Geotechnical Analyses of Guizhou Hotel

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ABSTRACT

This paper presents the geotechnical analyses of Guizhou Hotel, a thirty story (102-m high) building situated under complicated karst engineering geological conditions. Comprehensive geotechnical investigations prior to the design included the bore hole sampling, in-situ ultra-sound velocity testing, groundwater well-pumping, and laboratory testing for rock strength. Based on the field and laboratory data, the bedrocks within the construction site (about 20,000 m^2) was divided into four engineering geological units I_a, I_b, I_c, and I_d, ranging from simple engineering geological condition (I_a) to very complicated geological condition (I_d). Different subgrade bearing capacities were selected for the four units based on field and laboratory test results. Manually dug shaft foundations with different geometric shapes and sizes were considered for different units. Subgrade distress such as excess weathering and groundwater seepage were treated through construction measures. The field monitoring data during and after the construction indicated that very little overall and differential settlement had occurred for the structure and the geotechnical design for this high-rise building under the complicated karst geology had been a success.

Key Words: high-rise building, karst engineering geology, geotechnical investigation, bore-hole, in-situ ultra-sound velocity, manual dug shaft foundation.

INTRODUCTION

The Guizhou Hotel is a high-rise building which has a thirty-story main tower (102-m) surrounded by five-story (20-m) skirt-buildings. The building, which includes one level of basement, covers a total ground area of 550-m^2 and consists of a total construction area of 30,828-m^2. The upper structure for the main tower was reinforced Portland cement concrete (PCC) framed shear wall and the rest of the structures were reinforced PCC frames.

The construction site of the building was at downtown of Guiyang city, the capital of the southwest province of Guizhou, China, where karst formed most part of the terrains. The objective of this paper was to present the geotechnical analyses during the investigation and design process. Geotechnical field investigation and laboratory testing data were presented.

GEOTECHNICAL SITE CONDITIONS

Overall terrain

The construction site was located between two ancient rivers that formed "Y" shaped terrains. After years of erosion, three residual higher spots and one lower spot were formed. The lower spot collected water during most part of the year. The elevation for the lower spot was around 1,077-m, and for higher spots, 1079-m. The maximum difference of elevation was 5-m.

Soil strata and geological structures

The majority part of the site was covered by Quaternary clayey soils. The exposure of bedrock consisted about 0.6% of the total 20,000 m^2 construction site. The soil strata consisted of newly placed fills, agricultural clay, organics-rich red clay, and red clay. The depth of the covered soil above bedrock ranged from 1.20-m to 12.79-m with an average depth of 5.53-m. The bedrock consisted of doeomite, most grey to light grey in color, with orientations of 270^o to 330^o, and inclination of 8^o to 25^o.

The geological structure of the site was governed by three horizontally compressive faults (F_1, F_2 and F_3) that divided the site into four parts, as shown in Figure 1. The inclination angles for all three faults were above 80^o. The width of the faults varied from 0.20-m to 1.70-m, with broken calcite and ferrous or calcium well glued agglomerates. In addition, two major joints, with orientations of 105^o and 350^o, and inclinations of 15^o and 80^o, further weakened the integrity of the bedrocks. Figure 2 presents the statistics of the joints.

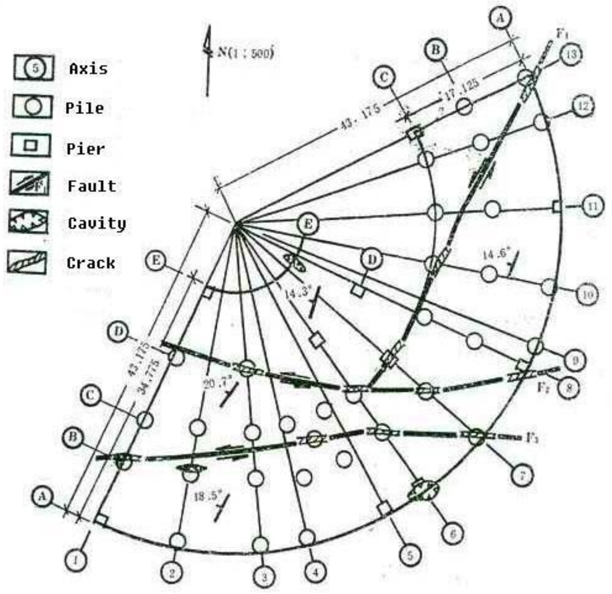

Fig. 1. Construction Plan and Geological Structures

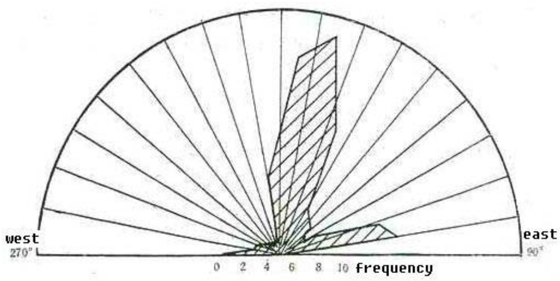

Fig. 2. Joint Statistics of Bedrocks

Ground water conditions

In addition to surface water, groundwater consisted of residual water within upper layers and water within cracks of bedrocks, Figure 3. During the dry seasons, surface water provided the source for groundwater supply, whereas during the rain seasons, pressurized groundwater within the bedrocks flowed into upper layers and surface.

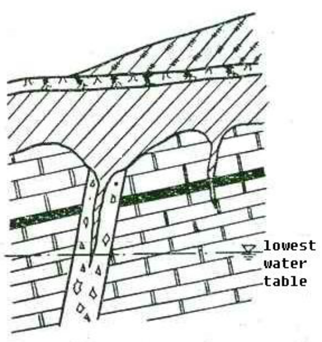

Fig. 3. Groundwater Structure

Simple pump well test indicated that the top Quaternary soils to be very impermeable, which had the coefficient of permeability ranged between 0.013 to 0.057 m/day.

Deep-well pumping tests were conducted to characterize the groundwater properties within the bedrocks. It was found that the maximum ground water pressure within the bedrock was 3-m above the floor of the designed basement, and the maximum volume of pressurized groundwater seepage was 3370 m^3/day. The calculated coefficient of permeability of bedrock was 1.03 m/sec. Figure 4 presents the results from a 205-m deep well pumping test.

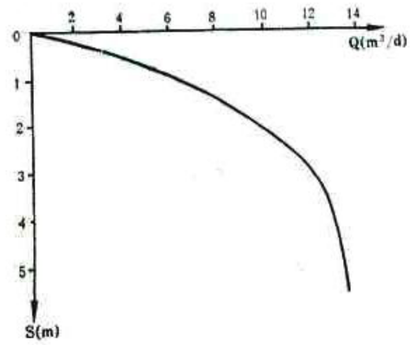

Fig. 4. Deep-well Pumping Test Curve

GEOTECHNICAL ANALYSES

Stability

A potential concern of the stability is that 12 piles would pass the crushed areas of the faults. A comprehensive evaluation of the regional geological activity indicated that the construction site was in a relative stable area. No active faults were found in the proximity. In addition, the sizes of the three faults found within the construction site were small, and the integrity of the calcite and agglomerates within the faulted areas kept relatively well. The overall conclusion was that the three faults within the construction site will not significantly compromise the stability of the pile foundations.

Subgrade bearing capacity

According to local experience, the doeomite found in the construction site will satisfy the bearing capacity need for most single and multi-story structures. However, when the designed bearing capacity is over 3.92 MPa in light weathered hard rocks, the Design Code [1] requires comprehensive analyses for the bedrocks.

Bore hole sampling, uniaxial compressive and ultrasound velocity tests were conducted to evaluate the strength characteristics of the bedrocks. Table 1 presents the results of the laboratory tests of the bedrocks. It was found that the ultrasound velocity correlated reasonably well to the uniaxial compressive strength of the rock specimens, Figure 5.

Table 1. Laboratory Test Results of the Bedrocks

rock types	uniaxial test method	height to diameter ratio	# of samples	compressive strength (MPa)	ultrasound velocity (km/s)
doeomite	dry	1:1	54	87 (27*)	5.0 (0.75)
	wet	1:1	40	82 (27)	5.1 (0.68)
	dry	1:2	11	57 (18)	5.4 (0.52)
calcite	dry	1:1	9	65 (22)	5.8 (0.45)
	wet	1:1	9	52 (20)	5.6 (0.36)
	dry	1:2	3	42 (7.3)	6.0 (0.35)
agglomerate	dry	1:1	6	60 (27)	4.3 (0.53)
	wet	1:1	21	52 (27)	4.2 (0.70)
	dry	1:2	3	15 (2.6)	4.5 (0.93)

* The numbers in parenthesis are the standard deviation.

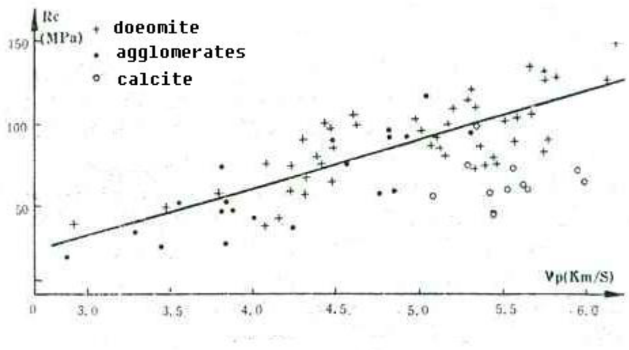

Fig. 5. Correlation between Ultrasound Velocity and Uniaxial Compressive Strength

To characterize the bearing capacities, the bedrocks within the construction site were classified into three basic bedrock units as "I" (doeomite), "II" (calcite), and "III" (agglomerate). Within the basic bedrock unit, the rocks were further classified into three sub-units as "a" (weak), "b" (medium), and "c" (good). Thus the total combination of nine bedrock units was 9. The bedrock units were characterized through core sampling rate (%), rock quality index (%), ultrasound velocity, point load strength index, and uniaxial compressive strength as illustrated in Table 2.

Table 2. Bedrock Strength Characterization for Doeomite

bedrock unit	I_a	I_b	I_c
core sampling rate (%)	44	64	80
rock quality index (%)	32	50	60
ultrasound velocity (km/sec)	<3.0	3.0 – 4.7	>4.7
point load strength index (MPa)	<2.5	2.5 – 3.0	3.0 – 3.5
compressive strength (MPa)	<40	40 – 100	50 – 130

The recommended design values of the bearing capacities for each rock unit were determined through statistical analysis at the confidence level of 99.9%. In the case of insufficient specimen numbers, lower values of bearing capacities were assigned to the rock units. The results of the recommended bearing capacities for each bedrock units are presented in Table 3.

Based on the types of bedrock unit and their depth, each individual piles were deigned with different lengths and cross-section areas.

Table 3. Design Bearing Capacities of Bedrocks

rock unit	# of samples	R_c (MPa)	$R_{c(\alpha=0.999)}$ (MPa)	K	[R] (MPa)
I_a	1	40.0		1/19 to 1/27	0.29
I_b	26	69.2	52.9		1.96
I_c	66	91.0	80.4		4.31
II_a	0			1/22 to 1/38	0.29
II_b	0				1.18
II_c	14	63.3	53.2		2.35
III_a	1	19.2		1/8 to 1/18	0.29
III_b	18	44.5	26.8		1.47
III_c	8	79.3	37.0		2.94

Rc – uniaxial compressive strength.
$Rc_{(\alpha=0.999)}$ – uniaxial compressive strength with 99.9% confidence level.
K – correction factor for bearing capacity.
[R] – allowable bearing capacity.

Treatment for subgrade distress

Four types of subgrade bedrock units were found within the envelope of the building after excavation. These units included: 1) unit Ic, with fresh and smooth bedrock, 2) unit Ib, with well developed joints and rough surface, 3) bedrocks with horizontal and vertical erosions from karst activities, and 4) subgrade located at the faulted area. Figure 6 illustrates these four types of subgrade conditions.

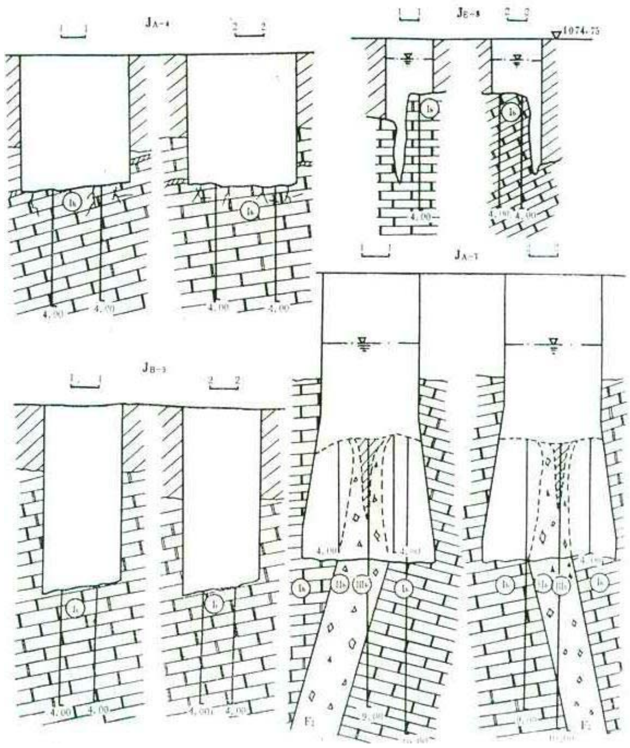

Fig. 6. Four types of subgrade conditions

The recommended treatment for Types 3 and 4 subgrade included cleaning the crushed rocks and back-filling the cavities with Portland cement concrete. In the case when cavities were difficult to clean, steel reinforcement was employed in addition to backfilling Portland cement concrete. Figure 7 presents a backfilling plan of cavity at the bottom of Pile J_{A-8}.

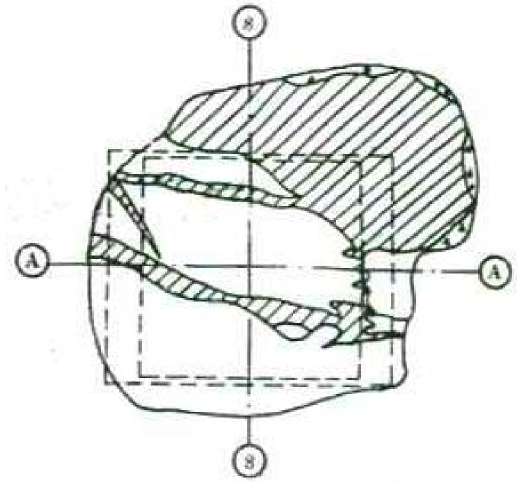

Fig. 7. Backfilling PCC under Pile J_{A-8} (hatched areas)

Since the maximum pressure head of the groundwater within the bedrock was 3.0-m above the bottom of the basement elevation, the hydraulic pressure to the basement would be 30 kPa without any treatment. It was recommended to setup four pumps in the basement to reduce the groundwater table. The designed capacity of the pump determined by the deep-well pump test was 2765 m^3/day.

CONSTRUCTION MONITORING RESULTS

Construction monitoring results indicated that the 30 story building had only 1-cm total settlement and 10-cm of tilt after the construction. The actual groundwater volume was 3370 m^3/day, which was 22% above the designed pumping capacity.

SUMMARY

Comprehensive geotechnical analyses for the Guizhou Hotel were conducted based on geotechnical field investigation and laboratory tests. The results from construction monitoring validated the conclusions from the geotechnical analyses and the geotechnical engineering design for this high-rise building under complicated karst geology had been a success.

REFERENCE

Ministry of Construction, [1974] "*Geotechnical and Foundation Design Code for Civil and Industrial Constructions,*" Beijing, China.