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SYNOPSIS

Grouting the cavities in cavernous carbonate formations is one of the techniques employed to achieve reliable bearing support for structures founded in and on such rock units. For this purpose, conventional exploration methods, such as test borings and geophysical measurements, can be employed to obtain the necessary subsurface data; but, they are usually limited in extent, expensive, time consuming, and can be misleading. These limitations can be overcome by employing percussion probing techniques. A case history is cited wherein percussion probing was successfully employed.

INTRODUCTION

Carbonate formations are rock units that contain limestones and dolomites. These units possess varying degrees of solubility in water, depending upon its acidity. Due to this, cavities form resulting in structural weakness of the rock formation. Sound rock above these openings tend to bridge or arch. If these bridges are not strong enough to span these openings and/or if they are weakened by natural phenomenon, such as jointing or weathering, or other causes, they can collapse.

Foundation Support in Cavernous Carbonates

The ability of the foundation material to support foundations in, on, and within the soil above these formations is affected by the location and extent of cavities within these rocks and the thickness and quality of rock between the cavities and the foundation. In some cases, it may be necessary to improve the quality of the rock mass to obtain the required strength. Several methods of improving foundation reponse and reliability within these formations have been reported in the literature (Wagener, 1984, Depman and Backe, 1976). A case history where grouting was performed to improve the foundation support will be presented in this paper.

Geology of Case History Cited

The project cited in this paper is located in central New Jersey and comprised a portion of a major corporate headquarters building complex. A literature review pertaining to the geology of the site was conducted. The site is located on the southeastern edge of the Highlands physiographic province and extends west into the adjacent Triassic Lowlands (Widmer, 1964). Regional bedrock mapping (New Jersey Department of Environmental Protection, 1974) indicated that four formations occurred at the site region, exhibiting evidence of Cambrian through Mesozoic Tectonic events which controlled the region's geologic development. From the oldest to the youngest, the formations found were: Hardyston Formation, Leithsville and Allentown Formations (all Cambrian), and the Border Conglomerate of the Brunswick Formation (Triassic). Basement rock is Precambrian Byram Gneiss.

The Leithsville Formation, which underlies the immediate vicinity of the project, is a dolomite rock. At least two members of this formation are believed to be present at the site (Markiewicz, et. al., 1981). The major member present is fine grained and thinly bedded with interbedded residual clay layers (the Hamburg member). A coarse grained and massively bedded, crystalline dolomitic limestone, which weathered in a pinnacled configuration, is the other member (the Califon member). The site is intensely folded and faulted. In addition, the literature indicated the bedrock contains cavities of varying sizes, some of which were found to have been filled with soil (Wheeler and Myers, 1976).

Subsurface Explorations Performed Prior to Grouting

Conventional subsurface explorations performed revealed the presence of a cavity under the proposed structure. In order to determine the exact location, extent, and configuration of this cavity, several conventional subsurface exploration techniques can be employed. Borings with rock coring tend to be slow and expensive, especially when performed at each proposed foundation location. Interpretation of subsurface conditions from more widely spaced, less frequent borings tend to be extremely misleading. Geophysical methods do not yield absolute subsurface information and frequently detect at best only the largest cavities. It is thus desirable to employ a technique, that would be more reliable than the geophysics, and more rapid and less expensive than the borings for performing the additional investigations necessary for grouting. This was accomplished by utilizing a closely spaced grid of percussion probes correlated to site conditions.

Percussion Probes

Percussion probes, commonly known as "Air Track Probes" were utilized to conduct detailed investigations of the location and the extent of the cavity below the proposed water tower. In this country, such probes have been used to verify the adequacy of the bearing stratum of caissons in carbonate formations. These probes have also been successfully utilized in South Africa in cavernous regions (Wagener, 1984). But at the time the authors employed this technique, they were not aware of the use of percussion probes for determining the extent of cavities.

The air track probe rig utilized for these investigations was a Crawalair ECM-350, equipped with VL-140 valveless drifter. Of the various drill bits tested, the 3-inch bit size was selected for use since it provided penetration rates that were easier to record but rapid enough to be economical. To provide the necessary compressed air, an Ingersoll Rand Spiro Flo DXL 750P compressor, delivering 750 cubic feet of air per minute at 125 psi was used. This equipment does not yield representative samples; but, it is possible to record the rates of penetration through different subsurface materials, as the probes penetrate through them. More details of the equipment used for percussion probing can be obtained from literature (Lifrieri and Raghu, 1982).

Basis for Interpreting the Probe Data

A site specific correlation was developed between percussion probe penetration rates and the type of material encountered for this project site. For this purpose, a test area was selected where borings were previously drilled. Probes were advanced adjacent to borings. Penetration data obtained from these probes were compared with the materials recovered from the borings. Based on this, a preliminary correlation could be established between the observed probe penetration rates and the quality of the subsurface materials, especially the rock. Utilizing these results, a judgement regarding the bearing strength of the material could be made.

As explorations progressed further for the complex, it became evident that these preliminary correlations had to be modified based on a visual inspection of the material penetrated in order to obtain quantitative data regarding the quality of the subsurface materials. To accomplish this, a probe rig was set up at the top of a slope of a near vertical excavation exposing rock and soil of various quality. Probes were advanced immediately behind the face of the slope. The quality of the rock exposed in the excavation could then be visually inspected and compared to the corresponding penetration rates observed during probing operations. Thus, a final and more realistic correlation was established between the penetration rates and the strength of the subsurface materials penetrated. This correlation is presented in Table 1. More details of these correlations, the limitations and interpretation of data based on a term called "Foundation Quality Index" are reported elsewhere (Lifrieri and Raghu, 1982).

Table 1

Penetration Rate of the Percussion Probe (Seconds per Foot)	Type of Material	Symbol
0 - 2	Void/Soil Filled Cavity	V
2 - 5	Loose Soil	S
5 - 15	Residual Soil	RS
15 - 30	Decomposed Rock	DR
Above 30	Sound Rock	R

Probing Program

Forty-five percussion probes were drilled at several locations around the perimeter of this structure which measured only 25 feet square (see Figure 1). Also shown in Figure 1 is the layout of the original proposed foundation for the structure. The penetration rates were recorded for each foot of each probe. The percussion probes were generally terminated upon penetrating at least 15 feet into competent bedrock free of cavities. A typical probe log is presented in Figure 2.

It should be noted that all 45 probes were drilled in only four days at a total cost, including inspection, of approximately $4,500. Since the overburden soil cover is relatively thin, detailed subsurface exploration by borings would involve a significant footage of rock coring. It was estimated that the cost to obtain, by means of test borings, similar information regarding the extent of the cavity beneath the structure would have been about fifteen times greater and would have required fifty to eighty rig days to complete.

The percussion probes indicated that the overburden soils were relatively thin and that the bedrock contained a large, continuous cavity beneath the entire plan area of the proposed structure. A typical subsurface cross section depicting the subsurface stratigraphy before grouting, as inferred from probing, is shown in Figure 3. For these conditions, several foundation design alternatives were considered.

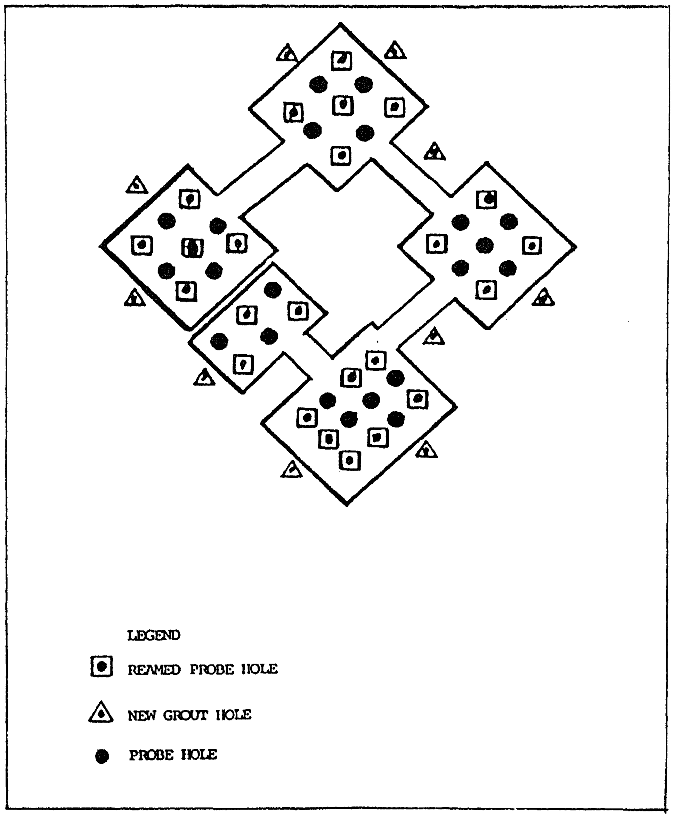

FIGURE 1 - LAYOUT PLAN OF STRUCTURE

PROBE LOG

PROJECT: Proposed Corporate Headquarters	PROBE 1 of 1
CLIENT:	SHEET 1 of 1
GROUNDWATER:	JOB NO.:
EQUIPMENT DETAILS: Bit - Carbide. Diameter - 3 in.	GROUND ELEVATION:
HAMMER: Type - VL140. Rating - 100 psi @ 750 cfm.	DATE:
RIG: Type - Crawlair ECM 350. Rods - Steel	INSPECTOR
COMPRESSOR: Type - IRDXL750. Rating - 125 psi @ 750 cfm.	DRILLER:

DEPTH (Feet)	PENETRATION (Seconds/Ft.)	SCHEMATIC	IDENTIFICATION OF STRATA	REMARKS
	8	Soft rock (fractured)	Residual soil and decomposed rock fragments	
	8			
	5			
	6			
5	6			
	6			
	9			
	65		Gray dust, rock fragments (gray dolomite)	
	60			
10	43			
	55			
	79			
	56			
	60			
15	98			
	81			
	75			
	85			
	48			
20	0	Void		19'-20.5' No resistance
	8			Approximately 4 in. soft layer (8 sec./ft.)
	45	Soft		
	50			
	100			
25	103			
	102			
	120			Ejecting brown residual soil
	99			
	97			
	115			
30			CD = 30 feet	
35				

FIGURE 2 - TYPICAL PROBE LOG

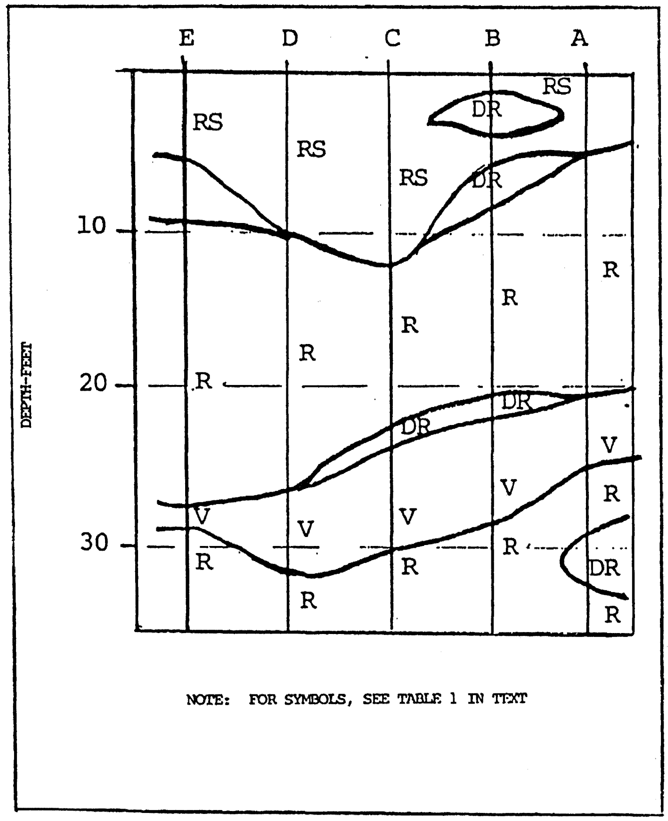

FIGURE 3 - SUBSURFACE STRATIGRAPHY AS INFERRED FROM PROBING

Foundation Design Scheme

It was determined that construction of a spread footing foundation system or a large mat foundation on the upper bedrock layer over the cavity could eventually lead to a potential settlement problem of the proposed structure. Economic analyses indicated that there would be a significant cost savings (over $50,000) if, rather than pre-drilling holes through the upper bedrock layer and driving steel H-piles to competent bedrock beneath the cavity, the cavity was to be filled with a cement grout and a mat foundation then constructed on the surface of the upper bedrock after the overburden soils were removed. Accordingly, it was decided to proceed with a grouting program.

Details of the Grouting Program

The grouting program required the use of 3¼ inch diameter grout holes placed in a grid pattern. The locations of the grout holes are shown in Figure 1. To reduce costs, many of the original percussion probe holes, which had been drilled with a 3-inch diameter bit, were over-reamed to the required diameter for grouting. Three inch diameter perforated grout pipes were inserted in the grout holes that extended through the cavities into the competent bedrock below. Cement-bulk filler grout was pumped into each hole under varying pressures until there was no more grout take (refusal). Provisions were made to perform secondary and tertiary grouting operations, if deemed necessary.

Rock Mass Quality After Grouting

After grouting, probes were advanced adjacent to the grout holes to determine rock mass quality and the extent of any remaining cavities. A comparison of the results of probes showing the rock mass qualities and extent of cavities before and after grouting is presented in Figure 4. It can be seen from this comparison that there was only a slight improvement in rock quality due to grouting. This was attributed to the fact that the grout was not able to displace the soil present in the cavities. It was decided to abandon plans to proceed with additional grouting. The grout pipes which had been in place were relied on to act as "needle piles" to help transfer the foundation load below the cavities into the competent bedrock below. The structure has not experienced any settlement since it was constructed several years ago. Hence, it may be concluded the limited benefit of the grouting program together with the beneficial support of the "needle piles" was effective in solving the problem presented by the cavities at this site. However, without the additional data obtained by post-grouting percussion probes, the need to incorporate the "needle piles" into the foundation would not have been known and the structure would probably have been subjected to unacceptable and perhaps objectionable movements.

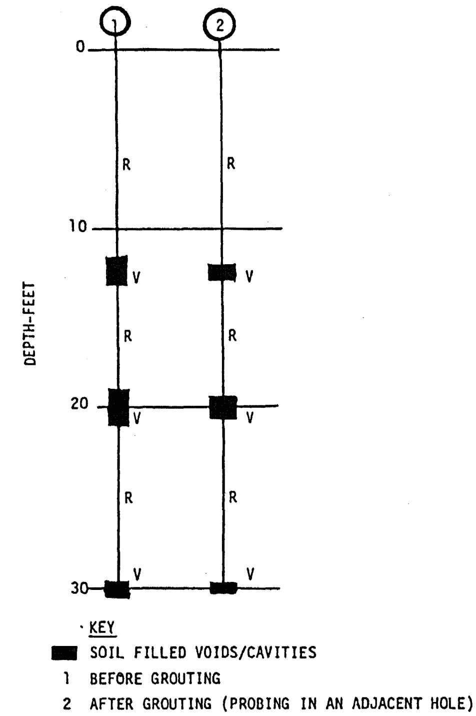

FIGURE 4 - ROCK MASS QUALITY BEFORE AND AFTER GROUTING

Conclusions

Some of the limitations and drawbacks involved in grouting cavernous carbonate formations have been presented in this paper. The need for determining the improvement of rock mass quality after grouting is also clearly demonstrated. A new technique based on percussion probe penetration rates to obtain the required subsurface information for grouting was developed. Also it was shown that this technique can be also employed to verify the effectiveness of grouting. This technique is shown to be superior to the conventional subsurface investigation in terms of accuracy, cost and speed.

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