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Geotechnical Evaluation and Foundation Scheme Research for Soft Soil Foundation Engineering Reconstruction and Expansion Project in Guangzhou Urban Area

Xingbao Wu, Wei Wei*

Guangdong Construction Polytechnic, Guangzhou 510440, China

Abstract

To address core geotechnical challenges in reconstruction projects within soft soil areas of the Pearl River Delta, this study employs the Guangzhou Urban Area Campus A Basketball Court Expansion Project as a case study. Through integrated survey methods combining drilling, in-situ testing, and laboratory experiments, we systematically investigated the site's engineering geological conditions, mechanical properties of soil layers, groundwater distribution patterns, and types of adverse geological phenomena. The findings reveal that the site represents a typical alluvial-originated non-uniform foundation in the Pearl River Delta, consisting of artificial fill layers, flow-plastic to soft plastic silt layers, loose fine sand layers, and weathered chalky siltstone formations. The silt layers exhibit high compressibility and low strength characteristics, while the fine sand layers demonstrate severe liquefaction potential. Considering a seismic fortification intensity of 7 degrees, the site is classified as structurally vulnerable for buildings. Geological assessments indicate that groundwater poses minimal corrosion risks to concrete structures, while overground soil layers exhibit moderate corrosive effects. Although the site demonstrates good geological stability suitable for construction, critical mitigation measures are required to prevent soft soil subsidence, sand liquefaction, uneven settlement, and pile foundation-induced disturbances to existing structures. The study recommends rotary drilling/boring cast-in-place piles as the primary foundation method, proposes targeted mitigation strategies, and provides technical references for similar soft soil reconstruction projects in Guangzhou urban areas.

Keywords

Detailed Geotechnical Investigation; Soft Soil Foundation; Sand Liquefaction; Foundation Stability; Pile Foundation Design.

1. Introduction

With the advancement of urban renewal initiatives, the renovation and expansion of existing primary and secondary school campuses have become a crucial component in upgrading urban public services. These projects commonly face challenges such as limited site space, proximity to existing structures, complex geological conditions, and stringent seismic design requirements. Particularly in soft soil regions like Guangzhou within the Pearl River Delta, the widespread distribution of sedimentary soft soils and loose sand layers exhibits adverse characteristics including high compressibility, low bearing capacity, and susceptibility to earthquake-induced liquefaction, posing significant risks to foundation design and construction processes.

Detailed geotechnical investigation serves as the fundamental prerequisite for engineering construction, with its accuracy directly determining the rationality of foundation designs and

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structural safety. While current research on geotechnical engineering for new constructions in soft-soil areas of the Pearl River Delta has reached maturity, further advancements are required in refined surveys for existing campus expansion projects, multidimensional geological assessments, and foundation optimization strategies for adjacent structures. Taking the basketball court expansion project at Campus A in Guangzhou urban area as a case study, this research comprehensively investigates site engineering geological conditions, conducts specialized evaluations of critical geotechnical issues, and proposes site-adaptive foundation solutions along with mitigation measures, providing theoretical and practical references for similar engineering projects.

2. Project Overview

2.1 Project Basic Information

This project is located in the old Fifth District of Guangzhou City. A 4-story U-shaped frame structure teaching building with cast-in-place pile foundations has already been constructed on the site. The proposed engineering work involves the expansion of a 2-story indoor basketball court and a 300m^2 small basement in the adjacent area of the existing building, with a total expanded construction area of approximately 2,000m^2.

In accordance with the “Code for Geotechnical Engineering Investigation” [1], this project is classified as Level II in terms of engineering importance, site conditions, and foundation grade, with an investigation level of Class B. The proposed building is designated as school teaching facilities, classified under Class B seismic fortification category with a seismic fortification intensity of 7 degrees, a design basic seismic acceleration of 0.10g, and a design earthquake group of Group 1.

2.2 Survey Workload and Technical Methods

This phase involves detailed geological surveying. Based on the proposed building layout and load characteristics, a total of 10 boreholes were installed (including 8 control boreholes and 2 general boreholes), with 5 newly added construction boreholes and 5 retained survey boreholes from the 2021 floor addition project. The boreholes are spaced at intervals of 10-20 meters. General boreholes penetrate continuous moderately to slightly weathered rock layers to a depth of no less than 2 meters, while control boreholes reach depths of at least 5 meters in these rock layers. The total borehole depth must meet or exceed 15 meters [2].

This investigation employed a comprehensive geotechnical engineering survey technology system, strictly adhering to current regulatory standards. Full-hole core sampling and rotary drilling were conducted to delineate the site's soil layer distribution and weathering characteristics. Thirty-five standard group pumping tests and four in-situ shear wave velocity measurements were performed to obtain critical in-situ mechanical and seismic data. Additionally, 44 geotechnical tests, 29 rock mechanics tests, and four soil-water corrosion tests were completed to accurately determine geotechnical parameters and corrosion properties.

3. Geotechnical and Hydrogeological Conditions of the Site

3.1 Regional Geology and Site Environment

The study area is located in the eastern part of the Guangzhou Fault Sag within the Guangdong Central Anticline Fold System of the South China Fold System. The dominant regional faults, Guang-San Fault and Guang-Zhong Fault, are situated at considerable distances from the survey site. No fault structures were detected within the exploration depth range, indicating good geological structural stability. The site features a Pearl River Delta alluvial plain topography. After artificial backfilling modifications, the terrain has become generally flat, with borehole openings at elevations ranging from 8.02m to 8.13m, presenting relatively simple topographical conditions.

The site exhibits a South subtropical marine monsoon climate with an annual average rainfall of 1738.6 mm, where the rainy season rainfall from April to September accounts for 81.25% of the annual total. Located south of the Pearl River tidal channel, the groundwater level is significantly

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influenced by seasonal rainfall and tidal forces, with water level fluctuations ranging approximately 2 m between wet and dry periods.

3.2 Engineering Properties of Geotechnical Layers

Based on borehole exposure data, the site's geotechnical strata can be stratified into four major categories from top to bottom: the overburden layer, Quaternary artificial fill layer, Quaternary alluvial soil layer, and Cretaceous weathered bedrock. The distribution characteristics and physical-mechanical properties of each stratum are as follows:

Artificial fill layer: Present throughout the site except for localized elevated areas, with a thickness ranging from 2.0m to 3.5m. The structure is loose and under-compacted, exhibiting low bearing capacity and poor uniformity, making it unsuitable as a bearing layer for proposed building foundations.

Quaternary alluvial soil layer: Widely distributed throughout the site, it can be divided into two sublayers. ① Mud layer, 1.1-4.2 m thick with a top burial depth of 2.0-3.5 m, exhibiting saturated flow-plastic to soft plastic consistency. With an average moisture content of 51.2% and compressive modulus of 2.35 MPa, this represents typical high-compressibility low-strength soft soil, for which the recommended characteristic bearing capacity value f_ak is 60 kPa. ② Fine sand layer, 2.6-6.4 m thick with a top burial depth of 3.4-6.2 m, characterized by loose structure and saturated moisture content. Serving as the primary groundwater aquifer and earthquake-induced liquefaction zone, the recommended f_ak value is 80 kPa.

Cretaceous basement rock: The site foundation consists of siltaceous mudstone classified as soft rock, divided into three weathering zones with widespread distribution and multi-layered soft-hard interlayers. ① Strongly weathered zone: Highly susceptible to water-induced softening, classified as extremely soft rock. Recommended f_ak value of 500 kPa, suitable as bearing layer for end-bearing friction piles. ② Moderately weathered zone: Natural uniaxial compressive strength standard value of 4.50 MPa, recommended f_ak value of 1100 kPa, serving as primary pile-end bearing layer for proposed projects. ③ Slightly weathered interlayer zone: Natural uniaxial compressive strength standard value of 7.5 MPa, recommended f_ak value of 2200 kPa, constituting high-quality pile-end bearing layer.

3.3 Groundwater Occurrence and Corrosiveness Assessment

Pumping tests are conducted on sand layers and strongly/medium weathered rock sections in strata, with the permeability coefficient K of each geotechnical layer calculated using the following formula:

$$k20=[0.366Q(lgR-lgrw)]/(H1Sw)$$

Q -- Pumping well inflow rate (m^3/d); R -- Influence radius (m); H1 -- Aquifer thickness from the pumping well to the bottom of the filter (m); rw -- Pumping hole radius (m); Sw -- Water level drop of pumping hole (m);

Based on pumping tests, geotechnical test results, and regional experience, the permeability coefficients for each geotechnical layer are determined as follows:

Artificial fill: k20=3.20×10^{-4} cm/s;

Silt soil: k20=4.74×10^{-8} cm/s;

Fine sand: laboratory K20 value = 4.13×10^{-3} cm/s, pumping test K20 value = 8.10×10^{-3}cm/s (for reference);

Strongly weathered siltstone: k20=5.21×10^{-3} cm/s;

Weathered siltstone: k20=3.20×10^{-6} cm/s.

Analysis indicates that the groundwater in the field area consists of two main types: Quaternary pore water and bedrock fracture water. Pore water is primarily found in fine sand layers, characterized by high water abundance and good permeability, with recharge sources from atmospheric precipitation. Bedrock fracture water occurs in strongly and moderately weathered rock zones, exhibiting poor water abundance and slight confining pressure characteristics. During the survey period, which coincided with the wet season, the stable water level in boreholes was measured at depths of 1.40–1.50 m and elevations of 6.54–6.75 m.

According to regulatory standards, the site environment is classified as Class II. The soil and water corrosivity assessment concludes that groundwater exhibits mild corrosiveness to concrete structures and steel reinforcement in reinforced concrete structures. Above the groundwater level, soil demonstrates moderate corrosiveness to concrete structures while showing slight corrosiveness to both steel reinforcement and steel structures. Therefore, corresponding anti-corrosion protective measures must be implemented in concrete structure engineering designs.

4. Evaluation of Key Issues in Geotechnical Engineering at Construction Sites

4.1 Site Stability and Building Suitability Analysis

Sand liquefaction can easily cause site subsidence and adversely affect building foundations and superstructures. Based on the measured number of blows from standard penetration tests and in accordance with the 'Code for Seismic Design of Buildings' (GB50011-2010), the calculation formula is as follows:

$$N_{cr} = N_o \beta \left[\ln\left(0.6d_s + 1.5\right) - 0.1d_w\right]\sqrt{3/\rho_c}$$

$$I_{LE} = \sum_{i=1}^{n}(1 - \frac{N_i}{N_{cri}})d_i W_i)$$

N_{cr}-- Critical value of standard penetration hammer impact number for liquefaction discrimination;

N_o -- Liquefaction identification criterion penetration hammer impact number reference value (seismic fortification intensity of 7 degrees, design basic seismic acceleration of 0.10g, N_o=7);

d_s -- standard penetration point depth (m) for saturated soil;

d_w --Groundwater level depth (m);

ρ_c -- percentage content of clay particles; when it is less than 3 or the soil is sandy, 3 should be adopted.

β-- adjustment coefficient, set at 0.80 for the first group of design earthquakes;

I_{LE}-- Liquefaction Index;

n -- The total number of standard penetration test points per borehole within the discrimination depth range;

$N_i$and N_{cri}-- the measured values and critical values of the standard penetration hammer impact number at point i, respectively. When the measured value exceeds the critical value, the critical value is adopted.

d_i -- The soil layer thickness of i point(m);

W_i--The stratigraphic influence weight function value per unit soil layer thickness of the i soil layer (unit: m^{-1}).

The test results indicate that the site exhibits moderate to severe liquefaction potential. Within the surveyed depth range, no adverse geological phenomena such as fault structures, karst formations, or landslides were identified. Regional active faults exert minimal impact on the site, demonstrating good structural stability. The site contains unique geotechnical conditions including soft soils and liquefiable sandy soils, classifying it as an earthquake-prone area for construction. Effective

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mitigation of engineering impacts requires appropriate foundation treatment and structural design measures.

4.2 Seismic Performance Evaluation of Sites

The seismic fortification intensity of the site is 7 degrees. The proposed teaching building is classified as Category B in seismic fortification requirements, necessitating enhanced seismic measures according to stricter standards. Based on shear wave velocity test results, the average equivalent shear wave velocity at the site is 117.27 m/s, indicating medium-soft soil with a cover layer thickness of 8.00–9.20 m. The building site category is classified as Class II, with a characteristic period of 0.35 seconds [3].

Standard penetration test results indicate that the site's saturated fine sand layer exhibits severe comprehensive liquefaction potential, making it prone to liquefaction-induced instability under seismic loads. Engineering measures must be implemented to mitigate liquefaction-induced settlement effects. The site's silty soft soil demonstrates low bearing capacity with equivalent shear wave velocities below 90 m/s, necessitating consideration of soft soil subsidence impacts under a 7-degree seismic fortification intensity. The distribution of thickly layered weak soils and liquefiable sand constitutes an unfavorable seismic environment for construction. Design efforts should focus on enhancing the integrated stiffness of foundations and superstructures to improve seismic resistance capabilities.

4.3 Foundation Uniformity and Risk Assessment of Adverse Geology

The site features diverse geotechnical strata with significant variations in mechanical properties of overlying soft soil layers. The underlying bedrock exhibits uneven weathering patterns and developed soft-hard interlayers, accompanied by pronounced stratigraphic thickness variations, classifying it as an inhomogeneous foundation. As this project involves adjacent expansion of existing structures, the newly constructed building demonstrates substantial load differences compared to the existing teaching building, which may lead to uneven settlement. Design specifications require settlement separation joints to be installed, with strict control measures ensuring adjacent column foundation settlement differences ≤0.003L and total foundation settlement ≤200mm.

Key risks in geotechnical engineering at site-specific conditions include: uneven settlement of artificial fill and silt layers that creates negative frictional resistance on pile foundations; liquefiable sandy soils prone to instability during earthquakes, often resulting in sand surges and borehole collapse during construction; strongly weathered rocks that soften and disintegrate upon water contact, with significant variations in weathering intensity and interlayer development potentially leading to insufficient thickness of pile-end bearing strata. Additionally, groundwater can cause concrete segregation in pile foundations and excessive sediment accumulation at pile bases. Large-scale construction dewatering operations may induce ground subsidence around structures, posing safety risks to existing buildings. These hazards require prioritized prevention measures in both design and construction phases.

5. Foundation Scheme Optimization

5.1 Comparison and Recommendation of Basic Types

Based on site geological conditions, load characteristics, and environmental constraints, a comparative analysis of the applicability of major pile types was conducted [4] (see Table 1).

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Table 1. Comparison of Applicability of Core Pile Foundation Scheme Tables

evaluative dimension	Manually excavated bored pile	Rotary drilling/drilling (punching) cast-in-place pile
geological adaptability	Passing through soft soil and sand layers is prone to water inrush and collapse, resulting in poor safety.	It can effectively penetrate various soil layers and weathered rock strata, demonstrating high pile reliability.
Construction safety	Multiple security risks exist due to local policy restrictions	Mechanized construction with low personnel safety risks and no policy restrictions
Environmental impact of surrounding areas	Precipitation is prone to induce surrounding land subsidence	Minimal construction disturbance with controllable impact on existing buildings
comprehensive economy	High security protection costs	High construction efficiency with superior overall economic performance

Through comprehensive analysis, the main structure of this project employs rotary drilling cast-in-place piles or bored (drilled) cast-in-place piles as foundation systems. The pile ends are anchored into continuous medium weathered rock and microweathered rock interlayers as the bearing stratum, with a minimum penetration depth of 1 meter. The piles are designed with an estimated diameter of 0.8 meters and lengths ranging from 10 to 20 meters. The characteristic vertical bearing capacity values for individual piles were determined through on-site static load tests (see Table 2 for details).

Table 2. Design Parameter Values for Geotechnical Layer Pile Foundations

Geotechnical Term	Characteristics of lateral friction resistance on pile side (kPa)	Characteristic value of pile end resistance (kPa)
plain fill	8	/
Silt soil	6	/
silty-fine sand	10	/
strongly weathered siltstone	80	/
Weathered siltstone mudstone	120	1200
slightly weathered siltstone	230	2300

For outdoor ground surfaces and road structures within the site, composite foundation treatment is implemented using deep mixing piles or high-pressure jet grouting piles. The pile bodies penetrate weak soil layers and liquefiable fine sand layers, effectively eliminating the risk of structural cracking and pipeline rupture caused by uneven settlement.

5.2 Foundation Pit Support Scheme

The project design includes a single-story basement with a planned area of 300m2, featuring a floor depth of-4.6m (locally reaching-5.6m). Given the spatial constraints of the site and its proximity to existing teaching buildings, stringent deformation control requirements were established. After comprehensive evaluation, a foundation pit support system combining steel sheet piles with internal bracing was recommended. The retaining structure utilizes reverse-buried dense steel sheet piles to effectively isolate groundwater from sand layers, while the steel beam internal bracing method prevents anchor rod-induced disturbances to surrounding building foundations. The recyclable nature of steel sheet piles eliminates concerns about concrete curing periods, aligning perfectly with the campus construction schedule requiring off-site work.

6. Conclusion and Prospects

6.1 Conclusion

This study focuses on the campus renovation and expansion project utilizing soft soil foundations in Guangzhou urban area. Through comprehensive surveying and multidimensional geological evaluation, the following conclusions are drawn:

(1) The study site features a typical heterogeneous foundation in the Pearl River Delta alluvial plain, consisting of an artificial fill layer, a flow-plastic to soft plastic-like silt layer, a loose fine sand layer, and Cretaceous weathered siltstone mudstone arranged vertically from top to bottom. The silt layer exhibits high compressibility and low strength, while the fine sand layer demonstrates severe comprehensive liquefaction potential. This site is classified as an unfavorable seismic location for buildings under a seismic fortification intensity of 7 degrees.

(2) The site exhibits favorable geological structural stability. Through appropriate foundation treatment and design, adverse engineering effects of special geotechnical conditions can be effectively mitigated, making it suitable for proposed construction projects.

(3) Groundwater in the site exhibits slight corrosiveness to concrete structures, while soil above the groundwater level demonstrates moderate corrosiveness. Groundwater is primarily confined within fine sand layers and is significantly influenced by seasonal variations and tidal forces, which substantially impacts pile foundation quality and construction safety.

(4) The recommended main building adopts rotary drilling/drilling (punching) cast-in-place pile foundations, with moderately weathered to slightly weathered rock serving as the pile end bearing layer. The foundation pit employs a steel sheet pile + internal support support system, which effectively ensures construction and operational safety during engineering implementation.

6.2 Outlook

Future research should focus on refined surveying technologies for campus expansion projects in soft soil areas, utilizing 3D geological modeling to achieve precise characterization of geological structures in confined spaces. Concurrently, studies should be conducted on pile-soil interaction mechanisms for soft-soil-liquefiable sand composite foundations, optimizing pile foundation design parameters and establishing construction environmental impact control systems adjacent to existing buildings. These efforts will facilitate green and intelligent engineering practices in urban sensitive zones.

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