# FORENSICS - SINKHOLE DAMAGE TO BUILDING

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## INTRODUCTION

Chiefland High School, Building Number 1 was a single-story structure in Chiefland, Fla., owned by the School Board of Levy County. This building was constructed in 1930-31 and consists of exterior bearing walls of brick masonry supported on shallow strip footings, wood stud interior bearing and nonbearing walls, and light-dimension lumber framing for rafters and ceiling joists. The exterior walls were unreinforced, consisting of three wythes of soft brick set in lime mortar. The floor system consisted of wood joists and girders supported on unreinforced brick piers and isolated concrete footings.

The area around Chiefland, along with other portions of North Florida, is classified as karst terrain, and is strongly prone to sinkhole development. The subsurface rock formations show as strongly pinnacled limerock outcroppings. The locally occurring sinkholes are of two types. The first is a slow raveling of sand into cavities in the underlying limerock, similar to sand running through an hourglass, which results in subsidence of the ground surface. This type of sinkhole can occur over a few hours, a few days, or a few weeks. The second type shows as a sudden collapse of soil into cavities in the limerock. The cohesion of the clayey soils above the cavity allows the surface to bridge over the subsurface cavity until it suddenly collapses into the cavity. These sinkhole types are shown in Figs. 1 and 2. The large house-swallowing type sinkholes, which are often reported in the mass media, do not occur in this area.

## SINKHOLE DEVELOPMENT AND STRUCTURAL DISTRESS

At approximately 3:15 PM on Friday, 1 March 1991, a school staff member reported feeling the floor "shudder" beneath her. During the ensuing weekend of 2-3 March, approximately 9 inches of rain fell in Chiefland. This rainfall backed up in the parking lots and fields on site. According to eyewitness accounts, approximately 12 inches of water was standing on the paved parking lot behind the building. Due to improper grading that did not route water away from the building and lack of drainage structures, much of this standing water flowed beneath the building through airflow vents in the stern wall and percolated into the subgrade.

During the weekend, several sinkholes of both types occurred near the school football field, approximately 1000 feet to the west of the building. On Monday, 4 March 1991, faculty members discovered that the interior walls in two classrooms in the north wing of the building had separated from the floors, and that the floors did not feel solid. School maintenance employees opened access plates through the floor, and the foundations were inspected. It was discovered that several of the interior piers had settled several centimeters, and some were not in contact with the floor girders.

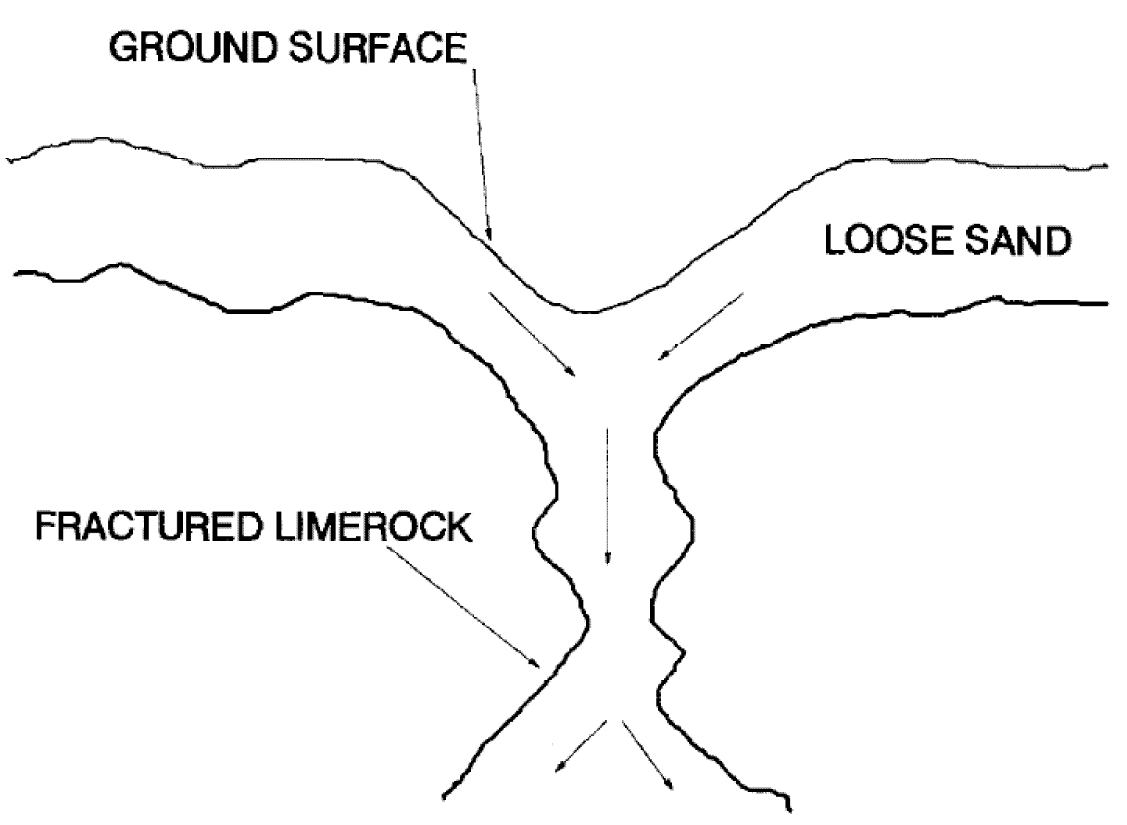


FIG. 1. Raveling-Type Sinkhole

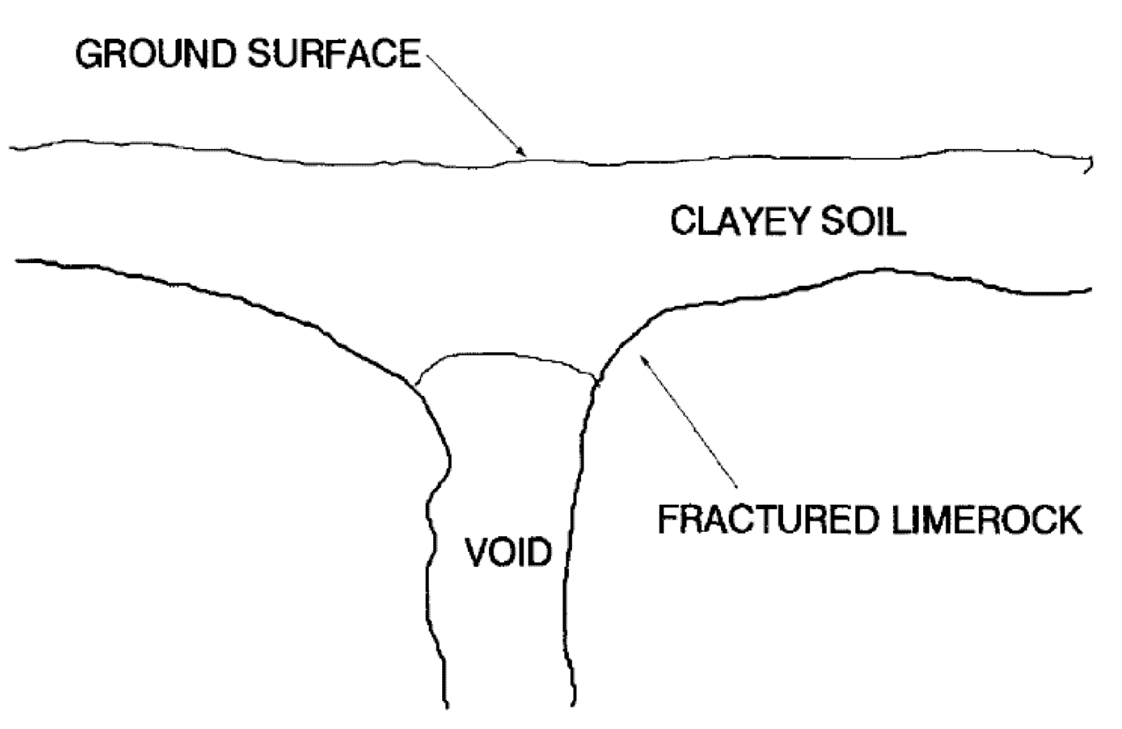


FIG. 2. Sudden-Collapse-Type Sinkhole

Later on Monday, 4 March 1991, the architect retained by the school board inspected the building and verified the settlements. He recommended that that the north wing of the building be closed off, and evacuation drills be held for the south wing of the building. He additionally recommended that a geotechnical engineering firm conduct subsurface investigations. Subsurface investigations were begun 5 March 1991. The testing consisted of soil borings to map the strata, pushrod tests to find soft spots that might indicate other sinkholes, and the use of ground penetration radar to possibly locate other uncollapsed cavities on site.

Subsurface Conditions

Soil borings and ground-penetration radar determined that a depression in the limerock beneath the surface was present in the area under the problem classrooms. The borings in this area generally found loose sand and clayey sand over limerock. The limerock was depressed under the classrooms, with the resulting bowl filled with very loose sand and clayey sand. The soil in the bowl had almost no resistance to the sampler, indicating that the soil was eroding into a fracture in the limerock. These loose soils are referred to as raveled soils. Probing was not able to find the exact location of the fracture, but this is not surprising since these holes can be quite small, on the order of less than half a meter in diameter. Boring logs for this area are shown in Fig. 3. Designations above the logs are the hole numbers. Standard penetration blow counts are shown to the right of the log.

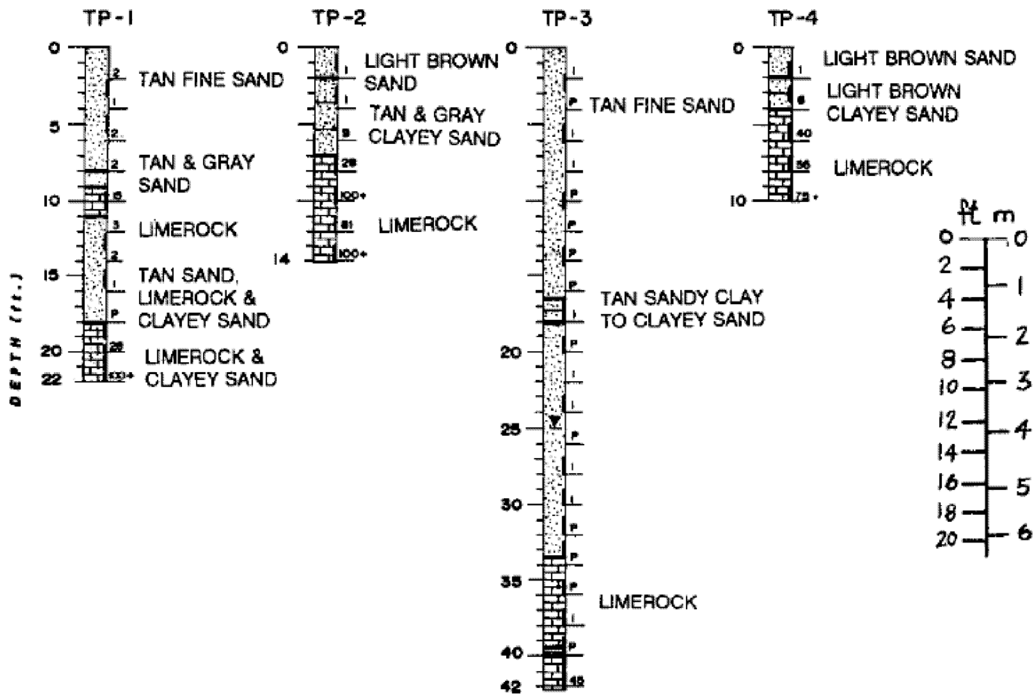


FIG 3. Boring Logs

Probing and boring found the limerock to be very pinnacled beneath the building. Soil borings often differed drastically from probings conducted a few meters away. It was not unusual to find many meters of loose or raveled soil 3 feet from borings that encountered limerock within 6 feet of the surface. Ground-penetration radar identified possible cavities in the limerock at two additional locations. Soil borings at these locations verified cavities in the limerock that had not yet collapsed.

It was the opinion of the geotechnical engineers that the soil beneath the two affected classrooms had been slowly eroding through a fracture over many years, but the rate of erosion was greatly increased by the very heavy rainfall during the previous weekend. In simple terms, the stormwater had washed the loose sands down through the fracture. Unless remedial measures were taken, the ground subsidence would continue. They additionally noted that the pinnacled limerock under the entire building was at high risk for the formation of more sinkholes of the slowly raveling kind shown in Fig. 1.

## Structural Evaluation

Now knowing somewhat the extent of the problems beneath the surface, it became necessary to assess damage to the structure aboveground. The writer was retained by the school board to undertake this evaluation in conjunction with the architect previously retained by the board.

At the time of inspection on 2 April 1991, the structural damage to the building resulting from the sinkhole was limited to the area immediately around the classrooms in the north wing. An inspection beneath the building revealed the extent of damage to the foundation system as shown in Fig. 4. A total of eighteen piers appeared to be affected by the subsidence, with damage being confined to the footings and brick piers. Above the floor, the wall separating the classrooms was cracked and settled (Fig. 5), and the ceiling above was cracked, also. The actual cost of structural repairs for this phase would be fairly modest, provided that the footings could be leveled again on firm support.

More important in the minds of the writer and the architect was the condition of the building from 60 years of differential settlement. The building had suffered from severe differential settlement since its construction in 1931, as verified from minutes of school board meetings held at that time. Because the exterior brick walls were much more heavily loaded than the interior footings, due to dead weight, the exterior walls settled differentially as much as 6 to 12 inches when compared to the interior walls and floors. This resulted in severe cracking in the brickwork. Conversations with long-time maintenance personnel indicated that cracks had been present and growing for many years. The surface sands on this site are very loose, with standard penetration blow counts on the order of 1 or 2. It is quite probable that 60 years ago, the foundations were constructed without consolidating the sands, thereby leading to the large settlements. Present practice would require compaction, thereby reducing settlements.

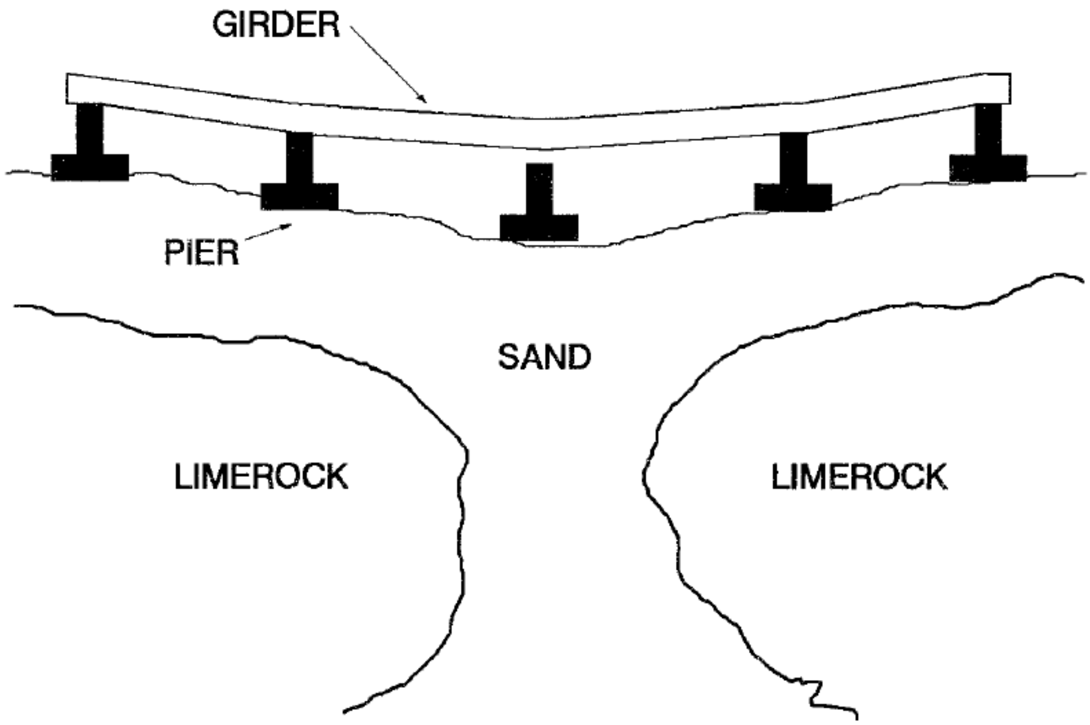


FIG. 4. Typical Settlement Damage Caused by Sinkhole

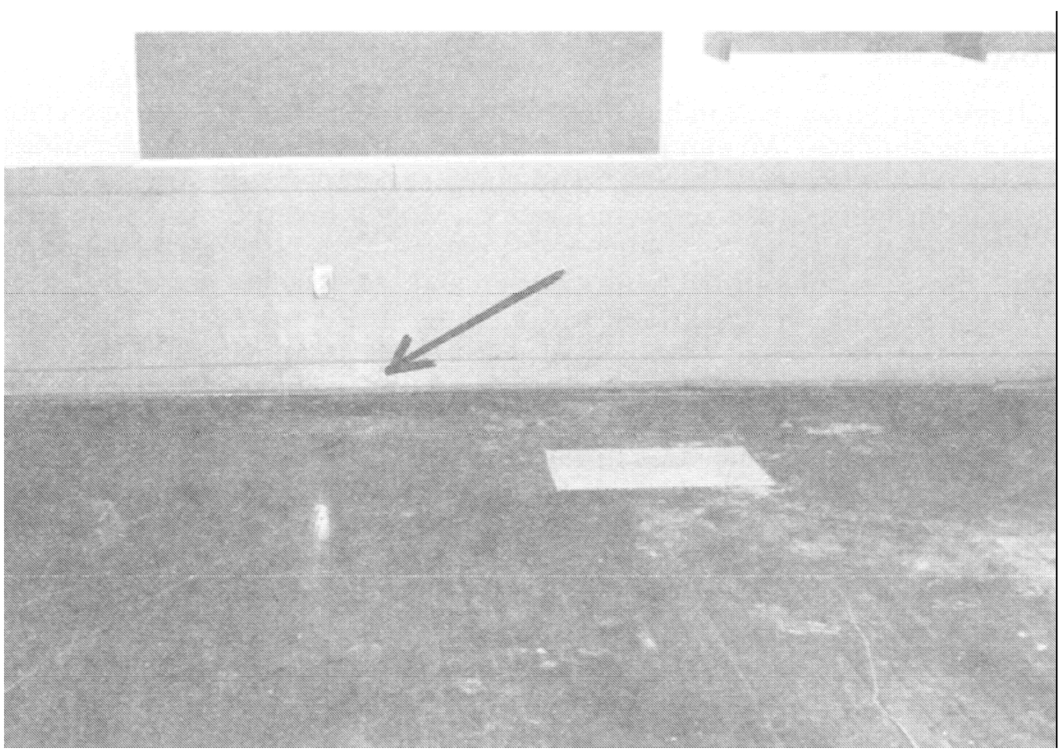

FIG. 5. Floor Settlement--Note Separation of Wall from Floor

Recommended Repairs

The geotechnical engineers formulated a recommended repair method to close off the current sinkhole. This plan consisted of injecting low-slump concrete grout under pressure through steel pipes to seal off the fractures and cavity related to the sinkhole. This grouting would form a cap above the sinkhole. After grouting was completed, underpinning of the foundations would occur. A pipe pile would be inserted beneath each foundation. This pipe would be jacked against the foundation until it hit the limerock or hardened grout, thereby resupporting the foundation.

This scheme had some problems associated with it. While it would take care of the present problem, it would do nothing to prevent other sinkholes from occurring in other places beneath the building. The geotechnical investigations indicated this as a possible future problem. Additionally, because of the brittle nature of the exterior brick walls, it was recommended that the exterior walls not be jacked back into position.

Probably most important was the overall condition of the building. Even if the underpinning were to be accomplished, severe structural, life-safety, and functional problems that developed over the 60-year life of the building would still exist. It was determined by the school board and the architect to be less costly to raze the existing structure and build a new, more functional structure on another site with better subsurface conditions, than to bring the existing building up to full code compliance. This is the route that is being presently pursued. The building is currently closed, with all activities being currently housed in temporary structures nearby.

**CONCLUSIONS**

It is easy to look back in hindsight and enumerate the problems associated with this building. We can list a few points that probably need restating.

First, it is extremely important to conduct complete subsurface evaluations before any structure is constructed. Money saved by not conducting this investigation can be spent many times over repairing problems that could have been identified before design and construction started. Current knowledge would have allowed us today to have constructed the building on this site using a mat foundation or through a combination of mat foundations and pressure grouting. An even better alternative would have been to build on an alternative site with better subsurface conditions.

Second, even with the poor subsurface conditions, the problems resulting from the sinkhole could have been delayed or prevented if proper site grading and drainage procedures were followed. Storm water should be routed away from buildings. In this case, when the water had no place else to go, it percolated into the subgrade under the building, accelerating the growth of the sinkhole. It was this lack of proper grading that caused the sinkhole to grow as rapidly as it did.

# QUIZ

## FORENSICS - SINKHOLE DAMAGE TO BUILDING

1. The mechanism that drives sinkhole development is _________.

    a. vibration
    b. clay
    c. water
    d. None of the above

2. Sinkhole development develops where underlying ___________ occurs:

    a. granite
    b. limerock
    c. peat
    d. basalt

3. Loose soils over a sinkhole are referred to as ______________ soils.

    a. raveled
    b. clayey
    c. silty
    d. none of the above

4. Sinkholes can be capped by _____________.

    a. installing pipe piles
    b. injecting low slump concrete grout
    c. excavating and filling
    d. filling the depression with debris

5. Subsurface investigations should be performed ______.

    a. when required by the insurance carrier
    b. only when damage occurs
    c. prior to construction
    d. are not necessary