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TALL BUILDING FOUNDATION PROBLEMS IN LIMESTONE REGIONS

by

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ABSTRACT

A brief discussion of the formation, deposition and character of soft limestone is presented with emphasis on the problem in the State of Pennsylvania. A case study of a six-story building using H-piles in this limestone region is illustrated. Cautions and advantages for using the H-pile in limestone regions are discussed.

INTRODUCTION

In recent years, land development in the U.S.A. has expanded significantly. Problematic limestone regions are frequently used for the construction of tall buildings. Because of the possibility of uncertain subsurface conditions in limestone areas, it is necessary that a foundation engineer pay considerable attention to these environmental conditions. Limestone is a relatively young geological formation which comprises about 10% of exposed rock on the earth's surface and it covers a large part of the U.S.A. Limestone regions are frequently blanketed with a layer of residual soil. Residual soils are often soft and loose, therefore, the designer of a tall building generally requires that foundations be supported directly on the rock surface. However, the rock properties in a limestone region can vary considerably from poor to good within a short distance. Commonly in these areas, the caisson (bored pile) is used because it is suitable for the relatively uncertain subsurface conditions. Pile foundations are much less expensive in comparison with caissons, however, certain precautions and thorough planning are needed in order to obtain satisfactory results.

The purpose of this paper is to discuss and identify the characteristics, formation, deposition of limestone, with emphasis on the problems in the State of Pennsylvania. A case study of a six-story parking garage will be used to illustrate the situation. It includes site investigation, pile loading, inspection of extracted piles, and a method for protecting the pile tip in rock formations.

CHARACTER OF LIMESTONE

The essentials of the solution processes involved can be exemplified by the chemistry of limestone solution. This rock consists of calcium carbonate in varying percentages. It is poorly soluble in water alone, but when carbon dioxide is added to the water, forming carbonic acid, the acid reacts with the
rock to form the compound calcium bicarbonate.

Carbon dioxide is taken by water from the atmosphere and from the soil air where it is concentrated due to the decay of organic materials. As the rock is removed, poorly soluble impurities, such as silica, alumina, iron oxides and carbonates and sulphur, are left behind forming the familiar reddish or yellowish soil of these areas.

Dolomite is a limestone in which some of the calcium has been replaced by infiltrating magnesium. It is less soluble than pure limestone but can also yield karst forms.

The "karst" is the world's best exhibit of erosion by solution. The land has been shaped by the removal of calcium and magnesium from rock deposits varying in composition from pure limestone to dolomite by water charged with carbon dioxide. Solutional features are developed here so extensively and variously as to become geologic models, and the term "karst topography" is applied to any terrain in which such features occur. These manifestations also appear where other soluble minerals, particularly rock salt and gypsum, form bedrocks at or near the surface, however, the term karst refers to the geologic consequences of solution as bicarbonates of pure or mixed carbonates of the alkaline earths especially of calcium and magnesium.

Since the prime condition for limestone solution is abundant rainfall to stimulate plant and carbon dioxide production, arid regions exhibit little karst development. Such development is favored if the strata are well jointed, when water will not stagnate but can pass readily through.

On most bedrock, drainage tends to be two-dimensional; in limestone it is three-dimensional. Channels are often ungraded because downcutting depends entirely upon solution. Streams flowing through these terrains become integrated by long established mutual surface features with a considerable influence of relative gradients and therefore, generally meet underground in the three-dimensional patterns represented by the joint systems.

Areas of erosion in limestone are defined by belts of solution-resistant rock. Limestone strata often grade into shale and vice-versa. Since shale typically is poorly jointed and its particles are small and well compacted, it tends to block circulation. Therefore, downward percolating water spreads out over the shale stratum or follows the dip until it reaches joints through which downward movement can be resumed.

Most common among karst features are the sinkholes which may occur in such number as to make the countryside appear quite pockmarked. Central Florida is one well-known example; another prominent area is southern Indiana where the sinkhole total is estimated at 300,000. Large numbers of sinkholes are also in Pennsylvania and Illinois.

All suspected sinkhole areas should be investigated in the field and cores drilled to a depth consistent with the characteristics of the proposed structure. If sinkholes are discovered, they should be avoided if possible, as correction is often difficult, costly and uncertain.

If a sinkhole cannot be avoided, it must be filled with suitable material and the eye sealed or bridged, thereby creating a firm foundation.
CASE HISTORY - H-PILE IN LIMESTONE REGION

A six-story parking garage to be erected in downtown Reading, Pennsylvania located in the Great Valley Section of the Valley and Ridge Province which is underlain by the Allentown Formation of Upper Cambrian age. The bedrock is primarily limestone with zones of shale laminations and layers of dolomite. The depth of fill above the bedrock ranges from 10 to 57 feet. There are many soft clay seams from which the boring recovery was very low. Voids ranging in size from small vugs to solution cavities with a maximum height of 4 feet are present (typical boring logs are shown in Fig. 1). The quality of the bedrock varies considerably from very poor to good within short distances as indicated in pile driving record and boring logs (Fig. 2).

A caisson foundation was designed but the cost of drilling was excessive. A pile foundation was then considered and on a preliminary basis found to be feasible and cost less than the caisson foundation.

Some factors concerning the use of driven piles into pinnacle limestone and shale areas are as follows:

1. Pile length variations typical of many limestone regions can occur within short distances. This is caused by the erratic soil and rock conditions.
2. Damage can occur to unreinforced pile tips.
3. When piles are driven into shale deposits, redriving may be necessary to properly seat the pile.
4. Piles tend to move laterally and have greater variation from the vertical than when used under more uniform subsurface conditions. This condition must be recognized in the design of the pile caps.

Accordingly, pile driving and extraction loading tests were conducted to provide a guideline establishing:

1. Proper pile hammer size and type.
2. Driven length and drill log information.
3. Pile size.
4. Pile tip protection in rock formation.
5. Pile capacity.
6. Allowance for lateral movement of pile top.
7. Pile driving criteria.

Laboratory tests for rock included tensile strength and unconfined strength tests. Thirty-six borings were taken in the 250 x 178 ft. site. Two pile-load tests and twelve pile extractions were performed to determine pile capacity and condition. During the pile-load test, reaction piles were used rather than weights which gave an opportunity to observe driving of additional piles.

Six HP12x53 reaction piles and one 10x42 test pile with a reinforced tip (APF75750) were driven at the site of Test Site No. 1 (see Fig. 2). At Pile Test No. 2, eight reaction piles and one HP10x42 test pile with a reinforced tip were driven. Six of the reaction piles were HP12x53, one was a HP10x57, and the other was a PP10.75x.312. Load-deflection data at both test sites was obtained.
All piles were extracted with an HB15 extractor at Test Site No. 1 where the piles were approximately 33 feet long. All reaction piles (HP12x53) suffered tip damage. The HP10x42 with a reinforced tip was not damaged in driving, as shown in Fig. 3. At Site No. 2 a 2-75B vibro extractor/hammer was required to extract the long (90 ft.) piles. Same observation was obtained. Figure 3 shows the pile tip damage without a reinforced steel Pruyn tip. From the above studies, the H-pile with steel Pruyn point pile-tip (APF75750) finally was recommended for use.

CONCLUSIONS

It is concluded that a pile foundation can satisfactorily be used in a pinnacled limestone subsurface at less cost than caissons. A comprehensive site investigation and protection of the pile-tip are required. In addition, the pile driving should be supervised by an engineer experienced in the use of piles in limestone areas.

ACKNOWLEDGMENT

John Graham and Co., Architects and Engineers, Reading Parking Authority; G. A. and F. A. Wagman, Inc., Contractor; Fisher, Fang and Associates, Inc. served as geotechnical engineering consultants to this study.
### Test Boring Logs

**Figure 1 Typical Boring Logs**

#### B-3
- **A** 15' 35' Silt Clayey, Sandy, Brm.
- **B** 35' 32' Comp. w/ Rock F rag, Fill.
- **C** 25' 32' Limestone, Silty, Limestone, Brm., Comp. w/ Limestone Brm.
- **D** 19' 8' Limestone, Brm., Comp. w/ Limestone Brm.
- **E** 19' 10' Void

#### D-11
- **A** 15' 74' Silt Clayey, Silty, Brm., Comp. w/ Rock F rag, Fill.
- **B** 65' 10' Silt Clayey, Brm., Comp. w/ Limestone Brm.
- **C** 18' 8' Limestone, Silty, Limestone, Brm., Comp. (Limestone, Brm.)
- **D** 26' 9' Void

#### C-12
- **A** 15' 53' Silt Clayey, Brm., Comp. w/ Limestone Brm.
- **B** 55' 19' Silt Clayey, Brm., Comp. w/ Limestone Brm., Fill.
- **C** 115' 12' Silt Clayey, Brm., Comp. w/ Limestone Brm., Fill.
- **D** 165' 13' Silt Clayey, Limestone, Brm., Comp. w/ Limestone Brm.
- **E** 215' 10' Silt Clayey, Limestone, Brm., Comp. w/ Limestone Brm., Fill.
- **F** 230' 14' Void

**END OF BORING AT 98.0'**

**END OF BORING AT 100.5'**
PILE LAYOUT AND BORING LOCATION

<table>
<thead>
<tr>
<th>PILE NO.</th>
<th>TYPE</th>
<th>DATE DRIVEN</th>
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<tbody>
<tr>
<td>1</td>
<td>HPI2 x 53</td>
<td>11-12-73</td>
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<tr>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
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<tr>
<td>7</td>
<td>HPI2 x 53</td>
<td>11-14-73</td>
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<tr>
<td>T.P.</td>
<td>HPI0 x 42</td>
<td>11-12-73</td>
</tr>
<tr>
<td>T.P. REDRIVEN</td>
<td>11-14-73 NO MOVEMENT</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2

PILE DRIVING RECORD
Figure 3 H-Pile with Pruyn Point Suffered Little Damage from Hard
Driving into Limestone Layers (see Arrow)