *Geologic and Geotechnical Assessment for the Evaluation of Sinkhole Claims* (available on line, see FGS web site - <http://www.dep.state.fl.us/geology/>, list of publications).

This past legislative session (2004) the Florida Legislature again requested an assessment of insurance coverage in response to sinkhole damage, and a study was requested to be done by the FSU College of Business, Department of Risk Management and Insurance, in consultation with the State Board of Administration and the Florida Geological Survey to provide recommendations on the feasibility of creating a "*Sinkhole Insurance Facility*," and to recommend "*uniform standards*" for the insurance industry to evaluate sinkhole loss claims; to analyze the potential for the facility *to provide training and educational services* to the public, engineers, and others; and to *maintain a public database* for confirmed sinkholes and paid sinkhole loss claims (among numerous other things, see Chapter 627.7077 Florida Statutes). FSU is to provide their report to the Financial Services Commission and the presiding officers of the Legislature. To assist FSU in this regard, the FGS convened "*Sinkhole Summit II*" to essentially update the 1992 effort and to offer our professional guidance responding to these requests for analysis from the Legislature. Many technologies and the understanding of subsurface karst processes have advanced during the last twelve years since the first Summit, and a modern update is in order. The FGS has numerous licensed professional geological staff with a vast knowledge and experience base with which to compile such a summary. Nevertheless, our desire was to gather a group of experts in one place to discuss the currently accepted practices used by the professional geoscience community, and compile a listing of those technologies and activities a competent professional would utilize in an assessment of a site to determine if karst processes are present or responsible for observed features. On August 27, 2004, ASC

Geosciences, Inc. convened a one-day specialty seminar in Tampa, Florida titled: "Sinkholes in Florida." This meeting was a gathering of geologist's, engineers, insurance and legal experts to discuss various aspects of sinkhole assessment, remediation and insurance claims in Florida. The FGS participated in this seminar, and announced at the meeting our desire for interested parties to contact the FGS regarding our solicitation for assistance in responding to FSU for the recently passed law, and the upcoming *Sinkhole Summit II*. We held the *Sinkhole Summit II* in the conference room of the FGS Headquarters at the Gunter Building in Tallahassee on September 28th, 2004. Twenty five professional geologists, geotechnical engineers, geoscience policy experts, and others representing private industry / consultants, regional, state and federal governmental agencies, academia, and agency insurance program experts participated either in person or through subsequent comments and editorial input. This report represents a compromise product from the FGS staff and the invited experts.

Sinkhole Summit II
September 28, 2004

Prior to gathering in Tallahassee, State Geologist, Dr. Walt Schmidt prepared and distributed a tentative agenda and a draft outline of generalized standards, concepts, and subjects intended for more detailed discussion and expansion during the meeting. Several professionals within the FGS involved with karst processes and hydrogeology, and those from outside agencies or private organizations were asked to offer suggestions or submit other alternative outlines or existing documents they were aware of which deal with geoscience / geotechnical engineering aspects of sinkhole investigations. One such document was submitted by Dr. Sam Upchurch, with SDII Global Corp., Tampa, FL. Upon review of the initial outline prepared by Dr. Schmidt and the more detailed document submitted from SDII Global, all agreed the more detailed report submitted by Dr. Upchurch was a document which had already addressed most of the issues that we anticipated were in need of inclusion in a report the FGS was intending to compile. We agreed to go through this document section by section and review and edit as appropriate for our purposes. The SDII Global Corp. document is titled: *Summary of Suggested Investigation Procedures For Evaluation of the Causes of Subsidence Damage To Residences*, by Sam B. Upchurch, SDII Global Corporation, 4509 George Road, Tampa, FL 33634, September 7, 2004, 12 p.

Sinkhole Summit II participants either in person at the meeting or providing subsequent commentary:
Dr. Walt Schmidt, PG, FGS (Chief & Florida State Geologist), Chairman
Mr. Mike Bascom, PG, Coordinator DEP Springs Initiative
Mr. Richard Benson, PG, Technos Inc. (President)
Ms. Paulette Bond, PG, FGS
Dr. Rick Copeland, PG, FGS
Dr. Richard Corbett, FSU College of Business
Dr. Rodney DeHan, Groundwater Research Scientist, FGS
Mr. David Fisher, Sinkhole Ombudsman, Florida Dept. of Financial Services
Mr. Tony Gilboy, PG, Manager, Southwest Florida Water Management District
Mr. Tom Greenhalgh, PG, FGS
Dr. Tom Herbert, PG, Lampl-Herbert, Inc.

Dr. Tom Kwader, PG, URS Corp. (Vice President, Senior Consulting Hydrogeologist)
Ms. Kathy McDonald, PG, Subsurface Evaluations, Inc.
Dr. Pat Maroney, Esq., FSU College of Business
Dr. Tom Missimer, PG, Missimer Groundwater Science, Inc.
Mr. Sandy Nettles, PG, N.S. Nettles & Associates, Inc.
Dr. Tony Randazzo, PG, Geohazards, Inc. (past Chair & Professor Emeritus UF Geology Dept.)
Mr. D.S. Saxena, PE, ASC Geosciences, Inc. (President and Senior Consultant)
Dr. Tom Scott, PG, FGS, Assistant State Geologist for Geologic Investigations.
Dr. Doug Smith, PG, Geohazards, Inc. (Professor Emeritus, UF Geology Dept.)
Mr. Steve Spencer, PG, FGS (State Sinkhole Database oversight)
Dr. Mark Stewart, PG, Professor (past Chair) USF Geology Department
Ms. Ann Tihansky, Hydrologist, U.S. Geological Survey, Tampa
Dr. Sam Upchurch, PG, SDII Global Corp. (past Chair, USF Geology Dept.)
Mr. Mike Wilson, PE, Ardaman & Associates
Ms. Lynn Yuhr, PG, Technos Inc. (Vice President)
Also observing the discussion on September 28th was Ms. Kelly Kubiak an attorney with Gunn-Merlin, PA.

Introduction

As was the case in 1992, there are still inconsistencies across geological and geotechnical engineering firms in the identification and cause of subsidence features observed impacting structures. Hence the Legislative request for another analysis. Our group was in agreement with the findings of the first Sinkhole Summit, in that the most recent discussions, again found the following:

1. Ideally, at least *two topical areas of professional expertise may be needed* for a complete and comprehensive assessment of any subsidence feature to determine if a sinkhole is the likely reason for the observed damage and if the structure remains safe or is salvageable. These include: a Professional Geologist or a Professional Geotechnical Engineer qualified in Geology, and where appropriate, a Professional Structural Engineer could be warranted by circumstances.

2. A stringent "standardized cookbook" approach is not feasible, because there is too much variability of local geology. Professional judgment must be allowed using the various professional tools available and the expertise of the professional. These various technologies, however, must be utilized in a competent manner along with routine professional care in making reasonable interpretations. There can be a *generalized listing of the steps, processes and tools* a competent professional would utilize or consider in carrying out such an investigation. These "protocols" are included later in this report.

3. It was also agreed by the group that a *Florida Sinkhole Insurance Facility* (as named in the legislation), should include an educational outreach component to assist Insurance adjusters with these difficult decisions, and to provide continuing education for Professional Geologists and Engineers in these agreed upon "standards" or "protocols." Leaflets, workshops and seminars could be conducted to continually update and inform

the professional community and provide outreach to the public. Such a facility could also coordinate and support the geoscience and geotechnical research needed to respond to and answer the continuing questions involving sinkholes. There are still many unresolved scientific questions, such as; where do sinkholes occur and can they be predicted? What kind of processes both natural and human-induced triggers these events? What kind of frequency do we see and what is this related to? Can any correlation be developed between hydrologic conditions and sinkhole occurrences? What technologies or tools are available to begin to address these concerns? Are there correlations with whether a sinkhole claim is paid or not and how the site investigation was carried out? Our group pointed out, **any such facility needs a permanent funding appropriation to be able to maintain a long-term functioning program.**

4. It was further agreed by the group that a *public database* should be maintained and made available to all interested parties. This currently exists at the Florida Geological Survey; however, their program does not have the staff or funding to perform site specific ground truthing for quality control of the data. Nor is there any current law or requirements to submit this data to the FGS. The FGS currently receives voluntary cooperation from many interested agencies (including County Emergency Management agencies) and private sector entities, but only a small fraction of the total sinkhole inventory is captured. In fact, significant amounts of data are purposely not made available to the public database for various reasons. Participants of *Sinkhole Summit II* voiced the importance of insuring that geologic and geotechnical investigations reports must be submitted to the public database and made available to the geoscience / engineering community in order to increase our understanding of the causes of sinkhole occurrences. A standardized or uniform form should be developed that would be a mandatory submittal. The FGS currently has such a form available to be submitted electronically, however, as noted above there are no requirements to use it or even to submit any records at all. With a more complete and meaningful database, the professional community can develop more effective ways to recognize and assess sinkhole risks and advise policy makers, land-use planners, the construction industry, home owners, and insurers to minimize loss and conserve and protect Florida's natural resources.

Discussion

In recent years, reports developed by consultants retained for subsidence investigations by the insurance industry and by property owners or their representatives have become more and more comprehensive, largely because of their use as evidence in litigation. Several of Florida's largest property insurance companies have developed formal or implied guidelines for sinkhole investigations. SDII Global prepared a summary of these guidelines for consideration of the Sinkhole Summit II participants. This report utilized that document as a starting point for our discussions and consensus final report.

It is important that all consultants or other professionals who perform this service produce thorough, unbiased, scientifically credible, evaluations as to the cause(s) of the damage that has resulted in a sinkhole claim. These guidelines are intended to ensure that the procedures followed by any geological consultants investigating sinkhole claims in Florida are thorough and consistent. The protocols are intended to ensure that sufficient information is gathered to assist in sinkhole claim evaluation and that standard methods that can withstand the evidentiary competence tests required for admission in state and federal court. It is the ultimate responsibility of the professional consultant to decide upon the steps necessary to complete an unbiased and scientifically competent investigation that is sufficient to detect sinkhole activity. Professional Engineers are licensed under Chapter 471 Florida Statutes, and Professional Geologists are licensed under Chapter 492 Florida Statutes. Both professions are regulated by Gubernatorial appointed Boards that oversee their respective profession, insure minimum competencies of their respective licensees and administer discipline.

The protocols provided herein are intended for the use of geological and geotechnical consultants to assist in standardizing subsidence claim investigations. These procedures are not intended to replace site-specific activities that reflect good professional geological practice and judgment. They are, however, offered as guidelines to assist in developing sufficient information to confirm the cause(s) of subsidence-related damage to a structure. These guidelines are listed in the sequence that typically should be followed, where possible.

Current Florida Statutes Covering Sinkhole Insurance

To eliminate some of the historical causes for confusion and poor understanding regarding the existing definitions and suggested sinkhole investigation standards currently found in the Florida Statutes, participants of *Sinkhole Summit II* recommend the following changes.

627.706 Sinkhole insurance.--

(1) Every insurer authorized to transact property insurance in this state shall make available coverage for insurable sinkhole losses on any structure, including contents of personal property contained therein, to the extent provided in the form to which the sinkhole coverage attaches.

(2) "Loss" means structural damage to the building. Contents coverage shall apply only if there is structural damage to the building.

(3) "Sinkhole loss" means 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 <u>naturally occurring</u> subterranean voids created by the action of water on a limestone or similar rock formation<u>s</u>.

(4) Every insurer authorized to transact property insurance in this state shall make a proper filing with the office for the purpose of extending the appropriate forms of property insurance to include coverage for insurable sinkhole losses.

History.--s. 2, ch. 81-280; s. 809(2nd), ch. 82-243; s. 79, ch. 82-386; s. 114, ch. 92-318; s. 8, ch. 2000-333; s. 1189, ch. 2003-261.

This proposed change reflects the lack of clarity of the term "sudden." Sinkholes may occur catastrophically and instantaneously, or on a sustained basis (imperceptibly over night, over weeks, a season, over years, or over dozens of years). Any and all can destroy a structure. Some observed features of a slow sinkhole many not be visible for some time after initial movement. The point is to identify a loss due to a sinkhole, the timing is generally not quantifiable, and the term sudden is not defined or generally applicable, as a result it has been defined as needed, causing constantly changing interpretations of the word. "Sudden" should either be deleted or replaced by "sudden and/or sustained." The term "naturally occurring" is proposed to modify subterranean voids, to clarify the legislative intent to deal with sinkhole loss caused from continuing geologic processes that occur throughout Florida. It is intended to eliminate the heretofore included categories of collapse from anthropogenic causes such as but not limited to; subsurface construction debris compaction, water line or sewer line collapse or leaks, tree stumps decay, past mining activities, or poorly designed wells.

627.707 Minimum standards for investigation of sinkhole claims by insurers; nonrenewals.--

(1) Upon receipt of a claim for a sinkhole loss, an insurer must meet the following minimum standards in investigating a claim:

(a) Upon receipt of a claim for a sinkhole loss, the insurer must make an inspection of the insured's premises to determine if there has been physical damage to the structure which may constitute a sinkhole loss ~~might be the result of sinkhole activity~~.

(b) If, upon the investigation pursuant to paragraph (a), the insurer discovers damage to a structure which is consistent with a sinkhole loss ~~activity~~ or if the structure is located in close proximity to a structure in which sinkhole damage has been verified, then prior to denying a claim, the insurer must obtain a written certification from an individual qualified to determine the existence of a sinkhole loss ~~activity~~, stating that the cause of the claim is not a sinkhole loss ~~activity~~, and that the analysis conducted was of sufficient scope to eliminate a sinkhole ~~activity~~ as the cause of damage within a reasonable professional probability. The written certification must also specify the professional discipline and professional licensure or registration under which the analysis was conducted.

(c) If the insurer obtains, pursuant to paragraph (b), written certification that the cause of the claim was not a sinkhole ~~activity~~, and if the policyholder has submitted the sinkhole claim without good faith grounds for submitting such claim, the policyholder shall reimburse the insurer for 50 percent of the cost of the analysis under paragraph (b); however, a policyholder is not required to reimburse an insurer more than $2,500 with respect to any claim. A policyholder is required to pay reimbursement under this paragraph only if the insurer, prior to ordering the analysis under paragraph (b), informs the policyholder of the policyholder's potential liability for reimbursement and gives the policyholder the opportunity to withdraw the claim.

(2) No insurer shall nonrenew any policy of property insurance on the basis of filing of claims for partial loss caused by sinkhole damage or clay shrinkage as long as the total of such payments does not exceed the current policy limits of coverage for property damage, and provided the insured has repaired the structure in accordance with the engineering recommendations upon which any payment or policy proceeds were based.

History.--s. 1, ch. 92-146; s. 4, ch. 93-401.

These proposed modifications reflect the need to clarify a loss due to a sinkhole. Sinkholes are features that intersect the land surface, potentially impacting structures located and built on near-surface, shallow geologic materials, including soils, sediments, rock, and fill. The depth of origin of the void caused by dissolution of limestone or other soluble geologic material varies with the local stratigraphy and hydrogeology. Solution action on subsurface limestones is present throughout all of Florida and can be found at most locations at depth. The term "sinkhole activity" has been used to suggest that subsurface, dissolution related features distant in terms of geographic vicinity or depth from the structure in question represent the process that has caused damage to the structure. This is not the case until the movement of geologic materials into the solution feature, void or cavern phenomena are near enough to the surface to cause a sinkhole loss. Instances of subsurface solution activity cannot be quantified with some threshold of depth, distance, and magnitude in order to qualify as a possible source of distress at the surface. This suggested statute wording change is to provide clarity and eliminate erroneous interpretations of distant, subsurface karst activity as reflecting a sinkhole loss at the land surface. The majority of participants in the *Sinkhole Summit II* feel this is an important point, and recommend this statute change be suggested to the Legislature.

Subsidence Investigation Protocols

[These procedures are not intended to be a sequential "cookbook" for the investigation of sinkholes. Listed here are various options / techniques available to the professional to chose. Appropriate decisions are site specific and based on circumstances, economics, time available, and other parameters.]

1. Use of Professional Judgment

a. These guidelines are intended to standardize subsidence investigations initiated to determine the presence of a sinkhole loss as defined in the Florida Statutes.

b. The professional investigator has the final responsibility for determining the specific procedures and amount of data necessary to complete the investigation in accordance with their professional license obligations and the requirements of §627.707 F.S.

c. Modifications of these methods or procedures, reflecting appropriate professional judgment, should be documented and justified.

d. These protocols are intended to be a comprehensive listing and brief discussion of those methods and procedures professionals have at their disposal to carry out such an investigation. Clearly site specific circumstances and economic capabilities of site owners must be reasonably weighed to determine what constitutes an adequate assessment to render a defendable interpretation. This is the call of the experienced professional carrying out the project. The goal is to minimize uncertainty in the final interpretation while maintaining a reasonable cost / benefit ratio.

2. Professional Qualifications

a. Professional engineering and professional geology firms are required to hold

Certificates of Authorization under Chapter 492 F.S. (geology) or Chapter 471 F.S. (engineering) to practice in the State of Florida. Similarly the individual professional consultant who performs subsidence investigations and who signs and seals work for geological or engineering firms, or practicing independently, must be licensed to practice as either a Professional Engineer qualified in geology, or a Professional Geologist in the State of Florida. Professionals doing work only for their parent company and others employed as teachers or instructors also must comply with these licensing requirements if such work is to be submitted to a government agency for public record.

b. The professional consultant should be expected to provide evidence of training and experience in identifying subsidence caused by sinkholes, expansive clays, organic-rich soils, slope stability, and other processes that cause subsidence. Appropriate training and expertise in the various subspecialties listed in these protocols should also be identified.

3. Professional Practice

a. At the conclusion of the investigation the professional will render an opinion within a reasonable degree of scientific or engineering probability as to the cause(s) of the damage in a professionally signed and sealed report.

b. It is not sufficient to simply rule out a sinkhole loss. The most reasonable cause of damage must be presented with supporting data.

c. ASTM or other published standard methods should be utilized wherever possible as appropriate based on professional judgment (i.e. standard geologic and geophysical field methods).

4. Initial Data Gathering

a. Background Data Collection - To the extent possible, it is recommended that the following information be obtained in order to better design and execute a subsidence investigation.

i. Regional / local geomorphology, areal extent of nearby geologic features, depth to competent rock, and lithologic, stratigraphic, and hydrogeologic characteristics of strata likely to be present at the site,

ii. Site elevation, topography, and drainage features as observed on relevant USGS 1:24,000 topographic quadrangle maps of the vicinity, supplemented by smaller scale, more detailed of same if available,

iii. Soil conditions as reported in the county soil survey,

iv. Nearby historic sinkholes as available from the FGS sinkhole database, local agencies, and private vendors (many are accessible on-line),

v. Historic aerial photographs that depict features that may represent sinkholes, wetlands, previous land uses, or other relevant features applicable to the site vicinity. It is important to keep in mind semi-circular depressions, wetlands, and other features observed on aerial photographs or other remotely sensed images may not always be sinkhole or karst features. Without ground truthing, these features must be treated as indicators, not proof of the existence of possible nearby sinkholes.

vi. Relative elevations of the surficial, intermediate, and/or Floridan aquifer system potentiometric surfaces as represented in current water management district or U. S. Geological Survey (USGS) maps, and elevations of surface water bodies in the vicinity of the site. Significant rainfall events that preceded the sinkhole loss date should be noted.

vii. Date of construction of the structure, notations of any additions, and other relevant information as obtained from the county property appraiser's web sites or owner (reference the source).

b. Preliminary Site Inspection

i. An interview with the owner(s) or owner representative(s)

1. Nature and extent of the damage to the structure,
2. Timing of damage,
3. Presence of additions to the building,
4. Nature and timing of any previous repairs,
5. Any known buried debris, removed tree stumps, old wells, etc., and
6. Information concerning other sinkhole claims in the immediate neighborhood of the site,

ii. Inspection of the grounds and immediate vicinity

1. Suspicious land surface features,
2. Overhanging trees and roots,
3. Land slopes,

4. Retaining walls,

5. Water bodies, recent changes in hydrologic conditions (rainfall events, changes in potentiometric level, nearby pumping centers?) and,

6. Utilities.

iii. Detailed photographs of the structure from all sides and of the observed damage / distress, including a sketch map showing the locations of damage and photographs, and

iv. Access issues for subsequent geophysical and geotechnical evaluation activities.

c. Organize the Results of the Preliminary Site Inspection in the form of field notes

i. A sketch map drawn to scale and photographs showing locations of damage to the structure in sufficient detail and dated that they can be identified at a later time.

ii. Maximum widths of cracks (where measured and location information, or photo location details).

iii. Land slope, depressions, soil erosion, stressed vegetation, and water features.

iv. Evidence of past or present stress to neighboring structures, driveways, streets, and retaining walls. Document trees, fences, or retaining walls that lean down slope.

v. Locations of septic tank, pool, gutters and downspouts, drainage ways, buried utilities, on-site water wells, and other hydrologic features.

vi. Results of owner interview including past performance of the structure and history and timing of the damage.

vii. Information concerning

1. Site flooding concerns or areas of historic flooding.

2. Proximity to wellfields or other ground-water extraction facilities,

3. New construction in the area (especially involving heavy equipment and/or blasting), and

4. Locations of nearby sinkholes or neighbors who have filed sinkhole claims, or sinkholes known to have been filled. Locations of houses or other structures that have been remediated because of a sinkhole loss. Determine if nearby structures on adjacent property have been grouted. Collect dates if available.

5. Geophysical Site Characterization

a. Concurrent with or following the site reconnaissance. Surface geophysical methods should be used (in most cases) to characterize subsurface geology, identify anomalous subsurface conditions, and to provide guidance in selecting locations for invasive tests such as trenches, borings, etc.

b. The investigation method or methods selected should be sufficient to allow interpretation to be able to discern shallow conditions that are likely to have directly affected the structure in order to conform to the definition of "sinkhole loss" contained in §627.706 F.S.

c. When making field measurements, it is highly recommended that more than one set of data be used to aid in an interpretation. When two or more sets of different data agree, there is a higher degree of confidence in the results and the associated interpretation. For example, if a Ground Penetrating Radar survey indicates the presence of broken dipping strata and a test boring placed in the center of the anomaly identifies very loose sediments or voids; we can have a high degree of confidence in the interpretation of the presence of an active sinkhole.

d. Applicable geophysical investigation methods which may be useful include;

i. Ground penetrating radar (GPR, including 3D-GPR),

ii. Electrical resistivity soundings or profiling (ER),

iii. 2-D Multi-electrode resistivity (2DER or MER),

iv. Capacitive-coupled resistivity (CCR, Ohm-Mapper),

v. Micro Gravity survey (MGS),

vi. Magnetometer, Metal Detector, or EM31 measurements (often used to identify buried utilities which may impact other geophysical measurements),

vii. Surface Wave measurements including Multispectral Analysis (MASW) and Spectral Analysis (SASW),

viii. Choice of geophysical method and data reduction techniques should be in accordance with relevant ASTM or other accepted methods and chosen as appropriate based on local stratigraphy, hydrogeology, terrain, and cultural features. The spatial coverage of surface geophysical data should be sufficient to extend beyond the boundary of the possible sinkhole affected area. The data density should be close enough to define small localized sinkhole conditions. As one example, see ASTM Standard Guide for Selecting Surface Geophysical Methods D 6429-99.

ix. There are other geophysical methods and technologies that are not typically used for shallow subsurface investigations; however they could have application in certain cases. Some of them are: Time-Domain Electromagnetic (TDEM) Surveys, Transient Electromagnetic (TEM) Soundings, Induced Polarization (IP), Seismic Refraction, Seismic Reflection, several cross-hole geophysical methods, and numerous remote sensing techniques. There may be other appropriate methods and new technologies are being developed by researchers continuously. If new technologies are utilized, they should be thoroughly documented in order to establish their acceptance in the geological / geophysical community, validity, and reproducibility of the method.

e. GPR is a commonly used method for Florida sinkhole investigations owing to its ability to resolve details of shallow soil and rock conditions. The main limitation of GPR is its site specific performance and the depth of penetration is limited by shallow clays, hardpan soils, or high conductivity pore fluids. Other methods can be used when they are appropriate to the problem and local subsurface geology. Note that electrical resistivity methods are less impacted by subsurface clays or groundwater quality; however, they are prone to unique interpretation problems when utilized in urban environments where conductive and/or resistive materials near buildings and other structures are present. Direct Current ER, however, has been shown to have depth capabilities much greater than GPR approaches. Also note CCR may have limited applications in Florida due to shallow water tables which yield higher conductivity reducing signal strength.

f. Ground penetrating radar (GPR) – has best application in dry sandy soil conditions (depth of penetration impacted by clay layers, hardpan soils, and groundwater quality).

i. A grid sufficient to ascertain near subsurface conditions should be designed by an experienced professional. Typically a maximum of an approximate 10-foot grid within the affected property is considered adequate.

ii. Include the interior of the structure, where appropriate.

iii. Identify affected areas on a site map for placement of subsurface tests (soil borings or soundings). The choice of boring location within an anomaly should consider proximity to the damaged structure and any significant surface or subsurface features located within an anomaly.

iv. A shielded antenna should always be used to avoid interference from overhead and metallic objects. GPR instrumentation conditions, including the frequency of the antenna used, time settings, and other relevant parameters, should be included in the report.

g. Electrical resistivity methods – can be especially useful where there is shallow groundwater, hardpan soils, or shallow clays (but the method is not limited to such situations, in fact it can be applied to deep groundwater and clay-free subsurface environments).

i. Electrical resistivity soundings (ER)

1. It is critical that the locations chosen for ER investigation be selected with cognizance of electrical interferences, such as fences, utilities, and the structure itself. All possible interference sources should be noted in the report and program design must account for such.

2. If ER is utilized, it is recommended that the ER investigation be coupled with GPR data or a second independent data set (such as borehole data).

3. All conditions of the testing, including electrode configuration(s), data reduction methods, and number of iterations required to produce the final interpretations, will be discussed in the report.

ii. Two dimensional electrical resistivity (2DER or MER)

1. All conditions of the testing, including electrode configuration(s), data conditioning (removal of data points, etc.), data reduction methods, and number of iterations to produce the final depth section or other interpretative results, must be discussed in the report.

2. It is critical that the locations chosen for these investigations be selected with cognizance of electrical interferences, such as fences, utilities, and the structure itself. Locations of potential interferences must be discussed in the report and accounted for in program design.

iii. Note that ASTM Standards D-6429, D6431-99, and G57-95a address various ER procedures and data acquisition procedures. These should be followed as appropriate or deviations noted and explained.

h. Capcitively-coupled resistivity methods (CCR).

i. Generally limited use in areas with shallow water table. However, instrument can penetrate to greater depths if the near-surface materials are relatively resistant. Shallow groundwater increases the conductivity resulting in reduced signal strength. Subject to the same conditions as identified for 2DER testing cited above.

i. All geophysical investigation reports should include:

   i. Site maps showing locations of all measurements (stations, profile lines, traverses soundings or grids) along with all other data collection procedures and a discussion of why these locations were selected.

   ii. Specific locations and interpretation of all anomalous areas.

   iii. Uninterpreted raw-data should be included as appendices.

   iv. Identify the limitations of the method, and any problems with data acquisition or data processing. Discuss any assumptions made or used as a precursor to interpreted results or data processing.

   v. If the results of measurements are processed and interpreted by computer (i.e. data is entered into software and a cross section contoured by computer) provide other independent data or steps to verify or confirm the results.

j. Because of the three dimensional aspects of sinkholes and other geologic hazards, every effort must be taken to ensure that the land surrounding the affected structure is adequately investigated, based on an understanding of the local and regional hydrogeology.

6. Floor Mapping (often a valuable tool to assist with the determination of structural causes of observed damage and could yield information corroborating or discounting a sinkhole as the likely cause)

a. Used to identify locations where the structure's floor is depressed or elevated beyond tolerances allowed by the applicable Florida Building Code.

b. Acceptable methods include (1) transit and stadia rod, (2) manometer, and (3) laser level.

c. A base location that can be reoccupied for subsequent mapping should be identified in the report and be as permanent as possible.

d. Care should be taken to minimize accumulation of error while moving the instrument, including use of closed loops or resection of "shot" points when utilizing transit or laser level.

e. Accuracy of the survey measurements should be at least 0.01 foot.

f. Differences in floor coverings should be accounted for.

   i. Paired measurement points located at floor-covering transitions.

   ii. Field notes should indicate the nature and thickness of floor coverings.

g. Results reported through properly contoured map with accurate scale and elevation representations. The base location and transitions in constructed floor elevations (sunken rooms, elevated rooms, etc.) should be indicated.

h. The results of the contour map should be compared to tolerances in floor elevation allowed by the building code prevalent at the time of construction of the structure.

7. Subsurface Geotechnical Testing & Geological Interpretations

a. Locations of all boreholes, soundings, and other testing activities to be reported.

   i. A control site or tie-back hole should be established for comparisons of anomalous results. In densely populated urban settings this may be difficult to access or not feasible due to overall scale of the feature vs. lot size.

   ii. Discuss why each testing site or line was selected.

   iii. Hole locations should be carefully located and measurements necessary to allow for relocation of the test holes should be indicated in the report.

b. All soil testing procedures should follow ASTM methods or other published procedures. Again professional judgment prevails and should be explained.

c. If there is more than one foot of relief on the site, a leveling device should be used to determine the relative elevations of each test hole. The benchmark used for these levels should be a permanent feature on the lot that can be easily located for future investigation.

d. Dynamic penetration tests, such as; the Standard Penetration Testing (SPT), Baecher penetration test (BPT), and dynamic cone penetration test (DCPT).

   i. SPT location criteria.

      1. Locations identified by the geophysical investigation as anomalous features.

2. May choose to explore only those geophysical anomalies nearest the structure, preferably near areas of greatest damage with adequate justification.

3. If no anomalies are detected or if the anomalies are distant from the damage identified during the initial site visit, locate the SPT tests in close proximity to the damaged portions of the structure.

4. If sinkhole loss related geophysical anomalies or known or suspected sinkholes are distant, a SPT boring can be placed between the feature and the house in order to determine if the house has been affected by the processes that may have caused the remote feature.

ii. Ensure that all potential subsurface causes of the damage are adequately characterized. Adequate characterization will include enough testing to reasonably confirm any subsurface cause(s) of the damage.

iii. Site and location specific drilling equipment (truck or trailer mounted models, hand augers, and tripod) should be used. The only rationale for not drilling where the cause of the damage is likely to be manifested should be human health and safety or inability to obtain legal access. These should be documented in the report.

iv. Utility location procedures should be followed to ensure the safety of drilling crews and others on site as well as the structure. Where local or state requirements exist for utilization of the services of utility location providers, they will be utilized. (note that utility location services will usually only work on public right-of-way and not on private property)

v. The boring materials recovered and their depths should be documented and described in the drilling log. It is recommended that these shallow soils be tested by a calibrated manual cone penetrometer in order to complete documentation of the relative strengths of materials encountered in the boreholes.

vi. All test holes should be backfilled or grouted in general accordance with applicable procedures established by the county or water management districts in Florida.

e. Cone penetration tests - mechanical (CPT), electric CPT, piezocone (CPTU), seismic piezocone (SCPTU), resistivity piezocone (RCPTU) and horizontal stress cone (HSC). Location criteria same as for d. above.

i. Use of CPT soundings often is used because the data may assist with the indication of raveling soils.

ii. Conductivity tips are useful to determine the presence and continuity of a clay confining layer.

iii. All sounding locations should be located relative to landmarks so they can be identified at a later date.

f. Auger Borings (hand, tripod, trailer, truck mounted, etc)

i. Advanced near the foundation for identification of soil depth and classification.

ii. A calibrated manual cone penetrometer is recommended for testing strengths of soils in the auger holes.

iii. All hand auger holes should be located relative to landmarks so they can be identified at a later date.

iv. If more than one foot of relief is present, the relative elevations of the borings should be determined by leveling.

v. It is recommended that a hand auger boring be advanced at each of the four primary corners of the structure and in any areas of concern, such as depressions elsewhere on the property.

vi. All holes created by auger boring will be properly filled.

g. Manual Cone Penetrometer (CPT) Soundings

i. Used for determination of the relative strengths of soils near the foundation of the structure and in areas of concern.

ii. Hand penetrometers should be calibrated.

iii. Report results of the soundings, including units of soil strength measurement.

iv. Report whether the soil strengths determined by CPT were taken in hand auger borings or other excavations where side friction is minimal or in undisturbed soil.

h. Foundation Test Pits

i. The consultant should attempt to obtain design documents from the owner or local building department if there is any question as to design elements in the foundation of the structure.

ii. If the foundation design and materials upon which the structure rests is unknown, at least one test pit should be dug in the vicinity of the most damaged part of the structure.

iii. It may be necessary for a qualified licensed engineer to supervise this activity to avoid exacerbation of the damage. A qualified engineer (geotechnical or structural) should prepare conclusions as to foundation issues based on the test pit and structural observations.

iv. Additional test pits may be required under the foundations of any additions to the structure. Appropriate backfilling must be done to insure foundation integrity.

i. Ground-water Levels

i. Depth of static water level should be measured in any hole where water is encountered. Elevation differences if present throughout the site or property should be noted and plotted. Where possible a water table map of the site, from this data should be prepared.

ii. If no groundwater is encountered, note in the log of each auger hole or piezometer reading.

j. Reporting

i. Boring logs should be prepared for all test holes (SPT, CPT, PCPT, hand auger, other test holes).

1. These should include detailed soil or rock descriptions, including the Unified Soil Classification (ASTM D-2487 or –2488) and notation of mottling, bedding, small-scale lithologic variations, grain size range (gradation), and Munsell colors. Other scientifically accepted description methods can also be utilized. These should be appropriately referenced and defined. Examples include: *Field Book for Describing and Sampling Soils,* 2002, published by the National Soil Survey Center, U.S. Dept. of Agriculture; *Manual of Field Geology,* by R.R. Compton, published by Wiley & Sons, Inc.; and *Handbook for Logging Carbonate Rocks,* by D.G. Bebout, and R.G. Loucks, Handbook 5, Texas Bureau of Economic Geology.

2. Terminology should conform to ASTM D-653 method or it should be defined and referenced within the report.

3. Note the depth of any partial or total loss of drilling fluid circulation.

4. Note weight-of-rod or weight-of-hammer strength materials and voids will be noted in the boring logs. Note variable depth of bedrock.

ii. Color photographs or soil samples should be taken of key soil conditions, such as the presence of debris or organics. Note whether sample is wet or dry when being photographed. A statement that roots were found is not sufficient to attribute the subsidence to decaying organics. If construction debris or other anthropogenic material is encountered, photograph sample materials to ensure adequate documentation.

iii. If site relief is more than one foot, the graphic logs of the borings in the report should be placed in their relative vertical positions using the arbitrary datum used for leveling of their elevations.

k. Soil / Sediment / Rock - Sample Containers

i. All soil, rock, or debris samples will be stored in properly marked, sealed containers in anticipation that they will be retained for long periods of time and are likely to be used as evidence.

ii. "Chain of custody" procedures should be established and followed.

l. Other down hole testing.

i. Based upon professional judgment and site specific circumstances (structure size, economics, etc.) geophysical logging may provide useful information. This typically may include a natural gamma log and an induction (conductivity) log. See ASTM Standard Guide for Planning and Conducting Borehole Geophysical Logging D 5753-95.

ii. As above (site specific judgment), hole to hole Up-hole or Down-hole testing may be utilized in some cases to provide seismic P and Shear wave velocities or resistivity or radar data. For hole to hole seismic tests see ASTM Standard Test Methods for Cross-hole Seismic Testing D 4428/D 4428M-91.

8. Laboratory Testing

a. If clay-rich strata are found within 20 feet of the land surface, the following laboratory tests are suggested:

i. A minimum of three samples should be tested according to these procedures.

ii. Atterberg limits.

iii. Percent natural moisture content.

iv. Gradation (grain-size) distribution information, including the fraction smaller than the 200-mesh U.S. Standard sieve.

v. It is recommended that the fraction smaller than the 200 mesh sieve should be determined to identify the percent silt and clay, and that a hydrometer test, or equivalent, be conducted to determine the percent smaller than 2 microns.

vi. If shrink / swell clays are suspected, an appropriate mineralogy test should be conducted. Typically this would be an x-ray diffraction interpretation. Alternatively elemental / chemical analysis also has use in this regard.

b. If organic-rich soils are suspected or detected within the exploration depth, the natural moisture content and percent organics should be determined on representative samples. If "peat" is recovered, then a grain size distribution and composition description should be carried out on such samples.

c. If debris, including natural wood fragments and construction debris, is detected and considered a possible cause of the damage, there is no need for laboratory testing.

i. Document the nature and extent of the debris through samples and photographs that illustrate the size and make-up of the debris.

ii. Samples of the debris will be collected and retained (see below), where practicable.

9. Structural Inspection

a. Many sinkhole claims may be the result of deterioration, construction defects or modifications in structures. Therefore, a qualified structural engineer should evaluate the damage that cannot be directly attributed to natural earth processes to ascertain the cause and origin of the damage and assess integrity of the structure.

b. The engineering inspection should be in concert with the geoscience assessment and be of a sufficient scope for determination as to whether the damage is consistent with sinkhole activity or some other geological process, anthropogenic subsurface causes (buried utilities, etc.) , or any structural or construction related causes.

i. Structural issues of concern include compliance with the prevalent building code at the time of construction,

ii. The effects of modification of the structure, including building additions, changes in load- and non-load-bearing walls, and modifications of the foundation, and

iii. The effects of leaking water or sewer lines, other buried utilities, wind damage, or other events that may cause damage.

c. The final report should include:

i. Photographs of the damage, including damage critical to cause determination, and information locating the subject(s) of the images(s).

ii. A listing of damage by room or elevation with analysis of damage causes, where evident.

iii. A statement as to the cause(s) of damage from the perspective of the structural analysis.

10. Final Report

a. Include all of the documentation cited above, plus

i. A simple explanation of the consultant's professional opinion as to the cause of the damage within a reasonable degree of engineering or scientific probability.

ii. Include all of the evidence used to draw conclusions concerning causation.

iii. It is not sufficient to say that the cause is not a sinkhole – the cause of damage should be suggested.

iv. All raw, uninterpreted data should be included as appendices. This allows the reader to better understand the data source used to derive the various anomalies and geologic or geotechnical interpretations, and it enables later investigators to understand the results.

b. If no cause can be identified, the investigator should recommend additional testing to determine the cause(s).

c. The report will contain a statement certifying the results of the investigation according to the requirements of §627.707 F.S.

d. All persons responsible for the interpretation of the data and preparation of the conclusions of the report shall be registered as either an engineer or geologist in Florida and will sign and seal the report indicating their profession and registration number.

e. A copy of the final report should be submitted to the Florida Geological Survey if legally permissible.

11. Retention of Samples and Data

a. All photographs, field notes, and other documentary materials will be retained by the consultant for an appropriate period of time.

b. All soil, sediment, rock, or debris samples will be retained by the consultant for an appropriate period of time.