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SINKHOLE DROPOUTS DUE TO UNDERGROUND UTILITY INSTALLATION ON CONSTRUCTION SITES

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ABSTRACT

The karst geologic setting of south-central Kentucky presents many challenges to engineers and construction firms. Karst areas are characterized by numerous sinkholes and subsurface drainage systems that can include caves, regolith arches, and highly irregular bedrock surfaces. The increased commercial and residential development in south central Kentucky, particularly Bowling Green which is in Warren County, has created an increased interest in the existence and location of these unmapped karst features, particularly regolith arches. Regolith arches are formed by the downward movement of fine-grained soils as a result of water infiltration from the ground surface into subsurface drainage systems. The reason for this interest in the location of unmapped karst features is the tendency for construction induced vibration and topographic changes to cause collapse of these regolith arches. It is well documented that construction and topographic changes can cause regolith arches to collapse. However, a lesser documented cause has become more common. This cause is the installation of underground utilities.

The primary way underground utilities can lead to the dropout of regolith arches is by directing water into an active regolith arch. This occurs because utility lines are typically backfilled with highly permeable gravel. In the Warren County area, native soils are silts and clays which possess a very low permeability. The gravel backfilled utility creates a conduit that captures a significant amount of surface runoff. If a regolith arch is located near an underground utility line, there is a dramatic increase in water volume entering the regolith arch than would have occurred had the utility line not been installed.

This paper will document two case histories in Bowling Green, Kentucky, which is in Warren County, where dropouts have developed due to the combination of construction activity and underground utility construction.

KEYWORDS

Sinkhole Dropouts Construction Regolith Arch Utility Lines Bowling Green Kentucky

INTRODUCTION

Bowling Green, Kentucky, is the only city in the United States built entirely on a sinkhole plain, known locally as the Pennyroyal Sinkhole Plain. The term "sinkhole" is one of the more commonly recognized geologic terms, along with earthquakes and volcanoes, primarily due to their often catastrophic results if they occur underneath a habited structure. As with earthquakes, the general geographic area in which sinkholes can occur is easily documented, however, the specific place and time a sinkhole dropout can occur is difficult if not impossible to predict. Although specific predictions are difficult, we have been able to determine the causes of the vast majority of sinkholes. The major causes of sinkhole dropouts are the results of manmade changes to natural drainage patterns and construction practices in general. One specific cause that is becoming more and more apparent is the occurrence of dropouts underneath recently constructed utility trenches. This paper will discuss this particular cause of sinkhole dropouts and will present two case histories that are typical of the hundreds of similar events that have occurred in Bowling Green.

THE SINKHOLE

The term "sinkhole" is commonly used to describe a steep walled pit or hole in the ground. While this is correct, the term is also used to describe shallow closed surface bowl shaped features that collect water and direct it down into the subsurface drainage system. In this paper, I will refer to sinkholes as the bowl shaped features and sinkhole dropouts as the steep walled holes or pits.

Sinkholes exist in sinkhole plains, which are relatively rare landscapes commonly referred to as "karst topography." This karst topography is usually formed on carbonate rock geologic features, such as limestone and dolomite. Over millions of years, groundwater (which has been turned into a mild carbonic acid by its reaction with atmospheric carbon dioxide) travels into cracks and fissures and dissolves the carbonate rock. As a result, underground drainage systems are formed. In simple terms, these underground drainage systems are a series of interconnected caves.

As fascinating as this geologic process is, it poses a significant challenge to engineers and planners. During the process, these cracks and fissures get larger and larger creating a soil "bridge" or arch which bridges the void created by the dissolved limestone, as shown in Fig. 1 below. This is technically referred to as a regolith arch.

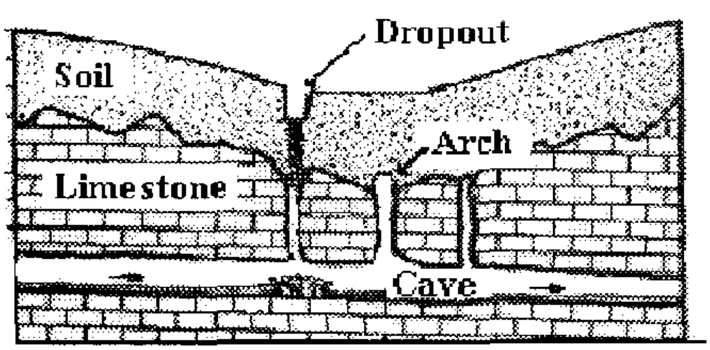

Fig. 1 Graphical representation of the process of a sinkhole dropout.

As water infiltrates from the ground surface into the underground drainage system through the regolith arch, fine soil particles are carried with it. At some point, enough of the soil is washed into the underground cave system that the remaining soil suddenly "drops out," instantly creating a void at the surface. In addition, construction activities, including earthmoving and other vibration inducing activities, at the ground surface can hasten the dropout. The negative implications of this occurrence anywhere on a construction site, particularly underneath a load-bearing structure, are obvious.

UTILITY EXCAVATIONS CAUSING SINKHOLE DROPOUTS

Causes of sinkhole dropouts are well documented (Crawford and Whallon 1985, Newton 1984, and Crawford et al 1989). Dropouts will occur in one of two ways: 1) regolith arch failure, which has been described above, or 2) bedrock collapse. Bedrock collapse occurs when the roof of a cave fails resulting in anything that was supported by this rock roof to fall into this newly created surficial void. Bedrock collapses are rare and will not be discussed here.

Regolith arch failures leading to sinkhole dropouts are very common and are of primary concern in the Bowling Green area. The majority of new construction sites of at least an acre in size will have at least one regolith arch dropout during the course of construction. A large commercial construction project in Bowling Green (more than 20 acres) currently in the earthwork phase had more than 15 dropouts within a few weeks.

Most regolith arch failures are caused by one or combination of the following; construction equipment vibration, change in natural surface drainage patterns, surface ponding and concentration, and underground utilities (Crawford et al, 1989). With regard to underground utilities specifically, Crawford links regolith arch failures to "Leaking Pipes." While leaking pipes certainly can and do cause regolith arch dropouts by directing water to an active regolith arch, this category should be divided into two sections, one for leaking pipes and another for water flow unrelated to the existing pipe that has made its way into the gravel backfill. While this distinction seems slight, the correction of the problem in each case varies dramatically. If a dropout occurs and it is attributed to leaking pipes when in fact the pipes are not leaking, then replacing the pipe will be an expensive repair that does not correct the problem. The water that caused the dropout may be coming from a different source entirely. If the water is coming from a source other than the pipe, remediation measures will depend on the source. Several regolith arch failures resulting in sinkhole dropouts have occurred recently due to external water sources in newly constructed utility line backfill.

The construction of underground utilities is done during the earthwork phase of a construction project. Earthwork begins with stripping the site of all vegetation and top soil. Then, the site is graded to direct water runoff so that it conforms with the layout of the specific project. At this point, roads are cut in and building pads are constructed. The newly graded ground surface is typically significantly different from the original resulting in very different surface water drainage patterns.

Most utility lines are constructed by excavating a trench (width and depth dependent on the size of the utility line), placing a bedding layer of gravel, placing the utility line, and then backfilling the excavation with gravel. An average utility line may be 2 feet wide by 3 feet deep. The depth of the lines will vary to allow for gravity fall. The soils in Warren County are typically silty clays which means that the gravel backfill in the utility lines will have a coefficient of permeability potentially a thousand times greater than the surrounding soil. This information combined with the fact that the surrounding ground surface will have been stripped of vegetation and top soil leads to a large amount of surface water collecting in these trenches during storms. This leads to the conclusion that during one large storm, a utility trench could direct a volume of water to a nearby regolith arch that would have taken many storms prior to construction.

THE LOWES SINKHOLE DROPOUT

In 1995, Lowes Corporation started construction on a new commercial facility. The building covered approximately 180,000 square feet with approximately three to four times that amount of space used for parking. The entire site including landscaped areas covered approximately 15 acres (estimated based on visual observations).

During the construction of this facility, two major dropouts occurred, both of which were regolith arch failures. The first occurred early in the earthwork phase of the project and was outside of the building area in a parking area. This failure was a typical regolith arch failure due to surficial construction activities including vibrations and surface drainage changes. This sinkhole dropout, as well as the second dropout, was very deep because the bedrock surface was at a depth of about 30 feet. This is significantly deeper than most areas in Bowling Green.

The second dropout was an example of utility lines causing a dropout and occurred further into the construction process. The site had been completely graded and the skeleton of the structure had been completed, including the roof. No paving had been completed but all parking areas and drives had been cut in and compacted smooth. This dropout occurred behind the building in the service drive area. The specific location of this dropout was directly underneath the intersection of two utility lines. One line was a forced water main running east-west and the other was a smaller water line running north-south. Both utility trenches were approximately 3 feet wide and were several hundred feet in length. The deepest line was approximately 5 feet deep and the other line was about 1 foot closer to the surface. In addition, there was a roof drain from the structure less than 100 feet away. Figure 2 below shows a schematic of the layout.

All of these factors combined to cause the dropout. The utility lines that were backfilled with highly permeable gravel served as a conduit to catch all the surface water and roof runoff and ultimately direct it to the regolith arch. Based on the fact that some heavy rains occurred shortly before the dropout, this regolith arch experienced a volume of water in a matter of days that would likely have taken many years. The dropout was observed immediately after it occurred and water was flowing

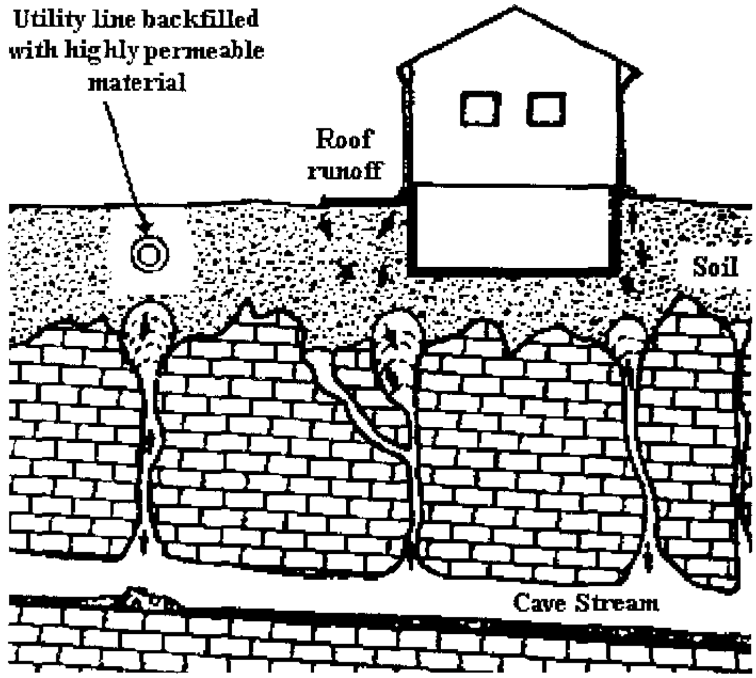

Fig. 2 Schematic of the cause of the Lowes dropout.

out of the gravel-filled utility excavations into the newly formed pit for approximately five hours. The rate of flow at the time the dropout was first observed was approximately five to 10 gallons per second and slowly diminished down to a trickle hours later.

As the sinkhole dropout was excavated so repairs could begin, the excavated soil was observed and had a sandy texture. This is typical in a regolith arch because most of the silts and clays have been washed down into the subsurface drainage system and the remaining coarser grained materials were acting as a bridge holding the surface in place. With this final piece of data, it became clear that excess water being diverted to an existing regolith arch via utility lines backfilled with gravel led to this sinkhole dropout.

STRIP MALL DROPOUT

In 1995, a private developer began construction on a commercial "strip mall" development. The site was occupied by a vacant building and associated parking area. The existing building was torn down and all existing paving was removed from the site so that the site was entirely exposed soil. This facility was approximately half the size as the new Lowes store and was completed in significantly less time.

This dropout occurred shortly after construction had been completed and was located underneath a water line in a low-lying section of the parking lot. Like the Lowes dropout, water was flowing from the gravel in the utility trench. Since construction had been completed and this commercial site was in operation, the dropout was not observed immediately. Although the initial volume of water flow was not observed, there was a small flow of water after a few hours. Also like the Lowes dropout, the soil was observed during the repair and it also had a sandy texture, indicative of an active regolith arch.

The reason this dropout did not occur during construction is likely due to the fact that since construction time was relatively short, the utility line was not exposed to as much water runoff. The runoff that it did experience during construction brought the regolith arch very close to failure, therefore, only a small amount of post construction water and surface traffic vibrations resulted in failure. The dropout was located within 50 feet of the edge of the parking lot and beyond the parking lot was exposed soil. Since water travels along the path of least resistance, a hydraulic gradient toward the highly permeable gravel backfill was likely formed resulting in the necessary amount of water to cause failure in the regolith arch.

CONCLUSIONS

In both of these cases, the utility lines remained intact and simply spanned the open pit. Careful excavation and remediation of the sinkhole dropouts allowed for 100% salvage of the utility lines. However, these are only two examples of hundreds of dropouts that have occurred in the Bowling Green area and several have caused severe structural damage to buildings. The location of future dropouts is difficult if not impossible to predict and the only thing preventing these types of dropouts under structures is probability.

While it is easy to document these occurrences and determine causes after the fact, preventive measures are as difficult as predicting locations. Consideration may be given to examining the process of utility installation. For example, one possible solution could be to use flowable fill to backfill utility trenches underneath the footprint of a building and 20 feet beyond. Flowable fill is a low strength, low-cost concrete that is slightly stronger than a stiff clay but has a much lower permeability than gravel. This would minimize the creation of a subsurface conduit for water that would be directed to an active regolith arch in the area of the structure, minimizing the potential for catastrophic failure.

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