Planning and Design Considerations in Karst Terrain

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ABSTRACT / This article discusses the various steps that the authors feel are necessary to the successful progression of an engineered project sited in karst terrain. The procedures require a multidisciplined approach with liaison and cooperation among the various parties to the project.

Initially, the prospective owner must have sufficient understanding of the potential engineering problems to incorporate the engineering geologist into the early stages of any planned acquisition. The first step in an investigation should include a review of the available geologic information, aerial photo interpretation, consultation with the State Geological Survey, and a geologic reconnaissance of the prospective site and surrounding area.

A go-no-go decision as to purchase can often be made at an early time. Although, in some instances, more study is needed for a particularly intriguing property.

The second stage should consider the various planning alternatives that are feasible based upon the limited available information. At this stage planning/purchase decisions can be made as to purchasing options, value of the property, design constraints, and the possible economic penalties that could be associated with the potential site construction. Various planning and construction alternatives should be considered in this phase of the work.

The third stage should include a site investigation program of moderate size, consisting of test pits and/or exploratory borings. The borings should be drilled using water as the drilling fluid, with an experienced crew and qualified technical inspection. The authors find the use of geophysical techniques can be extremely misleading unless used in conjunction with exploratory drilling. Successful evaluations using geophysical procedures occur only under ideal conditions.

The geotechnical viability of the plan and preliminary design should be investigated in the fourth phase. Additionally, the physical parameters required for the design of structures founded atop cavities can be obtained at this time. Several support schemes which incorporate cavity roof thickness, rock strength, and cavity space are discussed.

Possible construction procedures include excavation and dental concrete, grouting, piers or piles to sound rock, or moving to another area. The relative economies of these procedures are discussed in relation to the size and depth of the soil or rock cavity, possible future cavity formation, magnitude of loading and acceptable safety factors.

Introduction

This article attempts to describe the geotechnical aspects of what the authors believe are the appropriate procedures to employ in multi-phased, multi-disciplined studies for projects which may be located in karstic locations. In using the term geotechnical engineering, we prefer to consider it in the true meaning, not as it is sometimes used, as synonymous with soil mechanics or foundation engineering.

The carbonate rocks we will discuss herein are hard crystalline materials, when unweathered. They are the Cambro-Ordovician formations found in the valleys of the Appalachian range. They are found from Ontario to Alabama, causing a variety of problems, but still not well recognized as being of concern to construction and environmental well being. The many physical features resulting are well known: Mammoth Caves, Luray Caverns, Shenandoah Caverns, Natural Bridge(s), Crystal Cave, Howe Caverns, etc.

These carbonate rocks were deposited some 400 to 500 million years ago at the edge of the North American continental land mass, as it then existed. The continental margin was folded and faulted during the closing of the proto-Atlantic Ocean, and the carbonates were subsequently deposited within the fold-produced valleys. The thickness of the Appalachian carbonate deposits range widely, from less than a few feet to in excess of one thousand feet. Subsequent deformation along the edge of the continent resulted in

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extensive faulting, numerous shear zones, and in some instances recemented breccias. In many instances extensive deposits of carbonates were moved in fault blocks, fractured anticlines, and decollements, to their present positions. Water flow through these many fractures and faults has resulted in the formations of solution cavities and channels. Migration of unconsolidated overburden materials into these cavities and channels manifests itself in ground surface subsidence and dolines.

Construction above these hard crystalline formations can result in severe geotechnical problems. The causes and solution to these problems can be quite different than those of the more well know, more geologically recent, limestones of, for example, Florida or Puerto Rico. The authors' experiences in dealing with these "hard" carbonate rocks are in or near the Appalachians, however, similar deposits are found in the western United States, Canada, and South Africa, and we believe the results of our studies are broadly applicable.

For purposes of this discussion we can attempt to separate the various aspects of a multi-scope, geotechnical investigation of a site into coherent segments. Obviously in the real world some phases may nearly (or completely) disappear. There is almost always overlap, and sometimes budgetary or time constraints require the combination of the discrete segments, and too often, their compression into an almost amorphous mass of "do it now." From a chronological standpoint the phases of a project we would like to see are:

1. Prepurchase site evaluation
2. Prepurchase planning and conceptual design
3. Site investigation
4. Planning, layout, and design
5. Additional site studies where warranted
6. Final layout and design where necessary
7. Construction inspection and design changes where necessary

From a technical and presentation standpoint it is easier to categorize those chronological segments into:

1. Prepurchase Site Evaluation
2. Planning
3. Site Investigation
4. Geotechnical Engineering

It is these later four segments which we will use as the format of this article.

Prepurchase Site Evaluation

For the knowledgeable developer the best return on his investment occurs when the possible geologic hazards at a site, such as doline occurrence, are investigated prior to sinking money into a valueless site (or into a bottomless sinkhole). Unfortunately very few real estate development groups have the knowledge or the inclination to worry about geologic hazards until it is time to "start construction."

A great deal of information, suitable for preliminary evaluation within the carbonate rock formations of the East Coast, is available through Federal or State Survey data (our local State Surveys have provided invaluable assistance in many instances). Although different names abound, it is frequently possible to correlate formations, hence properties and performance, from state to state. Typical commonly available information may include:

1. Water-bearing potential (well yields) of a formation; generally the higher the water-bearing potential and greater the probability and density of cavities or shear zones;
2. The existence of caves or documented solution activity;
3. Grain size of limestones or dolomites (textural classification has sometimes been correlated with porosity, the larger the grain size the greater the susceptibility to solution);
4. The existence of faults or other macrogeologic forms of distress; and,
5. Unconfined compressive strength of sound rock.

Using these data, together with a site reconnaissance, and an inspection of aerial photos, many times allows the experienced engineering geologist to develop a realistic appreciation of the problems that can be faced in areas underlain by carbonate rocks. As will be subsequently discussed, these concerns can include much more than doline formation.

This preliminary evaluation can lead to a variety of decisions by the prospective owner/investor. He may decide to eliminate the site from further consideration, with only this small investment in time and money. If only a portion of the site can be developed economically, as a result of cavity-prone rocks, a reduction in the purchase price of the property can result. An additional alternative can be to perform further, more definitive, geological studies to better define the limits and scope of the problem.

Planning

If the areal extent of the sinkhole problem is known it may be possible to move major structures away from the areas of solution-prone carbonate rocks to areas underlain by sound materials. Noncritical facilities, such as golf courses, parks, ball fields and hiking trails, even roadways or parking areas, (which are lightly