A Case History of Site Instability Due to the Presence of a Shale Layer Above Sloping Bedrock

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ABSTRACT

A study conducted for St. Louis County of Missouri, United States of America classified several areas of the county as unstable for any type of construction because of the presence of high plastic shaley clay or clayey shale on sloping bedrock. These areas are considered to have a potential for site instability to occur due to any change in natural conditions that may increase the moisture content of the high plastic shaley clay or clayey shale. A two-story parking garage, founded on shallow foundations, constructed in one of the potentially unstable zones, showed some movement after several years of its construction. After movements in the structure were observed, further review of the subsurface conditions revealed that as a result of construction at the site, the clayey shale layer became exposed, thus, creating easy access for water to enter this layer. Infiltration of water caused softening of the clayey shale layer, which in turn caused movements in the structures constructed on the site. This paper presents the detailed information about the subsurface conditions and type of structures constructed on the site.

Key Words: Slope movement, Slope stability, Site instability, Shale

INTRODUCTION

Ensuring stability of both, natural and engineered slopes, continues to be a challenging problem in geotechnical engineering. The problem of slope instability has been studied extensively over the years. Typically, slope movement is divided into categories such as rock falls, surficial slope failure, gross slope failure, landslides, debris flow, and creep. The cause of the slope movement involves many variables including site geology, groundwater, weather, and vibration. Slope instability is usually associated with natural or engineered soil slopes which are steeper than 3 Horizontal to 1 Vertical (3H:1V). Failure of even gentler slopes is not uncommon, particularly when a weak soil zone exists within the slope. In several instances, potential of instability at a site may exist due to geological factors including composition (layering) and configuration of the bedrock. This factor becomes even more critical when site topography is such that the soil mass above the bedrock could move with relative ease.

Lutzen & Rockaway (1971) conducted a study for the St. Louis County area of Missouri and identified some areas within the county that are considered as hazardous for any type of construction because of the presence of highly plastic soil/shale on sloping bedrock. A two-story parking garage constructed in one of the potentially unstable zones identified by Lutzen & Rockaway (1971) showed some movement, several years after its construction. Information about the geology of the area, structure which showed movements, and possible reasons of movement are presented in this paper.

GEOLOGY OF THE AREA

Lutzen & Rockaway (1971) studied geological factors that influence land use in St. Louis County for the purposes of urban development in the county. Based on their study, they prepared a detailed engineering geology map of the county based on physical properties of bedrock and unconsolidated materials (soils) and defined the map units which represent specific engineering geologic conditions with respect to their significance in land use planning. They classified the geological environments that might influence or control land use as slight, moderate, or severe, which denotes the severity of potential land use or engineering problems caused by geological features.

Under the geology study performed by Lutzen and Rockaway (1971), the areas of St. Louis County are divided into ten map units, referred to as Unit I through X, to show their importance in land-use planning. The primary land units that are of importance to the current study are labeled Units VI through VIII dealing with shale. The map unit that is directly related to this case study is identified as Unit VI. A portion of the ST. Louis County region, which was identified as Unit VI by Lutzen and Rockaway (1971) is shown in Figure 1.

Figure 1. Map of St. Louis County, Missouri showing some of the Map Units - Unit VI is highlighted (Lutzen and Rockaway, 1971).

Lutzen and Rockaway (1971) described unit VI as being a part of the Maquoketa Formation, which is thinly laminated, silty, dolomitic shale, which locally contains nodules or lenses of shaley limestone. Also present in this area is the Glen Park, which is a thin to medium bedded limestone that varies from 2 to 3 feet in thickness. Another concern in Unit VI is the Warsaw Formation, which consists of shale, siltstone and a thin limestone sequence. Lutzen and Rockaway (1971) reported that slope stability is the main problem encountered in the shales of the Maquoketa and Warsaw Formations. The exposed weathered bedrock is very weak and any change in natural conditions that increase moisture content or steepens the slopes may lead to slope failure. The added moisture may come from septic tank effluent, stripping of vegetation, or interference with natural drainage. These areas have been classified as hazardous for any type of construction and therefore, they recommended that construction or planning in Unit VI area be initiated only after detailed engineering studies have been made.

SUBSURFACE CONDITIONS AT THE SITE

Geotechnology, Inc., a practicing firm in the St. Louis area, performed a detailed subsurface exploration at a site next to the site where the structure experienced some movements. This site is also a part of the same hill on which the structure where movements were observed, was constructed. Both sites had similar subsurface conditions. This site also exists in Map Unit VI delineated by Lutzen & Rockaway (1971), as shown in Figure 1.

The site topography map is shown in Figure 2. The site is located on a hill with the highest elevation on the south end being 620 feet above the mean sea level. The site slopes down to the north to an elevation of 560 feet. Several borings were drilled as a part of the subsurface exploration. Boring locations are shown in Figure 2. The soil borings revealed limestone bedrock exposed near the south end of the site and in other borings a clay layer, approximately 20 to 30 feet thick, was encountered as the surface stratum. The clay layer is underlain by an approximate 3-foot thick shale layer, which in turn is underlain by sloping limestone bedrock. Subsurface profile along a cross section A-A' (Refer to Figure 2 for location of A-A') is shown in Figure 3. Figure 3 shows the shale layer sloping down (towards the north) at an angle of approximately 10 degrees. Observations made from this site indicated a possibility that the shale layer is exposed in a dry creek bed at the far end of the site. The adjacent site and the site under discussion appear to share this dry creek bed.

CONCEPTUAL SITE PROFILES

The subsurface profile (Figure 3) shows that the geology at this site was consistent with the geology indicated in the study conducted by Lutzen & Rockaway (1971). Based on the subsurface conditions observed in the borings and the information from the study performed by Lutzen & Rockaway (1971), a conceptual sketch shown in Figure 4 was developed to represent the subsurface conditions at the site. Modifications to the site consisted of construction of a five-story office building and an attached two-story parking garage. The office building was supported on drilled shafts and shallow foundations bearing on bedrock whereas the parking garage was constructed on shallow footings bearing in soil. The finished floor elevations for the office building and the parking garage were such that the site required a cut at the highest point on the site and fill underneath a part of the garage. A conceptual sketch of the modified slope profile is shown in Figure 5, which also shows the modifications planned for the site. To achieve the required finished floor elevations, the site was cut within the footprint of the office building and part of the parking garage, and was filled under the north end of the parking garage.

DETERMINATION OF FACTOR OF SAFETY

It is believed that the construction at the site where movements were observed in the structure caused easy access for water to enter the shale layer. As reported by Lutzen & Rockaway (1971), a site within Unit VI has potential of becoming unstable due to any change in natural conditions that may increase the moisture content of the high plastic shaley clay or clayey shale. In order to study the effect of variation of angle of internal friction of clay layer on the stability of the site slope, a parametric study was conducted. The parametric study was performed for various angles of the main slope. Soil and rock properties were estimated from typical values available in the published literature. For the purpose of performing the parametric study, the parking garage was considered to be on shallow foundations at an allowable bearing pressure of 2,500 pounds per square foot (psf). Although, 2,500 psf pressure would be transferred to the soil only at the footing locations, for simplicity it was assumed to be uniformly distributed over the footprint of the garage. Commercially available, computer software, UTEXAS4 (Wright, 1999), with Spencer's method (Spencer 1967) of slices was used to perform the parametric study. UTEXAS4 is a general-purpose software for limit equilibrium slope stability computations. Critical failure surface was assumed to be located within the shale layer. Detailed information about the parametric study and the results are presented elsewhere (Hall 2002, and Kumar and Hall, 2003).

Figure 6 presents the variation of the factor of safety with the change in angle of internal friction of shale for the natural slope configuration. Each curve shown in the figure represents a different main slope angle. Figure 6 shows that within the range of values of the internal friction angle of shale studied, the factor of safety increases linearly with the increase in the angle of internal friction of shale. The increase in factor of safety observed is obvious because as the strength of the shale increases there is more resisting force available to prevent slip in the shale and hence, the slope is more stable. As discussed in a previous section, the main slope angle was measured to be approximately 10 degrees. From Figure 6, it is clear that the for a main slope angle of 10 degrees, the factor of safety of the slope will reach one when the angle of internal friction of shale reaches approximately 9.5 degrees which is a typical value of residual frictional angle of shale.

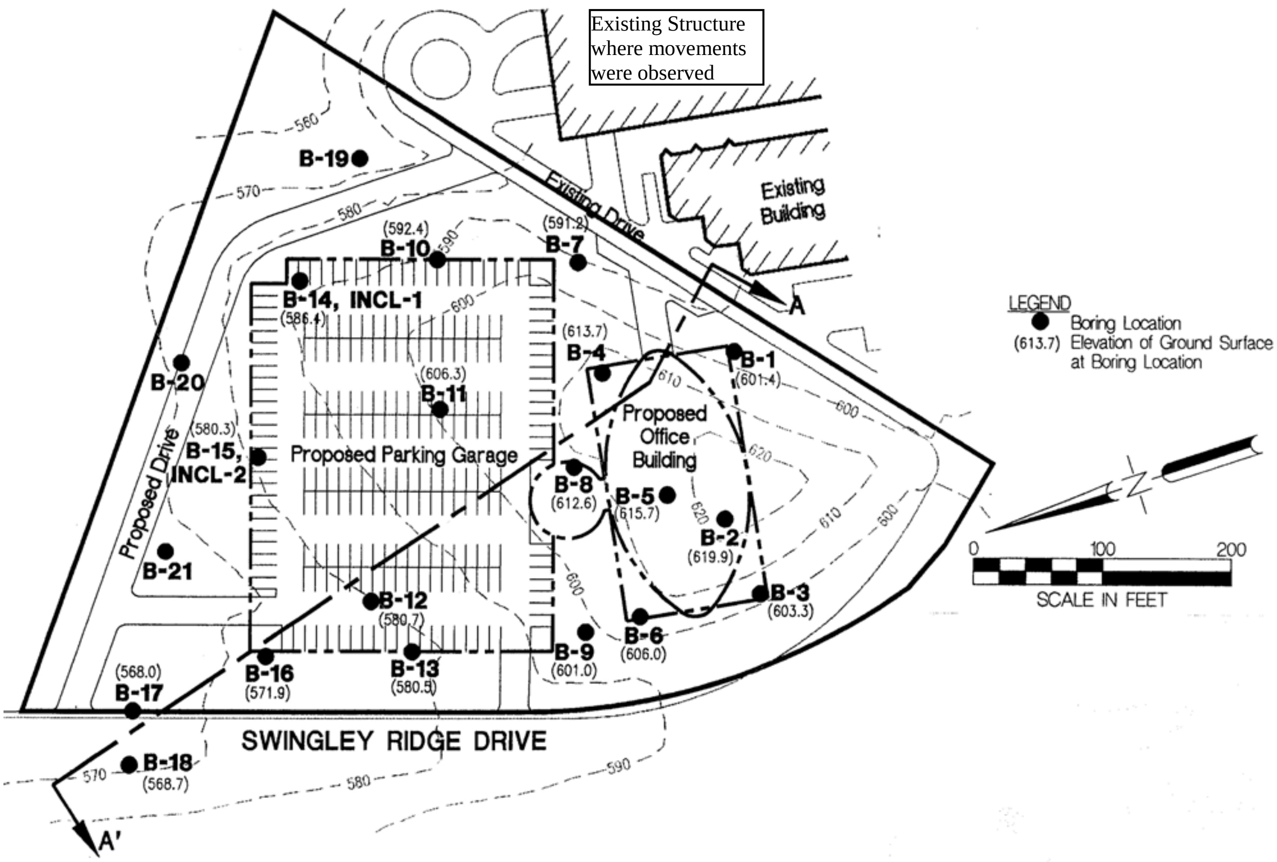

Figure 2 Topography Map including profile line AA' developed by Geotechnology, Inc.

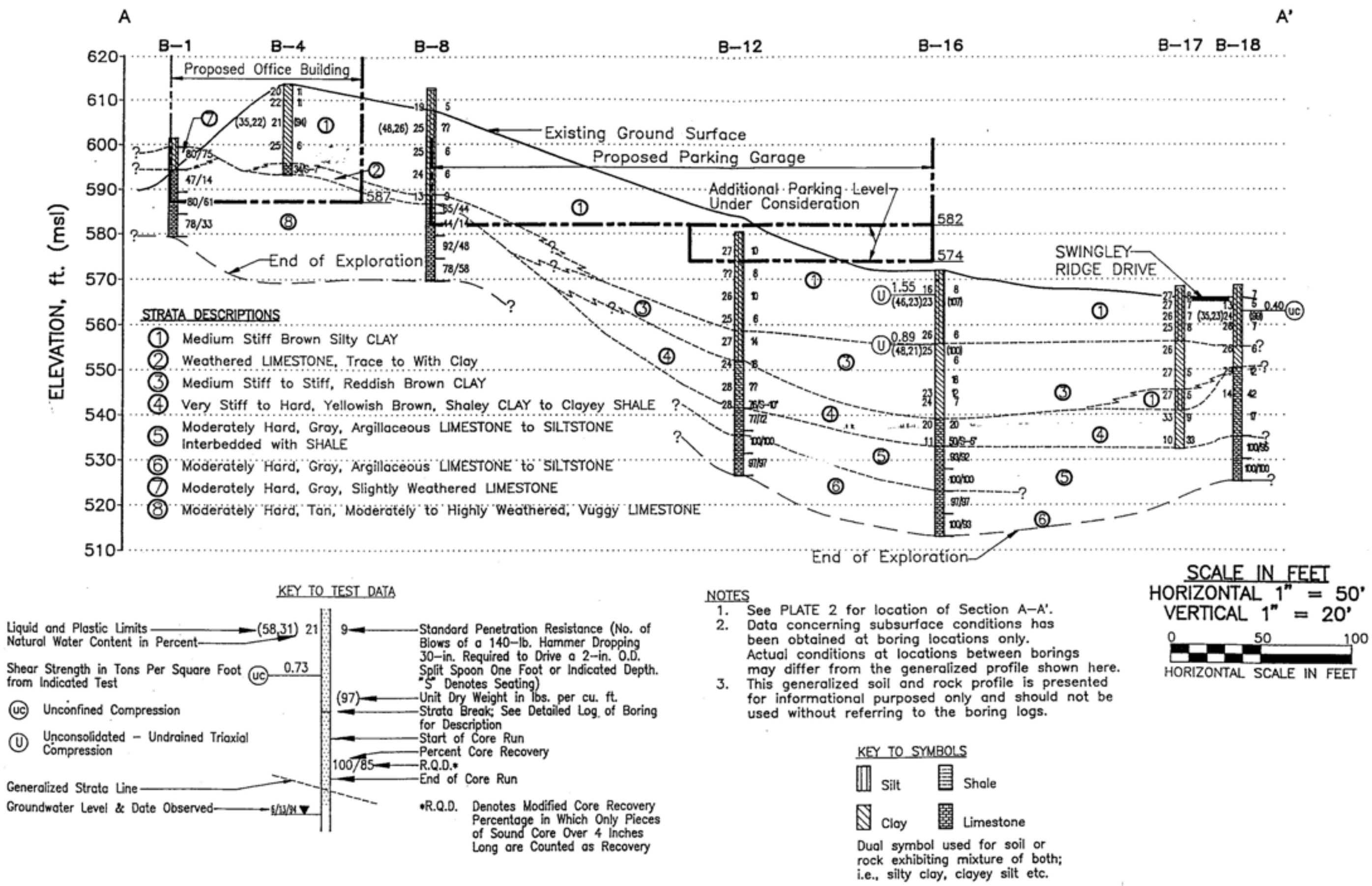

Figure 3 Subsurface Profile Developed by Geotechnology, Inc.

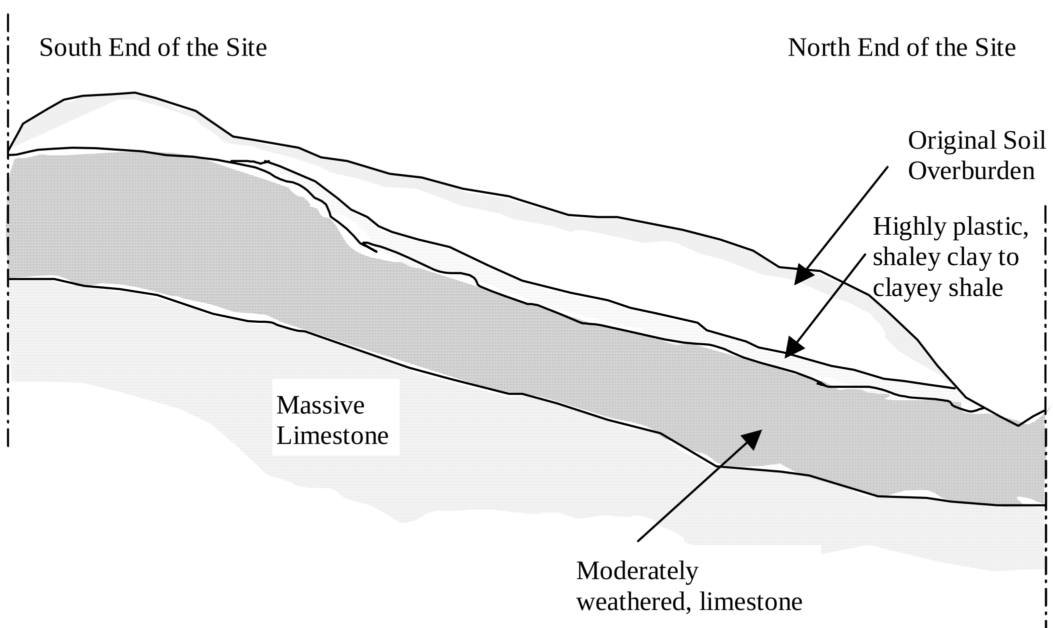

Figure 4. Conceptual sketch of the existing surface and subsurface conditions at the site.

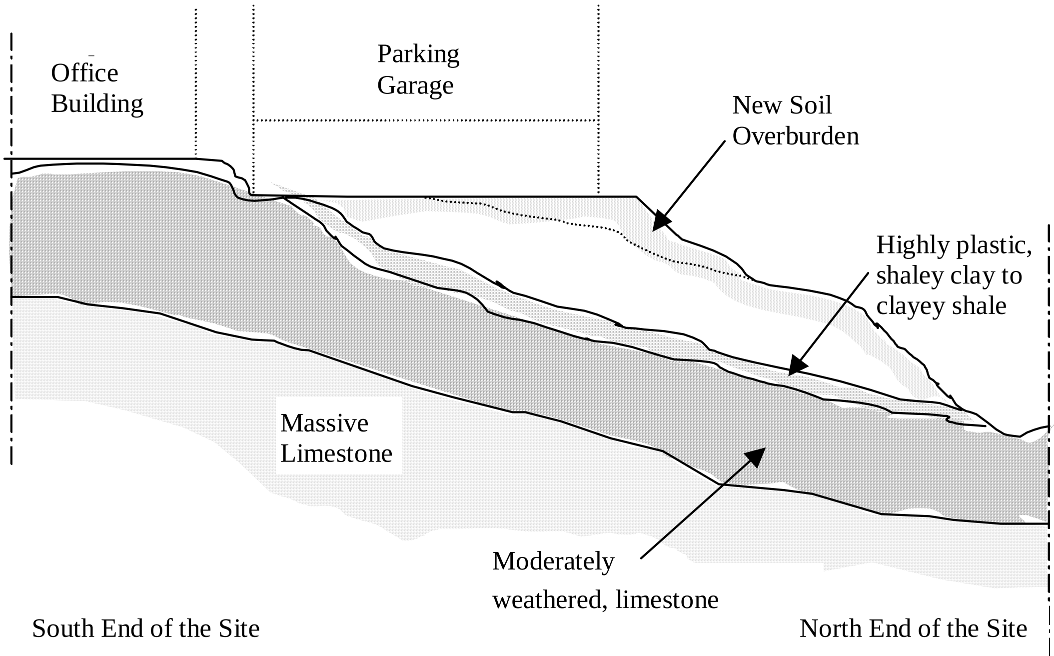

Figure 5. Conceptual sketch of the modified surface and subsurface conditions at the site.

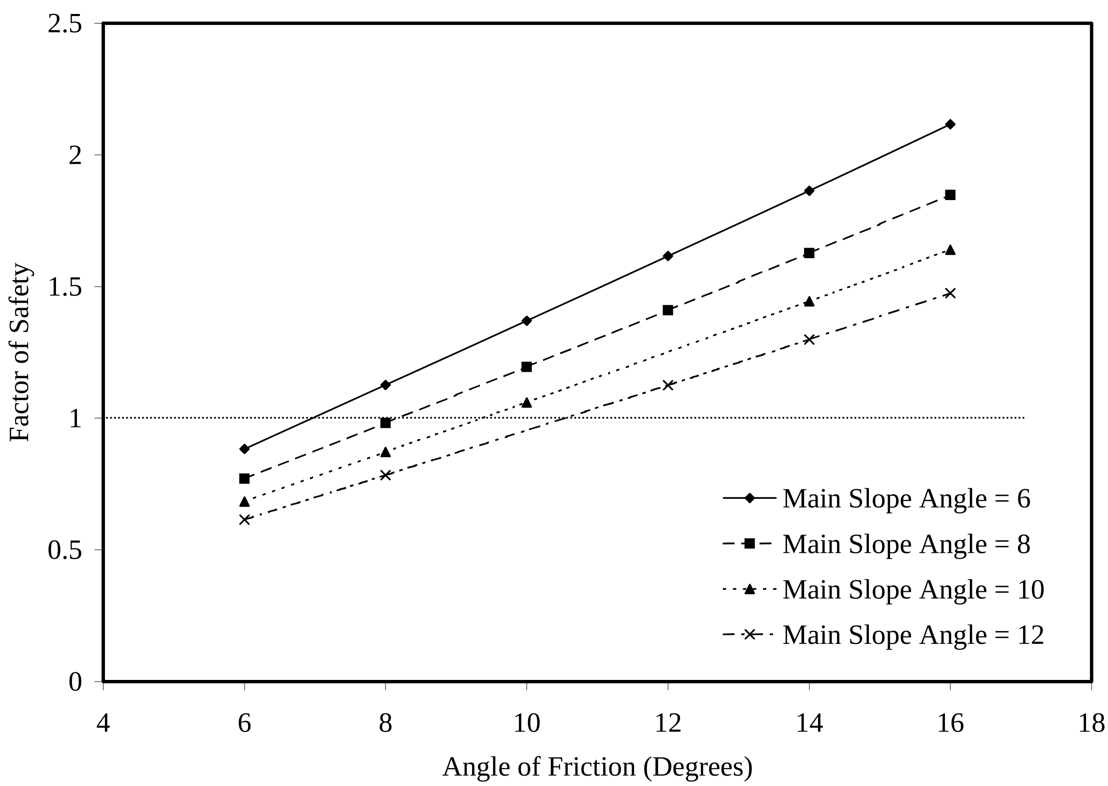

Figure 7 Variation of Factor of Safety with Angle of Internal Friction of Shale

CONCLUSIONS

A case study of a two-story parking garage where movements were observed after several years of construction is presented. The garage was founded on shallow footings and was built on a site where a high plastic shaley clay or clayey shale layer existed above a sloping limestone bedrock. Based on the observations made after the movements were observed, it was concluded that the construction at the site caused easy access for water to enter the shale layer, which softened the shale layer to its residual strength. The parametric study performed also showed that the factor of safety of the slope is likely to reduce to one when the angle of internal friction of shale clay/shale is approximately 9.5 degrees. The observations made from this case history are consistent with the study conducted by Lutzen & Rockaway (1971).

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