

Mapping and Prediction of Limestone Bedrock Problems

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ABSTRACT

Site evaluation for transportation routes and engineering structures located in limestone bedrock regions is often difficult. The highly irregular soil-bedrock interface and the presence of subsurface cavities make the results of such an investigation highly uncertain. A methodology has been prepared to assist the engineer with the planning of a thorough site evaluation that will minimize the degree of uncertainty. Preliminary studies consisting of the compilation of data from existing sources such as physiographic, engineering soils, pedologic, surficial and bedrock geology, topographic, drainage, and overburden thickness maps and reports are essential. A review of the current methods of remote sensing such as aerial photography, reflective and thermal infrared imagery, radar, radiometric data, and multispectral imagery is included. Combining this information with a knowledge of certain geologic indicators will identify areas that are more suitable to the siting of the route or structure under study. Preparation of a sinkhole density map is advocated for projects involving large areas. Areas of uncertainty can be further investigated employing geophysical techniques such as gravity, ground-probing radar, magnetics, seismic refraction, or electrical resistivity. The problems for which each of these techniques is appropriate are discussed. The compiled information can then be used as a guide to plan the location of subsequent borings.

When planning a transportation route or selecting a site for a structure in a limestone region, the engineer is faced with many unique problems that can often be solved only with experience gained from similar previous situations. However, it is unfortunate that even with such experience, many competent engineers are often fooled by the highly erratic nature of the soil and bedrock associated with karst regions. Selection of the appropriate techniques for site investigation and knowledge of their limitations are necessary to the correct interpretation of the collected data.

Two major engineering problems associated with the development of a residual soil weathered from carbonate rock are (a) the highly irregular soil-bedrock contact and (b) the frequent development of subsurface cavities that may or may not manifest themselves at the surface as sinkholes. The first problem may cause cost overruns when attempting to predict the amount of rock to be excavated in cut-and-fill operations for highways and makes the design and construction of deep foundations difficult. The second problem may lead to catastrophic collapse during or after construction, because of either alteration of the surface drainage or increased load from an embankment.

A methodology has been prepared that will enable

the engineer to make a step-by-step evaluation of a proposed site. A review of the current techniques of remote sensing and geophysical exploration was conducted to determine the most useful methods for performing a site investigation in a limestone region.

METHODOLOGY

The proposed methodology of site investigation for locating highway routes or other engineering structures in limestone regions is shown in Figure 1. It considers a wide variety of techniques that have been used successfully for investigations in karst regions. Of course, none of the methods can be used in all situations, so the physical situations and types of problems for which each is best suited are emphasized in the following sections.

PRELIMINARY STUDIES

The first step shown in Figure 1 is to determine the physiographic characteristics of the area under consideration. Various references can be consulted for this purpose (1,2,3,p.318). From this information the engineer can immediately anticipate the types of problems that are likely to be encountered at the site under investigation. Many states have mapped the surficial soils on the basis of parent material, landforms, or some other general engineering classification. Indiana, Arizona, Kentucky, Illinois, and Rhode Island have prepared such maps on a county basis. A more comprehensive program of soil mapping is being carried out by the Soil Conservation Service of the U.S. Department of Agriculture. Although mapping has been for agricultural purposes, the pedologic soils can be correlated with specific engineering properties, and engineering data are often included in many of the more recent survey reports. Surficial and bedrock geology maps are good sources of information. State geological surveys, in cooperation with the U.S. Geological Survey, have prepared these maps at a scale of 1:250,000. The extent of a limestone area can be seen immediately from such a map. Drainage maps may also be available and are useful in locating sinkholes and other surface features of karst topography. Overburden thickness maps provide general information on the depth to bedrock at a given site. Stereoscopic aerial photographs are an invaluable tool for delineating features of a site and getting an initial feel for the area without actually visiting it. They should be available from state or local planning agencies. Small-scale satellite imagery (ERTS) can be obtained from the National Aeronautics and Space Administration for use in large site selection studies. Although solution features are difficult to distinguish because of the small scale, regional trends may be observed.

RECONNAISSANCE DATA

If the information discussed previously is insufficient or not available, a remote sensing survey may

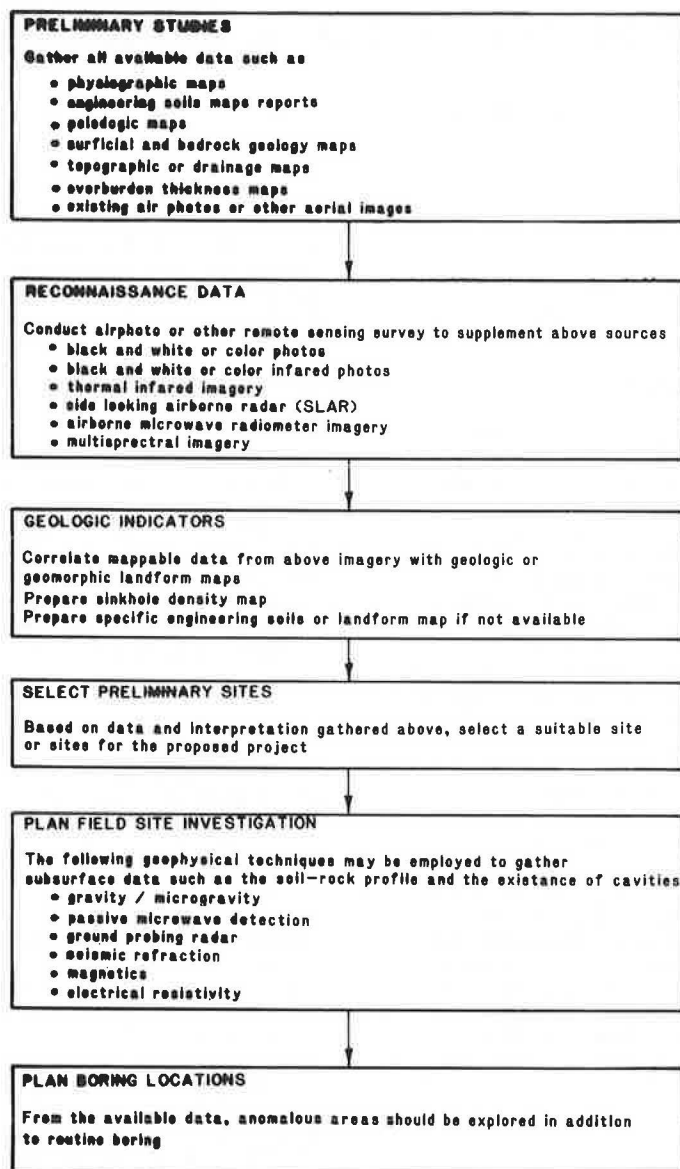


FIGURE 1 Methodology of site evaluation.

be conducted. The most common type of imagery is black-and-white or color photography, usually at scales between 1:24,000 and 1:62,500 (4,p.18). An experienced aerial photograph interpreter can delineate problem areas such as solution zones based on subtle topographic or reflectance features. Variations in topographic, drainage, and erosion characteristics, as well as vegetation, land use, and soil tones are important patterns that the interpreter looks for. Black-and-white or color reflective infrared photographs (about 0.7 to 1.1 μm in wavelength) have been used to map slight differences in soil or moisture content or both. Color infrared photographs are especially useful if a combination of films and filters is employed. An important clue for detecting solution activity in limestone is vegetative stress in the vicinity of a developing cavity. Such stress induces a change in reflectance (5). Near-surface features such as faults, fractures, and joints can also be delineated, which is important because they act as channels along which active dissolving takes place (4).

Thermal infrared imagery records emitted radia-

tion in the 8 to 14 μm wavelength band. Sinkholes are linked to subsurface drainage paths, which have air and water flowing through them, often at temperatures different from the ambient temperature. Some studies have been performed using thermography to distinguish differences in soil texture with good results (6). Both Stohr (7) and Rinker (8) concluded that thermal infrared imagery cannot distinguish sinkholes by itself, and that stereoscopic aerial photographic coverage or ground control or both are required supplements.

Side-looking airborne radar (SLAR) has been used to map fracture and fault traces (5). Airborne microwave radiometer surveys can detect subsurface voids by recording anomalies in the radiometric temperature of the ground surface. From data taken over a previously mapped cave, Dedman and Culver (9) have concluded that there is a correlation between temperature lows and the location of subsurface voids. Although not perfect, the technique shows sufficient promise to warrant more research. A relatively new technique of remote sensing is multispectral imagery, which requires an airborne line

scanner capable of recording data in several synchronous spectral bands. Good discussions are given by Wagner (10), West (11), and Mathews et al. (12). Multispectral imagery may be a valuable, if expensive, tool for delineating limestone residual soil boundaries.

GEOLOGIC INDICATORS

After enough information has been gained from the sources discussed, geologic and geotechnical interpretations are made to identify areas of high collapse potential. Williams and Vineyard (13) have compiled a list of geologic indicators of potential collapse in areas of limestone and dolomite in Missouri. They concluded that potential for catastrophic collapse is enhanced if the residual soil cover (a) is between 12 and 30 m (40 to 100 ft) thick, (b) contains the relict structure of parent rock, (c) has a low plasticity clay fraction (ML A-7-5), and (d) is draining poorly. Surface water that is diverted to the subsurface and a high density of natural sinkholes often indicate areas with a high potential for collapse.

For studies that encompass large areas, such as selection of transportation routes, preparation of a sinkhole density map may be helpful. Such a map was developed for Lawrence County, Indiana (Figure 2), and was prepared by simply counting the number of sinkholes per square mile from an existing drainage

map. Correlation of sinkhole density with geologic formation is possible, and routes can be aligned so that areas of high sinkhole concentration are avoided.

Most of this information has addressed only the problem of detection of subsurface solution features in karst areas. Delineation of the soil-bedrock contact must be made with more sophisticated techniques and will be discussed in the section on field investigation.

PRELIMINARY SITE SELECTION

Selection of preliminary sites can now be made based on the following points. The area should (a) be located within reasonable distance of existing transportation routes; (b) be accessible to exploration and construction equipment; (c) have a minimum of solution activity; (d) have favorable drainage characteristics; (e) contain a minimum of potential solution zones such as caves, joints, fractures, or faults; and (f) be located in reasonable proximity to engineering construction materials.

FIELD INVESTIGATION

When the site or sites have been selected, a field investigation can be performed. Problem areas can be

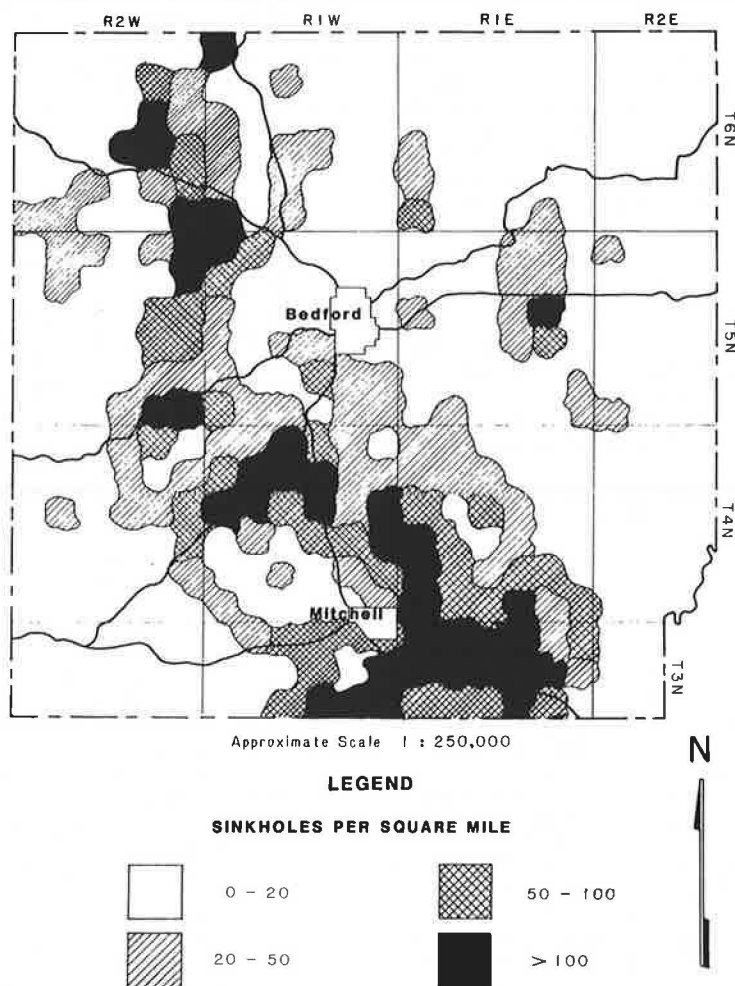


FIGURE 2 Sinkhole density map of Lawrence County.

identified from the preliminary reconnaissance work, and it is on these that much of the subsurface investigation should be concentrated. Geophysical techniques are efficient in limestone regions, and several techniques are discussed.

Gravity

Gravimetric techniques have long been used to detect anomalies in the earth's gravity field caused by differences in density among earth materials (14,15). Several studies have been conducted recently to evaluate the potential use of gravity methods for detecting subsurface voids (16-18), but the technique must often be coupled with another method to give satisfactory results.

Radar

Impulse or ground-probing radar has been the subject of recent studies (18,19). The reliability of this technique is questionable because of the wide variety in the electromagnetic properties of earth materials. However, if the equipment is chosen so that the output signal wavelength is comparable in size to the features that are to be detected, and if these features are not too deep, the technique can provide useful information about the subsurface profile.

Magnetics

Magnetic surveying is a technique that has shown limited potential in locating subsurface cavities (20). McDowell (21) describes a magnetic survey that was conducted over clay-filled sinkholes in chalk. McDowell concluded that although the method was successful in locating many of the sinkholes, the site must be free of any metal refuse that will interfere with the signal.

Seismic Refraction

Seismic refraction is a useful technique for delineating soil-bedrock interfaces in a limestone region, and it provides a quantitative measure of the depth to bedrock. Brooke and Brown (17) used refraction to locate a small cave and fault trace north of Santa Cruz, California. Although this is an instance where the technique was used for cavity detection, soil-bedrock profiling is the most efficient use of seismic refraction in limestone areas.

Electrical Resistivity

Much of the recent literature on detection of subsurface cavities in limestone has concluded that electrical resistivity methods are very efficient (17-19). Bates (22), in a comprehensive study of geophysical techniques used for detecting subsurface cavities, concluded that electrical resistivity methods give the best results. Good discussions of the details of the technique are given by Fountain (18), Clayton et al. (20), and Bates (22). Interpretation procedures can be found in Bates (22) and in the U.S. Army Corps of Engineers geophysical exploration manual (23). Problems associated with this method include outside interference with current, poor resistivity contrast between materials, dipping interfaces, and limitations due to equivalence and suppression in depth sounding (20).

Enough information should now be available for the engineer to plan an intelligent boring scheme to verify features identified by the remote sensing and geophysical surveys. Problem areas should be explored in detail, but no area should be completely ignored.

SUMMARY AND CONCLUSIONS

Problems that are unique to limestone bedrock and the residual soil derived from it require well-planned, thorough site evaluations if engineering structures and transportation routes are to be successfully constructed in such regions. Preliminary studies consisting of the compilation of data from existing sources of information are essential. Reconnaissance information may be required for large projects if existing sources are scarce. The preliminary information may reveal certain geologic indicators of potential problems in limestone, and the possible sites can be reduced to one or two areas. Locations where problems are anticipated should then be surveyed using a geophysical method or combination of methods. When the surveys have been completed and sufficient data have been collected, suspected problem areas can be verified with subsequent borings.

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Characteristics of Sinkhole Development and Implications for Potential Cavity Collapse

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ABSTRACT

The results of investigations conducted in the karstic coastal plain of Florida indicate that the potential for cavity collapse is significantly greater in topographic lows where existing sinkholes, depressions, and other surficial features are lineated. Fracture traces and these lineaments can be established by interpretation of aerial photographs. In one case study it was found that almost all recent sinkholes occurred in the vicinity of the intersection of lineaments. A high vertical permeability to promote solution of carbonates and to induce piping of overburdened soils seems typical of many cavity and sinkhole systems. Collapse of overburden into cavities generally appears to be triggered by depression of the water table followed by wet surface condi-

tions (e.g., well pumping and irrigation). Details of these investigations are presented with some emphasis on the lack of definitive geophysical and remote sensing methods for cavity detection. Several examples are presented to illustrate the difficulty in detecting subsurface cavities in conventional foundation investigations and in the analysis of the in situ conditions triggering the collapse. The subsidence of a portion of Interstate highway is discussed in relation to the observed in situ conditions.

Sinkholes and karst terrain are generally associated with the solution of limestone or, to a lesser degree, dolomite in regions with at least moderate